Maryland
Department of
the Environment

# Appendix A

## The Greenhouse Gas Emissions Reduction Act of 2009

# 2019 GGRA Draft Plan

# Appendix A

## CHAPTER 171

AN ACT concerning **Greenhouse Gas Emissions Reduction Act of 2009**

FOR the purpose of setting forth certain findings of the General Assembly; requiring the Department of the Environment to publish and update certain inventories based on certain measures on or before certain dates; requiring the State to reduce greenhouse gas emissions by a certain amount by a certain date and to develop a certain plan, adopt certain regulations, and implement certain programs that reduce greenhouse gas emissions; requiring the Department to submit a proposed plan to the Governor and the General Assembly on or before a certain date; requiring the Department to make the plan available to the public; requiring the Department to convene a series of public workshops for comment on the plan; requiring the Department to adopt a final plan in accordance with certain requirements on or before a certain date; requiring the Department to consult with State and local agencies under certain circumstances; prohibiting State agencies from adopting certain regulations; requiring the Department to take certain actions as it develops and implements the plan in a certain manner; requiring an institution of higher education in the State to conduct a certain study and submit it to the Governor and the General Assembly on or before a certain date; requiring the Governor to appoint a certain task force consisting of certain representatives to oversee the study; requiring that, to the extent practicable, the members appointed to the task force reflect the geographic, racial, and gender diversity of the State; authorizing certain greenhouse gas emissions sources to receive certain credits under certain circumstances; requiring the Department to submit a certain report to the Governor and the General Assembly in accordance with certain requirements on or before a certain date; authorizing the General Assembly to maintain, revise, or eliminate certain greenhouse gas emissions reduction requirements under certain circumstances; requiring the Department to monitor the implementation of a certain plan and to submit certain reports to the Governor and the General Assembly on or before certain dates; requiring the Department to include certain agencies and entities in certain discussions regarding certain matters; defining certain terms; making the provisions of this Act severable; providing for the correction of certain errors and obsolete provisions by the publishers of the Annotated Code; providing for the termination of a certain provision of this Act; and generally relating to the reduction of greenhouse gas emissions.

BY adding to Article – Environment Section 2–1201 through 2–1211 to be under the new subtitle "Subtitle 12. Greenhouse Gas Emissions Reductions" Annotated Code of Maryland (2007 Replacement Volume and 2008 Supplement)

SECTION 1. BE IT ENACTED BY THE GENERAL ASSEMBLY OF MARYLAND, That the Laws of Maryland read as follows:

### SUBTITLE 12. GREENHOUSE GAS EMISSIONS REDUCTIONS.

**2–1201.**

THE GENERAL ASSEMBLY FINDS THAT:

(1) GREENHOUSE GASES ARE AIR POLLUTANTS THAT THREATEN TO ENDANGER THE PUBLIC HEALTH AND WELFARE OF THE PEOPLE OF MARYLAND;

(2) GLOBAL WARMING POSES A SERIOUS THREAT TO THE STATE'S FUTURE HEALTH, WELL–BEING, AND PROSPERITY;

(3) WITH 3,100 MILES OF TIDALLY INFLUENCED SHORELINE, MARYLAND IS VULNERABLE TO THE THREAT POSED BY GLOBAL WARMING AND SUSCEPTIBLE TO RISING SEA LEVELS AND FLOODING, WHICH WOULD HAVE DETRIMENTAL AND COSTLY EFFECTS;

(4) THE STATE HAS THE INGENUITY TO REDUCE THE THREAT OF GLOBAL WARMING AND MAKE GREENHOUSE GAS REDUCTIONS A PART OF THE STATE'S FUTURE BY ACHIEVING A 25% REDUCTION IN GREENHOUSE GAS EMISSIONS FROM 2006 LEVELS BY 2020 AND BY PREPARING A PLAN TO MEET A LONGER–TERM GOAL OF REDUCING GREENHOUSE GAS EMISSIONS BY UP TO 90% FROM 2006 LEVELS BY 2050 IN A MANNER THAT PROMOTES NEW "GREEN" JOBS, AND PROTECTS EXISTING JOBS AND THE STATE'S ECONOMIC WELL–BEING;

(5) STUDIES HAVE SHOWN THAT ENERGY EFFICIENCY PROGRAMS AND TECHNOLOGICAL INITIATIVES CONSISTENT WITH THE GOAL OF REDUCING GREENHOUSE GAS EMISSIONS CAN RESULT IN A NET ECONOMIC BENEFIT TO THE STATE;

(6) IN ADDITION TO ACHIEVING THE REDUCTION ESTABLISHED UNDER THIS SUBTITLE, IT IS IN THE BEST INTEREST OF THE STATE TO ACT EARLY AND AGGRESSIVELY TO ACHIEVE THE MARYLAND COMMISSION ON CLIMATE CHANGE'S RECOMMENDED GOALS OF REDUCING GREENHOUSE GAS EMISSIONS BY 10% FROM 2006 LEVELS BY 2012 AND BY 15% FROM 2006 LEVELS BY 2015;

(7) WHILE REDUCTIONS OF HARMFUL GREENHOUSE GAS EMISSIONS ARE ONE PART OF THE SOLUTION, THE STATE SHOULD FOCUS ON DEVELOPING AND UTILIZING CLEAN ENERGIES THAT PROVIDE GREATER ENERGY EFFICIENCY AND CONSERVATION, SUCH AS RENEWABLE ENERGY FROM WIND, SOLAR, GEOTHERMAL, AND BIOENERGY SOURCES;

(8) IT IS NECESSARY TO PROTECT THE PUBLIC HEALTH, ECONOMIC WELL–BEING, AND NATURAL TREASURES OF THE STATE BY REDUCING HARMFUL AIR POLLUTANTS SUCH AS GREENHOUSE GAS EMISSIONS BY USING PRACTICAL SOLUTIONS THAT ARE ALREADY AT THE STATE'S DISPOSAL;

(9) CAP AND TRADE REGULATION OF GREENHOUSE GAS EMISSIONS IS MOST EFFECTIVE WHEN IMPLEMENTED ON A FEDERAL LEVEL;

(10) BECAUSE OF THE NEED TO REMAIN COMPETITIVE WITH MANUFACTURERS LOCATED IN OTHER STATES OR COUNTRIES AND TO PRESERVE EXISTING MANUFACTURING JOBS IN THE STATE, GREENHOUSE GAS EMISSIONS FROM THE MANUFACTURING SECTOR ARE MOST EFFECTIVELY REGULATED ON A NATIONAL AND INTERNATIONAL LEVEL; AND

(11) BECAUSE OF THE NEED TO REMAIN COMPETITIVE WITH OTHER STATES, GREENHOUSE GAS EMISSIONS FROM CERTAIN OTHER COMMERCIAL AND SERVICE SECTORS, INCLUDING FREIGHT CARRIERS AND GENERATORS OF ELECTRICITY, ARE MOST EFFECTIVELY REGULATED ON A NATIONAL LEVEL.

**2–1202.**

(A) IN THIS SUBTITLE THE FOLLOWING WORDS HAVE THE MEANINGS INDICATED.

(B) “ALTERNATIVE COMPLIANCE MECHANISM” MEANS AN ACTION AUTHORIZED BY REGULATIONS ADOPTED BY THE DEPARTMENT THAT ACHIEVES THE EQUIVALENT REDUCTION OF GREENHOUSE GAS EMISSIONS OVER THE SAME PERIOD AS A DIRECT EMISSIONS REDUCTION.

(C) “CARBON DIOXIDE EQUIVALENT” MEANS THE MEASUREMENT OF A GIVEN WEIGHT OF A GREENHOUSE GAS THAT HAS THE SAME GLOBAL WARMING POTENTIAL, MEASURED OVER A SPECIFIED PERIOD OF TIME, AS ONE METRIC TON OF CARBON DIOXIDE.

(D) “DIRECT EMISSIONS REDUCTION” MEANS A REDUCTION OF GREENHOUSE GAS EMISSIONS FROM A GREENHOUSE GAS EMISSIONS SOURCE.

(E) “GREENHOUSE GAS” INCLUDES CARBON DIOXIDE, METHANE, NITROUS OXIDE, HYDROFLUOROCARBONS, PERFLUOROCARBONS, AND SULFUR HEXAFLUORIDE.

(F) “GREENHOUSE GAS EMISSIONS SOURCE” MEANS A SOURCE OR CATEGORY OF SOURCES OF GREENHOUSE GAS EMISSIONS THAT HAVE EMISSIONS OF GREENHOUSE GASES THAT ARE SUBJECT TO REPORTING REQUIREMENTS OR OTHER PROVISIONS OF THIS SUBTITLE, AS DETERMINED BY THE DEPARTMENT.

(G) “LEAKAGE” MEANS A REDUCTION IN GREENHOUSE GAS EMISSIONS WITHIN THE STATE THAT IS OFFSET BY A CORRESPONDING INCREASE IN GREENHOUSE GAS EMISSIONS FROM A GREENHOUSE GAS EMISSIONS SOURCE LOCATED OUTSIDE THE STATE THAT IS NOT SUBJECT TO A SIMILAR STATE, INTERSTATE, OR REGIONAL GREENHOUSE GAS EMISSIONS CAP OR LIMITATION.

**(H) (1) "MANUFACTURING" MEANS THE PROCESS OF SUBSTANTIALLY TRANSFORMING, OR A SUBSTANTIAL STEP IN THE PROCESS OF SUBSTANTIALLY TRANSFORMING, TANGIBLE PERSONAL PROPERTY INTO A NEW AND DIFFERENT ARTICLE OF TANGIBLE PERSONAL PROPERTY BY THE USE OF LABOR OR MACHINERY.**

**(2) "MANUFACTURING", WHEN PERFORMED BY COMPANIES PRIMARILY ENGAGED IN THE ACTIVITIES DESCRIBED IN PARAGRAPH (1) OF THIS SUBSECTION, INCLUDES:**
**(I) THE OPERATION OF SAW MILLS, GRAIN MILLS, OR FEED MILLS;**
**(II) THE OPERATION OF MACHINERY AND EQUIPMENT USED TO EXTRACT AND PROCESS MINERALS, METALS, OR EARTHEN MATERIALS OR BY–PRODUCTS THAT RESULT FROM THE EXTRACTING OR PROCESSING; AND**
**(III) RESEARCH AND DEVELOPMENT ACTIVITIES.**

**(3) "MANUFACTURING" DOES NOT INCLUDE:**
**(I) ACTIVITIES THAT ARE PRIMARILY A SERVICE;**
**(II) ACTIVITIES THAT ARE INTELLECTUAL, ARTISTIC, OR CLERICAL IN NATURE;**
**(III) PUBLIC UTILITY SERVICES, INCLUDING GAS, ELECTRIC, WATER, AND STEAM PRODUCTION SERVICES; OR**
**(IV) ANY OTHER ACTIVITY THAT WOULD NOT COMMONLY BE CONSIDERED AS MANUFACTURING.**

**(I) "STATEWIDE GREENHOUSE GAS EMISSIONS" MEANS THE TOTAL ANNUAL EMISSIONS OF GREENHOUSE GASES IN THE STATE, MEASURED IN METRIC TONS OF CARBON DIOXIDE EQUIVALENTS, INCLUDING ALL EMISSIONS OF GREENHOUSE GASES FROM THE GENERATION OF ELECTRICITY DELIVERED TO AND CONSUMED IN THE STATE, AND LINE LOSSES FROM THE TRANSMISSION AND DISTRIBUTION OF ELECTRICITY, WHETHER THE ELECTRICITY IS GENERATED IN–STATE OR IMPORTED.**

**2–1203.**
**(A) ON OR BEFORE JUNE 1, 2011, THE DEPARTMENT SHALL PUBLISH:**
**(1) AN INVENTORY OF STATEWIDE GREENHOUSE GAS EMISSIONS FOR CALENDAR YEAR 2006; AND**
**(2) BASED ON EXISTING GREENHOUSE GAS EMISSIONS CONTROL MEASURES, A PROJECTED "BUSINESS AS USUAL" INVENTORY FOR CALENDAR YEAR 2020.**

**(B) THE DEPARTMENT SHALL REVIEW AND PUBLISH AN UPDATED STATEWIDE GREENHOUSE GAS EMISSIONS INVENTORY FOR CALENDAR YEAR 2011 AND FOR EVERY THIRD CALENDAR YEAR THEREAFTER.**

SECTION 2. AND BE IT FURTHER ENACTED, That the Laws of Maryland read as follows:

**2–1204.**

**THE STATE SHALL REDUCE STATEWIDE GREENHOUSE GAS EMISSIONS BY 25% FROM 2006 LEVELS BY 2020.**

SECTION 3. AND BE IT FURTHER ENACTED, That the Laws of Maryland read as follows:

**2–1205.**

**(A) THE STATE SHALL DEVELOP A PLAN, ADOPT REGULATIONS, AND IMPLEMENT PROGRAMS THAT REDUCE STATEWIDE GREENHOUSE GAS EMISSIONS IN ACCORDANCE WITH THIS SUBTITLE.**

**(B) ON OR BEFORE DECEMBER 31, 2011, THE DEPARTMENT SHALL:**
**(1) SUBMIT A PROPOSED PLAN TO THE GOVERNOR AND GENERAL ASSEMBLY;**
**(2) MAKE THE PROPOSED PLAN AVAILABLE TO THE PUBLIC; AND**
**(3) CONVENE A SERIES OF PUBLIC WORKSHOPS TO PROVIDE INTERESTED PARTIES WITH AN OPPORTUNITY TO COMMENT ON THE PROPOSED PLAN.**

**(C) (1) THE DEPARTMENT SHALL, ON OR BEFORE DECEMBER 31, 2012, ADOPT A FINAL PLAN THAT REDUCES STATEWIDE GREENHOUSE GAS EMISSIONS BY 25% FROM 2006 LEVELS BY 2020.**

**(2) THE PLAN SHALL BE DEVELOPED AS THE INITIAL STATE ACTION IN RECOGNITION OF THE FINDING BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE THAT DEVELOPED COUNTRIES WILL NEED TO REDUCE GREENHOUSE GAS EMISSIONS BY BETWEEN 80% AND 95% FROM 1990 LEVELS BY 2050.**

**(D) THE FINAL PLAN REQUIRED UNDER SUBSECTION (C) OF THIS SECTION SHALL INCLUDE:**
**(1) ADOPTED REGULATIONS THAT IMPLEMENT ALL PLAN MEASURES FOR WHICH STATE AGENCIES HAVE EXISTING STATUTORY AUTHORITY; AND**
**(2) A SUMMARY OF ANY NEW LEGISLATIVE AUTHORITY NEEDED TO FULLY IMPLEMENT THE PLAN AND A TIMELINE FOR SEEKING LEGISLATIVE AUTHORITY.**

**(E) IN DEVELOPING AND ADOPTING A FINAL PLAN TO REDUCE STATEWIDE GREENHOUSE GAS EMISSIONS, THE DEPARTMENT SHALL CONSULT WITH STATE AND LOCAL AGENCIES AS APPROPRIATE.**

**(F) (1) UNLESS REQUIRED BY FEDERAL LAW OR REGULATIONS OR EXISTING STATE LAW, REGULATIONS ADOPTED BY STATE AGENCIES TO IMPLEMENT THE FINAL PLAN MAY NOT:**
**(I) REQUIRE GREENHOUSE GAS EMISSIONS REDUCTIONS FROM THE STATE'S MANUFACTURING SECTOR; OR**
**(II) CAUSE A SIGNIFICANT INCREASE IN COSTS TO THE STATE'S MANUFACTURING SECTOR.**

**(2) PARAGRAPH (1) OF THIS SUBSECTION MAY NOT BE CONSTRUED TO EXEMPT GREENHOUSE GAS EMISSIONS SOURCES IN THE STATE'S MANUFACTURING SECTOR FROM THE OBLIGATION TO COMPLY WITH:**
**(I) GREENHOUSE GAS EMISSIONS MONITORING, RECORDKEEPING, AND REPORTING REQUIREMENTS FOR WHICH THE DEPARTMENT HAD EXISTING AUTHORITY UNDER § 2–301(A) OF THIS TITLE ON OR BEFORE OCTOBER 1, 2009; OR**
**(II) GREENHOUSE GAS EMISSIONS REDUCTIONS REQUIRED OF THE MANUFACTURING SECTOR AS A RESULT OF THE STATE'S IMPLEMENTATION OF THE REGIONAL GREENHOUSE GAS INITIATIVE.**

**(G) A REGULATION ADOPTED BY A STATE AGENCY FOR THE PURPOSE OF REDUCING GREENHOUSE GAS EMISSIONS IN ACCORDANCE WITH THIS SECTION MAY NOT BE CONSTRUED TO RESULT IN A SIGNIFICANT INCREASE IN COSTS TO THE STATE'S MANUFACTURING SECTOR UNLESS THE SOURCE WOULD NOT INCUR THE COST INCREASE BUT FOR THE NEW REGULATION.**

**2–1206.**
**IN DEVELOPING AND IMPLEMENTING THE PLAN REQUIRED BY § 2–1205 OF THIS SUBTITLE, THE DEPARTMENT SHALL:**
**(1) ANALYZE THE FEASIBILITY OF MEASURES TO COMPLY WITH THE GREENHOUSE GAS EMISSIONS REDUCTIONS REQUIRED BY THIS SUBTITLE;**

**(2) CONSIDER THE IMPACT ON RURAL COMMUNITIES OF ANY TRANSPORTATION RELATED MEASURES PROPOSED IN THE PLAN;**

**(3) PROVIDE THAT A GREENHOUSE GAS EMISSIONS SOURCE THAT VOLUNTARILY REDUCES ITS GREENHOUSE GAS EMISSIONS BEFORE THE IMPLEMENTATION OF THIS SUBTITLE SHALL RECEIVE APPROPRIATE CREDIT FOR ITS EARLY VOLUNTARY ACTIONS;**

**(4) PROVIDE FOR THE USE OF OFFSET CREDITS GENERATED BY ALTERNATIVE COMPLIANCE MECHANISMS EXECUTED WITHIN THE STATE, INCLUDING CARBON SEQUESTRATION PROJECTS, TO ACHIEVE COMPLIANCE WITH GREENHOUSE GAS EMISSIONS REDUCTIONS REQUIRED BY THIS SUBTITLE;**

**(5) ENSURE THAT THE PLAN DOES NOT DECREASE THE LIKELIHOOD OF RELIABLE AND AFFORDABLE ELECTRICAL SERVICE AND STATEWIDE FUEL SUPPLIES; AND**

**(6) CONSIDER WHETHER THE MEASURES WOULD RESULT IN AN INCREASE IN ELECTRICITY COSTS TO CONSUMERS IN THE STATE;**

**(7) CONSIDER THE IMPACT OF THE PLAN ON THE ABILITY OF THE STATE TO:**
**(I) ATTRACT, EXPAND, AND RETAIN COMMERCIAL AVIATION SERVICES; AND**
**(II) CONSERVE, PROTECT, AND RETAIN AGRICULTURE; AND**

**(8) ENSURE THAT THE GREENHOUSE GAS EMISSIONS REDUCTION MEASURES IMPLEMENTED IN ACCORDANCE WITH THE PLAN:**
**(I) ARE IMPLEMENTED IN AN EFFICIENT AND COST–EFFECTIVE MANNER;**
**(II) DO NOT DISPROPORTIONATELY IMPACT RURAL OR LOW–INCOME, LOW– TO MODERATE–INCOME, OR MINORITY COMMUNITIES OR ANY OTHER PARTICULAR CLASS OF ELECTRICITY RATEPAYERS;**
**(III) MINIMIZE LEAKAGE;**
**(IV) ARE QUANTIFIABLE, VERIFIABLE, AND ENFORCEABLE;**
**(V) DIRECTLY CAUSE NO LOSS OF EXISTING JOBS IN THE MANUFACTURING SECTOR;**
**(VI) PRODUCE A NET ECONOMIC BENEFIT TO THE STATE'S ECONOMY AND A NET INCREASE IN JOBS IN THE STATE; AND**
**(VII) ENCOURAGE NEW EMPLOYMENT OPPORTUNITIES IN THE STATE RELATED TO ENERGY CONSERVATION, ALTERNATIVE ENERGY SUPPLY, AND GREENHOUSE GAS EMISSIONS REDUCTION TECHNOLOGIES.**

**2–1207.**
**(A) (1) AN INSTITUTION OF HIGHER EDUCATION IN THE STATE SHALL CONDUCT AN INDEPENDENT STUDY OF THE ECONOMIC IMPACT OF REQUIRING GREENHOUSE GAS EMISSIONS REDUCTIONS FROM THE STATE'S MANUFACTURING SECTOR.**

**(2) THE GOVERNOR SHALL APPOINT A TASK FORCE TO OVERSEE THE INDEPENDENT STUDY REQUIRED BY THIS SECTION.**

**(3) THE TASK FORCE SHALL INCLUDE REPRESENTATIVES OF:**
**(I) LABOR UNIONS;**
**(II) AFFECTED INDUSTRIES AND BUSINESSES;**
**(III) ENVIRONMENTAL ORGANIZATIONS; AND**
**(IV) LOW–INCOME AND MINORITY COMMUNITIES.**

**(4) TO THE EXTENT PRACTICABLE, THE MEMBERS APPOINTED TO THE TASK FORCE SHALL REPRESENT THE GEOGRAPHIC, RACIAL, AND GENDER DIVERSITY OF THE STATE.**

**(B) ON OR BEFORE OCTOBER 1, 2015, THE INSTITUTION OF HIGHER EDUCATION RESPONSIBLE FOR THE INDEPENDENT STUDY SHALL COMPLETE AND SUBMIT THE STUDY TO THE GOVERNOR AND, IN ACCORDANCE WITH §2–1246 OF THE STATE GOVERNMENT ARTICLE, THE GENERAL ASSEMBLY.**

**2–1208.**
**(A) A GREENHOUSE GAS EMISSIONS SOURCE IN THE STATE'S MANUFACTURING SECTOR THAT IMPLEMENTS A VOLUNTARY GREENHOUSE GAS EMISSIONS REDUCTION PLAN THAT IS APPROVED BY THE DEPARTMENT ON OR BEFORE JANUARY 1, 2012, MAY BE ELIGIBLE TO RECEIVE VOLUNTARY EARLY ACTION CREDITS UNDER ANY FUTURE STATE LAW REQUIRING GREENHOUSE GAS EMISSIONS REDUCTIONS FROM THE MANUFACTURING SECTOR.**

**(B) A VOLUNTARY GREENHOUSE GAS EMISSIONS REDUCTION PLAN MAY INCLUDE MEASURES TO:**
**(1) REDUCE ENERGY USE AND INCREASE PROCESS EFFICIENCY; AND**
**(2) FACILITATE INDUSTRY–WIDE RESEARCH AND DEVELOPMENT DIRECTED TOWARD FUTURE MEASURES TO REDUCE GREENHOUSE GAS EMISSIONS.**

**2–1209.**
**(A) ON OR BEFORE OCTOBER 1, 2015, THE DEPARTMENT SHALL SUBMIT A REPORT TO THE GOVERNOR AND, IN ACCORDANCE WITH § 2–1246 OF THE STATE GOVERNMENT ARTICLE, THE GENERAL ASSEMBLY THAT INCLUDES:**

**(1) A SUMMARY OF THE STATE'S PROGRESS TOWARD ACHIEVING THE 2020 EMISSIONS REDUCTION REQUIRED BY THE PLAN UNDER § 2–1205 OF THIS SUBTITLE;**

**(2) AN UPDATE ON EMERGING TECHNOLOGIES TO REDUCE GREENHOUSE GAS EMISSIONS;**

**(3) A REVIEW OF THE BEST AVAILABLE SCIENCE, INCLUDING UPDATES BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, REGARDING THE LEVEL AND PACE OF GREENHOUSE GAS EMISSIONS REDUCTIONS AND SEQUESTRATION NEEDED TO AVOID DANGEROUS ANTHROPOGENIC CHANGES TO THE EARTH'S CLIMATE SYSTEM;**

**(4) RECOMMENDATIONS ON THE NEED FOR SCIENCE–BASED ADJUSTMENTS TO THE REQUIREMENT TO REDUCE STATEWIDE GREENHOUSE GAS EMISSIONS BY 25% BY 2020;**

**(5) A SUMMARY OF ADDITIONAL OR REVISED REGULATIONS, CONTROL PROGRAMS, OR INCENTIVES THAT ARE NECESSARY TO ACHIEVE THE 25% REDUCTION IN STATEWIDE GREENHOUSE GAS EMISSIONS REQUIRED UNDER THIS SUBTITLE, OR A REVISED REDUCTION RECOMMENDED IN ACCORDANCE WITH ITEM (4) OF THIS SUBSECTION;**

**(6) THE STATUS OF ANY FEDERAL PROGRAM TO REDUCE GREENHOUSE GAS EMISSIONS AND ANY TRANSITION BY THE STATE FROM ITS PARTICIPATION IN THE REGIONAL GREENHOUSE GAS INITIATIVE TO A COMPARABLE FEDERAL CAP AND TRADE PROGRAM; AND**

**(7) AN ANALYSIS OF THE OVERALL ECONOMIC COSTS AND BENEFITS TO THE STATE'S ECONOMY, ENVIRONMENT, AND PUBLIC HEALTH OF A CONTINUATION OR MODIFICATION OF THE REQUIREMENT TO ACHIEVE A REDUCTION OF 25% IN STATEWIDE GREENHOUSE GAS EMISSIONS BY 2020, INCLUDING REDUCTIONS IN OTHER AIR POLLUTANTS, DIVERSIFICATION OF ENERGY SOURCES, THE IMPACT ON EXISTING JOBS, THE CREATION OF NEW JOBS, AND EXPANSION OF THE STATE'S LOW CARBON ECONOMY.**

**(B) THE REPORT REQUIRED UNDER SUBSECTION (A) OF THIS SECTION SHALL BE SUBJECT TO A PUBLIC COMMENT AND HEARING PROCESS CONDUCTED BY THE DEPARTMENT.**

**2–1210.**

**ON REVIEW OF THE STUDY REQUIRED UNDER § 2–1207 OF THIS SUBTITLE, AND THE REPORT REQUIRED UNDER § 2–1209 OF THIS SUBTITLE, THE GENERAL ASSEMBLY MAY ACT TO MAINTAIN, REVISE, OR ELIMINATE THE 25% GREENHOUSE GAS EMISSIONS REDUCTION REQUIRED UNDER THIS SUBTITLE.**

**2–1211.**

**THE DEPARTMENT SHALL MONITOR IMPLEMENTATION OF THE PLAN REQUIRED UNDER § 2–1205 OF THIS SUBTITLE AND SHALL SUBMIT A REPORT, ON OR BEFORE OCTOBER 1, 2020, AND EVERY 5 YEARS THEREAFTER, TO THE GOVERNOR AND, IN ACCORDANCE WITH § 2–1246 OF THE STATE GOVERNMENT ARTICLE, THE GENERAL ASSEMBLY THAT DESCRIBES THE STATE'S PROGRESS TOWARD ACHIEVING:**

**(1) THE REDUCTION IN GREENHOUSE GAS EMISSIONS REQUIRED UNDER THIS SUBTITLE, OR ANY REVISIONS CONDUCTED IN ACCORDANCE WITH §2–1210 OF THIS SUBTITLE; AND**

**(2) THE GREENHOUSE GAS EMISSIONS REDUCTIONS NEEDED BY 2050 IN ORDER TO AVOID DANGEROUS ANTHROPOGENIC CHANGES TO THE EARTH'S CLIMATE SYSTEM, BASED ON THE PREDOMINANT VIEW OF THE SCIENTIFIC COMMUNITY AT THE TIME OF THE LATEST REPORT.**

SECTION 4. AND BE IT FURTHER ENACTED, That during the process outlined in § 2–1205(a) of the Environment Article, as enacted by Section 3 of this Act, the Department of the Environment shall include the Department of Agriculture, the Maryland Farm Bureau, the Maryland Association of Soil Conservation Districts, the Delmarva Poultry Industry, the Maryland Dairy Industry Association, and the Maryland Agricultural Commission in discussions on the role to be played by agriculture to reduce greenhouse gas emissions.

SECTION 4. 5. AND BE IT FURTHER ENACTED, That if any provision of this Act or the application thereof to any person or circumstance is held invalid for any reason in a court of competent jurisdiction, the invalidity does not affect other provisions or any other application of this Act which can be given effect without the invalid provision or application, and for this purpose the provisions of this Act are declared severable.

SECTION 5. 6. AND BE IT FURTHER ENACTED, That any reference in the Annotated Code of Maryland rendered incorrect or obsolete by the provisions of Section 6 of this Act shall be corrected by the publishers of the Annotated Code, in consultation with and subject to the approval of the Department of Legislative Services, with no further action required by the General Assembly.

SECTION 6. 7. AND BE IT FURTHER ENACTED, That Section 2 of this Act shall take effect October 1, 2009. It shall remain effective for a period of 7 years and 3 months, and at the end of December 31, 2016, with no further action required by the General Assembly, Section 2 of this Act shall be abrogated and of no further force and effect.

SECTION 7. 8. AND BE IT FURTHER ENACTED, That, except as provided in Section 6 7 of this Act, this Act shall take effect October 1, 2009.

**Approved by the Governor, May 7, 2009.**

Maryland
Department of
the Environment

# Appendix B

The Greenhouse Gas Emissions Reduction Act - Reauthorization

# 2019 GGRA Draft Plan

# SENATE BILL 323

M3

6lr0362
CF HB 610

By: **Senators Pinsky, Raskin, Benson, Brochin, Conway, Currie, Feldman, Ferguson, Guzzone, Kagan, Kelley, King, Klausmeier, Lee, Madaleno, Manno, Mathias, McFadden, Middleton, Miller, Nathan–Pulliam, Peters, Pugh, Ramirez, Rosapepe, Young, and Zirkin**
Introduced and read first time: January 27, 2016
Assigned to: Education, Health, and Environmental Affairs

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Committee Report: Favorable with amendments
Senate action: Adopted
Read second time: February 18, 2016

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CHAPTER ______

AN ACT concerning

## Greenhouse Gas Emissions Reduction Act – Reauthorization

FOR the purpose of repealing the termination date for a certain provision of law requiring the State to reduce statewide greenhouse gas emissions by a certain amount by a certain date; requiring the State to reduce statewide greenhouse gas emissions by a certain amount by a certain date; requiring the Department of the Environment to submit a proposed plan in accordance with certain requirements to the Governor and the General Assembly on or before a certain date; requiring the Department to adopt a final plan in accordance with certain requirements on or before a certain date; requiring an institution of higher education in the State to conduct a certain study in accordance with certain requirements and submit the study to the Governor and the General Assembly on or before a certain date; authorizing the General Assembly to maintain, revise, or eliminate certain statewide greenhouse gas emissions reduction requirements under certain circumstances; requiring the General Assembly to consider whether to continue certain manufacturing provisions under certain circumstances; altering the date by which the Department must monitor the implementation of certain plans and submit certain reports to the Governor and the General Assembly on or before certain dates; requiring the Department to include certain agencies and entities in certain discussions regarding certain matters; making the provisions of this Act severable; providing for the termination of a certain provision of this Act; and generally relating to the reduction of statewide greenhouse gas emissions.

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EXPLANATION: **CAPITALS INDICATE MATTER ADDED TO EXISTING LAW.**
**[**Brackets**]** indicate matter deleted from existing law.
Underlining indicates amendments to bill.
~~Strike out~~ indicates matter stricken from the bill by amendment or deleted from the law by amendment.

BY repealing and reenacting, with amendments,
Chapter 171 of the Acts of the General Assembly of 2009
Section 7

BY repealing and reenacting, with amendments,
Chapter 172 of the Acts of the General Assembly of 2009
Section 7

BY repealing and reenacting, without amendments,
Article – Environment
Section 2–1204
Annotated Code of Maryland
(2013 Replacement Volume and 2015 Supplement)

BY adding to
Article – Environment
Section 2–1204.1
Annotated Code of Maryland
(2013 Replacement Volume and 2015 Supplement)

BY repealing and reenacting, with amendments,
Article – Environment
Section 2–1205, 2–1206, 2–1207, 2–1210, and 2–1211
Annotated Code of Maryland
(2013 Replacement Volume and 2015 Supplement)

SECTION 1. BE IT ENACTED BY THE GENERAL ASSEMBLY OF MARYLAND, That the Laws of Maryland read as follows:

## Chapter 171 of the Acts of 2009

SECTION 7. AND BE IT FURTHER ENACTED, That Section 2 of this Act shall take effect October 1, 2009. **[**It shall remain effective for a period of 7 years and 3 months, and at the end of December 31, 2016, with no further action required by the General Assembly, Section 2 of this Act shall be abrogated and of no further force and effect.**]**

## Chapter 172 of the Acts of 2009

SECTION 7. AND BE IT FURTHER ENACTED, That Section 2 of this Act shall take effect October 1, 2009. **[**It shall remain effective for a period of 7 years and 3 months, and at the end of December 31, 2016, with no further action required by the General Assembly, Section 2 of this Act shall be abrogated and of no further force and effect.**]**

## Article – Environment

2–1204.

The State shall reduce statewide greenhouse gas emissions by 25% from 2006 levels by 2020.

SECTION 2. AND BE IT FURTHER ENACTED, That the Laws of Maryland read as follows:

### Article – Environment

**2–1204.1.**

**THE STATE SHALL REDUCE STATEWIDE GREENHOUSE GAS EMISSIONS BY 40% FROM 2006 LEVELS BY 2030.**

SECTION 3. AND BE IT FURTHER ENACTED, That the Laws of Maryland read as follows:

### Article – Environment

2–1205.

(a) The State shall develop **[**a plan**]** **PLANS**, adopt regulations, and implement programs that reduce statewide greenhouse gas emissions in accordance with this subtitle.

(b) On or before December 31, **[**2011**]** **2018**, the Department shall:

(1) Submit a proposed plan **THAT REDUCES STATEWIDE GREENHOUSE GAS EMISSIONS BY 40% FROM 2006 LEVELS BY 2030** to the Governor and General Assembly;

(2) Make the proposed plan available to the public; and

(3) Convene a series of public workshops to provide interested parties with an opportunity to comment on the proposed plan.

(c) (1) The Department shall, on or before December 31, 2012, adopt a final plan that reduces statewide greenhouse gas emissions by 25% from 2006 levels by 2020.

**(2) THE DEPARTMENT SHALL, ON OR BEFORE DECEMBER 31, 2019, ADOPT A FINAL PLAN THAT REDUCES STATEWIDE GREENHOUSE GAS EMISSIONS BY 40% FROM 2006 LEVELS BY 2030.**

**[**(2)**]** **(3)** The **[**plan**]** **PLANS** shall be developed **[**as the initial State action**]** in recognition of the finding by the Intergovernmental Panel on Climate Change that developed countries will need to reduce greenhouse gas emissions by between 80% and 95% from 1990 levels by 2050.

(d) The final [plan] **PLANS** required under subsection (c) of this section shall include:

(1) Adopted regulations that implement all plan measures for which State agencies have existing statutory authority; and

(2) A summary of any new legislative authority needed to fully implement the [plan] **PLANS** and a timeline for seeking legislative authority.

(e) In developing and adopting a final plan to reduce statewide greenhouse gas emissions, the Department shall consult with State and local agencies as appropriate.

(f) (1) Unless required by federal law or regulations or existing State law, regulations adopted by State agencies to implement [the] **A** final plan may not:

(i) Require greenhouse gas emissions reductions from the State's manufacturing sector; or

(ii) Cause a significant increase in costs to the State's manufacturing sector.

(2) Paragraph (1) of this subsection may not be construed to exempt greenhouse gas emissions sources in the State's manufacturing sector from the obligation to comply with:

(i) Greenhouse gas emissions monitoring, recordkeeping, and reporting requirements for which the Department had existing authority under § 2–301(a) of this title on or before October 1, 2009; or

(ii) Greenhouse gas emissions reductions required of the manufacturing sector as a result of the State's implementation of the Regional Greenhouse Gas Initiative.

(g) A regulation adopted by a State agency for the purpose of reducing greenhouse gas emissions in accordance with this section may not be construed to result in a significant increase in costs to the State's manufacturing sector unless the source would not incur the cost increase but for the new regulation.

2–1206.

In developing and implementing the [plan] **PLANS** required by § 2–1205 of this subtitle, the Department shall:

(1) Analyze the feasibility of measures to comply with the greenhouse gas emissions reductions required by this subtitle;

(2) Consider the impact on rural communities of any transportation related measures proposed in the [plan] **PLANS**;

(3) Provide that a greenhouse gas emissions source that voluntarily reduces its greenhouse gas emissions before the implementation of this subtitle shall receive appropriate credit for its early voluntary actions;

(4) Provide for the use of offset credits generated by alternative compliance mechanisms executed within the State, including carbon sequestration projects, to achieve compliance with greenhouse gas emissions reductions required by this subtitle;

(5) Ensure that the [plan does] **PLANS DO** not decrease the likelihood of reliable and affordable electrical service and statewide fuel supplies;

(6) Consider whether the measures would result in an increase in electricity costs to consumers in the State;

(7) Consider the impact of the [plan] **PLANS** on the ability of the State to:

(i) Attract, expand, and retain commercial aviation services; and

(ii) Conserve, protect, and retain agriculture; and

(8) Ensure that the greenhouse gas emissions reduction measures implemented in accordance with the [plan] **PLANS**:

(i) Are implemented in an efficient and cost–effective manner;

(ii) Do not disproportionately impact rural or low–income, low– to moderate–income, or minority communities or any other particular class of electricity ratepayers;

(iii) Minimize leakage;

(iv) Are quantifiable, verifiable, and enforceable;

(v) Directly cause no loss of existing jobs in the manufacturing sector;

(vi) Produce a net economic benefit to the State's economy and a net increase in jobs in the State; and

(vii) Encourage new employment opportunities in the State related to energy conservation, alternative energy supply, and greenhouse gas emissions reduction technologies.

2–1207.

(a) (1) An institution of higher education in the State shall conduct an independent study of the economic impact of requiring greenhouse gas emissions reductions from the State's manufacturing sector.

(2) The [Governor shall appoint a task force to] **MARYLAND COMMISSION ON CLIMATE CHANGE SHALL** oversee the independent study required by this section.

[(3) The task force shall include representatives of:

(i) Labor unions;

(ii) Affected industries and businesses;

(iii) Environmental organizations; and

(iv) Low–income and minority communities.

(4) To the extent practicable, the members appointed to the task force shall reflect the geographic, racial, and gender diversity of the State.]

(b) On or before October 1, [2015] **2022**, the institution of higher education responsible for the independent study shall complete and submit the study to the Governor and, in accordance with § 2–1246 of the State Government Article, the General Assembly.

2–1210.

On review of the study required under § 2–1207 of this subtitle, and the ~~report~~ **REPORTS** required under § ~~2–1209~~ **2–1211** of this subtitle, the General Assembly [may]**:**

**(1) MAY** act to maintain, revise, or eliminate the [25%] **40%** greenhouse gas emissions reduction required under **§ 2–1204.1 OF** this subtitle**; AND**

**(2) SHALL CONSIDER WHETHER TO CONTINUE THE SPECIAL MANUFACTURING PROVISIONS IN § 2–1205(F)(1) OF THIS SUBTITLE**.

2–1211.

The Department shall monitor implementation of the [plan] **PLANS** required under § 2–1205 of this subtitle and shall submit a report, on or before October 1, [2020] **2022**, and every 5 years thereafter, to the Governor and, in accordance with § 2–1246 of the State Government Article, the General Assembly that describes the State's progress toward achieving:

(1) The [reduction] **REDUCTIONS** in greenhouse gas emissions required under this subtitle, or any revisions conducted in accordance with § 2–1210 of this subtitle; and

(2) The greenhouse gas emissions reductions needed by 2050 in order to avoid dangerous anthropogenic changes to the Earth's climate system, based on the predominant view of the scientific community at the time of the latest report.

SECTION 4. AND BE IT FURTHER ENACTED, That during the process outlined in § 2–1205(a) of the Environment Article, as enacted by Section 3 of this Act, the Department of the Environment shall include the Department of Agriculture, the Maryland Farm Bureau, the Maryland Association of Soil Conservation Districts, the Delmarva Poultry Industry, the Maryland Dairy Industry Association, and the Maryland Agricultural Commission in discussions on the role to be played by agriculture to reduce greenhouse gas emissions.

SECTION 5. AND BE IT FURTHER ENACTED, That, if any provision of this Act or the application thereof to any person or circumstance is held invalid for any reason in a court of competent jurisdiction, the invalidity does not affect other provisions or any other application of this Act that can be given effect without the invalid provision or application, and for this purpose the provisions of this Act are declared severable.

SECTION 6. AND BE IT FURTHER ENACTED, That Section 2 of this Act shall take effect October 1, 2016. It shall remain effective for a period of 7 years and 3 months and at, the end of December 31, 2023, with no further action required by the General Assembly, Section 2 of this Act shall be abrogated and of no further force and effect.

SECTION 7. AND BE IT FURTHER ENACTED, That, except as provided in Section 6 of this Act, this Act shall take effect October 1, 2016.

Approved:

____________________________________________________

Governor.

____________________________________________________

President of the Senate.

____________________________________________________

Speaker of the House of Delegates.

Maryland
Department of
the Environment

# Appendix C

## Greenhouse Gas Emission Projections Documentation (2014-2030)

# 2019 GGRA Draft Plan

Maryland
Department of
the Environment

Larry Hogan
Governor

Boyd Rutherford
Lieutenant Governor

Ben Grumbles
Secretary

# State of Maryland

# Greenhouse Gas Emission Projections Documentation (2014 -2030)

November 8, 2018

Prepared by:
Maryland Department of the Environment

# Maryland Department of the Environment
## 2030 Business-as-Usual (BAU) Greenhouse Gas Emissions Projection

Air and Radiation Administration
1800 Washington Boulevard, Suite 730
Baltimore, Maryland 21230
Phone 410.537.4219 • Fax 410.537.4223

## ACKNOWLEDGEMENTS

The Maryland Department of the Environment (MDE) appreciates the time and assistance provided by numerous contacts throughout Maryland, in neighboring States, and at federal agencies. Special appreciation is extended to the staff at several Maryland State Agencies for their input, in particular to:

- Office of Surface Mining Reclamation and Enforcement, with particular thanks to Cunningham, Thomas.
- PJM with particular thanks to staff member Ken Schuyler
- Maryland Forest Services, with particular thanks to Forester Robert Felft
- Maryland Department of Agriculture, particular thanks to Philip Davidson
- Controller of Maryland-Field Enforcement Division, particular thanks to Chuck Ulm

MDE would also like to express their appreciation to staff at MDE Air and Radiation Administration (ARA) compliance unit and Solid Waste-waste diversion division who provided valuable data during the development of this report.

Source Documentation:

- MDE-Air and Radiation Administration
    - MDE – ARA Compliance Program
    - MDE – ARA Permits Program
    - MDE – ARA Air Quality Planning Program
    - MDE – ARA Mobile Source Program
    - MDE – Solid Waste Program

- Maryland Department of Labor, License and Regulation
- Maryland Department of Transportation
- Maryland Department of Planning

Lead Agency and Quality Assurance:MDE ARA Air Quality Policy & Planning Division

MDE is the agency responsible for preparing and submitting the completed baseline GHG emissions inventory for Maryland. The MDE ARA Air Quality Planning Division compiled the GHG emissions inventory for the State of Maryland.

# Acronyms and Key Terms

| | |
|---|---|
| BOD | Biochemical Oxygen Demand |
| Btu | British Thermal Unit |
| C | Carbon* |
| $CaCO_3$ | Calcium Carbonate |
| CCS | Center for Climate Strategies |
| CEC | Commission for Environmental Cooperation in North America |
| CFCs | Chlorofluorocarbons* |
| $CH_4$ | Methane* |
| CO | Carbon Monoxide* |
| $CO_2$ | Carbon Dioxide* |
| $CO_2e$ | Carbon Dioxide Equivalent* |
| CRP | Federal Conservation Reserve Program |
| DOE | Department of Energy |
| DOT | Department of Transportation |
| EEZ | Exclusive Economic Zone |
| EIA | US DOE Energy Information Administration |
| EIIP | Emission Inventory Improvement Program |
| EPA | United States Environmental Protection Agency |
| FAA | Federal Aviation Administration |
| FAPRI | Food and Agricultural Policy Research Institute |
| FERC | Federal Energy Regulatory Commission |
| FHWA | Federal Highway Administration |
| FIA | Forest Inventory Analysis |
| Gg | Gigagrams |
| GHG | Greenhouse Gas* |
| GWh | Gigawatt-hour |
| GWP | Global Warming Potential* |
| $H_2O$ | Water Vapor* |
| HBFCs | Hydrobromofluorocarbons* |
| HC | Hydrocarbon |
| HCFCs | Hydrochlorofluorocarbons* |
| HFCs | Hydrofluorocarbons* |

| | |
|---|---|
| HWP | Harvested Wood Products |
| IPCC | Intergovernmental Panel on Climate Change* |
| kg | Kilogram |
| $km^2$ | Square Kilometers |
| kWh | Kilowatt-hour |
| lb | Pound |
| LF | Landfill |
| LFG | Landfill Gas |
| LFGTE | Landfill Gas Collection System and Landfill-Gas-to-Energy |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas |
| MAAC | Mid-Atlantic Area Council |
| MANE-VU | Mid-Atlantic/Northeast Visibility Union |
| MDDNR | Maryland Department of Natural Resources |
| MDE | Maryland Department of the Environment |
| Mg | Megagram |
| MMBtu | Million British Thermal Units |
| MMt | Million Metric Tons |
| MMtC | Million Metric Tons Carbon |
| $MMtCO_2e$ | Million Metric tons Carbon Dioxide Equivalent |
| MSW | Municipal Solid Waste |
| Mt | Metric ton (equivalent to 1.102 short tons) |
| MWh | Megawatt-hour |
| $N_2O$ | Nitrous Oxide* |
| NASS | National Agriculture Statistical Service |
| NEI | National Emissions Inventory |
| NEMS | National Energy Modeling System |
| NF | National Forest |
| NMVOCs | Nonmethane Volatile Organic Compound* |
| $NO_2$ | Nitrogen Dioxide* |
| $NO_x$ | Nitrogen Oxides* |
| $O_3$ | Ozone* |
| ODS | Ozone-Depleting Substance* |
| OH | Hydroxyl Radical* |

| | |
|---|---|
| OPS | Office of Pipeline Safety |
| PFCs | Perfluorocarbons* |
| ppb | Parts per Billion |
| ppm | Parts per Million |
| ppt | Parts per Trillion |
| ppmv | Parts per Million by Volume |
| RCI | Residential, Commercial, and Industrial |
| RGGI | Regional Greenhouse Gas Initiative |
| RPS | Renewable Portfolio Standard |
| SAR | Second Assessment Report* |
| SED | State Energy Data |
| $SF_6$ | Sulfur Hexafluoride* |
| Sinks | Removals of carbon from the atmosphere, with the carbon stored in forests, soils, landfills, wood structures, or other biomass-related products. |
| SIT | State Greenhouse Gas Inventory Tool |
| $SO_2$ | Sulfur Dioxide* |
| t | Metric Ton |
| T&D | Transmission and Distribution |
| TAR | Third Assessment Report* |
| TOG | Total Organic Gas |
| TWh | Terawatt-hour |
| UNFCCC | United Nations Framework Convention on Climate Change |
| US | United States |
| US DOE | United States Department of Energy |
| US EPA | United States Environmental Protection Agency |
| USDA | United States Department of Agriculture |
| USFS | United States Forest Service |
| USGS | United States Geological Survey |
| VMT | Vehicle Mile Traveled |
| VOCs | Volatile Organic Compound* |
| WW | Wastewater |
| yr | Year |

# Table of Contents

# INDEX OF TABLES

# 1.0 EXECUTIVE SUMMARY

## 1.1 OVERVIEW

This document describes the procedures the Maryland Department of the Environment (MDE) used to project the greenhouse gas (GHG) emissions that would occur in Maryland in year 2030, under a Business as Usual (BAU) scenario, where no new measures or policies to reduce GHG emissions are implemented. The analysis is provided to assess the amount of GHG reductions necessary to achieve the Maryland Greenhouse Gas Emissions Reduction Act of 2016 (GGRA) goal of a 40% reduction in GHG emissions by 2030 from a 2006 baseline.

The 2030 BAU GHG emissions projection uses the Maryland 2014 Periodic GHG emissions Inventory as the reference Base Year. Surrogate growth factors were developed and applied to the 2014 Base Year to project the GHG emissions from 2014 to 2030. As fully described in the Base Year 2014 Inventory documentation[1], the emission sources are divided into the following eight source categories:

- Electricity Supply
- Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Transportation Energy Use
- Industrial Processes
- Fossil Fuel Production Industry
- Agriculture
- Waste Management
- Forestry and Land Use

The emission projection estimates outlined in this document have been calculated on a state-wide basis and have not been spatially allocated to the county level unless otherwise stated. Descriptions of each emission source category are presented in the following sections.

## 1.2 Business-Business-as-Usual 2030 Emissions

Maryland’s anthropogenic 2030 BAU GHG emissions and anthropogenic sinks (carbon storage) were estimated by projecting Maryland‘s GHG emissions from a 2014 Base Year using derived growth factors, specific to each of the different sectors. Sector specific growth factors were derived from several surrogate future growth forecast sources including:

- Maryland Department of Planning; “Population and Household Population Projections[2]”
- Maryland Department of Transportation; “On-Road Inventory Development Process[3]”
- Maryland Department of Labor, Licensing and Regulation; “Maryland Industrial Projection Workforce Information and Performance (2014-2024)[4]”
- PJM Load Forecast Report[5]
- EPA State Inventory Tool (SIT) Projection Tools[1]

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[1] http://mde.maryland.gov/programs/Air/ClimateChange/Pages/GreenhouseGasInventory.aspx
[2] https://planning.maryland.gov/MSDC/Pages/s3_projection.aspx
[3] http://mde.maryland.gov/programs/Air/ClimateChange/MCCC/STWG/OnRoadInventoryMDOT.pdf
[4] http://www.dllr.state.md.us/lmi/iandoproj/industry.shtml
[5] http://pjm.com/~/media/library/reports-notices/load-forecast/2016-load-report.ashx

Table ES-1 correlates the 2014 GHG emission inventory source sector with the surrogate used for growth and the place where the surrogate growth data was obtained.

**Table ES-1: GHG Source Categories – Growth Factor Surrogate and Source**

| Source Category | Surrogate Growth Factor | Source of Surrogate Data | URL |
|---|---|---|---|
| **Electricity Supply** | Electricity Consumption | PJM Load Forecast | http://pjm.com/~/media/library/reports-notices/load-forecast/2016-load-report.ashx |
| **Residential Fuel Consumption** | Housing Data | Maryland Department of Planning | https://planning.maryland.gov/MSDC/Pages/s3_projection.aspx |
| **Commercial and Industrial Fuel Consumption** | Employment Data | Maryland Department of Labor, Licensing & Regulation | http://www.dllr.state.md.us/lmi/iandoproj/industry.shtml |
| **On-Road Transportation** | Vehicle Miles Traveled | Maryland Department of Transportation | https://planning.maryland.gov/MSDC/Pages/s3_projection.aspx |
| **Off-Road Transportation** | Non-Road MOVES Model Projection Data | Non-Road MOVES Model | https://www.epa.gov/moves/moves2014a-latest-version-motor-vehicle-emission-simulator-moves |
| **Fossil Fuel Industry** | SIT Tool Projections | EPA SIT Projection Tool | https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool |
| **Industrial** | SIT Tool Projections | EPA SIT Projection Tool | https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool |
| **Agriculture** | SIT Tool Projections | EPA SIT Projection Tool | https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool |
| **Waste Management** | County Population | Maryland Department of Planning | https://planning.maryland.gov/MSDC/Pages/s3_projection.aspx |

Emissions projections are assumed to indicate only what the future emissions would be if the assumptions that underpin the projections continue to occur. Projections are not forecasts or predictions about what will happen. In the preparation of these projections therefore, MDE assumptions are based on the forecasted growth in the gross domestic product, population, and economic growth, consistent with the MDE understanding of these assumptions as the expected drivers of future emissions.

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[1] https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool

## 1.3 Projection Results

The projected 2030 GHG BAU emissions in Maryland were based on the Maryland statewide GHG emissions inventory for the base Year 2014 with respect to existing policy and regulations, without any consideration for any new policy or regulation implementation to reduce the GHG emissions from the base Year 2014. Year 2030 emissions were estimated to be approximately 106.04 million metric tons (MMT) of *gross*[1] $CO_2$e emissions (consumption basis).

Estimates of carbon sinks within Maryland's forests, including urban forests and land use changes, have been kept constant in this projection due to lack of reliable data and estimation methodology. The current estimates of 11.65 MMT$CO_2$e was retained as the estimated amount of Forest biomass and agricultural soils carbon sinks that will be stored in 2030 in Maryland. This leads to *net projected* emissions of 94.40 MMTT$CO_2$e in Maryland in 2030. Table ES-2 provides a summary of the projected 2030 GHG emissions for Maryland.

There are three principal sources of GHG emission in Maryland: electricity consumption; transportation; and residential, commercial, and industrial (RCI) fossil fuel use. Electricity consumption emissions are projected to account for 34% of gross GHG emissions in 2030. Transportation is projected to account for 40% of Maryland's gross GHG emissions in 2030, while RCI fuel use is projected to account for 16% of Maryland's 2030 gross GHG emissions. A graphical representation of the 2030 GHG emissions by source sector is presented in Figure ES-1.

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[1] Excluding GHG emissions removed due to forestry and other land uses.

**Figure ES-1: Gross Projected GHG Emissions by Sector, 2030, Maryland**

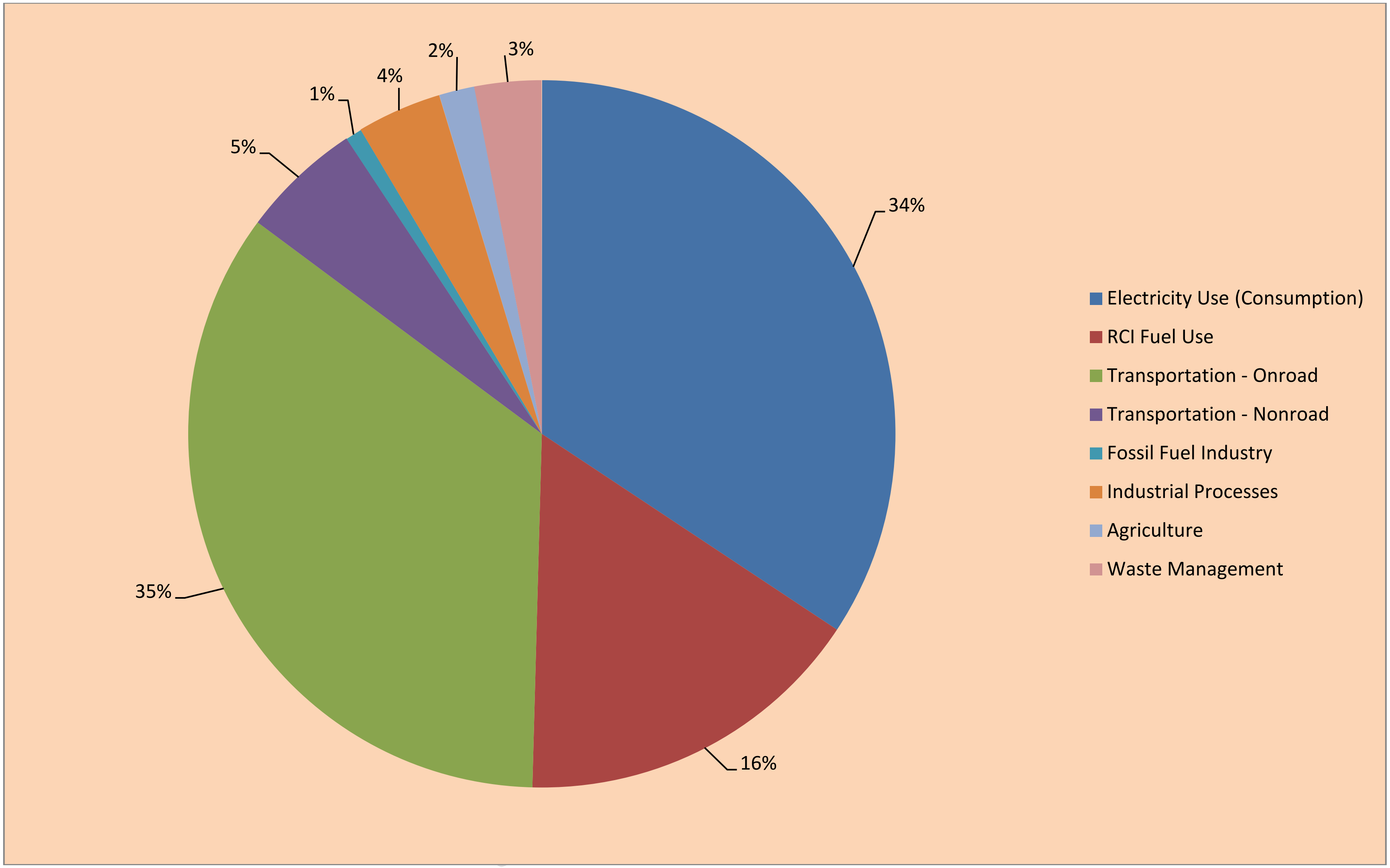
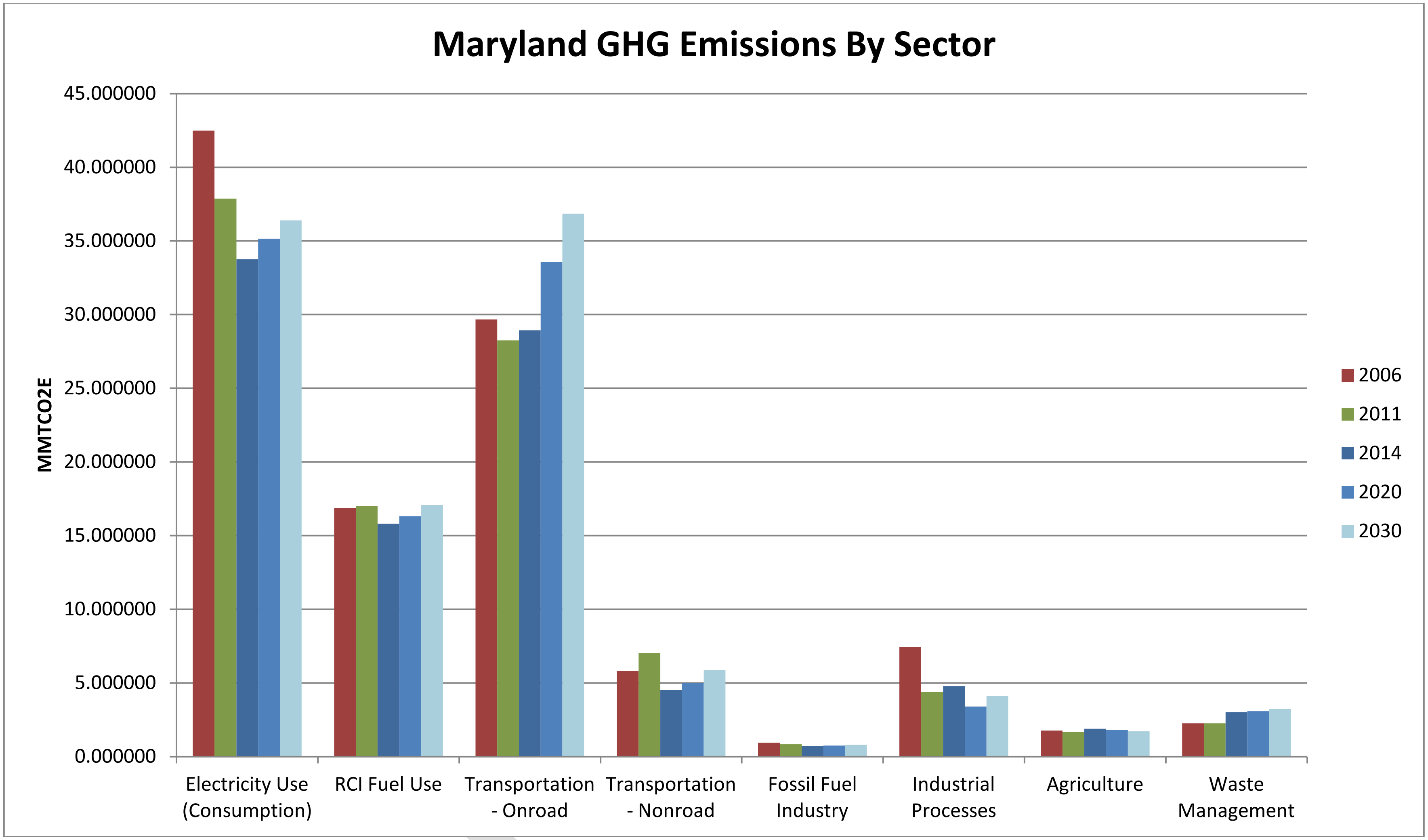


Figure ES-1 shows the how each sector contributes to the projected 2030 greenhouse gas emissions. Below, Figure ES-2 shows another representation of how each sector contributes to greenhouse gas emissions in mmtCO$_2$.

**Figure ES-2: Maryland GHG Projected Emissions by Sector**



Maryland's projected emission in 2030 (106.04 MMTCO$_2$E) will represent a slight decline in GHG emission from the 2006 Base Year.

## 1.5 EMISSIONS SUMMARY

### Table ES-2: Maryland 2030 GHG Emissions Projection, by Sector

| **Source Category** | **Fuel Type** | **Year** | | | |
|---|---|---|---|---|---|
| | | **2006 (MMtCO$_2$e)** | **2011 (MMtCO$_2$e)** | **2014 (MMtCO$_2$e)** | **2030 (MMtCO$_2$e)** |
| **Energy Use (CO$_2$, CH$_4$, N$_2$O)** | | 95.75995003 | **90.966191** | **83.737002** | **96.97318** |
| **Electricity Use (Consumption)$^b$** | | 42.**47567455** | **37.86012929** | **33.760155** | **36.402415** |
| | Electricity Production (in-state) | **32.16484764** | **24.546391** | **19.911764** | **21.4704556** |
| | *Coal* | 28.27769105 | 21.931503 | 18.395077 | 19.8347717 |
| | CO$_2$ | 28.13057387 | 21.84771288 | 18.270289 | 19.7001826 |
| | CH$_4$ | 0.006356915 | 0.008782304 | 0.029584 | 0.03190727 |
| | N$_2$O | 0.140760271 | 0.075008138 | 0.095204 | 0.10268183 |
| | *Natural Gas* | 3.649880813 | 2.418826 | 1.116462 | 1.20414343 |
| | CO$_2$ | 3.64841301 | 2.41333025 | 1.083775 | 1.16888964 |
| | CH$_4$ | 0.000592766 | 0.000878591 | 0.002444 | 0.00263548 |
| | N$_2$O | 0.000875036 | 0.004617224 | 0.030243 | 0.03261831 |
| | *Oil* | 0.237275776 | 0.196062 | 0.400225 | 0.43154052 |
| | CO$_2$ | 0.236572609 | 0.194627796 | 0.399099 | 0.43032561 |
| | CH$_4$ | 0.00017791 | 0.000100932 | 0.000309 | 0.00033312 |
| | N$_2$O | 0.000525257 | 0.001333067 | 0.000818 | 0.0008818 |
| | *Wood* | 0 | 0.004705 | 0.000000 | 0 |
| | CO$_2$ | 0 | 0.004668225 | 0.000000 | 0 |
| | CH$_4$ | 0 | 1.16527E-05 | 0.000000 | 0 |
| | N$_2$O | 0 | 2.53259E-05 | 0.000000 | 0 |
| | *MSW/LFG* | | | | |
| | Net Imported Electricity | 10.31082691 | **13.30903291** | **13.848392** | **14.9319594** |
| **Residential/Commercial/Industrial (RCI) Fuel Use** | | 16.87079695 | **17.000426** | **15.803958** | **17.06540** |
| | Coal | 2.997788692 | 2.956523 | 1.507120 | 1.71561 |
| | CO$_2$ | 2.976126985 | 2.935725929 | 1.496749 | 1.70360 |
| | CH$_4$ | 0.007134829 | 0.006470354 | 0.003227 | 0.00374 |
| | N$_2$O | 0.014526878 | 0.014327213 | 0.007144 | 0.00827 |
| | Natural Gas & LPG | 9.21041471 | **9.981745** | **10.710212** | 11.46348 |
| | CO$_2$ | 9.18802397 | 9.956569199 | 10.682922 | 11.43444 |
| | CH$_4$ | 0.016000535 | 0.01780597 | 0.019803 | 0.02109 |
| | N$_2$O | 0.006390205 | 0.007370279 | 0.007487 | 0.00796 |
| | Petroleum | 4.576524718 | **3.951282** | **3.472479** | **3.76789** |
| | CO$_2$ | 4.557477225 | 3.935724312 | 3.458150 | 3.75206 |
| | CH$_4$ | 0.008508848 | 0.006658166 | 0.006760 | 0.00730 |
| | N$_2$O | 0.010538645 | 0.008899469 | 0.007569 | 0.00853 |
| | Wood | 0.086068834 | **0.110875** | **0.113322** | **0.11842** |
| | CO$_2$ | 0 | 0 | 0.000000 | 0.00000 |
| | CH$_4$ | 0.061142772 | 0.081869159 | 0.087520 | 0.090688 |
| | N$_2$O | 0.024926062 | 0.029005541 | 0.025801 | 0.02774 |

| Source Category | Fuel Type | Year | | | |
|---|---|---|---|---|---|
| | | 2006 ($MMtCO_2e$) | 2011 ($MMtCO_2e$) | 2014 ($MMtCO_2e$) | 2030 ($MMtCO_2e$) |
| **Transportation** | | 35.47159388 | **35.269544** | **33.452999** | **42.7032357** |
| | Onroad Gasoline | 23.7595 | 22.526256 | 22.555441 | 28.7261932 |
| | $CO_2$ | 23.195 | 22.51905514 | 22.472039 | 28.6199748 |
| | $CH_4$ | 0.0462 | 0.006365838 | 0.006896 | 0.00878288 |
| | $N_2O$ | 0.5183 | 0.000835306 | 0.076505 | 0.09743548 |
| | Nonroad Gasoline | 1.044117546 | **2.736630** | **1.106684** | **1.36134321** |
| | $CO_2$ | 1.039550516 | 2.73189329 | 1.083478 | 1.32505867 |
| | $CH_4$ | 0.000920455 | 0.000945048 | 0.023206 | 0.02305543 |
| | $N_2O$ | 0.003646576 | 0.003791989 | 0.000000 | 0.00000000 |
| | Onroad Diesel | 5.9103 | **5.720819** | **6.381042** | **8.1267778** |
| | $CO_2$ | 5.907 | 5.720528739 | 6.360214 | 8.10025167 |
| | $CH_4$ | 0.0003 | 8.14833E-05 | 0.000096 | 0.00012165 |
| | $N_2O$ | 0.003 | 0.000209191 | 0.020732 | 0.02640448 |
| | Nonroad Diesel | 1.503926174 | **2.155778** | **1.994101** | **2.66266107** |
| | $CO_2$ | 1.488082933 | 2.133145965 | 1.993972 | 2.66252129 |
| | $CH_4$ | 0.004221409 | 0.006155096 | 0.000130 | 0.00013978 |
| | $N_2O$ | 0.011621832 | 0.016476938 | 0.000000 | 0.00000000 |
| | Rail | 0.238839589 | **0.187039** | **0.187038** | **0.18703846** |
| | $CO_2$ | 0.236600579 | 0.185305079 | 0.185304 | 0.18530411 |
| | $CH_4$ | 0.000391175 | 0.000303006 | 0.000303 | 0.00030301 |
| | $N_2O$ | 0.001847835 | 0.001431341 | 0.001431 | 0.00143134 |
| | Marine Vessels (Gas & Oil) | 0.997636149 | **0.353949** | **0.124965** | **0.1780107** |
| | $CO_2$ | 0.988598138 | 0.350663389 | 0.123832 | 0.17639727 |
| | $CH_4$ | 0.00147329 | 0.000535566 | 0.000188 | 0.00026787 |
| | $N_2O$ | 0.00756472 | 0.002749902 | 0.000945 | 0.00134556 |
| | Lubricants, Natural Gas, and LPG | 0.295955146 | **0.455045** | **0.279941** | **0.37061003** |
| | $CO_2$ | 0.295955146 | 0.455044849 | 0.275343 | 0.36452274 |
| | $CH_4$ | 0 | 0 | 0.00459805 | 0.00761276 |
| | $N_2O$ | 0 | 0 | 0 | 0.00000000 |
| | Jet Fuel and Aviation Gasoline | 1.721319275 | **1.134027** | **0.823787** | **1.09060121** |
| | $CO_2$ | 1.703343607 | 1.12251132 | 0.815404 | 1.07950256 |
| | $CH_4$ | 0.001626024 | 0.000882398 | 0.000668 | 0.00088412 |
| | $N_2O$ | 0.016349643 | 0.01063328 | 0.007716 | 0.01021453 |
| **Fossil Fuel Industry** | | 0.941884638 | **0.836092** | **0.719889** | **0.8021223** |
| | Natural Gas Industry | 0.811536367 | 0.694295 | 0.584861 | 0.65558129 |
| | $CO_2$ | 0.000128636 | 0.000327149 | 0.000353 | 0.00039475 |
| | $CH_4$ | 0.811336294 | 0.693785907 | 0.584313 | 0.65496732 |
| | $N_2O$ | 7.14367E-05 | 0.000181679 | 0.000196 | 0.00021922 |
| | Oil Industry | 0 | 0.000000 | 0.000000 | 0.00000000 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |
| | Coal Mining | 0.130348272 | 0.141797468 | 0.135028 | 0.14654101 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |

| Source Category | Fuel Type | Year | | | |
|---|---|---|---|---|---|
| | | 2006 (MMtCO$_2$e) | 2011 (MMtCO$_2$e) | 2014 (MMtCO$_2$e) | 2030 (MMtCO$_2$e) |
| | $CH_4$ | 0.130348272 | 0.141797468 | 0.135028 | 0.14654101 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |
| **Industrial Processes** | | 7.441042334 | **4.398573** | **4.784851** | **4.10595168** |
| | Cement Manufacture | 1.483241728 | 0.918256 | 1.580721 | 1.96165908 |
| | $CO_2$ | 1.483241728 | 0.918255613 | 1.580721 | 1.96165908 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |
| | Limestone and Dolomite | 0.113941192 | 0.08560464 | 0.143916 | 0.18688424 |
| | $CO_2$ | 0.113941192 | 0.08560464 | 0.143916 | 0.18688424 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |
| | Soda Ash | 0.04761102 | 0.040365129 | 0.039670 | 0.03172051 |
| | $CO_2$ | 0.04761102 | 0.040365129 | 0.039670 | 0.03172051 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.000000 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |
| | Iron and Steel | 3.597116387 | 0.90971244 | 0.000000 | 0.00000000 |
| | $CO_2$ | 3.597116387 | 0.90971244 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |
| | ODS Substitutes | 1.971282442 | 2.276383733 | 2.972674 | 1.9013601 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.0000000 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.0000000 |
| | HFC, PFC, $SF_6$ | 1.971282442 | 2.276383733 | 2.972674 | 1.9013601 |
| | Electricity Transmission and Dist. | 0.227222585 | 0.1673 | 0.047322 | 0.02379465 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | HFC, PFC, $SF_6$ | 0.227222585 | 0.1673 | 0.047322 | 0.02379465 |
| | Semiconductor Manufacturing | 0 | 0 | 0.000000 | 0.00000000 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | HFC, PFC, $SF_6$ | 0 | 0 | 0.000000 | 0.00000000 |
| | Ammonia and Urea Production (Nonfertilizer Usage) | 0.000626981 | 0.00095119 | 0.000548 | 0.00053311 |
| | $CO_2$ | 0.000626981 | 0.00095119 | 0.000548 | 0.00053311 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | HFC, PFC, $SF_6$ | 0 | 0 | 0.000000 | 0.00000000 |
| | Aluminum Production | 0 | 0 | 0.000000 | 0.00000000 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | HFC, PFC, $SF_6$ | 0 | 0 | 0.000000 | 0.00000000 |
| **Agriculture** | | 1.771426158 | **1.661948** | **1.892149** | **1.71831397** |
| | Enteric Fermentation | 0.41906793 | 0.371870 | 0.337974 | 0.31980921 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0.41906793 | 0.371869619 | 0.337974 | 0.31980921 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |

| Source Category | Fuel Type | Year | | | |
|---|---|---|---|---|---|
| | | 2006 ($MMtCO_2e$) | 2011 ($MMtCO_2e$) | 2014 ($MMtCO_2e$) | 2030 ($MMtCO_2e$) |
| | Manure Management | 0.32126318 | 0.324513 | 0.320611 | 0.33708254 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0.091393836 | 0.094279619 | 0.090378 | 0.09502113 |
| | $N_2O$ | 0.229869344 | 0.230233016 | 0.230233 | 0.24206141 |
| | Agricultural Soils | 1.019673739 | 0.954137285 | 0.993803 | 0.79393854 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $N_2O$ | 1.019673739 | 0.954137285 | 0.993803 | 0.79393854 |
| | Agricultural Burning | 0.006273052 | 0.006280 | 0.234613 | 0.26147327 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $CH_4$ | 0.003893109 | 0.003780396 | 0.143309 | 0.15971573 |
| | $N_2O$ | 0.002379944 | 0.002499543 | 0.091304 | 0.10175754 |
| | Urea Fertilizer Usage | 0.005148257 | 0.005148257 | 0.005148 | 0.00601040 |
| | $CO_2$ | 0.005148257 | 0.005148257 | 0.005148 | 0.00601040 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.00000000 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.00000000 |
| **Waste Management** | | 2.257117951 | **2.257118** | **3.0069** | **3.24201588** |
| | Waste Combustion | 1.292301717 | **1.429459** | **1.297629** | 1.42275964 |
| | $CO_2$ | 1.272171161 | 1.429417755 | 1.297587 | 1.42271392 |
| | $CH_4$ | 0 | 8.86112E-06 | 0.000009 | 0.0000009 |
| | $N_2O$ | 0.020130556 | 3.27724E-05 | 0.000033 | 0.000035933 |
| | Landfills | 0.388955279 | **0.555365** | **1.1079** | **1.2147575** |
| | $CO_2$ | 0.151585044 | 0.467790091 | 0.313143 | 0.343339 |
| | $CH_4$ | 0.237370235 | 0.087575305 | 0.79480 | 0.8714185 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.0000000 |
| | Wastewater Management | 0.542860955 | **0.558046** | **0.568317** | 0.56831654 |
| | $CO_2$ | 0 | 0 | 0.000000 | 0 |
| | $CH_4$ | 0.377311419 | 0.392496531 | 0.402767 | 0.40276700 |
| | $N_2O$ | 0.165549536 | 0.165549536 | 0.165550 | 0.16554954 |
| | Residential Open Burning | 0.033 | **0.033000** | **0.033000** | **0.0361822** |
| | $CO_2$ | 0.033 | 0.033 | 0.033000 | 0.0361822 |
| | $CH_4$ | 0 | 0 | 0.000000 | 0.0000000 |
| | $N_2O$ | 0 | 0 | 0.000000 | 0.0000000 |
| **Gross Emissions (Consumption Basis, Excludes Sinks)** | | **107.2295365** | **99.283830** | **93.4209** | **106.03946** |
| **Emissions Sinks** | | -11.79034917 | -11.847884 | -11.650369 | -11.6504 |
| | Forested Landscape | -10.44657783 | -10.44657783 | -10.4466 | -10.4466 |
| | Urban Forestry and Land Use | -1.331309142 | -1.433719701 | -1.2009 | -1.2009 |
| | Agricultural Soils (Cultivation Practices) | -0.051420445 | -0.021306845 | -0.0514 | -0.0514 |
| | Forest Fires | 0.038958248 | 0.053720414 | 0.0485 | 0.0485 |
| | $CH_4$ | 0.032452487 | 0.044749474 | 0.0404 | 0.0404 |
| | $N_2O$ | 0.00650576 | 0.008970941 | 0.0081 | 0.0081 |
| **Net Emissions (Consumptions Basis) (Including forestry, land use, and ag sinks)** | | 95.4391873 | **87.435946** | **81.7705** | **94.38909** |

# 2.0 Emission Projection Methodology

## 2.1 OVERVIEW

This section describes the data sources, key assumptions, and the methodology used to develop the 2030 BAU emission projection estimate for Maryland. The 2030 business-as-usual GHG emission inventory was estimated by projecting Maryland Base Year 2014 GHG Emissions, using Maryland specific growth factors for each of the different economic sectors. Growth factors are derived from several sources including; business economics employment projections, housing projections data and on-road mobile vehicle miles traveled projection data from MDOT. For the electricity consumption sector, the region's electrical load projection from PJM, the regional transmission organization, was used to develop the growth factors for the consumption of electrical energy. In all cases, the projection calculations reflect economic data or some other activity patterns to estimate future emissions. The 2030 projection uses the following general equations to estimate emissions by sector and by pollutant type:

**2030 BAU Forecast (MMT)** = **2014 Base Year Emissions (MMT)** x **Growth Factor (2015-2030)**

## 2.2 Electricity Supply by PJM

GHG emissions from the electrical sector are estimated on a consumption basis. As such, the electricity supply sector accounts for emissions occurring as a result of the combustion of fossil fuel at electricity generating facilities located both in and outside of the State. Carbon dioxide ($CO_2$) represented more than 99.5% of total sector emissions, with methane ($CH_4$) and nitrous oxide ($N_2O$) $CO_2$-equivalent emissions comprising the balance.

Maryland is a net importer of electricity, meaning that the State consumes more electricity than is produced in the State. For this projection, it was assumed that all power generated in Maryland was consumed in Maryland, and that remaining electricity demand was met by imported power.

The 2030 in-state and imported electricity generation emissions were derived from the statewide electricity demand forecasts by PJM Interconnection[1], a regional transmission organization (RTO), that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia). The projected PJM electrical consumption forecast was applied to the fuel-specific 2014 GHG emissions from the Electricity Consumption Sector.

The PJM load forecast model is an econometric model that produced estimates of non-coincident and coincident peak loads for each PJM zone, location deliverability area (LDA) and the RTO. It

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[1] http://www.pjm.com/~/media/library/reports-notices/load-forecast/2016-load-report.ashx

uses local economic activity, weather, and day-type variables as explanatory variables/drivers. The model uses trends in equipment and appliance usage, anticipated economic growth and historical weather patterns to estimate growth in peak load and energy use. Recent improvements to the model include the addition of variables that reflect consumer behavioral trends to capture reductions in electricity use from more efficient lighting, air conditioning and heating, electronics and industrial processes.

The forecasted load demand in Maryland was used as a surrogate growth factor for both the in-state and imported electricity generation emissions in 2030. The 2030 Business-as-Usual emissions projection for the electric power sector is 36.40 $MMTCO_2E$.

**Table 2.1: Maryland Base Year 2014 Electric Sector GHG Emissions, by Fuel Type**

| | | Emissions | Emissions | Emissions | Emissions |
|---|---|---|---|---|---|
| | Consumption | $CO_2$ | $CH_4$ | $N_2O$ | Total |
| **Fuel Type** | **(Billion Btu)** | **($MMTCO_2E$)** | **($MMTCO_2E$)** | **($MMTCO_2E$)** | **($MMTCO_2E$)** |
| Coal | 186,207.44 | 18.2702886 | 0.02958395 | 0.095204565 | 18.39507712 |
| Petroleum | 3,901.03 | 0.399098633 | 0.000308856 | 0.000817578 | 0.400225068 |
| Natural Gas | 18,638.71 | 1.083775233 | 0.002443579 | 0.030242811 | 1.116461623 |
| | | **19.7532** | **0.0323** | **0.1263** | **19.9118** |

**Table 2.2: Maryland Electric Sector GHG Projection Emissions by Fuel Type**

| Fuel Type | 2014 Emissions ($MMTCO_2E$) | 2020 Emissions ($MMTCO_2E$) | 2025 Emissions ($MMTCO_2E$) | 2030 Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| **Coal** | 18.2702886 | 19.02153 | 19.27427 | 19.69985 |
| **Petroleum** | 0.39909863 | 0.415509 | 0.42103 | 0.430326 |
| **Natural Gas** | 1.08377523 | 1.128338 | 1.14333 | 1.168575 |
| **TOTAL** | **19.7531625** | **20.56538** | **20.83863** | **21.29875** |

## Table 2.3: Electricity Usage Sector (Consumption-Based) Growth Factor

| PJM MID-ATLANTIC LOAD FORECAST[1] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2014** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| AE | 10,531 | 10,399 | 10,407 | 10,441 | 10,441 | 10,387 | 10,328 | 10,315 | 10,309 | 10,340 | 10,303 | 10,282 | 10,260 | 10,267 | 10,224 | 10,175 |
| | | | 0.10% | 0.30% | 0.00% | -0.50% | -0.60% | -0.10% | -0.10% | 0.30% | -0.40% | -0.20% | -0.20% | 0.10% | -0.40% | -0.50% |
| BGE | 32,863 | 34,075 | 34,236 | 34,461 | 34,568 | 34,640 | 34,644 | 34,789 | 34,934 | 35,200 | 35,259 | 35,402 | 35,552 | 35,826 | 35,908 | 36,003 |
| | | | 0.50% | 0.70% | 0.30% | 0.20% | 0.00% | 0.40% | 0.40% | 0.80% | 0.20% | 0.40% | 0.40% | 0.80% | 0.20% | 0.30% |
| DPL | 18,753 | 19,108 | 19,277 | 19,439 | 19,519 | 19,561 | 19,551 | 19,608 | 19,671 | 19,816 | 19,846 | 19,918 | 20,002 | 20,155 | 20,185 | 20,205 |
| | | | 0.90% | 0.80% | 0.40% | 0.20% | -0.10% | 0.30% | 0.30% | 0.70% | 0.20% | 0.40% | 0.40% | 0.80% | 0.10% | 0.10% |
| JCPL | 23,172 | 22,880 | 23,151 | 23,437 | 23,531 | 23,383 | 23,260 | 23,288 | 23,337 | 23,471 | 23,453 | 23,491 | 23,558 | 23,700 | 23,736 | 23,733 |
| | | | 1.20% | 1.20% | 0.40% | -0.60% | -0.50% | 0.10% | 0.20% | 0.60% | -0.10% | 0.20% | 0.30% | 0.60% | 0.20% | 0.00% |
| METED | 15,606 | 16,014 | 16,245 | 16,483 | 16,607 | 16,610 | 16,617 | 16,729 | 16,842 | 17,028 | 17,113 | 17,259 | 17,428 | 17,643 | 17,794 | 17,916 |
| | | | 1.40% | 1.50% | 0.80% | 0.00% | 0.00% | 0.70% | 0.70% | 1.10% | 0.50% | 0.90% | 1.00% | 1.20% | 0.90% | 0.70% |
| PECO | 40,910 | 41,882 | 42,434 | 42,989 | 43,274 | 43,236 | 43,211 | 43,435 | 43,692 | 44,121 | 44,290 | 44,585 | 44,946 | 45,444 | 45,765 | 46,049 |
| | | | 1.30% | 1.30% | 0.70% | -0.10% | -0.10% | 0.50% | 0.60% | 1.00% | 0.40% | 0.70% | 0.80% | 1.10% | 0.70% | 0.60% |
| PENLC | 18,057 | 18,062 | 18,049 | 18,082 | 18,065 | 18,129 | 18,079 | 18,086 | 18,071 | 18,118 | 18,089 | 18,116 | 18,135 | 18,184 | 18,157 | 18,142 |
| | | | -0.10% | 0.20% | -0.10% | 0.40% | -0.30% | 0.00% | -0.10% | 0.30% | -0.20% | 0.10% | 0.10% | 0.30% | -0.10% | -0.10% |
| PEPCO | 31,100 | 32,057 | 32,242 | 32,501 | 32,644 | 32,759 | 32,751 | 32,879 | 33,016 | 33,282 | 33,357 | 33,520 | 33,690 | 33,955 | 34,053 | 34,172 |
| | | | 0.60% | 0.80% | 0.40% | 0.40% | 0.00% | 0.40% | 0.40% | 0.80% | 0.20% | 0.50% | 0.50% | 0.80% | 0.30% | 0.30% |
| PL | 40,639 | 41,380 | 41,835 | 42,339 | 42,563 | 42,583 | 42,526 | 42,710 | 42,905 | 43,282 | 43,400 | 43,680 | 43,996 | 44,439 | 44,705 | 44,911 |
| | | | 1.10% | 1.20% | 0.50% | 0.00% | -0.10% | 0.40% | 0.50% | 0.90% | 0.30% | 0.60% | 0.70% | 1.00% | 0.60% | 0.50% |
| PS | 44,118 | 45,085 | 45,430 | 45,811 | 45,934 | 45,880 | 45,678 | 45,734 | 45,772 | 45,953 | 45,922 | 45,997 | 46,072 | 46,278 | 46,255 | 46,209 |
| | | | 0.80% | 0.80% | 0.30% | -0.10% | -0.40% | 0.10% | 0.10% | 0.40% | -0.10% | 0.20% | 0.20% | 0.40% | 0.00% | -0.10% |
| RECO | 1,512 | 1,535 | 1,537 | 1,542 | 1,541 | 1,546 | 1,539 | 1,538 | 1,537 | 1,541 | 1,539 | 1,536 | 1,534 | 1,536 | 1,529 | 1,525 |
| | | | 0.10% | 0.30% | -0.10% | 0.30% | -0.50% | -0.10% | -0.10% | 0.30% | -0.10% | -0.20% | -0.10% | 0.10% | -0.50% | -0.30% |
| UGI | 1,055 | 1,036 | 1,046 | 1,056 | 1,058 | 1,048 | 1,042 | 1,042 | 1,042 | 1,045 | 1,041 | 1,044 | 1,045 | 1,052 | 1,054 | 1,055 |
| | | | 1.00% | 1.00% | 0.20% | -0.90% | -0.60% | 0.00% | 0.00% | 0.30% | -0.40% | 0.30% | 0.10% | 0.70% | 0.20% | 0.10% |
| PJM MID-ATLANTIC | 278,318 | 283,513 | 285,889 | 288,581 | 289,745 | 289,762 | 289,226 | 290153 | 291,128 | 293,197 | 293,612 | 294,830 | 296,218 | 298,479 | 299,365 | 300,095 |
| | | | 0.80% | 0.90% | 0.40% | 0.00% | -0.20% | 0.30% | 0.30% | 0.70% | 0.10% | 0.40% | 0.50% | 0.80% | 0.30% | 0.20% |
| FE-EAST | 56,835 | 56,956 | 57,445 | 58,002 | 58,203 | 58,122 | 57,956 | 58,103 | 58,250 | 58,617 | 58,655 | 58,866 | 59,121 | 59,527 | 59,687 | 59,791 |
| | | | 0.90% | 1.00% | 0.30% | -0.10% | -0.30% | 0.30% | 0.30% | 0.60% | 0.10% | 0.40% | 0.40% | 0.70% | 0.30% | 0.20% |
| PLGRP | 41,694 | 42,416 | 42,881 | 43,395 | 43,621 | 43,631 | 43,568 | 43,752 | 43,947 | 44,327 | 44,441 | 44,724 | 45,041 | 45,491 | 45,759 | 45,966 |
| | | | 1.10% | 1.20% | 0.50% | 0.00% | -0.10% | 0.40% | 0.40% | 0.90% | 0.30% | 0.60% | 0.70% | 1.00% | 0.60% | 0.50% |
| **GROWTH FACTOR** | **1** | **1.01867** | **1.02720** | **1.03688** | **1.04106** | **1.04112** | **1.03919** | **1.0425** | **1.04603** | **1.05346** | **1.05495** | **1.05933** | **1.06431** | **1.07244** | **1.07562** | **1.07825** |

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[1] http://pjm.com/~/media/library/reports-notices/load-forecast/2016-load-report.ashx, Table E-1

## 2.3 Residential, Commercial, and Industrial Sector

This section accounts for emissions associated with direct fossil fuel used in the residential, commercial and the industrial sector to provide space and process heating. Projected BAU growth in emissions in the residential sector is due primarily to the expected increase in housing and assumed increase use of natural gas for office building and small business sources of combustion, including small boilers, water heaters, and appliances in the commercial and industrial sectors.

### 2.3.1 Residential Sector

To project residential sector emissions, MDE used the Base Year 2014 emissions and estimated 2030 emissions based on the growth in projected households in Maryland. Housing projections were obtained from the Maryland Department of Planning (MDP).

**Table 2.3.1: Maryland Base Year 2014 Residential Sector GHG Emissions, by Fuel Type**

| **Fuel Type** | **Emissions $CO_2$ ($MMTCO_2E$)** | **Emissions $CH_4$ ($MMTCO_2E$)** | **Emissions $N_2O$ ($MMTCO_2E$)** | **Emissions Total ($MMTCO_2E$)** |
|---|---|---|---|---|
| Coal | 0.0000000000 | 0.0000000000 | 0.0000000000 | 0.0000000000 |
| Distillate Fuel | 1.3776390768 | 0.0039229941 | 0.0034746519 | 1.3850367229 |
| Kerosene | 0.0247979623 | 0.0000713540 | 0.0000631992 | 0.0249325155 |
| LPG | 0.4833485256 | 0.0016478764 | 0.0014595477 | 0.4864559498 |
| Natural Gas | 5.0414319192 | 0.0094802387 | 0.0027989276 | 5.0537110855 |
| Wood | **0.0000000000** | 0.0687231309 | 0.0135264575 | 0.0822495884 |
|  |  |  | **Total** | **7.03** |

## Table 2.3.2: Residential Sector Growth – Housing Projection Estimates[1]

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Census | Census | Census | Census | Census | Projection | | Projection | | Projection | | Projection | | | | |
| | 1970 | 1980 | 1990 | 2000 | 2010 | 2015 | | 2020 | | 2025 | | 2030 | | | | |
| | 1,174,933 | 1,460,865 | 1,748,991 | 1,980,859 | 2,156,411 | 2,242,088 | | 2,325,516 | | 2,416,861 | | 2,503,843 | | | | |
| | | | | | | | | | | | | | | | | |
| | Extrapolated Housing Data | | | | | | | | | | | | | | | |
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| **House-holds** | 2,224,952 | 2,242,088 | 2,258,773 | 2,275,459 | 2,292,145 | 2,308,830 | 2,325,516 | 2,343,785 | 2,362,054 | 2,380,323 | 2,398,592 | 2,416,861 | 2,434,258 | 2,451,654 | 2,469,050 | 2,486,447 | 2,503,843 |
| | | | | | | | | | | | | | | | | |
| | Growth Factors | | | | | | | | | | | | | | | |
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| **Growth Factor** | 1 | 1.007701 | 1.007442 | 1.007387 | 1.007333 | 1.007279 | 1.007227 | 1.007856 | 1.007795 | 1.0077344 | 1.007675 | 1.007617 | 1.007198 | 1.007146 | 1.007096 | 1.007046 | 1.006996 |

## Table 2.3.3: Maryland Residential Sector GHG Projection Emissions by Fuel Type

| Fuel Type | 2014 Emissions ($MMTCO_2E$) | 2020 Emissions ($MMTCO_2E$) | 2025 Emissions ($MMTCO_2E$) | 2030 Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| **Coal** | 0.0000000000 | 0.0000000000 | 0.0000000000 | 0.0000000000 |
| **Distillate Fuel** | 1.3850367229 | 1.3950462145 | 1.3955859673 | 1.3947271058 |
| **Kerosene** | 0.0249325155 | 0.0251126998 | 0.0251224160 | 0.0251069554 |
| **LPG** | 0.4864559498 | 0.4899715076 | 0.4901610809 | 0.4898594295 |
| **Natural Gas** | 5.0537110855 | 5.0902336395 | 5.0922030852 | 5.0890692782 |
| **Wood** | 0.0822495884 | 0.0828439961 | 0.0828760490 | 0.0828250460 |
| **TOTAL** | 7.0324 | 7.0832 | 7.0859 | 7.0816 |

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[1] http://www.mdp.state.md.us/msdc/S3_Projection.shtml, Prepared by the Maryland Department of Planning, Projections and State Data Center, August 2017

### 2.3.2 Commercial and Industrial Sector

To project the commercial and industrial sector emissions, MDE used the Base Year 2014 emissions and projected 2030 emissions based on employment projections from Maryland Department of Labor, Licensing and Regulation (DLLR).

**Table 2.3.2: Maryland Base Year 2014 Commercial Sector GHG Emissions, by Fuel Type**

| Fuel Type | Consumption (Billion Btu) | $CO_2$ Emissions ($MMTCO_2E$) | $CH_4$ Emissions ($MMTCO_2E$) | $N_2O$ Emissions ($MMTCO_2E$) | GHG Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| Coal | 198 | 0.01870759 | 4.16758E-05 | 0.00009228 | 0.0188 |
| Distillate Fuel | 9,215 | 0.68113232 | 0.001939607 | 0.00171794 | 0.6848 |
| Kerosene | 102 | 0.00746133 | 2.14693E-05 | 0.00001902 | 0.0075 |
| LPG | 2,638 | 0.16286542 | 0.000555256 | 0.00049180 | 0.1639 |
| Motor Gasoline | 171 | 0.01220452 | 3.59927E-05 | 0.00003188 | 0.0123 |
| Residual Fuel | 19 | 0.00142589 | 3.99919E-06 | 0.00000354 | 0.0014 |
| Natural Gas | 78,599 | 4.16733983 | 0.007836539 | 0.00231364 | 4.1775 |
| Wood | 2,333 | 0 | 0.013956395 | 0.00274697 | 0.0167 |
|  |  |  |  | **Total** | **5.0829** |

## Table 2.3.3: Maryland Base Year 2014 Industrial Sector GHG Emissions, by Fuel Type

| Fuel Type | Total Consumption (Billion Btu) | Non-Energy Consumption (Billion Btu) | $CO_2$ Emissions ($MMTCO_2E$) | $CH_4$ Emissions ($MMTCO_2E$) | $N_2O$ Emissions ($MMTCO_2E$) | GHG Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|
| Coking Coal | - | - | - | - | - | - |
| Other Coal | 15,627 | 232 | 1.4780 | 0.0032 | 0.0072 | 1.4885 |
| Asphalt and Road Oil | 15,346 | 17,999 | (0.1998) | (0.0002) | (0.0005) | (0.2005) |
| Aviation Gasoline Blending Components | - | - | - | - | - | - |
| Crude Oil | - | - | - | - | - | - |
| Distillate Fuel | 6,743 | 106 | 0.4945 | 0.0004 | 0.0012 | 0.4962 |
| Feedstocks, Naphtha less than 401 F | - |  | - | 0.0000 | 0.0000 | 0.0000 |
| Feedstocks, Other Oils greater than 401 F | - |  | - | 0.0000 | 0.0000 | 0.0001 |
| Kerosene | 15 | - | 0.0011 | 0.0000 | 0.0000 | 0.0011 |
| LPG | 1,313 | 1,413 | 0.0272 | (0.0000) | (0.0000) | 0.0271 |
| Lubricants | 1,988 | 1,781 | 0.1334 | 0.0000 | 0.0000 | 0.1334 |
| Motor Gasoline | 4,253 | - | 0.3035 | 0.0003 | 0.0008 | 0.3046 |
| Motor Gasoline Blending Components | - | - | - | - | - | - |
| Misc. Petro Products | 270 | - | 0.0201 | - | - | 0.0201 |
| Petroleum Coke | - | - | - | - | - | - |
| Pentanes Plus |  | - | - | 0.0000 | 0.0000 | 0.0000 |
| Residual Fuel | 241 | - | 0.0181 | 0.0000 | 0.0000 | 0.0181 |
| Still Gas | - | - | - | - | - | - |
| Special Naphthas | 2,956 | 516 | 0.2138 | 0.0002 | 0.0005 | 0.2144 |
| Unfinished Oils | - | - | - | - | - | - |
| Waxes | 146 | 106 | 0.0061 | - | - | 0.0061 |
| Natural Gas | 15,474 | 599 | 0.8008 | 0.0003 | 0.0004 | 0.8015 |
| Wood | 8,205 | NA | - | 0.0049 | 0.0097 | 0.0146 |
|  |  |  |  |  | **Total** | **3.3253** |
|  |  |  |  |  |  |  |

### Table 2.3.4: 2030 Commercial and Industrial Sectors BAU Projection Growth Factor

**MARYLAND 2010-2020 INDUSTRY PROJECTIONS**

http://www.dllr.state.md.us/lmi/iandoproj/industry.shtml

| | Employment | |
|---|---|---|
| **NAICS DESCRIPTION** | **2014** | **2024** |
| Total All Industries | 198,493 | 215,638 |
| Self-Employed and Unpaid Family Workers, All Jobs | 196,649 | 213,799 |
| Total Wage and Salary Employment | 1,844 | 1,839 |

### Table 2.3.4.2: 2030 Commercial and Industrial Sectors BAU Projection Growth Factor

| | Forecasted Employment | | | Employment Growth Factors | |
|---|---|---|---|---|---|
| **Years** | **Total All Industries** | **Self-Employed and Unpaid Family Workers, All Jobs** | **Total Wage and Salary Employment** | **Total All Industries** | **Self-Employed and Unpaid Family Workers, All Jobs** |
| 2014 | 198,493 | 196,649 | 1,844 | | |
| 2015 | 200,208 | 198,364 | 1,844 | 1.008637584 | 1.008721122 |
| 2016 | 201,922 | 200,079 | 1,843 | 1.017275168 | 1.017442245 |
| 2017 | 203,637 | 201,794 | 1,843 | 1.025912753 | 1.026163367 |
| 2018 | 205,351 | 203,509 | 1,842 | 1.034550337 | 1.03488449 |
| 2019 | 207,066 | 205,224 | 1,842 | 1.043187921 | 1.043605612 |
| 2020 | 208,780 | 206,939 | 1,841 | 1.051825505 | 1.052326734 |
| 2021 | 210,495 | 208,654 | 1,841 | 1.060463089 | 1.061047857 |
| 2022 | 212,209 | 210,369 | 1,840 | 1.069100674 | 1.069768979 |
| 2023 | 213,924 | 212,084 | 1,840 | 1.077738258 | 1.078490102 |
| 2024 | 215,638 | 213,799 | 1,839 | 1.086375842 | 1.087211224 |
| 2025 | 217,353 | 215,514 | 1,839 | 1.095013426 | 1.095932346 |
| 2026 | 219,067 | 217,229 | 1,838 | 1.10365101 | 1.104653469 |
| 2027 | 220,782 | 218,944 | 1,838 | 1.112288595 | 1.113374591 |
| 2028 | 222,496 | 220,659 | 1,837 | 1.120926179 | 1.122095714 |
| 2029 | 224,211 | 222,374 | 1,837 | 1.129563763 | 1.130816836 |
| 2030 | 225,925 | 224,089 | 1,836 | 1.138201347 | 1.139537958 |

### Table 2.3.5: Maryland Commercial Sector GHG Projection Emissions by Fuel Type

| Fuel Type | 2014 Emissions (MMTCO$_2$E) | 2020 Emissions (MMTCO$_2$E) | 2025 Emissions (MMTCO$_2$E) | 2030 Emissions (MMTCO$_2$E) |
|---|---|---|---|---|
| **Coal** | 0.0188415437 | 0.0198180162 | 0.0206317433 | 0.0214454704 |
| **Distillate Fuel** | 0.6847898595 | 0.7202794399 | 0.7498540903 | 0.7794287406 |
| **Kerosene** | 0.0075018188 | 0.0078906044 | 0.0082145923 | 0.0085385803 |
| **LPG** | 0.1639124787 | 0.1724073257 | 0.1794863649 | 0.1865654040 |
| **Motor Gasoline** | 0.0122723929 | 0.0129084159 | 0.0134384350 | 0.0139684542 |
| **Residual Fuel** | 0.0014334321 | 0.0015077205 | 0.0015696274 | 0.0016315344 |
| **Natural Gas** | 4.1774900101 | 4.3939905402 | 4.5744076487 | 4.7548247572 |
| **Wood** | 0.0167033678 | 0.0175690283 | 0.0182904120 | 0.0190117958 |
| **TOTAL** | 5.0829 | 5.3464 | 5.5659 | 5.7854 |

### Table 2.3.6: Maryland Commercial Sector GHG Projection Emissions by Fuel Type

| Fuel Type | 2014 Emissions (MMTCO$_2$E) | 2020 Emissions (MMTCO$_2$E) | 2025 Emissions (MMTCO$_2$E) | 2030 Emissions (MMTCO$_2$E) |
|---|---|---|---|---|
| **Other Coal** | 1.4884574638 | 1.5655975238 | 1.6298809071 | 1.6941642905 |
| **Distillate Fuel** | 0.4961518276 | 0.5218651467 | 0.5432929126 | 0.5647206786 |
| **Feedstocks, Naphtha less than 401 F** | 0.0000027371 | 0.0000028790 | 0.0000029972 | 0.0000031154 |
| **Feedstocks, Other Oils greater than 401 F** | 0.0000627559 | 0.0000660082 | 0.0000687185 | 0.0000714288 |
| **Kerosene** | 0.0011009986 | 0.0011580584 | 0.0012056082 | 0.0012531581 |
| **LPG** | 0.0271406924 | 0.0285472725 | 0.0297194226 | 0.0308915727 |
| **Lubricants** | 0.1334373967 | 0.1403528572 | 0.1461157409 | 0.1518786247 |
| **Motor Gasoline** | 0.3046042879 | 0.3203905590 | 0.3335457849 | 0.3467010109 |
| **Misc. Petroleum Products** | 0.0201115810 | 0.0211538738 | 0.0220224512 | 0.0228910286 |
| **Pentanes Plus** | 0.0000099159 | 0.0000104298 | 0.0000108581 | 0.0000112863 |
| **Residual Fuel** | 0.0181464460 | 0.0190868948 | 0.0198706020 | 0.0206543093 |
| **Special Naphthas** | 0.2143824763 | 0.2254929564 | 0.2347516899 | 0.2440104233 |
| **Waxes** | 0.0061306399 | 0.0064483634 | 0.0067131330 | 0.0069779026 |
| **Natural Gas** | 0.8015052390 | 0.8430436529 | 0.8776589978 | 0.9122743428 |
| **Wood** | 0.0145692821 | 0.0153243425 | 0.0159535595 | 0.0165827765 |
| **TOTAL** | 3.5258 | 3.7085 | 3.8608 | 4.0131 |

## 2.4 Transportation Energy Use

Emissions estimated for this sector are the result of fossil-fuel consumed primarily for transportation purposes, both on-road mobile sources and non-road mobile sources of transportation. On-road mobile sources include the vehicles traditionally operated on public roadways, including:

- Cars
- Light-duty trucks
- Vans
- Buses
- Other diesel vehicles

Other modes of transportation, such as airplanes, trains and commercial marine vessels are included under the general category of non-road mobile sources. Non-road mobile sources also include the following motorized vehicles and equipment, which are normally not operated on public roadways:

- MOVES – Non-road Model Sources
    - Lawn and garden equipments
    - Agricultural or farm equipment
    - Logging equipment
    - Industrial equipment
    - Construction equipment
    - Airport service equipment
    - Recreational land vehicles or equipment
    - Recreational marine equipment

- Off-model Non-road Emission Sources
    - Locomotives
    - Aircraft
        - Commercial aviation
        - Air taxis
        - General aviation
        - Military aviation
    - Commercial Marine Vessels

- Lubricants, Natural Gas, and LPG

### 2.4.1 Transportation – On-Road Mobile Projections

Typically, traffic volumes and vehicle miles traveled (VMT) within the SHA traffic database are used to forecast future year emissions. Several alternatives are available to determine forecast growth rates, ranging from historical VMT trends to the use of Metropolitan Planning Organization-based travel models that include forecast demographics for distinct areas in each county.

For the 2030 BAU scenario, MDE used the Base Year 2014 and estimated 2030 emissions based on the growth in projected VMT derived from the Maryland Department of Transportation (MDOT) "VMT projection to 2030" [1]. The average statewide annualized growth rate in VMT is approximately 1.5%. This BAU estimate assumes no change in vehicle fleet mix over time.

As a result of the VMT and fleet mix assumptions, GHG emissions in 2030 from the transportation sector as a whole are expected to be 42.69 $MMTCO_2e$. The predicted emissions are dominated by emissions from on-road transportation (e.g., passenger cars and heavy-duty trucks).

**Table 2.4.1: 2030 Transportation MD VMT 2030 Projections**

| **MD VMT 2020 - 2030 Projections** | | |
|---|---|---|
| 2014 | 2020 | 2030 |
| 56,400 | 65,442 | 71,830 |

**Table 2.4.2: 2030 Transportation Growth Factors.**

| **MD 2015- 2030 VMT Forecasts and Growth Factors** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| Forecast VMT | 56,400 | 57,907 | 59,414 | 60,921 | 62,428 | 63,935 | 65,442 | 66,081 | 66,720 |
| GF_2014Based | 1.0000 | 1.0267 | 1.0534 | 1.0802 | 1.1069 | 1.1336 | 1.1603 | 1.1716 | 1.1830 |
| | | | | | | | | | |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | |
| Forecast VMT | 67,358 | 67,997 | 68,636 | 69,275 | 69,914 | 70,552 | 71,191 | 71,830 | |
| GF_2014Based | 1.1943 | 1.2056 | 1.2170 | 1.2283 | 1.2396 | 1.2509 | 1.2623 | 1.2736 | |

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[1] http://mde.maryland.gov/programs/Air/ClimateChange/MCCC/STWG/OnRoadInventoryMDOT.pdf

**Table 2.4.3: 2014-2030 BAU On-Road Emissions**

| Year | VMT | Growth Factor 2014 Based | 2014 On Road GHG Emissions ($MMTCO_2e$) | | |
|---|---|---|---|---|---|
| | | | Gasoline | Diesel | Total |
| 2014 | 56,400[1] | 1.0000 | 22.5554 | 6.3810 | 28.9365 |
| 2015 | 57,907 | 1.0267 | 23.1581 | 6.5515 | 29.7097 |
| 2016 | 59,414 | 1.0534 | 23.7608 | 6.7220 | 30.4828 |
| 2017 | 60,921 | 1.0802 | 24.3635 | 6.8925 | 31.2560 |
| 2018 | 62,428 | 1.1069 | 24.9662 | 7.0630 | 32.0292 |
| 2019 | 63,935 | 1.1336 | 25.5688 | 7.2335 | 32.8024 |
| 2020 | 65,442[2] | 1.1603 | 26.1715 | 7.4040 | 33.5756 |
| 2021 | 66,081 | 1.1716 | 26.4270 | 7.4763 | 33.9033 |
| 2022 | 66,720 | 1.1830 | 26.6824 | 7.5486 | 34.2310 |
| 2023 | 67,358 | 1.1943 | 26.9379 | 7.6209 | 34.5588 |
| 2024 | 67,997 | 1.2056 | 27.1934 | 7.6931 | 34.8865 |
| 2025 | 68,636 | 1.2170 | 27.4489 | 7.7654 | 35.2143 |
| 2026 | 69,275 | 1.2283 | 27.7043 | 7.8377 | 35.5420 |
| 2027 | 69,914 | 1.2396 | 27.9598 | 7.9100 | 35.8697 |
| 2028 | 70,552 | 1.2509 | 28.2153 | 7.9822 | 36.1975 |
| 2029 | 71,191 | 1.2623 | 28.4707 | 8.0545 | 36.5252 |
| 2030 | 71,830[3] | 1.2736 | 28.7262 | 8.1268 | 36.8530 |

### 2.4.2 Transportation – Non-Road Mobile (MOVES Model) Projections

The non-road portion of the MOVES model (version 2014a) was used to project emissions from non-road model transportation subcategories. Non-road MOVES model runs for 2014 (base year), 2020, 2025 and 2030 were simulated and provided the basis for establishing growth factors for the source sector. For each annual simulation (2020, 2025 and 2030), the forecasted future emissions of $CO_2$ and $CH_4$ were summed separately for all non-road gasoline, non-road diesel and non-road other fuel use. Emissions for years not simulated were linearly extrapolated from corresponding model runs. Growth factors were then calculated per fuel type per pollutant by dividing the projection year $CO_2$ or $CH_4$ emissions by the 2014 base year emissions.

The ‘Lubricants, NG, and LPG’ source category was similarly grown from growth factors derived from the “other fuel” MOVES model future projections. These growth factors were then applied to the 2014 Emissions Inventory to project future emissions.

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[1] 2014 MDOT Actual VMT
[2] 2020 MDOT VMT Projection – MOVES
[3] 2030 MDOT VMT Projection – MOVES

**Table 2.4.4: 2014-2030 MOVES-Based Growth Factors**

**MOVES Based Growth Factors**

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|
| Non-Road Diesel CO2 | 1 | 1.019845 | 1.039689 | 1.059534 | 1.079379 | 1.099224 | 1.119068 | 1.1418 | 1.164533 |
| Non-Road Gasoline CO2 | 1 | 1.014589 | 1.029179 | 1.043768 | 1.058358 | 1.072947 | 1.087537 | 1.101176 | 1.114816 |
| Other | 1 | 1.020051 | 1.040102 | 1.060153 | 1.080204 | 1.100255 | 1.120306 | 1.14107 | 1.161833 |
| | | | | | | | | | |
| Non-Road Diesel CH4 | 1 | 1.000553 | 1.001107 | 1.00166 | 1.002214 | 1.002767 | 1.003321 | 1.010227 | 1.017134 |
| Non-Road Gasoline CH4 | 1 | 0.98609 | 0.97218 | 0.958271 | 0.944361 | 0.930451 | 0.916541 | 0.923151 | 0.92976 |
| Other | 1 | 1.005736 | 1.011472 | 1.017209 | 1.022945 | 1.028681 | 1.034417 | 1.042037 | 1.049657 |

| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | |
|---|---|---|---|---|---|---|---|---|---|
| Non-Road Diesel CO2 | 1.187265 | 1.209997 | 1.232729 | 1.25324 | 1.273752 | 1.294263 | 1.314774 | 1.335286 | |
| Non-Road Gasoline CO2 | 1.128455 | 1.142094 | 1.155734 | 1.169181 | 1.182628 | 1.196074 | 1.209521 | 1.222968 | |
| Other | 1.182597 | 1.20336 | 1.224123 | 1.243284 | 1.262445 | 1.281605 | 1.300766 | 1.319926 | |
| | | | | | | | | | |
| Non-Road Diesel CH4 | 1.02404 | 1.030946 | 1.037853 | 1.045498 | 1.053143 | 1.060788 | 1.068433 | 1.076078 | |
| Non-Road Gasoline CH4 | 0.93637 | 0.942979 | 0.949589 | 0.958375 | 0.967161 | 0.975947 | 0.984733 | 0.993519 | |
| Other | 1.057277 | 1.064896 | 1.072516 | 1.189143 | 1.30577 | 1.422397 | 1.539023 | 1.65565 | |

### Table 2.4.5: 2014-2030 MOVES NON-ROAD Model Transportation Sector Projected $CO_2$ Emissions

| Fuel Type Description | 2014 CO2 (tpy) | 2014 CO2 (MMTCO2e) | 2015 | 2020 | 2030 |
|---|---|---|---|---|---|
| Compressed Natural Gas (CNG) | 16642.24619 | 0.015097579 | 0.015400302 | 0.016913915 | 0.019927695 |
| Gasoline | 1194330.698 | 1.0834777 | 1.099285097 | 1.178322082 | 1.325058672 |
| Liquefied Petroleum Gas (LPG) | 182467.4814 | 0.16553158 | 0.168850665 | 0.185446092 | 0.218489514 |
| Marine Diesel Fuel | 88359.70954 | 0.080158515 | 0.081749236 | 0.089702845 | 0.107034504 |
| Nonroad Diesel Fuel | 2109619.432 | 1.913812995 | 1.95179204 | 2.14168727 | 2.555486786 |
| Fuel Type Categories | | | | | |
| Non-Road Gasoline | 1194330.698 | 1.0834777 | 1.099285097 | 1.178322082 | 1.325058672 |
| Non-Road Diesel | 2197979.141 | 1.993971509 | 2.033541277 | 2.231390115 | 2.66252129 |
| Other | 199109.7276 | 0.180629159 | 0.184250967 | 0.202360008 | 0.238417209 |
| | | | | | |
| Total | 3591419.566 | 3.258078368 | 3.317077341 | 3.612072205 | 4.225997171 |

### Table 2.4.6: 2014 MOVES NON-ROAD Model Transportation Sector $CH_4$ Emissions

| Fuel Type Description | 2014 CH4 (tpy) | 2014 CH4 (MMTCO2e) | 2015 | 2020 | 2030 |
|---|---|---|---|---|---|
| Compressed Natural Gas (CNG) | 213.2824954 | 0.004063216 | 0.004086523 | 0.004203061 | 0.006727264 |
| Gasoline | 1218.097711 | 0.023205814 | 0.022883025 | 0.021269083 | 0.023055428 |
| Liquefied Petroleum Gas (LPG) | 28.07393477 | 0.000534833 | 0.000537901 | 0.00055324 | 0.000885496 |
| Marine Diesel Fuel | 0.142074009 | 2.70663E-06 | 2.70813E-06 | 2.71562E-06 | 2.91255E-06 |
| Nonroad Diesel Fuel | 6.676364601 | 0.000127191 | 0.000127261 | 0.000127613 | 0.000136867 |
| Fuel Type Categories | | | | | |
| Non-Road Gasoline | 1218.097711 | 0.023205814 | 0.022883025 | 0.021269083 | 0.023055428 |
| Non-Road Diesel | 6.81843861 | 0.000129897 | 0.000129969 | 0.000130329 | 0.000139779 |
| Other | 241.3564302 | 0.004598049 | 0.004624424 | 0.004756301 | 0.00761276 |
| | | | | | |
| Total | 1466.27258 | 0.02793376 | 0.027637418 | 0.026155713 | 0.030807967 |

### Table 2.4.7: 2025 MOVES NON-ROAD Model Transportation Sector GHG Emissions

| Year | MOVES NON-Road Model Source Category | CH4 (Tons) | CO2 (Tons) | CH4 (MMTCO2e) | CO2 (MMTCO2e) | Total Emissions (MMTCO2e) |
|---|---|---|---|---|---|---|
| 2025 | Agricultural Equipment | 8.56633834 | 256443.725 | 0.000163195 | 0.232641644 | 0.23280484 |
| 2025 | Commercial Equipment | 206.825817 | 378504.026 | 0.003940211 | 0.343372796 | 0.347313007 |
| 2025 | Construction and Mining Equipment | 63.1407737 | 1766919.42 | 0.001202886 | 1.602921031 | 1.604123917 |
| 2025 | Diesel | 4.63923997 | 107303.972 | 8.83813E-05 | 0.097344447 | 0.097432828 |
| 2025 | Gasoline 2-Stroke | 222.198117 | 199259.562 | 0.004233066 | 0.180765087 | 0.184998153 |
| 2025 | Gasoline 4-Stroke | 39.0585089 | 98288.1647 | 0.000744098 | 0.08916545 | 0.089909549 |
| 2025 | Gasoline, 4-Stroke | 0.07105521 | 109.26526 | 1.3535E-06 | 9.91237E-05 | 0.000100477 |
| 2025 | Industrial Equipment | 60.7859973 | 464168.851 | 0.001158027 | 0.421086555 | 0.422244581 |
| 2025 | Lawn and Garden Equipment | 637.053156 | 906451.898 | 0.012136414 | 0.822318659 | 0.834455072 |
| 2025 | Logging Equipment | 1.74406623 | 11391.057 | 0.000033226 | 0.010333785 | 0.010367011 |
| 2025 | LPG | 0.0002335 | 3.78963037 | 4.5E-09 | 3.43789E-06 | 3.44234E-06 |
| 2025 | Recreational Equipment | 111.00263 | 95276.212 | 0.002114696 | 0.086433055 | 0.088547751 |
| 2025 | Underground Mining Equipment | 0.41672976 | 3719.83549 | 7.9391E-06 | 0.003374575 | 0.003382514 |
| 2025 | Airport Ground Support Equipment | 0.7703163 | 27060.4615 | 1.46751E-05 | 0.024548818 | 0.024563493 |

## Table 2.4.8: 2030 MOVES NON-ROAD Model Transportation Sector GHG Emissions

| Year | MOVES NON-Road Model Source Category | CH4 (Tons) | CO2 (Tons) | CH4 (MMTCO2e) | CO2 (MMTCO2e) | Total Emissions (MMTCO2e) |
|---|---|---|---|---|---|---|
| 2030 | Agricultural Equipment | 8.512088658 | 273992.3548 | 0.000162163 | 0.24856148 | 0.248723643 |
| 2030 | Airport Ground Support Equipment | 0.837051721 | 30148.09419 | 1.59466E-05 | 0.027349869 | 0.027365815 |
| 2030 | Commercial Equipment | 206.3335221 | 414867.0648 | 0.003930832 | 0.376360763 | 0.380291595 |
| 2030 | Construction and Mining Equipment | 64.05371461 | 1911619.134 | 0.001220279 | 1.734190293 | 1.735410571 |
| 2030 | Diesel | 5.214343948 | 115895.4071 | 9.93378E-05 | 0.105138459 | 0.105237797 |
| 2030 | Gasoline 2-Stroke | 226.7756548 | 204288.1604 | 0.004320272 | 0.18532695 | 0.189647223 |
| 2030 | Gasoline 4-Stroke | 33.15323752 | 100281.5473 | 0.000631598 | 0.090973815 | 0.091605413 |
| 2030 | Gasoline, 4-Stroke | 0.074173693 | 114.1786849 | 1.41307E-06 | 0.000103581 | 0.000104994 |
| 2030 | Industrial Equipment | 65.16189431 | 498739.1654 | 0.00124139 | 0.452448191 | 0.453689581 |
| 2030 | Lawn and Garden Equipment | 681.8456233 | 976812.3613 | 0.012989748 | 0.886148545 | 0.899138293 |
| 2030 | Logging Equipment | 1.856819174 | 10964.03651 | 3.5374E-05 | 0.009946398 | 0.009981773 |
| 2030 | LPG | 0.00018552 | 4.052434149 | 3.53431E-09 | 3.6763E-06 | 3.67984E-06 |
| 2030 | Recreational Equipment | 109.8149824 | 96781.46518 | 0.00209207 | 0.087798597 | 0.089890667 |
| 2030 | Underground Mining Equipment | 0.454360574 | 3981.373879 | 8.65596E-06 | 0.003611839 | 0.003620495 |

### 2.4.3 Transportation – Marine Vessel Projections

Marine vessel GHG emissions were projected using employment data. State-level employment data was collected from the Maryland Department of Labor, Licensing and Regulation[1]. Employment data from NAICS code 483 (reflecting water transportation) was chosen as the growth surrogate for marine vessels. GHG projected emission estimates for marine vessels are presented below.

**Table 2.4.9: 2014 Transportation Marine Vessel Sector GHG Emissions**

| Fuel Type | Consumption (gallon) | Consumption (Billion Btu) | | Emission Factor (Lbs C/Million Btu) | | Combustion Efficiency (%) | | Emissions (short tons carbon) | Emissions (MMTCE) | Emissions (MMTCO2e) |
|---|---|---|---|---|---|---|---|---|---|---|
| Distillate Fuel - Vessel Bunkering | 3,042,000 | 422 | x | 44.43 | x | 100.0% | = | 9,372 | 0.009 | 0.031 |
| Residual Fuel-Vessel Bunkering | 7,938,000 | 1,235 | x | 45.11 | x | 100.0% | = | 27,855 | 0.025 | 0.093 |
| **TOTAL** | | | | | | | | | | **0.124** |

**Table 2.4.10: 2014-2030 Transportation Marine Vessel Sector GHG Projected Emissions**

| Marine Vessel Projections | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
| **Marine Vessels (Gas and Oil)** | 0.124965 | 0.12828 | 0.1316 | 0.134911 | 0.138226 | 0.141541 | 0.144857 | 0.148172 | 0.151488 |
| **Growth Factor** | 1 | 1.026531 | 1.079592 | 1.079592 | 1.106122 | 1.132653 | 1.159184 | 1.185714 | 1.212245 |
| **Year** | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | |
| **Marine Vessels (Gas and Oil)** | 0.154803 | 0.158119 | 0.161434 | 0.164749 | 0.168065 | 0.17138 | 0.174695 | 0.178011 | |
| **Growth Factor** | 1.238776 | 1.265306 | 1.291837 | 1.318367 | 1.344898 | 1.371429 | 1.397959 | 1.42449 | |

### 2.4.4 Transportation – Rail Projections

Rail GHG emissions were projected using employment data. State-level employment data was collected from the Maryland Department of Labor, Licensing and Regulation[2]. Employment data from NAICS code 482 (reflecting rail transportation) was chosen as the growth surrogate for railroads. Growth in this source sector is expected to remain constant.

**Table 2.4.11: 2014 Transportation Rail Sector GHG Emissions**

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[1] http://www.dllr.state.md.us/lmi/iandoproj/industry.shtml

| Distillate Fuel – Locomotive | | CO2 Emissions | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Consumption (gallon) | | Consumption (Billion Btu) | | Emission Factor (lbs C/Million Btu) | | Combustion Efficiency (%) | | Emissions (short tons carbon) | Emissions (MMTCO2E) |
| 18,081,260 | x | 2,508 | x | 44.43 | x | 100% | = | 55,708 | 0.185 |
| | | N2O Emissions | | | | | | | |
| | | Density (kg/gallon) | | N2O EF (g/kg fuel) | | N2O EM (Gigagrams) | | N2O (MT) | N2O (MMTCO2E) |
| 18,081,260 | x | 3.192 | x | 0.08 | x | 0.0046172306 | = | 4.617 | 0.001 |
| | | CH4 Emissions | | | | | | | |
| | | Density (kg/gallon) | | CH4 EF (g/kg fuel) | | CH4 EM (Gigagrams) | | CH4 (MT) | CH4 (MMTCO2E) |
| 18,081,260 | x | 3.192 | x | 0.25 | = | 0.014428845 | = | 14.42885 | 0.000303 |
| | | | | | | | | Total | 0.187 |

**Table 2.4.12: 2014 Transportation Rail Sector GHG Emissions**

| Marine Vessel Projections (2015 - 2030) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Rail Sector** | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 |
| **Growth Factor** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | |
| **Rail Sector** | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | 0.187038 | |
| **Growth Factor** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |

### 2.4.5 Transportation – Aircraft Projections

Aircraft GHG emissions were projected using operations data from the FAA Terminal Area Forecast for Baltimore-Washington Thurgood Marshall Airport[1]. Airport-specific take-off and landings operations data was collected from the Federal Aviation Administration. GHG projected emission estimates for aircraft transportation are presented below.

**Table 2.4.13: 2014 Transportation Aircraft Sector GHG Emissions**

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[1] https://www.faa.gov/data_research/aviation/taf/media/taf_summary_fy_2016-2045.pdf

| Fuel Type | Consumption (gallon) | Consumption (Billion Btu) | Emission Factor (lbs C/Million Btu) | Combustion Efficiency (%) | Emissions (tons carbon) | Emissions (MMTCO$_2$E) |
|---|---|---|---|---|---|---|
| Aviation Gasoline | 2,058,000 | 175 | 41.53 | 100.0% | 3,634 | 0.012 |
| Jet Fuel, Kerosene | 48,636,000 | 11,121 | 43.43 | 100.0% | 241,503 | 0.803 |
| **TOTAL** | | | | | | **0.823787** |

**Table 2.4.14: Transportation Aircraft Sector GHG Projected Emissions**

| **Aircraft Sector Projections (2015 - 2030)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Aircraft Sector** | 0.823787 | 0.817117 | 0.827123 | 0.863810 | 0.877150 | 0.890491 | 0.903832 | 0.922509 | 0.941186 |
| **Growth Factor** | 1 | 0.991903 | 1.004049 | 1.048583 | 1.064777 | 1.080972 | 1.097166 | 1.119838 | 1.14251 |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** |
| **Aircraft Sector** | 0.959862 | 0.978539 | 0.997216 | 1.015893 | 1.034570 | 1.053247 | 1.071924 | 1.090601 | |
| **Growth Factor** | 1.165182 | 1.187854 | 1.210526 | 1.233198 | 1.25587 | 1.278543 | 1.301215 | 1.323887 | |

### 2.4.6 Transportation – Lubricants, Natural Gas and LPG Projections

As stated above, the 'Lubricants, NG, and LPG' source category was grown from growth factors derived from the "other fuel" MOVES model future projections. These growth factors were then applied to the 2014 Emissions Inventory to project future emissions.

**Table 2.4.15: 2014 Transportation Sector Lubricant GHG Emissions**

| Fuel Type | Consumption (Billion Btu) | Non-Energy Consumption (Billion Btu) | Storage Factor (%) | Net combustible Consumption (Billion Btu) | Emission Factor (lbs C/Million Btu) | Combustion Efficiency (%) | Emissions (short tons carbon) | Emissions (MMTCO$_2$E) |
|---|---|---|---|---|---|---|---|---|
| Lubricants | 1,466 | 1,427 | 9% | 1,295 | 43.97 | 100.00% | 28,474 | 0.095 |
| | | | | | $CH_4$ | $CO_2$ | $CH_4$ | $CO_2$ |
| | | | | | (short tons/yr) | (short tons/yr) | (MMTCO$_2$E) | (MMTCO$_2$E) |
| Compressed Natural Gas | | | | | 213.28 | 16,642.25 | 0.0041 | 0.0151 |
| Liquefied Petroleum Gas (LPG) | | | | | 28.07 | 182,467.48 | 0.0005 | 0.1655 |
| Total | | | | | | | | 0.2756 |

**Table 2.4.16a: Transportation – Lubricants, NG and LPG Sector GHG Projected Emissions ($CO_2$)**

| Lubricants, NG and LPT Sector Projections (2015 - 2030) CO2 (MMTCO2e) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Lubricant, NG and LPT Sector** | 0.275343 | 0.280864 | 0.286385 | 0.291906 | 0.297427 | 0.302947 | 0.308468 | 0.314185 | 0.3199 |
| **Growth Factor** | 1 | 1.020051 | 1.040102 | 1.060153 | 1.080204 | 1.100255 | 1.120306 | 1.14107 | 1.16183 |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | |
| **Lubricant, NG and LPT Sector** | 0.32562 | 0.331337 | 0.337054 | 0.342329 | 0.347605 | 0.352881 | 0.358157 | 0.363432 | |
| **Growth Factor** | 1.182597 | 1.20336 | 1.224123 | 1.243284 | 1.262445 | 1.281605 | 1.300766 | 1.319926 | |

**Table 2.4.16b: Transportation – Lubricants, NG and LPG Sector GHG Projected Emissions ($CH_4$)**

| Lubricants, NG and LPT Sector Projections (2015 - 2030) CH4 (MMTCO2e) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Lubricant, NG and LPT Sector** | 0.004598 | 0.004624 | 0.004651 | 0.004677 | 0.004704 | 0.00473 | 0.004756 | 0.004791 | 0.00483 |
| **Growth Factor** | 1 | 1.005736 | 1.011472 | 1.017209 | 1.022945 | 1.028681 | 1.034417 | 1.042037 | 1.04966 |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | |
| **Lubricant, NG and LPT Sector** | 0.004861 | 0.004896 | 0.004931 | 0.005468 | 0.006004 | 0.00654 | 0.007077 | 0.007613 | |
| **Growth Factor** | 1.057277 | 1.064896 | 1.072516 | 1.189143 | 1.30577 | 1.422397 | 1.539023 | 1.65565 | |

## 2.5 Fossil Fuel Production Industry

This section reports GHG emissions that are released during the production, processing, transmission, and distribution of fossil fuels, (primarily natural gas and coal) in Maryland. $CH_4$ emissions released via leakage and venting from oil and gas fields, processing facilities, and natural gas pipelines, and also fugitive $CH_4$ emissions resulting from coal mining are estimated in this section. Additionally, $CO_2$ emissions associated with the combustion of natural gas in compressor engines (referred to as pipeline fuel) are estimated.

GHG emissions in 2030 from the fossil fuel industry are expected to increase slightly to 0.8070 MMTCO2E from the base Year 2014, 0.72 MMTCO2E. This projected increase is assumed to be due to the continued increase in natural gas use, expansion of transmission and distribution facilities in Maryland.

To project the fossil fuel industry 2030 GHG emissions, MDE used the Base Year 2014 emissions and estimated 2030 emissions based on the growth in projected GHG emission of the natural gas industry and coal mining industry derived from the EPA State Inventory Tool (SIT) Forecast Module. The forecast module projects a state’s future energy consumption based on regional energy consumption levels downscaled to the state level.

### Table 2.5.1: Base Year 2014 GHG Emissions from Pipeline Natural Gas Combustion

| | $CO_2$ (lbs/MMBtu) | $N_2O$ (Mt/BBtu) | $CH_4$ (Mt/BBtu) | Total Emissions |
|---|---|---|---|---|
| **Emission Factors** | 31.87 | 9.496E-05 | 0.00094955 | |
| Total Natural Gas Consumption (Billion Btus) | 6,644.0 | 6,644.0 | 6,644.0 | |
| Combustion Efficiency (%) | 100% | 100% | 100% | |
| **Emissions ($MMTCO_2E$)** | 0.000352 | 0.0001956 | 0.000132 | **0.000680** |

### Table 2.5.2: Base Year 2014 GHG Emissions from Natural Gas Production

| **Production Sector** | **Activity Data** | **Emission Factor (metric tons $CH_4$ per year per activity unit)** | **$CH_4$ Emissions (metric tons)** | **$CH_4$ Emissions ($MMTCO_2E$)** |
|---|---|---|---|---|
| Total number of wells | 7 | 4.10 | 28.72 | 0.00060 |
| **Total** | | | **28.72** | **0.00060** |

## Table 2.5.3: Base Year 2014 GHG Emissions from Natural Gas Transmission

| **Transmission Sector** | **Activity Data** | **Emission Factor (metric tons $CH_4$ per year per activity unit)** | **$CH_4$ Emissions (metric tons)** | **$CH_4$ Emissions ($MMTCO_2E$)** |
|---|---|---|---|---|
| Miles of transmission pipeline | 978 | 0.6185 | 105 | 0.01270 |
| Number of gas transmission compressor stations | 6 | 983.7 | 5,773 | 0.12124 |
| Number of gas storage compressor stations | 1 | 964.1 | 1,415 | 0.02971 |
| **Total** | | | **7,793** | **0.16365** |

## Table 2.5.4: Base Year 2014 GHG Emissions from Natural Gas Distribution

| **Distribution Sector** | **Activity Data** | **Emission Factor** (metric tons $CH_4$ per year per activity unit) | **$CH_4$ Emissions** (metric tons) | **$CH_4$ Emissions** ($MMTCO_2E$) |
|---|---|---|---|---|
| **Distribution pipeline** | | | | |
| Miles of cast iron distribution pipeline | 1,278 | 5.80 | 7,417.16 | 0.156 |
| Miles of unprotected steel distribution pipeline | 35 | 2.12 | 74 | 0.002 |
| Miles of protected steel distribution pipeline | 2,817 | 0.06 | 169 | 0.004 |
| Miles of plastic distribution pipeline | 3,292 | 0.37 | 1,223 | 0.026 |
| **Services** | | | | |
| Total number of services | 544,843 | 0.02 | 8,318 | 0.175 |
| Number of unprotected steel services | 77,194 | 0.03 | 2,528 | 0.053 |
| Number of protected steel services | 78,296 | 0.00 | 266 | 0.006 |
| **Total** | | | **19,997** | **0.420** |

### Table 2.5.5: 2030 GHG Emissions Growth Factor from Natural Gas Distribution

| EPA State Inventory Tool Projections (2015 - 2030) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Natural Gas** | 0.780144 | 0.785796 | 0.791791 | 0.797786 | 0.803781 | 0.809776 | 0.815771 | 0.82728 | 0.838789 |
| **Oil (petro)** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Growth Factor** | 1 | 1.007246 | 1.01493 | 1.022615 | 1.030299 | 1.037984 | 1.045668 | 1.060421 | 1.075173 |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** |
| **Natural Gas** | 0.850298 | 0.861807 | 0.873316 | 0.873548 | 0.87378 | 0.874013 | 0.874245 | 0.874477 | 0.874477 |
| **Oil (petro)** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Growth Factor** | 1.089925 | 1.104677 | 1.11943 | 1.119727 | 1.120025 | 1.120323 | 1.120621 | 1.120918 | 1.120918 |

### Table 2.5.6: Base Year 2014 $CH_4$ Emissions from Coal Mining

| **Underground Mines** | | | | | |
|---|---|---|---|---|---|
| **Measured Ventilation Emissions (mcf)** | **Degasification System Emissions (mcf)** | **Methane Recovered from Degasification Systems and Used for Energy (mcf)** | **Emissions (mcf $CH_4$)** | **Emissions ($MTCH_4$)** | **Emissions ($MTCO_2E$)** |
| 0 | 0 | 0 | 0.00 | - | - |

| **Surface Mines** | | | | |
|---|---|---|---|---|
| Surface Coal Production ('000 short tons) | Basin-specific EF ($ft^3$/short ton) | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| 1,200 | 119.0 | 142,800 | 5,091 | 106,901 |

| **Post Mining Activity – Underground Mines** | | | | |
|---|---|---|---|---|
| Coal Production ('000 short tons) | Basin & Mine-specific EF ($ft^3$/short ton) | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| 700 | 45.0 | 31,486 | 605 | 12,695 |
| **Post Mining Activity – Surface Mines** | | | | |
| Coal Production ('000 short tons) | Basin- & Mine-specific EF ($ft^3$/short ton) | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| 1,200 | 19.3 | 23,205 | 446 | 9,356 |
| | | | | |
| **Post Mining Activity – SubTotal** | | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| | | 54,691 | 1,050 | 22,051 |

| | |
|---|---|
| **Total Coal Mining Emissions ($MTCO_2e$)** | **128,953** |
| **Total Coal Mining Emissions ($MMTCO_2e$)** | **0.128953** |

## Table 2.5.7: 2030 Growth Factor from Coal Mining

| | EPA State Inventory Tool Projections (2015 - 2030) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| Coal Mining | 0.174577 | 0.169348 | 0.169574 | 0.169799 | 0.170024 | 0.170249 | 0.170474 | 0.161682 | 0.159423 |
| **Growth Factor** | 1 | 0.970049 | 0.971338 | 0.972627 | 0.973916 | 0.975205 | 0.976494 | 0.926136 | 0.913192 |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** |
| Coal Mining | 0.157163 | 0.154903 | 0.175959 | 0.150384 | 0.148124 | 0.145864 | 0.143605 | 0.189462 | 0.189462 |
| **Growth Factor** | 0.900248 | 0.887304 | 1.007916 | 0.861417 | 0.848473 | 0.835529 | 0.822585 | 1.085262 | 1.085262 |

## 2.6 Industrial Processes

Emissions estimated in the industrial sector accounts for only process-related GHG emissions from the four main industrial processes that occurs in the State:

1. $CO_2$ emissions from cement production, soda ash, dolomite and lime/limestone consumption;
2. $CO_2$ emissions from iron and steel production;
3. Sulfur hexafluoride (SF6) emissions from electric power transmission and distribution (T&D) system transformers use, and
4. Hydrofluorocarbon (HFC) and perfluorocarbon (PFC) emissions resulting from the consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment.

The projection for the industrial processes emissions used the Base Year 2014 emissions and estimated 2030 emissions based on the growth in projected process emissions. This was done for each of the industries in Maryland using the EPA SIT Projection module industrial sector emissions projections.

The projection for ODS substitutes uses a source-specific EPA model which projects emissions of ODS substitutes nationwide. Maryland emissions in 2030 were determined by prorating national emissions based on population. SF6 emissions from the power sector now and in the future are expected to occur solely as the result of leaks. Leaks from transmission equipment are not expected to increase over time from current estimates.

The projected BAU 2030 emissions (4.11 $MMTCO_2E$) from the industrial sector is estimated to be slightly lower than the Base Year 2014 (4.79 $MMTCO_2E$) due to the exit of the iron and steel industry in Maryland.

The EPA SIT tool projects a state's future emissions based on a linear trend based on historical data.

**Table 2.6.1: Base Year 2014 Cement Industry Process $CO_2$ Emissions**

| MD TOTAL CEMENT GHG EMISSIONS (Lehigh + Holcim) | $CO_2$ Emissions |
|---|---|
| MD Summary Cement Process $CO_2$ Emissions (short tons) | 1,742,448 |
| | |
| MD Summary Cement Process $CO_2$ Emissions (metric tons) | 1,580,721 |
| | |
| MD Summary Cement Process $CO_2$ Emissions ($MMTCO_2E$) | 1.58 |

### Table 2.6.2: Base Year 2014 Iron and Steel Industry Process $CO_2$ Emissions.

| Source | Pollutant | $CO_2$ Emissions (metric tons) | $CO_2$ Emissions (short tons) | Data Source |
|---|---|---|---|---|
| **Bleeders** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| | $CH_4$ | 0.00 | 0.00 | |
| | $N_2O$ | 0.00 | 0.00 | |
| **L Blast Furnace** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| | $CH_4$ | 0.0 | 0.00 | |
| | $N_2O$ | | - | |
| **Sinter Plant** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| **BOF** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| **Total** | $CO_2$ | 0.0 | 0.0 | |
| | $CH_4$ | 0.0 | 0.0 | |
| | $N_2O$ | 0.00 | 0.00 | |

### Table 2.6.3: Base Year 2014 Soda Ash Consumption $CO_2$ Emissions.

| | **Consumption (Metric Tons)** | **Emission Factor (t $CO_2$/t production)** | **Emissions ($MTCO_2E$)** | **Emissions ($MMTCO_2E$)** |
|---|---|---|---|---|
| Soda Ash | 95,590 | 0.4150 | 39,670 | **0.040** |

### Table 2.6.4: Base Year 2014 Limestone and Dolomite Use $CO_2$ Emissions.

| | **Consumption (Metric Tons)** | **Emission Factor (t $CO_2$/t production)** | **Emissions ($MTCO_2E$)** | **Emissions ($MMTCO_2E$)** |
|---|---|---|---|---|
| Limestone | 327,081 | 0.44 | 143,916 | **0.144** |

### Table 2.6.5: Base Year 2014 Non-Fertilizer Urea Use $CO_2$ Emissions.

| | **Non-Fertilizer Consumption (Metric Tons)** | **Emission Factor (mt $CO_2$/mt activity)** | **Emissions ($MTCO_2E$)** | **Emissions ($MMTCO_2E$)** |
|---|---|---|---|---|
| Urea | 751 | 0.73 | 548 | 0.000547 |

## Table 2.6.6: Base Year 2014 $SF_6$ Emissions from Electrical T&D[1] System.

| | | |
|---|---|---|
| Total US $SF_6$ Emissions from Electric Power T & D ($MMTCO_2E$) | 2.0E+06 | A |
| $SF_6$ GWP | 23,900 | B |
| US Total $SF_6$ Consumed (metric tons) | 83.68 | 'C = A/B |
| | | |
| Total US Electric Sales (MWh) (2014) | 3,764,700,267 | D |
| MD Total Electric Sales (MWh) (2014) | 61,683,869 | E |
| MD Apportioned $SF_6$ Consumption (metric tons) | 1.3711 | $F = C \times \frac{E}{D}$ |
| | | |
| Emission Factor | 1.0 | G |
| $SF_6$ Emissions (metric tons) | 1.3711 | H= G*F |
| $SF_6$ Emissions ($MTCO_2E$) | 32,768.82 | I=G*B |
| $SF_6$ Emissions ($MMTCO_2E$) | 0.03277 | $J=I/10^6$ |

## Table 2.6.7: Base Year 2014 HFC & PFCs Emissions from ODS Substitutes

| | |
|---|---|
| Total US GHG 2014 Emissions from ODS substitute (Metric tons $CO_2$ Eq.) | 158,600,000 |
| MD 2014 Population | 5,976,407 |
| US 2014 Population | 318,857,056 |
| Apportioned State Emissions ($MMTCO_2e$) | 2.972 |

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[1] T&D: Transmission and Distribution

## Table 2.6.8: (2015- 2030) Industrial Emission Projections

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|
| Cement Manufacturing | 722,252 | 864,412 | 866,538 | 868,664 | 870,791 | 872,917 | 875,043 | 877,170 | 879,296 |
| Limestone & Dolomite | 190,657 | 166,926 | 172,303 | 177,680 | 183,057 | 188,434 | 193,811 | 199,188 | 204,565 |
| Soda Ash | 40,154 | 40,222 | 39,681 | 39,140 | 38,599 | 38,058 | 37,518 | 36,977 | 36,436 |
| Iron and Steel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ODS Substitutes | 3,021,269 | 973,578 | 1,038,860 | 1,104,249 | 1,169,743 | 1,235,339 | 1,301,035 | 1,382,135 | 1,463,239 |
| Electricity Power Transmission and Distribution Systems | 91,740 | 54,252 | 53,362 | 52,472 | 51,582 | 50,692 | 49,801 | 49,509 | 49,216 |
| Semiconductor Manufacturing | 8,880 | 9,107 | 9,333 | 9,559 | 9,786 | 10,012 | 10,239 | 10,465 | 10,692 |
| Ammonia and Urea Production (Nonfertilizer) | 808 | 836 | 832 | 829 | 826 | 822 | 819 | 816 | 812 |
| Aluminum Production | 187,101 | 184,643 | 182,185 | 179,727 | 177,269 | 174,811 | 172,353 | 169,895 | 167,437 |

## Table 2.6.9: (2015- 2030) Industrial Emission Projections

| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|
| Cement Manufacturing | 881,422 | 883,549 | 885,675 | 887,802 | 889,928 | 892,054 | 894,181 | 896,307 | 896,307 |
| Limestone & Dolomite | 209,942 | 215,319 | 220,696 | 226,073 | 231,450 | 236,827 | 242,203 | 247,580 | 247,580 |
| Soda Ash | 35,895 | 35,354 | 34,813 | 34,272 | 33,731 | 33,190 | 32,649 | 32,108 | 32,108 |
| Iron and Steel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ODS Substitutes | 1,544,349 | 1,625,465 | 1,706,585 | 1,751,808 | 1,797,004 | 1,842,175 | 1,887,321 | 1,932,442 | 1,932,442 |
| Electricity Power Transmission and Distribution Systems | 48,924 | 48,632 | 48,339 | 47,897 | 47,455 | 47,013 | 46,571 | 46,129 | 46,129 |
| Semiconductor Manufacturing | 10,918 | 11,144 | 11,371 | 11,597 | 11,824 | 12,050 | 12,276 | 12,503 | 12,503 |
| Ammonia and Urea Production (Nonfertilizer) | 809 | 806 | 802 | 799 | 795 | 792 | 789 | 785 | 785 |
| Aluminum Production | 164,980 | 162,522 | 160,064 | 157,606 | 155,148 | 152,690 | 150,232 | 147,774 | 147,774 |

## Table 2.6.10: 2030 Industrial Growth Factors

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|
| Cement Manufacturing | 1.00 | 1.20 | 1.20 | 1.20 | 1.21 | 1.21 | 1.21 | 1.21 | 1.22 |
| Limestone & Dolomite | 1.00 | 0.88 | 0.90 | 0.93 | 0.96 | 0.99 | 1.02 | 1.04 | 1.07 |
| Soda Ash | 1.00 | 1.00 | 0.99 | 0.97 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 |
| Iron and Steel | | | | | | | | | |
| ODS Substitutes | 1.00 | 0.32 | 0.34 | 0.37 | 0.39 | 0.41 | 0.43 | 0.46 | 0.48 |
| Electricity Power Transmission and Distribution Systems | 1.00 | 0.59 | 0.58 | 0.57 | 0.56 | 0.55 | 0.54 | 0.54 | 0.54 |
| Semiconductor Manufacturing | 1.00 | 1.03 | 1.05 | 1.08 | 1.10 | 1.13 | 1.15 | 1.18 | 1.20 |
| Ammonia and Urea Production (Nonfertilizer) | 1.00 | 1.03 | 1.03 | 1.03 | 1.02 | 1.02 | 1.01 | 1.01 | 1.01 |
| Aluminum Production | 1.00 | 0.99 | 0.97 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 | 0.89 |

| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|
| Cement Manufacturing | 1.22 | 1.22 | 1.23 | 1.23 | 1.23 | 1.24 | 1.24 | 1.24 | 1.24 |
| Limestone & Dolomite | 1.10 | 1.13 | 1.16 | 1.19 | 1.21 | 1.24 | 1.27 | 1.30 | 1.30 |
| Soda Ash | 0.89 | 0.88 | 0.87 | 0.85 | 0.84 | 0.83 | 0.81 | 0.80 | 0.80 |
| Iron and Steel | | | | | | | | | |
| ODS Substitutes | 0.51 | 0.54 | 0.56 | 0.58 | 0.59 | 0.61 | 0.62 | 0.64 | 0.64 |
| Electricity Power Transmission and Distribution Systems | 0.53 | 0.53 | 0.53 | 0.52 | 0.52 | 0.51 | 0.51 | 0.50 | 0.50 |
| Semiconductor Manufacturing | 1.23 | 1.25 | 1.28 | 1.31 | 1.33 | 1.36 | 1.38 | 1.41 | 1.41 |
| Ammonia and Urea Production (Nonfertilizer) | 1.00 | 1.00 | 0.99 | 0.99 | 0.98 | 0.98 | 0.98 | 0.97 | 0.97 |
| Aluminum Production | 0.88 | 0.87 | 0.86 | 0.84 | 0.83 | 0.82 | 0.80 | 0.79 | 0.79 |

## 2.7 Agriculture

The emissions estimated in this section refer to non-energy $CH_4$ and $N_2O$ emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon in agricultural soils are also estimated in this section. Energy emissions (combustion of fossil fuels in agricultural equipment) are not included in this section, but are already accounted for under the RCI and non-road transportation sub-sector.

2030 BAU emissions from the agriculture sector are projected to slightly decrease to 1.72 $MMTCO_2E$ from the Base Year emissions level (1.89 $MMTCO_2E$). The projection for the agriculture emissions used the Base Year 2014 emissions and estimated 2030 emissions using the agriculture sector of the EPA SIT Projection module.

## Table 2.7.1: Base Year 2014 $CH_4$ Generation from Manure Management

| | Number of Animals ('000 head) | Typical Animal Mass (TAM) (kg) | Volatile Solids (VS) [kg VS/1000 kg animal mass/day] | Total VS (kg/yr) | Max Pot. Emissions ($m^3$ $CH_4$/ kg VS) | Weighted MCF | $CH_4$ Emissions ($m^3$) |
|---|---|---|---|---|---|---|---|
| **Dairy Cattle** | | | | | | | |
| Dairy Cows | 50.0 | 680 | 10.0 | 122,985,884 | 0.24 | 0.118 | 3,488,359 |
| Dairy Replacement Heifers | 25.0 | 476 | 8.4 | 36,587,282 | 0.17 | 0.012 | 77,547 |
| **Beef Cattle** | | | | | | | |
| Feedlot Heifers | 3.9 | 420 | 4.4 | 2668,401 | 0.33 | 0.013 | 11,556 |
| Feedlot Steer | 7.4 | 420 | 4.0 | 4,592,625 | 0.33 | 0.013 | 19,663 |
| Bulls | 4.0 | 750 | 5.2 | 6,613,800 | 0.17 | 0.011 | 12,368 |
| Calves | 33.0 | 118 | 6.4 | 9,110,597 | 0.17 | 0.011 | 17,037 |
| Beef Cows | 38.0 | 533 | 7.5 | 55,404,515 | 0.17 | 0.011 | 103,606 |
| Beef Replacement Heifers | 10 | 420 | 7.6 | 11,636,201 | 0.17 | 0.011 | 21,760 |
| Steer Stockers | 15.0 | 318 | 8.1 | 14,028,947 | 0.17 | 0.011 | 26234 |
| Heifer Stockers | 8.0 | 420 | 8.6 | 10,412,881 | 0.17 | 0.011 | 19,472 |
| **Swine** | | | | | | | |
| Breeding Swine | 3.0 | 198 | 2.6 | 563,706 | 0.48 | 0.301 | 81,336 |
| Market Under 60 lbs | 7.00 | 16 | 8.8 | 357,046 | 0.48 | 0.300 | 51,443 |
| Market 60-119 lbs | 4.0 | 41 | 5.4 | 320,090 | 0.48 | 0.300 | 46,119 |
| Market 120-179 lbs | 3.0 | 68 | 5.4 | 401,020 | 0.48 | 0.300 | 57,779 |
| Market over 180 lbs | 4.0 | 91 | 5.4 | 715,473 | 0.48 | 0.300 | 103,086 |
| **Poultry** | | | | | | | |
| Layers | | | | | | | |
| Hens > 1 yr | 2,364.0 | 2 | 10.8 | 16,773,998 | 0.39 | 0.051 | 335,113 |
| Pullets | 708.0 | 2 | 9.7 | 4,512,013 | 0.39 | 0.051 | 90,142 |
| Chickens | 10.0 | 2 | 10.8 | 70,956 | 0.39 | 0.051 | 1,418 |
| Broilers | 52,327.0 | 1 | 15 | 257,841,293 | 0.36 | 0.015 | 1,392,343 |
| Turkeys | 421.0 | 7 | 9.7 | 10,135,743 | 0.36 | 0.015 | 54,733 |
| **Other** | | | | | | | |
| Sheep on Feed | 0 | 25 | 9.2 | - | 0.36 | 0.012 | - |
| Sheep Not on Feed | 12.0 | 80 | 9.2 | 3,225,600 | 0.19 | 0.011 | 6,740 |
| Goats | 15.0 | 64 | 9.5 | 2,895,360 | 0.17 | 0.011 | 5,413 |
| Horses | 80.0 | 450 | 10 | 131,400,000 | 0.33 | 0.011 | 477,804 |
| **TOTAL** | | | | | | | **6,501,072** |

## Table 2.7.2: Base Year 2014 $N_2O$ Generation from Manure Management.

| | Number of Animals ('000 head) | Typical Animal Mass (TAM) (kg) | Nitrogen Produced (kg/1000 kg Animal mass/day) | Total K-Nitrogen Excreted (kg) |
|---|---|---|---|---|
| **Dairy** | | | | |
| Dairy Cows | 50.0 | 680 | 0.440 | 5,460,400 |
| Dairy Replacement Heifers | 25.0 | 476 | 0.310 | 1,346,485 |
| **Beef Cattle** | | | | |
| Feedlot Heifers | 3.9 | 420 | 0.300 | 179,913 |
| Feedlot Steer | 7.4 | 420 | 0.300 | 340,096 |
| **Swine** | | | | |
| Breeding Swine | 3.0 | 198 | 0.235 | 50,950 |
| Market Under 60 lbs | 7.0 | 16 | 0.600 | 24,344 |
| Market 60-119 lbs | 4.0 | 41 | 0.420 | 24,896 |
| Market 120-179 lbs | 3.0 | 68 | 0.420 | 31,190 |
| Market over 180 lbs | 4.0 | 91 | 0.420 | 55,648 |
| **Poultry** | | | | |
| Layers | | | | |
| Hens > 1 yr | 2,364.0 | 2 | 0.830 | 1,289,113 |
| Pullets | 708.0 | 2 | 0.620 | 288,397 |
| Chickens | 10.0 | 2 | 0.830 | 8,725 |
| Broilers | 52,327.0 | 1 | 1.100 | 18,908,361 |
| Turkeys | 421.0 | 7 | 0.740 | 282,849 |
| **Other** | | | | |
| Sheep on Feed | 0 | 25 | 0.420 | - |
| Sheep Not on Feed | 12.0 | 80 | 0.420 | 147,168 |
| **TOTAL** | | | | **30,118,367** |

## Table 2.7.3: Base Year 2014 $CH_4$ Emissions from Enteric fermentation

| Animal | Number of Animals ('000 head) | Emission Factor (kg $CH_4$/head) | Emissions (kg $CH_4$/year) | Emissions (MMT-$CH_4$/Year) | Emissions (MMTCO$_2$E) |
|---|---|---|---|---|---|
| **Dairy Cattle** | | | | | |
| Dairy Cows | 50.0 | 138.9 | 6,776,398 | 0.0039 | 0.142 |
| Dairy Replacement Heifers | 25.0 | 66.0 | 1,800,648 | 0.0010 | 0.038 |
| **Beef Cattle** | | | | | |
| Beef Cows | 38.0 | 94.4 | 3,252,618 | 0.0190 | 0.068 |
| Beef Replacement Heifers | 10.0 | 66.7 | 591,889 | 0.0030 | 0.012 |
| Heifer Stockers | 8.0 | 59.8 | 228,301 | 0.0010 | 0.005 |
| Steer Stockers | 15.0 | 57.9 | 860,117 | 0.0050 | 0.018 |
| Feedlot Heifers | 3.9 | 43.2 | 223,054 | 0.0010 | 0.005 |
| Feedlot Steer | 7.4 | 42.0 | 420,454 | 0.0020 | 0.009 |
| Bulls | 4.0 | 97.6 | 212,000 | 0.0010 | 0.004 |
| **Other** | | | | | |
| Sheep | 24.0 | 8.0 | 192,000 | 0.0010 | 0.004 |
| Goats | 13.0 | 5.0 | 65,000 | 0.0000 | 0.001 |
| Swine | 21.0 | 1.5 | 31,500 | 0.0000 | 0.001 |
| Horses | 80.0 | 18.0 | 1,440,000 | 0.0080 | 0.030 |
| **TOTAL** | | | | **0.092** | **0.338** |

### Table 2.7.4: Base Year 2014 $CH_4$ Emissions from Manure Management

| | Emissions ($m^3$ $CH_4$) | Emissions (Metric Tons $CH_4$) | Emissions ($MMTCH_4$) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| **Dairy Cattle** | | | | |
| Dairy Cows | 3,488,359 | 2309 | 0.002 | 0.048 |
| Dairy Replacement Heifers | 77,547 | 51 | 0.000 | 0.001 |
| **Beef Cattle** | | | | |
| Feedlot Heifers | 11,556 | 8 | 0.000 | 0.000 |
| Feedlot Steer | 19,663 | 13 | 0.000 | 0.000 |
| Bulls | 12,368 | 8 | 0.000 | 0.000 |
| Calves | 17,037 | 11 | 0.000 | 0.000 |
| Beef Cows | 103,606 | 69 | 0.000 | 0.001 |
| Beef Replacement Heifers | 21,760 | 14 | 0.000 | 0.000 |
| Steer Stockers | 26,234 | 17 | 0.000 | 0.000 |
| Heifer Stockers | 19,472 | 13 | 0.000 | 0.000 |
| **Swine** | | | | |
| Breeding Swine | 81,336 | 54 | 0.000 | 0.001 |
| Market Under 60 lbs | 51,443 | 34 | 0.000 | 0.001 |
| Market 60-119 lbs | 46,119 | 31 | 0.000 | 0.001 |
| Market 120-179 lbs | 57,779 | 38 | 0.000 | 0.001 |
| Market over 180 lbs | 103,086 | 68 | 0.000 | 0.001 |
| **Poultry** | | | | |
| Layers | | | | |
| Hens > 1 yr | 335,113 | 222 | 0.000 | 0.005 |
| Pullets | 90,142 | 60 | 0.000 | 0.001 |
| Chickens | 1,418 | 1 | 0.000 | 0.000 |
| Broilers | 1,392,343 | 922 | 0.001 | 0.019 |
| Turkeys | 54,733 | 36 | 0.000 | 0.001 |
| **Other** | | | | |
| Sheep on Feed | - | - | 0.000 | 0.000 |
| Sheep Not on Feed | 6,740 | 4 | 0.000 | 0.000 |
| Goats | 5,413 | 4 | 0.000 | 0.000 |
| Horses | 477,804 | 316 | 0.000 | 0.007 |
| **TOTAL** | **6,501,072** | **4,304** | **0.004** | **0.090** |

## Table 2.7.5: Base Year 2014 $CH_4$ from Agricultural Residue Burning

| Crop | Crop Production (metric tons) | Amt of Dry Matter Burned (metric tons) | Carbon Content (tons C/ tons dm) | Total C Released (metric tons C) | $CH_4$-C Emission ratio | $CH_4$ Emission (metric tons $CH_4$) | $CH_4$ GWP | $CH_4$ Emissions (MMTCO$_2$E) |
|---|---|---|---|---|---|---|---|---|
| Barley | 1,642,480 | 1,718.06420 | 0.4485 | 20,184 | 0.007 | 134.56 | 21 | 0.0028258 |
| Corn | 48,552,667 | 26,599.6937 | 0.4478 | 485,764 | 0.007 | 3,238.43 | 21 | 0.0680070 |
| Peanuts | - | - | 0.4500 | - | 0.007 | - | 21 | - |
| Rice | - | - | 0.3806 | - | 0.007 | - | 21 | - |
| Soybeans | 17,206,332 | 21,856.0174 | 0.4500 | 347,317 | 0.007 | 2,315.45 | 21 | 0.0486244 |
| Sugarcane | - | - | 0.4235 | - | 0.007 | - | 21 | - |
| Wheat | 12,961,899 | 10,130.3992 | 0.4428 | 170,369 | 0.007 | 1,135.79 | 21 | 0.0238516 |
| **Total $CH_4$ from Agriculture Residue Burning (MMTCO$_2$E)** | | | | | | | | **0.143** |

## Table 2.7.6: Base Year 2014 $N_2O$ from Agricultural Residue Burning

| Crop | Crop Production (metric tons) | Amt of Dry Matter Burned (metric tons) | N Content (metric tons N/ metric tons dm) | Total N Released (metric tons N) | $N_2O$ -N Emission Ratio | ($N_2O$ - N) Emissions (metric tons $N_2O$) | $N_2O$ Emissions (metric tons $N_2O$) | $N_2O$ GWP | $N_2O$ Emissions (MMTCO$_2$E) |
|---|---|---|---|---|---|---|---|---|---|
| Barley | 1,642,480 | 1,718.0642 | 0.0077 | 346.53 | 0.007 | 0.09 | 3.812 | 310 | 0.0011817 |
| Corn | 48,552,667 | 26,599.693 | 0.0058 | 6,291.72 | 0.007 | 1.39 | 69.209 | 310 | 0.0214548 |
| Peanuts | - | - | 0.0106 | - | 0.007 | - | 0.0000 | 310 | - |
| Rice | - | - | 0.0072 | - | 0.007 | - | 0.0000 | 310 | - |
| Soybeans | 17,206,332 | 21,856.017 | 0.023 | 17,751.77 | 0.007 | 3.11 | 195.269 | 310 | 0.0605335 |
| Sugarcane | - | - | 0.004 | - | 0.007 | - | 0.0000 | 310 | - |
| Wheat | 12,961,899 | 10,130.399 | 0.0062 | 2,385.47 | 0.007 | 0.30 | 26.240 | 310 | 0.0081344 |
| **Total $N_2O$ from Agriculture Residue Burning (MMTCO$_2$E)** | | | | | | | | | **0.09130** |

## Table 2.7.7: Base Year 2014 $N_2O$ Emissions from Manure Management

| | Total N Emission from Manure Management (kg $N_2O$-N) | Total N Emission from Manure Management (kg $N_2O$) | Total $N_2O$ Emission (MMT) | Total $N_2O$ Emission from Manure Management ($MMTCO_2E$) |
|---|---|---|---|---|
| **Dairy** | | | | |
| Dairy Cows | 29,984 | 49,221 | 0.00416 | 0.01526 |
| Dairy Replacement Heifers | 14,786 | 23,235 | 0.00196 | 0.00720 |
| **Beef Cattle** | | | | |
| Feedlot Heifers | 3,587 | 5,637 | 0.00048 | 0.00175 |
| Feedlot Steer | 6,807 | 10,696 | 0.00090 | 0.00332 |
| **Swine** | | | | |
| Breeding Swine | 26 | 80 | 0.00001 | 0.00002 |
| Market Under 60 lbs | 24 | 74 | 0.00001 | 0.00002 |
| Market 60-119 lbs | 33 | 103 | 0.00001 | 0.000003 |
| Market 120-179 lbs | 31 | 98 | 0.00001 | 0.00003 |
| Market over 180 lbs | 42 | 131 | 0.00001 | 0.000004 |
| **Poultry** | | | | |
| Layers | | | | |
| Hens > 1 yr | 5,937 | 9,427 | 0.00080 | 0.00292 |
| Pullets | 356 | 565 | 0.00005 | 0.00018 |
| Chickens | 31 | 49 | 0.00000 | 0.000002 |
| Broilers | 383,556 | 602,731 | 0.05096 | 0.18685 |
| Turkeys | 25,860 | 40,638 | 0.00344 | 0.01260 |
| **Other** | 0.0 | 0 | | |
| Sheep on Feed | 0.0 | 0 | 0.00000 | 0.0000 |
| Sheep Not on Feed | 0.0 | 0 | 0.00000 | 0.0000 |
| **TOTAL** | | **742,687** | **0.06279** | **0.23023** |

## Table 2.7.8: Base Year 2014 Direct $N_2O$ Emissions from Fertilizer Application (Agriculture Soils).

| | Synthetic Fertilizer | Organic Fertilizer |
|---|---|---|
| | | |
| Total Fertilizer Use (kg N) | 29,610,536 | 24,559,856 |
| Total N in Fertilizers (Calendar Year) | 24,559,856 | 31,404,891 |
| Volatilization Rate | 10% | 20% |
| Nitrogen Content of Fertilizer | 0 | 4.1% |
| Unvolatized N (kg) | 22,103,871 | 1,030,080.4 |
| Direct Emission factor ($N_2$0 -N) | 0.0100 | 0.0125 |
| Direct Emission (kg $N_2$0 - N) | 221,038.7 | 12,876.00 |
| Direct Emission (kg $N_2$0) | 347,346.54 | 20,233.7 |
| Direct Emission (metric tons $N_2$0) | 347.35 | 20.23 |
| Direct Emission (MMT $N_2$0) | 0.00034735 | 0.0000202 |
| Direct Emission (MMT$CO_2$E) | 0.107677425 | 0.00062725 |
| **Total Direct Emission (MMT$CO_2$E)** | **0.11394879** | |

## Table 2.7.9: Base Year 2014 Indirect $N_2O$ Emissions from Fertilizer Application - (Released to Atmosphere)

| | Synthetic Fertilizer | Organic Fertilizer |
|---|---|---|
| | | |
| Total Fertilizer Use (kg N) | 29,610,536 | 24,559,856 |
| Total N in Fertilizers (Calendar Year) | 24,559,856 | 31,404,891 |
| Volatilization Rate | 10% | 20% |
| Nitrogen Content of Fertilizer | 0 | 4.1% |
| Volatized N (kg) | 3,394,525.4 | 257,520.1 |
| $N_2$O from Volatilization Emission Factor ($N_2$0 -N) | 0.01 | 0.01 |
| Indirect Emission (kg $N_2$0 -N) | 33,945.254 | 2,575.2 |
| Indirect Emission (kg $N_2$0) | 53,342.54 | 4,046.8 |
| Indirect Emission (metric tons $N_2$0) | 53.3425 | 4.0467 |
| Indirect Emission (MMT $N_2$0) | 0.000053342 | 0.000004047 |
| Indirect Emission (MMT$CO_2$E) | 0.016536188 | 0.0012544908 |
| Total Indirect Emission (MMT$CO_2$E) | **0.01328614** | |

## Table 2.7.10: Base Year 2014 Indirect $N_2O$ Emissions from Fertilizer Application - (Runoff /Leaching)

|  | **Synthetic Fertilizer** | **Organic Fertilizer** | **Manure Excreted** |
|---|---|---|---|
|  |  |  |  |
| Total Fertilizer Use (kg N) | 29,610,536 | 24,559,856 |  |
| Total N in Fertilizers-kg (Calendar Year) | 24,559,856 | 31,404,891 | 30,118,367 |
| Volatilization Rate | 10% | 20% | 20% |
| Nitrogen Content of Fertilizer | 100% | 4.1% | 100% |
| Unvolatized N (kg) | 22,103,870.4 | 1,030,080.43 | 9,878,824.38 |
| **Leached / Runoff Rate** | 30% | 30% | 30% |
| Leached / Runoff N (kg) | 6,631,161.12 | 309,024.129 | 2,963,647.3 |
| Indirect Emission factor ($N_20$ -N) | 0.0075 | 0.0075 | 0.0075 |
| Indirect Emission (kg $N_20$ -N) | 49,733.71 | 2,317.68 | 1,094.17 |
| Indirect Emission (kg $N_20$) | 78,152.97 | 3,642.07 | 22,227.36 |
| Leached /Runoff Emission (metric tons $N_20$) | 78.15 | 3.642 | 22.23 |
| Indirect Emission (MMT $N_20$) | 0.00007815297 | 0.000003642 | 0.0000222735 |
| Leached /Runoff Emission (MMTCO$_2$E) | 0.02422742 | 0.001129041 | 0.000689048 |
| Total Leached /Runoff Emission (MMTCO$_2$E) | **0.0032246941** |  |  |

## Table 2.7.11: Base Year 2014 Direct $N_2O$ Emissions from Agriculture Crop Residue

| | **Crop Residues** | **Legumes** |
|---|---|---|
| | **N Returned to Soils (kg)** | **N-Fixed by Crops (kg)** |
| | 36,786,057 | 54,229,732 |
| | | |
| Direct $N_2O$ Emissions Factor | 0.0100 | 0.0100 |
| Direct $N_2O$ Emission kg ($N_2O$ -N)/ Yr | 367,860.57 | 542,297.32 |
| Direct $N_2O$ Emission (kg $N_2O$) | 578,066.61 | 852,181.50 |
| Direct $N_2O$ Emission (metric tons) | 578.07 | 852.18 |
| Direct $N_2O$ Emission (MMT) | 0.0005780667 | 0.0008521815 |
| Direct Emissions (MMTCO$_2$E) | 0.179200649 | 0.264176265 |
| | | |
| **Total $N_2O$ Emission from Residue (MMTCO$_2$E)** | **0.4433769** | |

## Table 2.7.12: Base Year 2014 $N_2O$ Emissions from Manure Application

| | **Livestock Emissions** (metric tons $N_2O$) | **$N_2O$ GWP** | **Livestock Emissions** (MMT CO$_2$E) |
|---|---|---|---|
| | | | |
| Indirect $N_2O$ Emissions | 117 | 310 | **0.03618** |
| | | | |
| Direct $N_2O$ Emissions -Manure Applied to Soil | 717 | 310 | 0.22242 |
| Direct $N_2O$ Emissions -Pasture, Range and Paddock | 294 | 310 | 0.09123 |
| Sum Direct $N_2O$ Emissions | **1,016** | | **0.31366** |
| | | | |
| **Total Animal $N_2O$ Emisssions (MMTCO$_2$E)** | **0.34984** | | |

## Table 2.7.13: Base Year 2014 Indirect $N_2O$ Emissions from Animal Waste Runoff - (Released to the Atmosphere)

|  | Number of Animals ('000 head) | **Total K-Nitrogen Excreted** (kg) | **Volatilization Rate** | **$NH_3$-NOx Emission Factor** | **Indirect Animal $N_2O$ Emissions** (metric tons N) | **Indirect Animal $N_2O$ Emissions** (metric tons $N_2O$) | **$N_2O$ GWP** | **Indirect Animal $N_2O$ Emissions** ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|---|
| **Dairy Cattle** |  |  |  |  |  |  |  |  |
| Dairy Cows | 50.0 | 5,460,400 | 20% | 1% | 10.9 | 17.13 | 310 | 0.0053 |
| Dairy Replacement Heifers | 25.0 | 1,346,485 | 20% | 1% | 2.7 | 4.242 | 310 | 0.0013 |
| **Beef Cattle** |  |  |  |  |  |  |  |  |
| Feedlot Heifers | 3.9 | 179,913 | 20% | 1% | 0.40 | 0.63 | 310 | 0.0002 |
| Feedlot Steer | 7.4 | 340,096 | 20% | 1% | 0.70 | 1.10 | 310 | 0.0003 |
| Bulls | 4.0 | 339,450 | 20% | 1% | 0.70 | 1.10 | 310 | 0.0003 |
| Calves | 33.0 | 426,393 | 20% | 1% | 0.90 | 1.41 | 310 | 0.0004 |
| Beef Cows | 38.0 | 2,439,594 | 20% | 1% | 4.5 | 7.07 | 310 | 0.0022 |
| Steer Stockers | 15.0 | 539,726 | 20% | 1% | 1.10 | 1.73 | 310 | 0.0005 |
| Total Beef Heifers | 18.0 | 855,414 | 20% | 1% | 1.70 | 2.67 | 310 | 0.0008 |
| **Swine** |  |  |  |  |  |  |  |  |
| Breeding Swine | 3.0 | 50,950 | 20% | 1% | 0.102 | 0.16 | 310 | 0.00005 |
| Market Under 60 lbs | 7.0 | 24,344 | 20% | 1% | 0.049 | 0.08 | 310 | 0.00002 |
| Market 60-119 lbs | 4.0 | 24,896 | 20% | 1% | 0.050 | 0.08 | 310 | 0.00002 |
| Market 120-179 lbs | 3.0 | 31,190 | 20% | 1% | 0.060 | 0.09 | 310 | 0.00003 |
| Market over 180 lbs | 4.0 | 55,648 | 20% | 1% | 0.111 | 0.17 | 310 | 0.00005 |
| **Poultry** |  |  |  |  |  |  |  |  |
| Layers |  |  |  |  |  |  |  |  |
| Hens > 1 yr | 2,364.0 | 1,289,113 | 20% | 1% | 2.578 | 4.05 | 310 | 0.0013 |
| Pullets | 708.0 | 288,397 | 20% | 1% | 0.577 | 0.91 | 310 | 0.0003 |
| Chickens | 16.0 | 8,725 | 20% | 1% | 0.017 | 0.03 | 310 | 0.00001 |
| Broilers | 52,327.0 | 18,908,361 | 20% | 1% | 37.817 | 59.43 | 310 | 0.01842 |
| Turkeys | 154.0 | 282,849 | 20% | 1% | 0.566 | 0.90 |  | 0.00028 |
| **Other** |  |  |  |  |  |  |  |  |
| Sheep on Feed | - | - |  |  |  |  |  |  |
| Sheep Not on Feed | 12.0 | 147,168 | 20% | 1% | 0.0294 | 0.05 | 310 | 0.00001 |
| Goats | 15.0 | 157,680 | 20% | 1% | 0.315 | 0.50 | 310 | 0.00001 |
| Horses | 80.0 | 3,942,000 | 20% | 1% | 7.884 | 12.40 | 310 | 0.0038 |
| **TOTAL** |  | **37,138,792** |  |  | 74 | 62.42 |  | **0.0358912** |

## Table 2.7.14: Base Year 2014 Direct $N_2O$ Emissions from Manure Applied to Soil

| | Number of Animals ('000 head) | K-N Excreted by System (kg) Managed Systems | Volatilization Rate | Ground Nitrogen Emission Factor | Poultry Manure Not Mnage | Direct Animal $N_2O$ Emissions (metric tons N) Manure Applied to Soils | Direct Animal $N_2O$ Emissions (metric tons $N_2O$) | $N_2O$ GWP | Direct Animal $N_2O$ Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|---|---|
| **Dairy Cattle** | | | | | | | | | |
| Dairy Cows | 50.0 | 2,676,859 | 20% | 0.0125 | | 51 | 80.142 | 310 | 0.0248 |
| Dairy Replacement Heifers | 25.0 | 660,089 | 20% | 0.0125 | | 13 | 20.43 | 310 | 0.0063 |
| **Beef Cattle** | | | | | | | | | |
| Feedlot Heifers | 3.9 | 179,913 | 20% | 0.0125 | | 2 | 3.143 | 310 | 0.0000 |
| Feedlot Steer | 7.4 | 340,096 | 20% | 0.0125 | | 3 | 4.71 | 310 | 0.0015 |
| Bulls | 4.0 | NA | 20% | | | | | | - |
| Calves | 33.0 | NA | 20% | | | | | | - |
| Beef Cows | 38.0 | NA | 20% | | | | | | - |
| Steer Stockers | 15.0 | NA | 20% | | | | | | - |
| Total Beef Heifers | 18.0 | NA | 20% | | | | | | - |
| **Swine** | | | | | | | | | |
| Breeding Swine | 3.0 | 40,179 | 20% | 0.0125 | | 0.0 | 0.0 | 310 | 0.0000 |
| Market Under 60 lbs | 7.0 | 19,198 | 20% | 0.0125 | | 0.0 | 0.00 | 310 | 0.0000 |
| Market 60-119 lbs | 4.0 | 19,633 | 20% | 0.0125 | | 0.0 | 0.00 | 310 | 0.0000 |
| Market 120-179 lbs | 3.0 | 24,597 | 20% | 0.0125 | | 0.0 | 0.00 | 310 | 0.0000 |
| Market over 180 lbs | 4.0 | 43,884 | 20% | 0.0125 | | 0.0 | 0.00 | 310 | 0.0000 |
| **Poultry** | | | | | | | | | |
| Layers | | | | | | | | | |
| Hens > 1 yr | 2,364.0 | 1,289,113 | 20% | 0.0125 | 4.20% | 12 | 18.857 | 310 | 0.0059 |
| Pullets | 708.0 | 288,397 | 20% | 0.0125 | 4.20% | 3 | 4.71 | 310 | 0.0000 |
| Chickens | 16.0 | 8,725 | 20% | 0.0125 | 4.20% | 0 | 0.00 | 310 | 0.0000 |
| Broilers | 52,327.0 | 18,908,361 | 20% | 0.0125 | 4.20% | 181 | 284.42 | 310 | 0.0882 |
| Turkeys | 154.0 | 282,849 | 20% | | | 3 | 4.71 | | 0.0015 |
| **Other** | | | | | | | | | |
| Sheep on Feed | - | - | | | | | | | |
| Sheep Not on Feed | 12.0 | - | 20% | | | | | 310 | - |
| Goats | 15.0 | NA | 20% | | | | | 310 | - |
| Horses | 80.0 | NA | 20% | | | | | 310 | - |
| **TOTAL** | | | | | | **269** | **421.13** | | **0.1281** |

### Table 2.7.15: Base Year 2014 Direct $N_2O$ Emissions from Pasture, Range, and Paddock

| | Number of Animals ('000 head) | **K-N Excreted by System (kg):** | **Direct Animal $N_2O$ Emissions** (metric tons N) | **Direct Animal $N_2O$ Emissions** (metric tons $N_2O$) | **$N_2O$ GWP** | **Direct Animal $N_2O$ Emissions** (MMTCO$_2$E) |
|---|---|---|---|---|---|---|
| | | **Unmanaged Systems - Pasture, Range, and Paddock** | | **Pasture, Range, and Paddock** | | |
| **Dairy Cattle** | | | | | | |
| Dairy Cows | 50.0 | 360,170 | 7.20 | 11.31 | 310 | 0.0035 |
| Dairy Replacement Heifers | 25.0 | 88,815 | 1.78 | 2.80 | 310 | 0.0009 |
| **Beef Cattle** | | | | | | |
| Feedlot Heifers | 3.9 | NA | | | | |
| Feedlot Steer | 7.4 | NA | | | | |
| Bulls | 4.0 | 339,450 | 6.79 | 10.67 | 310 | 0.0033 |
| Calves | 33.0 | 426,393 | 8.53 | 13.40 | 310 | 0.0042 |
| Beef Cows | 38.0 | 2,439,594 | 48.79 | 76.67 | 310 | 0.0238 |
| Steer Stockers | 10.0 | 539,726 | 10.79 | 16.96 | 310 | 0.0053 |
| Total Beef Heifers | 15.0 | 855,414 | 17.11 | 26.89 | 310 | 0.0083 |
| **Swine** | | | | | | |
| Breeding Swine | 3.0 | 10,771 | 0.22 | 0.35 | 310 | 0.0001 |
| Market Under 60 lbs | 7.0 | 5,146 | 0.10 | 0.16 | 310 | 0.0005 |
| Market 60-119 lbs | 4.0 | 5,263 | 0.11 | 0.17 | 310 | 0.0001 |
| Market 120-179 lbs | 3.0 | 6,594 | 0.13 | 0.20 | 310 | 0.0001 |
| Market over 180 lbs | 4.0 | 11,764 | 0.24 | 0.38 | 310 | 0.0001 |
| **Poultry** | | | | | | |
| Layers | | | | | | |
| Hens > 1 yr | 2,364.0 | NA | | | | |
| Pullets | 708.0 | NA | | | | |
| Chickens | 10.0 | NA | | | | |
| Broilers | 52,327.0 | NA | | | | |
| Turkeys | 421.0 | 28,285 | 0.57 | 0.90 | | 0.00028 |
| **Other** | | | | | | |
| Sheep on Feed | - | - | | | | |
| Sheep Not on Feed | 12.0 | 147,168 | 2.94 | 4.62 | 310 | 0.0014 |
| Goats | 13.0 | 157,680 | 3.15 | 4.95 | 310 | 0.0015 |
| Horses | 80.0 | 3,942,000 | 78.84 | 123.89 | 310 | 0.0384 |
| **TOTAL** | | | **187.28** | | | **0.0912** |

### Table 2.7.16: (2015 – 2030) Emission Projection

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|
| Enteric Fermentation | 0.5109 | 0.5141 | 0.5142 | 0.5140 | 0.5148 | 0.5144 | 0.5142 | 0.5135 | 0.4965 |
| Manure Management | 0.3723 | 0.3734 | 0.3741 | 0.3749 | 0.3757 | 0.3766 | 0.3776 | 0.3786 | 0.3814 |
| Agricultural Soils | 0.9073 | 0.8708 | 0.8611 | 0.8514 | 0.8416 | 0.8319 | 0.8222 | 0.8124 | 0.8027 |
| Agricultural Burning | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0017 | 0.0017 |
| Urea Fertilizer Usage | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

### Table 2.7.17: (2015 – 2030) Emission Projection

| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|
| Enteric Fermentation | 0.4949 | 0.4932 | 0.4916 | 0.4900 | 0.4883 | 0.4867 | 0.4850 | 0.4834 | 0.4834 |
| Manure Management | 0.3825 | 0.3837 | 0.3850 | 0.3863 | 0.3876 | 0.3889 | 0.3902 | 0.3915 | 0.3915 |
| Agricultural Soils | 0.7930 | 0.7832 | 0.7735 | 0.7638 | 0.7540 | 0.7443 | 0.7346 | 0.7248 | 0.7248 |
| Agricultural Burning | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0018 | 0.0018 |
| Urea Fertilizer Usage | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0018 | 0.00000 |

### Table 2.7.18: (2015 – 2030) 2030 BAU Growth Factors

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|
| Enteric Fermentation | 1.0000 | 1.0063 | 1.0065 | 1.0061 | 1.0078 | 1.0069 | 1.0066 | 1.0051 | 0.9719 |
| Manure Management | 1.0000 | 1.0030 | 1.0049 | 1.0069 | 1.0092 | 1.0116 | 1.0143 | 1.0168 | 1.0244 |
| Agricultural Soils | 1.0000 | 0.9598 | 0.9491 | 0.9383 | 0.9276 | 0.9169 | 0.9062 | 0.8954 | 0.8847 |
| Agricultural Burning | 1.0000 | 1.0072 | 1.0143 | 1.0215 | 1.0286 | 1.0358 | 1.0429 | 1.0501 | 1.0572 |
| Urea Fertilizer Usage | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

**Table 2.7.19: (2015 – 2030) 2030 BAU Growth Factors**

| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|
| Enteric Fermentation | 0.9687 | 0.9655 | 0.9623 | 0.9591 | 0.9559 | 0.9527 | 0.9495 | 0.9463 | 0.9463 |
| Manure Management | 1.0273 | 1.0305 | 1.0340 | 1.0375 | 1.0409 | 1.0444 | 1.0479 | 1.0514 | 1.0514 |
| Agricultural Soils | 0.8740 | 0.8633 | 0.8525 | 0.8418 | 0.8311 | 0.8203 | 0.8096 | 0.7989 | 0.7989 |
| Agricultural Burning | 1.0644 | 1.0716 | 1.0787 | 1.0859 | 1.0930 | 1.1002 | 1.1073 | 1.1145 | 1.1145 |
| Urea Fertilizer Usage | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

## 2.8 Waste Management

GHG emissions from Maryland's waste management practices are estimated in this section. Emissions were estimated from the three (3) main classes of waste management in Maryland; (1) solid waste management, mainly in the form of $CH_4$ emissions from municipal and industrial solid waste landfills (including $CH_4$ that is flared or captured for energy production); (2) wastewater management, including $CH_4$ and $N_2O$ from municipal and industrial wastewater (WW) treatment facilities; and (3) $CH_4$ and $N_2O$ from municipal solid waste incinerations.

Landfill emissions were projected based on a 2020 estimate of waste deposition in California landfills. Waste deposition data was then used to determine future methane generation from landfills statewide. The landfill emissions projection applies the same estimation technique used to develop current inventory estimates, but uses the projected amounts of waste in landfills. Staff assumed that the composition of the waste and the number of landfills with landfill gas collection systems would remain the same.

Projected BAU emissions in 2020 for landfills are 7.7 MMTCO2E. This projection uses a recognized landfill gas emissions model developed by the Intergovernmental Panel on Climate Change (IPCC) and data from the California Integrated Waste Management Board (CIWMB). The project reflects assumptions regarding the continued decay of existing waste in landfills and estimates on the amount and character of new waste deposited in landfills through 2020.

### Table 2.8.1: Base Year 2014 Waste Combustion Emissions

|  | 2014 |  |
|---|---|---|
| **MD Summary** |  |  |
| MSW Processed (tons) | 1,443,604 |  |
| MSW HHV (mmbtu/short tons) | 9.95 | EPA factor |
| MSW Heat Input (mmbtu) | 14,363,863 |  |
| $CO_2$ Emission Factor-(kg $CO_2$/mmbtu) | 90.7 | EPA factor |
| $CO_2$ Emission (kg $CO_2$) | 1,302,802,356 |  |
| $CO_2$ Emission Estimate (short tons $CO_2$) | 1,436,079 | EPA factor |
|  |  |  |
|  |  |  |
| **$CO_2$ Emission CEM Readings (short tons $CO_2$)** | **1,430,321** |  |
| $CH_4$ Emission Factor (kg/mmbtu) | 0.032 |  |
| $CH_4$ Emissions (kg) | 459,643.61 |  |
| $CH_4$ Emissions (short tons) | 506.67 | EPA factor |
|  |  |  |
| **$CH_4$ Emissions (short tons)** | **9.83** | **CEM/ECR** |
|  |  |  |
| $N_2O$ Emission Factor (kg/mmbtu) | 0.0042 |  |
| $N_2O$ Emissions (kg) | 60,328.22 |  |
| $N_2O$ Emissions (short tons) | 66.50 | EPA factor |
|  |  |  |
| **$N_2O$ Emissions (short tons)** | **36.12** |  |

### Table 2.8.2: Base Year 2014 Landfill Emissions.

| | |
|---|---|
| MSW $CH_4$ Generation ( short ton $CH_4$) | 126,314 |
| MSW Generation ( $MTCO_2E$) | 2,406,400 |
| Industrial Generation ($MTCO_2E$) | 168,448 |
| **Potential $CH_4$ Emissions ($MTCO_2E$)** | **2,574,848** |
| | |
| Flared $CH_4$ (short tons) | 19,359 |
| Flared $CH_4$ ($MTCO_2E$) | 368,799 |
| Landfill Gas-to-Energy (tons) | 39,578 |
| Landfill Gas-to-Energy ($MTCO_2E$) | 754,001 |
| **$CH_4$ Avoided ($MTCO_2E$)** | **1,122,800** |
| Oxidation at MSW Landfills (tons) | 32,243.72 |
| | |
| Oxidation at MSW Landfills ($MTCO_2E$) | 614,271 |
| Oxidation at Industrial Landfills ($MTCO_2E$) | 42,999 |
| **Total $CH_4$ Emissions ($MTCO_2E$)** | **794,778** |
| | |
| $CO_2$ Emission from (Flaring + LFGTE) ($MTCO_2E$) | 254,654 |
| $CO_2$ Emission from (Flaring + LFGTE) ($MMTCO_2E$) | 0.2547 |
| $CO_2$ Emission from Landfill ($MTCO_2E$) | 313,143 |
| $CO_2$ Emission from Landfill ($MMTCO_2E$) | 0.3131 |
| Total $CH_4$ Emissions ($MMTCO_2E$) | 0.7948 |

## Table 2.8.3: 2030 BAU Waste Management Growth Factors.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | **Census** | **Census** | **Census** | **Census** | **Census** | | | | |
| | 1970 | 1980 | 1990 | 2000 | 2010 | | | | |
| | 1,174,933 | 1,460,865 | 1,748,991 | 1,980,859 | 2,156,411 | | | | |
| | | | | | | | | | |
| | **Forecasted Census** | | | | | | | | |
| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | | |
| | 2,242,088 | 2,325,516 | 2,416,861 | 2,503,843 | 2,578,303 | 2,646,523 | 2,706,300 | | |
| | | | | | | | | | |
| | **Extrapolated Census** | | | | | | | | |
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Population** | 2,224,952 | 2,242,088 | 2,258,773 | 2,275,459 | 2,292,145 | 2,308,830 | 2,325,516 | 2,343,785 | 2,362,054 |
| | | | | | | | | | |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** |
| **Population** | 2,380,323 | 2,398,592 | 2,416,861 | 2,434,258 | 2,451,654 | 2,469,050 | 2,486,447 | 2,503,843 | 2,518,735 |
| | | | | | | | | | |
| | **Growth Factors** | | | | | | | | |
| **Year** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** |
| **Growth Factor** | 1.0000 | 1.007701 | 1.007442 | 1.007387 | 1.007333 | 1.007279 | 1.007227 | 1.007856 | 1.007795 |
| | | | | | | | | | |
| **Year** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** |
| **Growth Factor** | 1.0077344 | 1.007675 | 1.007617 | 1.007198 | 1.007146 | 1.007096 | 1.007046 | 1.006996 | 1.006996 |
| | | | | | | | | | |

## 2.9 Forestry and Land Use

This section provides an assessment of the net GHG flux[1] (the balance between the emission and uptake of GHGs) resulting from land uses, land-use changes, and forests management activities in Maryland. The GHG emissions estimated in this section includes $CO_2$ emissions from urea fertilizer use, $CH_4$ and $N_2O$ emissions from wildfires and prescribed forest burns and $N_2O$ from synthetic fertilizers application to settlement soils. Carbon uptake (sequestration) pathways estimated in this section include; carbon stored in above ground biomass, below ground biomass, dead wood, and litters- (forest carbon flux), carbon stored in the form landfilled yard trimmings and food scraps, carbon stored in harvested wood product/wood product in landfills and carbon stored in urban trees.

Future emission projection for the forestry sector poses a unique challenge because it includes emissions from forest management activities and land-use changes, including wildfires, prescribed forest burning and urea fertilizer use, as well as removal (or sinks) of $CO_2$ from the atmosphere due to carbon sequestration into woody materials, and the 2030 BAU projection should account for both the positive emissions and negative removals into a single, net value. As a result of the uncertainty in estimating the several factors that can affect the 2030 BAU forest sector, MDE is assuming the 2030 BAU will remain same as Base Year 2014.

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[1] The term “flux” is used here to encompass both emissions of greenhouse gases to the atmosphere, and removal of C from the atmosphere. Removal of C from the atmosphere is also referred to as “carbon sequestration”.

Maryland
Department of
the Environment

# Appendix D

## 2017 Greenhouse Gas Emission Inventory Documentation

# 2019 GGRA Draft Plan

Maryland
Department of
the Environment

**Larry Hogan**
Governor

**Boyd Rutherford**
Lieutenant Governor

**Ben Grumbles**
Secretary

# State of Maryland 2017 Greenhouse Gas Emission Inventory Documentation

**July 26, 2019**

**Prepared by:**
**Maryland Department of the Environment**

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# Maryland Department of the Environment
# Greenhouse Gas Emissions Inventory Documentation

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Source Documentation:

- MDE-Air and Radiation Administration
    - MDE – ARA Compliance Program
    - MDE – ARA Permits Program
    - MDE – ARA Air Quality Policy and Planning Program
    - MDE – ARA Greenhouse Gas Program
    - MDE – ARA Mobile Source Program
    - MDE – Solid Waste Program
    - MDE - Land and Materials Administration Mining Program

- Maryland Department of Agriculture
- Maryland Department of Transportation
- Maryland Department of Planning

Lead Agency and Quality Assurance:MDE-ARA Air Quality Policy & Planning Division

The MDE is the agency responsible for preparing and submitting the completed baseline GHG emissions inventory for Maryland. The MDE Air and Radiation Administration (ARA) Air Quality Policy & Planning Division compiled the GHG emissions inventory for the State of Maryland.

## Acronyms and Key Terms

| | |
|---|---|
| BOD | Biochemical Oxygen Demand |
| Btu | British Thermal Unit |
| C | Carbon* |
| $CaCO_3$ | Calcium Carbonate |
| CCS | Center for Climate Strategies |
| CEC | Commission for Environmental Cooperation in North America |
| CFCs | Chlorofluorocarbons* |
| $CH_4$ | Methane* |
| CO | Carbon Monoxide* |
| $CO_2$ | Carbon Dioxide* |
| $CO_2e$ | Carbon Dioxide Equivalent* |
| CRP | Federal Conservation Reserve Program |
| DOE | Department of Energy |
| DOT | Department of Transportation |
| EEZ | Exclusive Economic Zone |
| EIA | US DOE Energy Information Administration |
| EIIP | Emission Inventory Improvement Program |
| EPA | United States Environmental Protection Agency |
| FAA | Federal Aviation Administration |
| FAPRI | Food and Agricultural Policy Research Institute |
| FERC | Federal Energy Regulatory Commission |
| FHWA | Federal Highway Administration |
| FIA | Forest Inventory Analysis |
| Gg | Gigagrams |
| GHG | Greenhouse Gas* |
| GWh | Gigawatt-hour |
| GWP | Global Warming Potential* |
| $H_2O$ | Water Vapor* |
| HBFCs | Hydrobromofluorocarbons* |
| HC | Hydrocarbon |
| HCFCs | Hydrochlorofluorocarbons* |
| HFCs | Hydrofluorocarbons* |

| | |
|---|---|
| HWP | Harvested Wood Products |
| IPCC | Intergovernmental Panel on Climate Change* |
| kg | Kilogram |
| $km^2$ | Square Kilometers |
| kWh | Kilowatt-hour |
| lb | Pound |
| LF | Landfill |
| LFG | Landfill Gas |
| LFGTE | Landfill Gas Collection System and Landfill-Gas-to-Energy |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas |
| MAAC | Mid-Atlantic Area Council |
| MANE-VU | Mid-Atlantic/Northeast Visibility Union |
| MDDNR | Maryland Department of Natural Resources |
| MDE | Maryland Department of the Environment |
| Mg | Megagram |
| MMBtu | Million British Thermal Units |
| MMt | Million Metric Tons |
| MMtC | Million Metric Tons Carbon |
| $MMtCO_2e$ | Million Metric tons Carbon Dioxide Equivalent |
| MSW | Municipal Solid Waste |
| Mt | Metric ton (equivalent to 1.102 short tons) |
| MWh | Megawatt-hour |
| $N_2O$ | Nitrous Oxide* |
| NASS | National Agriculture Statistical Service |
| NEI | National Emissions Inventory |
| NEMS | National Energy Modeling System |
| NF | National Forest |
| NMVOCs | Nonmethane Volatile Organic Compound* |
| $NO_2$ | Nitrogen Dioxide* |
| $NO_x$ | Nitrogen Oxides* |
| $O_3$ | Ozone* |
| ODS | Ozone-Depleting Substance* |
| OH | Hydroxyl Radical* |

| | |
|---|---|
| OPS | Office of Pipeline Safety |
| PFCs | Perfluorocarbons* |
| ppb | Parts per Billion |
| ppm | Parts per Million |
| ppt | Parts per Trillion |
| ppmv | Parts per Million by Volume |
| RCI | Residential, Commercial, and Industrial |
| RGGI | Regional Greenhouse Gas Initiative |
| RPS | Renewable Portfolio Standard |
| SAR | Second Assessment Report* |
| SED | State Energy Data |
| $SF_6$ | Sulfur Hexafluoride* |
| Sinks | Removals of carbon from the atmosphere, with the carbon stored in forests, soils, landfills, wood structures, or other biomass-related products. |
| SIT | State Greenhouse Gas Inventory Tool |
| $SO_2$ | Sulfur Dioxide* |
| t | Metric Ton |
| T&D | Transmission and Distribution |
| TAR | Third Assessment Report* |
| TOG | Total Organic Gas |
| TWh | Terawatt-hour |
| UNFCCC | United Nations Framework Convention on Climate Change |
| US | United States |
| US DOE | United States Department of Energy |
| US EPA | United States Environmental Protection Agency |
| USDA | United States Department of Agriculture |
| USFS | United States Forest Service |
| USGS | United States Geological Survey |
| VMT | Vehicle Mile Traveled |
| VOCs | Volatile Organic Compound* |
| WW | Wastewater |
| yr | Year |

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# 1.0 EXECUTIVE SUMMARY

## 1.1 OVERVIEW

The Maryland General Assembly passed the Greenhouse Gas Emissions Reduction Act, Senate Bill -SB 278 and House Bill - HB 315 in 2009, which is codified in Maryland Annotated Codes, Title 2, Subtitle 1203[1]. The Bill requires the Department of the Environment to publish and update an inventory of statewide greenhouse gas emissions for calendar year 2006; requires the State to reduce statewide greenhouse gas emissions by 25% from 2006 levels by 2020; and requires the State to develop and adopt a specified plan, adopt specified regulations, and implement specified programs to reduce greenhouse gas emissions.

Additionally, the Bill specifically mandates the Department of the Environment to prepare and publish an updated annual inventory of statewide greenhouse gas emissions for calendar year 2017.

To comply with this mandate, the Maryland Department of the Environment (MDE) presents this report that estimates the statewide emissions of Greenhouse Gas (GHGs) for calendar year 2017. Statewide activity data from agriculture, fossil fuel combustion, industrial processes, natural gas transmission and distribution, transportation, solid waste, and wastewater treatment were used to develop the periodic 2017 inventory.

The report and the emissions inventory is divided into seven major sectors that contribute to greenhouse gases emissions in Maryland:

- Electricity use and supply
- Residential, commercial and industrial fossil fuel combustion (RCI)
- Transportation
- Industrial processes
- Fossil fuel industry (fugitive emissions – greenhouse gas released from leakage)
- Waste management
- Agriculture

Maryland's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the periodic year (2017) using a set of generally accepted principles and guidelines for State GHG emissions, relying to the extent possible on Maryland-specific input data.

The inventory covers the six types of gases included in the US Greenhouse Gas Inventory: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$). Emissions of these GHGs are presented using a common metric, carbon dioxide equivalence ($CO_2e$), which indicates the relative contribution of each gas,

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[1] § 2-1203. Statewide greenhouse gas inventory. http://www.michie.com/maryland/lpExt.dll?f=templates&eMail=Y&fn=main-h.htm&cp=mdcode/dea9.

per unit mass, to global average radiative force on a global warming potential- (GWP-) weighted basis (see Section 1.4.1).[1]

Table ES-1 provides a summary of the 2017 GHG emissions for Maryland. Activities in Maryland accounted for approximately 78.49 million metric tons (MMT) of *gross*[2] $CO_2e$ emissions (consumption basis) in 2017, an amount equal to about 26.80 % reduction of the total Maryland gross GHG (107.23 MMTCO2e) emissions in 2006.

Estimates of carbon sinks within Maryland's forests, including urban forests and land use changes, have also been included in this report. The current estimates indicated that about 11.72 $MMTCO_2e$ was stored in Maryland forest biomass and agricultural soils in 2017. This leads to *net* emissions of 66.77 $MMTTCO_2e$ in Maryland in 2017.

There are three principal sources of GHG emission in Maryland: electricity consumption; transportation; and residential, commercial, and industrial (RCI) fossil fuel use. Electricity consumption accounted for 30 % of gross GHG emissions in 2017. Transportation accounted for 41 % of Maryland's gross GHG emissions in 2017, while RCI fuel use accounted for 18 % of Maryland's 2017 gross GHG emissions.

A graphical representation of the 2017 GHG emissions by source sector is presented in Figure ES-1.

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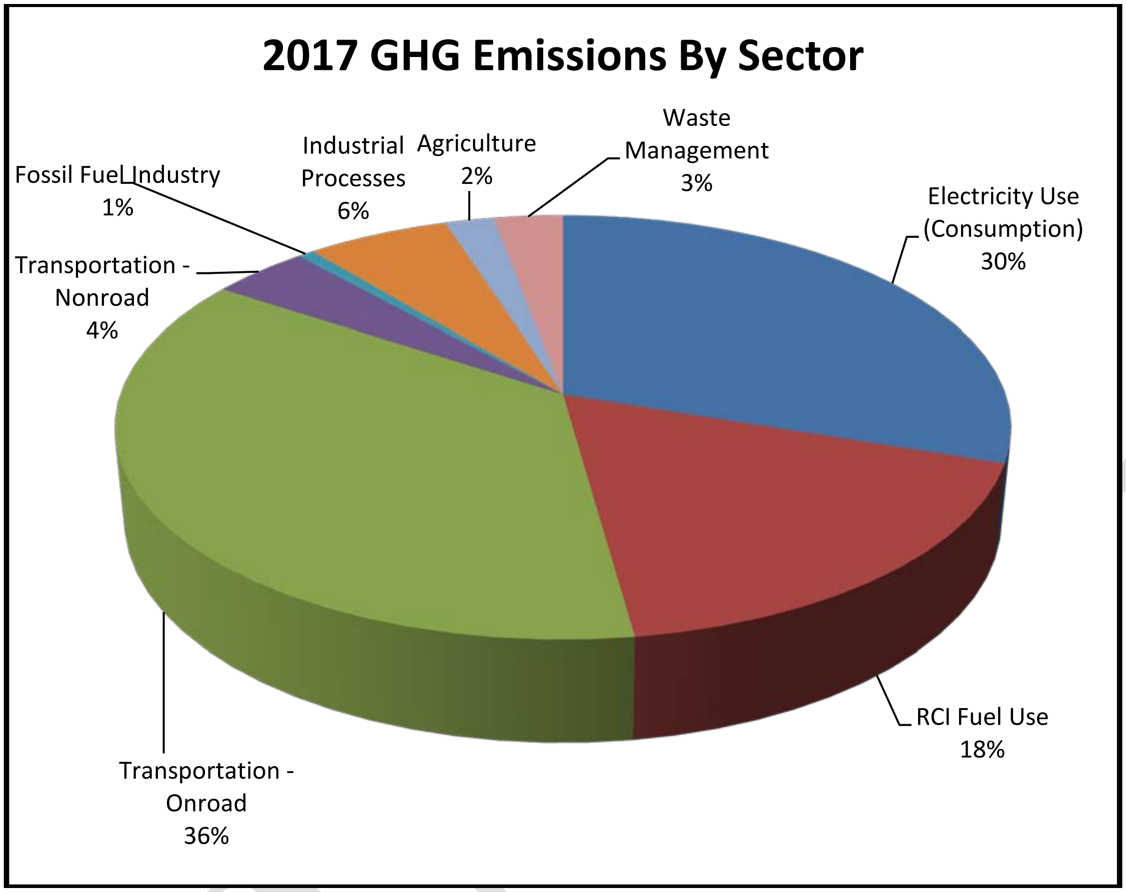
[1] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth–atmosphere system (IPCC, 2001). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth). See: Boucher, O., et al. "Radiative Forcing of Climate Change." Chapter 6 in *Climate Change 2001: The Scientific Basis*. Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm.

[2] Excluding GHG emissions removed due to forestry and other land uses.

**FIGURE ES-1: GROSS GHG EMISSIONS BY SECTOR, 2017, MARYLAND**



A comparison of the 2006 Base Year, 2017 Periodic and 2020 Business-as-usual inventories, as illustrated in Figure ES-2 and shown numerically in Table ES-1, shows a decline (approximately 27 %) in Maryland's gross GHG emissions in 2017 from the 2006 Base Year.

## 1.2 EMISSIONS SUMMARY

### Table ES-1: Maryland Periodic 2017 GHG Emissions, by Sector

| SOURCE CATEGORY | | 2006 ( MMtCO$_2$e) | 2017 ( MMtCO$_2$e) | 2020 (MMtCO$_2$e) |
|---|---|---|---|---|
| **Energy Use (CO$_2$, CH$_4$, N$_2$O)** | | 95.75995003 | **69.90456** | 125.3426075 |
| **Electricity Use (Consumption)[b]** | | 42.47567455 | **23.68039** | 58.7927804 |
| | Electricity Production (in-state) | 32.16484764 | **11.6514** | 42.87607466 |
| | *Coal* | 28.27769105 | 8.7510 | 33.78898734 |
| | CO$_2$ | 28.13057387 | 8.6828 | 33.61319714 |
| | CH$_4$ | 0.006356915 | 0.0212 | 0.007595873 |
| | N$_2$O | 0.140760271 | 0.0470 | 0.16819432 |
| | *Natural Gas* | 3.649880813 | 2.7514 | 8.448329699 |
| | CO$_2$ | 3.64841301 | 2.7470 | 8.444932197 |
| | CH$_4$ | 0.000592766 | 0.0008 | 0.001372068 |
| | N$_2$O | 0.000875036 | 0.0037 | 0.002025434 |
| | *Oil* | 0.237275776 | 0.1490 | 0.638757627 |
| | CO$_2$ | 0.236572609 | 0.1483 | 0.636878026 |
| | CH$_4$ | 0.00017791 | 0.0004 | 0.000475562 |
| | N$_2$O | 0.000525257 | 0.0004 | 0.00140404 |
| | *Wood* | 0 | 0.0000 | 0 |
| | CO$_2$ | 0 | 0.0000 | 0 |
| | CH$_4$ | 0 | 0.0000 | 0 |
| | N$_2$O | 0 | 0.0000 | 0 |
| | *MSW/LFG* | | | |
| | Net Imported Electricity | 10.31082691 | **12.02896** | 15.91670574 |
| **Residential/Commercial/Industrial (RCI) Fuel Use** | | 16.87079695 | **13.87073** | 18.84224894 |
| | Coal | 2.997788692 | 1.16917 | 4.197594934 |
| | CO$_2$ | 2.976126985 | 1.16100 | 4.167405746 |
| | CH$_4$ | 0.007134829 | 0.00254 | 0.009849136 |
| | N$_2$O | 0.014526878 | 0.00563 | 0.020340052 |
| | Natural Gas & LPG | 9.21041471 | **9.73527** | 9.996587616 |
| | CO$_2$ | 9.18802397 | 9.71068 | 9.971684867 |
| | CH$_4$ | 0.016000535 | 0.01777 | 0.017922089 |
| | N$_2$O | 0.006390205 | 0.00683 | 0.00698066 |
| | Petroleum | 4.576524718 | **2.91030** | 4.556581609 |
| | CO$_2$ | 4.557477225 | 2.89906 | 4.527502018 |

| SOURCE CATEGORY | | 2006<br>( MMtCO$_2$e) | 2017<br>( MMtCO$_2$e) | 2020<br>(MMtCO$_2$e) |
|---|---|---|---|---|
| | $CH_4$ | 0.008508848 | 0.00558 | 0.009214914 |
| | $N_2O$ | 0.010538645 | 0.000565 | 0.019864676 |
| | Wood | 0.086068834 | **0.05599** | 0.091484784 |
| | $CO_2$ | 0 | 0.000000 | 0 |
| | $CH_4$ | 0.061142772 | 0.04061 | 0.067513098 |
| | $N_2O$ | 0.024926062 | 0.01538 | 0.023971687 |
| **Transportation** | | 35.47159388 | **31.80433** | 46.78388945 |
| | Onroad Gasoline | 23.7595 | 22.40003 | 30.70935375 |
| | $CO_2$ | 23.195 | 22.32288 | 29.97973274 |
| | $CH_4$ | 0.0462 | 0.006379 | 0.059713889 |
| | $N_2O$ | 0.5183 | 0.070767 | 0.669907113 |
| | Nonroad Gasoline | 1.044117546 | **0.959707** | 1.063830439 |
| | $CO_2$ | 1.039550516 | 0.942401 | 1.059010076 |
| | $CH_4$ | 0.000920455 | 0.017306 | 0.000996549 |
| | $N_2O$ | 0.003646576 | 0.0000 | 0.003823814 |
| | Onroad Diesel | 5.9103 | **6.17588** | 7.8804 |
| | $CO_2$ | 5.907 | 6.15662 | 7.876 |
| | $CH_4$ | 0.0003 | 0.00009 | 0.0004 |
| | $N_2O$ | 0.003 | 0.01916 | 0.004 |
| | Nonroad Diesel | 1.503926174 | **0.954964** | 1.849891371 |
| | $CO_2$ | 1.488082933 | 0.95450 | 1.830352665 |
| | $CH_4$ | 0.004221409 | 0.000466 | 0.005243769 |
| | $N_2O$ | 0.011621832 | 0.0000 | 0.014294937 |
| | Rail | 0.238839589 | **0.167036** | 0.297300341 |
| | $CO_2$ | 0.236600579 | 0.165473 | 0.294513289 |
| | $CH_4$ | 0.000391175 | 0.000273 | 0.000486923 |
| | $N_2O$ | 0.001847835 | 0.000129 | 0.00230013 |
| | Marine Vessels (Gas & Oil) | 0.997636149 | **0.11507** | 1.745970666 |
| | $CO_2$ | 0.988598138 | 0.11444 | 1.730153174 |
| | $CH_4$ | 0.00147329 | 0.00013 | 0.002578417 |
| | $N_2O$ | 0.00756472 | 0.00050 | 0.013239075 |
| | Lubricants, Natural Gas, and LPG | 0.295955146 | **0.33332** | 0.474922542 |
| | $CO_2$ | 0.295955146 | 0.33028 | 0.474922542 |
| | $CH_4$ | 0 | 0.00304 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | Jet Fuel and Aviation Gasoline | 1.721319275 | **0.69832** | 2.762220349 |

| SOURCE CATEGORY | | 2006<br>( $MMtCO_2e$) | 2017<br>( $MMtCO_2e$) | 2020<br>($MMtCO_2e$) |
|---|---|---|---|---|
| | $CO_2$ | 1.703343607 | 0.69118 | 2.733374593 |
| | $CH_4$ | 0.001626024 | 0.00062 | 0.0026093 |
| | $N_2O$ | 0.016349643 | 0.00652 | 0.026236456 |
| **Fossil Fuel Industry** | | 0.941884638 | **0.549117** | 0.923688683 |
| | Natural Gas Industry | 0.811536367 | 0.458283 | 0.793340412 |
| | $CO_2$ | 0.000128636 | 0.000442 | 0.000125751 |
| | $CH_4$ | 0.811336294 | 0.457596 | 0.793144825 |
| | $N_2O$ | 7.14367E-05 | 0.000246 | 6.9835E-05 |
| | Oil Industry | 0 | 0.0000 | 0 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | Coal Mining | 0.130348272 | 0.090834 | 0.130348272 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0.130348272 | 0.090834 | 0.130348272 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| **Industrial Processes** | | 7.441042334 | **4.69577** | 10.24474052 |
| | Cement Manufacture | 1.483241728 | 1.51184 | 2.092130448 |
| | $CO_2$ | 1.483241728 | 1.51184 | 2.092130448 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | Limestone and Dolomite | 0.113941192 | 0.14589 | 0.212053625 |
| | $CO_2$ | 0.113941192 | 0.14589 | 0.212053625 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | Soda Ash | 0.04761102 | 0.039568 | 0.047600367 |
| | $CO_2$ | 0.04761102 | 0.039568 | 0.047600367 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | Iron and Steel | 3.597116387 | 0.0000 | 3.851428544 |
| | $CO_2$ | 3.597116387 | 0.0000 | 3.851428544 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | ODS Substitutes | 1.971282442 | 2.956638 | 4.041527541 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0 | 0.0000 | 0 |

| SOURCE CATEGORY | | 2006 ( $MMtCO_2e$) | 2017 ( $MMtCO_2e$) | 2020 ($MMtCO_2e$) |
|---|---|---|---|---|
| | HFC, PFC, $SF_6$ | 1.971282442 | 2.956638 | 4.041527541 |
| | Electricity Transmission and Dist. | 0.227222585 | 0.0403671 | 0 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | HFC, PFC, $SF_6$ | 0.227222585 | 0.04037 | 0 |
| | Semiconductor Manufacturing | 0 | 0.0000 | 0 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | HFC, PFC, $SF_6$ | 0 | 0.0000 | 0 |
| | Ammonia and Urea Production (Nonfertilizer Usage) | 0.000626981 | 0.001469 | 0.001553245 |
| | $CO_2$ | 0.000626981 | 0.001469 | 0.001553245 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | HFC, PFC, $SF_6$ | 0 | 0.0000 | 0 |
| | Aluminum Production | 0 | 0.0000 | 0 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | HFC, PFC, $SF_6$ | 0 | 0.0000 | 0 |
| **Agriculture** | | 1.771426158 | **1.61428** | 1.8593378 |
| | Enteric Fermentation | 0.41906793 | 0.38195 | 0.513375915 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0.41906793 | 0.38195 | 0.513375915 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | Manure Management | 0.32126318 | 0.30721 | 0.288792819 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0.091393836 | 0.093867 | 0.056315177 |
| | $N_2O$ | 0.229869344 | 0.213343 | 0.232477642 |
| | Agricultural Soils | 1.019673739 | 0.908171 | 1.046309668 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 1.019673739 | 0.90817 | 1.046309668 |
| | Agricultural Burning | 0.006273052 | 0.00628 | 0.00571114 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0.003893109 | 0.00378 | 0.003563812 |
| | $N_2O$ | 0.002379944 | 0.0025 | 0.002147328 |
| | Urea Fertilizer Usage | 0.005148257 | 0.01067 | 0.005148257 |
| | $CO_2$ | 0.005148257 | 0.01067 | 0.005148257 |

| SOURCE CATEGORY | | 2006 ( $MMtCO_2e$) | 2017 ( $MMtCO_2e$) | 2020 ($MMtCO_2e$) |
|---|---|---|---|---|
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| **Waste Management** | | 2.257117951 | **2.27859** | 2.602876711 |
| | Waste Combustion | 1.292301717 | **1.187777** | 1.492576145 |
| | $CO_2$ | 1.272171161 | 1.187493 | 1.469325857 |
| | $CH_4$ | 0 | 0.000251 | 0 |
| | $N_2O$ | 0.020130556 | 3.28E-05 | 0.023250289 |
| | Landfills | 0.388955279 | **0.457213** | 0.449233614 |
| | $CO_2$ | 0.151585044 | 0.122958 | 0.175076933 |
| | $CH_4$ | 0.237370235 | 0.334255 | 0.274156681 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| | Wastewater Management | 0.542860955 | **0.60060** | 0.622952777 |
| | $CO_2$ | 0 | 0.0000 | 0 |
| | $CH_4$ | 0.377311419 | 0.407993 | 0.431747205 |
| | $N_2O$ | 0.165549536 | 0.19261 | 0.191205572 |
| | Residential Open Burning | 0.033 | **0.0330** | 0.038114174 |
| | $CO_2$ | 0.033 | 0.0330 | 0.038114174 |
| | $CH_4$ | 0 | 0.0000 | 0 |
| | $N_2O$ | 0 | 0.0000 | 0 |
| **Gross Emissions (Consumption Basis, Excludes Sinks)** | | 107.2295365 | **78.49321** | 140.0495625 |
| | ***decrease relative to 2006*** | | 26.80 % | |
| **Emissions Sinks** | | -11.79034917 | -11.72206 | -11.75139092 |
| | Forested Landscape | -10.44657783 | -10.4466 | -10.44657783 |
| | Urban Forestry and Land Use | -1.331309142 | -1.24056 | -1.331309142 |
| | Agricultural Soils (Cultivation Practices) | -0.051420445 | -0.05142 | -0.051420445 |
| | Forest Fires | 0.038958248 | 0.016502 | 0.038958248 |
| | $CH_4$ | 0.032452487 | 0.013746 | 0.032452487 |
| | $N_2O$ | 0.00650576 | 0.002756 | 0.00650576 |
| **Net Emissions (Consumptions Basis) (Including forestry, land use, and ag sinks)** | | 95.4391873 | **66.77115** | 128.2981716 |
| | ***decrease relative to 2006*** | | 30.04 % | |

**Figure ES-2: Gross GHG Emissions Comparison by Sector, 2006, 2011, 2014, 2017 & 2020**

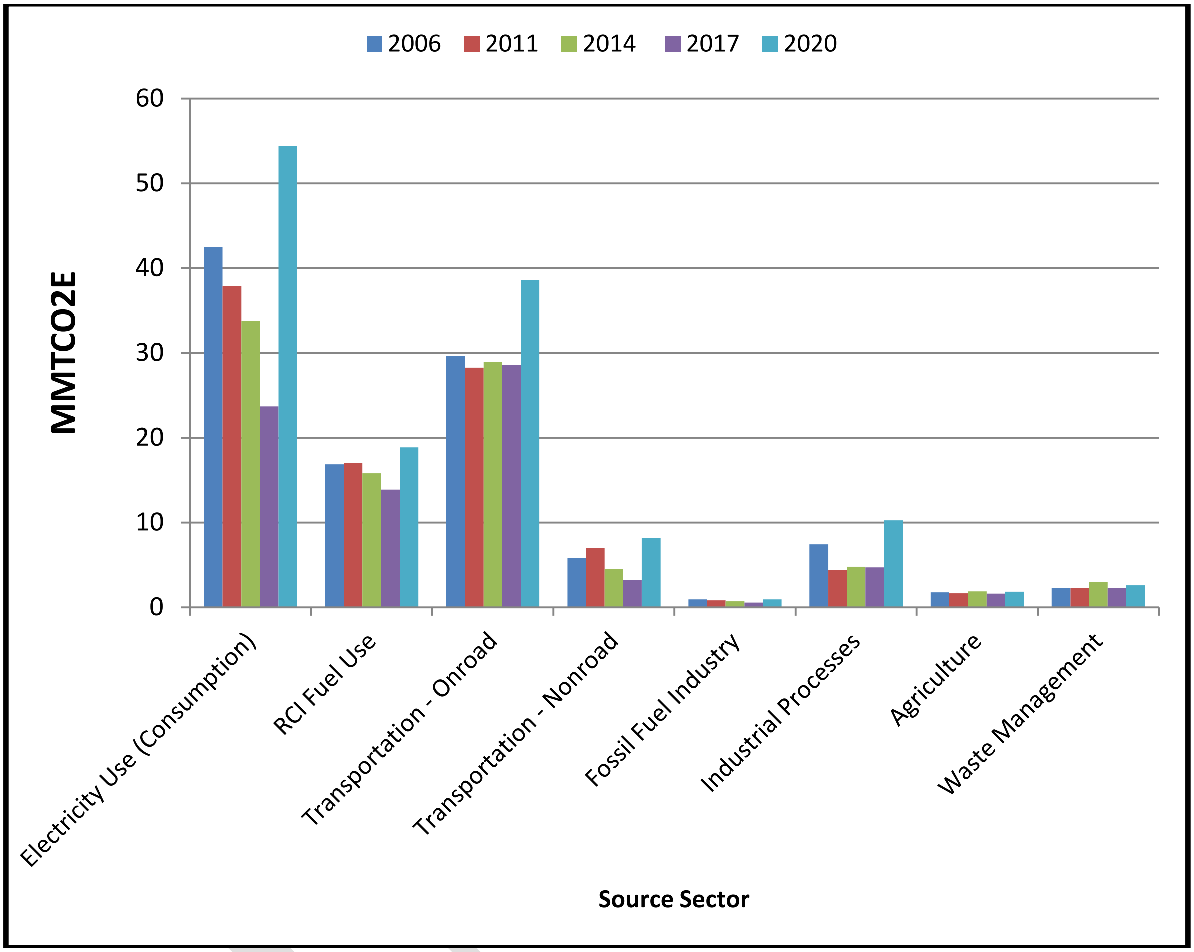
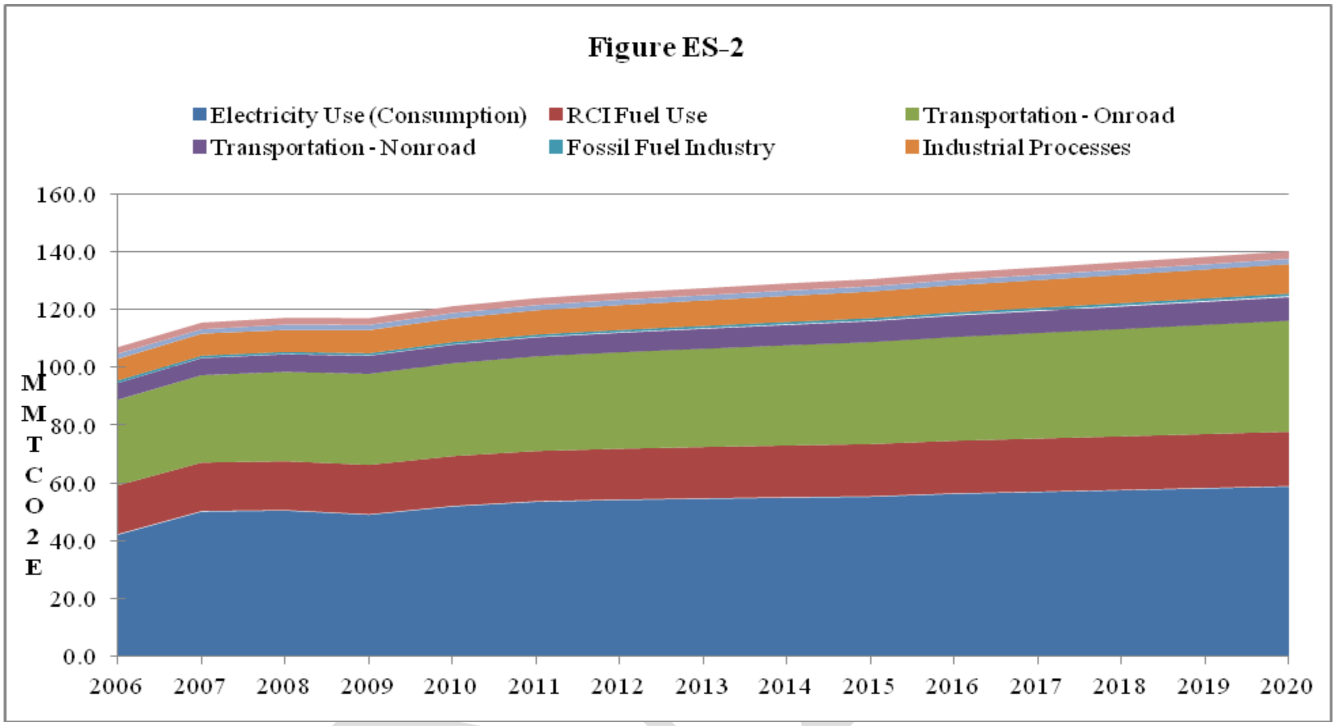


**FIGURE ES-3: MARYLAND GROSS GHG EMISSIONS BY SECTOR, 2006-2020: BASE YEAR AND PROJECTED**



## 1.3 SOURCE CATEGORIES

This document describes the inventory procedures the Maryland Department of the Environment (MDE) used to compile the 2017 periodic emissions inventory of the greenhouse gas pollutants; carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxides ($N_2O$), Sulfur hexafluoride ($SF_6$), chlorofluorocarbons (CFC) and hydro chlorofluorocarbons (HCFC). The emission sources are divided into the following eight source categories:

- Electricity Supply
- Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Transportation Energy Use
- Industrial Processes
- Fossil Fuel Production Industry
- Agriculture
- Waste Management
- Forestry and Land Use

The inventory procedures outlined in this document have been calculated on a state-wide basis and have not been spatially allocated to the county level unless otherwise stated. Descriptions of each emission source category are presented in the following paragraphs:

### 1.3.1 Electricity Supply

The electricity supply sector account for emissions occurring as a result of the combustion of fossil fuel at electricity generating facilities located both in and outside of the State. Carbon dioxide ($CO_2$) represented more than 99.37 % of total sector emissions, with methane ($CH_4$) and nitrous oxide ($N_2O$) $CO_2$-equivalent emissions comprising the balance.

Maryland is a net importer of electricity, meaning that the State consumes more electricity than is produced in the State. For this analysis, it was assumed that all power generated in Maryland was consumed in Maryland, and that remaining electricity demand was met by imported power. Sales associated with imported power accounted for 45.76 % of the electricity consumed in Maryland in 2017.[1] GHG emissions from power produced in-state are dominated by coal use, followed by emissions from oil use and natural gas use. As shown in Figure ES-1, electricity consumption accounted for about 30 % of Maryland's gross GHG emissions in 2017 (about 24 $MMtCO_2e$).

In 2017, emissions associated with Maryland's electricity consumption (23.68 $MMtCO_2e$) were about 12.03 $MMtCO_2e$ higher than those associated with electricity production (11.65 $MMtCO_2e$). The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity to meet Maryland's electricity demand.[2] The consumption-based approach can better reflect the emissions (and emissions reductions) associated with activities occurring in Maryland, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for policy-making.

### 1.3.2 Residential, Commercial, and Industrial (RCI) Fuel Combustion

This section accounts for emissions associated with direct fossil fuel used in the residential, commercial and the industrial sector to provide space and process heating.

### 1.3.3 Transportation Energy Use

Emissions estimated for this sector are the result of fossil-fuel consumed primarily for transportation purposes, both onroad mobile sources and nonroad mobile sources of transportation. Onroad mobile sources include the vehicles traditionally operated on public roadways. These include:

- Cars
- Light-duty trucks
- Vans
- Buses
- Other diesel vehicles

---

[1] In 2017, Total Maryland Retail Sales of Electricity (gross) were 62,873,438 MWh, of which 28,769,198 MWh (i.e., 46 %) were estimated to be from imports.

[2] Estimating the emissions associated with electricity use requires an understanding of the electricity sources (both in-state and out-of-state) used by utilities to meet consumer demand. The current estimate reflects some very simple assumptions, as described in Appendix A.

Other modes of transportation, such as airplanes, trains and commercial marine vessels are included under the general category of Nonroad mobile sources. Nonroad mobile sources also include motorized vehicles and equipment, which are normally not operated on public roadways. These include:

- Lawn and garden equipment
- Agricultural or farm equipment
- Logging equipment
- Industrial equipment
- Construction equipment
- Airport service equipment
- Recreational land vehicles or equipment
- Recreational marine equipment
- Locomotives
- Commercial aviation
- Air taxis
- General aviation
- Military aviation
- Commercial Marine Vessels

As shown in Figure ES-1, the transportation sector accounted for about 41 % of Maryland's gross GHG emissions in 2017 (about 32 MMtCO$_2$e). Maryland's 2017 Onroad gasoline vehicles accounted for about 70 % of transportation GHG emissions. Onroad diesel vehicles accounted for another 19 % of emissions, and air travel for roughly 2 %. Marine vessels, rail, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 9 % of transportation emissions.

### 1.3.4 Industrial Processes

Emissions estimated in the industrial sector account for only process related GHG emission from the four main industrial processes that occurs in the state;

(1) $CO_2$ emissions from cement production, soda ash, dolomite and lime/ limestone consumption;
(2) $CO_2$ emissions from iron and steel production;
(3) Sulfur Hexafluoride ($SF_6$) emissions from electric power transmission and distribution (T&D) system, transformers use, and
(4) Hydrofluorocarbons (HFC) and Perfluorocarbons (PFC) emissions resulting from the consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment.

### 1.3.5 Fossil Fuel Production Industry

This section reports GHG emissions that are released during the production, processing, transmission, and distribution of fossil fuels, (primarily natural gas and coal) in the state. Methane ($CH_4$) emissions released via leakage and venting from oil and gas fields, processing facilities, and natural gas pipelines and fugitive $CH_4$ emission during coal mining are estimated in this section, as well as carbon dioxide ($CO_2$) emissions associated with the combustion of natural gas in compressor engines (referred to as pipeline fuel).

### 1.3.6 Agriculture.

The emissions estimated in this section refer to non-energy methane ($CH_4$) and nitrous oxide ($N_2O$) emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon in agricultural soils are also estimated in this section. Energy emissions (combustion of fossil fuels in agricultural equipment) are not included in this section, but are already accounted for under the RCI and Nonroad transportation sub- sector.

### 1.3.7 Waste Management

GHG emissions from Maryland's waste management practices were estimated in this section from the three (3) main classes of waste management in Maryland; (1) solid waste management, mainly in the form of $CH_4$ emissions from municipal and industrial solid waste landfills (including $CH_4$ that is flared or captured for energy production); (2) wastewater management, including $CH_4$ and $N_2O$ from municipal and industrial wastewater (WW) treatment facilities ; and (3) $CH_4$ and $N_2O$ from municipal solid waste incinerations.

### 1.3.8 Forestry and Land Use

This section provides an assessment of the net Greenhouse gas flux[1] resulting from land uses, land–use changes, and forests management activities in Maryland. The balance between the emission and uptake of GHGs is known as GHG flux. The GHG emissions estimated in this section includes $CO_2$ emissions from urea fertilizer use, $CH_4$ and $N_2O$ emissions from wildfires and prescribed forest burns, and $N_2O$ from synthetic fertilizers application to settlement soils. Carbon uptake (sequestration) pathways estimated in this section include; carbon stored in above ground biomass, below ground biomass, dead wood, and litters- (forest carbon flux), carbon stored in the form landfilled yard trimmings and food scraps, carbon stored in harvested wood product/ wood product in landfills as well as carbon stored in urban trees.

## 1.4 BASIC ASSUMPTIONS

### 1.4.1 Greenhouse Gas Pollutant Global Warming Potential (GWP)

Carbon dioxide has a Global Warming Potential (GWP) of exactly 1 (since it is the baseline unit to which all other greenhouse gases are compared). Equivalent $CO_2$ ($CO_2e$) is the concentration of $CO_2$ would cause the same level of radiative forcing as a given type and concentration of greenhouse gas. Maryland used the established Intergovernmental Panel on Climate Change (IPCC) global warming potential's for the greenhouse gas pollutants.

**Table ES-2: IPCC Global Warming Potential for GHG**

| **GHG Pollutant** | **GWP** |
|---|---|
| Carbon Dioxide ($CO_2$) | 1 |
| Methane ($CH_4$) | 21 |
| Nitrous Oxide ($N_2O$) | 310 |
| Sulfur Hexafluoride ($SF_6$) | 23,900 |
| Perfluorocarbons (PFCs) | 9,200 |
| Hydro Chlorofluorocarbons (HCFC) | 11,700 |

### 1.4.2 Confidentiality

This document does not contain any confidential information; however, confidential information/data are included in the documentation of emissions calculations for major sources categories.

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[1] The term "flux" is used here to encompass both emissions of greenhouse gases to the atmosphere, and removal of C from the atmosphere. Removal of C from the atmosphere is also referred to as "carbon sequestration".

## 1.5 DOCUMENT ORGANIZATION

Detailed descriptions of the specific assumptions, source information, and calculations on which the inventory is based are presented in the sections described below.

Section 2.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations for the electricity supply sector.

Section 3.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the residential, commercial, and industrial fuel combustion sector.

Section 4.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the on-road mobile transportation energy use sector.

Section 5.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the non-road mobile transportation energy use sector.

Section 6.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the industrial processes sector.

Section 7.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the fossil fuel production industry sector.

Section 8.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the agricultural sector.

Section 9.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the waste management sector.

Section 10.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the forestry and land use sector.

# 2.0 ELECTRICITY SUPPLY

## 2.1 OVERVIEW

This section describes the data sources, key assumptions, and the methodology used to develop the periodic 2017 inventory of greenhouse gas (GHG) emissions associated with meeting electricity demand in Maryland. It also describes the data sources and key assumptions used in developing the periodic 2017 GHG emissions associated with meeting electricity demand in the state.

The methodology used to develop the MD inventory of GHG emissions associated with electricity consumption is based on a bottom up approach for in-state electricity generation and also includes emission estimates for imported electricity. There are four fundamental premises of the GHG inventory developed for MD, as briefly described below:

- Developing the consumption estimate involves tallying up the GHG emissions associated with consumption of electricity in MD, regardless of where the electricity is produced. As MD is a net importer of electricity, a consumption-based emission estimate will be different than a production-based estimate.

- The GHG inventory is estimated based on emissions at the point of electric generation only. That is, GHG emissions associated with upstream fuel cycle process such as primary fuel extraction, transport to refinery/processing stations, refining, beneficiation, and transport to the power station are not included.

- As an approximation, it was assumed that all power generated in MD was consumed in MD. In fact, some of the power generated in MD is exported. However, given the similarity in the average carbon intensity of MD power stations and that of power stations in the surrounding MAPP region, the potential error associated with this simplifying assumption is small, on the order of 2%, plus or minus.

## 2.2 DATA SOURCES

- MDE's Annual Emissions Certification Reports (MD ECR): The annual emission certification reports from electric generating facilities are the primary source of information for the emission estimates for the 2017 GHG periodic inventory. The certification reports were validated by the electric power facilities and submitted to the Air and Radiation Administration (ARA) Compliance Program. Engineers with the compliance program reviewed the emission certification reports for accuracy.

- Regional Greenhouse Gas Initiative (RGGI): The RGGI program (Summary Level Emission Report) report and data sets can be accessed through the following website: https://rggi-coats.org/eats/rggi/index.cfm?fuseaction=search.rggi_summary_report_input&clearfuseattribs=true.). This report was used to QA/QC emission data reported in MD ECR.

- EPA Clean Air Market Division (CAMD): This is a database file available from the EPA Clean Air Market Division under the Emissions Collection and Monitoring Plan System (ECMPS). The information in the database is based on information collected from utilities. Additional data provided includes fuel consumption and net generation in power stations by plant type. The ECMPS report and data was used to QA/QC heat input data reported in MD Emission Certification Reports. This information can be accessed from: http://ampd.epa.gov/ampd/QueryToolie.html.

- US EPA State Greenhouse Gas Inventory Tool (SIT): http://www.epa.gov/statelocalclimate/resources/tool.html

- *Global warming potentials:* These are based on values proposed by the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report. This information can be accessed directly from http://www.ipcc.ch/pub/reports.htm.

- US Energy Information Administration: Electricity Data Browser-Retail Sales of Electricity. This database was used to determine total sales of electricity across all sectors. The document can be accessed through the following website:

  http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_es.html&sid=MD

  https://www.eia.gov/electricity/data/browser/

## 2.3 GREENHOUSE GAS INVENTORY METHODOLOGY

### 2.3.1 Carbon Dioxide ($CO_2$) Direct Emissions

Maryland 2017 electric generating unit $CO_2$ emissions were compiled from the annual Emissions Certification Reports submitted to MDE Air and Radiation Administration Compliance Program. The Compliance Program is responsible for collecting annual air emissions that are certified as accurate from large Maryland facilities. The MDE Annual Emissions Certification Report formed the basis for the estimation of $CO_2$ emission from electric power plants.

The 2017 annual emission certification reports data, submitted by power plant operators in Maryland, were cross-checked against both the EPA's Clean Air Markets Division (CAMD) emissions reporting and tracking database and the EPA's Mandatory Green House Gases Reporting Program (GHGRP) – GHG data. The CAMD data reports $CO_2$ emissions from fossil fuel fired plants with a generating capacity of 25 megawatts or greater; through EPA's Emissions Collection and Monitoring Plan System (ECMPS), where reported data are; hourly value for measured parameters, calculated hourly emission value, instrument calibration data and aggregated summary data. While the GHGRP database - (GHG data) provides the same information as well as $CH_4$, and $N_2O$ emissions; this database covers additional units (electricity generators) not reported under the acid rain program. These databases provide a readily accessible, annually updated source of GHG emissions from the electric power plant and were accessed by MDE during verification of emissions reported in MDE Annual Emission Certification Report.

#### 2.3.1.1 Clean Air Markets Division (CAMD) Sources.

Maryland has a substantial database of both small and large air emission sources compiled over the last eighteen years. Regulated facilities are required to submit annual Emissions Certification Reports to MDE ARA Compliance Program. The Compliance Program facility inspectors verify the submitted emission estimates for accuracy and completeness. This unit level $CO_2$ emission data was compiled to the facility level and formed the basis for the estimation of $CO_2$ emission for the state.

MDE verified CAMD facility emissions data with MDE Certification Report emission data through the following steps:

1. Identified the CAMD facilities that report $CO_2$ emissions to EPA through the CAMD database.
2. Compiled a list of CAMD generating unit and facility codes.
3. Cross-referenced the CAMD units with the MD Emission Certification Reports.
4. Downloaded CAMD emissions data from EPA CAMD database from January 2014 through December 2017 for all facilities and units in Maryland
5. Compiled 2017 $CO_2$ emissions data for RGGI units.
6. Compiled energy consumption (MMBTU) data from the ARP database for the CAMD units.
7. Compared the CAMD emission estimates to the MD Emission Certification Report emission estimates.
8. Reconciled any discrepancies.

#### 2.3.1.2 Greenhouse Gas Reporting Program (GHGRP) Sources

The entire fossil fuel electric generation units' annual GHG emissions data submitted under the U.S. Environmental Protection Agency's (EPA) Mandatory GHG Reporting program were reviewed, the verification focused primarily on direct emissions from fossil fuel usage for electric power generation, a review of the procedures used to compile the emission estimates, a review of estimated emissions for completeness and accuracy in calculations. Data in supporting spreadsheets were also examined, including reviews of combined emissions from unit's combusting a mixture of fuels.

For electric power plant units without Continuous Emissions Monitors (CEM), the fuel-use methodology was used to review the emission estimates. Fossil fuel consumption data and facility specific fuel heat content were compiled on a unit basis and used to estimate energy consumption in MMBtu. EPA Mandatory Greenhouse Reporting Program, 40 CFR parts 98, Subpart C default Emission factors was used to estimate $CO_2$ emissions.

MDE verified the reported emissions from the GHGRP sources through the following steps:

1. Compiled fossil fuel consumption data for all electric power generating units from the MDE Emission Certification Reports.
2. Estimated energy consumption (BBTU) from all generating units using facility specific heat contents from the MDE Emission Certification Reports.
3. Applied EPA 40 CFR part 98, Subpart C default Emission factors to estimate emissions.

4. Compared the emissions estimates to the emissions reported through the EPA GHGRP.
5. Reconciled any discrepancies.

### 2.3.2 Additional Direct Emissions ($CH_4$ and $N_2O$)

2017 annual direct emissions of $CH_4$ and $N_2O$ from Maryland electric generating units were compiled from the annual Emissions Certification Report submitted to MDE Air and Radiation Administration Compliance Program.

### 2.3.3 Imported Electricity Indirect Emissions ($CO_2$, $CH_4$ and $N_2O$)

Maryland is a net importer of electricity, meaning that the State consumes more electricity than is produced in the State. For this analysis, it was assumed that all power generated in Maryland was consumed in Maryland, and that remaining electricity demand was met by imported power. Sales associated with imported power accounted for 46 % of the electricity consumed in Maryland in 2017.[1] GHG emissions from power produced in-state are dominated by coal use, followed by emissions from oil use and natural gas use.

The electricity imported to meet the Maryland's demand was assume to have come from the PJM Interconnection, a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.[2]

The fuel mix within the PJM region required to generate the electricity is presented in Table 2-1.

**Table 2-1: PJM 2017 Fuel Mix [3]**

| FUEL TYPE | PJM PERCENTAGE |
|---|---|
| Coal | 32.20 |
| Nuclear | 35.90 |
| Natural Gas | 26.7 |
| Oil | 0.20 |
| Hydroelectric | 1.10 |
| Solid Waste | 0.50 |
| Wind | 2.60 |
| Captured $CH_4$ | 0.30 |

The PJM website also provides the data to calculate a $CO_2$ emission rate in metric tons per megawatt-hour for each fuel type. These calculated rates were used as the computed emission factors per fuel type in the analysis. The PJM data is presented in Table 2-2.

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[1] In 2017, Total Maryland Retail Sales(gross) were 62,873,438 MWh, of which 28,769,198 (i.e., 46 %) were estimated to be from imports.

[2] http://www.pjm.com/about-pjm/who-we-are.aspx.

[3] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=243.

## Table 2-2: PJM System Mix – Year 2017

| Year | Fuel | # of Certificates (MWh) | Percentage by Fuel | Carbon Dioxide | Total $CO_2$ (lbs) | $CO_2$ Emission Rate (lbs/MWh) | $CO_2$ Emission Rate (metric tons/MWh) |
|---|---|---|---|---|---|---|---|
| 2017 | Biomass – Other Biomass Liquids | | | | | | |
| | Biomass – Other Biomass Gases | **6,944** | **0.0009** | **0.0005** | **385,777.78** | **55.5556** | **0.0252** |
| 2017 | Captured Methane - Coal Mine Gas | 174,422 | 0.0218 | 0.2534 | 202,745,572.48 | | |
| 2017 | Captured Methane - Landfill Gas | 2,434,489 | 0.3043 | 0.3383 | 270,649,894.41 | | |
| | | **2,608,911** | **0.3261** | | **473,395,466.89** | **181.4533** | **0.0823** |
| 2017 | Coal - Bituminous and Anthracite | 218,197,895 | 27.2697 | 573.2461 | 458,681,585,558.18 | | |
| 2017 | Coal - Sub-Bituminous | 28,312,580 | 3.5384 | 80.4875 | 64,402,237,812.29 | | |
| 2017 | Coal - Waste/Other | 11,298,702 | 1.4121 | 37.8107 | 30,253,652,837.01 | | |
| | | **257,809,177** | **32.2202** | | **553,337,476,207.48** | **2,146.3064** | **0.9734** |
| 2017 | Gas - Natural Gas | 213,401,721 | 26.6702 | 239.4274 | 191,577,937,977.80 | | |
| 2017 | Gas – Other | 314,490 | 0.0393 | 0.6546 | 523,829,908.40 | | |
| 2017 | Gas – Propane | 260 | 0.0000 | 0.00009 | 0.000 | | |
| | | **213,716,471** | **26.7095** | | **192,101,767,886.20** | **898.8627** | **0.4076** |
| 2017 | Hydro – Conventional | **9,018,092** | **1.1271** | 0.00000 | 0.0 | | |
| 2017 | Nuclear | **287,461,082** | **35.926** | 0.00000 | 0.0 | | |
| 2017 | Oil - Distillate Fuel Oil | 152,409 | 0.019 | 0.3665 | 293,988,939.47 | | |
| 2017 | Oil - Jet Fuel | 2719 | 0.0000 | 0.0007 | 0.0 | | |
| 2017 | Oil - Residual Fuel Oil | 101142 | 0.0126 | 0.3179 | 255,182,871.43 | | |
| 2017 | Oil – Petroleum Coke | 1,042145 | 0.1302 | 3.6492 | 2,920,887,506.91 | | |
| 2017 | Oil - Waste/Other Oil | 13,666 | 0.0017 | 0.0026 | 2,090,094.12 | | |
| | | **1,309,633** | **0.1635** | | **3,472,149,411.93** | **2,651.2385** | **1.2024** |
| 2017 | Solar- Photovoltaic | **1,467,762** | **0.1834** | **0.0000** | **0.0** | | |
| 2017 | Solid Waste - Municipal Solid Waste | 3,734,939 | 0.4668 | 11.0547 | 8,845,036,453.15 | | |
| 2017 | Solid Waste – Tire Derived Fuel | 1,239 | 0.0002 | 0.0043 | 2,663,850.00 | | |
| | | **3,736,178** | **0.467** | | **8,847,700,303.15** | **2,368.1153** | **1.0740** |
| 2017 | Wind | **21,025,373** | **2.6277** | **0.00000** | **0.0** | | |
| 2017 | Wood - Black Liquor | 308,906 | 0.0386 | 0.1956 | 156,533,713.99 | | |
| 2017 | Wood - Wood/Wood Waste Solids | 1,453,764 | 0.1817 | 0.6161 | 492,935,608.37 | | |
| | | **1,762,670** | **0.2203** | | **649,469,322.36** | **368.4577** | **0.1671** |
| | **Total** | **800,148,957** | **100.00** | | **758,882,344.78** | **948.43** | **0.4301** |

MDE compiled $CO_2$ emission estimates from imported electricity by utilizing the following methods and sources of information:

- Obtain the total electricity consumption for the State of Maryland from EIA Electricity Data Browser database (SEDS)[1];
- Adjust the Total Retail Sales (Consumption) data to account for electricity transmission and distribution loss (6.25%) to estimate the Gross State Electricity Consumption data;
- Obtain the total gross electricity generated in the State of Maryland from EIA[2];
- Estimate the amount of imported electricity (MWh) in 2017 by subtracting the Gross State Electricity generated from the Gross State Electricity Consumption;
- Download PJM electricity generation fuel mix.[3]
- Apportion the amount of imported electricity by fuel type using the PJM fuel mix;
- Compute the $CO_2$ emission factors per fuel type (tons/MWh) from the PJM data.[4];
- Estimate $CO_2$ emissions.

**Table 2-3: Electricity Imported to Maryland (MWh)**

| | | 2017 | Source of Data | Data Source Web Address |
|---|---|---|---|---|
| A | **Total Electric Consumption (MWh) - Retail Sales** | 59,175,000 | EIA Electricity Data | http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_es.html&sid=MD |
| B | **MD -Electricity Losses (MWh) (Transmission and Distribution)** | 6.25% | MEA | |
| C | **Total Electricity Consumption (MWh) –** Gross Consumption | 62,873,438 | A*(1+B) | |
| D | MD In-State Gross - Electricity Generated (MWh) | 34,104,240 | EIA SEDS | http://www.eia.gov/electricity/data/state/ |
| E | **Imported Electricity to Meet MD Demand (MWh)** | **28,769,198** | C – D | |

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[1] http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_es.html&sid=MD.

[2] http://www.eia.gov/electricity/data/state/

[3] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=243.

[4] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=227&TabName=System%20Mix%20By%20Fuel

## Table 2-4: Electricity Imported to Maryland by Fuel Type, (MWH)

| | Coal | Nuclear | Natural Gas | Oil | Hydro-electric | Solid Waste | Wind | Captured $CH_4$ | Total |
|---|---|---|---|---|---|---|---|---|---|
| PJM Electricity Generation Fuel Mix 2017 (%) | 32.2 | 35.9 | 26.7 | 0.2 | 1.1 | 0.5 | 2.6 | 0.3 | 100 |
| Maryland 2017 Import Share by Fuel Type (MWh) | 9,028,638 | 10,068,249 | 7,484,635 | 45,956 | 315,806 | 130,862 | 736,975 | 91,351 | 28,015,764 |
| Imported Electric $CO_2$ Emissions Factors (tons/MWh) | 0.97 | | 0.41 | 1.20 | | 1.07 | | 0.08 | |
| Imported Electric $CO_2$ Emissions (metric tons) | 8,757,779 | | 3,068,700 | 55,147 | | 140,022 | | 7,308 | 12,028,957 |
| Imported Electric $CO_2$ Emissions ($MMTCO_2$) | 11.45 | | 3.07 | 0.06 | | 0.14 | | 0.01 | 12.028957 |

## 2.4 GREENHOUSE GAS INVENTORY RESULTS

The result of Maryland 2017 GHG emissions from the electricity generating units is shown in Table 2-5 and 2-6. The annual GHG emission from units sharing a common stack, or units with multiple fossil fuel combustion were disaggregated by apportioning the emissions to the respective fuel type by the following equation:

$$(CO_2\text{ Emission})_A = \frac{(\text{Heat Input})_A}{(\text{Heat Input})_A + (\text{Heat Input})_B} \times (\text{ECMPS } CO_2\text{ Emission})_{\text{Unit}}$$

Where $(CO_2\text{ Emission})_A$ : Cumulative $CO_2$ Emission (e.g. units with both coal and oil combustion)

$(\text{Heat Input})_A$: Heat Input of Fossil Fuel A (e.g. Coal)
$(\text{Heat Input})_B$: Heat Input of Fossil Fuel B (e.g. Natural Gas)
$(\text{ECMPS } CO_2\text{ Emissions})_{\text{Unit}}$: Direct Unit's $CO_2$ measurement either CEM or Calculated.

Heat input is calculated according to appendix D of 40 CFR part 75 or 40 CFR 75.19. The high heat values used in the GHG emissions disaggregation calculations for each fuel in MMBtu were from the facility's specific heating values reported in the emission certification reports.

## Table 2-5: $CO_2$ Emissions from Electric Generating Units by Fuel Type.

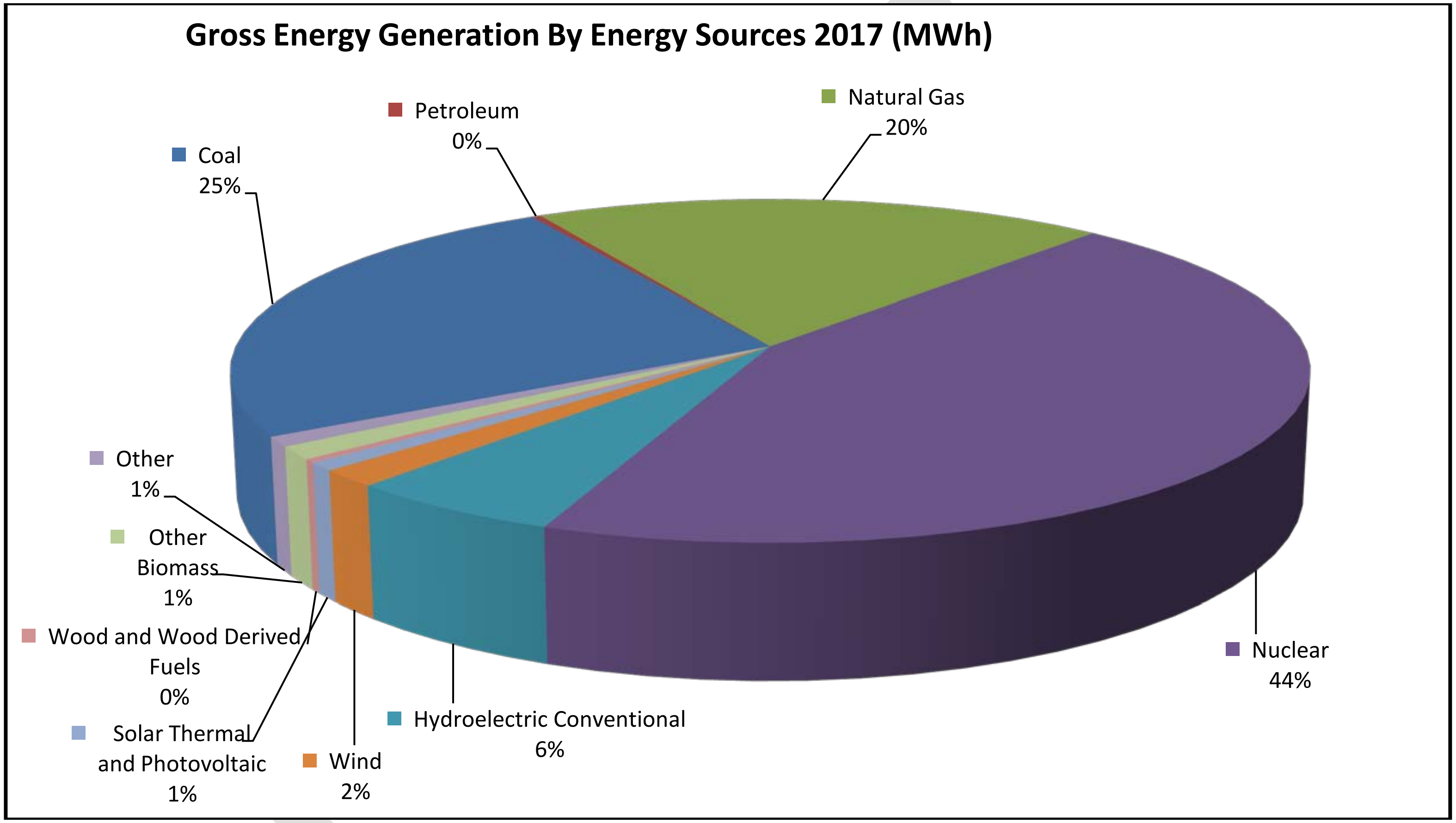
| Electric Power Sector $CO_2$ Emissions – ALL Units – 2017 | | | | | |
|---|---|---|---|---|---|
| **Fuel Type** | **MMBTU** | **$CO_2$ Emission (short tons)** | **$CO_2$ Emission (metric tons)** | **$CO_2$ Emission ($MMTCO_2$)** | **$CO_2$ Emission (MMTC)** |
| Coal | 111,492,020 | 9,571,102.58 | 8,682,751.12 | 8.68 | 2.368 |
| Distillate Fuel | 1,836,609 | 159,907.04 | 145,065.11 | 0.15 | 0.040 |
| Residual Fuel | 220,827 | 3,515.25 | 3,188.98 | 0.00 | 0.001 |
| Natural Gas | 444,724,033 | 3,028,048.92 | 2,746,997.53 | 2.75 | 0.749 |
| **Total** | | **12,762,573.78** | **11,578,002.73** | **11.58** | **3.158** |

## Table 2-6: Electric Power - GHG Emissions by Pollutant – 2017 Year

| **Fuel Type** | **Consumption (Billion Btu)** | **Emissions $CO_2$ ($MMTCO_2E$)** | **Emissions $N_2O$ ($MMTCO_2E$)** | **Emissions $CH_4$ ($MMTCO_2E$)** | **Emissions Total ($MMTCO_2E$)** |
|---|---|---|---|---|---|
| Coal | 111,492.02 | 8.68 | 0.0470 | 0.02122 | 8.7510 |
| Distillate Fuel | 1,836.61 | 0.15 | 0.0003 | 0.0004 | 0.1458 |
| Residual Fuel | 220.83 | 0.000 | 3.3886E-05 | 1.3782E-05 | 0.0032 |
| Natural Gas | 444,724.03 | 2.75 | 0.0037 | 0.0008 | 2.7515 |
| | | **11.58** | **0.0510** | **0.0224** | **11.6514** |

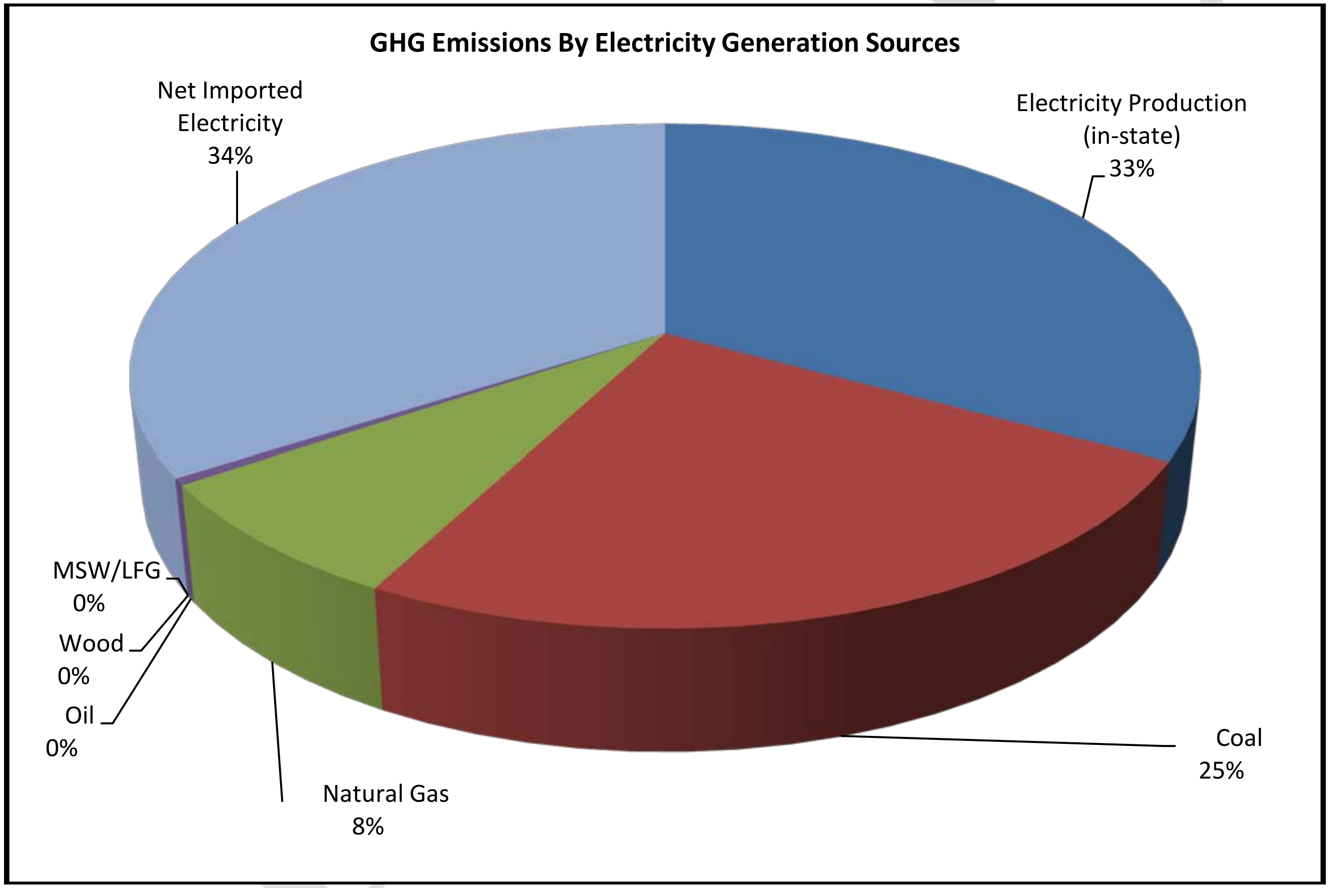
The gross energy generated by source type is shown in Figure 2-1.

**FIGURE 2-1: GROSS ENERGY GENERATION BY ENERGY SOURCE (MWH)**



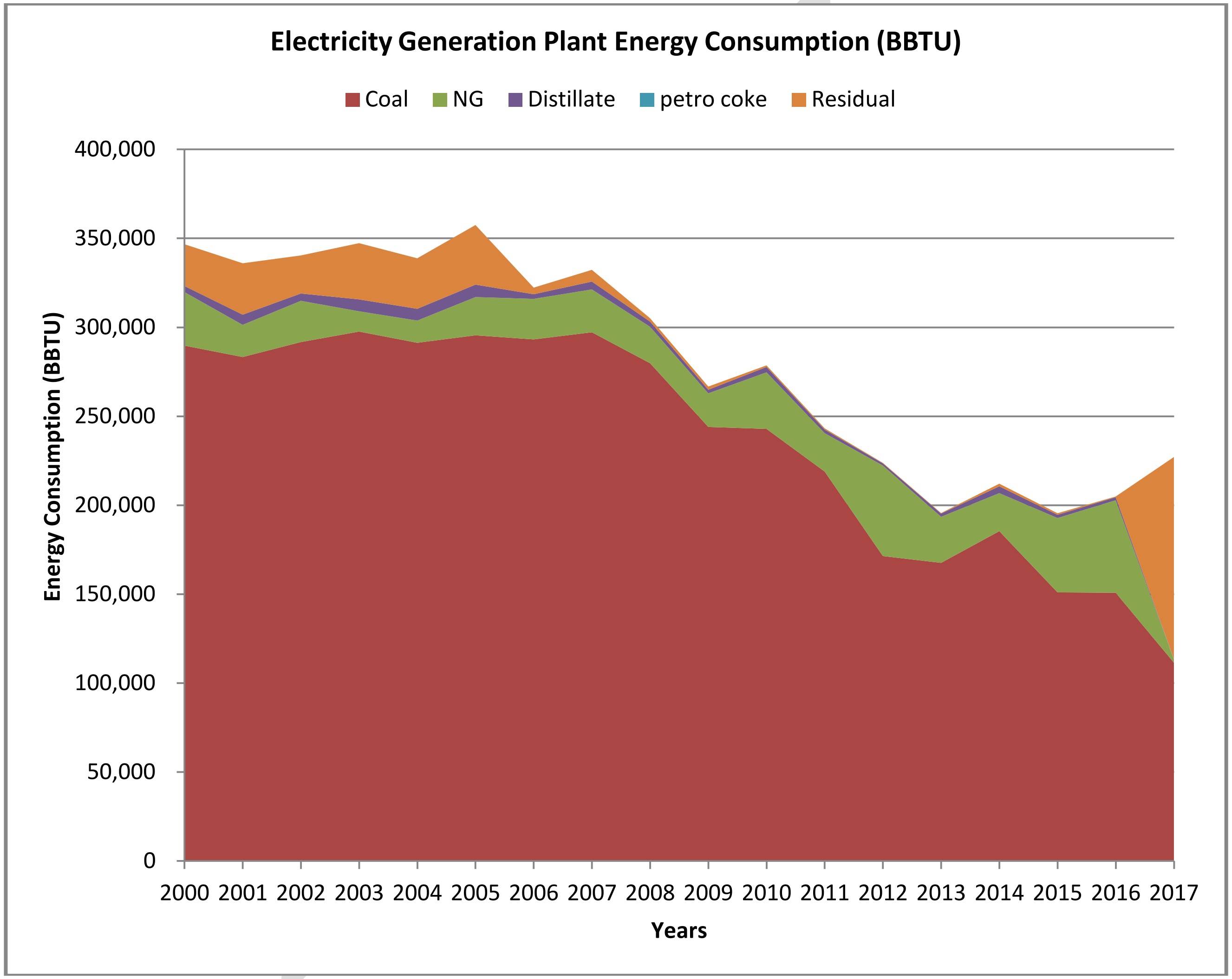
The greenhouse gas emission generated by source type is shown in Figure 2-2.

**FIGURE 2-2: EMISSIONS BY ELECTRIC GENERATING SOURCE SECTORS (MMTCO$_2$E)**

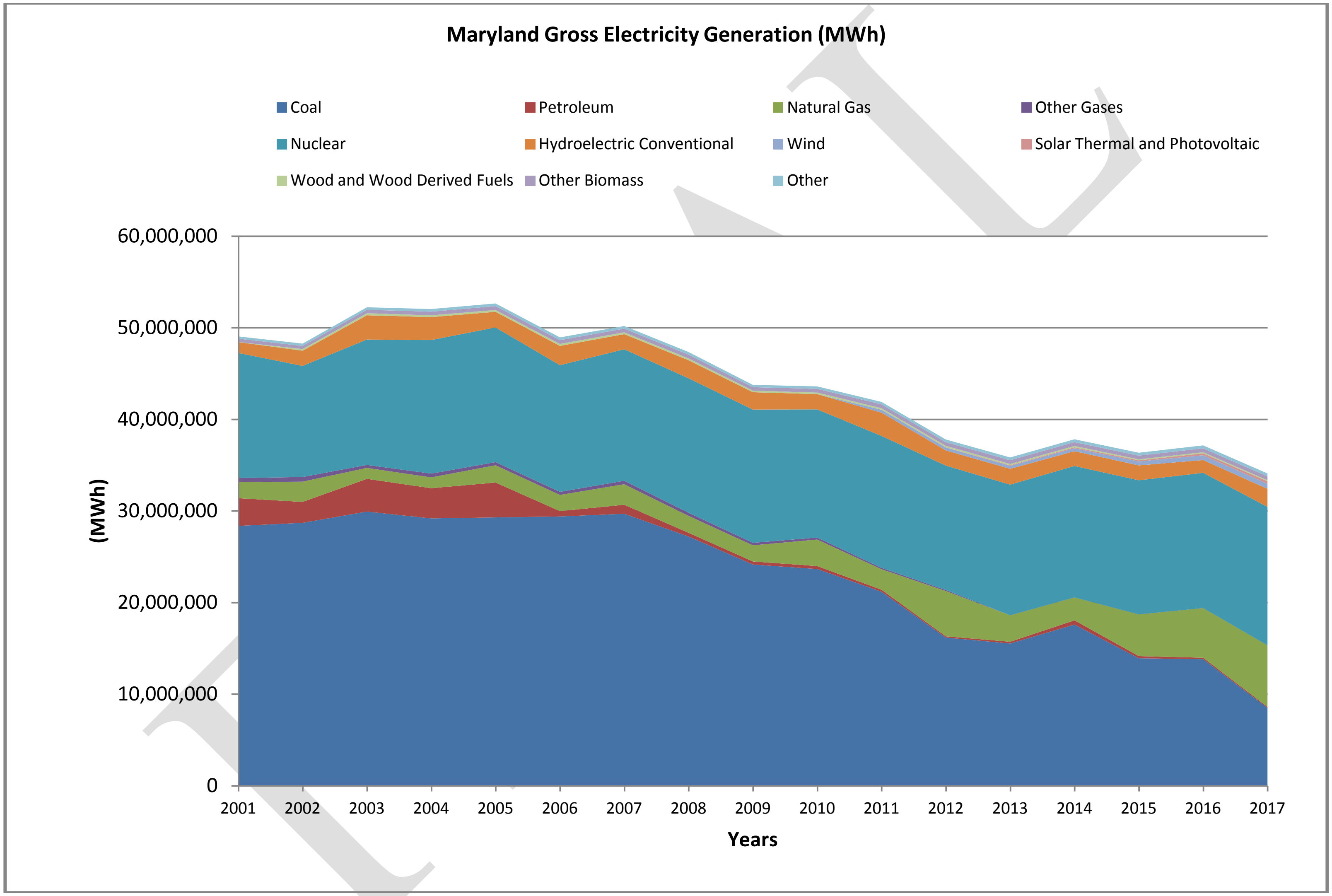


The primary energy used to produce electricity consumed in Maryland is shown in Figure 2-3.

FIGURE 2-3: PRIMARY ENERGY USE AT MD POWER STATIONS, PLUS IMPORTS



## FIGURE 2-4: GROSS GENERATION AT MARYLAND POWER STATIONS, PLUS IMPORTS



# 3.0 Residential, Commercial, and Industrial (RCI) Fuel Combustion

## 3.1 OVERVIEW

This section describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions for the year 2017 associated with residential, commercial and industrial (RCI) sector fuel combustion in Maryland. Maryland GHG emissions were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[1], [2] The 2017 GHG inventory for the RCI sector was prepared using the SIT software with the state-specific updated input data imported to the tool.

This section addresses only RCI sector emissions associated with the direct use of energy sources such as; natural gas, petroleum, coal and wood, to provide space heating, water heating, process heating, cooking and other energy end-uses. Emissions associated with RCI sector electricity consumption are accounted for under the electric generation section. Activities in the RCI sectors produce carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) emissions.

Results are presented in units of carbon dioxide equivalents ($CO_2e$), often in million metric tons ($MMTCO_2e$), for each gas for comparative purposes following the guidance of the Intergovernmental Panel on Climate Change[3], a widely accepted procedure for greenhouse gas analysis. Selected results for emissions in Maryland and a detailed description of the 2017 inventory are presented here.

## 3.2 DATA SOURCES

- State-consumption data derived from EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS) 2017: State Energy Data System (SEDS): 2017 (updates by energy source). Consumption Estimates (EIA 2017). https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

- Default state synthetic natural gas data obtained from Table 2 of EIA's Historical Natural Gas Annual (EIA 2017), and Table 2 for Natural Gas Annual publications from 2010-2017 http://www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html

- In-state agencies, such as state energy commissions or public utility commissions

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[1] $CO_2$ emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter 1, "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels," August 2004.

[2] $CH_4$ and $N_20$ emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter 1, "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels," August 2004.

[3] Intergovernmental Panel on Climate Change

- US EPA State Greenhouse Gas Inventory Tool (SIT)
  http://www.epa.gov/statelocalclimate/resources/tool.html

## 3.3 GREENHOUSE GAS INVENTORY METHODOLOGY

Maryland base year (2006) and periodic year (2017) GHG emissions from the RCI sector were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[1]

Several key variables are necessary for estimating $CO_2$ emissions for fossil fuel combustion from the State Greenhouse Gas Inventory Tool (SIT). These variables include consumption by fuel type and sector, combustion efficiencies, carbon contents, and non-energy use storage factors. Default data is provided within the SIT program and Maryland selected the default data for the emission estimates. Information for combustion efficiencies, carbon contents, and non-energy use storage factors are discussed individually below.

### Energy Consumption by Fuel Type and Sector

Energy consumption data for Maryland was collected from the EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS) EIA (June 28, 2019 Release). [2]

### Combustion Efficiencies

Combustion efficiency is defined as the percent carbon oxidized by the fuel type. This percent is applied if the carbon is not completely oxidized during the combustion of fossil fuels. The fraction oxidized was assumed to be 100 percent for petroleum, coal, and natural gas based on guidance from IPCC (2006).

### Carbon Contents

Another data type required is the carbon content data. The carbon content coefficients used in the SIT module are from the EIA's *Electric Power Annual* EIA (2009a). Carbon content represents the maximum amount of carbon emitted per unit of energy released, assuming 100 percent combustion efficiency. Coal has the highest carbon content of the major fuel types, petroleum has roughly 75 percent of carbon per energy as compared to coal, and natural gas has about 55 percent. However, carbon contents also vary within the major fuel types, as noted below:

- Carbon emissions per ton of coal vary considerably depending on the coal's composition of carbon, hydrogen, sulfur, ash, oxygen, and nitrogen. While variability of carbon emissions on a mass basis can be considerable, carbon emissions per unit of energy (e.g., per Btu) vary less.

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[1] Emission Inventory Improvement Program, Volume VIII: Chapter. 1. "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004. (ii) Emission Inventory Improvement Program, Volume VIII: Chapter. 2. "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.

[2] EIA SEDS data are available at https://www.eia.gov/state/seds/seds-data-complete.php?sid=MD

- The carbon/energy ratio of different petroleum fractions generally correlates with API (American Petroleum Institute) gravity (Marland and Rotty 1984).[1] Lighter fractions (e.g., gasoline) usually have less carbon per unit energy than heavier fractions (e.g., residual fuel oil).
- Natural gas is a mixture of several gases, and the carbon content depends on the relative proportions of methane, ethane, propane, other hydrocarbons, $CO_2$, and other gases, which vary from one gas production site to another.

The carbon contents of fuels used in the 2017 periodic GHG emissions inventory are listed in Table 3-1 below.

**Table 3-1: Carbon Content of Fuels**

| Fuel | 2017 Carbon Content (lb C/MBTU) |
|---|---|
| Asphalt and Road Oil | 45.27 |
| Aviation Gasoline | 41.57 |
| Distillate Fuel | 44.47 |
| Jet Fuel, Kerosene | 43.43 |
| Jet Fuel, Naphtha | 43.51 |
| Kerosene | 43.97 |
| LPG (industrial) | 37.28 |
| LPG (energy only) | 37.11 |
| Lubricants | 44.53 |
| Motor Gasoline | 42.90 |
| Residual Fuel | 45.15 |
| Misc. Petro Products | 44.42 |
| Feedstocks, Naphtha | 40.86 |
| Feedstocks, Other Oils | 43.43 |
| Pentanes Plus | 40.06 |
| Petroleum Coke | 61.34 |
| Still Gas | 40.08 |
| Special Naphthas | 43.47 |
| Unfinished Oils | 44.77 |
| Waxes | 43.60 |

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[1] Variations in petroleum are most often expressed in terms of specific gravity at 15 degrees Celsius. The API gravity, where API gravity = 141.5/specific gravity – 131.5, is an indication of the molecular size, carbon/hydrogen ratio, and hence carbon content of a crude oil.

| Fuel | 2017 Carbon Content (lb C/MBTU) |
|---|---|
| Residential Coal | 56.79 |
| Commercial Coal | 56.79 |
| Industrial Coking Coal | 56.20 |
| Industrial Other Coal | 56.85 |
| Electric Power Coal | 55.80 |
| Natural Gas | 31.90 |
| Aviation Gasoline Blending Components | 41.56 |
| Motor Gasoline Blending Components | 42.90 |
| Crude Oil | 44.77 |

### Non-Energy Use Storage Factors

The final type of data needed in the worksheet is the percent of carbon in each fuel that is stored from non-energy uses. Many fossil fuels have potential non-energy uses. For example, LPG is used for production of solvents and synthetic rubber; oil is used to produce asphalt, naphtha, and lubricants, and coal is used to produce coke, yielding crude light oil and crude tar as by-products that are used in the chemical industry.

However, not all non-energy uses of fossil fuels result in carbon storage. For example, the carbon from natural gas used in ammonia production is oxidized quickly. Many products from the chemical and refining industries are burned or decompose within a few years, and the carbon in coke is oxidized when the coke is used. The SIT module provides national default values for storage factors. The national defaults were used as Maryland state-level fractions and are presented below:

Table 3-2: Non-Energy Use Storage Factors

| Fuel | 2017 Storage Factor Used |
|---|---|
| Asphalt and Road Oil | 100% |
| Distillate Fuel | 50% |
| LPG | 62% |
| Lubricants | 9% |
| Residual Fuel | 50% |
| Feedstocks, Naphtha | 62% |
| Feedstocks, Other Oils | 62% |
| Misc. Petro Products | 0% |
| Pentanes Plus | 62% |
| Petroleum Coke | 30% |
| Still Gas | 80% |
| Special Naphthas | 0% |
| Waxes | 58% |
| Industrial Coking Coal | 10% |
| Natural Gas | 62% |

### 3.3.1 Carbon Dioxide ($CO_2$) Direct Emissions

$CO_2$ emissions for fossil fuel combustion in the residential and commercial sectors were calculated by multiplying energy consumption in these sectors by carbon content coefficients for each fuel. These quantities are then multiplied by fuel-specific percentages of carbon oxidized during combustion (a measure of combustion efficiency). The resulting fuel emission values, in pounds of carbon, are then converted to $MMTCO_2e$.

Industrial sector $CO_2$ emissions are calculated in the same way, except emissions from fossil fuels not used for energy production are factored separately. In accordance with the EIIP guidelines, non-energy sector consumption of fossil fuel is first subtracted from total fuels, and then multiplied by carbon storage factors for each fuel type. This is necessary because a portion of the fossil fuel is used for non-energy uses and can be sequestered (stored) for a significant period of time (e.g., more than 20 years). For example, LPG is used for the production of solvents and synthetic rubber, and oil is used to produce asphalt, napthas, and lubricants. The carbon that is stored is assumed to remain unoxidized for long periods of time, meaning that the carbon is not converted to $CO_2$. After the portion of stored carbon is subtracted, the resulting (net) combustible consumption for each fuel is then used to calculate industrial sector emissions.

### 3.3.1.1 Residential Fossil Fuel Combustion

Emissions associated with the residential fossil fuel combustion sector was estimated using default data used in SIT from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data (SED)*[1]; containing annual amount of coal, oil, natural gas and other fuel types in Billion Btu consumed by each sector.

The general equation used for converting residential energy consumption to $MMTCO_2e$ is as follows:

$$\text{Emissions } (MMTCO_2E) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718474 \times (44/12)}{1{,}000{,}000}$$

Where:

Consumption (BBtu) = total heat content of the applicable fuel consumed
Emission Factor = established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%) = percentage completeness of the combustion of the fuel.
0.90718474 = constant used to convert from short tons to metric tons.
0.0005 = constant used to convert from pounds to short tons.
1,000,000 = conversion factor converts metric tons to Million metric tons
44/12 = conversion factor converts from carbon to carbon dioxide

### 3.3.1.2 Commercial Fossil Fuel Combustion

Emissions associated with the commercial fossil fuel combustion sector was estimated using default data used in SIT from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data (SED)*[2]; containing annual amount of coal, oil, natural gas and other fuel types in Billion Btu consumed by each sector.

The general equation used for converting commercial energy consumption to $MMTCO_2e$ is as follows:

$$\text{Emissions } (MMTCO_2E) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718474 \times (44/12)}{1{,}000{,}000}$$

Where:

Consumption (BBtu) = total heat content of the applicable fuel consumed
Emission Factor = established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%) = percentage completeness of the combustion of the fuel.
0.90718474 = constant used to convert from short tons to metric tons.
0.0005 = constant used to convert from pounds to short tons.

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[1] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

[2] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

1,000,000 = conversion factor converts metric tons to Million metric tons
44/12 = conversion factor converts from carbon to carbon dioxide

#### 3.3.1.3 Industrial Fossil Fuel Combustion

Emissions associated with the industrial fossil fuel combustion sector was estimated using default data used in SIT from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data (SED)*[1]; containing annual amount of coal, oil, natural gas and other fuel types in Billion Btu consumed by each sector.

The general equations used for converting industrial energy consumption to $MMTCO_2e$ are as follows:

$$\text{Net Consumption (BBtu)} = \textbf{[}\ \text{Total Consumption (BBtu)} - \text{Non-Energy Consumption (BBtu)}\ \textbf{]} \times \text{Storage Factor (\%)}$$

$$\text{Emissions } (MMTCO_2E) = \frac{\text{Net Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718474 \times (44/12)}{1{,}000{,}000}$$

Where:

Total Consumption (BBtu) = total heat content of the applicable fuel consumed
Non-Energy Consumption (BBtu) = Non-energy use of the fuel type
Storage Factor (%) = Non-energy use storage factor
Net Consumption (BBtu) = total heat content of the applicable fuel consumed
Emission Factor = established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%) = percentage completeness of the combustion of the fuel.
0.90718474 = constant used to convert from short tons to metric tons.
0.0005 = constant used to convert from pounds to short tons.
1,000,000 = conversion factor converts metric tons to Million metric tons
44/12 = conversion factor converts from carbon to carbon dioxide

Emission estimates from wood combustion include only $N_2O$ and $CH_4$. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with U.S. EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.

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[1] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

### 3.3.2 Additional Direct Emissions ($CH_4$ and $N_2O$)

**$CH_4$ and $N_2O$ Emissions from RCI**

Similar to $CO_2$ emission estimation, $CH_4$ and $N_2O$ emissions from the RCI sector were calculated by multiplying the State's energy consumption (in BBtu) by the default EPA –SIT emissions factors and the resulting emission in metric tons was then multiply by the global warming potential (GWP) of the respective pollutants. ($CH_4$ =21, $N_2O$ =310).

**Table 3-3: General $CH_4$/$N_2O$ Emissions Equation.**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fuel Type | Consumption (Billion Btu) | X | Emission Factor (metric tons $CH_4$ /BBtu) | = | $CH_4$ /$N_2O$ Emissions (metric tons) | x | GWP | = | Emissions ($MMTCO_2E$) |

## 3.4 GREENHOUSE GAS INVENTORY RESULTS

### 3.4.1 Residential Fossil Fuel Combustion Results

**Table 3-4: 2017 Residential Sector $CO_2$ Emissions by Fuel Type**

| Fuel Type | Consumption (Billion Btu) | Emission Factor (lbs C/Million Btu) | Combustion Efficiency (%) | Emissions (short tons carbon) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| Coal | 0 | 56.79 | 100.0% | 0.0 | 0.0000 |
| Distillate Fuel | 10,426 | 44.47 | 100.0% | 231,822.11 | 0.771337920 |
| Kerosene | 149 | 44.01 | 100.0% | 3,278.75 | 0.010909315 |
| LPG | 6,277 | 37.11 | 100.0% | 116,470.62 | 0.387530808 |
| Natural Gas | 79,376 | 31.90 | 100.0% | 1,266,047.20 | 4.212498170 |
| | | | | **Total** | **5.382276213** |

## Table 3-5: 2017 Residential Sector $CH_4$ Emissions by Fuel Type

| Fuel Type | Consumption (Billion Btu) | Emission Factor (metric tons $CH_4$ /BBtu) | Emissions (metric tons $CH_4$) | GWP | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| Coal | 0 | 0.30069 | 0.000 | 21 | 0.0000 |
| Distillate Fuel | 10,426 | 0.01002 | 104.50 | 21 | 0.0022 |
| Kerosene | 149 | 0.01002 | 1.49 | 21 | 0.0000 |
| LPG | 6,277 | 0.01002 | 62.92 | 21 | 0.0013 |
| Natural Gas | 79,376 | 0.00475 | 376.86 | 21 | 0.0079 |
| Wood | 4,790 | 0.28487 | 1,364.50 | 21 | 0.0287 |
| | | | | **Total** | **0.0401** |

## Table 3-6: 2017 Residential Sector $N_2O$ Emissions by Fuel Type

| Fuel Type | Consumption (Billion Btu) | Emission Factor (metric tons $N_2O$/BBtu) | Emissions (metric tons $N_2O$) | GWP | Emissions $MMTCO_2E$) |
|---|---|---|---|---|---|
| Coal | 0 | 0.00150 | 0.0000 | 310 | 0.0000 |
| Distillate Fuel | 10,426 | 0.00060 | 6.27 | 310 | 0.0019 |
| Kerosene | 149 | 0.00060 | 0.0896 | 310 | 0.0000 |
| LPG | 6,277 | 0.00060 | 3.7749 | 310 | 0.0012 |
| Natural Gas | 79,376 | 0.00009 | 7.5372 | 310 | 0.0023 |
| Wood | 4,790 | 0.00380 | 18.1934 | 310 | 0.0056 |
| | | | | **Total** | **0.0111** |

### 3.4.2 Commercial Fossil Fuel Combustion Results

**Table 3-7: 2017 Commercial Sector $CO_2$ Emissions by Fuel Type**

| Fuel Type | Consumption (Billion Btu) | Emission Factor (lbs C/Million Btu) | Combustion Efficiency (%) | Emissions (short tons carbon) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| Coal | 0 | 56.79 | 100.0% | 0.00 | 0.0000 |
| Distillate Fuel | 5,563 | 44.47 | 100.0% | 123,693.31 | 0.4116 |
| Kerosene | 47 | 44.01 | 100.0% | 1,034.24 | 0.0034 |
| LPG | 3,078 | 37.11 | 100.0% | 57,112.73 | 0.1900 |
| Motor Gasoline | 8,686 | 42.90 | 100.0% | 186,317.92 | 0.6199 |
| Residual Fuel | 33 | 45.11 | 100.0% | 744.32 | 0.0025 |
| Natural Gas | 75,700 | 31.90 | 100.0% | 1,207,415.00 | 4.0174 |
| | | | | **Total** | **5.2449** |

**Table 3-8: 2017 Commercial Sector $CH_4$ Emissions by Fuel Type**

| Fuel Type | Consumption (Billion Btu) | Emission Factor (metric tons $CH_4$ /BBtu) | Emissions (metric tons $CH_4$) | GWP | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| Coal | 0 | 0.01002 | 0.00 | 21 | 0.00000 |
| Distillate Fuel | 5,563 | 0.01002 | 55.76 | 21 | 0.0011709 |
| Kerosene | 47 | 0.01002 | 0.47 | 21 | 9.892E-06 |
| LPG | 3,078 | 0.01002 | 30.85 | 21 | 0.00647869 |
| Motor Gasoline | 8,686 | 0.01002 | 87.06 | 21 | 0.001828269 |
| Residual Fuel | 33 | 0.01002 | 0.33 | 21 | 6.9459E-06 |
| Natural Gas | 75,700 | 0.00475 | 359.40 | 21 | 0.0075475 |
| Wood | 1,301 | 0.28487 | 370.61 | 21 | 0.0077877 |
| | | | | **Total** | **0.01899** |

**Table 3-9: 2017 Commercial Sector $N_2O$ Emissions by Fuel Type**

| Fuel Type | Consumption (Billion Btu) | Emission Factor (metric tons $N_2O$/BBtu) | Emissions (metric tons $N_2O$) | GWP | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| Coal | 0 | 0.00150 | 0.00 | 310 | 0.0000 |
| Distillate Fuel | 5,563 | 0.00060 | 3.345 | 310 | 0.0010 |
| Kerosene | 47 | 0.00060 | 0.028 | 310 | 0.0000 |
| LPG | 3,078 | 0.00060 | 1.851 | 310 | 0.0006 |
| Motor Gasoline | 8,686 | 0.00060 | 5.224 | 310 | 0.0016 |
| Residual Fuel | 33 | 0.00060 | 0.020 | 310 | 0.0000 |
| Natural Gas | 75,700 | 0.00009 | 7.188 | 310 | 0.0022 |
| Wood | 1,301 | 0.00380 | 4.941 | 310 | 0.0015 |
| | | | | **Total** | **0.0070** |

### 3.4.3 Industrial Fossil Fuel Combustion Results

**Table 3-10: 2017 Industrial Sector $CO_2$ Emissions by Fuel Type**

| Fuel Type | **Total Consumption (Billion Btu)** | **Non-Energy Consumption (Billion Btu)** | **Storage Factor (%)** | **Net combustible Consumption (Billion Btu)** | **Emission Factor (lbs C/Million Btu)** | **Combustion Efficiency (%)** | **Emissions (short tons carbon)** | **Emissions ($MMTCO_2E$)** |
|---|---|---|---|---|---|---|---|---|
| Coking Coal | 0.0 | 0 | 10% | 0 | 56.20 | 100.0% | 0.00 | 0.00 |
| Other Coal | 12,275 | 201 | 0% | 12,275 | 56.85 | 100.0% | 348,933.61 | 1.1610 |
| Asphalt and Road Oil | 16,869 | 16,869 | 100% | 0 | 45.31 | 100.0% | 0.00 | 0.00 |
| Aviation Gasoline Blending Components | 0 | 0 | 0% | 0 | 41.57 | 100.0% | 0.00 | 0.00 |
| Crude Oil | 0 | 0 | 0% | 0 | 44.77 | 100.0% | 0.00 | 0.00 |
| Distillate Fuel | 5,309 | 32 | 50% | 5,293 | 44.47 | 100.0% | 117,691.51 | 0.3916 |
| Feedstocks, Naphtha less than 401 F | 0.0 | 0 | 62% | 0 | 40.86 | 100.0% | 0.00 | 0.00 |
| Feedstocks, Other Oils greater than 401 F | 0.0 | 0 | 62% | 0 | 44.43 | 100.0% | 0.00 | 0.00 |
| Kerosene | 7 | 7 | 0% | 7 | 43.97 | 100.0% | 153.90 | 0.0005 |
| LPG | 1,486 | 1,224 | 62% | 728 | 37.11 | 100.0% | 13,508.67 | 0.0449 |
| Lubricants | 946 | 946 | 9% | 859 | 44.53 | 100.0% | 18,687.33 | 0.0622 |
| Motor Gasoline | 2,865 | 2,865 | 0% | 2,865 | 42.90 | 100.0% | 61,455.31 | 0.2045 |
| Motor Gasoline Blending Components | 0 | 0 | 0% | 0 | 42.90 | 100.0% | 0.00 | 0.00 |
| Misc. Petro Products | 293 | 293 | 0% | 293 | 44.77 | 100.0% | 6,559.34 | 0.0218 |
| Petroleum Coke | 0 | 0 | 30% | 0 | 61.34 | 100.0% | 0.00 | 0.00 |
| Pentanes Plus | 0.0 | 0 | 62% | 0 | 42.06 | 100.0% | 0.00 | 0.00 |
| Residual Fuel | 91 | 91 | 50% | 46 | 45.15 | 100.0% | 1,027.16 | 0.0034 |
| Still Gas | 0 | 0 | 80% | 0 | 40.11 | 100.0% | 0.00 | 0.00 |
| Special Naphtha | 2,795 | 2,649 | 0% | 2,795 | 43.51 | 100.0% | 60,805.23 | 0.2023 |
| Unfinished Oils | 0 | 0 | 0% | 0 | 44.77 | 100.0% | 0.00 | 0.00 |
| Waxes | 100 | 100 | 58% | 42 | 43.64 | 100.0% | 916.44 | 0.0030 |
| Natural Gas | 16,489 | 512 | 62% | 16,172 | 31.90 | 100.0% | 257,945.39 | 0.8583 |
| | | | | | | **Total** | 887,683.90 | **2.9536** |

## Table 3-11: 2017 Industrial Sector $CH_4$ Emissions by Fuel Type

| Fuel Type | Total Consumption (Billion Btu) | Non-Energy Consumption (Billion Btu) | Emission Factor (metric tons $CH_4$ /BBtu) | Emissions (metric tons $CH_4$) | GWP | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|
| Coking Coal | 0.0 | 0.0 | 0.01002 | 0.0 | 21 | 0.0 |
| Other Coal | 12,275 | 201 | 0.01002 | 121.017 | 21 | 0.0025 |
| Asphalt and Road Oil | 16,869 | 16,869 | 0.00301 | 0.0 | 21 | 0.00 |
| Aviation Gasoline Blending Components | 0.0 | 0.0 | 0.00301 | 0.0 | 21 | 0.00 |
| Crude Oil | 0.0 | 0.0 | 0.00301 | 0.0 | 21 | 0.00 |
| Distillate Fuel | 5,309 | 32 | 0.00301 | 15.87 | 21 | 0.0003 |
| Feedstocks, Naphtha less than 401 F | 0.0 | 0.0 | 0.00301 | 0.00 | 21 | 0.00 |
| Feedstocks, Other Oils greater than 401 F | 0.0 | 0.0 | 0.00301 | 0.00 | 21 | 0.00 |
| Kerosene | 7 | 7 | 0.00301 | 0.00 | 21 | 0.00 |
| LPG | 1,486 | 1,224 | 0.00301 | 0.7874 | 21 | 0.0000 |
| Lubricants | 946 | 946 | 0.00301 | 0.0 | 21 | 0.00 |
| Motor Gasoline | 2,865 | 2,865 | 0.00301 | 0.0 | 21 | 0.0000 |
| Motor Gasoline Blending Components | 0.0 | 0 | 0.00301 | 0.0 | 21 | 0.00 |
| Misc. Petro Products | 293 | 293 | 0.00301 | 0.0 | 21 | 0.0000 |
| Petroleum Coke | 0.0 | 0 | 0.00301 | 0.0 | 21 | 0.00 |
| Pentanes Plus | 0.0 | 0 | 0.00301 | 0.0 | 21 | 0.00 |
| Residual Fuel | 91 | 91 | 0.00301 | 0.0 | 21 | 0.0000 |
| Still Gas | 0 | 0 | 0.00301 | 0.0 | 21 | 0.00 |
| Special Naphthas | 2,795 | 2,649 | 0.00301 | 0.4397 | 21 | 0.000 |
| Unfinished Oils | 0.0 | 0 | 0.00301 | 0.0 | 21 | 0.00 |
| Waxes | 100 | 100 | 0.00301 | 0.00 | 21 | 0.0000 |
| Natural Gas | 16,489 | 512 | 0.00095 | 15.17 | 21 | 0.0003 |
| Wood | 6,971 | NA | 0.02849 | 198.58 | 21 | 0.0042 |
| | | | | | **Total** | **0.0074** |

## Table 3-12: 2017 Industrial Sector $N_2O$ Emissions by Fuel Type

| Fuel Type | Total Consumption (Billion Btu) | Non-Energy Consumption (Billion Btu) | Emission Factor (metric tons $N_2O$/BBtu) | Emissions (metric tons $N_2O$) | GWP | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|
| Coking Coal | 0.0 | 0.0 | 0.00150 | 0.00 | 310 | 0.00 |
| Other Coal | 12,275 | 201 | 0.00150 | 18.15 | 310 | 0.0056 |
| Asphalt and Road Oil | 16,869 | 16,869 | 0.00060 | 0.00 | 310 | 0.00 |
| Aviation Gasoline Blending Components | 0.0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Crude Oil | 0.0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Distillate Fuel | 5,309 | 32 | 0.00060 | 3.17 | 310 | 0.0010 |
| Feedstocks, Naphtha less than 401 F | 0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Feedstocks, Other Oils greater than 401 F | 0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Kerosene | 7 | 7 | 0.00060 | 0.00 | 310 | 0.000 |
| LPG | 1,486 | 1,224 | 0.00060 | 0.16 | 310 | 0.000 |
| Lubricants | 946 | 946 | 0.00060 | 0.00 | 310 | 0.00 |
| Motor Gasoline | 2,865 | 2,865 | 0.00060 | 0.00 | 310 | 0.000 |
| Motor Gasoline Blending Components | 0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Misc. Petro Products | 293 | 293 | 0.00060 | 0.00 | 310 | 0.0000 |
| Petroleum Coke | 0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Pentanes Plus | 0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Residual Fuel | 91 | 91 | 0.00060 | 0.00 | 310 | 0.00 |
| Still Gas | 0 | 0 | 0.00060 | 0.00 | 310 | 0.00 |
| Special Naphthas | 2,795 | 2,649 | 0.00060 | 0.09 | 310 | 0.000 |
| Unfinished Oils | 0 | 0 | 0.00060 | 0.00 | 310 | 0.00- |
| Waxes | 100 | 100 | 0.00060 | 0.00 | 310 | 0.000 |
| Natural Gas | 16,489 | 512 | 0.00009 | 1.52 | 310 | 0.0005 |
| Wood | 6,971 | NA | 0.00380 | 26.48 | 310 | 0.0082 |
| | | | | | **Total** | **0.0154** |

# 4.0 Transportation On-Road Mobile Energy Use

## 4.1 OVERVIEW

The purpose of this section is to explain how Maryland estimates emissions from highway vehicles for inclusion in its emission inventories and State Implementation Plans (SIP).

In accordance with the standard methodology for the development of highway vehicle emissions inventories, all of the emissions estimates documented herein are based on emission factors developed using the United States Environmental Protection Agency's (U.S. EPA's) latest version of the MOVES emissions factor model and appropriate activity levels i.e., vehicle miles traveled (VMT) estimates developed from the vehicle count data maintained by the State Highway Administration (SHA) of the Maryland Department of Transportation (MDOT).

The official highway vehicle inventory for the Maryland portion of the Washington, D.C. Ozone Non-attainment Area (comprising the counties of Calvert, Charles, Frederick, Montgomery, and Prince George's) has been developed by the Metropolitan Washington Council of Governments (MWCOG) and has been documented by that Organization under separate cover.

### 4.1.1 Highway Vehicle Emissions Inventory

The operation of highway vehicles has proven to be a significant contributor to air pollution, particularly to ground-level ozone, as they emit both Volatile Organic Compounds (VOCs), and Oxides of Nitrogen (NOx) during operation. Ground-level ozone is not created directly rather, it is formed through a chemical reaction between VOCs and NOx in the presence of sunlight. Highway vehicles also emit other pollutants such as Carbon Monoxide (CO), Particulate Matter smaller than 2.5 microns (PM2.5), Particulate Matter smaller than 10 microns (PM10), Sulfur Dioxide ($SO_2$), and Ammonia ($NH_3$) in addition to the greenhouse gases such as Carbon Dioxide, Methane, and Nitrous Oxide.

This inventory includes all the pollutants mentioned above, in summer daily and yearly time periods, appropriately.

Estimating the emission rate and activity levels of all vehicles on the road during a typical day is a complicated endeavor. If every vehicle emitted the same amount of pollution all the time, one could simply multiply those emission standards (emission rate in grams of pollution per mile) times the number of miles driven (activity level) to estimate total emissions. The fact is that emission rates from all vehicles vary over the entire range of conditions under which they operate. These variables include ambient air temperature, speed, traffic conditions, road types, road topography, operating mode (whether started cold or started hot, whether accelerating or decelerating) and fuel. The inventory must also account for non-exhaust or evaporative emissions. In addition, the fleet is composed of several generations, types of vehicles and their emission control technologies, each of which performs differently. This requires that the composition of the fleet (vehicle ages and types) must also be included in the estimation algorithm.

In order to estimate both the rate at which emissions are being generated and to calculate vehicle miles traveled (VMT), Maryland examines its road network and fleet to estimate vehicle activity. For ozone-related inventories, this is done for a typical summer weekday in 2017. For the annual inventories, this is done for each of the twelve months in 2017 and aggregated for the entire year. The entire process is extremely complex and involves large amounts of various data sets.

Computer models have been developed to perform these calculations by simulating the travel of vehicles on the State's roadway system. These models then generate emission rates (or emission factors) for different vehicle types for area-specific conditions and then combine them in summary form. The "area-specific conditions" include fleet characteristics such as vehicle population and vehicle age distribution, roadway and travel characteristics, meteorology, control programs in place, mandated fuel requirements, etc.

### 4.1.2 Periodic Inventory Methodology:

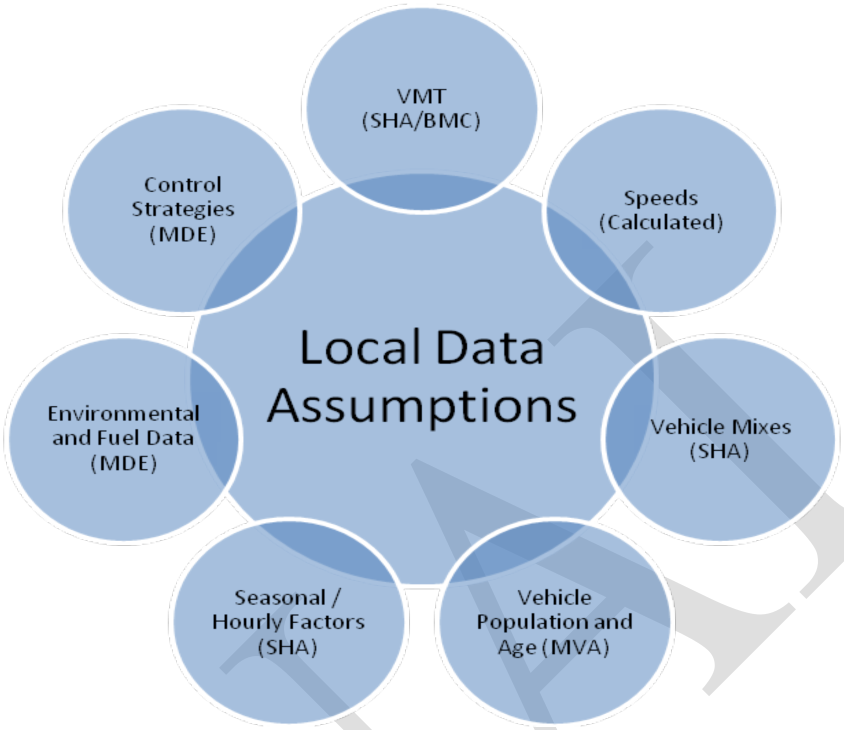
Guidance documents from EPA were used to develop the highway emissions inventory. They include:

*Policy Guidance on the Use of MOVES2014 and Subsequent Minor Revisions for SIP Development, Transportation Conformity, and Other Purposes*, US EPA Office of Air and Radiation, EPA-420-B-12-010, April 2012.

*Using MOVES to prepare Emission Inventories in State Implementation Plans and Transportation Conformity: Technical Guidance for MOVES2014b and MOVES2014b.* US EPA Office of Air and Radiation, and Office of Transportation and Air Quality, EPA-420-B-12-028, April 2012.
*Motor Vehicle Emission Simulator, User Guide for MOVES2014a*, EPA-420-B-10-036, August 2014 and *User Guide for MOVES2014b*, EPA-420-B-12-001b June 2012

The methodologies used to produce the emission data conform to the recommendations provided in EPA's technical guidance. A mix of local data and national default (internal to MOVES2014a) data has been used for this submission. As illustrated in Figure 4.1, local data has been used for the primary data items that have a significant impact on emissions. Local data inputs to the analysis process reflect the latest available planning assumptions using data obtained from the Maryland Department of Environment (MDE), Motor Vehicle Administration (MVA), Maryland State Highway Administration (SHA), Baltimore Metropolitan Council (BMC), Metropolitan Washington Council of Governments (MWCOG) and other local/national sources.

**FIGURE 4-1: LOCAL DATA INPUTS USED FOR EMISSIONS INVENTORY**



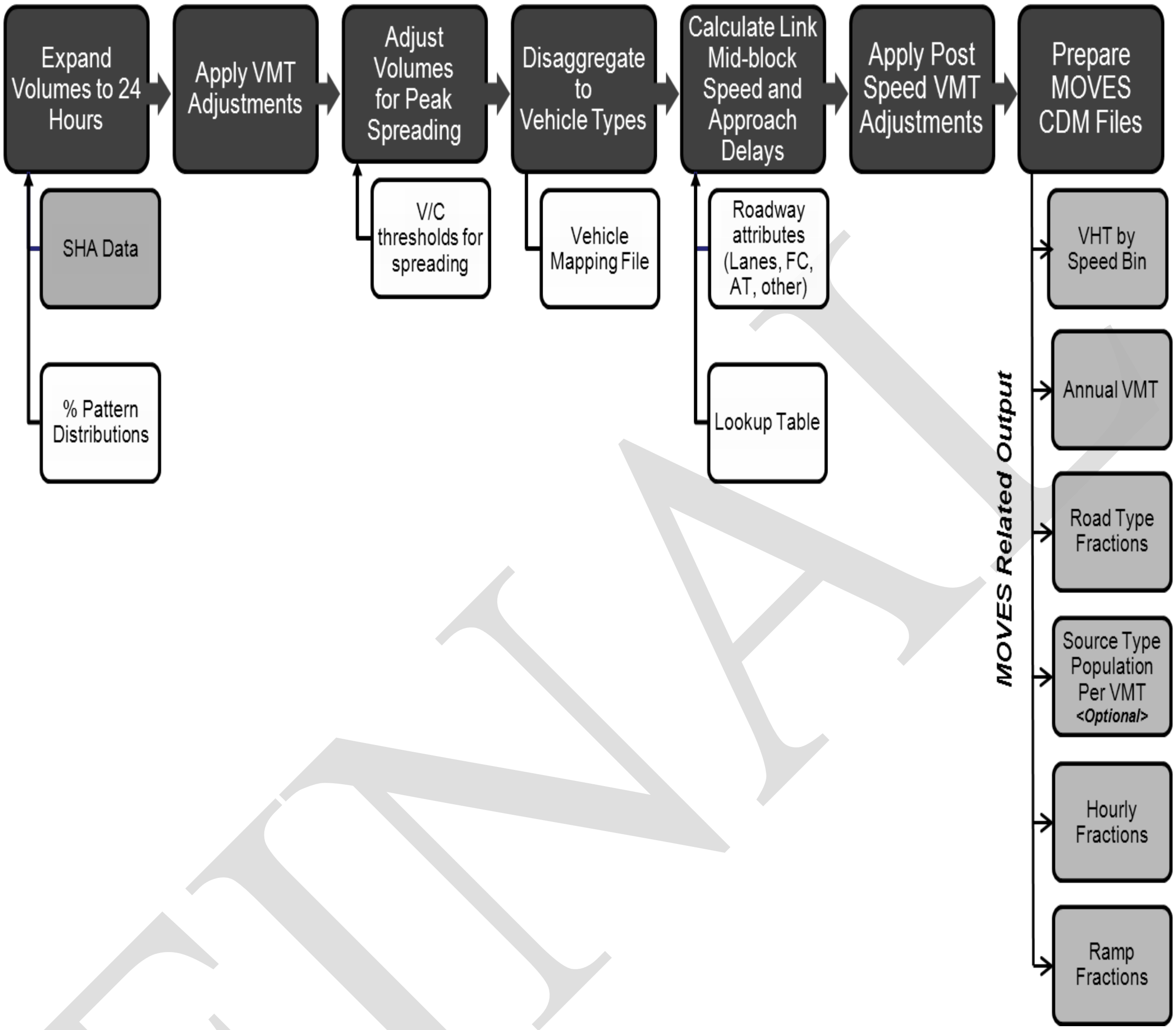
The analysis methodology is consistent with past statewide inventory efforts including the 2017 National Emissions Inventory (NEI) submission. This includes the use of statewide traffic roadway data and custom post-processing software (PPSUITE) to calculate hourly speeds and prepare key traffic input files to the MOVES2014a emission model. PPSUITE consists of a set of programs that perform the following functions:

- Analyzes highway operating conditions.
- Calculates highway speeds.
- Compiles vehicle miles of travel (VMT) and vehicle type mix data.
- Prepares MOVES runs and processes MOVES outputs.

PPSUITE is a widely used and accepted tool for estimating speeds and processing emissions rates. It is has been used for past SIP highway inventories in Maryland, Pennsylvania, and New Jersey. The software is based upon accepted transportation engineering methodologies. For example, PPSUITE utilizes speed and delay estimation procedures based on planning methods provided in the Highway Capacity Manual, a report prepared by the Transportation Research Board (TRB) summarizing current knowledge and analysis techniques for capacity and level-of-service analyses of the transportation system.

The PPSUITE process is integral to producing key input files to the MOVES emission model. Figure4.2 summarizes the key functions of PPSUITE and the traffic-related input files prepared for MOVES.

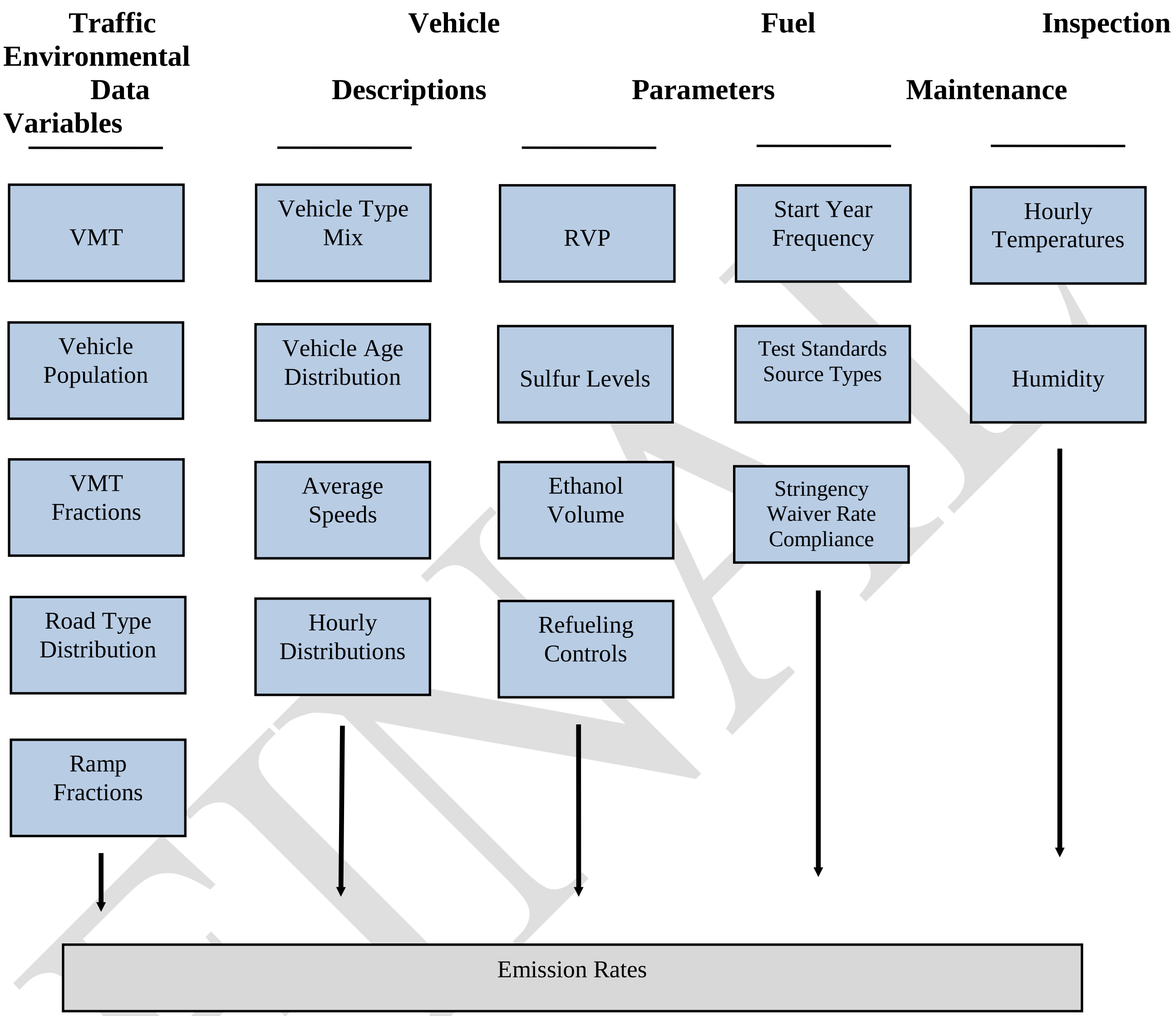
FIGURE 4-2: EMISSION CALCULATION PROCESS



## 4.2 DATA SOURCES

A large number of inputs to MOVES are needed to fully account for the numerous vehicle and environmental parameters that affect emissions levels. These include traffic flow characteristics, vehicle descriptions, fuel parameters, inspection/maintenance program parameters, and environmental variables as shown in Figure 4.3.

**FIGURE 4-3: EXAMPLES OF KEY MOVES INPUT DATA**



MOVES includes a default national database of meteorology, vehicle fleet, vehicle activity, fuel, and emission control program data for every county; but EPA cannot certify that the default data is the most current or best available information for any specific area. As a result, local data is recommended for use for analyses SIPs.

A mix of local and default data is used for this inventory. Local data sources are used for all inputs that have a significant impact on calculated emission rates. These data items are discussed in the following sections.

**Roadway Data:**
The roadway data input to emissions calculations for this inventory is based on information from the "universal" highway database maintained by the Maryland SHA. SHA obtains this information from periodic visual and electronic traffic counts. The SHA data is dynamic, since it is continually reviewed and updated from new traffic counts. Information on roadways included in the National Highway System is reviewed at least annually, while information on other roadways is reviewed at least biennially.

On a triennial basis, a current "snapshot" of the SHA database is taken and downloaded to provide an up-to-date record of the state's highway system for estimating emissions. This emissions inventory is based on 2017 data which is the most current "snapshot" of the SHA data. The following information is extracted from the database for emission calculations:

- Lanes and distances
- volumes representing Average Annual Daily Traffic (AADT)
- truck percentages and urban/rural classifications
- functional class codes

The volumes and distances are used in calculating highway VMT totals for each county. As discussed in the next section, adjustments are needed to convert the volumes to an average summer weekday . The lane values, area type, and functional class are important inputs for determining the congestion and speeds for individual highway segments. Truck percentages are used in the speed determination process and are used to split volumes to individual vehicle types used by the MOVES software.

Maryland classifies its road segments by function, as well as whether it is located in an urban or rural area, as indicated below in Figure 4.4. The urban/rural (UR) and functional classes (FC) are important indicators of the type and function of each roadway segment. These values are also used to determine the MOVES Road Type classification that has an important impact on the emission factors for each roadway segment. Equivalencies between the SHA and MOVES indices are discussed in later sections.

**FIGURE 4-4: MDOT URBAN/RURAL AND FUNCTIONAL CLASS CODES**

| | | |
|---|---|---|
| Urban/Rural Code | 1=Rural | |
| | 2=Small Urban | |
| | 3=Urban | |
| Functional Class | Rural Functional Classes Used For Rural Areas | Urban Functional Classes Used For Urban Areas |
| | ------------------------------------ | ------------------------------------------ |
| | 1=Rural Freeway | 11=Urban Freeway |
| | 2=Rural Other Principal Arterial | 12=Urban Expressway |
| | 6=Rural Minor Arterial | 14=Urban Principal Arterial |
| | 7=Rural Major Collector | 16=Urban Minor Arterial |
| | 8=Rural Minor Collector | 17=Urban Collector |
| | 9=Rural Local | 19=Urban Local |

The PPSUITE processing software allows for many additional variables other than those available in the SHA database. Using these variables improves the calculation of congested speeds. Such variables include information regarding free-flow speeds and capacities and other physical roadway features (e.g. traffic signals) that can affect a roadway's calculated congested speed. This data can be determined from lookup tables based on a roadway segment's urban/rural code and functional class. Much of the lookup table data was developed from information contained in the Highway Capacity Manual.

### 4.2.1 Other Supporting Traffic Data:

Other traffic data is used to adjust and disaggregate traffic volumes. Key sources used in these processes include the following:

*HPMS VMT*: According to EPA guidance, baseline inventory VMT computed from the SHA highway segment volumes must be adjusted to be consistent with HPMS VMT totals. Although it has some limitations, the HPMS system is currently in use in all 50 states and is being improved under FHWA direction. Adjustment factors are calculated which adjust the base year 2017 SHA download VMT to be consistent with the reported 2017 HPMS totals for that year. These factors are applied to all county, urban/rural code, and facility group combinations within the region. These adjustments are important for accounting for missing local roadway VMT that is not contained within or represented by the state-owned roadway system.

*Seasonal Factors*: The SHA contains AADT volumes that are an average of all days in the year, including weekends and holidays. An ozone emission analysis, however, is based on a typical July or summer weekday. Therefore, the SHA volumes must be seasonally adjusted. The seasonal factors were developed based on the 2017 report *ATR Station Reports in the Traffic Trends System Report Module* from the SHA website. These factors are applied to the existing SHA AADT to produce July weekday volumes. The same factors are also used to develop the MOVES daily and monthly VMT fraction files.

*Hourly Patterns*: Speeds and emissions vary considerably depending on the time of day. Therefore, it is important to estimate the pattern by which roadway volume varies by hour of the day. Pattern data is in the form of a percentage of the daily volumes for each hour. Distributions are provided for all the counties within the region and by each facility type grouping. This data was developed from 2017 24-hour count data obtained from the SHA website. The same factors are also used to develop the MOVES hourly fraction file.

### 4.2.2 Vehicle Class Data:

Emission rates within MOVES vary significantly by the type of vehicle. The MOVES model produces emissions and rates by thirteen MOVES vehicle source types. However, VMT is input to MOVES by six HPMS vehicle groups. Figure 4.5 summarizes the distinction between each classification scheme.

Figure 4-5: MOVES Source Types and HPMS Vehicle Groups

| SOURCE TYPES | |
|---|---|
| 11 | Motorcycle |
| 21 | Passenger Car |
| 31 | Passenger Truck |
| 32 | Light Commercial Truck |
| 41 | Intercity Bus |
| 42 | Transit Bus |
| 43 | School bus |
| 51 | Refuse Truck |
| 52 | Single Unit Short-haul Truck |
| 53 | Single Unit Long-haul Truck |
| 54 | Motor Home |
| 61 | Combination Short-haul Truck |
| 62 | Combination Long-haul Truck |

| HPMS Class Groups | |
|---|---|
| 10 | Motorcycle |
| 20 | Passenger Car |
| 30 | Passenger/Light Truck |
| 40 | Buses |
| 50 | Single Unit Trucks |
| 60 | Combination Trucks |

For this regional inventory, vehicle type pattern data was developed for each county and functional class combination based on SHA classification counts and internal MOBILE6.2 and MOVES defaults. As the first step, SHA count data was used to develop percentage splits to the following four vehicle groups:

- Autos
- Heavy trucks
- Motorcycles
- Buses

Following procedures used for previous SIP efforts, the vehicle groups were expanded to the 28 MOBILE6.2 weight-based vehicle types. Using procedures provided in EPA technical guidance, the MOBILE6.2 vehicle classes were mapped to the MOVES source type and HPMS class groups.

The vehicle type percentages are also provided to the capacity analysis section of PPSUITE to adjust the speeds in response to trucks. That is, a given number of larger trucks take up more roadway space than a given number of cars, and this is accounted for in the speed estimation process by adjusting capacity using information from the Highway Capacity Manual.

### 4.2.3 Vehicle Ages:

Vehicle age distributions are input to MOVES for each county by the thirteen source types. The distributions reflect the percentage of vehicles in the fleet up to 31 years old. The vehicle age distributions were prepared by MDE based on information obtained from MVA registration data.

The vehicle age distributions are based on 2017 MVA registration data that included cleaning of duplicate, expired, and non-eligible vehicles such as trailers and the farm tractors accounted for in the Area Source category of emissions. The data was transformed into two sets of MOBILE6 vehicle types; one conforming to MOBILE6-28 vehicle type and the other to MOBILE6-16 composite vehicle type system using a SAS-based computer program.

The MOVES model input age distributions were produced utilizing the available EPA MS-Excel-based vehicle registration converter tool. This tool assisted in converting the MOBILE6.2-based data into the MOVES source type categories.

### 4.2.4 Vehicle Population Data:

The information on the vehicle fleet including the number and age of vehicles impacts forecasted start and evaporative emissions within MOVES. MOVES model requires the population of vehicles by the thirteen source type categories. This data was prepared in-house by MDE for the analysis year 2017 utilizing another SAS-based computer program similar to the one discussed in the previous vehicle age section. Maryland county vehicle registration data was used to estimate vehicle population for light-duty and medium duty vehicles for all counties in the region. MOVES default values were adopted for the heavy duty MOVES vehicle types 52, 53, 61 and 62.

### 4.2.5 Environmental and Fuel Data:

Information on environmental, fuel, vehicle technology and other control strategy assumptions were determined based on a review of MOVES2014a default information by MDE.

Evaporative emissions are influenced significantly by the temperatures of the surrounding air. Ozone analysis temperature and humidity values were determined by MDE as follows using the procedures documented in EPA's technical guidance.

**Meteorological Data*:*** Along the lines of MD fuel data, 2017 meteorological data for hourly average MOVES inputs of temperature and relative humidity was also compiled on a triennial basis for every county in MD. The month by month raw hourly-data sets came from the National Climate Data Center of NOAA based on weather data collected at the airport situated closest to the county modeled. Hourly average temperature and humidity computations were developed from the 24 hourly values for every hour in a given month. For the Baltimore Area, since the data source is one for the entire area (BWI Airport situated in Anne Arundel County of MD), the same set of data was used for all the constituent city/counties of the Baltimore Area.

**Fuel Data:** MDE obtains monthly fuel data reports regularly from the MD Fuel Laboratory which is under the jurisdiction of MD Fuel Tax Division of the Office of the Comptroller of MD. These fuel reports are generated by testing samples collected in the field (gas stations) for the purpose of fuel regulation enforcement. It covers all counties in MD. Since the data entry of these samples is a huge task, compilation of fuel data to yield input parameters for MOBILE or MOVES modeling is confined only to the years for which emission inventories are due for submission to EPA on a triennial basis beginning with the baseline year of 1990. 2017 happens to be a year of such periodic emission inventories. As such 2017 fuel data was compiled and fuel data parameters were developed separately for the 14 MD counties with EPA mandates to dispense only reformulated gasoline requirements and the 10 remaining counties dispensing conventional gasoline.

Two sets of fuel data inputs (Fuel Formulation and Fuel Supply tables) required by MOVES model were developed in-house for every county in MD. The fuel parameters changed from the MOVES defaults are as follows:

| | |
|---|---|
| fuelFormulationID | Unique ID used for easy recognition |
| fuelSubtypeID | Selected per guidance based on ethanol content of gasoline |
| sulfurLevel | Computed from the local fuel data |
| ETOHVolume | Computed from the local fuel data |
| aromaticContent | Computed from the local fuel data |
| olefinContent | Computed from the local fuel data |
| benzineContent | Computed from the local fuel data |
| E200 | Computed from the local fuel data |
| E300 | Computed from the local fuel data |

### 4.2.6 Other Vehicle Technology and Control Strategy Data:

The MOVES2014a default I/M data was reviewed and updated by MDE for all the counties in the region. The current I/M program known as Vehicle Emission Inspection Program (VEIP) assumed for the analysis year 2017 is described below.

**MD Vehicle Emission Inspection Program:** This program tests model year 1977 and newer gasoline powered vehicles weighing up to 26,000 lb. The test is done biennially, and on change of ownership. There is a two year grace period for new vehicles. Light duty vehicles model year 1996 and newer, and model year 2014 and newer vehicles weighing up to 14,000 lb get the OBD test. All other vehicles get an idle test with a gas cap pressure test and a visual check for the presence of a catalytic converter. The compliance factors reflect the observed fail and waiver rates observed in the program, combined with an assumed 96% compliance rate for vehicles showing up for testing. Heavy duty vehicles have an additional factor, reflecting the fraction of vehicles in the weight range covered by the program. This was derived from documentation comparing the MOVES and MOBILE vehicle classes. The significantly higher compliance rate for the gas cap check reflects the much higher retest pass rate for this check.

**Federal Programs:** Current federal vehicle emissions control and fuel programs are incorporated into the MOVES2014a software. These include the National Program standards covering model year vehicles through 2016. Modifications of default emission rates are required to reflect the early implementation of the National Low Emission Vehicle Program (NLEV) program in Maryland. To reflect these impacts, EPA has released instructions and input files that can be used to model these impacts. This inventory utilized the August 2014 version of the files (http://www.epa.gov/oms/models/moves/tools.htm).

### 4.2.7 State Vehicle Technology Programs:

*MD Clean Car Program:* Under the Maryland Clean Cars Act of 2007 Maryland adopted the California Low Emission Vehicle (LEV II) program. This program began implementation in 2014. This program requires all 2014 model year and newer vehicles (GVWR up to 14,000 lbs.) registered in Maryland to meet California emission standards for both criteria and greenhouse gas pollutants. This program also contains a zero emission vehicles component that requires the manufactures to produce a certain percentage of zero emission vehicles (electric, fuel cell, etc.) for purchase in the state. California has just adopted new amendments to the Low-Emission Vehicle regulation entitled LEV III (third generation low emission vehicle standards). These amendments create more stringent emission standards for new motor vehicles. These new standards will be phased-in over the 2015-2025 model years.

The impacts of this program were modeled for all analysis years using EPA's guidance document, *Instructions for Using LEV and NLEV Inputs for MOVES, EPA-420-B-10-003, January 2010*. EPA provided input files to reflect the CAL LEVII program with the standard phase-in schedules for new emission standards. Modifications to those schedules were done as per EPA's instructions, to reflect a later start for the State of Maryland beginning with vehicle model year 2014.

## 4.3 ANALYSIS METHODOLOGY

The previous sections have summarized the input data used for computing speeds and emission rates for this highway emissions inventory. This section explains how PPSUITE and MOVES uses that input data to produce emission estimates. Figure 4.6 provides a more detailed overview of the PPSUITE analysis procedure using the available traffic data information described in the previous section.

### 4.3.1 VMT Preparation

Producing an emissions inventory with PPSUITE requires a complex process of disaggregation and aggregation of vehicle activities. Data is available and used on a very small scale -- individual ½ mile roadway segments for each of the 24 hours of the day. This data needs to be processed individually to determine the distribution of vehicle hours of travel (VHT) by speed and then aggregated by vehicle class to determine the input VMT to the MOVES emission model. As an example key steps in the preparation of VMT for a summer daily run include:

- *Apply Seasonal Adjustments* - PPSUITE takes the input daily volumes from SHA (which represents AADT traffic) and seasonally adjusts the volumes to an average weekday in July. This adjustment utilizes factors developed for each functional class and urban/rural code. VMT can then be calculated for each link using the adjusted weekday volumes.

- *Disaggregate to Hours* - After seasonally adjusting the link volume, the volume is split to each hour of the day. This allows for more accurate speed calculations (effects of congested hours) and allows PPSUITE to prepare the hourly VMT and speeds for input to the MOVES model.

- *Peak Spreading* - After dividing the daily volumes to each hour of the day, PPSUITE identifies hours that are unreasonably congested. For those hours, PPSUITE then spreads a portion of the volume to other hours within the same peak period, thereby approximating the "peak spreading" that normally occurs in such over-capacity conditions.

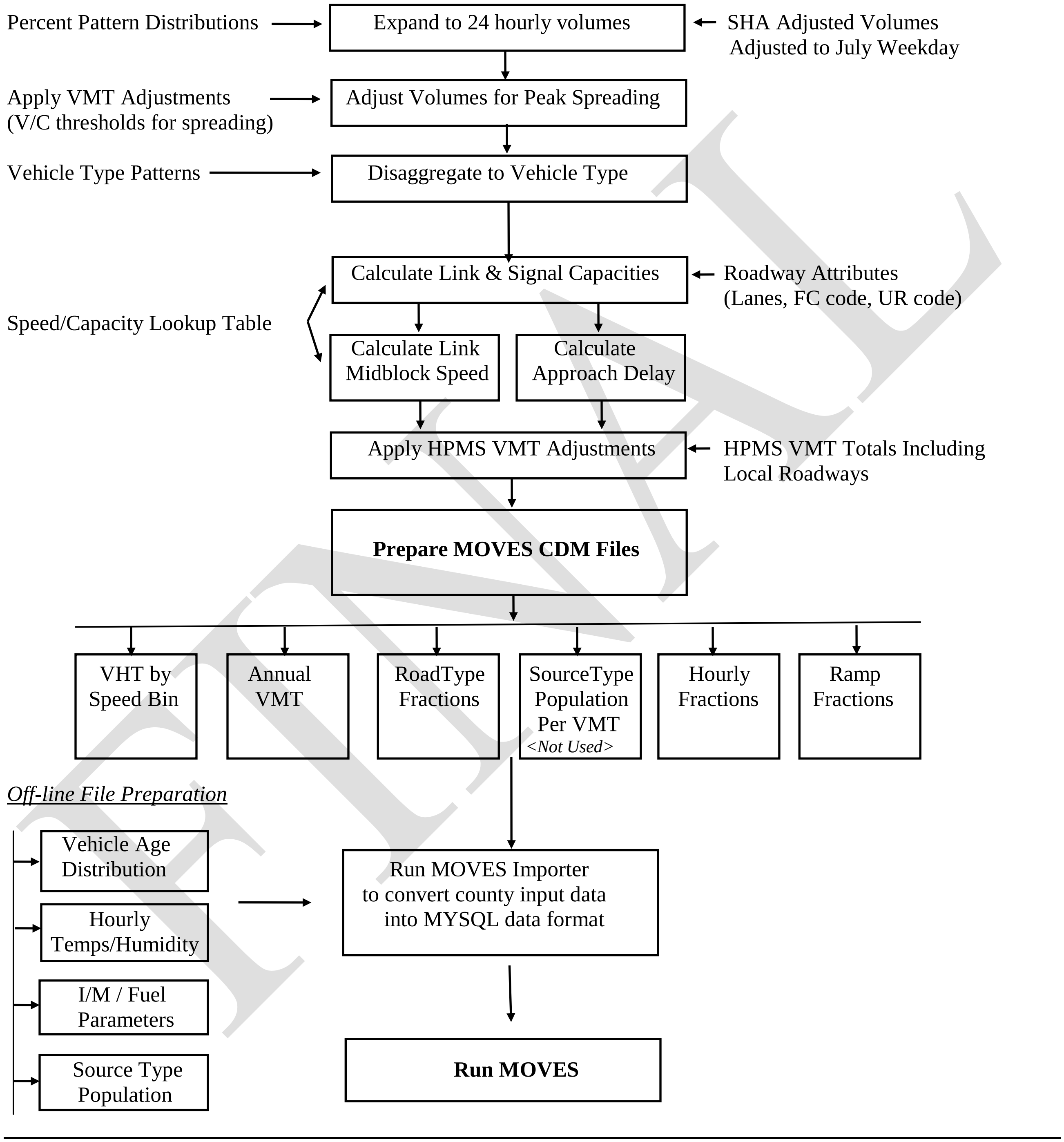
- *Disaggregation to Vehicle Types* - EPA requires VMT estimates to be prepared by source type, reflecting specific local characteristics. As a result, for Maryland's emission inventory runs, the hourly volumes are disaggregated to the six HPMS MOVES vehicle grouping based on count data assembled by SHA in combination with MOVES defaults as described in the previous section.

- *Apply HPMS VMT Adjustments* - Volumes must also be adjusted to account for differences with the HPMS VMT totals, as described previously. VMT adjustment factors are provided as input to PPSUITE, and are applied to each of the roadway segment volumes. These factors were developed from the latest HPMS download (conducted triennially); however, they are also applied to any future year runs. The VMT added or subtracted to the SHA database assumes the speeds calculated using the original volumes for each roadway segment for each hour of the day.

# FIGURE 4-6: PPSUITE SPEED/EMISSION ESTIMATION PROCEDURE

***PPSUITE Analysis Process***

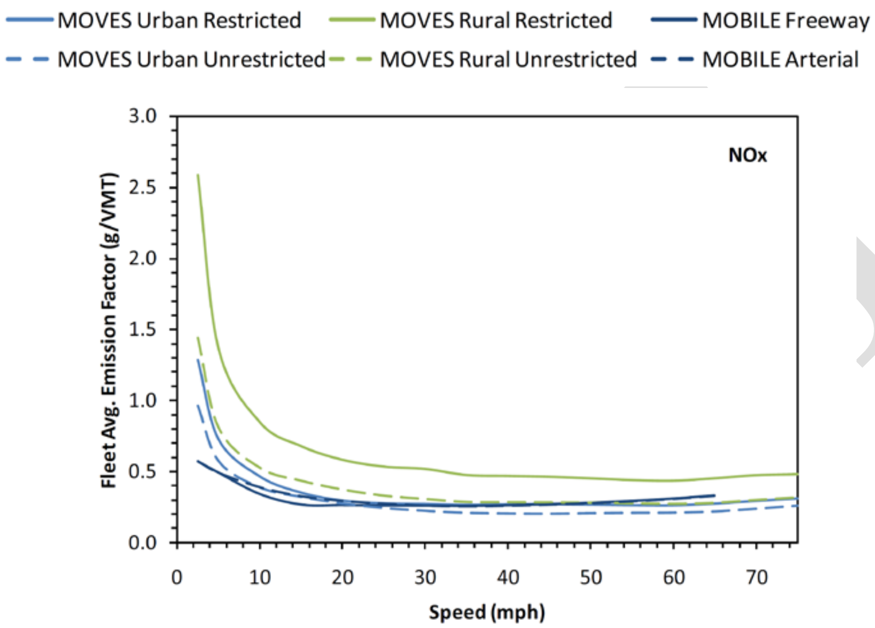
***(The Following steps are Performed For Each SHA Roadway Segment)***



## Speed Estimation:

Emissions for many pollutants (including both VOC and NOx) vary significantly with travel speed. While VOCs generally decrease as speed increases, NOx decreases at the low speed range and increases at higher speeds, as illustrated in Figure 4.7.

**FIGURE 4-7: EMISSION FACTOR VS. SPEED VARIANCES (NOX)**



*Source: Figure 3 from Implications of the MOVES2010 Model on Mobile Source Emission Estimates, Air & Waste Management Association, July 2010.*

EPA recognizes that the estimation of vehicle speeds is a difficult and complex process. Because emissions are so sensitive to speeds, it recommends special attention be given to developing reasonable and consistent speed estimates; it also recommends that VMT be disaggregated into subsets that have roughly equal speed, with separate emission factors for each subset. At a minimum, speeds should be estimated separately by road type.

The computational framework used for this analysis meets and exceeds that recommendation. Speeds are individually calculated for each roadway segment and hour and include the estimated delays encountered at signals. Rather than accumulating the roadway segments into a particular road type and calculating an average speed, each individual link hourly speed is represented in the MOVES vehicle hours of travel (VHT) by speed bin file. This MOVES input file allows the specification of a distribution of hourly speeds. For example, if 5% of a county's arterial VHT operates at 5 mph during the AM peak hour and the remaining 95% operates at 65 mph, this can be represented in the MOVES speed input file. For the highway emissions inventory, distributions of speeds are input to MOVES by road type and source type by each hour of the day.

To calculate speeds, PPSUITE first obtains initial capacities (how much volume the roadway can serve before heavy congestion) and free-flow speeds (speeds assuming no congestion) from the speed/capacity lookup data. As described in previous sections, this data contains default roadway information indexed by the urban/rural code and functional class. For areas with known characteristics, values can be directly coded to the SHA database and the speed/capacity data can be overridden. However, for most areas where known information is not available, the speed/capacity lookups provide valuable default information regarding speeds, capacities, signal characteristics, and other capacity adjustment information used for calculating congested delays and speeds. The result of this process is an estimated average travel time for each hour of the day for each highway segment. The average time multiplied by the volume produces vehicle hours of travel (VHT).

### 4.3.2 Developing the MOVES Traffic Input Files:

The PPSUITE software is responsible for producing the following MOVES input files during any analysis run:

- VMT by HPMS vehicle class
- VHT by speed bin
- Road type distributions
- Ramp fractions

These files are text formatted files with a *.csv extension. The files are provided as inputs within the MOVES county data importer.

*VMT Input File:* VMT is the primary traffic input that affects emission results. The roadway segment distances and traffic volumes are used to prepare estimates of VMT. PPSUITE performs these calculations and outputs the MOVES annual VMT input file to the County Data Manager (CDM).

*VHT by Speed Bin File*: As described in the previous section, the PPSUITE software prepares the MOVES VHT by speed bin file which summarizes the distribution of speeds across all links into each of 16 MOVES speed bins for each hour of the day by road type. This robust process ensures that MOVES emission rates are used to the fullest extent and is consistent with the methods and recommendations provided in EPA’s technical guidance.

*Road Type Distributions*: In MOVES, typical drive cycles and associated operating conditions vary by the type of roadway. MOVES define five different road types as follows:

| | |
|---|---|
| 1 | Off-Network |
| 2 | Rural Restricted Access |
| 3 | Rural Unrestricted Access |
| 4 | Urban Restricted Access |
| 5 | Urban Unrestricted Access |

For this inventory, the MOVES road type distribution file is automatically generated by PPSUITE using defined equivalencies. The off-network road type includes emissions from vehicle starts, extended idle activity, and evaporative emissions. Off-network activity in MOVES is primarily determined by the Source Type Population input. The remaining distribution among road types is determined by equating the functional class with each MOVES road type as follows:

- MOVES Road Type (2) = SHA Functional Class (1)
- MOVES Road Type (3) = SHA Functional Class (2,6,7,8,9)
- MOVES Road Type (4) = SHA Functional Class (11,12)
- MOVES Road Type (5) = SHA Functional Class (14,16,17,19)

*Ramp Fractions*: Since ramps are not directly represented within the SHA database information, it is assumed that 8% of the Freeway VHT is ramp VHT. This is consistent with national default values within MOVES and recommendations provided in EPA's technical guidance.

### 4.3.3 MOVES Runs:

After computing speeds and aggregating VMT and VHT, PPSUITE prepares traffic-related inputs needed to run EPA's MOVES2014a software. Additional required MOVES inputs are prepared external to the processing software and include temperatures, I/M program parameters, fuel characteristics, vehicle fleet age distributions and source type population.

The MOVES county importer is run in batch mode. This program converts all data files into the MYSQL formats used by the MOVES model. At that point a MOVES run specification file (*.mrs) is created which specifies options and key data locations for the run. MOVES is then executed in batch mode.

MOVES can be executed using either the *inventory* or *rate-based* approaches. For this highway emissions inventory, MOVES is applied using the *inventory-based* approach. Under this method, actual VMT and population are provided as inputs to the model; MOVES is responsible for producing the total emissions for the region. Under the rate-based approach, MOVES would produce emission factors, after which PPSUITE would apply the emission factors to the link data and calculate total regional emissions.

## 4.4 GREENHOUSE GAS INVENTORY RESULTS

The 2017 emission results for the Maryland statewide GHG inventory are provided in Table 4.1.

### 4.4.1 Emission Estimates

**Table 4-1: 2017 Annual Highway Vehicle Emissions Inventories for Greenhouse Gases (Metric tons per year)**

| 2017 PEI GHG Annual Estimates for MD using MOVES2014a Model | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | $CO_2$ E in grams per year | | | | | $CO_2$ E in MMTons |
| County | Gasoline | Diesel | CNG | Ethanol (E85) | All Fuels | 2017 PEI |
| Allegany | 3.08001E+11 | 1.22747E+11 | 2.61387E+08 | 1.69249E+09 | 4.32702E+11 | 0.43 |
| Anne Arundel | 2.31063E+12 | 5.87374E+11 | 1.02115E+09 | 1.34278E+10 | 2.91246E+12 | 2.91 |
| Baltimore | 3.18991E+12 | 9.01693E+11 | 9.31873E+08 | 1.80212E+10 | 4.11056E+12 | 4.11 |
| Calvert | 2.81481E+11 | 5.21102E+10 | 1.25760E+08 | 1.60742E+09 | 3.35324E+11 | 0.34 |
| Caroline | 1.45260E+11 | 4.74093E+10 | 2.22157E+07 | 7.53482E+08 | 1.93445E+11 | 0.19 |
| Carroll | 5.20561E+11 | 1.13378E+11 | 1.67540E+08 | 3.00682E+09 | 6.37113E+11 | 0.64 |
| Cecil | 4.55752E+11 | 2.35577E+11 | 4.37007E+08 | 2.53163E+09 | 6.94298E+11 | 0.69 |
| Charles | 4.87875E+11 | 1.03256E+11 | 1.23812E+08 | 2.60843E+09 | 5.93863E+11 | 0.59 |
| Dorchester | 1.35056E+11 | 3.83858E+10 | 2.09591E+08 | 6.76566E+08 | 1.74328E+11 | 0.17 |
| Frederick | 1.20906E+12 | 3.24125E+11 | 5.06871E+08 | 6.88356E+09 | 1.54058E+12 | 1.54 |
| Garrett | 1.79262E+11 | 9.10803E+10 | 1.63034E+08 | 1.16410E+09 | 2.71669E+11 | 0.27 |
| Harford | 9.50935E+11 | 2.46234E+11 | 6.01613E+08 | 5.55978E+09 | 1.20333E+12 | 1.20 |
| Howard | 1.56975E+12 | 4.45846E+11 | 9.70677E+08 | 9.24606E+09 | 2.02582E+12 | 2.03 |
| Kent | 7.50820E+10 | 2.64686E+10 | 7.40913E+07 | 3.94144E+08 | 1.02019E+11 | 0.10 |
| Montgomery | 2.97240E+12 | 7.08430E+11 | 3.29952E+09 | 1.66322E+10 | 3.70076E+12 | 3.70 |
| Prince George's | 3.56562E+12 | 8.51768E+11 | 2.09049E+09 | 1.76185E+10 | 4.43710E+12 | 4.44 |
| Queen Anne's | 3.21539E+11 | 1.31287E+11 | 1.67345E+08 | 1.83868E+09 | 4.54833E+11 | 0.45 |
| Saint Mary's | 3.50739E+11 | 9.51675E+10 | 1.42719E+08 | 1.90235E+09 | 4.47951E+11 | 0.45 |
| Somerset | 9.80952E+10 | 2.78526E+10 | 1.93020E+07 | 4.93160E+08 | 1.26460E+11 | 0.13 |
| Talbot | 2.27129E+11 | 6.69189E+10 | 5.21762E+07 | 1.27472E+09 | 2.95375E+11 | 0.30 |
| Washington | 7.55019E+11 | 3.90304E+11 | 3.80486E+08 | 3.85812E+09 | 1.14956E+12 | 1.15 |
| Wicomico | 3.79141E+11 | 9.95495E+10 | 4.12890E+08 | 1.98666E+09 | 4.81090E+11 | 0.48 |
| Worcester | 3.04289E+11 | 8.80718E+10 | 5.76077E+08 | 1.70333E+09 | 3.94640E+11 | 0.39 |
| Baltimore City | 1.40851E+12 | 3.61590E+11 | 3.39877E+09 | 6.89540E+09 | 1.78039E+12 | 1.78 |
| State of MD | 2.22011E+13 | 6.15662E+12 | 1.61564E+10 | 1.21777E+11 | 2.84957E+13 | **28.50** |
| | | | | | | |
| **$CO_2$ Emissions ($MMTCO_2E$)** | **2.22E+01** | **6.16E+00** | **1.62E-02** | **1.22E-01** | **2.85E+01** | |
| | | | | | | |

Notes: Column totals may not add due to rounding.

**Table 4-2: 2017 Annual State Summary On-Road GHG Emissions (MMtCO$_2$e)**

| | VMT (Millions) | CO$_2$ | CH$_4$ | N$_2$O | CO$_2$e |
|---|---|---|---|---|---|
| **TOTAL** | **59,892** | **28.50** | **0.006467** | **0.08993** | **28.5964** |

### 4.4.2 Fuel Consumption Estimates

The MOVES output energy rates can be converted to fuel consumption values using standard conversion rates for gasoline and diesel fuel. Table 4.3 below provides the estimated 2017 fuel consumption values. The 2017 values were compared to available information from FHWA and the Energy Information Administration (EIA).

**Table 4-3: 2017 Fuel Consumption Estimates**

| Scenario | Fuel Type | MOVES2014a Output | | Actual Statewide Fuel Sales[2] *(Thousand gallons)* |
|---|---|---|---|---|
| | | Energy Consumption *(Trillion BTU)* | Estimated Fuel Consumption[1] *(Thousand Gallons)* | |
| 2017 | Gasoline | 290.3 | 2,410,004 | 2,786,302 |
| | Diesel | 78.7 | 572,693 | 521,857 |

[1] Assumes following conversion rates:

- 1 gallon of gasoline fuel = 120,452 BTU
- 1 gallon of diesel fuel = 137,381 BTU

[2] On-highway Gasoline Fuel Consumption:

- Statement of Gasoline Consumption Report from the following web page of the Comptroller of MD https://finances.marylandtaxes.gov/static_files/revenue/motorfuel/annualreport/FuelAnnualReportFY2017.pdf

On-highway Diesel Fuel Consumption:

- 2017 Sale of Distillate Fuel Oil by End Use, Maryland – On Highway Report from U.S Energy Information Administration http://www.eia.gov/dnav/pet/PET_CONS_821USEA_A_EPD2D_VAH_MGAL_A.htm

# 5.0 Transportation Non-Road Mobile Energy Use

## 5.1 OVERVIEW

This section describes the data sources, key assumptions, and the methodology used to develop a periodic 2017 inventory of greenhouse gas (GHG) emissions associated with Maryland's non-road transportation sector. The primary GHGs produced by the transportation sector are carbon dioxide, methane and nitrous oxide.

Transportation GHGs are emitted largely as a result of energy combustion, with different levels of emissions associated with different fuels. Energy consumption, in turn, is a function of vehicle travel activity and vehicle fuel economy, which is determined based on vehicle stock (including vehicle type, size, and fuel type), speeds and other operating characteristics of vehicles (including idling), and levels of vehicle maintenance and care.

Sources of GHG emission in the non-road mobile transportation sector include modes of transportation, such as airplanes, trains and commercial marine vessels. Nonroad mobile sources also include motorized vehicles and equipment, which are normally not operated on public roadways. Nonroad mobile sources are broken up into NONROAD Model source categories and Off-model source categories. The two types of nonroad source categories are listed below:

**NONROAD Model Source Categories**

- Lawn and Garden Equipment
- Airport Service Equipment
- Recreational Land Vehicles or Equipment
- Recreational Marine Equipment
- Light Commercial Equipment
- Industrial Equipment
- Construction Equipment
- Agricultural or Farm Equipment
- Logging Equipment

**Off-Model Source Categories**

- Railroads
- Aviation
- Commercial Marine Vessels

In order to enhance the accuracy of the 2017 GHG emissions in the transportation sector, the Department used two methodologies approved by the EPA for developing the 2017 emissions inventory for nonroad categories. The NONROAD Model source categories listed above were estimated using the NONROAD Model that EPA recently incorporated into the MOVES Model. The other source categories were estimate using traditional EPA emission factors.

## 5.2 NONROAD MODEL SOURCE CATEGORIES

The Motor Vehicle Emissions Simulator (MOVES) incorporates the current version of the NONROAD model to calculate emissions. EPA integrated the NONROAD model into the MOVES model to produce county-level mobile source emission inventories from a national county database that can be easily updated which includes onroad and Nonroad data for each state.

Both MOVES-NONROAD and previous versions of the NONROAD Model use the same formulas and methods to calculate emissions. However, MOVES-NONROAD and MOVES-ONROAD now share the same input files for meteorology and fuel parameters, to estimate emissions.

### 5.2.1 Emission Calculation Methodology

The MOVES-NONROAD Model calculates past, present, and future emission inventories (i.e., tons of pollutant) for all Nonroad equipment categories except commercial marine, locomotives, and aircraft. Fuel types included in the model are: gasoline, diesel, compressed natural gas, and liquefied petroleum gas. The model estimates exhaust and evaporative hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), sulfur dioxide ($SO_2$), methane ($CH_4$) and carbon dioxide ($CO_2$). The user may select a specific geographic area (i.e., national, state, or county) and time period (i.e., annual, monthly, seasonal, or daily) for analysis.

The NONROAD model estimates emissions for each specific type of Nonroad equipment by multiplying the following input data estimates:

- Equipment population for base year (or base year population grown to a future year), distributed by age, power, fuel type, and application;
- Average load factor expressed as average fraction of available power;
- Available power in horsepower;
- Activity in hours of use per year; and
- Emission factor with deterioration and/or new standards.

The emissions are then temporally and geographically allocated using appropriate allocation factors. There are several input files that provide necessary information to calculate and allocate emissions estimates. These input files correspond to the basic data needed to provide the calculations: emission factors, base year equipment population, activity, load factor, average lifetime, scrap page function, growth estimates, and geographic and temporal allocation. Maryland specific input files were utilized to synchronize the MOVES-NONROAD Model emissions with the MOVES-ONROAD Model emissions.

The MOVES-NONROAD Model output files produced monthly daily emission estimates. Annual NONROAD Model emission estimates were calculated from these daily model output files.

## 5.3 OFF MODEL SOURCE CATEGORIES

### 5.3.1 Emission Calculation Methodology

Off-Model nonroad source category emissions are calculated by collecting fossil fuel consumption fuel estimates.

#### 5.3.1.1 Carbon Dioxide ($CO_2$) Direct Emissions

Carbon dioxide emissions generally are a direct product of fossil fuel combustion. The amount of $CO_2$ produced is a product of the amount of fuel combusted, the carbon content of the fuel, and the fraction of carbon that is oxidized when the fuel is combusted. Maryland transportation sector $CO_2$ emissions were estimated using methods developed by the EPA (and consistent with international guidelines on GHG emissions developed by the Intergovernmental Panel on Climate Change).

For fuel used for non-energy purposes (e.g. lubricants), the fuel quantity was multiplied by a storage factor and then subtracted from the carbon emissions, to avoid double-counting.

Maryland 2017 periodic non-road mobile transportation sector $CO_2$ emissions were estimated based on data provided by EIA (State Energy Data) for the following fuels: aviation gasoline, distillate fuel, jet fuel kerosene, jet fuel naphtha, LPG, motor gasoline, residual fuel, natural gas, and lubricants. The EIA State Energy Data for gasoline consumption was compared to the Maryland Comptroller data on gasoline sales. The gasoline consumption was essentially equal once ethanol was removed from the MD Comptroller data. The 2017 fossil fuel consumption data for locomotives was obtained from MDE compliance survey. Fuel consumption data is presented in Table 5.1.

**Table 5-1: Default Energy Consumption in Maryland**

| Fuel Type | Consumption (gallon) | Consumption (Billion Btu) | Source of Data |
|---|---|---|---|
| Aviation Gasoline | 1,638,000 | 196 | EIA State Energy Data – Maryland Consumption |
| Jet Fuel, Kerosene | 69,510,000 | 9,381 | EIA State Energy Data – Maryland Consumption |
| Distillate Fuel - Locomotive | 16,285,444 | 2,237 | MDE Survey |
| Distillate Fuel – Vessel Bunkering | 3,584,000 | 424 | EIA State Energy Data/EIA Sales Data – Maryland Consumption |
| Residual Fuel –Vessel Bunkering | 2,436,000 | 170 | EIA State Energy Data – Maryland Consumption |
| Transportation Lubricants | 14,784,000 | 2,135 | EIA State Energy Data – Maryland Consumption |

The transportation fossil fuel combustion data are converted to energy consumption by multiplying the fossil fuel data (in $m^3$, tons, $ft^3$) by the carbon content coefficients for each fuel. These quantities are then multiplied by a combustion efficiency factor (a fuel-specific percentage of carbon oxidized during combustion). The resulting emissions, in pounds of carbon, are then converted to million metric tons of carbon dioxide equivalent ($MMTCO_2e$). The general equation for calculating $CO_2$ emissions from transportation energy consumption is as follows:

$$\text{Emissions }(\text{MMTCO}_2\text{E}) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718474 \times (44/12)}{1{,}000{,}000}$$

Where:

Consumption (BBtu) = total heat content of the applicable fuel consumed
Emission Factor = established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%) = Combustion efficiency refers to the percentage of the fuel that is actually consumed when the fuel is combusted; many fuels often do not combust entirely, and the leftover fuel is emitted as soot or particulate matter. For the fuels analyzed in this report, the combustion efficiencies ranged from 99.0 to 99.5 percent.
0.9071847 = constant used to convert from short tons to metric tons.
0.0005 = constant used to convert from pounds to short tons.
1,000,000 = conversion factor converts metric tons to Million metric tons
44/12 = conversion factor converts from carbon to carbon dioxide

### 5.3.1.2 Additional Direct Emissions ($CH_4$ and $N_2O$)

To calculate $CH_4$ and $N_2O$ emissions from non-road transportation sector, the following data are required:

- Fossil fuel consumption by fuel type and;
- Emission factors by fuel type

The general emissions equation is as follows:

$$\text{Emissions }(\text{MMTCO}_2\text{E}) = \frac{\text{Consumption (Btu or Gallon)} \times \text{Density (kg/gal) OR Energy Content (kg/MBtu)} \times \text{Emission Factor (g/kg fuel)} \times \text{Combustion Efficiency (\%)} \times \text{GWP}}{1{,}000{,}000}$$

Where:

Emissions: MMTCO$_2$E (Million Metric Tons of CO$_2$ Equivalent)
Consumption: MBtu (Million BTUs or Gallons)
Density: Kg/gal
Energy Content: kg/MBtu
Emission Factor: (grams per kilograms fuel)
Combustion Eff: Percentage (100%)
GWP: Global Warming Potential ($N_20$ = 310, $CH_4$ = 21)
1,000,000: Conversion Factor (Metric Tons to Million Metric Tons)

## 5.4 DATA SOURCES

- EIA’s State Energy Data.
- http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=US

- US EPA State Greenhouse Gas Inventory Tool (SIT)
  http://www.epa.gov/statelocalclimate/resources/tool.html

- EIA, Distillate Fuel Oil and Kerosene Sales By End-Use.
  http://www.eia.gov/dnav/pet/pet_cons_821usea_dcu_SMD_a.htm.

- EPA Non-Road Model.
  http://www.epa.gov/otaq/nonrdmdl.htm.

- Controller of Maryland - Statement of Gasoline Consumption.
  https://finances.marylandtaxes.gov/static_files/revenue/motorfuel/annualreport/FuelAnnualReportFY2017.pdf

## 5.5 GREENHOUSE GAS INVENTORY RESULTS

**Table 5-2: 2017 MOVES-NONROAD Model Transportation Sector GHG Emissions**

| MOVES-NONROAD Model Source Category | $CH_4$ (short tons) | $CO_2$ (short tons) | $CH_4$ ($MMTCO_2E$) | $CO_2$ ($MMTCO_2E$) | Total Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| Compressed Natural Gas | 144.77 | 15,882.55 | 0.0028 | 0.0144 | 0.172 |
| Non-Road Gasoline | 908.43 | 1,038,820.12 | 0.0173 | 0.9424 | 0.9597 |
| Liquefied Petroleum Gas (LPG) | 14.77 | 166,851.41 | 0.0003 | 0.1514 | 0.1516 |
| Marine Diesel Fuel | 1.56 | 55,961.49 | 0.0000 | 0.0508 | 0.0508 |
| Non-Road Diesel Fuel | 24.46 | 1,052,155.32 | 0.0005 | 0.9545 | 0.9550 |
| **TOTAL** | **1,093.99** | **2,329,670.88** | **0.0208** | **2.1134** | **2.1343** |

## Table 5-3: 2017 Off-Model Nonroad Transportation Sector $CO_2$ Emissions

| Fuel Type | Consumption (gallon) | Consumption (Billion Btu) | Emission Factor (lbs C/Million Btu) | Combustion Efficiency (%) | Emissions (tons carbon) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|
| Aviation Gasoline | 1,638,000 | 196 | 41.57 | 100.0% | 4,074 | 0.014 |
| Jet Fuel, Kerosene | 69,510,000 | 9,381 | 43.43 | 100.0% | 203,717 | 0.678 |
| Distillate Fuel - Locomotive | 16,285,444 | 2,237 | 44.47 | 100.0% | 49,747 | 0.165 |
| Distillate Fuel – Vessel Bunkering | 3,584,000 | 492 | 44.47 | 100.0% | 10,948 | 0.036 |
| Residual Fuel – Vessel Bunkering | 2,436,000 | 363 | 45.15 | 100.0% | 8,195 | 0.027 |
| **TOTAL** | | | | | | **0.920** |

## Table 5-4: 2017 Off-Model Nonroad Transportation Sector Emissions from Lubricant Consumption

| Consumption (Billion Btu) | Non-Energy Consumption (Billion Btu) | Storage Factor (%) | Net combustible Consumption (Billion Btu) | Emission Factor (lbs C/Million Btu) | Combustion Efficiency (%) | Emissions (short tons carbon) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|
| 2,135 | 1,427 | 9% | 2,003 | 44.53 | 100.0% | 44,600 | 0.148 |

## Table 5-5: 2017 Off-Model Nonroad Transportation Sector $CH_4$ and $N_2O$ Emissions

| Fuel Type | Consumption (gallon) | Consumption (Billion Btu) | $N_2O$ EF g/kg fuel | $CH_4$ EF g/kg fuel | Emissions $N_2O$ ($MTCO_2E$) | Emissions $CH_4$ ($MTCO_2E$) |
|---|---|---|---|---|---|---|
| Aviation Gasoline | 1,638,000 | 196 | 0.04 | 2.64 | 0.1745 | 11.51718 |
| Jet Fuel, Kerosene | 69,510,000 | 9,381 | 0.08 | 0.45 | 20.8633 | 18.15111 |
| Distillate Fuel - Locomotive | 16,285,444 | 2,237 | 0.08 | 0.45 | 4.1587 | 12.99578 |
| Distillate Fuel – Vessel Bunkering | 3,584,000 | 492 | 0.08 | 0.18 | 0.9152 | 2.86003 |
| Residual Fuel – Vessel Bunkering | 2,436,000 | 363 | 0.08 | 0.25 | 0.6967 | 2.00300 |

# 6.0 Industrial Processes

## 6.1 OVERVIEW

Industry emits greenhouse gases in two basic ways: through the combustion of fossil fuels for energy production and through a variety of raw material transformation and production processes. The emissions associated with fossil fuel combustion are accounted for in the energy use section – Industrial (RCI), and the indirect $CO_2$ emissions from consumption of electricity have also been accounted for under the Energy Use section - Electric Generation. This section of the report will focus on additional industrial processes related to greenhouse gas emissions. Industrial process GHG emissions occur in the following industrial source sectors:

- Iron and Steel Production
- Cement Manufacture
- Lime Manufacture
- Limestone and Dolomite Use
- Nitric Acid Production
- Adipic Acid Production
- Ozone Depleting Substances Substitution
- Semiconductor Manufacture
- Magnesium Production
- Electric Power Transmission and Distribution Systems
- HCFC-22 Production
- Aluminum Production

Many of these industrial processes did not have production facilities in Maryland in 2017. Calculating emissions from these source categories was not necessary. These industries are:

- Nitric acid production
- Adipic acid production
- HCFC-22 production
- Aluminum production
- Iron and Steel Production

The following sections discuss the data sources, methods, assumptions, and results used to construct the 2017 periodic emissions inventory.

## 6.2 DATA SOURCES

- MDE's Annual Emissions Certification Reports 2017.
- EPA ghgdata: Greenhouse Gas Emissions from Large Facilities. http://ghgdata.epa.gov/ghgp.
- US EPA State Greenhouse Gas Inventory Tool (SIT) http://www.epa.gov/statelocalclimate/resources/tool.html

## 6.3 GREENHOUSE GAS INVENTORY METHODOLOGY

This section provides the methodologies used to estimate $CO_2$, $N_2O$, and HFC, PFC, and $SF_6$ emissions from Industrial Processes. The sectors included in Industrial Processes are cement production, lime manufacture, limestone and dolomite use, soda ash manufacture and consumption, iron and steel production, ammonia manufacture, consumption of substitutes for ozone depleting substances, semiconductor manufacture, electric power transmission and distribution, and magnesium production and processing. The two primary methods used in the calculation of greenhouse gas emissions inventory for the industrial process sector were the MD annual emission certification report and the EPA SIT. Since the methodology varies by sector, they are discussed separately below.

### 6.3.1 Carbon Dioxide ($CO_2$) Industrial Process Emissions

### 6.3.1.1 Cement Manufacture

The cement production process comprises the following two steps: (1) clinker production and (2) finish grinding. Essentially, all GHG emissions from cement manufacturing are $CO_2$ emissions from clinker production. There are no $CO_2$ emissions from the finish grinding process, during which clinker is ground finely with gypsum and other materials to produce cement[1]. However, $CO_2$ emissions are associated with the electric power consumed by plant equipment such as the grinders; which have been accounted for under the energy use section – electric generation.

Cement is produced from raw materials such as limestone, chalk, shale, clay, and sand. These raw materials are quarried, crushed, finely ground, and blended to the correct chemical composition. Small quantities of iron ore, alumina, and other minerals may be added to adjust the raw material composition. The fine raw material is fed into a large rotary kiln (cylindrical furnace) that rotates while the contents are heated to extremely high temperatures. The high temperature causes the raw material to react and form a hard nodular material called "clinker". Clinker is cooled and ground with approximately 5 percent gypsum and other minor additives to produce Portland cement. The heart of clinker production is the rotary kiln where the pyroprocessing stage occurs.

Three important processes occur with the raw material mixture during pyroprocessing. First, all moisture is driven from the materials. Second, the calcium carbonate in limestone dissociates into $CO_2$ and calcium oxide (free lime); this process is called calcination. Third, the lime

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[1] EPA Office of Air and Radiation: Available And Emerging Technology for Reducing Greenhouse Gas Emission from the Portland Cement Industry. http://www.epa.gov/nsr/ghgdocs/cement.pdf

and other minerals in the raw materials react to form calcium silicates and calcium aluminates, which are the main components of clinker. This third step is known as clinkering or sintering. The formation of clinker concludes the pyroprocessing stage.[1]

Clinker production GHG emissions are from the combustion of carbon-based fuels such as coal, petroleum coke, fuel oil and natural gas in the cement kiln. Another significant source of process $CO_2$ emissions is from the calcination of limestone (carbonates) that forms clinker and from calcination of carbonates that forms clinker kiln dust (CKD).

Cement manufacturing *process-related* $CO_2$ emissions estimated in this section includes:

Carbon Dioxide ($CO_2$) from:

- Raw materials converted to Clinker;
- Calcinations of Clinker Kiln Dust (CKD) leaving the Kiln system and;
- Organic carbon content of Raw Meal.

Emissions from cement production consist of emissions produced during the cement clinker process. (Emissions from masonry cement are accounted for in the Lime Production estimates).

### 2017 $CO_2$ Industrial Process Emissions Estimation

The industrial process 2017 GHG emission inventory for the cement industry in Maryland was compiled from the annual emission certification reports from cement industries operating in Maryland. The certification reports were validated by the cement facilities and submitted to the Air and Radiation Administration (ARA) Compliance Program. Engineers with the compliance program reviewed the emission certification reports for accuracy. The emission certification reports were then cross-checked with a report the facility submitted to the EPA GHG Reporting Program (GHGRP) under 40 CFR 98 by an engineer with the ARA Planning Program.

### 6.3.1.2 Iron and Steel Industry

Steel production creates $CO_2$ emissions from process and energy sources. Direct energy related emissions from the combustion of fossil fuels including coal, petroleum coke, carbon, fuel oil and natural gas have been addressed in the R/C/I fossil fuel combustion section. An indirect and significantly smaller amount of $CO_2$ emissions from the consumption of electricity have also been accounted for under the energy use section - electric generation.

Steel is an alloy of iron usually containing less than one percent carbon[1]. The process of steel production occurs in several sequential steps. The two types of steelmaking technology in use today are the basic oxygen furnace (BOF) and the electric arc furnace (EAF). Although these two technologies use different input materials, the output for both furnace types is molten steel which is subsequently formed into steel mill products. The BOF input materials are molten iron, scrap, and oxygen. In the EAF, electricity and scrap are the input materials used. A more detailed description of the Iron and Steel manufacturing process is available in the U.S. EPA office of Compliance Notebook Project report - Profile of the Iron and Steel Industry which is available at this website: http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/iron.html

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[1] EPA Office of Compliance Notebook Project. Profile of the Iron and Steel Industry, Sept 1995.

This section of the report focuses on the iron and steel manufacturing processes that produce greenhouse gas emissions. Predominant sources of *process-related* $CO_2$ emissions in the iron and steel manufacturing estimated in this section include:

- Sinter Strand;
- L-Blast Furnace (Iron production);
- Basic Oxygen Furnace –Steel Production (BOF) and;
- Bleeders.

**Sintering** is one of the first processes involved in primary iron and steel making; sinter strand is where the raw material mix (including iron ore fines, pollution control dusts, coke breeze, water treatment plant sludge, and flux) are agglomerated into a porous mass for charging to the blast furnace[1]. In the sinter production process, direct $CO_2$ emissions occur due to fuel used in the sintering process, from the recycling of residue materials and in form of process-related emissions from limestone calcination.

**Blast Furnace**, crude iron is produced by the reduction of iron oxide ores in the blast furnace. The combustion of coke, petroleum coke, or coal provides the carbon monoxide (CO) required to reduce the iron oxides to iron and provides additional heat to melt the iron and impurities[2]. Carbon dioxide ($CO_2$) emissions are produced as the coal/coke is oxidized. Furthermore, during iron production, $CO_2$ emissions occur through the calcination of carbonate fluxes. Calcination occurs when the heat of the blast furnace causes fluxes containing limestone ($CaCO_3$) and magnesium carbonate ($MgCO_3$) to form lime (CaO), magnesium oxide (MgO), and $CO_2$. The CaO and MgO are needed to balance acid constituents from the coke and iron ore. Although some carbon is retained in the iron (typically 4 percent carbon by weight), most of the carbon is emitted as $CO_2$.

**Steelmaking Using the Basic Oxygen Furnace (BOF);** Low carbon steel is produced in the BOF, where a mixture of crude iron and scrap steel (typically 30% scrap and 70% molten iron) is converted in the presence of pure oxygen to molten steel[2]. $CO_2$ emissions also occur, although to a much lesser extent, during the production of steel. $CO_2$ emissions occur as carbon present in the iron is oxidized to $CO_2$ or CO. The produced crude steel has 0.5 to 2 percent carbon content by weight.

**Bleeders;** The vast majority of GHGs ($CO_2$) emission in iron and steel production are emitted from the blast furnaces stove stacks during the fusion of raw material mix (iron ore fines, coke breeze) and limestone to form high quality sinter for use as feed to the L-Blast Furnace. A significant amount of emissions also result from the combustion of the excess blast furnace gases produced during the chemical reaction process of the L-Blast Furnace. The blast furnace gas is mostly nitrogen, carbon monoxide, and particulate matter.

Bleeder valves are located on top of the blast furnace to act as safety valves to prevent over-pressurization of the furnace structure that could result in an explosion. Combustion of the excess blast furnace gas (that were not needed for power) generates GHG emissions that are released to the atmosphere through the stove stacks.

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[1] http://ec.europa.eu/clima/policies/ets/docs/BM%20study%20-Iron%20and%20steel.pdf .

[2] Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance. http://www.epa.gov/climateleaders/documents/resources/ironsteel.pdf.

**2017 $CO_2$ Industrial Process Emissions Estimation**

No GHG emissions was estimated for the Iron and Steel industry in Maryland for the periodic year 2017 GHG emissions, due to the closure of Maryland only Iron and Steel plant.

### 6.3.1.3 Limestone and Dolomite Use

The primary source of $CO_2$ emissions from limestone consumption is the calcination of limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) to create lime (CaO). These compounds are basic raw materials used by a wide variety of industries, including construction, agriculture, chemicals, metallurgy, glass manufacture, and environmental pollution control. Limestone and dolomite are collectively referred to as limestone by the industry.

There are a variety of emissive and non-emissive uses of Limestone. Emissive application of Limestone (including dolomite) includes; limestone's used as a flux or purifier in metallurgical furnaces, as a sorbent in flue gas desulfurization systems in utility and industrial plants, and as a raw material in glass manufacturing, or as an input for the production of dead-burned dolomite, mine dusting or acid water treatment, acid neutralization, and sugar refining. Limestone is heated during these processes, generating carbon dioxide as a byproduct.[1]

$$CaCO_3 + \text{Heat} \rightarrow CaO + CO_2$$

Non-emissive application of Limestone includes; limestone used in poultry grit, as asphalt fillers and in the manufacture of papers.[2] Greenhouse gas emissions from limestone and dolomite use for industrial purposes were estimated by multiplying the quantity of limestone and dolomite consumed and an emission factor.

Emissions from limestone and dolomite- use was estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, with default state consumption data and emission factors, in accordance with the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector. SIT input data for Maryland is based on the state's population and the national per capital consumption data from the US EPA national GHG inventory report [3] 1990-2016.

The emissions are then converted from metric tons of carbon equivalents (MTCE) to metric tons of carbon dioxide equivalents ($MTCO_2e$). For default data, each state's total limestone consumption (as reported by USGS) is multiplied by the ratio of national limestone consumption for industrial uses to total national limestone consumption.

Equation 6.1: Emission Equation for Limestone and Dolomite Use

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[1] Documentation for Emissions of Greenhouse Gases in the United States 2006 (October 2008) –DOE/EIA 0636 (2006)

[2] Technical Support Document: Limestone and Dolomite Use, Office of Air and Radiation, U.S. EPA, January 22, 2009.

[3] U.S. Greenhouse Gas Inventory Report 1990 -2016.
https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html

$$\text{Emissions } (MTCO_2E) = \text{Consumption (metric tons)} \times \text{Emission Factor } (MT\ CO_2/MT \text{ Production}$$

Where:

Emissions = Total emissions from the Limestone and Dolomite Use
Consumption = Quantity of limestone/dolomite consumed
Emission Factor = Emission Factor (0.44)

#### 6.3.1.4 Soda Ash Manufacture and Consumption

Commercial soda ash (sodium carbonate) is used in many familiar consumer products, such as glass, soap and detergents, paper, textiles, and food. Most soda ash is consumed in glass and chemical production. Other uses include water treatment, flue gas desulfurization, soap and detergent production, and pulp and paper production. Carbon dioxide is also released when soda ash is consumed (See Chapter 6 of EIIP guidance documents).

Emissions from soda ash manufacture and consumption was estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, with default state consumption data and emission factors, in accordance with the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector. SIT input data for Maryland is based on the state's population and the national per capital consumption data from the US EPA national GHG inventory[1].

Equation 5.2: Emission Equation for Soda Ash Manufacture and Consumption

$$\text{Emissions } (MTCO_2E) = \text{MD per capital Consumption (metric tons)} \times \text{Emission Factor } (MT\ CO_2/MT \text{ Production})$$

Where:

Emissions = Total emissions from the Soda Ash Manufacture and Consumption

MD per capital Consumption = (MD Pop/USA Pop) * (US Total Soda Ash Consumption)

Emission Factor = Emission Factor (0.4150)

#### 6.3.1.5 Non-Fertilizer Urea Use $CO_2$ Emissions

Urea is consumed in a variety of uses, including as a nitrogenous fertilizer, in urea-formaldehyde resins, and as a deicing agent. The Carbon (C) in the consumed urea is assumed to be released into the environment as $CO_2$ during use. The majority of $CO_2$ emissions associated with urea consumption are those that results from its use as a fertilizer.[2] These emissions are accounted for in

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[1] U.S. Greenhouse Gas Inventory Report 1990 -2016 https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

[2] Inventory of U.S.Greenhouse Gas Emissions and Sinks: 1990- 2016

Land Use section of this document, Section 10. $CO_2$ emissions associated with other uses of Urea are accounted for in this section.

Emissions from non-fertilizer urea use was estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, with default state consumption data and emission factors, in accordance with the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector. SIT input data for Maryland is based on the state's population and the national per capital consumption data from the US EPA national GHG inventory [1].

Emissions from urea application are calculated by multiplying the quantity of urea applied by their respective emission factors. Emissions from urea application are subtracted from emissions due to ammonia production. The emissions are then converted from metric tons of carbon equivalents (MTCE) to metric tons of carbon dioxide equivalents ($MTCO_2e$).

Equation 5.3: Emission Equation for Urea Consumption

$$\begin{array}{c} \text{Emissions} \\ (MTCO_2E) \end{array} = \begin{array}{c} \text{Urea} \\ \text{Consumption} \\ \text{(metric tons)} \end{array} \times \begin{array}{c} \text{Emission Factor} \\ (MT\ CO_2/MT \\ \text{Activity} \end{array}$$

Where:

Emissions = Total emissions from the Urea Consumption
Urea Consumption = Quantity of urea consumed
Emission Factor = Emission Factor (0.73)

### 6.3.2 Additional Direct Emissions ($SF_6$, HFC, PFC)

#### 6.3.2.1 $SF_6$ from Electrical Transmission and Distribution Equipment.

Sulfur hexafluoride ($SF_6$) is used for electrical insulation, arc quenching, and current interruption in electrical transmission and distribution equipment. $SF_6$ emissions from electrical transmission and distribution systems are the largest global source category for $SF_6$.[1] Emissions of $SF_6$ stem from a number of sources including, switch gear through seals (especially from older equipment), equipment installation, servicing and disposal.

Emissions from electric power transmission and distribution are estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, with default state consumption data and emission factors, in accordance with the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector. SIT input data for Maryland is based on the state's population and the national per capital consumption data from the US EPA national GHG inventory[2].

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[1] Documentation for *Emissions of Greenhouse Gases in the United States 2006* ***October 2008***
[2] U.S. Greenhouse Gas Inventory Report 1990 -2016
https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

Emissions from electric power transmission and distribution are calculated by multiplying the quantity of SF$_6$ consumed by an emission factor. The resulting emissions are then converted from metric tons of SF$_6$ to metric tons of carbon equivalents (MTCE) and metric tons of carbon dioxide equivalents (MTCO$_2$e). The default assumption is that the emission factor is 1, i.e. all SF$_6$ consumed is used to replace SF$_6$ that was emitted. Default activity data for this sector equals national SF$_6$ emissions apportioned by state electricity sales divided by national electricity sales.

The general equation used to estimate greenhouse gas emissions from transmission and distribution equipment is as follows:

Equation 5.4: Emission Equation for Electric Power Transmission and Distribution

$$\text{Emissions (MTCO}_2\text{E)} = \text{SF}_6\text{ Consumption (metric tons SF}_6\text{)} \times \text{Emission Factor (MT SF}_6\text{/MT Consumption)} \times \text{GWP}_{\text{SF6}}$$

Where:

Emissions = Total emissions from the Transmission and Distribution Equipment
SF$_6$ Consumption = Quantity of SF$_6$ consumed
Emission Factor = Emission Factor (1)
GWP$_{\text{SF6}}$ = Global Warming Potential

### 6.3.2.2 HFCs and PFCs from Ozone-Depleting Substance (ODS) Substitutes.

**Hydrofluorocarbons** (HFCs) and **Perfluorocarbons** (PFCs) are used as substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment. Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) have hundreds of uses, but the bulk of emissions come from a few broad categories of use such as: as refrigerants or working fluids in air conditioning and refrigeration equipment, as solvents in various industrial processes, and as blowing agents for making insulating foams.[1]

Emissions from HFCs, PFCs, and SF$_6$ from ODS substitute production are estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, with default state consumption data and emission factors, in accordance with the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector. SIT input data for Maryland is based on the state's population and the national per capital consumption data from the US EPA national GHG inventory[2].

Emissions of HFCs, PFCs, and SF$_6$ from ODS substitute production are estimated by apportioning national emissions to each state based on population. State population data was provided by the U.S. Census Bureau (http://www.census.gov). The resulting state emissions are then converted from metric tons of CO$_2$ equivalents to metric tons of carbon equivalents (MTCE) and metric tons of carbon dioxide equivalents (MTCO$_{2e}$e).

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[1] Inventory of U.S. *Greenhouse Gases Emissions (1990-2016).*

[2] [2] U.S. Greenhouse Gas Inventory Report 1990 -2016
https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html

### Equation 5.5: Emission Equation for Apportioning Emissions from the Consumption of Substitutes for ODS

$$\text{Emissions } (\text{MTCO}_2\text{e}) = \text{National ODS Substitute Emissions } (\text{MTCO}_2\text{e}) \times \frac{\text{State Population}}{\text{National Population}}$$

Where:

Emissions = Total emissions from the Consumption of Substitutes for ODS
National ODS = National ODS Substitute Emissions
State Population = Maryland State Population
National Population = United States Population

## 6.4 GREENHOUSE GAS INVENTORY RESULTS

### Table 6-1: Cement Industry Process $CO_2$ Emissions

| Lehigh | Consumption | Units | % Biomass | $CO_2$ Emissions (metric tons) | $CH_4$ Emissions (metric tons $CH_4$) | $N_2O$ Emissions (metric tons $N_2O$) | Source of Data |
|---|---|---|---|---|---|---|---|
| **Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category Exhausted to CEM Stack** | | | | | | | |
| -Coal | 270,533 | metric tons | | 587,726 | 66.71 | 9.74 | MDE ECR |
| - DBS (Dry Bio-Solids) (Preheater/ Precalciner Kiln) | 6,850 | metric tons | **1.0%** | **19,292** | 2.67 | 0.35 | MDE ECR |
| - #2 Oil | 315,658 | Gallons | | 4,778 | 0.13 | 0.03 | MDE ECR |
| - Fly Ash | 4,335 | metric tons | | 33,968 | 0.07 | 0.01 | MDE ECR |
| | | | | | | | |
| **Kiln Fossil Fuel Combustion (Calculation)** | | | | **645,765** | **69.58** | **10.13** | **Sum** |
| | | | | | | | |
| **Kiln System Total $CO_2$ (CEM Measured)** | | | | **1,929,239** | 69.58 | 10.13 | CEM |
| | | | | | | | |
| **Industrial Process Emissions = Total Emissions – Fossil Fuel Combustion Emissions** | | | | | | | |
| **Cement Production-Process $CO_2$ (metric tons) = Kiln System Total $CO_2$ - Kiln Fossil Fuel Combustion $CO_2$** | | | | **1,283,474** | | | Difference |
| | | | | | | | |
| | | | | | | | |
| **Non-Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category** | | | | | | | |
| Finish Mill (#2 Oil) | 6,887 | Gallons | | 738.44 | 0.0300 | 0.0060 | MDE ECR |
| | | | | | | | |
| **Total Facility $CO_2$= Kiln System $CO_2$ + Non-Kiln $CO_2$** | | | | 1,929,977.44 | 69.61 | 10.1 | **MDE ECR** |
| **Kiln Fossil Fuel Combustion (short tons)** | | | | **711,955** | **76.71** | **11.17** | |
| **Kiln System Total $CO_2$ (CEM Measured) (short tons)** | | | | **2,126,985** | 76.71 | 11.17 | |
| | | | | | | | |
| **Cement Production-Process $CO_2$ (short tons) = Kiln System Total $CO_2$ - Kiln Fossil Fuel Combustion $CO_2$** | | | | **1,415,030** | | | **Conversion MT to Ton** |
| | | | | | | | |
| **Total Facility $CO_2$ (short tons) = Kiln System $CO_2$ + Non-Kiln $CO_2$** | | | | 2,127,798.91 | 76.73 | 11.2 | MDE ECR |
| | | | | | | | |

| Holcim | Consumption | Units | % Biomass | $CO_2$ Emissions (metric tons) | $CH_4$ Emissions (metric tons $CH_4$) | $N_2O$ Emissions (metric tons $N_2O$) | Source of Data |
|---|---|---|---|---|---|---|---|
| **Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category Exhausted to CEM Stack** | | | | | | | |
| -Coal | 67,130 | Short Tons | | 147,680.0 | 1.56 | 2.330 | MDE ECR |
| - #2 Oil | 197,684 | Gallons | | 1,804.0 | 0.020 | 0.140 | MDE ECR |
| - Tire | 1,921 | Short Tons | | 5,368.0 | 0.05 | 0.070 | MDE ECR |
| **Kiln Fossil Fuel Alone $CO_2$ (Calculation)** | | | | **154,852.0** | **1.63** | **2.44** | Sum |
| | | | | | | | |
| **Non-Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category** | | | | | | | |
| Raw Meal - # 2 Oil | | Gallons | | | | | |
| | | | | | | | |
| **Kiln System Total $CO_2$ (CEM Measured).** | | | | **383,002** | **16.88** | **0.00** | |
| **Kiln Fossil Fuel Alone $CO_2$ (Calculation)** | | | | **154,852** | **1.63** | **2.44** | |
| **Cement Process $CO_2$ (metric tons) = (Total Kiln $CO_2$) - (Kiln Fossil Fuel Alone $CO_2$)** | | | | **228,150** | **52** | **7.4** | |
| **Total Facility $CO_2$ Emission = (Kiln System Total $CO_2$) + (Non Kiln $CO_2$)** | | | | **383,002** | **16.88** | **2.44** | |
| **Kiln System Total $CO_2$ (CEM Measured) (short tons)** | | | | **422,188** | **18.61** | **0.00** | |
| **Kiln Fossil Fuel Alone $CO_2$ (Calculated) (short tons)** | | | | **170,695.23** | **1.8** | **2.7** | |
| **Cement Process $CO_2$ (short tons) = (Total Kiln $CO_2$) - (Kiln Fossil Fuel Alone $CO_2$)** | | | | **251,489.75** | **57** | **8.2** | |
| **Total Facility $CO_2$ Emission(short tons) = (Kiln System Total $CO_2$) + (Non Kiln $CO_2$)** | | | | **422,183.10** | **18.61** | **2.69** | |

| MD TOTAL CEMENT GHG EMISSIONS (Lehigh + Holcim) | $CO_2$ Emissions |
|---|---|
| **MD Summary Cement Process $CO_2$ Emissions (short tons)** | **1,666,519** |
| | |
| **MD Summary Cement Process $CO_2$ Emissions (metric tons)** | **1,511,840** |
| | |
| **MD Summary Cement Process $CO_2$ Emissions (MMTCO$_2$E)** | **1.51** |

## Table 6-3: Iron and Steel Industry Process $CO_2$ Emissions.

| Source | Pollutant | $CO_2$ Emissions (metric tons) | $CO_2$ Emissions (short tons) | Data Source |
|---|---|---|---|---|
| **Bleeders** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| | $CH_4$ | 0.00 | 0.00 | |
| | $N_2O$ | 0.00 | 0.00 | |
| **L Blast Furnace** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| | $CH_4$ | 0.0. | 0.00 | |
| | $N_2O$ | | - | |
| **Sinter Plant** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| **BOF** | $CO_2$ | 0.0 | 0.0 | MDE ECR |
| **Total** | $CO_2$ | 0.0 | 0.0 | |
| | $CH_4$ | 0.0 | 0.0 | |
| | $N_2O$ | 0.00 | 0.00 | |

## Table 6-4: Soda Ash Consumption $CO_2$ Emissions.

| | Consumption (Metric Tons) | Emission Factor (t $CO_2$/t production) | Emissions ($MTCO_2E$) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| Soda Ash | 95,344 | 0.4150 | 39,568 | **0.040** |

## Table 6-5: Limestone and Dolomite Use $CO_2$ Emissions.

| | Consumption (Metric Tons) | Emission Factor (t $CO_2$/t production) | Emissions ($MTCO_2E$) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| Limestone | 331,571 | 0.44 | 145,891 | **0.146** |

## Table 6-6: 2017 Non-Fertilizer Urea Use $CO_2$ Emissions.

| | Non-Fertilizer Consumption (Metric Tons) | Emission Factor (mt $CO_2$/mt activity) | Emissions ($MTCO_2E$) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| Urea | 2,013 | 0.73 | 1,469 | 0.001469 |

## Table 6-7: $SF_6$ Emissions from Electrical T&D[1] System.

| | | |
|---|---|---|
| Total US $SF_6$ Emissions from Electric Power T & D ($MMTCO_2E$) | 2.51E+06 | A |
| $SF_6$ GWP | 23,900 | B |
| US Total $SF_6$ Consumed (metric tons) | 105.09 | 'C = A/B |
| | | |
| Total US Electric Sales (MWh) (2017) | 3,681,995 | D |
| MD Total Electric Sales (MWh) (2017) | 59,174 | E |
| MD Apportioned $SF_6$ Consumption (metric tons) | 1.6890 | $F = C \times \frac{E}{D}$ |
| | | |
| Emission Factor | 1 | G |
| $SF_6$ Emissions (metric tons) | 1.6890 | H= G*F |
| $SF_6$ Emissions ($MTCO_2E$) | 40,367.04 | I=H*B |
| $SF_6$ Emissions ($MMTCO_2E$) | **0.040367** | J=I/1E-06 |

## Table 6-8: HFC & PFCs Emissions from ODS Substitutes

| | |
|---|---|
| Total US GHG 2017 Emissions from ODS substitute ($MMTCO_2E$) | 159.10 |
| | |
| MD 2017 Population | 6,052,177 |
| | |
| US 2017 Population | 325,719,178 |
| | |
| Apportioned State Emissions ($MMTCO_2E$) | **2.9566** |
| | |

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[1] T&D: Transmission and Distribution

# 7.0 Fossil Fuel Production Industry

## 7.1 OVERVIEW

The inventory for this subsector of the Energy Supply sector includes methane ($CH_4$), nitrous oxide ($N_2O$), and carbon dioxide ($CO_2$) emissions associated with the production, processing, transmission, and distribution of fossil fuels in Maryland. The emissions from the Fossil Fuel Production Industry in Maryland include emissions from natural gas systems (including production, transmission, venting and flaring, and distribution) and coal production. There is no oil production or oil or natural gas processing in Maryland.

**Natural Gas Production:** In natural gas production, wells are used to withdraw raw gas from underground formations. Wells must be drilled to access the underground formations, and often require natural gas well completion procedures or other practices that vent gas from the well depending on the underground formation. The raw gas commonly requires treatment in the form of separation of gas/liquids, heating, chemical injection, and dehydration before being compressed and injected into gathering lines. Combustion emissions, equipment leaks, and vented emissions arise from the wells themselves, gathering pipelines, and all well-site natural gas treatment processes and related equipment and control devices.[1] Methane emissions estimation from the natural gas production depends on the number of producing wellheads and the amount of produced natural gas.

**Natural Gas Venting and Flaring:** The final step after a well is drilled is to clean the well bore and reservoir near the well. This is accomplished by producing the well to pits or tanks where sand, cuttings, and other reservoir fluids are collected for disposal. This step is also useful to evaluate the well production rate to properly size the production equipment.[2] The natural gas produced from this completion process is either vented to atmosphere or flared. During normal operation of the natural gas production, natural gas liquids and various other constituents from the raw gas are separated, resulting in "pipeline quality" gas that is compressed and injected into the transmission pipelines. These separation processes include acid gas removal, dehydration, and fractionation. Methane emissions produced from this separation process are either vented to atmosphere or flared. Methane emissions estimation depends on the number and size of gas processing facilities.

**Natural Gas Transmission:** Natural gas transmission involves high pressure, large diameter pipelines that transport natural gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies or to large volume customers. A variety of facilities support the overall system, including metering stations, maintenance facilities, and compressor stations located along pipeline routes. Compressor station facilities containing large reciprocating and / or centrifugal compressors, move the gas throughout

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[1] EPA GREENHOUSE GAS EMISSIONS REPORTING FROM THE PETROLEUM AND NATURAL GAS INDUSTRY- (BACKGROUND TECHNICAL SUPPORT DOCUMENT) http://www.epa.gov/climatechange/emissions/downloads10/Subpart-W_TSD.pdf.

[2] Methane Emission Factor Development Project for Select Sources in the Natural Gas Industry http://www.utexas.edu/research/ceer/GHG/files/Task-1-Update-Draft.pdf.

the transmission pipeline system. Methane emissions estimation from the natural gas transmission depends on the number and size of compressor stations and the length of transmission pipelines.[1]

Natural gas is also injected and stored in underground formations, or stored as LNG in above ground storage tanks during periods of low demand (e.g., spring or fall), and then withdrawn, processed, and distributed during periods of high demand (e.g., winter and summer). Compressors, pumps, and dehydrators are the primary contributors to methane emissions from these underground and LNG storage facilities. Emission estimation from such facilities will depend on the number of storage stations.
Imported and exported LNG also requires transportation and storage. These processes are similar to LNG storage and require compression and cooling processes. GHG emissions in this segment are related to the number of LNG import and export terminals and LNG storage facilities.

**Natural Gas Distribution:** Natural gas distribution pipelines take high-pressure gas from the transmission pipelines at “city gate” stations, reduce and regulate the pressure, and distribute the gas through primarily underground mains and service lines to individual end users. There are also underground regulating vaults between distribution mains and service lines. GHG emissions from distribution systems are related to the pipelines, regulating stations and vaults, and customer/residential meters. Equipment counts and GHG emitting practices can be related to the number of regulating stations and the length of pipelines.

**Coal Mining:** Methane ($CH_4$) is produced during the process of coal formation.[1] Only a fraction of this produced methane remains trapped under pressure in the coal seam and surrounding rock strata. This trapped methane is released during the mining process when the coal seam is fractured. Methane released in this fashion will escape into the mine works, and will eventually escape into the atmosphere. The amount of methane ($CH_4$) released during coal mining depends on a number of factors, the most important of which are coal rank, coal seam depth, and method of mining. Underground coal mining releases more methane than surface or open-pit mining because of the higher gas content of deeper seams.

$CH_4$ is a serious safety threat in underground coal mines because it is highly explosive in atmospheric concentrations of 5 to 15 percent. There are two methods for controlling $CH_4$ in underground mines: use of ventilation systems and use of degasification systems. Ventilation systems are employed at most underground mines, but in especially gassy mines, the use of a ventilation system alone may be inadequate to degasify a mine so that it meets federal regulations with regard to maximum $CH_4$ concentrations. In such cases, a degasification system may be installed to help degasify the mine prior to, during, or after mining. The $CH_4$ recovered from these systems is usually of sufficient quality that the $CH_4$ can be sold to a pipeline or used for any number of applications, including electricity generation. Methane emissions from coal mining are estimated from the sum of emissions from underground mining, surface mining, post-mining activities, and emissions avoided due to recovery.

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[1] CH4 EMISSIONS: COAL MINING AND HANDLING (IPCC -*Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories)*
http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_7_Coal_Mining_Handling.pdf.

## 7.2 DATA SOURCES

- U.S Department of Transport, Office of Pipeline Safety (OPS). http://phmsa.dot.gov/pipeline/library/data-stats
- EIA's Number of Producing Wells. https://www.eia.gov/dnav/ng/NG_PROD_WELLS_S1_A.htm
- EIA States Energy Data- Maryland Natural Gas Consumption By End Use: https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm
- Maryland Department of the Environment, Maryland Bureau of Mines Coal Division**.** https://mde.maryland.gov/programs/LAND/mining/Pages/BureauofMinesAnnualReports.aspx
- U.S Department of Transport, Office of Pipeline Safety (OPS). " Distribution and Transmission Annuals data: 2010 -Present" https://cms.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-summary-statistics
- Emission Inventory Improvement Program (EIIP), *Volume VIII: Chapter 5.*[1]
- Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter 1.[2]
- Maryland Department of the Environment Bureau of Mines. https://mde.maryland.gov/programs/land/mining/pages/bureauofminesannualreports.aspx

## 7.3 GREENHOUSE GAS INVENTORY METHODOLOGY

2017 emissions from natural gas production, transmission and distribution are estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software default emission factors and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the natural gas and oil system. Pipeline natural gas combustion GHG emission was estimated with the SIT fossil fuel combustion method and emission factors. Emissions were estimated by multiplying the SIT default emissions factor by the activities data for each section.

### 7.3.1 Carbon Dioxide ($CO_2$) Direct Emissions

**Table 7-1: Natural Gas Compressor Combustion Activity Data.**

| | Activity Data and Emission factors Required | Activity Data Sources |
|---|---|---|
| Natural Gas – Combustion as Pipeline fuel | Billion Btu of natural gas consumed as pipeline fuel. | EIA[3] |

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[1] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005

[2] EIIP, *Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.

[3] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm

#### 7.3.1.1 Natural Gas – Compressor Engines.

Compressor stations, which maintain the pressure in the natural gas transmission and distribution pipeline, generally include upstream scrubbers, where the incoming gas is cleaned of particles and liquids before entering the compressors. Reciprocating engines and turbines are used to drive the compressors. Compressor stations normally use pipeline gas to fuel the compressor. They also use the gas to fuel electric power generators to meet the compressor stations' electricity requirements.

Maryland 2017 GHG emissions from pipeline natural gas consumption for compressor station were estimated using Equation 6.0. EIA State's natural gas pipeline and distribution use data (as pipeline natural gas) provided in Million cubic feet were multiplied by state specific natural gas heat content[1] to obtain State's Natural Gas Pipeline and Distribution Use in British thermal units (Btu). Btu data was multiply by emissions factors supplied by EPA in SIT to estimate emissions from pipeline natural combustion in 2017.

Equation 6.0: Emission Equation for Natural Gas Production, Transmission and Distribution

$$\text{Emissions }(\text{MTCO}_2\text{E}) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times 0.90718 \times 44/12}{1{,}000{,}000}$$

Where:

Emissions = Total emissions from the Production, Transmission and Distribution of Natural Gas
Consumption = Quantity of Natural Gas (BBtu)
Emission Factor = Emission Factor
0.0005 = Conversion Factor (Lbs to Tons)
0.90718 = Conversion Factor (Tons to Metric Tons)
44/12 = Conversion Factor (Carbon to $CO_2$)
1,000,000 = Conversion Factor (Metric Tons to Million Metric Tons)

#### 7.3.1.2 Natural Gas Combustion –Vented and Flared

Since no new natural gas production well was developed in Maryland in 2017, no emission was estimated for this sub section of the inventory. The U.S. Energy Information Administration (EIA)[2] does not report any natural gas venting and flaring in Maryland.

### 7.3.2 Additional Direct Emissions ($CH_4$, $N_2O$).

To estimate methane ($CH_4$) and nitrous oxide ($N_2O$) emissions from natural gas systems, MDE followed the general methodology outlined in the EIIP guidance.[3] Maryland specific activity data in 2017 (see table 7.2) were multiplied by the respective EPA SIT default emissions factors to estimate

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[1] EIA State Energy Data System 2017 Production Technical Notes; https://www.eia.gov/state/seds/sep_prod/Prod_technotes.pdf

[2] EIA's Natural Gas Pipeline and Distribution Use (MMcf). https://www.eia.gov/dnav/ng/ng_sum_lsum_a_EPG0_vgp_mmcf_a.htm

[3] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005

emissions from natural gas systems. Similarly, $CH_4$ and $N_2O$ emissions from coal mining operations were estimated using the EPA SIT and the EIIP guidance[1]. The year 2017 coal production data was obtained from the 2017 Maryland Bureau of Mines Annual Report[2].

**Table 7-2: Natural Gas Activity Data.**

| | **Activity Data and Emission factors Required** | **Activity Data Sources** |
|---|---|---|
| **Natural Gas – Production.** | Number of Wells | EIA[3] |
| **Natural Gas - Transmissions** | Miles of transmission pipelines | OPS[4] |
| | Number of gas processing plants | |
| | Number of gas transmission compressor stations | |
| | Number of gas storage compressor station. | |
| **Natural Gas - Distribution** | Miles of cast iron distribution pipeline | OPS |
| | Miles of unprotected steel distribution pipelines | |
| | Miles of protected steel distribution pipeline | |
| | Miles of plastic distribution pipelines | |
| | Number of services | |
| | Number of unprotected steel services | |
| **Natural Gas – Combustion as Pipeline fuel** | Billion Btu of natural gas consumed as pipeline fuel. | EIA[5] |
| **Coal Mining** | Metric tons of coal produced | MDE |

### 7.3.2.1 Natural Gas Production

Emissions from Natural Gas Production are calculated as the sum of methane emissions from the three categories of production sites: onshore wells, offshore shallow water platforms, and offshore deepwater platforms. Emissions from the natural gas production are estimated using Equation 6.2

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[1] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 4. "Methods for Estimating Methane Emissions from Coal Mining", March 2005.

[2] Maryland Bureau of Mines. Annual Report. https://mde.maryland.gov/programs/land/mining/pages/bureauofminesannualreports.aspx

[3] US Department of Energy, Energy Information Administration, "Natural Gas Navigation- Maryland Natural Gas Number of Gas and Gas Condensate Wells," accessed from: http://www.eia.gov/dnav/ng/hist/na1170_smd_8a.htm.

[4] U.S Department of Transport, Office of Pipeline Safety, "2017 Distribution and Transmission Annuals Data" from:. https://cms.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-natural-gas-transmission-gathering-systems

[5] US Department of Energy, Energy Information Administration, Natural Gas Pipeline and Distribution Use (MMcf). https://www.eia.gov/dnav/ng/ng_sum_lsum_a_EPG0_vgp_mmcf_a.htm

by multiplying the number of gas production sites (wells or platforms) by a site-specific emission factor. The resulting methane emissions are then converted to metric tons of $CO_2$ equivalent and metric tons of carbon equivalent, and summed across the three types of production sites. The State of Maryland does not have any offshore water platforms; therefore, all emissions estimated are from Maryland onshore natural gas production.

Equation 6.2: Emission Equation for Natural Gas Production

| | | | | | | |
|---|---|---|---|---|---|---|
| Emissions<br>($MTCO_2E$) | = | Activity Data<br>(No. of Wells) | x | Emission Factor<br>(metric tons $CH_4$/Year/Activity Unit) | x | GWP |

Where:

Emissions = Total emissions from Natural Gas Combustion
Activity Data = Number of Natural Gas Wellheads in Maryland
Emission Factor = Emission Factor
GWP = Global Warming Potential of $CH_4$

### 7.3.2.2 Natural Gas Transmission.

Emissions from Natural Gas Transmission are calculated as the sum of methane emissions from the pipelines that transport the natural gas, the natural gas processing stations, the natural gas transmission compressor stations, and gas storage compressor facilities. Emissions from the natural gas transmission are estimated using Equation 6.3, by multiplying the activity factor (e.g., miles of pipeline or number of stations) for each source and the source-specific emission factor. Methane emissions are then converted to metric tons of $CO_2$ equivalent and metric tons of carbon equivalent, and then summed across all sources.

Equation 6.3: Emission Equation for Natural Gas Systems

| | | | | | | |
|---|---|---|---|---|---|---|
| Emissions<br>($MTCO_2E$) | = | Activity Data<br>(BBtu) | x | Emission Factor<br>(metric tons $CH_4$/ Activity data units) | x | GWP |

Where:

Emissions = Total emissions from Natural Gas Transmission
Activity Data = Varies but includes: Miles of transmission pipeline, Number of gas processing plants, Number of gas storage compressor stations, Number of gas transmission compressor stations
Emission Factor = Emission Factor
GWP = Global Warming Potential of $CH_4$

### 7.3.2.3 Natural Gas Distribution

Emissions from Natural Gas Distribution are calculated as the sum of methane emissions from the natural gas distribution pipelines and end services. Methane emissions from the distribution pipelines were estimated by multiplying the activity factor for each type of pipeline (e.g., miles of plastic distribution pipeline) by the corresponding emission factor. Methane emissions from the end services were estimated using Equation 6.4 by multiplying the number of services by a general emission factor and type-specific emission factors. The combined methane emissions from the pipeline and services are then converted to metric tons of $CO_2$ equivalent and metric tons of carbon equivalent, and summed.

Equation 6.4: Emission Equation for Natural Gas Distributions

Emissions ($MTCO_2E$) = Activity Data (BBtu) x Emission Factor (metric tons $CH_4$/ Activity data units) x GWP

Where:

Emissions = Total emissions from Natural Gas Distribution
Activity Data = Varies but includes: Total number of services, Number of unprotected steel services, Number of protected steel services, Miles of cast iron pipeline, Miles of protected steel pipe, Miles of unprotected steel pipe, Miles of plastic pipe
Emission Factor = Emission Factor
GWP = Global Warming Potential of $CH_4$

### 7.3.2.4 Natural Gas Venting and Flaring.

Emissions from Natural Gas Venting and Flaring are calculated as the sum of the percent of methane emissions flared (20%) and the percent of the methane emissions vented (80%) into the atmosphere during the natural gas production well development process. Since no new well was developed in 2017, no emissions were estimated for this section in 2017

### 7.3.2.5 Coal Mining.

There are three sources of methane ($CH_4$) emissions from coal mining: underground mining, surface mining, and post-mining activities. Emissions from post-mining activities may be further subdivided into emissions from underground-mined coal and emissions from surface mined coal. Net methane emissions from coal mining are estimated as the sum of methane emissions from underground mining, surface mining, and post-mining activities.

Total Emissions = **Emissions from Underground Mines** + **Emissions from Surface Mines** + **Emissions From Post-Mining Emissions**

Emissions from the surface coal mining operation are estimated by multiplying the amount of coal produced (tons) by a basin-specific emission factor.

Surface Mining $CH_4$ Emissions ($ft^3$) = Coal Production (short tons) x Basin-Specific Emissions Factor ($ft^3$/ short tons)

Methane emissions from underground mines, accounted for $CH_4$ recovered by the two controlling measures deployed in underground mining operations: methane emitted from ventilation systems and methane emitted from degasification systems. The net emissions from the degasification systems and the methane recovered from degasification system (and used for energy purpose) are added to the measured ventilation emissions to estimated methane emissions from the underground mines.

$$\text{Underground Mining } CH_4 \text{ Emissions (Mcf)} = \text{Measured Ventilation Emissions (Mcf)} + \text{Degasification System Emissions (Mcf)} - \text{Methane Recovered from Degasification System and used for Energy (Mcf)}$$

Emissions from the post mining operations such as transportation and coal handling are estimated by summing the post-mining emissions from underground and surface mines. The emissions are calculated as the product of coal production times an emission factor specific to the basin and mine-type. The resulting methane emissions are then converted to metric tons of $CO_2$ equivalent and metric tons of carbon equivalent. No emissions were estimated for underground coal mining operation in Maryland.

$$\text{Post-Mining Activities } CH_4 \text{ Emissions } (ft^3) = \text{Coal Production (short tons)} \quad \text{Basin/Mine -Specific Emissions Factor } (ft^3\text{/ short tons})$$

Emissions from abandoned coal mines are calculated by summing the emissions from mines that are vented, sealed, or flooded.

## 7.4 GREENHOUSE GAS INVENTORY RESULTS

**Table 7.3: 2017 GHG Emissions from Pipeline Natural Gas Combustion**

| | $CO_2$ (lbs/MMBtu) | $N_2O$ (Mt/BBtu) | $CH_4$ (Mt/BBtu) | Total Emissions |
|---|---|---|---|---|
| **Emission Factors** | 31.87 | 9.496E-05 | 0.00094955 | |
| Total Natural Gas Consumption (Billion Btus) | 8,342.5 | 8,342.5 | 8,342.5 | |
| Combustion Efficiency (%) | 100% | 100% | 100% | |
| **Emissions ($MMTCO_2E$)** | 0.000442 | 0.0002456 | 0.000166 | **0.000854** |

## Table 7.4: 2017 GHG Emissions from Natural Gas Production

| Production Sector | Activity Data | Emission Factor (metric tons $CH_4$ per year per activity unit) | $CH_4$ Emissions (metric tons) | $CH_4$ Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| Total number of wells | 5 | 4.10 | 20.51 | 0.00043 |
| **Total** | | | **20.51** | **0.00043** |

## Table 7.5: 2017 GHG Emissions from Natural Gas Transmission

| Transmission Sector | Activity Data | Emission Factor (metric tons $CH_4$ per year per activity unit) | $CH_4$ Emissions (metric tons) | $CH_4$ Emissions ($MMTCO_2E$) |
|---|---|---|---|---|
| Miles of transmission pipeline | 995 | 0.6185 | 616 | 0.01293 |
| Number of gas transmission compressor stations | 6 | 983.7 | 5,875 | 0.12338 |
| Number of gas storage compressor stations | 1 | 964.1 | 1,440 | 0.03023 |
| **Total** | | | **7,931** | **0.16654** |

## Table 7.6: 2017 GHG Emissions from Natural Gas Distribution

| **Distribution Sector** | **Activity Data** | **Emission Factor** (metric tons $CH_4$ per year per activity unit) | **$CH_4$ Emissions** (metric tons) | **$CH_4$ Emissions** ($MMTCO_2E$) |
|---|---|---|---|---|
| **Distribution pipeline** | | | | |
| Miles of cast iron distribution pipeline | 1,222 | 5.80 | 7,092.15 | 0.149 |
| Miles of unprotected steel distribution pipeline | 209 | 2.12 | 442 | 0.009 |
| Miles of protected steel distribution pipeline | 5,310 | 0.06 | 319 | 0.007 |
| Miles of plastic distribution pipeline | 8,243 | 0.37 | 3,064 | 0.064 |
| **Services** | | | | |
| Total number of services | 1,043 | 0.02 | 16 | 0.00033 |
| Number of unprotected steel services | 75,380 | 0.03 | 2,469 | 0.052 |
| Number of protected steel services | 126,342 | 0.00 | 430 | 0.009 |
| **Total** | | | **13,831** | **0.290** |

## Table 7.7: 2017 $CH_4$ Emissions from Coal Mining.

| **Underground Mines** | | | | | |
|---|---|---|---|---|---|
| **Measured Ventilation Emissions (mcf)** | **Degasification System Emissions (mcf)** | **Methane Recovered from Degasification Systems and Used for Energy (mcf)** | **Emissions (mcf $CH_4$)** | **Emissions ($MTCH_4$)** | **Emissions ($MTCO_2E$)** |
| 0 | 0 | 0 | 0.00 | - | - |

| **Surface Mines** | | | | |
|---|---|---|---|---|
| Surface Coal Production ('000 short tons) | Basin-specific EF ($ft^3$/short ton) | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| 1,070 | 119.0 | 127,341 | 2,445 | 51,344 |

| **Post Mining Activity – Underground Mines** | | | | |
|---|---|---|---|---|
| Coal Production ('000 short tons) | Basin & Mine-specific EF ($ft^3$/short ton) | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| 1,382 | 45.0 | 62,180 | 1,194 | 25,071 |
| **Post Mining Activity – Surface Mines** | | | | |
| Coal Production ('000 short tons) | Basin- & Mine-specific EF ($ft^3$/short ton) | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| 1,070 | 19.3 | 20,693 | 397 | 8,343 |
| | | | | |
| **Post Mining Activity – SubTotal** | | Emissions ('000 $ft^3$ $CH_4$) | Emissions ($MTCH_4$) | Emissions ($MTCO_2E$) |
| | | 82,873 | 1,591 | 33,414 |

| **Total Coal Mining Emissions ($MTCO_2e$)** | **84,758** |
|---|---|
| **Total Coal Mining Emissions ($MMTCO_2e$)** | **0.84758** |

# 8.0 Agriculture

## 8.1 OVERVIEW

The emissions discussed in this section refer to non-energy methane ($CH_4$) and nitrous oxide ($N_2O$) emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon in agricultural soils are also covered. Energy emissions (combustion of fossil fuels in agricultural equipment) are included in the residential, commercial, and industrial (RCI) sector estimates.

There are two livestock sources of greenhouse gas (GHG) emissions: **enteric fermentation** and **manure management**. Methane emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit $CH_4$ as a by-product. More $CH_4$ is produced in ruminant livestock because of digestive activity in the large fore-stomach. Methane and $N_2O$ emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more $CH_4$ is produced because decomposition is aided by $CH_4$-producing bacteria that thrive in oxygen-limited aerobic conditions. Under aerobic conditions, $N_2O$ emissions are dominant.

The management of **agricultural soils** can result in $N_2O$ emissions and net fluxes of carbon dioxide ($CO_2$) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in $N_2O$ emissions. Nitrogen additions drive underlying soil nitrification and denitrification cycles, which produce $N_2O$ as a by-product. The emissions estimation methodologies used in this inventory account for several sources of $N_2O$ emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, sewage sludge, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation. Both direct and indirect emissions of $N_2O$ occur from the application of manure, fertilizer, and sewage sludge to agricultural soils. Direct emissions occur at the site of application. Indirect emissions occur when nitrogen leaches to groundwater/surface runoff or volatilizes and is transported off-site before entering the nitrification/denitrification cycle.

The net flux of $CO_2$ in agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of $CO_2$ into agricultural soils. In addition, soil disturbance from the cultivation of histosols releases large stores of carbon from the soil to the atmosphere. Other agricultural soils emissions include $CH_4$ and $N_2O$ from crop residue burning. Also, $CH_4$ emissions occur during rice cultivation. Finally, the practice of adding limestone and dolomite to agricultural soils results in $CO_2$ emissions.

## 8.2 DATA SOURCES

- United States Department of Agriculture (USDA) http://www.nass.usda.gov/Statistics_by_State/Maryland/index.asp.
- Maryland Department of Agriculture, State Chemist Section-Product Registration. http://mda.maryland.gov/plants-pests/Pages/state_chemist.aspx.
- Food and Agricultural Policy Research Institute (FAPRI) http://www.fapri.iastate.edu/outlook/2007/
- US EPA State Greenhouse Gas Inventory Tool (SIT).
- EIIP, *Volume VIII*: Chapter 8.[1]
- EIIP, *Volume VIII*: Chapter 10.[2]
- EIIP, *Volume VIII*: Chapter 11.[3]

## 8.3 GREENHOUSE GAS INVENTORY METHODOLOGY

Maryland Agricultural GHG emission was estimated using the (US EPA) State Greenhouse Gas Inventory Tool (SIT) software with reference to the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector [5, 6, 7] and the national GHG inventory.[4] The input data that are needed to estimate these emissions are the populations of domestic animals, metric tonnes of nitrogen fertilizer consumed, metric tonnes of crop produced and the agriculture-waste management system adopted. The input data are multiplied by the default SIT emission factor developed for the US for each type of animal. The input data used for these calculations are shown in Table 8.1.

### 8.3.1 Carbon Dioxide ($CO_2$) Direct Emissions

Estimation of carbon dioxide ($CO_2$) emission from urea fertilizer, limestone and dolomite application (liming) to agriculture soils in Maryland was accounted for under the Land Use, Land use change and Forestry section of the inventory.

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[1] EIIP, Volume VIII: Chapter 8." Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004

[2] EIIP, Volume VIII: Chapter 10." Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004.

[3] EIIP, Volume VIII: Chapter 11." Methods for Estimating Greenhouse Gas Emissions from Field Burning of Agricultural Residues", August 2004

[4] US Inventory of greenhouse Gas Emissions and Sinks: 1990 -2016, US Environmental Protection Agency, (2018). (http://epa.gov/climatechange/emissions/index.html )

### 8.3.2 Additional Direct Emissions ($CH_4$, $N_2O$)

#### 8.3.2.1 Methane Emissions from Domestic Animals –Enteric Fermentation.

Methane produced during digestion is a significant part of the global methane budget. As food is digested, microbes break down the organic matter creating methane by enteric fermentation. Ruminant animals, such as cows, emit an especially large amount of methane through their digestive process. In Maryland, the most significant methane from animal sources originates from livestock on farms.

#### 8.3.2.2 Methane and $N_2O$ from Manure management

Methane is produced by the anaerobic decomposition of the organic matter in manure. The amount of methane produced by manure varies depending on the storage system used to manage it. Emissions estimates from manure management are based on manure that is stored and treated at livestock operations. The emissions are estimated as a function of the domestic animal population, and the types of waste management systems used.

#### 8.3.2.3 Methane and $N_2O$ Emissions from Agricultural soils.

Emissions from manure that is applied to agricultural soils as an amendment or deposited directly to pasture and grazing land by grazing animals are accounted for in this section; in addition, emissions from fertilizer application to agricultural soil are also estimated under this subsection. Synthetic fertilizer emissions were estimated by multiplying the total amount of fertilizer nitrogen consumed in Maryland by the SIT default emissions factor. This emissions factor is the amount of $N_2O$, in kilograms, emitted in each year, per kilogram of nitrogen applied to the soil in that year. The $N_2O$ emissions from manure application to agriculture were estimated as a function of domestic animal population in the state in the inventory years.

Emissions from agriculture residue burnings was estimated by multiplying the amount (e.g., bushels or tons) of each crop produced by a series of factors to calculate the amount of crop residue produced, the resultant dry matter, the carbon/nitrogen content of the dry matter, and the fraction of residue burned.

Details of the input data used for the estimations are described in the input data tables;

## Table 8.0: 2017 MD Input Data - Animal Populations

| | **Number of Animals (thousand head)** |
|---|---|
| **Dairy Cattle** | |
| Dairy Cows | 53 |
| Dairy Replacement Heifers | 28 |
| **Beef Cattle** | |
| Feedlot Heifers | 4 |
| Feedlot Steer | 7 |
| Bulls | 4 |
| Calves | 36 |
| Beef Cows | 42 |
| Beef Replacement Heifers | 10 |
| Steer Stockers | 15 |
| Heifer Stockers | 7 |
| **Swine** | |
| Breeding Swine | 2 |
| Market Under 60 lbs | 9 |
| Market 60-119 lbs | 7 |
| Market 120-179 lbs | 4 |
| Market over 180 lbs | 4 |
| **Poultry** | |
| Layers | |
| Hens > 1 yr | 2,292 |
| Pullets | 184 |
| Chickens | 12 |
| Broilers | 53,073 |
| Turkeys | 704 |
| **Other** | |
| Sheep on Feed | 0 |
| Sheep Not on Feed | 24 |
| Goats | 12 |
| Horses | 79 |

### Table 8.1: 2017 MD Input Data - Fertilizer Consumption.

| | Total Fertilizer Use (kg N) | Total N (kg) in Fertilizers (Calendar Year) |
|---|---|---|
| | | |
| **Synthetic** | 40,158,687 | 26,103,147 |
| | | |
| **Organic** | 26,724,473 | 26,724,473 |
| Dried Blood | - | - |
| Compost | - | - |
| Dried Manure | 486,298 | 486,298 |
| Activated Sewage Sludge | 25,853,131 | 25,853,131 |
| Other | 385,044 | 385,044 |
| *Dried Manure (%)* | 2 % | 2% |
| *Non-Manure Organics* | 26,238,175 | 23,238,175 |
| *Manure Organics* | 486,298 | 486,298 |

### Table 8.2: 2017 MD Input Data - Crop Productions.

| Crop Type | Units | Crop Production | Crop Production (metric tons) |
|---|---|---|---|
| Alfalfa | '000 tons | 140 | 127,008 |
| Corn for Grain | '000 bushels | 46,870 | 1,190,552 |
| All Wheat | '000 bushels | 12,540 | 341,282 |
| Barley | '000 bushels | 2,880 | 62,703 |
| Soybeans | '000 bushels | 17,903 | 487,243 |
| **TOTAL** | | | **2,208,787** |

### Table 8.3: 2017 MD Crop Residues Dry Matter Burned.

| Crop | Crop Production (metric tons) | Residue/Crop Ratio | Fraction Residue Burned | Dry Matter Fraction | Burning Efficiency | Combustion Efficiency | Amt of Dry Matter Burned (metric tons) |
|---|---|---|---|---|---|---|---|
| Barley | 62,703 | 1.2 | 0.03 | 0.93 | 0.930 | 0.880 | 771 |
| Corn | 1,190,552 | 1.0 | 0.03 | 0.91 | 0.930 | 0.880 | 11,911 |
| Peanuts | - | 1.0 | 0.03 | 0.86 | 0.930 | 0.880 | - |
| Rice | - | 1.4 |  | 0.91 | 0.930 | 0.880 | - |
| Soybeans | 487,243 | 2.1 | 0.03 | 0.87 | 0.930 | 0.880 | 9,835 |
| Sugarcane | - | 0.8 | 0.03 | 0 | 0.930 | 0.880 | - |
| Wheat | 341,282 | 1.3 | 0.03 | 0.93 | 0.930 | 0.880 | 4,486 |

### Table 8.4: 2017 $CH_4$ Generation from Manure Management

| | Number of Animals ('000 head) | Typical Animal Mass (TAM) (kg) | Volatile Solids (VS) [kg VS/1000 kg animal mass/day] | Total VS (kg/yr) | Max Pot. Emissions ($m^3$ $CH_4$/ kg VS) | Weighted MCF | $CH_4$ Emissions ($m^3$) |
|---|---|---|---|---|---|---|---|
| **Dairy Cattle** | | | | | | | |
| Dairy Cows | 53.0 | 680 | 10.0 | 130,365,037 | 0.24 | 0.118 | 3,697,660 |
| Dairy Replacement Heifers | 28.0 | 476 | 8.4 | 40,977,756 | 0.17 | 0.012 | 86,852 |
| **Beef Cattle** | | | | | | | |
| Feedlot Heifers | 3.9 | 420 | 4.4 | 2,668,401 | 0.33 | 0.013 | 11,556 |
| Feedlot Steer | 7.4 | 420 | 4.0 | 4,592,625 | 0.33 | 0.013 | 19,663 |
| Bulls | 4.0 | 750 | 5.2 | 6,613,800 | 0.17 | 0.011 | 12,368 |
| Calves | 36.0 | 118 | 6.4 | 9,938,833 | 0.17 | 0.011 | 18,586 |
| Beef Cows | 42.0 | 533 | 7.5 | 61,236,569 | 0.17 | 0.011 | 114,512 |
| Beef Replacement Heifers | 10 | 420 | 7.6 | 11,636,201 | 0.17 | 0.011 | 21,760 |
| Steer Stockers | 15.0 | 318 | 8.1 | 14,028,947 | 0.17 | 0.011 | 26,234 |
| Heifer Stockers | 7.0 | 420 | 8.6 | 9,111,271 | 0.17 | 0.011 | 17,038 |
| **Swine** | | | | | | | |
| Breeding Swine | 2.0 | 198 | 2.6 | 375,804 | 0.48 | 0.301 | 54,224 |
| Market Under 60 lbs | 9.00 | 16 | 8.8 | 459,059 | 0.48 | 0.300 | 66,142 |
| Market 60-119 lbs | 7.0 | 41 | 5.4 | 560,158 | 0.48 | 0.300 | 80,708 |
| Market 120-179 lbs | 4.0 | 68 | 5.4 | 534,693 | 0.48 | 0.300 | 77,039 |
| Market over 180 lbs | 4.0 | 91 | 5.4 | 715,473 | 0.48 | 0.300 | 103,086 |
| **Poultry** | | | | | | | |
| Layers | | | | | | | |
| Hens > 1 yr | 2,292.0 | 2 | 10.8 | 16,263,115 | 0.39 | 0.051 | 324,907 |
| Pullets | 184.0 | 2 | 9.7 | 1,172,614 | 0.39 | 0.051 | 23,427 |
| Chickens | 12.0 | 2 | 10.8 | 85,147 | 0.39 | 0.051 | 1,701 |
| Broilers | 53,072.7 | 1 | 15 | 261,515,729 | 0.36 | 0.015 | 1,412,185 |
| Turkeys | 704.0 | 7 | 9.7 | 16,949,082 | 0.36 | 0.015 | 91,525 |
| **Other** | | | | | | | |
| Sheep on Feed | 0 | 25 | 9.2 | - | 0.36 | 0.012 | - |
| Sheep Not on Feed | 24.0 | 80 | 9.2 | 6,451,200 | 0.19 | 0.011 | 13,481 |
| Goats | 12.0 | 64 | 9.5 | 2,672,640 | 0.17 | 0.011 | 4,997 |
| Horses | 80.0 | 450 | 10 | 129,921,750 | 0.33 | 0.011 | 472,429 |
| **TOTAL** | | | | | | | **6,752,079** |

## Table 8.5: 2017 $N_2O$ Generation from Manure Management.

|  | Number of Animals ('000 head) | Typical Animal Mass (TAM) (kg) | Total K-Nitrogen Excreted (kg) |
|---|---|---|---|
| **Dairy** |  |  |  |
| Dairy Cows | 53.0 | 680 | 7,852,125 |
| Dairy Replacement Heifers | 28.0 | 476 | 1,927,462 |
| **Beef Cattle** |  |  |  |
| Feedlot Heifers | 3.9 | 420 | 218,344 |
| Feedlot Steer | 7.4 | 420 | 422,465 |
| **Swine** |  |  |  |
| Breeding Swine | 2.0 | 198 | 29,269 |
| Market Under 60 lbs | 9.0 | 16 | 47,993 |
| Market 60-119 lbs | 7.0 | 41 | 56,016 |
| Market 120-179 lbs | 4.0 | 68 | 53,469 |
| Market over 180 lbs | 4.0 | 91 | 71,547 |
| **Poultry** |  |  |  |
| Layers |  |  |  |
| Hens > 1 yr | 2,292.0 | 2 | 1,189,617 |
| Pullets | 184.0 | 2 | 95,502 |
| Chickens | 12.0 | 2 | 8,672 |
| Broilers | 53,072.7 | 1 | 16,737,007 |
| Turkeys | 704.0 | 7 | 1,092,080 |
| **Other** |  |  |  |
| Sheep on Feed | 0.0 | 25 | - |
| Sheep Not on Feed | 24.0 | 80 | 315,360 |
| **TOTAL** |  |  | **30,118,367** |

## Table 8.6: 2017 Agriculture Crop Residue Nitrogen Generated (kg)

| Crop Type | Crop Production (metric tons) | Residue ; Crop Mass Ratio | Fraction Residue Applied | Residue Dry Matter Fraction | N Content of Residue | N Returned to Soils (kg) | N- content of aboveground Biomass for N-fixing Crop | N-Fixed by Crops (kg) |
|---|---|---|---|---|---|---|---|---|
| Alfalfa | 127,008 | 0 | 0 | 0.85 | NA | NA | 0.03 | 3,238,704 |
| Corn for Grain | 1,190,552 | 1 | 0.9 | 0.91 | 0.0058 | 5,655,359 |  | NA |
| All Wheat | 341,282 | 1.3 | 0.9 | 0.93 | 0.0062 | 2,302,361 |  | NA |
| Barley | 62,703 | 1.2 | 0.9 | 0.93 | 0.0077 | 484,940 |  | NA |
| Sorghum for Grain |  | 1.4 | 0.9 | 0.91 | 0.0108 |  |  | NA |
| Oats |  | 1.3 | 0.9 | 0.92 | 0.0070 |  |  | NA |
| Rye |  | 1.6 | 0.9 | 0.90 | 0.0048 |  |  | NA |
| Millet |  | 1.4 | 0.9 | 0.89 | 0.0070 |  |  | NA |
| Rice |  | 1.4 |  | 0.91 | 0.0072 |  |  | NA |
| Soybeans | 487,243 | 2.1 | 0.9 | 0.87 | 0.0230 | 18,426,977 | 0.03 | 39,422,794 |
| Peanuts |  | 1 | 0.9 | 0.86 | 0.0106 |  |  | - |
| Dry Edible Beans |  | 2.1 | 1.6 | 0.87 | 0.0168 |  |  | - |
| Dry Edible Peas |  | 1.5 | 0.9 | 0.87 | 0.0168 |  |  | - |
| Austrian Winter Peas |  | 1.5 | 0.9 | 0.87 | 0.0168 |  |  | - |
| Lentils |  | 2.1 | 1.6 | 0.87 | 0.0168 |  |  | - |
| Wrinkled Seed Peas |  | 1.5 | 0.9 | 0.87 | 0.0168 |  |  | - |
| Red Clover |  |  |  |  |  | NA |  | - |
| White Clover |  |  |  |  |  | NA |  | - |
| Birdsfoot Trefoil |  |  |  |  |  | NA |  | - |
| Arrowleaf Clover |  |  |  |  |  | NA |  | - |
| Crimson Clover |  |  |  |  |  | NA |  | - |
| **TOTAL** | **2,208,787** |  |  |  |  | **26,869,637** |  | **42,661,498** |

## 8.4 GREENHOUSE GAS INVENTORY RESULTS

### Table 8.7: 2017 $CH_4$ Emissions from Enteric fermentation

| Animal | Number of Animals ('000 head) | Emission Factor (kg $CH_4$/head) | Emissions (kg $CH_4$/year) | Emissions (MMT-$CH_4$/Year) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|
| **Dairy Cattle** | | | | | |
| Dairy Cows | 53.0 | 144.5 | 7,658,500 | 0.0077 | 0.161 |
| Dairy Replacement Heifers | 28.0 | 66.0 | 1,848,000 | 0.0018 | 0.039 |
| **Beef Cattle** | | | | | |
| Beef Cows | 42.0 | 94.4 | 3,964,800 | 0.0040 | 0.083 |
| Beef Replacement Heifers | 10.0 | 66.7 | 667,000 | 0.0007 | 0.014 |
| Heifer Stockers | 10.0 | 60.1 | 601,000 | 0.0006 | 0.013 |
| Steer Stockers | 15.0 | 57.9 | 868,500 | 0.0009 | 0.018 |
| Feedlot Heifers | 3.9 | 43.2 | 168,998 | 0.0002 | 0.004 |
| Feedlot Steer | 7.4 | 42.0 | 310,590 | 0.0003 | 0.007 |
| Bulls | 4.0 | 97.6 | 390,400 | 0.0004 | 0.008 |
| **Other** | | | | | |
| Sheep | 24.0 | 8.0 | 192,000 | 0.0002 | 0.004 |
| Goats | 12.0 | 5.0 | 60,000 | 0.0001 | 0.001 |
| Swine | 23.0 | 1.5 | 34,500 | 0.0000 | 0.001 |
| Horses | 79.1 | 18.0 | 1,423,800 | 0.0014 | 0.030 |
| **TOTAL** | | | | **0.0182** | **0.382** |

### Table 8.8: 2017 $CH_4$ Emissions from Manure Management

| | Emissions ($m^3$ $CH_4$) | Emissions (Metric Tons $CH_4$) | Emissions (MMT$CH_4$) | Emissions (MMT$CO_2$E) |
|---|---|---|---|---|
| **Dairy Cattle** | | | | |
| Dairy Cows | 3,697,660 | 2,448 | 0.002 | 0.051 |
| Dairy Replacement Heifers | 86,852 | 57 | 0.000 | 0.001 |
| **Beef Cattle** | | | | |
| Feedlot Heifers | 11,556 | 8 | 0.000 | 0.000 |
| Feedlot Steer | 19,663 | 13 | 0.000 | 0.000 |
| Bulls | 12,368 | 8 | 0.000 | 0.000 |
| Calves | 18,586 | 12 | 0.000 | 0.000 |
| Beef Cows | 114,512 | 76 | 0.000 | 0.002 |
| Beef Replacement Heifers | 21,760 | 14 | 0.000 | 0.000 |
| Steer Stockers | 26,234 | 17 | 0.000 | 0.000 |
| Heifer Stockers | 17,038 | 11 | 0.000 | 0.000 |
| **Swine** | | | | |
| Breeding Swine | 54,224 | 36 | 0.000 | 0.001 |
| Market Under 60 lbs | 66,142 | 44 | 0.000 | 0.001 |
| Market 60-119 lbs | 80,708 | 53 | 0.000 | 0.001 |
| Market 120-179 lbs | 77,039 | 51 | 0.000 | 0.001 |
| Market over 180 lbs | 103,086 | 68 | 0.000 | 0.001 |
| **Poultry** | | | | |
| Layers | | | | |
| Hens > 1 yr | 324,907 | 215 | 0.000 | 0.005 |
| Pullets | 23,427 | 16 | 0.000 | 0.000 |
| Chickens | 1,701 | 1 | 0.000 | 0.000 |
| Broilers | 1,412,185 | 935 | 0.001 | 0.020 |
| Turkeys | 91,525 | 61 | 0.000 | 0.001 |
| **Other** | | | | |
| Sheep on Feed | - | - | 0.000 | 0.000 |
| Sheep Not on Feed | 13,481 | 9 | 0.000 | 0.000 |
| Goats | 4,997 | 3 | 0.000 | 0.000 |
| Horses | 472,429 | 313 | 0.000 | 0.007 |
| **TOTAL** | **6,752,079** | **4,470** | **0.004** | **0.094** |

## Table 8.9: 2017 $CH_4$ from Agricultural Residue Burning

| Crop | Crop Production (metric tons) | C Content (m- tons C/m-tons dm) | Total C Released (metric tons C) | $CH_4$ - C Emission Ratio | $CH_4$ Emissions (metric tons $CH_4$) | $CH_4$ GWP | $CH_4$ Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|
| Barley | 62,703 | 0.4485 | 771 | 0.007 | 5.14 | 21 | 0.000011 |
| Corn | 1,190,552 | 0.4478 | 11911 | 0.007 | 79.41 | 21 | 0.001668 |
| Peanuts | - | 0.45 | - | 0.007 | - | 21 | - |
| Rice | - | 0.3806 | - | 0.007 | - | 21 | - |
| Soybeans | 487,243 | 0.45 | 9835 | 0.007 | 65.57 | 21 | 0.001377 |
| Sugarcane | - | 0.4235 | - | 0.007 | - | 21 | - |
| Wheat | 341,282 | 0.4428 | 4486 | 0.007 | 29.9 | 21 | 0.000628 |
| | | | | | | | |
| **Total $CH_4$ from Agriculture Residue Burning ($MMTCO_2E$)** | | | | | | | **0.003683** |

## Table 8.10: 2017 $N_2O$ from Agricultural Residue Burning

| Crop | Crop Production (metric tons) | N Content (m- tons N/m-tons dm) | Total N Released (metric tons N) | $N_2O$ -N Emission Ratio | ($N_2O$ - N) Emissions (metric tons $N_2O$) | $N_2O$ Emissions (metric tons $N_2O$) | $N_2O$ GWP | $N_2O$ Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|---|
| Barley | 62,703 | 0.0077 | 13.23 | 0.007 | 0.09 | 0.146 | 310 | 0.000045 |
| Corn | 1,190,552 | 0.0058 | 154.28 | 0.007 | 1.39 | 1.697 | 310 | 0.000526 |
| Peanuts | - | 0.0106 | - | 0.007 | - | 0 | 310 | - |
| Rice | - | 0.0072 | - | 0.007 | - | 0 | 310 | - |
| Soybeans | 487,243 | 0.023 | 502.69 | 0.007 | 3.11 | 5.53 | 310 | 0.001714 |
| Sugarcane | - | 0.004 | - | 0.007 | - | 0 | 310 | - |
| Wheat | 341,282 | 0.0062 | 62.81 | 0.007 | 0.3 | 0.691 | 310 | 0.000214 |
| | | | | | | | | |
| **Total $N_2O$ from Agriculture Residue Burning ($MMTCO_2E$)** | | | | | | | | **0.002500** |

## Table 8.11: 2017 $N_2O$ Emissions from Manure Management

| | Number of Animals ('000 head) | Total K-Nitrogen Excreted (kg) | Unvolatilized N from Manure in Anaerobic Lagoons and Liquid Systems (kg) | Unvolatilized N from Manure in Solid Storage, Drylot & Other Systems (kg) | Emissions from Anaerobic Lagoons and Liquid Systems (kg N2O-N) | Emissions from Solid Storage, Drylot, & Other Systems (kg N2O-N) | Total $N_2O$ Emissions (kg $N_2O$) | Emissions (MTCE) | Emissions (MMTCE) | Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dairy** | | | | | | | | | | |
| Dairy Cows | 53.0 | 7,852,125 | 2,125,872 | 1,831,372 | 2,126 | 36,627 | 60,898 | 5,149 | 0.00515 | 0.01888 |
| Dairy Replacement Heifers | 28.0 | 1,927,462 | 521,838 | 944,902 | 522 | 18,898 | 29,697 | 2,511 | 0.00251 | 0.00921 |
| **Beef Cattle** | | | | | | | | | | |
| Feedlot Heifers | 3.9 | 218,344 | NA | 218,344 | NA | 4,367 | 6,862 | 580 | 0.00058 | 0.00213 |
| Feedlot Steer | 7.4 | 422,465 | NA | 422,465 | NA | 8,449 | 13,277 | 1,123 | 0.00112 | 0.00412 |
| **Swine** | | | | | | | | | | |
| Breeding Swine | 2.0 | 29,269 | 22,577 | 1,198 | 23 | 24 | 73 | 6 | 0.00001 | 0.00002 |
| Market Under 60 lbs | 9.0 | 47,993 | 37,020 | 1,964 | 37 | 39 | 120 | 10 | 0.00001 | 0.00004 |
| Market 60-119 lbs | 7.0 | 56,016 | 43,208 | 2,293 | 43 | 46 | 140 | 12 | 0.00001 | 0.00004 |
| Market 120-179 lbs | 4.0 | 53,469 | 41,244 | 2,188 | 41 | 44 | 134 | 11 | 0.00001 | 0.00004 |
| Market over 180 lbs | 4.0 | 71,547 | 55,189 | 2,928 | 55 | 59 | 179 | 15 | 0.00002 | 0.00006 |
| **Poultry** | | | | | | | | | | |
| Layers | | | | | | | | | | |
| Hens > 1 yr | 2,292.0 | 1,189,617 | 59,481 | 1,130,136 | 59 | 5,651 | 8,973 | 759 | 0.00076 | 0.00278 |
| Pullets | 184.0 | 95,502 | 4,775 | 90,726 | 5 | 454 | 720 | 61 | 0.00006 | 0.00022 |
| Chickens | 12.0 | 8,672 | 434 | 8,239 | 0 | 41 | 65 | 5 | 0.00001 | 0.00002 |
| Broilers | 53,072.7 | 16,737,007 | NA | 16,737,007 | NA | 334,740 | 526,020 | 44,473 | 0.04447 | 0.16307 |
| Turkeys | 704.0 | 1,092,080 | NA | 1,092,080 | NA | 21,842 | 34,323 | 2,902 | 0.00290 | 0.01064 |
| **Other** | | | | | | | | | | |
| Sheep on Feed | 0.0 | - | NA | - | NA | - | - | - | - | - |
| Sheep Not on Feed | 24.0 | 315,360 | NA | 213,844 | NA | 4,277 | 6,721 | 568 | 0.00057 | 0.00208 |
| **TOTAL** | | **30,118,367** | **2,911,638** | **22,699,687** | **2,912** | **435,557** | **688,202** | **58,184** | **0.05818** | **0.21334** |

**Table 8.12: 2017 Direct $N_2O$ Emissions from Fertilizer Application (Agriculture Soils).**

| | **Synthetic Fertilizer** | **Organic Fertilizer** |
|---|---|---|
| | | |
| Total Fertilizer Use (kg N) | 40,158,687 | 26,724,473 |
| Total N in Fertilizers (Calendar Year) | 26,103,147 | 26,238,175 |
| Volatilization Rate | 10% | 20% |
| Nitrogen Content of Fertilizer | 0 | 4.10% |
| Unvolatized N (kg) | 23,492,832 | 860,612.14 |
| Unvolatized N (metric tons) | 23,493 | 860.61 |
| Direct Emission factor ($N_20$ -N) | 0.01 | 0.0125 |
| Direct Emission (metric) ( $N_20$ - N) | 234.93 | 10.76 |
| Ratio $N_2O$-$N_2$ | 1.57 | 1.57 |
| Direct Emission (metric ) ( $N_20$) | 369.17 | 16.90 |
| $N_2O$ GWP | 310 | 310 |
| Direct Emission (MMTCO$_2$E) | 0.114443654 | 0.003334872 |
| **Total Direct Emission (MMTCO$_2$E)** | **0.1178** | |

**Table 8.13: 2017 Indirect $N_2O$ Emissions from Fertilizer Application (Released to Atmosphere)**

| | **Synthetic Fertilizer** | **Organic Fertilizer** |
|---|---|---|
| | | |
| Total Fertilizer Use (kg N) | 40,158,687 | 26,724,473 |
| Total N in Fertilizers (Calendar Year) | 26,103,147 | 26,238,175 |
| Volatilization Rate | 10% | 20% |
| Nitrogen Content of Fertilizer | 0 | 4.10% |
| Volatized N (kg) | 2,610,315 | 215,153.04 |
| Volatized N (metric tons) | 2,610 | 215.15 |
| $N_2O$ from Volatilization - Emission Factor ($N_20$ -N) | 0.01 | 0.0125 |
| Indirect Emission (metric) ( $N_20$ -N) | 26.10 | 2.69 |
| Ratio $N_2O$-$N_2$ | 1.57 | 1.57 |
| Indirect Emission (metric) ( $N_20$) | 41.02 | 4.23 |
| $N_2O$ GWP | 310 | 310 |
| Indirect Emission (MMTCO$_2$E) | 0.0127 | 0.0013 |
| **Total Indirect Emission (MMTCO$_2$E)** | **0.0140** | |

## Table 8.14: 2017 Indirect $N_2O$ Emissions from Fertilizer Application (Runoff /Leaching)

| | **Synthetic Fertilizer** | **Organic Fertilizer** | **Manure Excreted** |
|---|---|---|---|
| | | | |
| Total Fertilizer Use (kg N) | 40,158,687 | 26,724,473 | |
| Total N in Fertilizers-kg (Calendar Year) | 26,103,147 | 26,238,175 | 38,991,102 |
| Volatilization Rate | 10% | 20% | 0% |
| Nitrogen Content of Fertilizer | 100% | 4.10% | 1.0% |
| Unvolatized N (kg) | 23,492,832 | 860,612 | |
| **Leached / Runoff Rate** | 30% | 30% | 30% |
| Leached / Runoff N (kg) | 7,047,849.69 | 258,183.64 | 11,697,330.60 |
| Leached / Runoff N (metric tons) | 7,048 | 258 | 11,697 |
| Indirect Emission factor ($N_20$ -N) | 0.0075 | 0.0075 | 0.0075 |
| Indirect Emission (metric tons) ( $N_20$ -N) | 52.86 | 1.94 | 87.73 |
| Ratio $N_2O$-$N_2$ | 1.57 | 1.57 | 1.57 |
| Indirect Emission (metric tons) ($N_20$) | 83.06 | 3.04 | 137.86 |
| $N_2O$ GWP | 310 | 310 | 310 |
| Leached /Runoff Emission (MMTCO$_2$E) | 0.03 | 0.0009 | 0.04 |
| Total Leached /Runoff Emission (MMTCO$_2$E) | **0.06943** | | |

## Table 8.15: 2017 Direct $N_2O$ Emissions from Agriculture Crop Residue

| | **Crop Residues** | **Legumes** |
|---|---|---|
| | **N Returned to Soils**<br>**(kg)** | **N-Fixed by Crops**<br>**(kg)** |
| | 26,869,637 | 42,661,498 |
| | | |
| Direct $N_2O$ Emissions Factor | 0.01 | 0.01 |
| Direct $N_2O$ Emission kg ($N_2O$ -N)/ Yr | 268,696.37 | 426,614.98 |
| **Ratio $N_2O$- N** | 1.571428571 | 1.571428571 |
| Direct $N_2O$ Emission (kg $N_2O$) | 422,237.15 | 670,394.97 |
| Direct $N_2O$ Emission (metric tons) | 422.2371529 | 670.3949686 |
| Direct $N_2O$ Emission (MMT) | 0.000422237 | 0.000670395 |
| GWP | 310 | 310 |
| Direct Emissions (MMT$CO_2$E) | 0.130893517 | 0.20782244 |
| | | |
| **Total $N_2O$ Emission from Residue (MMT$CO_2$E)** | **0.338715958** | |

## Table 8.16: 2017 $N_2O$ Emissions from Manure Application

| | **Livestock Emissions** (metric tons $N_2O$) | **$N_2O$ GWP** | **Livestock Emissions** (MMT $CO_2$E) |
|---|---|---|---|
| | | | |
| Indirect $N_2O$ Emissions | 123.0 | 310 | **0.03799** |
| | | | |
| Direct $N_2O$ Emissions -Manure Applied to Soil | 755 | 310 | 0.23395 |
| Direct $N_2O$ Emissions -Pasture, Range and Paddock | 309.0 | 310 | 0.09568 |
| Sum Direct $N_2O$ Emissions | **1,063** | | **0.32964** |
| | | | |
| **Total Animal $N_2O$ Emisssions (MMT$CO_2$E)** | **0.37763** | | |

### Table 8.17: 2017 Indirect $N_2O$ Emissions from Animal Waste Runoff (Released to the Atmosphere).

|  | Number of Animals ('000 head) | **Total K-Nitrogen Excreted** (kg) | **Volatilization Rate** | **$NH_3$-NOx Emission Factor** | **Indirect Animal $N_2O$ Emissions** (metric tons N) | **Indirect Animal $N_2O$ Emissions** (metric tons $N_2O$) | **$N_2O$ GWP** | **Indirect Animal $N_2O$ Emissions** ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|---|
| **Dairy Cattle** |  |  |  |  |  |  |  |  |
| Dairy Cows | 53 | 5,788,024 | 20% | 1% | 11.58 | 0.1819093 | 310 | 5.63919E-05 |
| Dairy Replacement Heifers | 28 | 1,508,063 | 20% | 1% | 3.02 | 0.0473962 | 310 | 1.46928E-05 |
| **Beef Cattle** |  |  |  |  |  |  |  |  |
| Feedlot Heifers | 3.9 | 179,913 | 20% | 1% | 0.36 | 0.0056544 | 310 | 1.75287E-06 |
| Feedlot Steer | 7.4 | 340,096 | 20% | 1% | 0.68 | 0.0106887 | 310 | 3.31351E-06 |
| Bulls | 4 | 339,450 | 20% | 1% | 0.68 | 0.0106684 | 310 | 3.30721E-06 |
| Calves | 36 | 465,156 | 20% | 1% | 0.93 | 0.0146191 | 310 | 4.53195E-06 |
| Beef Cows | 42 | 2,696,394 | 20% | 1% | 5.39 | 0.0847438 | 310 | 2.62706E-05 |
| Steer Stockers | 15 | 539,726 | 20% | 1% | 1.08 | 0.0169628 | 310 | 5.25847E-06 |
| Total Beef Heifers | 17 | 807,891 | 20% | 1% | 1.62 | 0.0253908 | 310 | 7.87117E-06 |
| **Swine** |  |  |  |  |  |  |  |  |
| Breeding Swine | 2 | 33,967 | 20% | 1% | 0.07 | 0.0010675 | 310 | 3.30935E-07 |
| Market Under 60 lbs | 9 | 31,299 | 20% | 1% | 0.06 | 0.0009836 | 310 | 3.04946E-07 |
| Market 60-119 lbs | 7 | 43,568 | 20% | 1% | 0.09 | 0.0013692 | 310 | 4.24475E-07 |
| Market 120-179 lbs | 4 | 41,587 | 20% | 1% | 0.08 | 0.0013070 | 310 | 4.05178E-07 |
| Market over 180 lbs | 4 | 55,648 | 20% | 1% | 0.11 | 0.0017489 | 310 | 5.4217E-07 |
| **Poultry** |  |  |  |  |  |  |  |  |
| Layers |  |  |  |  |  | 0 |  |  |
| Hens > 1 yr | 2,292.0 | 1,249,851 | 20% | 1% | 2.50 | 0.0392810 | 310 | 1.21771E-05 |
| Pullets | 184 | 74,951 | 20% | 1% | 0.15 | 0.0023555 | 310 | 7.30233E-07 |
| Chickens | 12 | 6,544 | 20% | 1% | 0.01 | 0.0002056 | 310 | 6.37545E-08 |
| Broilers | 53,072. | 19,177,82 | 20% | 1% | 38.36 | 0.6027314 | 310 | 0.00018684 |
| Turkeys | 704 | 1,293,023 | 20% | 1% | 2.59 | 0.0406378 |  | 0 |
| **Other** |  |  |  |  |  |  |  |  |
| Sheep on Feed | - | - |  |  | 0.00 | 0 |  |  |
| Sheep Not on Feed | 24 | 294,336 | 20% | 1% | 0.59 | 0.00925056 | 310 | 2.86767E-06 |
| Goats | 12 | 126,144 | 20% | 1% | 0.25 | 0.0039645 | 310 | 1.229E-06 |
| Horses | 80 | 3,897,653 | 20% | 1% | 7.80 | 0.1224976 | 310 | 3.79743E-05 |
| **TOTAL** |  | **38,991,102** |  |  | **77.98** | **1.2254346** |  | **0.00036728** |

## Table 8.18: 2017 Direct $N_2O$ Emissions from Manure Applied to Soil

| | **Number of Animals ('000 head)** | **K-N Excreted by System (kg)**<br>**Managed Systems** | **Volatili-zation Rate** | **Ground Nitrogen Emission Factor** | **Poultry Manure Not Mnage** | **Direct Animal $N_2O$ Emissions** (metric tons N) **Manure Applied to Soils** | **Direct Animal $N_2O$ Emissions** (metric tons $N_2O$) | **$N_2O$ GWP** | **Direct Animal $N_2O$ Emissions** ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|---|---|
| **Dairy Cattle** | | | | | | | | | |
| Dairy Cows | 53.0 | 2,837,470 | 20% | 0.0125 | | 54 | 1.06194 | 310 | 0.0248 |
| Dairy Replacement Heifers | 28.0 | 739,300 | 20% | 0.0125 | | 14 | 0.27669 | 310 | 0.0063 |
| **Beef Cattle** | | | | | | | | | |
| Feedlot Heifers | 3.9 | 179,913 | 20% | 0.0125 | | 2 | 0.03534 | 310 | 0.0000 |
| Feedlot Steer | 7.4 | 340,096 | 20% | 0.0125 | | 3 | 0.066805 | 310 | 0.0015 |
| Bulls | 4.0 | NA | 20% | | | | | | - |
| Calves | 36.0 | NA | 20% | | | | | | - |
| Beef Cows | 42.0 | NA | 20% | | | | | | - |
| Steer Stockers | 15.0 | NA | 20% | | | | | | - |
| Total Beef Heifers | 17.0 | NA | 20% | | | | | | - |
| **Swine** | | | | | | | | | |
| Breeding Swine | 2.0 | 26,786 | 20% | 0.0125 | | 0.0 | 0.005262 | 310 | 0.0000 |
| Market Under 60 lbs | 9.0 | 24,683 | 20% | 0.0125 | | 0.0 | 0.004848 | 310 | 0.0000 |
| Market 60-119 lbs | 7.0 | 34,357 | 20% | 0.0125 | | 0.0 | 0.006749 | 310 | 0.0000 |
| Market 120-179 lbs | 4.0 | 32,795 | 20% | 0.0125 | | 0.0 | 0.006442 | 310 | 0.0000 |
| Market over 180 lbs | 4.0 | 43,884 | 20% | 0.0125 | | 0.0 | 0.008620 | 310 | 0.0000 |
| **Poultry** | | | | | | | | | |
| Layers | | | | | | | | | |
| Hens > 1 yr | 2,292.0 | 1,249,851 | 20% | 0.0125 | 4.20% | 12 | 0.235196 | 310 | 0.0059 |
| Pullets | 184.0 | 74,951 | 20% | 0.0125 | 4.20% | 1 | 0.014104 | 310 | 0.0000 |
| Chickens | 12.0 | 6,544 | 20% | 0.0125 | 4.20% | 0 | 0.001232 | 310 | 0.0000 |
| Broilers | 53,072.7 | 19,177,820 | 20% | 0.0125 | 4.20% | 181 | 3.608855 | 310 | 0.0882 |
| Turkeys | 704.0 | 1,293,023 | 20% | | | 12 | 0.243319 | | 0.0015 |
| **Other** | | | | | | | | | |
| Sheep on Feed | - | - | | | | | | | |
| Sheep Not on Feed | 24.0 | - | 20% | | | | | 310 | - |
| Goats | 12.0 | NA | 20% | | | | | 310 | - |
| Horses | 79.0 | NA | 20% | | | | | 310 | - |
| **TOTAL** | | | | | | **284** | **5.5754** | | **0.00165** |

## Table 8.19: 2017 Direct $N_2O$ Emissions from Pasture, Range and Paddock.

| | Number of Animals ('000 head) | **K-N Excreted by System (kg):** | **Direct Animal $N_2O$ Emissions** (metric tons N) | **Direct Animal $N_2O$ Emissions** (metric tons $N_2O$) | **$N_2O$ GWP** | **Direct Animal $N_2O$ Emissions** ($MMTCO_2E$) |
|---|---|---|---|---|---|---|
| | | **Unmanaged Systems - Pasture, Range, and Paddock** | | **Pasture, Range, and Paddock** | | |
| **Dairy Cattle** | | | | | | |
| Dairy Cows | 53.0 | 5,788,024 | 7.64 | 0.14998 | 310 | 0.000046 |
| Dairy Replacement Heifers | 28.0 | 1,508,063 | 1.99 | 0.03908 | 310 | 0.000012 |
| **Beef Cattle** | | | | | | |
| Feedlot Heifers | 3.9 | NA | | | | |
| Feedlot Steer | 7.4 | NA | | | | |
| Bulls | 4.0 | 339,450 | 6.79 | 0.13336 | 310 | 0.000041 |
| Calves | 36.0 | 465,156 | 9.30 | 0.182740 | 310 | 0.000057 |
| Beef Cows | 42.0 | 2,696,394 | 53.93 | 1.059300 | 310 | 0.000328 |
| Steer Stockers | 15.0 | 539,726 | 10.79 | 0.212035 | 310 | 0.000066 |
| Total Beef Heifers | 17.0 | 807,891 | 16.16 | 0.31739 | 310 | 0.000098 |
| **Swine** | | | | | | |
| Breeding Swine | 2.0 | 33,967 | 0.14 | 0.00282 | 310 | 0.000001 |
| Market Under 60 lbs | 9.0 | 31,299 | 0.13 | 0.002599 | 310 | 0.000001 |
| Market 60-119 lbs | 7.0 | 43,568 | 0.18 | 0.0036184 | 310 | 0.000001 |
| Market 120-179 lbs | 4.0 | 41,587 | 0.18 | 0.003454 | 310 | 0.000001 |
| Market over 180 lbs | 4.0 | 55,648 | 0.24 | 0.004622 | 310 | 0.000001 |
| **Poultry** | | | | | | |
| Layers | | | | | | |
| Hens > 1 yr | 2,292.0 | NA | | | | |
| Pullets | 184.0 | NA | | | | |
| Chickens | 12.0 | NA | | | | |
| Broilers | 53,072.7 | NA | | | | |
| Turkeys | 704.0 | 1,293,023 | 2.59 | 0.05080 | | 0.00000 |
| **Other** | | | | | | |
| Sheep on Feed | - | - | | | | |
| Sheep Not on Feed | 24.0 | 294,336 | 5.89 | 0.11563 | 310 | 0.000036 |
| Goats | 12.0 | 126,144 | 2.52 | 0.04956 | 310 | 0.000015 |
| Horses | 79.1 | 3,897,653 | 77.95 | 1.531221 | 310 | 0.000475 |
| **TOTAL** | | | **196.42** | | | **0.00118** |

# 9.0 Waste Management

## 9.1 OVERVIEW

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management
    - methane (CH4) and carbon dioxide ($CO_2$) emissions from waste decomposition at municipal and industrial solid waste landfills, accounting for both fugitive and flared GHG from $CH_4$ that is flared or captured for energy production (this includes both open and closed landfills);
- Solid waste combustion
    - $CH_4$, carbon dioxide ($CO_2$), and nitrous oxide ($N_2O$) emissions from the controlled combustion of solid waste in incinerators or waste to energy plants or open burning of waste (e.g. at city dumps or in residential burn barrels); and
- Wastewater (WW) management
    - $CH_4$ and $N_2O$ from municipal wastewater
    - $CH_4$ from industrial WW treatment facilities.

## 9.2 DATA SOURCES

- EPA Landfill Gas Emissions Models Version 3.02.
  http://www.epa.gov/ttn/catc/products.html#software.
  http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf.
- MDE's Annual Emissions Certification Reports.
- MDE's Annual Solid Waste Reports.
- US EPA State Greenhouse Gas Inventory Tool (SIT)
  http://www.epa.gov/statelocalclimate/resources/tool.html
- EPA Mandatory Greenhouse Gas Reporting Rule (40 CFR Part 98)
  http://www.epa.gov/climatechange/emissions/ghgrulemaking.html

## 9.3 GREENHOUSE GAS INVENTORY METHODOLOGY

Historic GHG emissions (1990 – 2005) from municipal solid waste (MSW) landfills in Maryland was estimated by MDE using the default input data (tonnes of waste –in-place ) of the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[1] The key factor in the estimation of Landfill emissions is the rate of $CH_4/CO_2$ generation within the waste mass. Although other factors, such as the rate of oxidation as $CH_4$ passes through overlying soil, and the presence and efficiency of landfill gas collection systems are also important.

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[1] Emission Inventory Improvement Program, Volume VIII: Chapter. 13. "Methods for Estimating Greenhouse Gas Emissions from Municipal Solid Waste", August 2004.

For the 2017 periodic emissions inventory, MDE estimated the MSW landfills GHG emissions inventory from the available MSW Landfills data, with landfills specific input data (year opened, year closed, waste acceptance rate) and control device information (LFG collection efficiency and flares efficiency), from the State's Title V permit (Annual Compliance Certification Report). MDE solid waste Department provided addition list of landfills in the state with annual waste emplacement data that were used to supplement the Title V permit landfills. These additional data included information on many sites that do not submit annual compliance certification report, as well as updated information on sites that do submit. (E.g. waste emplacement data, information on control devices).

Maryland's MSW Landfills were classified into two main groups; Controlled and Uncontrolled Landfills. Controlled Landfill sites have devices installed on them to collect the Landfill gases (LFG) which are either flared or combusted to generate energy or electricity (LFGTGE) while uncontrolled landfill sites does not have any LFG collection devices.

In 2017, there were 42 active sites in Maryland. Four of these sites are controlled by flares, eleven were landfill- gas- to- energy (LFGTE) plants, the rest (27) of the sites were assumed to be uncontrolled. The list of landfills did not include the approximately 300 small town landfills that have closed since 1960.

**Landfill Gas (LFG) Generation**

Landfill gas is generated by the decomposition of organic municipal solid waste by bacteria naturally present in the waste dumped in the landfill and in the soil used to cover the landfill. Organic waste includes food, garden waste, street sweepings, textiles, wood and paper products.

The composition, quantity and rate of landfill gas generation are dependent on the types of waste that are decomposing and the level of microbial activity within the wastes. By volume, at near steady- state, LFG is typically composed of approximately 55 percent $CH_4$, 40 percent $CO_2$, 5 percent $N_2$, and smaller amounts of NMOCs such as benzene, vinyl chloride, chloroform, 1,1-dichloroethene, carbon tetrachloride, and other Non-Methane-Organic-Compounds (NMOCs)[1]. In addition, non-organic species such as hydrogen sulfide and vapor phase mercury are often found in LFG.

Bacteria decompose landfill waste in four phases[2]. The composition of the gas produced changes with each of the four phases of decomposition. Landfills often accept waste over a 20- to 30-year period, so waste in a landfill may be undergoing several phases of decomposition at once.
This means that older waste in one area might be in a different phase of decomposition than more recently buried waste in another area.

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[1] EPA: Guidance For Evaluating Landfill Gas emissions From Closed or Abandoned Facilities. http://www.cluin.org/download/char/epa-600-r-05-123.pdf

[2] ATSDR, 2001a. *Landfill Gas Primer – An Overview for Environmental Health Professionals, Chapter 2: Landfill Gas Basics.* Agency for Toxic Substances and Disease Registry (ATSDR). November 2001. http://www.atsdr.cdc.gov/hac/landfill/html/ch2.html

**Phase I**

During the first phase of decomposition, aerobic bacteria—bacteria that live only in the presence of oxygen—consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is carbon dioxide. Nitrogen content is high at the beginning of this phase, but declines as the landfill moves through the four phases. Phase I continues until available oxygen is depleted. Phase I decomposition can last for days or months, depending on how much oxygen is present when the waste is disposed of in the landfill. Oxygen levels will vary according to factors such as how loose or compressed the waste was when it was buried.

**Phase II**

Phase II decomposition starts after the oxygen in the landfill has been used up. Using an anaerobic process (a process that does not require oxygen), bacteria convert compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols such as methanol and ethanol. The landfill becomes highly acidic. As the acids mix with the moisture present in the land-fill, they cause certain nutrients to dissolve, making nitrogen and phosphorus available to the increasingly diverse species of bacteria in the landfill. The gaseous byproducts of these processes are carbon dioxide and hydrogen. If the landfill is disturbed or if oxygen is somehow introduced into the landfill, microbial processes will return to Phase I.

**Phase III**

Phase III decomposition starts when certain kinds of anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid. This process causes the landfill to become a more neutral environment in which methane-producing bacteria begin to establish themselves. Methane-and acid-producing bacteria have a symbiotic, or mutually beneficial, relationship. Acid-producing bacteria create compounds for the methanogenic bacteria to consume. Methanogenic bacteria consume the carbon dioxide and acetate, too much of which would be toxic to the acid-producing bacteria.

**Phase IV**

Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant. Phase IV landfill gas usually contains approximately 45% to 60% methane by volume, 40% to 60% carbon dioxide, and 2% to 9% other gases, such as sulfides. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill. Gas production might last longer, for example, if greater amounts of organics are present in the waste, such as at a landfill receiving higher than average amounts of domestic animal waste.

For cellulose, the principal sources of gas from landfill waste, typical conversion reactions can be represented by the following three reactions:

## Aerobic Oxidation

$$C_6H_{12}O_6 + O_2 \xrightarrow{\text{Aerobic bacterial}} CO_2 + H_2O + \text{Biomass} + \text{Heat} \quad \text{(I)}$$

## Anaerobic Oxidation

$$C_6H_{12}O_6 \xrightarrow{\text{Anaerobic bacterial}} CH_4 + CO_2 + \text{Biomass} + \text{Heat} \quad \text{(II)}$$

## Methanogenesis Reaction

$$\text{Acetic Acid}: \quad (CH_3COO^-) + H_2O \xrightarrow{\text{Methanogenic bacterial}} CH_4 + HCO_3^- \quad \text{(III)}$$

$$4H_2O + CO_2 \xrightarrow{\text{Methanogenic bacterial}} CH_4 + 2H_2O \quad \text{(IV)}$$

As the LFG gases rises to the surface of the landfill, some oxidation of $CH_4$ to $CO_2$ occurs near the soil surface, where aerobic degraders persist. In landfills with active gas collection system, the LFG is collected prior to reaching this aerobic soil layer, along with some infiltration air.

### 9.3.1 Carbon Dioxide ($CO_2$) Direct Emissions.

### 9.3.1.1 Carbon Dioxide Emissions from Landfill Gas

Carbon dioxide ($CO_2$) emissions from municipal solid waste (MSW) landfills were estimated from the Landfill's cumulative and annual MSW tonnage report collected by MDE's Solid Waste Program and the annual emission certificate report from MDE's Air Quality Program. The landfills specific placement data were applied as the input data to EPA's Landfill Gas Emissions Model (LandGEM) to estimate the $CO_2$ emissions generation rate of each of the landfills.

The total $CO_2$ gas generated from all the Landfills were summed and estimated to be the $CO_2$ emissions from Maryland in 2017 since there is no feasible control technology to control the emission of the $CO_2$ emissions.

MDE calculated the 2017 carbon dioxide ($CO_2$) emissions from the Municipal Solid Waste (MSW) landfills operating in Maryland through the following steps:

1. Identified all the MSW Landfills sites that report annual emissions to the MDE Title V Compliance Program.
2. Compiled detailed information about the listed Landfill facilities, including reported amount of waste in place, LFG collection efficiency, flare control efficiency and Landfills $CO_2$ generation rate (LandGEM output).
3. Identified the Landfill facilities that do not report annual emissions to MDE Title V Compliance Program.

4. Compiled detailed information of Landfill facility that do not submit annual emission certificate report from the MDE Solid Waste Annual Report, including landfills ; year of opening, closure year, waste design capacity, annual waste acceptance rate from open year to current year or closure year and the collection/ control efficiencies.

5. Applied the annual waste accepted data from the opening year to current year or closure to the EPA LandGEM Model.

6. Extract the $CO_2$ generation rate data (LandGEM Output) from each of the landfills.

7. Summed all the $CO_2$ generation rate data to estimate Maryland 2017 carbon dioxide emission from Landfills.

### 9.3.1.2 Carbon Dioxide Emissions from Landfill Gas Flaring/Energy Conversion.

Estimation of carbon dioxide ($CO_2$) emission from Landfill gas flaring / conversion to energy generation was based on the amount of $CH_4$ collected by the collection system from the total amount of $CH_4$ generated from the Landfill and the control devices efficiency. $CO_2$ emission estimate was based on the stoichiometric combustion reaction; equation (1) below.

$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O \quad \text{…………….. (Equation 1)}$$

1 Kmol $CH_4$ => 1 Kmol $CO_2$
16 g $CH_4$ => 44 g $CO_2$
1 g $CH_4$ => 2.75 g $CO_2$

### 9.3.1.3 Carbon Dioxide Emissions ($CO_2$) from Municipal Solid Waste Combustion

Carbon dioxide ($CO_2$) emission from Municipal Solid Waste (MSW) combustion in incinerators was estimated by multiplying the tonnages of MSW combusted in Maryland in 2017 by the default EPA Municipal Solid Waste heat value and $CO_2$ emission factor[1].

### 9.3.1.4 Carbon Dioxide Emissions ($CO_2$) from Open Burning Combustion

Open burning of MSW at residential sites (e.g. backyard burn barrels) also contributes to GHG emissions. According to a Mid-Atlantic/Northeast Visibility Union (MANE-VU) report on open burning in residential areas, 62,404 tons of MSW was burned in Maryland in 2000.[2] This contributes to only 0.03 $MMtCO_2e$ in GHG emissions in 2000 based on SIT default waste characteristics and emission factors. Due to a lack of historical data from other years, it is assumed that open burning of MSW stays constant from 1990-2005. Emissions are held constant after 2005 due to uncertainty in the future levels of open burning activity.

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[1] Table C -1 To Subpart C of Part 98- Default $CO_2$ Emission factors and High Heat Values for Various Type of Fuel. Federal Register, Vol.74, No.209.

[2] Open Burning in Residential Areas, Emissions Inventory Development Report, MANE-VU, prepared by E. H. Pechan & Associates, Inc, January, 2004.

### 9.3.2 Additional Direct Emissions ($CH_4$ and $N_2O$)

#### 9.3.2.1 Methane Gas Emissions from Landfill Gas

Emissions from municipal solid waste landfills and combustion were calculated using site specific data collected by the MDE's solid waste and air quality programs. Throughput data reported on individual facility's air emission inventories were used to tabulate the total quantity of landfill gas flared, landfill gas collected in landfill-to-gas-energy projects, and municipal solid waste combusted. The total quantity of municipal solid waste landfill was tabulated from individual landfill reporting to the solid waste program. Emissions were also refined by using state-specific proportions of discards that are plastics, synthetic rubbers, and synthetic instead of SIT default values to calculate $CO_2$ emissions from municipal solid waste combustion.

MDE calculated the 2017 methane ($CH_4$) emissions from the Municipal Solid Waste (MSW) landfills operating in Maryland through the following steps:

1. Identified all the MSW Landfills sites that report annual emissions to the MDE Title V Compliance Program.

2. Compiled detailed information about the listed Landfill facilities, including reported amount of waste in place, LFG collection efficiency, flare control efficiency and Landfills $CH_4$ generation rate (LandGEM output).

3. Identified the Landfill facilities that do not report annual emissions to MDE Title V Compliance Program.

4. Compiled detailed information of Landfill facility that do not submit annual emission certificate report from the MDE Solid Waste Annual Report, including landfills ; year of opening, closure year, waste design capacity, annual waste acceptance rate from open year to current year or closure year and the collection/ control efficiencies.

5. Grouped the Landfills into broad two categories; Landfills with control device- Controlled Landfills and those without control device-Uncontrolled landfills.

6. Controlled Landfills are further sub divided into Flared Landfills and Landfill –Gas-To-Energy (LFGTE) landfills.

7. Applied $CH_4$ GWP to $CH_4$ generated (metric tons) to estimate **MSW $CH_4$ generation** ($MTCO_2E$).

8. Assumed Industrial Solid Waste Landfill $CH_4$ generation = 7% of MSW $CH_4$ Generation.

9. Estimated **Industrial Solid Waste Landfills**, $CH_4$ generation ($MTCO_2E$).

10. Summed both MSW and Industrial Solid Waste $CH_4$ generation to obtain **Potential $CH_4$** ($MTCO_2E$)

11. Applied Landfills specific LFG collection efficient to $CH_4$ generated to estimate amount of **$CH_4$ collected.**
12. Applied Landfills specific flare control efficiency to the amount of $CH_4$ collected to estimate amount of **$CH_4$ flared and Landfill –Gas-To- Energy (LFGTE)** $CH_4$ usage.

13. Summed both Flared $CH_4$ and LFGTE $CH_4$ to obtain **$CH_4$ Avoided.**

14. Subtract amount of **$CH_4$ collected** by the collection devices from the total amount of **$CH_4$ generated** (LandGEM Output) by the Municipal Solid Waste Landfills to estimate the amount of **Uncollected $CH_4$**.

15. Apply EPA default surface oxidation factor (10%) to **Uncollected $CH_4$** to estimate Municipal Landfills **fugitive $CH_4$ emission.**

16. Assumed Industrial Solid Waste Landfill $CH_4$ Uncollected = 7% of MSW $CH_4$ Uncollected.

17. Estimated **Industrial Solid Waste Landfills**, Uncollected $CH_4$ ($MTCO_2E$).

18. Summed both Municipal and Industrial Uncollected $CH_4$ to obtain **Oxidized $CH_4$.**

19. Calculated Net $CH_4$ Emissions from Landfills by Equation (2).

$$\text{Net CH}_4\text{ Emissions} = \text{Municipal Landfill CH}_4\text{ Generation} - \text{Municipal Landfill CH}_4\text{ Flaring or Recovery} - \text{CH}_4\text{ Oxidation by Soil at MSW Landfills} + \text{Industrial Landfill CH}_4\text{ Generation} - \text{CH}_4\text{ Oxidation by Soil at Industrial Landfills}$$

### 9.3.2.2 Methane Gas Emissions from Wastewater

The estimation of GHG emissions from municipal wastewater treatment were calculated using SIT based on state population, assumed biochemical oxygen demand (BOD), and emission factors for $N_2O$ and $CH_4$. The key SIT default values are shown in Table 9.1.

### Table 9.1: SIT Key Default Values for Municipal Wastewater Treatment.

| Default Values for Municipal Wastewater Treatment Variables [1] | Value |
|---|---|
| BOD | 0.09 kg /day-person |
| Amount of BOD anaerobically treated | 16.25% |
| $CH_4$ emission factor | 0.6 kg/kg BOD |
| Maryland residents not on septic | 75% |
| Water treatment $N_2O$ emission factor | 4.0 g $N_2O$/person-yr |
| Biosolids emission factor | 0.01 kg $N_2O$-N/kg sewage-N |

## 9.4 GREENHOUSE GAS INVENTORY RESULTS

### Table 9.2: 2017 $CO_2$ and $N_2O$Emissions from MSW Combustion

| **MSW Processed (tons)** | **1,298,472** |
|---|---|
| **$CO_2$ Emissions** | |
| Default high Heat Value (MMBtu/S tons) | 9.95 |
| Default $CO_2$ Emission factor (kg /MMBtu) | 90.7 |
| $CO_2$ Emissions ( tons/yr) | 1,308,965 |
| $CO_2$ Emissions ( metric tons/yr) | **1,187,472** |
| $CO_2$ Emissions ( million metric tons/yr) | 1.187472 |
| **$N_2O$ Emissions** | |
| Default $N_2O$ Emission factor (kg /MMBtu) | 4.20E-03 |
| $N_2O$ Emissions ( metric tons/yr) | 54.26 |
| $N_2O$ GWP | 310 |
| **$N_2O$ Emissions ( $MMTCO_2E$)** | **0.01016** |

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[1] Emission Inventory Improvement Program, Volume 8, Chapter 12.

### Table 9.3: 2017GHG Emissions from Landfills

| | | |
|---|---|---|
| MSW $CH_4$ Generation ( short ton $CH_4$) | (A) | 101,154 |
| | | |
| $CH_4$ GWP | (B) | 21 |
| | | |
| MSW Generation ( $MTCO_2E$) | (C) = (A) x (B) x 0.9071847 | 1,927,062 |
| | | |
| Industrial Generation ($MTCO_2E$) | (D) = (C) *7% | 134,894 |
| | | |
| Potential $CH_4$ ($MTCO_2E$) | (E) = (C) +(D) | 562,352 |
| | | |
| Flared $CH_4$ (tons) | (F) | 18,219 |
| | | |
| Flared $CH_4$ ($MTCO_2E$) | (G) = (F) *(B) | 347,094 |
| | | |
| Landfill Gas-to-Energy (tons) | (H) | 39,579 |
| | | |
| Landfill Gas-to-Energy ($MTCO_2E$) | (I) = (H)*(B) | 754,017 |
| | | |
| $CH_4$ Avoided ($MTCO_2E$) | (J) =(I) +(G) | **1,101,111** |
| | | |
| Oxidation at MSW Landfills (tons) | (K) | 32,208 |
| | | |
| Oxidation at MSW Landfills ($MTCO_2E$) | (L) =(K) *(B) | 613,587 |
| | | |
| Oxidation at Industrial Landfills ($MTCO_2E$) | (M) =(L) *7% | **42,951** |
| | | |
| Total $CH_4$ Emissions ($MTCO_2E$) | (N) =(E)- (J)-(L) -(M) | **334,255** |
| | | |
| **$CO_2$ Emission from (Flaring + LFGTE) ($MMTCO_2E$)** | **(O)** | **0.1230** |
| $CO_2$ Emissions From Landfill Gas ($MMTCO_2E$) | | **0.3682** |

**Table 9.4: 2017 $CH_4$ Emissions Calculation for Municipal Wastewater Treatment.**

| | | | |
|---|---|---|---|
| State Population | | A | 6,052,177 |
| | | | |
| Per Capita $BOD_5$ | (kg/day) | B | 0.0900 |
| | | | |
| Days per Year | (days) | C | 365 |
| | | | |
| Unit Conversion | (metric tons/kg) | D | 0.001 |
| | | | |
| Emission Factor | (Gg $CH_4$/Gg $BOD_5$) | E | 0.6000 |
| | | | |
| WW $BOD_5$ anaerobically digested | (percent) | F | 16.25% |
| | | | |
| Emissions | (metric tons $CH_4$) | G= A x B x C x D x E x F | 19,384.4 |
| | | | |
| $CH_4$ GWP | ($CO_2$ Eq.) | H | 21 |
| | | | |
| Unit Conversion | (MMT/MT) | I | 0.000001 |
| | | | |
| C/$CO_2$ | | J= (12/44) | 0.27 |
| | | | |
| Emissions | (MMTCE) | K= G x H x I x J | 0.111 |
| | | | |
| Emissions | ($MMTCO_2E$) | 'L = K* (44/12) | 0.4071 |

## Table 9.5: 2017 $N_2O$ Emissions from Municipal Wastewater Treatment.

| | | | |
|---|---|---|---|
| State Population | | A | 6,052,177 |
| | | | |
| Fraction of Population not on Septic | | B | 81% |
| | | | |
| Direct $N_2O$ Emissions from Wastewater Treatment | (g $N_2O$/person/year) | C | 4.0 |
| | | | |
| Unit Conversion | (g/metric ton) | D | 1E-06 |
| | | | |
| Emissions | (Metric Tons $N_2O$) | E=A*B*C*D | 19.71 |
| | | | |
| $N_2O$ GWP | ($CO_2$ Eq.) | F | 310 |
| | | | |
| Unit Conversion | (MMT/MT) | G | 0.000001 |
| | | | |
| $C/CO_2$ | | H | 0.27 |
| | | | |
| Emissions | (MMTCE) | I =E*F*G*H | 0.002 |
| | | | |
| Emissions | ($MMTCO_2E$) | J = I* (44/12) | 0.0061 |

# Table 9.6: 2017 $N_2O$ Emissions from Biosolids Fertilizers.

| | Formula | Result |
|---|---|---|
| Population (person – 2017) | A | 6,052,177 |
| Per Capital Protein Consumption (kg / capital/day) | B = 41.90 | 45.2 |
| Protein Consumed (kg) | C = A * B | 273,558,400 |
| Fraction of Nitrogen in Protein (FRAC $_{NPR}$) | D = 16% | 16% |
| Nitrogen Consumed (kg) | E = C *D | 43,769,344.06 |
| Fraction of Non Consumption Nitrogen | F = 1.75 | 1.75 |
| Total Nitrogen in Domestic Wastewater (kg) | G = E * F | 76,596,352.11 |
| **Total Nitrogen in Domestic Wastewater (metric tons)** | **H = G / 1,000** | 76,596.35 |
| | | |
| **Direct $N_2O$ Emission from Wastewater Treatment (metric tons $N_2O$)** | I | 19.65 |
| **Biosolids Available N (metric tons)** | **J = ( H – I)** | **76,577** |
| Percentage Biosolids used as Fertilizer | K= 0% | 0% |
| Indirect Emission factor for Biosolids fertilizer (kg $N_2O$-N/kg Sewage Nitrogen Produced) | M | 0.01 |
| Conversion from N to $N_2O$ - Ratio of ($N_2O$-N) | N = (44/28) | 1.5714 |
| | | |
| **$N_2O$ Emissions from Biosolids Fertilizer (metric tons $N_2O$)** | O = J* (1 - K)*M*N | **601.67** |
| $N_2O$ GWP | P | 310 |
| MMT/MT Conversion | Q= 1/1E+06 | 0.00 |
| C/$CO_2$ Conversion | R =12/44 | 0.2727 |
| Emissions from Biosolids (MMTCE) | S=O*P*Q*R | 0.050869 |
| | | |
| Direct $N_2O$ Emission from Wastewater Treatment (MMTCE) | T=I*P*Q*R | 0.001661 |
| | | |
| Total Emission Biosolids (MMTCE) | U=S+T | 0.0525 |
| | | |
| C/$CO_2$ Conversion | V=44/12 | 3.67 |
| | | |
| **$N_2O$ Emissions from Biosolids Fertilizer (MMTCO$_2$E)** | **V = U*V** | **0.1926** |

# 10.0 Forestry and Land Use

## 10.1 OVERVIEW

This section provides an assessment of the “net carbon dioxide flux” resulting from land uses, land–use changes, and forests (LULUCF) management activities in Maryland. The term “net carbon dioxide flux” is used here to encompass both emissions of greenhouse gases to the atmosphere, and removal (sinks) of carbon dioxide from the atmosphere. The balance between the emission and uptake is known as flux.

As a result of biological processes (e.g., growth and mortality) and anthropogenic activities (e.g., harvesting, thinning, and other removals), carbon is continuously cycled through ecosystem components, as well as between the forest ecosystem and the atmosphere. For example, the growth of trees results in the uptake of carbon from the atmosphere and storage in living trees. Through photosynthesis, $CO_2$ is taken up by trees and plants and converted to carbon in biomass within the forests. As these trees age, they continue to accumulate carbon until they reach maturity, at which point their carbon storage remains relatively constant. As trees die or drop branches and leaves on the forest floor, decay processes will release carbon to the atmosphere and also increase soil carbon. Some carbon from forests is also stored in wood products, such as lumber, furniture and other durable wood products; and also in landfills, because when wood products are disposed of, they do not decay completely, and a portion of the carbon gets stored indefinitely, as with landfilled yard trimmings and food scraps. The net change in forest carbon is the change in the amount of carbon stored in each of these pools (i.e., in each ecosystem component) over time.

Activities in Maryland that can contribute to the GHG flux includes; clearing an area of forest to create cropland, restocking a logged forest, draining a wetland, or allowing a pasture to revert to grassland. In the United States, forest management is believed to be the primary activity responsible for net sources of carbon dioxide to the atmosphere. Carbon in the form of yard trimmings and food scraps can also be sequestered in landfills, as well as in trees in urban areas.

In addition to carbon flux from forest management, urban trees, and landfills, other sources of GHGs under the category of land-use change and forestry are $CO_2$ emissions from liming of agricultural soils, emissions of methane ($CH_4$), and nitrous oxide ($N_2O$) from forest fires, and $N_2O$ emissions from fertilization of settlement and forest soils.

GHG emission estimates for 2017 were calculated using the EPA SIT software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[1] However, the SIT only contains default activity data for year 2013. MDE was not able to obtain the default year 2017 input data required by the SIT software to estimate the GHG emission. MDE is applying the year 2013 data as surrogate for the periodic year 2017 and will continue evaluating information as it becomes available, and will update year 2017 data when available.

In general, the SIT methodology applies emission factors developed for the US to activity data for the land use and forestry sectors.

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[1] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8.

Within the EPA SIT software LULUCF module, there are six sections:

- forest carbon flux;
- liming of agricultural soils;
- urban trees;
- $N_20$ from settlement soils;
- non-$CO_2$ emissions from forest fires; and
- carbon storage in landfilled yard trimmings and food scraps

Since the methodology varies considerably among these sources/sinks, the details of each will be discussed in its respective step, following this general methodology discussion.

## 10.2 DATA SOURCES

- Urban Forest Data.
  Forester Rob Feldt of Maryland Forest Services, Maryland Department of Natural Resources.

- US EPA State Greenhouse Gas Inventory Tool (SIT).
  http://www.epa.gov/statelocalclimate/resources/tool.html

- Municipal Solid Waste in the United States; 2006 Facts and Figures (EPA 2007)
  http://www.epa.gov/osw/nonhaz/municipal/pubs/msw06.pdf.

- AAPFCO (2014) Commercial Fertilizers 2014.
  Association of American Plant Food Control Officials. University of Kentucky, Lexington, KY.

- Maryland Solid Waste Management and Diversion Report (2017) ; Input Data to EPA WARM Model

  http://www.mde.state.md.us/programs/LAND/RecyclingandOperationsprogram/Pages/index.aspx

## 10.3 GREENHOUSE GAS INVENTORY METHODOLOGY

### 10.3.1 Forest Carbon Flux

The method used for calculating forest carbon flux is shown in Equation 1.3.1. The calculation is a sum of the fluxes for above- and belowground biomass, dead wood, litter, soil organic carbon, and wood products in use and in landfills.

Two methodologies are used to calculate carbon emissions/storage (flux) from forest carbon using USDA Forest Service estimates of each state's forest carbon stocks.

(1) The first methodology applies to aboveground biomass, belowground biomass, dead wood, and forest floor litter and soil organic carbon. USDA Forest Service estimates for each state's forest carbon stocks are provided for 1990-2009. These estimates are outputs of the Carbon Calculation Tool (CCT) which produces state-level annualized estimates of carbon stock and flux. The Carbon Calculation Tool is a computer application that reads publicly available forest inventory data collected by the U.S. Forest Service's Forest Inventory and Analysis Program (FIA) and generates state-level annualized estimates of carbon stocks on forest land based. Forest Carbon stocks and net annual Carbon stock change were determined according to a stock-difference method, which involves applying Carbon estimation factors to forest inventory data and interpolating between successive inventory-based estimates of Forest Carbon stocks.

**Stock-difference method**

The stock-difference method involves the measurement of carbon stocks in relevant pools at 2 points in time to assess carbon stock changes. The following equation is applied:

$$\Delta C = \frac{(Ct_2 - Ct_1)}{(t_2 - t_1)}$$

Where:

$\Delta C$ annual change in carbon stocks in the pool, tC/yr

$Ct_1$ carbon stocks in the pool at time $t_1$, tC

$Ct_1$ carbon stocks in the pool at time $t_2$, tC

EPA has updated this source category many times since the 2006 base year inventory was produced. Each time the forest carbon flux emission/sink calculation was influenced by:

- New updated models and model output data
- New sources of input data such as time intervals

When the model is updated or the inputs are changed, the emission/sink values change not only for future years but for the 2006 base year as well. MDE has decided to keep the forest carbon flux emission/sink calculation at the 2006 base year level for future year in order to maintain a constant 2006 base year inventory and to allow for accurate evaluations between future year anthropogenic greenhouse gas emission inventories and the base year.

(2) The second methodology used applies to wood products and landfills (i.e. harvested wood products). Since the CCT does not produce estimates for the entire time series, default carbon emissions/storage from forest carbon flux are calculated by using USDA Forest Service estimates of each state's harvested wood stocks in 1987, 1992, and 1997. Changes from 1987-1992 and from 1992-1997 are each divided by 5 (the number of intervening years) to determine the average annual change. This average annual change is then applied for each year, giving total annual change. For the years 1998-2007, the average annual change for 1992-1997 is used as proxy data.

For more information, please consult the Land Use, Land-Use Change, and Forestry chapter of the EPA SIT Program User's Guide.

**Equation 1.3.1: Forest Carbon Flux Equation**

Emissions or Sequestration ($MMTCO_2e$) = Aboveground Biomass Carbon Flux + Belowground Biomass Carbon Flux + Dead Wood Carbon Flux + Litter Carbon Flux + Soil Organic Carbon Flux + Wood Products Carbon Flux + Landfills Carbon Flux

### 10.3.2 Liming of Agricultural Soils

Limestone ($CaCO_3$) and dolomite ($CaMg (CO_3)_2$) are added to soils by land managers to remedy acidification. When these compounds come in contact with acidic soils, they degrade, thereby generating $CO_2$. This section presents the methodology MDE used to estimate the $CO_2$ emissions from the application of limestone and dolomite to agricultural soils.

The emissions are calculated by summing carbon emissions from the application of both limestone and dolomite to soil. The quantity of limestone and dolomite applied to agricultural soil in Maryland (metric tons) are multiplied by their default carbon emission factors, the resulting carbon emissions are then converted to million metric tons of carbon dioxide equivalent, and then summed.

The default emission factors are based on West & McBride (2005)[1].

For more information please consult the Land Use, Land-Use Change, and Forestry chapter of the User's Guide.

No default data on the application of limestone and dolomite to Agriculture soil could be found for the State of Maryland. Therefore, national percent limestone applied to Agriculture soil were multiplied by Maryland total limestone consumption to estimate the amount of limestone applied to agriculture soil.

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[1] West, T.O.; McBride, A.C. "The contribution of agricultural lime to carbon dioxide emissions in the United States: dissolution, transport, and net emissions," Agricultural Ecosystems & Environment. 2005, 108, 145-154.

$$\text{MD Limestone applied to Agric Soil} = \text{(National \% Limestone Applied to Agricultural Soil )} \times \text{(Total MD Limestone Consumption)}$$

### Equation 1.3.2: Liming Emissions Equation

$$\textbf{Emissions (MMTCO}_2\textbf{E)} = \frac{\textbf{Total Limestone or Dolomite Applied to Soil (1,000 metric tons)} \times \textbf{Emission Factor (tons C/ ton limestone or dolomite)} \times \textbf{44/12 (ratio of CO}_2\textbf{ to C)}}{\textbf{1,000,000 (MT/MMTCO}_2\textbf{e)}}$$

### 10.3.3 Urea Fertilization

The use of urea as a fertilizer results in $CO_2$ emissions that were previously fixed during the industrial production process. According to U.S. EPA (2009), urea in the presence of water and urease enzymes is converted into ammonium ($NH_4^-$), hydroxyl ion ($OH^-$) and bicarbonate ($HCO_3^-$). The bicarbonate then evolves into CO2 and water. This section presents the methodology for calculating the $CO_2$ emissions from the application of urea to agricultural soils.

The amount of urea applied to soil is multiplied by the carbon emission factor, and then converted to million metric tons carbon dioxide equivalent. The amount of urea applied to soils was obtained from two sources within the EPA SIT Program:

1. APFCO (2014) Commercial Fertilizers 2014. Association of American Plant Food Control Officials and the Fertilizer Institute. University of Kentucky, Lexington, KY.

2. TVA (1992b) Fertilizer Summary Data 1992. Tennessee Valley Authority, Muscle Shoals, AL.

The emission factor for urea application as a fertilizer to soils is recorded in metric tons of carbon per metric ton of urea. The default emission factor is based on IPCC (2006).

The SIT modules estimated $CO_2$ emissions due to the application of urea fertilizer using Equation 1.3.3.

### Equation 1.3.3: Urea Emissions Equation

$$\textbf{Emissions (MMTCO}_2\textbf{e)} = \frac{\textbf{Total Urea Applied to Soil (metric tons)} \ \textbf{X} \ \textbf{Emission Factor (tons C/ton urea)} \ \textbf{X} \ \textbf{44/12 (ratio of CO}_2\textbf{ to C)}}{\textbf{1,000,000 (MT/MMTCO}_2\textbf{e)}}$$

Where:

Emissions = Amount of carbon dioxide emitted from urea fertilization ($MMTCO_2E$)
Total Urea Applied = Amount of urea applied for the year in which carbon stocks are being estimated (metric tons)
Emission Factor = Emission factor for direct emissions of $CO_2$ (0.2 tons C / ton Urea)
0.01 = Conversion Factor – converts metric tons N2O-N to metric tons N (0.01)
44/12 = Conversion Factor – converts C to $CO_2$ (44/12)
1,000,000 = Conversion Factor – converts Metric Tons to Million Metric Tons

### 10.3.4 Urban Trees

Carbon can be sequestered in trees in urban areas. Changes in carbon stocks in urban trees are equivalent to tree growth minus biomass losses resulting from pruning and mortality. Net carbon sequestration can be calculated using data on ground cover area or number of trees.

To estimate $CO_2$ sequestration by urban trees, the following steps were followed:

1. Obtain data on the area of urban tree cover;
2. Calculate $CO_2$ flux; and
3. Convert units to metric tons of carbon dioxide equivalent (MT $CO_2$e).

Maryland historic net carbon flux from urban tree was adopted from the EPA SIT software; this tool uses default urban area data multiplied by a state estimate of the percent of urban area with tree cover to estimate the total area of urban tree cover. The 2017 periodic year estimate was calculated using Equation 1.3.4 below, with updated input data; total urban area ($km^2$) and percent of urban area with tree cover.

MDE obtained the updated periodic year 2017 Total Urban Area ($km^2$) data and the percent Urban Area coverage from the Maryland Forest Services. Periodic Year 2014 Sequestration was estimated from Urban Tree with the equation below, using SIT default C sequestration factor.

**Equation 1.3.4: Urban Trees Equation**

$$\text{Sequestration } (\text{MMTCO}_2\text{e}) = \frac{\text{Total Urban Area } (\text{km}^2) \;\text{X}\; \text{Urban Area with Tree Cover } (\%) \;\text{X}\; 100\ (\text{ha/km}^2) \quad \text{Carbon Sequestration Factor (metric tons C/ha/yr)} \;\text{x}\; 44/12\ (\text{ratio of CO}_2\text{ to C})}{1{,}000{,}000\ (\text{MT/MMTCO}_2\text{e})}$$

### 10.3.5 Settlement Soils

Settlement soils include all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.

MDE utilized the EPA SIT software for the estimation of nitrous oxide ($N_2O$) emissions from synthetic fertilizer application to soil in settled area such as lawns, golf courses, and other landscaping occurring within settled areas. The SIT modules estimated $N_2O$ emissions due to the application of synthetic fertilizer to settlement soils using Equation 1.3.5.

### Equation 1.3.5: Emission Equation for Direct $N_2O$ Emissions from Settlement Soils

$$\underset{(\text{MMTCO}_2\text{e})}{\text{Sequestration}} = \frac{\begin{array}{c}\text{Total Synthetic}\\ \text{Fertilizer}\\ \text{(metric ton N)}\end{array} \times \begin{array}{c}\text{Emission}\\ \text{Factor}\\ \text{(percent)}\end{array} \times \begin{array}{c}0.01\\ (\text{metric tons N}_2\text{0-N/}\\ \text{metric ton N)}\end{array} \quad \begin{array}{c}\text{GWP}\\ (310)\end{array} \times \begin{array}{c}44/28\\ (\text{ratio of N}_2\text{O to}\\ \text{N}_2\text{O -N)}\end{array}}{1{,}000{,}000\ (\text{MT/MMTCO}_2\text{e})}$$

Where:

Sequestration = Amount of carbon removed ($MMTCO_2e$)
Total Synthetic Fertilizer = Amount of synthetic fertilizer applied for the year in which carbon stocks are being estimated (metric tons of nitrogen)
Emission Factor = Emission factor for direct emissions on $N_2O$ (1.0 percent default value)
0.01 = Conversion Factor - converts metric tons $N_2O$-N to metric tons N (0.01)
GWP = Global Warming Potential, $N_20$ to $CO_2$ (310)
44/28 = Conversion Factor - converts $N_2O$-N to $N_20$ (44/28)
1,000,000 = Conversion Factor – converts Metric Tons to Million Metric Tons

## 10.3.6 Forest Fires

Biomass burned in forest fires emits $CO_2$, $CH_4$ and $N_2O$, in addition to many other gases and pollutants. $CO_2$ emissions from forest fires are inherently captured under total forest carbon flux calculations, but $CH_4$ and $N_2O$ must be estimated separately. All fires—wildfires and prescribed burns—emit these greenhouse gases.

Calculating the emissions of $N_2O$ and $CH_4$ from burned forests requires determining the amount of carbon released by the fire (by multiplying the area burned, the fuel load, and the combustion efficiency) and then factoring in the emission ratio for each gas.

Data on the area burned (hectares) per forest type was collected from the Maryland DNR, Forest Services Department for the base year. MDE applied the 2017 DNR wildfires and prescribed burns data to the EPA SIT default emission factors (grams of gas/kilogram of dry matter combusted), fuel load (kilograms dry matter per hectare) and combustion efficiency (percent) to estimate the base year non-$CO_2$ GHG emissions. Fuel load default biomass densities were adapted from Smith et al. (2001) and U.S. EPA 92009).

For more information, please consult the Land Use, Land-Use Change, and Forestry chapter of the EPA SIT Program User's Guide.

The equation below shows the method used to calculate $N_2O$ and $CH_4$ emissions from forest fires.

### Equation 1.3.6: Forest Fires Emissions Equation

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Emissions ($MMTCO_2e$)** | = | **Area Burned (ha)** | X | **Average Biomass Density (kg dry matter/ha)** | x | **Combustion Efficiency (%)** | x | **Emission Factor (g gas/kg dry matter burned)** | x | **GWP** |

### Table 10.1: Forest Fire Data Inputs

| **Forest Type** | **Area Burned (ha)** | **Average Biomass Density (kg d.m. / ha)** | **Combustion Efficiency** | **$CH_4$ Emission Factor (g/kg dry matter burned)** | **$N_2O$ Emission Factor (g/kg dry matter burned)** | **$CH_4$ GWP** | **$N_2O$ GWP** |
|---|---|---|---|---|---|---|---|
| Primary tropical forests | 0 | 152,440 | 36% | 8.1 | 0.11 | 21 | 310 |
| Secondary tropical forests | 0 | 152,440 | 55% | 8.1 | 0.11 | 21 | 310 |
| Tertiary tropical forests | 0 | 152,440 | 59% | 8.1 | 0.11 | 21 | 310 |
| Boreal forest | 0 | 152,440 | 34% | 8.1 | 0.11 | 21 | 310 |
| Eucalypt forests | 0 | 152,440 | 63% | 8.1 | 0.11 | 21 | 310 |
| Other temperate forests | 480 | 152,440 | 45% | 8.1 | 0.11 | 21 | 310 |
| Shrublands | 436 | 152,440 | 72% | 8.1 | 0.11 | 21 | 310 |
| Savanna woodlands (early/dry season burns) | | 152,440 | 40% | 4.6 | 0.12 | 21 | 310 |
| Savanna woodlands (mid/late season burns) | | 152,440 | 74% | 4.6 | 0.12 | 21 | 310 |

## 10.3.7 Landfilled Yard Trimmings and Food Scraps

When wastes of biogenic origin (such as yard trimming and food scraps) are landfilled and do not completely decompose, the carbon that remains is effectively removed from the global carbon cycle. This section of the inventory account for such carbon, it estimates the carbon stored in landfills by yard trimmings and food scraps.

Estimates of net carbon flux of landfilled yard trimmings and food scraps can be calculated by estimating the change in landfill carbon stocks between inventory years based on methodologies presented in IPCC (2003) and IPCC (2006). Carbon stock estimates were calculated by:

Step 1. determining the mass of landfilled carbon resulting from yard trimmings or food scraps discarded in a given year;
Step 2. adding the accumulated landfilled carbon from previous years; and
Step 3. Subtracting the portion of carbon landfilled in previous years that have decomposed.

The EPA SIT software module uses equation 1.3.7 below to calculate carbon sequestration associated with landfilled yard trimmings and food scraps.

## Equation 1.3.7: Emission Equation for Landfilled Yard Trimmings and Food Scraps

$$LFC_{i,t} = \sum W_{i,n} \times \left(1 - MC_i\right) \times ICC_i \times \left\{\left[CS_i \times ICC_i\right] + \left[\left(1 - \left(CS_i \times ICC_i\right)\right) \times e - kx\left(t - n\right)\right]\right\}$$

Where:

$LFC_{i,t}$ = the stock of carbon in landfills in year t, for waste i (grass, leaves, branches, food scraps)
t = the year for which carbon stocks are being estimated
$W_{i,n}$ = the mass of waste I disposed in landfills in year n, in units of wet weight
n = the year in which the waste was disposed, where $1960 < n < t$
$MC_i$ = moisture content of waste i
CSi = the proportion of initial carbon that is stored for waste i
$ICC_i$ = the initial carbon content of waste i
e = the natural logarithm
k = the first order rate constant for waste i, and is equal to 0.693 divided by the half-life for decomposition

Due to the complexity of these calculations, more detail about the methodology is provided below. For more information, please consult the Land Use, Land-Use Change, and Forestry Chapter of the User's Guide to the EPA SIT program.

The required basic data inputs include:

- Grass, leaves, and branches constituting yard trimmings (percent)
- Yard trimmings and foods scraps landfilled, 1960-present (tons)
- Initial carbon content of yard trimmings and food scraps (percent)
- Dry weight/wet weight ratio of yard trimmings and foods scraps (percent)
- Proportion of carbon stored permanently for yard trimmings and foods scraps (percent)
- Half-life of degradable carbon for yard trimmings and foods scraps (years)

### Step 1: Mass of Landfilled Carbon.

To determine the total landfilled carbon stocks for a given year, the following factors are estimated:

1. the composition of the yard trimmings,
2. the mass of yard trimmings and food scraps discarded in the state's landfills,
3. the carbon storage factor of the landfilled yard trimmings and food scraps, and
4. the rate of decomposition of the degradable carbon (based on a model of carbon fate).

Due to the number of factors involved, the Landfilled Yard Trimmings and Food Scraps sector worksheet is arranged by a series of steps, presented below:

1. The amount of landfilled yard trimmings and food scraps for periodic year 2017 was extracted from the Maryland Solid Waste Management and Diversion Report (Input Data to WARM Model)

.

a. Apportion the total landfilled yard trimmings to individual components, as a percent of grass, leaves, and branches. Default percentages are available within the module, and are provided by Oshins and Block (2000) and are presented in the table below.

**Table 10.2 - Default Composition of Yard Trimmings**

| Content of yard trimmings | Default |
|---|---|
| % Grass | 30% |
| % Leaves | 40% |
| % Branches | 30% |

b. Default data for the total annual landfilled yard trimmings and food scraps from 1960 to 2006 in short tons of wet weight is provided within the module and was used by MDE. MDE updated the default data with Maryland specific annual landfilled yard trimmings and food scraps from year 2007 to date, with certified reported landfilled data submitted to the MDE Solid Waste Program.

The default data from Franklin Associates (2008) is a national total for yard trimmings and food scraps, and is distributed to each state based on state population. The tool uses the percentage entered for yard trimmings in the previous step to allocate the amount of yard trimmings distributed among grass, leaves, and branches.

State Total Landfilled Trimmings (grass/leaves/branches) = State Population x National per Capita landfilled Total yard trimmings factor x Content of Yard Trimmings (%)

Where:

State Total Landfilled Trimmings (grass/leaves/branches) = Total Amount of Grass, Leaves and Branches landfilled in Maryland in a given year
State Population = Population of Maryland in a given year 2006 = 5,602,258
National per Capita landfilled total Yard Trimmings Factor = National per capita factor for Landfilled Yard Trimmings 2006 = 0.0335680699
Content of Yard Trimmings (%) = Default composition of Yard Trimmings from Table 10.2

State Total Landfilled Food Scraps = State Population x National per Capita landfilled Food Scraps Factor

Where:

State Total Landfilled Food Scraps = Total Amount of Food Scraps landfilled in Maryland in a given year
State Population = Population of Maryland in a given year 2006 = 5,602,258
National per Capita landfilled total Yard Trimmings Factor = National per capita factor for Landfilled Yard Trimmings

**Step 2: Amount of Carbon Added Annually.**

To calculate the amount of carbon added to landfills annually, the following steps were taken:

a. Default data for the initial carbon content percent for grass, leaves, branches, and food scraps is provided in the module and are taken from Barlaz (1998).

**Table 10.3: Initial Carbon Content**

Key Assumptions

| Initial Carbon Content | Default |
|---|---|
| Grass | 45% |
| Leaves | 46% |
| Branches | 49% |
| Food Scraps | 51% |

b. Default data on the dry weight to wet weight ratio for grass, leaves, branches, and food scraps, is drawn from Tchobanoglous, et al. (1993).

**Table 10.4: Dry Weight/Wet Weight Ratio**

| **Dry Weight/Wet Weight ratio** | **Default** |
|---|---|
| Grass | 30% |
| Leaves | 70% |
| Branches | 90% |
| Food Scraps | 30% |

**Step 3: Total Annual Stock of Landfilled Carbon.**

The amount of carbon added annually to landfills is then calculated from the above data using the equation below:

$$\text{Mass additions of carbon} = \frac{\text{landfilled materials, wet weight} \times \text{initial carbon content} \times \text{dry weight} \times \text{Metric tons to short ton}}{\text{wet weight ratio}}$$

The total annual stock of landfilled carbon is calculated by the following steps:

a. Use the default proportions, based on Barlaz (1998, 2005, and 2008).

### Table 10.5: Proportion of Carbon Stored Permanently

| Proportion of Carbon Stored Permanently | Default |
|---|---|
| Grass | 53% |
| Leaves | 85% |
| Branches | 77% |
| Food Scraps | 16% |

b. Use the default data from IPCC (2006) for the half-life of the degradable carbon in each of the materials in years.

### Table 10.6: Half-life of Degradable Carbon

| Half-life of degradable carbon (years) | Default |
|---|---|
| Grass | 5 |
| Leaves | 20 |
| Branches | 23.1 |
| Food Scraps | 3.7 |

### Step 4: Annual Flux of Carbon Stored.

Annual carbon stocks are calculated by summing the carbon remaining from all previous years' deposits of waste. The stock of carbon remaining in landfills from any given year is calculated as follows:

$$\text{Remaining Carbon Stock} = \text{Initial C Addition} \times \left[ \text{Proportion of C Stored Permanently} + (1-\text{Proportion of C Stored Permanently}) \times e^{\frac{(\ln(0.5)}{\text{Half-life of degradable C}}} \right]$$

To calculate stocks for any given year, the remaining stocks for all previous years are summed.

## 10.4 GREENHOUSE GAS INVENTORY RESULTS

### Table 10.7: 2017 Summary of Land Use, Land –Use Change, and Forestry Emissions and Sequestration in Maryland. ($MMTCO_2e$)

| | 2017 |
|---|---|
| **Forest Carbon Flux** | **(10.4980)** |
| Aboveground Biomass | (7.4829) |
| Belowground Biomass | (1.4221) |
| Dead Wood | (0.5848) |
| Litter | (0.2320) |
| Soil Organic Carbon | (0.0514) |
| Total wood products and landfills | (0.7248) |
| **Liming of Agricultural Soils** | **0.0315228** |
| Limestone | 0.0315228 |
| Dolomite | 0.00000 |
| **Urea Fertilization** | **0.01067** |
| **Urban Trees** | **(1.09292)** |
| **Landfilled Yard Trimmings and Food Scraps** | **(0.16864)** |
| Grass | (0.00955) |
| Leaves | (0.04901) |
| Branches | (0.04428) |
| Landfilled Food Scraps | (0.06579) |
| **Forest Fires** | **0.01650** |
| $CH_4$ | 0.01375 |
| $N_2O$ | 0.00276 |
| **$N_2O$ from Settlement Soils** | **0.02110** |
| **Total** | **(11.67987)** |

### Table10.8: 2017 $CO_2$ Emissions from Urea Fertilizer Use

| | Total Urea Applied to Soil | | Emission Factor | | Carbon Emissions | | Carbon Dioxide-to -Carbon Ratio (44/12) | | Carbon Dioxide Emissions | Carbon Dioxide Emissions |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | (Metric Tons) | | (Ton C/Ton urea) | | (MT) | | | | ($MTCO_2E$) | ($MMTCO_2E$) |
| 2017 | 14,547 | x | 0.2 | = | 2,909 | x | 3.66667 | = | 10,668 | 0.01067 |

## Table 10.9: 2017 $CO_2$ Emissions from Liming of Soil

| **Year** | | **Total Applied to Soil ('000 Metric Tons)** | | **Emission Factor (Ton C/Ton limestone)** | | **Emissions (Ton C)** | | **$C-CO_2$ Ratio** | **Carbon Dioxide Emissions ($MTCO_2E$)** | | **Total Carbon Dioxide Emissions ($MMTCO_2E$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | Limestone | 145,713.80 | x | 0.059 | = | 8,597 | x | (44/12) | 31,523 | = | 0.031522752 |
| 2017 | Dolomite | 0 | x | 0.064 | = | 0 | | | 0 | = | 0 |
| | | | | | | | | | | | 0.031522752 |

## Table 10.10: 2017 $CH_4$ Emissions from Forest Fire.

| Forest Type | Area Burned (ha) | Average Biomass Density (kg d.m. / ha) | Combustion efficiency | Emission Factor (g/kg dry matter burned) | $CH_4$ Emitted (metric tons) | $CH_4$ GWP | Emissions $MMTCO_2E$ |
|---|---|---|---|---|---|---|---|
| Primary tropical forests | | 152,440 | 36% | 8.1 | - | 21 | - |
| Secondary tropical forests | | 152,440 | 55% | 8.1 | - | 21 | - |
| Tertiary tropical forests | | 152,440 | 59% | 8.1 | - | 21 | - |
| Boreal forest | | 152,440 | 34% | 8.1 | - | 21 | - |
| Eucalypt forests | | 152,440 | 63% | 8.1 | - | 21 | - |
| Other temperate forests | 480 | 152,440 | 45% | 8.1 | 480 | 21 | 0.0056 |
| Shrublands | 436 | 152,440 | 72% | 8.1 | 436 | 21 | 0.0081 |
| Savanna woodlands (early dry season burns) | | 152,440 | 40% | 4.6 | - | 21 | - |
| Savanna woodlands (mid/late season burns) | | 152,440 | 74% | 4.6 | - | 21 | - |
| Total | | | | | | | **0.0137** |

## Table 10.11: 2017 $N_2O$ Emissions from Synthetic Fertilizer Application to Settlement Soils.

| Year | Total Synthetic Fertilizer Applied to Settlements (Metric Tons N) | Emission Factor (percent) | $N_2O$-N | Direct $N_2O$ Emissions (Metric Tons $N_2O$ Emitted) | $N_2O$ GWP | Carbon Dioxide Emissions ($MTCO_2E$) | Total Carbon Dioxide Emissions ($MMTCO_2E$) |
|---|---|---|---|---|---|---|---|
| 2017 | 4,336 | 1% | 1.57 | 68.1 | 310 | 21,111 | 0.02110 |

### Table 10.12: 2017 $N_2O$ Emissions from Forest Fire.

| Forest Type | Area Burned (ha) | Average Biomass Density (kg d.m. / ha) | Combustion efficiency | Emission Factor (g/kg dry matter burned) | $N_2O$ Emitted (metric tons) | $N_2O$ GWP | Emissions $MMTCO_2E$ |
|---|---|---|---|---|---|---|---|
| Primary tropical forests | 0 | 152,440 | 36% | 0.11 | - | 310 | - |
| Secondary tropical forests | 0 | 152,440 | 55% | 0.11 | - | 310 | - |
| Tertiary tropical forests | 0 | 152,440 | 59% | 0.11 | - | 310 | - |
| Boreal forest | 0 | 152,440 | 34% | 0.11 | - | 310 | - |
| Eucalypt forests | 0 | 152,440 | 63% | 0.11 | - | 310 | - |
| Other temperate forests | 480 | 152,440 | 45% | 0.11 | 3.6202 | 310 | 0.0011 |
| Scrublands | 436 | 152,440 | 72% | 0.11 | 5.2692 | 310 | 0.0016 |
| Savanna woodlands (early dry season burns) | 0 | 152,440 | 40% | 0.12 | - | 310 | - |
| Savanna woodlands (mid/late season burns) | 0 | 152,440 | 74% | 0.12 | - | 310 | - |
| Total | | | | | | | **0.0028** |

### Table 10.13: 2017 C- Storage in Urban Trees.

| **Year** | **2017** |
|---|---|
| Total Urban Area ($km^2$) | 4,773.70 |
| | |
| Urban Area with Tree Cover(Percent) | 28% |
| | |
| Total Area of Urban Tree Cover ($km^2$) | 1,538.32 |
| Hectare/ $km^2$ | 100 |
| Total Area of Urban Tree Cover (ha) | 153,832 |
| | |
| Carbon Sequestration Factor (metric tons C /hectare/year) | 2.23 |
| | |
| Carbon Sequested (metric tons) | 343,045.36 |
| | |
| Carbon dioxide-to-Carbon Ratio (44/12) | 3.67 |
| | |
| Carbon Dioxide Removed (metric tons) | 1,092,920 |
| | |
| Carbon Sequested ($MMTCO_2E$) | **-1.09292** |

## Table 10.14: Net Sequestrations/ Emissions (MMTCO$_2$e) - Landfilled Yard Trimmings and Food Scraps (2011 -2017).

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Grass | -0.0069 | -0.0091 | -0.0137 | -0.0127 | -0.0127 | -0.0127 | -0.00955 |
| Leaves | -0.0481 | -0.057 | -0.0778 | -0.0709 | -0.0709 | -0.0709 | -0.04901 |
| Branches | -0.0431 | -0.0515 | -0.0711 | -0.0646 | -0.0646 | -0.0646 | -0.04428 |
| Food Scraps | -0.0615 | -0.0501 | -0.0619 | -0.0701 | -0.0701 | -0.0701 | -0.06579 |
| Total | (0.1595) | (0.1678) | (0.2246) | (0.2182) | (0.2182) | (0.2182) | (0.16864) |

## Table 10.15: -Net Séquestration/ Emissions (MMTCO$_2$e)- Forest Carbon Flux (2011 -2017).

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Aboveground Biomass | -7.4829 | -7.4829 | -7.4829 | -7.4829 | -7.4829 | -7.4829 | -7.4829 |
| Belowground Biomass | -1.4221 | -1.4221 | -1.4221 | -1.4221 | -1.4221 | -1.4221 | -1.4221 |
| Dead Wood | -0.5848 | -0.5848 | -0.5848 | -0.5848 | -0.5848 | -0.5848 | -0.5848 |
| Litter | -0.232 | -0.232 | -0.232 | -0.232 | -0.232 | -0.232 | -0.232 |
| Soil Organic Carbon | -0.0514 | -0.0514 | -0.0514 | -0.0514 | -0.0514 | -0.0514 | -0.0514 |
| Total | (10.498) | (10.498) | (10.498) | (10.498) | (10.498) | (10.498) | (10.498) |

## Table 10.16: Net Sequestrations/ Emissions (MMTCO$_2$e) - Wood Products and Landfills (2011 -2017).

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Total wood products and landfills | (0.7248) | (0.7248) | (0.7248) | (0.7248) | (0.7248) | (0.7248) | (0.7248) |
| | | | | | | | |

Maryland
Department of
the Environment

# Appendix E

## NG Life-Cycle GHG Emissions Inventory Attributable to Fracked Gas in 2017

# 2019 GGRA Draft Plan

Maryland
Department of
the Environment

Larry Hogan
Governor

Boyd Rutherford
Lieutenant Governor

Ben Grumbles
Secretary

***---Preliminary Draft----***

# *State of Maryland*

# *Natural Gas Life-Cycle Greenhouse Gas Emissions Inventory Attributable to Fracked Gas in 2017*

**January 31, 2019**

**Prepared by:**
**Maryland Department of the Environment**
**Climate Change Division**

# Maryland Department of the Environment
# 2017 GHG Life-Cycle Emissions Inventory from Fracked Natural Gas

Maryland Department of the Environment
Air and Radiation Administration
1800 Washington Boulevard, Suite 730
Baltimore, Maryland 21230
Phone 410.537.3255 • Fax 410.537.4223

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| µg/m3 | microgram(s) per cubic meter |
| AERMAP | AERMOD terrain preprocessor |
| AERMET | AERMOD meteorological preprocessor |
| AERMOD | American Meteorological Society/EPA Regulatory Model |
| AQS | Air Quality System |
| BPIPPRM | Building Profile Input Program for the Plume Rise Model Enhancements algorithm |
| CAA | Clean Air Act |
| CEV | Critical emission value |
| CFR | Code of Federal Regulations |
| COA | Consent Order and Agreement |
| CSAPR | Cross State Air Pollution Rule (CSAPR) |
| EGU | Electric Generating Unit |
| EMF | Emission Modeling Framework |
| EPA | U.S. Environmental Protection Agency |
| FGD | Flue gas desulfurization |
| FIP | Federal Implementation Plan |
| FR | Federal Register |
| g/s | gram(s) per second |
| LAER | Lowest Achievable Emission Rate |
| lb/hr | pound(s) per hour |
| MACT | Maximum Achievable Control Technology |
| MARAMA | Mid-Atlantic Regional Air Management Association |
| MATS | Mercury and Air Toxic Standards |
| MDE | Maryland Department of the Environment |
| NAAQS | National Ambient Air Quality Standard |
| NEI | National Emission Inventory |
| NESHAP | National Emission Standards for Hazardous Air Pollutants |
| NID | Novel integrated desulfurization |
| NOV | Notice of Violation |
| NOx | Nitrogen oxides |
| NSPS | New Source Performance Standards |
| NSR | New Source Review |
| ppb | parts per billion |
| ppm | parts per million |
| RACM | Reasonably Available Control Measure |
| RACT | Reasonably Available Control Technology |
| RFP | Reasonable Further Progress |
| SCC | Source Classification Code |
| SIP | State Implementation Plan |
| $SO_2$ | Sulfur dioxide |
| SOx | Sulfur oxides |
| TSD | Technical Support Document |
| TSP | Total Suspended Particles |
| TVOP | Title V Operating Permit |

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# EXECUTIVE SUMMARY

This report provides an analysis of out-of state, fracking-related greenhouse gas emissions that Maryland may take responsibility for and potentially offset. The analysis includes fugitive leakage emissions and well construction emissions. The report uses the total methane consumption for year 2016 as a baseline and analyzes various scenarios that represent the amount of natural gas consumed due to fracking activities. The first scenario uses the US Energy Information Administration (EIA) statistic that 67% of the natural gas consumed is derived from fracking. The other three cases are justified by the fact that before 2006, there was no fracking in Maryland and the surrounding areas.

The analysis found that Maryland will have to offset between 0.1053 and 1.696 mmtCO2e. This represents less than 2% of the inventory in the worst case.

At the time of writing, we were limited to using 2016 consumption data.

# 1.0 BACKGROUND

The Maryland Department of the Environment (MDE) was tasked with additional greenhouse gas emission inventory requirements by the Maryland Commission on Climate Change in the 2017 Annual Report. The Maryland Commission on Climate Change recommended[1] the following to MDE:

> The Commission recommends that MDE continue to work with the STWG, the University of Maryland, and the Departments of Natural Resources and Agriculture to ensure that MDE's Greenhouse Gas Emission Inventory is locally relevant and complete. Specifically MDE should continue to examine improvements to: life cycle emissions of fossil fuels extracted out of state but burned in state, and emissions sink methodologies for in-state forests, wetlands, and agriculture. As required by law, this work will be completed by the end of 2018 as part of the final publication of the 2017 emissions inventory

The Maryland Commission on Climate Change through the Mitigation Working Group worded the recommendation to MDE as follows:

> Regarding the State's GHG Emissions Inventory, due in 2018, the MWG recommends that MDE continue to work with the STWG, the University of Maryland, and the Departments of Natural Resources and Agriculture to ensure that the Inventory is both locally relevant and complete. This includes consideration of life-cycle emissions generated by out-of-state extraction, processing, and transportation of fossil fuel energy consumed in-state; and applying advanced methods to generate a more accurate accounting of emissions sinks such as agricultural soil and forestry management.

This report documents MDE's work on the life cycle greenhouse gas emissions of fossil fuels extracted out of state but burned in state with a focus on natural gas fracking operations.

---

[1] http://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/MCCC_2017_final.pdf

# 2.0 PURPOSE AND OBJECTIVE

## 2.1 Purpose

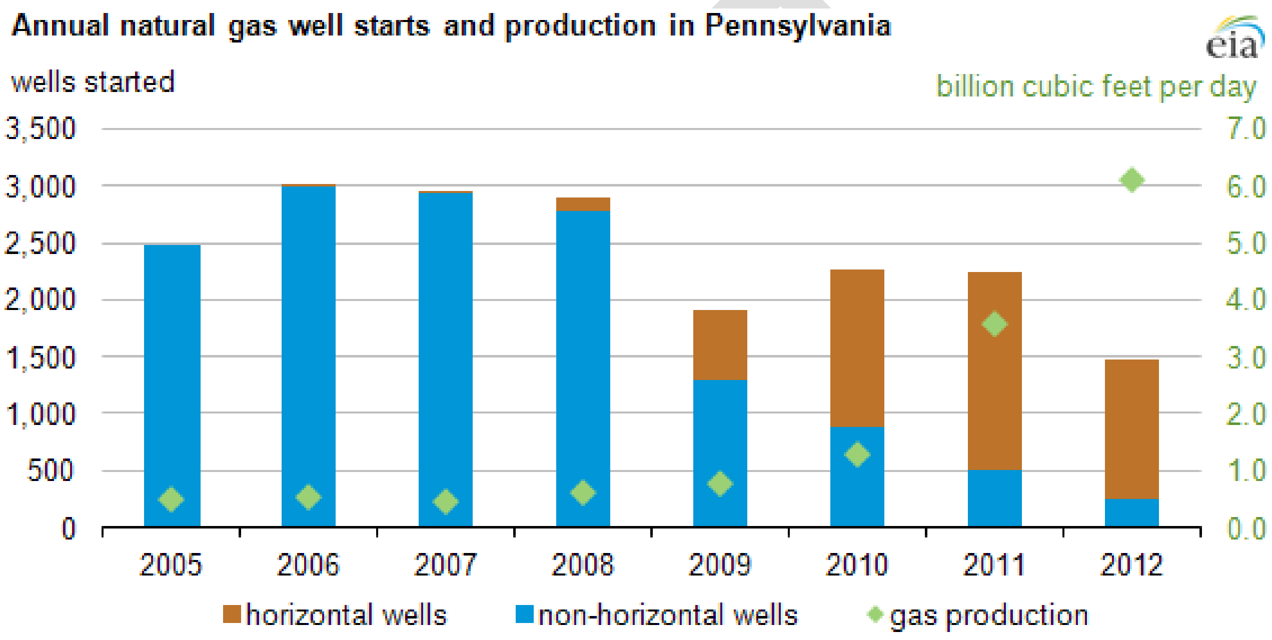
The purpose of this document is to provide a report, complete with methods, data, calculations and references that satisfy the recommendations of the Maryland Commission on Climate Change regarding the life-cycle emissions of fracked natural gas consumed in Maryland.

## 2.2 Objective

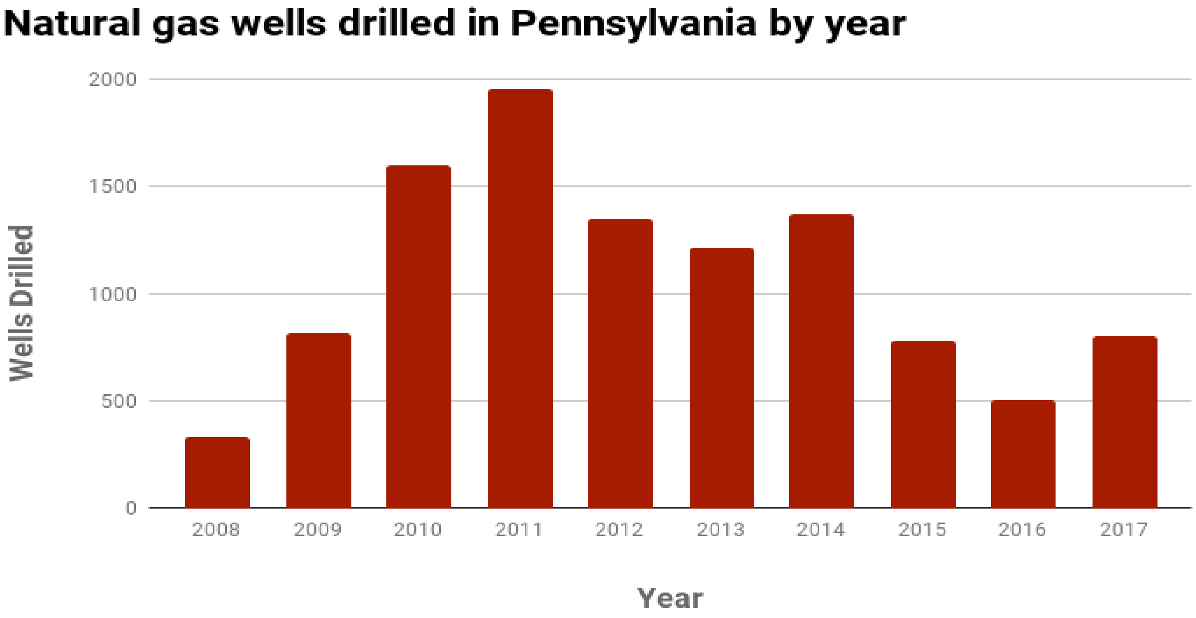
Prepare a 2017 GHG emissions inventory that accounts for the life-cycle greenhouse gas emissions from the consumption of the additional natural gas attributable to the fracking industry in nearby states.

# 3.0 HISTORY OF UNCONVENTIONAL WELLS/FRACKING IN THE MARCELLUS SHALE REGION

As can be seen from the following graphs and information, the construction of unconventional natural gas fracking wells in the Marcellus Shale region did not start until after 2006. The majority of wells were started after 2010. This point is important within a Maryland greenhouse gas emissions inventory context because the consumption of fracked natural gas in Maryland during the calendar year 2006 for the MD GHG Base Year Emissions Inventory can be considered negligible.



Source: Pennsylvania Department of Environmental Protection.
Note: New wells, or well starts, reflect the number of spudded wells, or wells that began drilling during the year. The figure above does not reflect the number of wells drilled, completed, or permitted.



Source: Pennsylvania Department of Environmental Protection. Wells drilled indicates number of unconventional (horizontally drilled) wells. 2017 data reflects the number of wells drilled through mid-December.

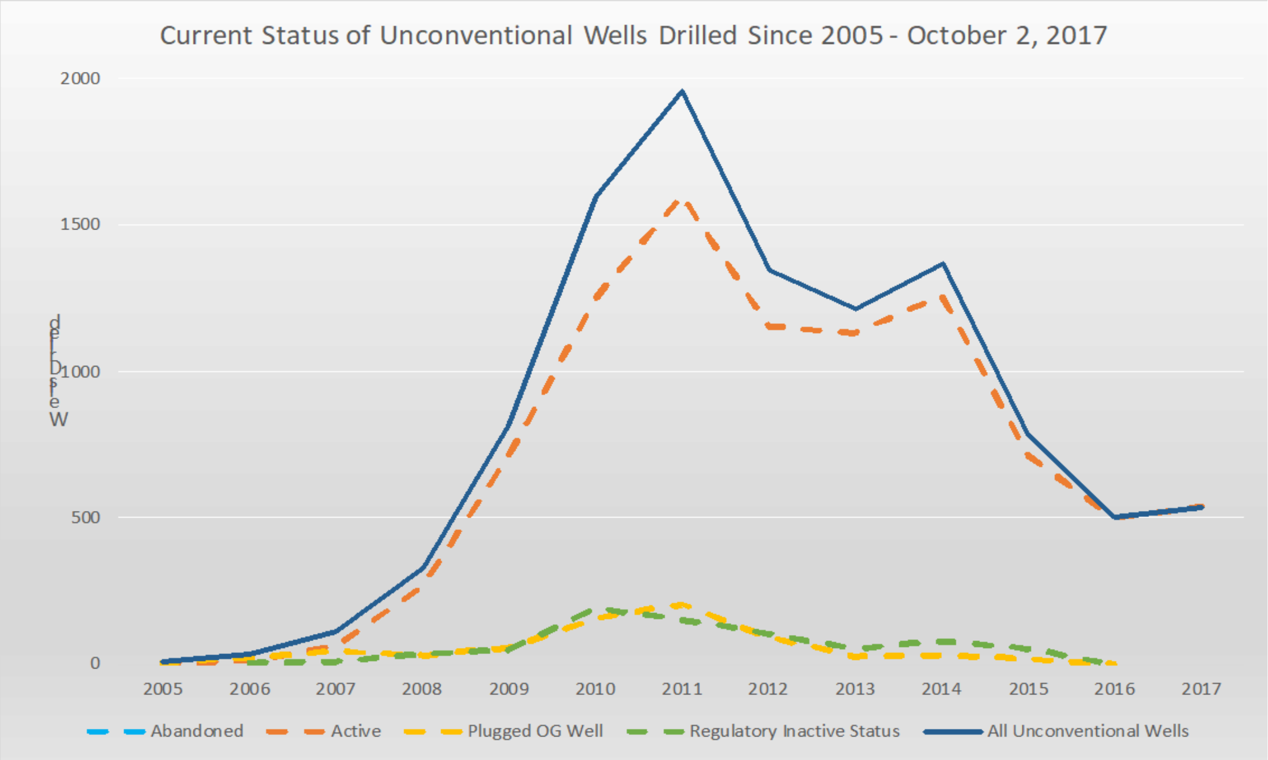


Chart 1: This chart shows the current status of unconventional wells in Pennsylvania, arranged by the year the well was drilled. Note that there are two abandoned wells in 2009 and one more in 2014, although those totals are not visible at this scale.
https://www.fractracker.org/2017/10/life-expectancy-marcellus-shale/

# 4.0 METHODS AND PROCEDURES

Three distinct processes contribute to GHG emissions in the production, distribution and consumption of natural gas from fracking wells. These processes are:

1. Construction/Development of the unconventional fracking well
2. Distribution of the natural gas
3. Combustion of the natural gas

### *Construction/Development of the Well*

Greenhouse gas emissions are produced during the construction and development of the well. This is a one-time event in the life time of a well. Sources of greenhouse gas emissions during the construction and development of a well include:

- Drilling Rigs
- Hydraulic Fracturing Pumps
- Mud Degassing
- Well Completion Venting

### *Distribution of Natural Gas from the Well*

Sources of greenhouse gas emissions during the distribution of natural gas from out-of-state unconventional fracking wells include:

- Leakage from pipelines, fittings and pumping stations

In-state distribution of the gas is already included in the 2017 greenhouse gas emissions inventory.

### *Combustion of the Supplied Natural Gas*

The combustion of natural gas supplied from out-of-state unconventional fracking wells is already included in the 2017 greenhouse gas emissions inventory.

## 4.1 Methodology for Estimating Emissions

The main equation used to estimate the greenhouse gas emissions from the consumption of natural gas from out-of-state unconventional fracking wells is provided below:

**Equation 1: Main GHG Emission Estimate Equation**

| | | | | |
|---|---|---|---|---|
| Total Annual GHG Emissions from NG Consumption from Out-of-State Fracking Wells (CO2$_{E}$) | = | Annual Fugitive Leakage Emissions from Natural Gas Consumed in Maryland from Out-of-State Fracking Wells | + | Annualized Well Construction Emissions from Natural Gas Consumed by Maryland from Out-of-State Fracking Wells |

### 4.1.1 Leakage Emissions

The equation used to estimate the greenhouse gas emissions from the fugitive leakage of the natural gas consumed by Maryland from out-of-state unconventional fracking wells is provided below:

**Equation 2: GHG Leakage Emission Estimate Equation**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fugitive Leakage Emissions from NG Consumption from Out-of-State Fracking Wells (CO2$_{E}$) | = | Amount of NG Consumed by MD from Out-of-State Fracking Wells | X | Leakage Rate (%) | X | % of Methane in NG Stream | X | GWP Methane | X | Percentage of Pipeline Outside MD |

*Amount of Natural Gas Consumed from Out-of-State Fracking Wells*

MDE collected total annual natural gas consumption data from the U.S. Energy Information Administration (EIA)[2]. The data was used as a baseline to establish the quantity of natural gas consumed by the State of Maryland prior to the installation and development of unconventional fracking wells in neighboring states. Prior to 2006, the consumption of natural gas produced from unconventional fracking wells in Maryland can be considered negligible (See Section 3). Table 1 below reports the total amount of natural gas consumed by all sources in Maryland per year.

---

[2] U.S. Energy Information Administration - https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm

**Table 1: Consumption of Natural Gas in MD – Total All Sources[3]**

| Date | Maryland Natural Gas Total Consumption (MMcf) | |
|---|---|---|
| 1997 | 212,017 | |
| 1998 | 188,552 | |
| 1999 | 196,350 | |
| 2000 | 212,133 | |
| 2001 | 178,376 | |
| 2002 | 196,276 | |
| 2003 | 197,024 | |
| 2004 | 194,725 | |
| 2005 | 202,509 | |
| 2006 | 182,294 | |
| 2007 | 201,053 | → Start date for the installation and development of unconventional natural gas fracking wells in neighboring states |
| 2008 | 196,067 | |
| 2009 | 196,510 | |
| 2010 | 212,020 | |
| 2011 | 193,986 | |
| 2012 | 208,946 | |
| 2013 | 197,356 | |
| 2014 | 207,103 | |
| 2015 | 215,005 | |
| 2016 | 218,683 | |
| 2017 | | |
| 1997 – 2005 Average | 197,551 | |
| Min | 178,376 | |
| Max | 212,133 | |

The EIA data shows that prior to 2007, the start date for the installation and development of natural gas fracking wells in neighboring states, the maximum amount of natural gas consumed was 212,133 MMcf in 2000, the minimum was 182,294 in 2006 and the average between 1997 and 2005 was 197,551. The production of and infrastructure for natural gas consumption in Maryland, prior to the installation and development of natural gas fracking wells in neighboring states, was capable of delivering 212,133 MMcf of natural gas per year. Natural gas supplied above these levels could be attributed to unconventional natural gas fracking activities.

Another method to determine the amount of natural gas consumed in Maryland due to fracking wells in neighboring states would be to establish the percent of the total natural gas nationally that is produced from fracking and apply the percentage to that consumed in Maryland. Nationally, fracking produces two-thirds (67 percent)[4] of the natural gas in the United States, according to the US Energy Information Administration, and approximately 50 percent of the nation's oil.

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[3] U.S. Energy Information Administration (EIA) – Natural Gas Consumption by End Use – Maryland https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm

[4] https://www.eia.gov/todayinenergy/detail.php?id=26112

### *LEAKAGE RATE*

The process of delivering natural gas from a wellhead to a consumer is not a closed system; leakage does occur in the infrastructure along the way. The leakage rate has been studied by scientists, scholars and engineers. The leakage rate varies from study to study. A short synopsis of some of the leakage rate studies is summarized below.

> *Journal of Cleaner Production - Volume 148, 1 April 2017, Pages 118-126*[5]
> A synthesis of new methane ($CH_4$) emission data from a recent series of ground-based field measurements shows that 1.7% of the methane in natural gas is emitted between extraction and delivery (with a 95% confidence interval from 1.3% to 2.2%). This synthesis was made possible by a recent series of methane emission measurement campaigns that focused on the natural gas supply chain, production through distribution. The new data were translated to a standard basis, augmented with other data sources as needed, and simulated using a Monte Carlo-enabled, life cycle model.
>
> *Environmental Defense Fund*
> The findings reported feature measurements at over 400 well pads in six basins and scores of midstream facilities, data from component measurements, and aerial surveys covering large swaths of U.S. oil and gas infrastructure.
>
> Steve Hamburg, EDF's chief scientist, says that still leaves out the "fat-tail" super-emissions. He reckons about 2-2.5% of the gas flowing through the American supply chain leaks out, in total. "The new study estimates the current leak rate from the U.S. oil and gas system is 2.3 percent, versus the current EPA inventory estimate of 1.4 percent."[6]
>
> *EPA Study*
> The EPA 2012 study found the leakage rate to be 2.4%, with a 95% confidence interval of 1.9-3.1%.[7].
>
> *$CO_2$ Scorecard*
> Another study[8] by $CO_2$ Scorecard uses three scenarios based on EPA data; one with the leakage rate set to 1.22%, one with a leakage rate set to 1.50% that was deemed more realistic, and one at 2.00% that "many organizations estimate that a leakage rate of 2-3% cancels out all of natural gas's $CO_2$ emissions advantage over coal.

MDE decided to use the highest leakage rate of 2.5% to be even more conservative that the Environmental Defense Fund.

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[5] https://www.sciencedirect.com/science/article/pii/S0959652617301166
[6] https://www.edf.org/media/new-study-finds-us-oil-and-gas-methane-emissions-are-60-percent-higher-epa-reports-0
[7] U.S. Environmental Protection Agency (2011) Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2009 (EPA Publication 430-R-11-005).
[8] https://co2scorecard.org/home/researchitem/28

*PERCENT OF METHANE IN NATURAL GAS STREAM*

An EPA study[9] and other literature searches[10,11] show that the percent of methane in pipeline natural gas is approximately 98%.

*GLOBAL WARMING POTENTIAL - METHANE*

The following table includes the 100-year time horizon global warming potential (GWP) of methane ($CH_4$) relative to $CO_2$.

**Table 2: Global warming potential (GWP) values[12] relative to $CO_2$**

| Industrial designation or common name | Chemical formula | GWP values for 100-year time horizon | |
|---|---|---|---|
| | | Second Assessment Report (SAR) | Fourth Assessment Report (AR4) |
| Carbon dioxide | $CO_2$ | 1 | 1 |
| Methane | $CH_4$ | 21 | 25 |
| Nitrous oxide | $N_2O$ | 310 | 298 |

MDE is using the IPCC Fourth Assessment Report (AR4) GWP of 25 for methane.

*PERCENTAGE OF PIPELINE OUTSIDE OF MARYLAND*

The percentage represents the amount of pipeline that transmits the fracked natural gas from Pennsylvania to Maryland that is outside of Maryland. MDE followed the main transmission pipelines from Washington County, Pennsylvania to Baltimore, Maryland. This map is presented in Appendix C.

In a best case scenario the fracked natural gas would travel from the wells in Washington County, PA due south into Maryland. In a worst case scenario, the fracked natural gas would travel from the wells in Washington County, PA toward Philadelphia and turn south into Maryland. MDE chose the worst case scenario in order to offset the maximum amount of fugitive gas released in transmission. This percentage was estimated to be 85.7%.

### 4.1.2 Annualized Well Construction Emissions

Greenhouse gas (GHG) emissions from unconventional natural gas fracking activities occur not only from the lost fugitive gas in the transmission and distribution stream, but also in the construction of the wells themselves. In order to quantify GHG emissions from the well construction activities, MDE collected well production emissions data from the Commonwealth of Pennsylvania.

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[9] https://www.epa.gov/natural-gas-star-program/overview-oil-and-natural-gas-industry
[10] http://scifun.chem.wisc.edu/chemweek/methane/methane.html
[11] https://www.uniongas.com/about-us/about-natural-gas/chemical-composition-of-natural-gas
[12] http://www.ipcc.ch/publications_and_data/ar4/wg1/en/errataserrata-errata.html#table214

PA DEP collects methane and carbon dioxide emissions data from each well site location. The data is specific to the geographic coordinates of every well permit and includes a wide variety of construction equipment including blow-down vents, dehydrators, drill rigs, engines, heaters, pumps and tanks. PA DEP created a spreadsheet[13] that MDE used to estimate the GHG emissions from well construction for the number of wells necessary to supply Maryland with the amount of natural gas consumed by out-of-state fracking wells. In order to use the spreadsheet, MDE needed to determine how many wells were necessary to produce the excess natural gas on a case-by-case basis. MDE took the average production of the 50 biggest wells in Washington County, PA and determined how many wells on average it would take to supply Maryland with the difference in fuel from 2006.

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[13] https://www3.epa.gov/carbon-footprint-calculator/tool/userarchiveversion/documents/SubW_Screening_Tool_Onshore_Production.xls

# 5.0 RESULTS AND CONCLUSIONS

The greenhouse gas emissions attributable to unconventional natural gas fracking wells in neighboring states is directly proportional to the amount of natural gas assumed to come from the wells. MDE completed four separate analyses. Each of the analyses varied the amount of natural gas consumed in Maryland attributable to unconventional fracking wells. The other variables were kept constant; these variables include the following:

| | | |
|---|---|---|
| **Leakage Rate Percent** | **2.5%** | |
| **Global warming potential** | **25** | |
| **NG Conversion** | **48,700** | **$ft^3$/metric ton** |
| **NG $CH_4$ %** | **0.98** | **% $CH_4$ in NG Stream** |

The main equation used to estimate the greenhouse gas emissions from the consumption of natural gas from out-of-state unconventional fracking wells is provided below:

**Equation 1: Main GHG Emission Estimate Equation**

Total Annual GHG Emissions from NG Consumption from Out-of-State Fracking Wells ($CO2_E$) = Annual Fugitive Leakage Emissions from Natural Gas Consumed in Maryland from Out-of-State Fracking Wells + Annualized Well Construction Emissions from Natural Gas Consumed by Maryland from Out-of-State Fracking Wells

Where the equation used to estimate the greenhouse gas emissions from the fugitive leakage of the natural gas consumed by Maryland from out-of-state unconventional fracking wells is provided below:

**Equation 2: GHG Leakage Emission Estimate Equation**

Fugitive Leakage Emissions from NG Consumption from Out-of-State Fracking Wells ($CO2_E$) = Amount of NG Consumed by MD from Out-of-State Fracking Wells X Leakage Rate (%) X % of Methane in NG Stream X GWP Methane X Percentage of Pipeline Outside MD

The four separate analyses and the results are described below.

## 5.1 Scenario 1 – National Percent of Natural Gas Attributable to Fracking Applied to Maryland Consumption

*Assumption*

According to the U.S. Energy Information Administration[14], 67% of the natural gas in consumed in the U.S is derived from fracking.

*Basis*

The U.S. EIA tracks the amount of natural gas produced in the U.S. and the type of well used in the production. The 67 percent number is the most recent data available.

Equations 1, 2 and 3 are used to estimate the greenhouse gas emissions.

*AMOUNT OF NATURAL GAS CONSUMED FROM OUT-OF-STATE FRACKING WELLS*

In this scenario the amount of natural gas consumed from unconventional out-of-state fracking wells is considered to be 67 (⅔) percent of the total amount of natural gas consumed in the state. In 2016 this amounted to 146,518 mmcf of natural gas.

Equation 2 then yields the following greenhouse gas emissions for fugitive leakage emissions.

$$\text{MMT CO2E} = \frac{(218{,}683 \times 0.67 \times 1{,}000{,}000 \times 0.025 \times 0.98 \times 25 \times .857)}{(48{,}700 \times 1{,}000{,}000)}$$

$$\text{MMT CO2E} = 1.578$$

The PA DEP's spreadsheet was used to determine the well construction emissions. In this scenario, 19 wells were necessary to supply Maryland with the 146,518 mmcf of natural gas.

2016 Total Emissions = (0.1163 + 1.578)
2016 Total Emissions = 1.696 mmtCO2e

---

[14] https://www.eia.gov/todayinenergy/detail.php?id=26112

## 5.2 Scenario 2 – All Consumption above 2006 Level Attributable to Fracking

*Assumption*

The difference in natural gas consumption from the current year and 2006 consumption is due to fracking.

*Basis*

Before 2006 there was no fracking in Maryland and the surrounding region. Assuming all natural gas consumption since then is due to fracking will lead us to the least conservative estimate possible.

Equations 1 and 2 are used to estimate the greenhouse gas emissions.

*AMOUNT OF NATURAL GAS CONSUMED FROM OUT-OF-STATE FRACKING WELLS*

In this scenario the amount of natural gas consumed from unconventional out-of-state fracking wells is considered to be the difference natural gas consumed in the state from the specific year minus 2006's consumption. In 2016 this amounted to 36,389 mmcf of natural gas. Equation 2 then yields the following greenhouse gas emissions for fugitive leakage emissions.

$$\text{MMT CO2E} = \frac{((218{,}683 - 182{,}294) \times 1{,}000{,}000 \times 0.025 \times 0.98 \times 25 \times .857)}{(48{,}700 \times 1{,}000{,}000)}$$

$$\text{MMT CO2E} = 0.3923$$

The PA DEP's spreadsheet was used to determine the well construction emissions. In this scenario, 5 wells were necessary to supply Maryland with the 36,389 mmcf of natural gas.

Total Emissions = (0.05286) + 0.3923
Total Emissions = 0.4451 mmtCO2e

## 5.3 Scenario 3 – Consumption above the Average Consumption between 1997 - 2005 Attributable to Fracking

*Assumption*
The difference in natural gas consumption from the current year and the average consumption of 1997-2005 is due to fracking.

*Basis*
Before 2006 there was no fracking in Maryland and the surrounding region. Assuming all natural gas consumption since then is due to fracking will lead us to the least conservative estimate possible. Using the average of 1997-2005 is an alternative that takes more data into account, aiming for a more accurate estimate.

Equations 1 and 2 are used to estimate the greenhouse gas emissions.

*AMOUNT OF NATURAL GAS CONSUMED FROM OUT-OF-STATE FRACKING WELLS*
In this scenario the amount of natural gas consumed from unconventional out-of-state fracking wells is considered to be the difference natural gas consumed in the state from the specific year minus the average consumption of 1997-2005. In 2016 this amounted to 21,132 mmcf of natural gas. Equation 2 then yields the following greenhouse gas emissions for fugitive leakage emissions.

$$\text{MMT CO2E} = \frac{((218{,}683 - 197{,}551) \times 1{,}000{,}000 \times 0.025 \times 0.98 \times 25 \times .857)}{(48{,}700 \times 1{,}000{,}000)}$$

$$\text{MMT CO2E} = 0.2278$$

The PA DEP's spreadsheet was used to determine the well construction emissions. In this scenario, 3 wells were necessary to supply Maryland with the 21,132 mmcf of natural gas.

Total Emissions = 0.04379 + 0.2278
Total Emissions = 0.2716 mmtCO2e

## 5.4 Scenario 4 – Consumption above Maximum Consumption in MD between 1997 - 2006 Attributable to Fracking

### Assumption

The difference in natural gas consumption from the current year and max consumption year between 1997 and 2006 is due to fracking.

### Basis

Before 2006 there was no fracking in Maryland and the surrounding region. Using the year with the maximum natural gas consumption of 1997-2005 is an alternative that sets a lower bound for our cases, and will be the most conservative estimate.

Equations 1 and 2 are used to estimate the greenhouse gas emissions.

*Amount of Natural Gas Consumed from Out-of-State Fracking Wells*

In this scenario the amount of natural gas consumed from unconventional out-of-state fracking wells is considered to be the difference natural gas consumed in the state from the specific year minus 2000's consumption. In 2016 this amounted to 6,550 mmcf of natural gas. Equation 2 then yields the following greenhouse gas emissions for fugitive leakage emissions.

$$\text{MMT CO2E} = \frac{((218{,}683 - 212{,}133) \times 1{,}000{,}000 \times 0.025 \times 0.98 \times 25 \times .857)}{(48{,}700 \times 1{,}000{,}000)}$$

$$\text{MMT CO2E} = 0.07061$$

The PA DEP's spreadsheet was used to determine the well construction emissions. In this scenario, 1 well was necessary to supply Maryland with the 6,550 mmcf of natural gas.

Total Emissions = 0.03472 + 0.07061
Total Emissions = 0.1053

## 5.5 Conclusions

In order to account for consumption of natural gas in Maryland due to natural gas fracking well emissions in other states, Maryland will have to offset between 0.1053 and 1.696 mmtCO2e.

# APPENDICES

## Appendix A – EIA Total Natural Gas Consumption in Maryland

## Appendix B – Unconventional Natural Gas Production

## Appendix C – Percentage of Natural Gas Pipeline Outside of Maryland

# APPENDIX A: EIA Total Natural Gas Consumption in Maryland

| Date | Maryland Natural Gas Total Consumption (MMcf) |
|---|---|
| 1997 | 212,017 |
| 1998 | 188,552 |
| 1999 | 196,350 |
| 2000 | 212,133 |
| 2001 | 178,376 |
| 2002 | 196,276 |
| 2003 | 197,024 |
| 2004 | 194,725 |
| 2005 | 202,509 |
| 2006 | 182,294 |
| 2007 | 201,053 |
| 2008 | 196,067 |
| 2009 | 196,510 |
| 2010 | 212,020 |
| 2011 | 193,986 |
| 2012 | 208,946 |
| 2013 | 197,356 |
| 2014 | 207,103 |
| 2015 | 215,005 |
| 2016 | 218,683 |
| 2017 | |
| 1997 – 2005 Average | 197,551 |

Data Source:
U.S. Energy Information Administration (EIA) – Natural Gas Consumption by End Use – Maryland
https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm

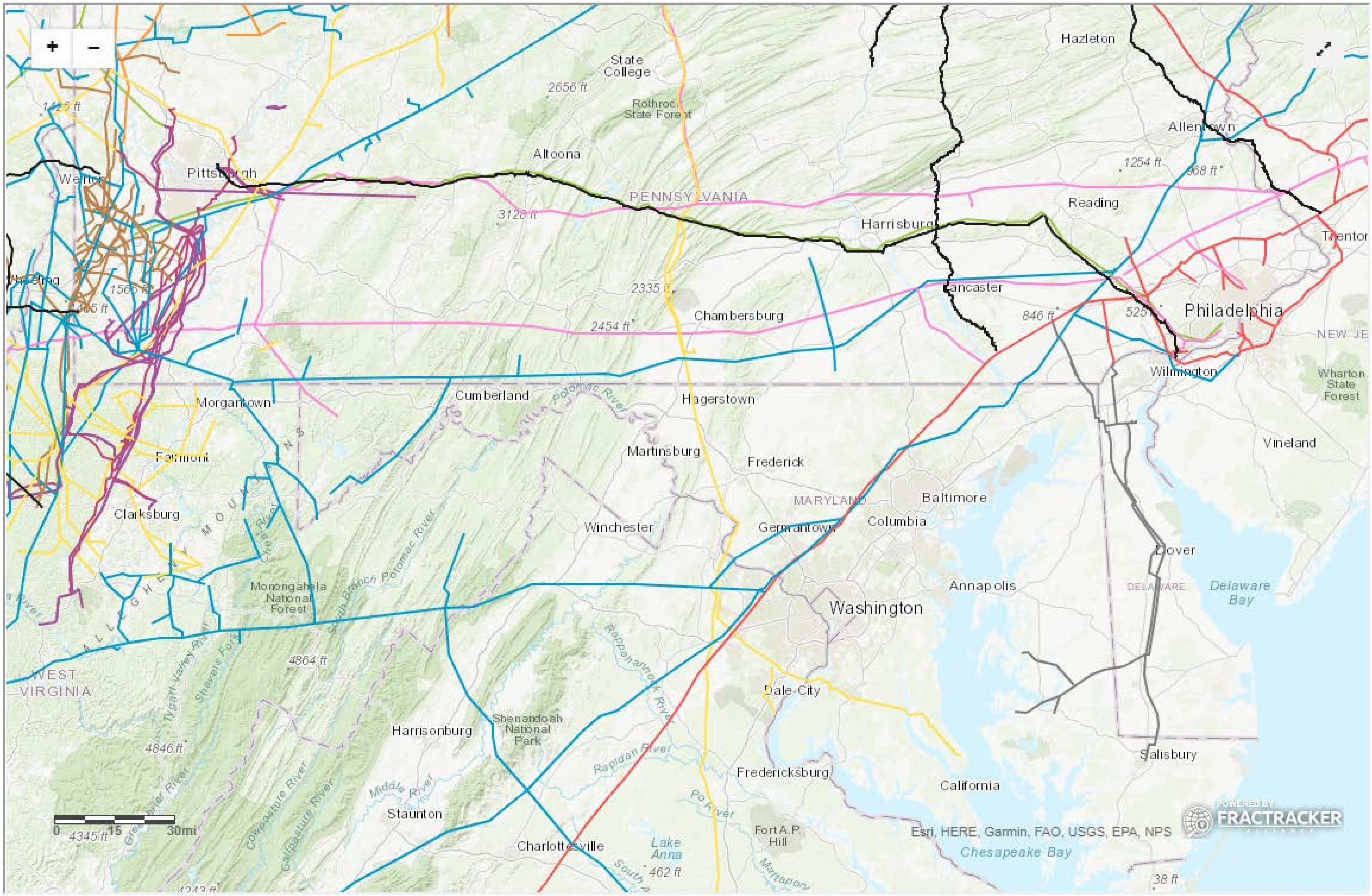
# APPENDIX B: Unconventional Natural Gas Well Production

# PENNSYLVANIA NATURAL GAS FRACKING WELLS - WASHINGTON COUNTY - PRODUCTION - 2016

| Well Name | Well Location | Well Owner | Production (mcf) |
|---|---|---|---|
| X-MAN 5H | Washington County \| Amwell Township | Gas company: RICE | 11,147,649 |
| HULK 8H | Washington County \| Amwell Township | Gas company: RICE | 10,188,867 |
| HULK 4H | Washington County \| Amwell Township | Gas company: RICE | 9,981,502 |
| MONO 4H | Washington County \| North Bethlehem Township | Gas company: RICE | 9,566,283 |
| BROVA 11H | Washington County \| North Bethlehem Township | Gas company: RICE | 9,051,675 |
| HULK 6H | Washington County \| Amwell Township | Gas company: RICE | 8,894,418 |
| US NATURAL RESOURCES UNIT 10H | Washington County \| Somerset Township | Gas company: RANGE | 8,892,389 |
| US NATURAL RESOURCES UNIT 8H | Washington County \| Somerset Township | Gas company: RANGE | 8,775,712 |
| HAROLD HAYWOOD WAS 3H | Washington County \| Carroll Township | Gas company: EQT | 8,336,063 |
| R SMITH 592302 | Washington County \| Carroll Township | Gas company: EQT | 8,226,795 |
| R. SMITH 592300 | Washington County \| Carroll Township | Gas company: EQT | 8,182,121 |
| US NATURAL RESOURCES UNIT 7H | Washington County \| Somerset Township | Gas company: RANGE | 8,098,811 |
| SWAGLER 6H | Washington County \| Somerset Township | Gas company: RICE | 7,753,259 |
| IRON MAN 2H | Washington County \| North Bethlehem Township | Gas company: RICE | 7,709,554 |
| DMC PROPERTIES UNIT 10H | Washington County \| Donegal Township | Gas company: RANGE | 7,653,677 |
| WATERBOY 2H | Washington County \| South Strabane Township | Gas company: RICE | 7,633,418 |
| BRUCE WAYNE A 5H | Washington County \| Somerset Township | Gas company: RICE | 7,590,559 |
| WOLVERINE 10H | Washington County \| Fallowfield Township | Gas company: RICE | 7,550,917 |
| US NATURAL RESOURCES UNIT 1H | Washington County \| Somerset Township | Gas company: RANGE | 7,509,289 |
| LUSK 3H | Washington County \| West Pike Run Township | Gas company: RICE | 7,505,226 |
| MAD DOG 2020 9H | Washington County \| West Pike Run Township | Gas company: RICE | 7,491,997 |
| CRUM NV55CHS | Washington County \| Morris Township | Gas company: CNX | 7,341,067 |
| CONSOL NV57GHS | Washington County \| Morris Township | Gas company: CNX | 7,320,787 |
| WATERBOY 4H | Washington County \| South Strabane Township | Gas company: RICE | 7,237,383 |
| MAD DOG 2020 5H | Washington County \| West Pike Run Township | Gas company: RICE | 7,217,543 |
| ZORRO 2H | Washington County \| North Bethlehem Township | Gas company: RICE | 7,211,088 |
| ZORRO 4H | Washington County \| North Bethlehem Township | Gas company: RICE | 7,114,035 |
| ZORRO 12H | Washington County \| North Bethlehem Township | Gas company: RICE | 7,112,693 |
| CRUM NV55EHS | Washington County \| Morris Township | Gas company: CNX | 7,092,172 |
| MONO 3H | Washington County \| North Bethlehem Township | Gas company: RICE | 7,077,962 |

| Well Name | Well Location | Well Owner | Production (mcf) |
|---|---|---|---|
| COFFIELD/GOTTSCHALK NV34JHS | Washington County \| Morris Township | Gas company: CNX | 7,064,743 |
| CONSOL NV57CHS | Washington County \| Morris Township | Gas company: CNX | 7,057,533 |
| CRUM NV55DHS | Washington County \| Morris Township | Gas company: CNX | 7,036,440 |
| MARCHEZAK JOHN 11528 6H | Washington County \| Somerset Township | Gas company: RANGE | 7,005,841 |
| BROVA 9H | Washington County \| North Bethlehem Township | Gas company: RICE | 6,985,394 |
| MONO 1H | Washington County \| North Bethlehem Township | Gas company: RICE | 6,980,881 |
| GOLDEN GOOSE 8H | Washington County \| North Bethlehem Township | Gas company: RICE | 6,972,823 |
| R SMITH 592299 | Washington County \| Carroll Township | Gas company: EQT | 6,939,464 |
| TRAX FARMS 592309 | Washington County \| Union Township | Gas company: EQT | 6,931,540 |
| BIER ALBERT 11409 2H | Washington County \| North Strabane Township | Gas company: RANGE | 6,910,832 |
| X-MAN 7H | Washington County \| Amwell Township | Gas company: RICE | 6,891,663 |
| CONSOL NV57JHS | Washington County \| Morris Township | Gas company: CNX | 6,880,198 |
| BROVA 3H | Washington County \| North Bethlehem Township | Gas company: RICE | 6,804,626 |
| BROVA 7H | Washington County \| North Bethlehem Township | Gas company: RICE | 6,802,426 |
| BIG DADDY SHAW 6H | Washington County \| Somerset Township | Gas company: RICE | 6,760,695 |
| MONO 7H | Washington County \| North Bethlehem Township | Gas company: RICE | 6,758,712 |
| MAD DOG 2020 0H | Washington County \| West Pike Run Township | Gas company: RICE | 6,758,703 |
| BROVA 4H | Washington County \| North Bethlehem Township | Gas company: RICE | 6,757,596 |
| WATERBOY 8H | Washington County \| South Strabane Township | Gas company: RICE | 6,750,199 |
| COFFIELD/GOTTSCHALK NV34GHS | Washington County \| Morris Township | Gas company: CNX | 6,725,720 |

# APPENDIX C: Percentage of Natural Gas Pipeline Outside of Maryland



[15]

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[15] https://www.alleghenyfront.org/mapping-the-pipeline-boom/

Maryland
Department of
the Environment

# Appendix F

### Documentation of Maryland PATHWAYS Scenario Modeling

# 2019 GGRA Draft Plan

Energy+Environmental Economics
101 Montgomery Street | Suite 1600 | San Francisco, CA 94104 | 415.391.5100 | www.ethree.com

# Documentation of Maryland PATHWAYS Scenario Modeling

*August 29, 2019*

**Prepared for the Maryland Department of Environment**

**On behalf of the Regional Economic Studies Institute at Towson University**

**By Energy and Environmental Economics, Inc.**

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**Vivian Li**

**Snuller Price**

# Contents

# 1 Executive Summary

## 1.1 Report Background

The Regional Economic Studies Institute (RESI) at Towson University has been contracted to develop a macroeconomic assessment of Maryland's greenhouse gas (GHG) reduction policies by the Maryland Department of the Environment. The project is divided into two phases;

- The first phase (2017) included the development of a reference case of GHG emissions for Maryland consistent with existing energy policies in the LEAP model. This work was presented to the Mitigation Working Group of the Maryland Commission on Climate Change in February, 2018.
- The second phase (2018-2019) includes an evaluation of deeper GHG reduction scenarios with additional and more aggressive measures.

This report provides documentation for the assumptions, methods, and results of the both phases of the project.

## 1.2 Reference Case Results

This study developed a long-term projection of Maryland's GHG emissions based on existing policies that are in place to reduce emissions, as well as forecasted future economic activity and population in the state. The forecast based on existing policies provides a starting point for Phase 2 of the project which considered additional and increased actions to achieve Maryland's established GHG emissions targets.

Based on Maryland's 2014 inventory, the most recently available data at the time of the study, the largest categories of GHG emissions are electricity generation, transportation, and direct energy combustion in buildings (see Figure 1-1). Electricity generation emissions are dominated by in-state coal generation as well as imports from PJM. Transportation emissions are largely attributed to passenger vehicles. Direct emissions from buildings are mostly from water heating and space heating end uses.

*Figure 1-1. Maryland 2014 Gross GHG Emissions by Sector and Subsector (93.4 MMT CO2e)*[1]

We project historical emissions into the future using the LEAP tool (Long-range Energy Alternatives Planning system)[2] which accounts for the natural rate of equipment and infrastructure roll-over, electricity sector operations and trends in energy use. This projection without any Maryland policy is used to develop a Baseline Scenario. To develop the Reference Scenario, existing Maryland policies are translated into their impacts on new equipment and infrastructure and then used to adjust future assumptions, resulting in the reference case forecast. For example, given the renewable portfolio standard (RPS), we assume that the generation mix includes an increasing share of renewable generation until the existing RPS goal of 25% is reached in 2020. The most important existing policies considered in the development of the reference case include the renewable portfolio standard (RPS), EmPOWER efficiency, and zero emission vehicle (ZEV) memorandum of understanding (MOU). A complete list of policies in the Baseline and Reference Scenarios is provided in this report.

In Figure 1-2 we compare the Reference Scenario emissions trajectory to Maryland's climate goals. The current goals are set to reach greenhouse gas (GHG) emissions levels 25% below 2006 levels by 2020, 40%

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[1] Industry includes emissions from direct energy combustion; Industrial Process emissions include non-combustion categories such as cement and refrigerants. Emissions categorization into transportation and building subsectors are a result from E3 PATHWAYS modeling.

[2] More information on the LEAP software can be found at www.energycommunity.org

by 2030 and 80% by 2050. The Reference Scenario reaches the 2020 goal and shows that additional GHG emission reductions are necessary to meet the 2030 and 2050 goals.

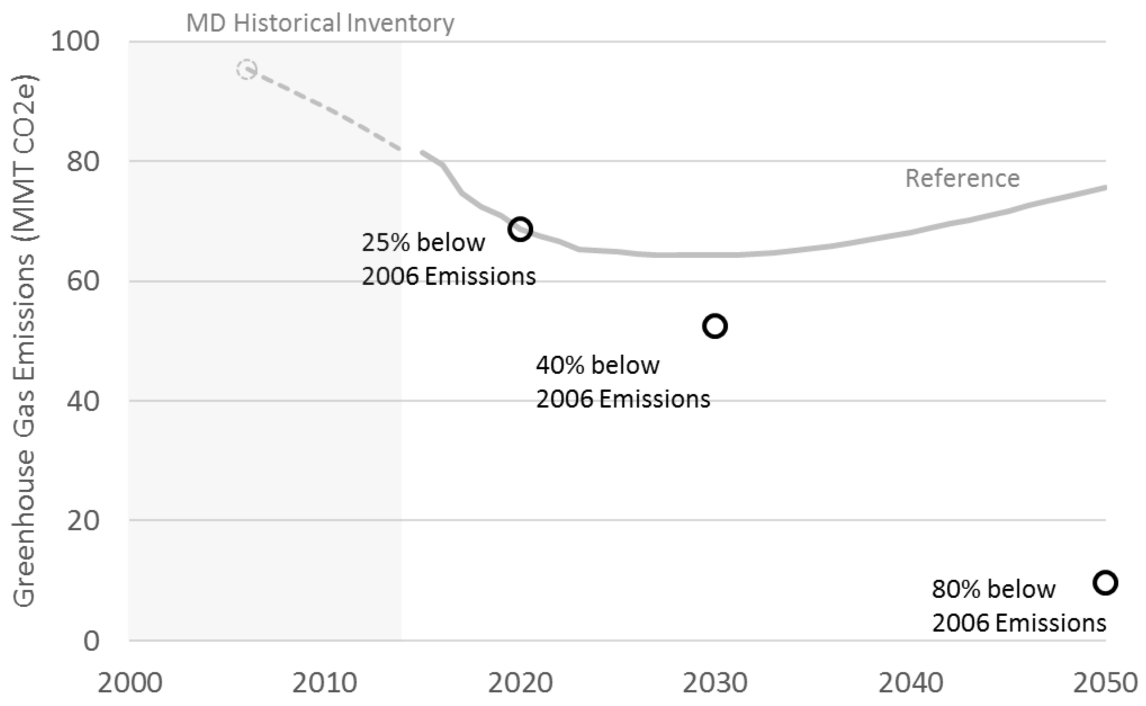

*Figure 1-2. Maryland Net GHG Emissions Results for Reference Scenario, 2015-2050 compared to the adopted GHG targets*[3]

Table 1-1 shows the GHG goals for each target year and the difference relative to the modeled Reference Scenario. GHG targets in Maryland are calculated primarily on a gross emissions basis, meaning that percent reductions are calculated based on 2006 gross emissions (107.2 MMT CO2e) and emissions sinks from land use are then subtracted (11.8 MMT CO2e).

*Table 1-1. Maryland Net GHG Targets Compared to Reference Scenario Net GHG Emission Results*

| [MMT CO2e] | 2020 | 2030 | 2050 |
|---|---|---|---|
| GHG Target | 68.6 | 52.5 | 9.7 |
| Reference Scenario | 68.6 | 64.3 | 75.7 |
| *Difference* | *0.0* | *11.7* | *66.0* |

## 1.3 Policy Scenario Results

Figure 1-3 shows the results for all policy scenarios explored as a part of this analysis. Each policy scenario was designed with a specific philosophy in mind.

1. **Policy Scenario 1**: Continuation or extension of current programs

---

[3] GHG emissions are displayed as net GHG emissions after sinks. GHG goals are calculated as a percent below gross emissions (i.e. without land use sinks) and then emissions sinks are subtracted to calculate net emissions.

2. **Policy Scenario 2**: New programs and changing program frameworks & long-term measures to achieve 2050 GHG target
3. **Policy Scenario 3**: Carbon pricing program in addition to complementary policy (specified by the Maryland Commission on Climate Change)
4. **Policy Scenario 4**: Revised version of Policy Scenario 2

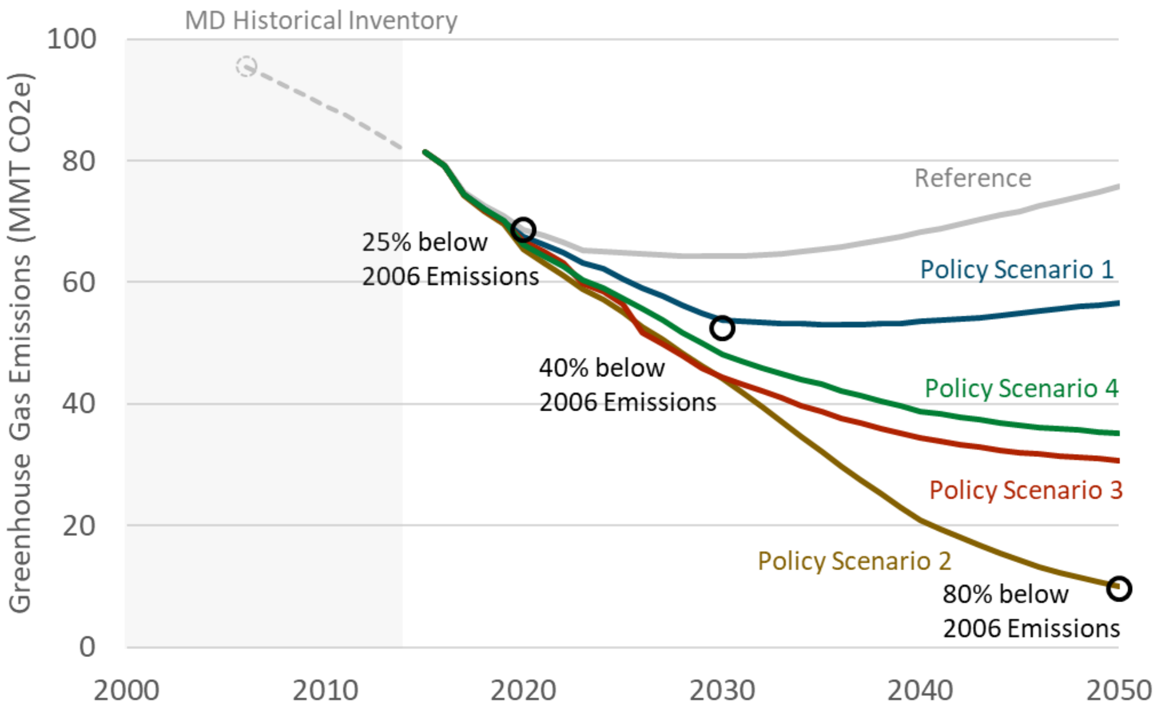

*Figure 1-3. Maryland Net GHG Emissions Results for Policy Scenarios, 2015-2050 compared to the adopted GHG targets*

All Policy Scenarios meet the 2020 goal. Policy Scenario 1, which represents an extension of existing efforts, including building efficiency and the state's RPS get close but falls short of the 2030 goal. Policy Scenarios 2, 3, and 4 meet the 2030 goal. Policy Scenario 3's included carbon pricing mechanism has the most effect between 2020 and 2030, after which the reductions taper off and the scenario falls short of the 2050 goal. Policy Scenario 2 meets the 2050 GHG target by including targeted complementary policies and measures to reduce GHGs in all sectors of Maryland's economy. Policy Scenario 4 is a revised version of Policy Scenario 2 that constitutes MDE's draft plan to achieve the 2030 GHG target. Policy Scenario 4 highlights the need for additional policy mechanisms to achieve the emission reductions necessary to meet the 2050 economy-wide GHG goal.

*Table 1-2. Policy Scenario Net GHG Emission Results*

| [MMT CO2e] | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Policy Scenario 1 | 67.5 | 53.9 | 53.5 | 56.6 |
| Policy Scenario 2 | 65.4 | 44.1 | 21.0 | 9.9 |
| Policy Scenario 3 | 66.7 | 44.4 | 34.5 | 30.7 |
| Policy Scenario 4 | 66.2 | 48.1 | 38.7 | 35.2 |
| GHG Goals | 68.6 | 52.5 | 31.1 | 9.7 |

We also ran several sensitivities on Policy Scenario 4 to test the impact on emissions of federal action and consumer adoption. The three sensitivities were defined as follows:

1. **Low Adoption**: Evaluates the impact of only achieving half of the projected sales of new electric vehicles and efficient household appliances
2. **Low CAFE**: Evaluates the impact of removing the improvements in federal Corporate Average Fuel Economy standards from 2021-2026
3. **Low Adoption and Low CAFE**: Evaluates the combined impact of lower consumer adoption and lower fuel economy standards for light-duty vehicles.

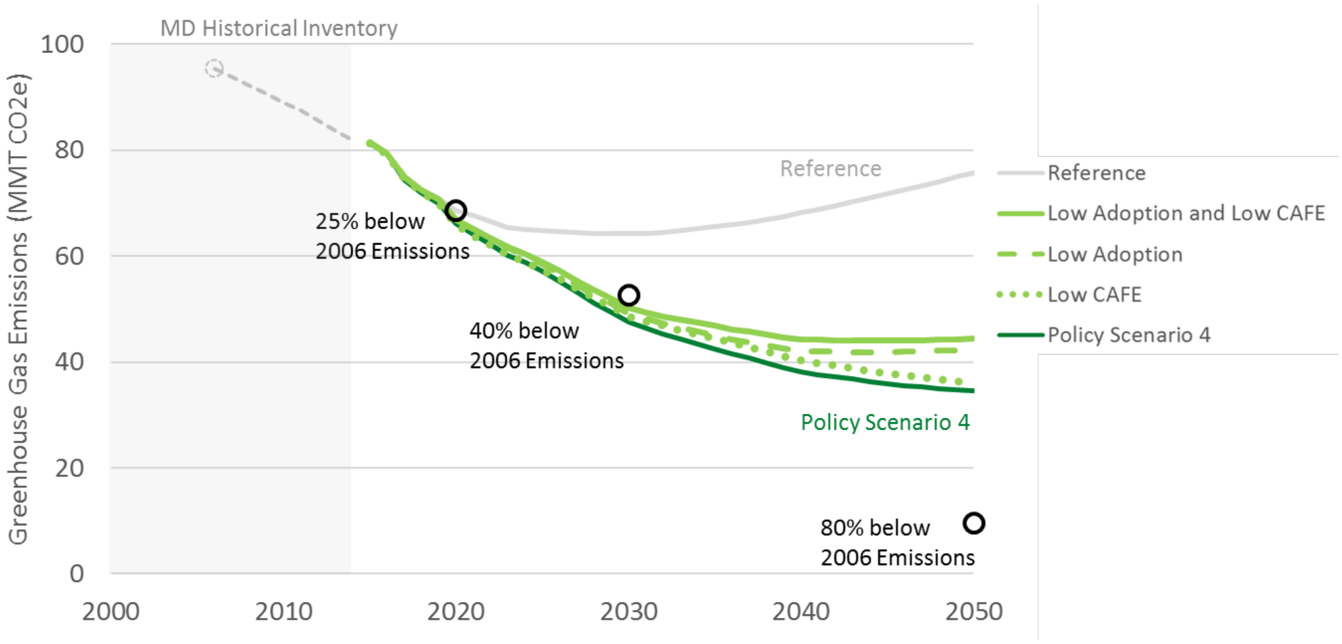

*Figure 1-4. Maryland Net GHG Emissions for Sensitivities on Policy Scenario 4, 2015-2050*

Figure 1-4 highlights the fact that even with more conservative assumptions on consumer adoption of devices and federal action on fuel economy standards, the measures and actions in Policy Scenario 4 are sufficient to meet Maryland's 2030 GHG target. By 2050, however, the lower levels of consumer adoption creates a significant emissions gap as the state tries to reach its 2050 GHG goal.

# 2 Approach

## 2.1 PATHWAYS Model Philosophy

This study used a PATHWAYS model to develop the reference case emission projection. The PATHWAYS model is an economy-wide representation of infrastructure, energy use, and emissions within a specific jurisdiction. The PATHWAYS model represents bottom-up and user-defined emissions accounting scenarios to test "what if" questions around future energy and climate policies. PATHWAYS modeling typically includes the following features:

- Detailed stock rollover in residential, commercial and transportation subsectors
- Hourly treatment of the electricity supply sector
- Sustainable biomass feedstock supply curves
- Non-combustion and non-energy emissions

The inclusion of both supply and demand sectors captures interactions between sectors such as increased penetration of electric vehicles and a changing mix of technologies supplying electricity. The focus of the Pathways model is to compare user-defined policy and market adoption scenarios and to track physical accounting of energy flows within all sectors of the economy.

## 2.2 PATHWAYS in LEAP

E3 built a bottom-up PATHWAYS model of the Maryland economy using the LEAP tool (Long-range Energy Alternatives Planning system)[4]. This model quantifies the energy and emissions associated with the projected trends in energy use and complementary policies targeting future mitigated emissions. We modeled the period of 2015-2050.

LEAP is an integrated, scenario-based modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks. LEAP is not a model of a specific energy system, but rather a modeling framework that can be adapted for different jurisdictions.

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[4] LEAP is developed by the Stockholm Environment Institute. More information on the LEAP software can be found at www.energycommunity.org

E3 built a model of Maryland's energy and non-energy emission sources, projecting them through 2050 using different scenarios to understand current trajectories and different pathways that can be reached through complementary policies within the state.

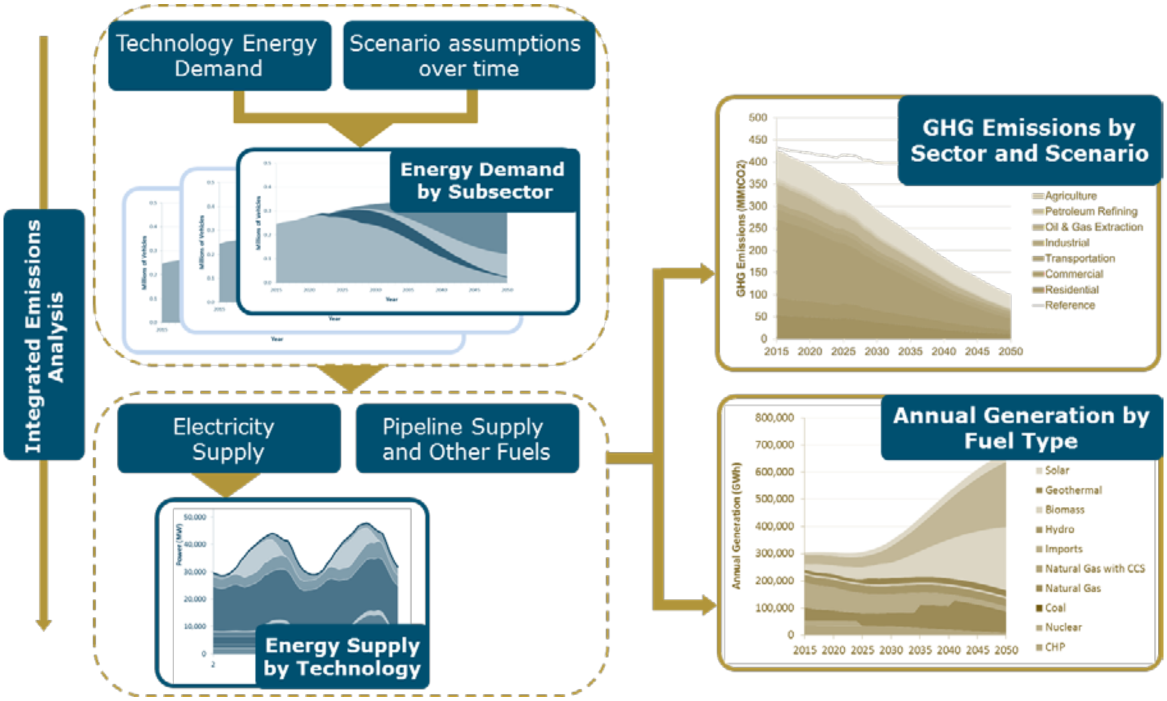

*Figure 2-1. PATHWAYS Energy Modeling Framework*

## 2.3 Scenarios

E3 modeled six scenarios to evaluate a range of emissions reductions from complementary policies.

- **Baseline Scenario**: counterfactual scenario without key Maryland policies
- **Reference Scenario**: a current policy scenario, including the renewable portfolio standard (RPS), EmPOWER efficiency in buildings, and zero emission vehicle (ZEV) memorandum of understanding (MOU)
- **Four Policy Scenarios**

The Baseline Scenario represents a counterfactual scenario without key Maryland policies, such as the RPS, EmPOWER efficiency, and ZEV MOU. In the Baseline Scenario, greenhouse gas emissions increase slowly over time due to population and economic growth, without the introduction of any new policies to mitigate emissions. The Baseline Scenario is only used as a counterfactual for measuring efficiency measures, and not for any key result metrics. The Reference Scenario layers on additional existing policies in Maryland. Specific assumptions for each scenario are shown in Table 2-1.

*Table 2-1. Key Assumptions in Baseline and Reference Scenario*

| | **Baseline Scenario** | **Reference Scenario (Existing Policies)** |
|---|---|---|
| *Renewable Portfolio Standard* | None | 25% RPS by 2020 |
| *RGGI* | None | 30% cap reduction from 2020 to 2030 |
| *Nuclear power* | Assume Calvert Cliffs retires in 2034/2036 at end of license, and is replaced with electricity imports | Assume Calvert Cliffs is relicensed in 2034/2036 at end of license |
| *Existing coal power plants* | IPM planned retirements (670 MW of coal by 2023) | IPM planned retirements (670 MW of coal by 2023) |
| *Rooftop PV* | Current levels of 200 MW | Moderate growth from current levels of 200 MW (2% a year; 400 MW in 2050) |
| *Energy Efficiency (Res., Com. & Industrial)* | None | EmPOWER goals for 2015-2023, Calibrated to EmPOWER filing targets |
| *Electrification of buildings (e.g. NG furnace to heat pumps)* | None | None |
| *Transportation* | Federal CAFE standards for LDVs by 2026 | Federal CAFE standards for LDVs by 2026, Meets ZEV mandate by 2025 (270,000 ZEVs) |
| *Other transportation sectors (e.g. aviation)* | AEO 2017 reference scenario growth rates by fuel | AEO 2017 reference scenario growth rates by fuel |
| *Industrial energy use* | AEO 2017 reference scenario growth rates by fuel | AEO 2017 reference scenario growth rates by fuel |
| *Biofuels* | Existing ethanol and biodiesel blends, but no assumed increase | Existing ethanol and biodiesel blends, but no assumed increase |
| *Other (fossil fuel industry, industrial processes, agriculture, waste management, forestry)* | Assume held constant at MDE 2014 GHG Inventory levels | Assume held constant at MDE 2014 GHG Inventory levels |

Each policy scenario was designed with a specific philosophy in mind. Detailed assumptions for each Scenario are detailed in Table 2-2.

- **Policy Scenario 1**: Continuation or extension of current programs
- **Policy Scenario 2**: New programs and changing program frameworks
- **Policy Scenario 3**: Carbon pricing program in addition to complementary policy
- **Policy Scenario 4**: MDE's draft plan to achieve the 2030 GHG target

*Table 2-2. Key Assumptions in Policy Scenarios*

|  | **Policy Scenario 1** | **Policy Scenario 2** | **Policy Scenario 3** | **Policy Scenario 4** |
|---|---|---|---|---|
| *Economy-Wide Carbon Price* | None | None | Escalating carbon price beginning in 2020 | None |
| *Renewable Portfolio Standard* | 25% RPS by 2020<br>50% RPS by 2030 | 25% RPS by 2020<br>100% Clean and Energy Standard (CARES) by 2040 | 25% RPS by 2020<br>50% RPS by 2030 | 25% RPS by 2020<br>100% CARES by 2040 |
| *RGGI* | 30% cap reduction from 2020 to 2030 | 30% cap reduction from 2020 to 2030, additional 60% reduction from 2030 to 2050 | 30% cap reduction from 2020 to 2030 |  |
| *Nuclear power* | Assume Calvert Cliffs is relicensed in 2034/2036 at end of license |  |  |  |
| *Existing coal power* | IPM planned retirements (670 MW of coal by 2023) | Maryland complies with RGGI cap by ramping down coal generation | Coal generation decreases as carbon fee makes dispatch uneconomic | Maryland complies with RGGI cap by ramping down coal generation |
| *Rooftop PV* | Continued growth in deployment until net metering cap (1500 MW in 2030) |  |  |  |
| *Energy Efficiency (Res., Com. & Industrial)* | Continued effort for efficiency in buildings (50% high efficiency electric sales by 2030, 25% for natural gas appliance sales) | Aggressive effort for efficiency in buildings (100% high efficiency electric and natural gas sales by 2030) | Aggressive effort for efficiency in buildings (100% high efficiency electric and natural gas sales by 2030) | Continued effort for efficiency in buildings (50% high efficiency electric sales by 2030, 25% for natural gas appliance sales) |
| *Electrification of buildings (e.g. NG furnace to heat pumps)* | Moderate electrification (increase of 15% in electric heat pump sales) | Aggressive electrification (heat pump sales increase to 95% by 2050) | Aggressive electrification (heat pump sales increase to 95% by 2050) | Moderate electrification (increase of 15% in electric heat pump sales) |
| *Fuel Economy Standards* | Federal CAFE standards for LDVs through 2026 |  |  |  |
| *Zero Emission Vehicles in Light Duty* | Increased sales after 2025 (530,000 by 2030, 1.4 Million by 2050) | Aggressive sales after 2025 (800,000 by 2030, 5 Million by 2050) | Aggressive sales after 2025 (800,000 by 2030, 5 Million by 2050) | Increased sales after 2025, and aggressive sales after 2030 (530,000 by 2030, 4.5 Million by 2050) |
| *Heavy Duty Vehicles* | None | Aggressive sales of electric and diesel hybrid HDVs after 2030; | Truck stop electrification and zero-emission truck | Truck stop electrification and zero-emission truck corridors |

| | | | | |
|---|---|---|---|---|
| | | truck stop electrification and zero-emission truck corridors | corridors | |
| *Vehicle Miles Traveled* | 1.4% annual growth with additional smart transit measures | 0.9% growth: Additional smart growth and transit measures | 1.0% growth: Additional smart growth and transit measures | 0.9% growth: Additional smart growth and transit measures |
| *Other transportation sectors (e.g. buses, construction vehicles)* | AEO 2017 reference scenario growth rates by fuel | Electrification of 50% of transit buses by 2030, 100% by 2050; Electrification of 50% of construction vehicles by 2050 | Electrification of 50% of transit buses by 2030, 100% by 2050; | Electrification of 50% of transit buses by 2030, 10% by 2050 None |
| *Industrial energy use* | 10% reduction below Reference Scenario by 2050, 20% for electricity use | 30% reduction below Reference Scenario by 2050 | 10% reduction below Reference Scenario by 2050, 20% for electricity use | 10% reduction below Reference Scenario by 2050, 20% for electricity use |
| *Biofuels* | Existing ethanol and biodiesel blends | Advanced sustainable biofuels blended into diesel and natural gas | Existing ethanol and biodiesel blends | Existing ethanol and biodiesel blends |
| *Other (fossil fuel industry, industrial processes, agriculture, waste management, forestry)* | Additional acreage in forest management and healthy soils conservation practices | More aggressive measures in forest management and healthy soils | Additional acreage in forest management and healthy soils conservation practices | Additional acreage in forest management and healthy soils conservation practices |

In addition to Policy Scenarios, we developed three sensitivities on Policy Scenario 4 to test the impact on emissions of federal action and consumer adoption. The three sensitivities were defined as follows:

1. **Low Adoption**: Evaluates the impact of only achieving half of the projected sales of new electric vehicles and efficient household appliances
2. **Low CAFE**: Evaluates the impact of removing the improvements in federal Corporate Average Fuel Economy standards from 2021-2026
3. **Low Adoption and Low CAFE**: Evaluates the combined impact of lower consumer adoption and lower fuel economy standards for light-duty vehicles.

*Table 2-3. Key Assumptions in Policy Scenario 4 Sensitivities*

| | **Policy Scenario 4** | **Low Adoption** | **Low CAFE** | **Low Adoption and Low CAFE** |
|---|---|---|---|---|
| *Energy Efficiency (Res., Com. & Industrial)* | Continued effort for efficiency in buildings (50% high efficiency electric sales by 2030, 25% for natural gas appliance sales) | Lower adoption of efficient devices in buildings (25% high efficiency electric sales by 2030, 12.5% for natural gas appliance sales) | Continued effort for efficiency in buildings (50% high efficiency electric sales by 2030, 25% for natural gas appliance sales) | Lower adoption of efficient devices in buildings (25% high efficiency electric sales by 2030, 12.5% for natural gas appliance sales) |
| *Electrification of buildings (e.g. NG furnace to heat pumps)* | Moderate electrification (increase of 15% in electric heat pump sales) | Lower adoption of electric space heaters and water heaters (increase of 7.5%) | Moderate electrification (increase of 15% in electric heat pump sales) | Lower adoption of electric space heaters and water heaters (increase of 7.5%) |
| *Fuel Economy Standards* | Federal CAFE standards for LDVs through 2026 | | Federal CAFE standards for LDVs through 2021 | |
| *Zero Emission Vehicles in Light Duty* | Increased sales after 2025, and aggressive sales after 2030 (530,000 by 2030, 4.5 Million by 2050) | Half of adoption in PS4 (260,000 by 2030, 2.3 Million by 2050) | Increased sales after 2025, and aggressive sales after 2030 (530,000 by 2030, 4.5 Million by 2050) | Half of adoption in PS4 (260,000 by 2030, 2.3 Million by 2050) |

One final sensitivity was designed to test the emissions impact of Calvert Cliffs Nuclear Power Plant retiring at the end of its license. All scenarios assumed that this plant was relicensed through 2050, but for this sensitivity we assumed that it retired at the end of its scheduled license, and de-rated annual capacity based on the months of operation each year as documented in Table 2-4.

*Table 2-4. Calvert Cliffs Nuclear Power Plant Capacity by Year*

| Year | 2033 | 2034 | 2035 | 2036 | 2037 |
|---|---|---|---|---|---|
| Nuclear Capacity (MW) | 1708 | 1350.5 | 850 | 602.1 | 0 |

## 2.4 Inputs

To populate the PATHWAYS model, we focused on in-state data sources where possible, supplementing with national data sets to fill remaining data gaps. Specific inputs are listed below.

### 2.4.1 KEY DRIVERS AND DEMOGRAPHICS

In 2014, Maryland had a population of 5.97 Million people residing in 2.3 Million households. In each sector of the economy, we create a representation of a base year (2014) of infrastructure and energy, and then identify key variable that drive activity change over the duration of each scenario (2015-2050). Table 2-5 identifies the key drivers behind each sector's energy consumption in the reference scenario. Additional detail is available in the sections that follow.

*Table 2-5. Key Drivers by Pathways Sector in the Reference Scenario*

| **Sector** | **Key Driver** | **Compound annual growth rate [%]** | **Data Source** |
|---|---|---|---|
| *Residential* | Households | 0.73-0.53% | Maryland Department of Planning (varies over time)[5] |
| *Commercial* | Households | 0.73-0.53% | Maryland Department of Planning (varies over time) |
| *Industry* | Energy growth | Varies by fuel | EIA AEO 2017 |
| *On Road Transportation* | VMT | 1.7% | Maryland DOT |
| *Off Road Transportation* | Energy growth | 0.76% | Population growth rate from Maryland Department of Planning |
| *Electricity Generation* | Electric load growth | 0.5% (average 2015-2050) | Built up from Pathways demands in Buildings, Industry, Transportation |

### 2.4.2 BUILDING SECTOR REPRESENTATION

#### *2.4.2.1 Base Year*

The Maryland LEAP model includes a stock-rollover representation of 10 residential and 9 commercial building subsectors, including space heating, water heating, and lighting. Sectoral energy demand is benchmarked to energy consumption by fuel from the Maryland GHG inventory for 2014 and is disaggregated by subsector based on the EIA National Energy Modeling System (NEMS) technology characterization. All residential and commercial subsectors are listed in Table 2-6.

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[55] Available online: https://planning.maryland.gov/MSDC/Documents/popproj/HouseholdProj.pdf

*Table 2-6. Building 2014 Energy Consumption by Subsector in Maryland*

| Sector | Subsector | Energy Use in 2014 [Tbtu] | Percent of 2014 Energy Use [%] |
|---|---|---|---|
| Residential | Air conditioning | 7 | 2% |
| | Clothes drying | 5 | 1% |
| | Clothes washing | 1 | 0% |
| | Cooking | 9 | 2% |
| | Dishwashing | 1 | 0% |
| | Freezing | 1 | 0% |
| | Lighting | 5 | 1% |
| | Refrigeration | 9 | 2% |
| | Space heating | 82 | 20% |
| | Water heating | 43 | 10% |
| | Residential Other* | 60 | 14% |
| Commercial | Air conditioning | 2 | 1% |
| | Cooking | 8 | 2% |
| | General service lighting | 10 | 2% |
| | High intensity discharge lighting | 5 | 1% |
| | Linear fluorescent lighting | 2 | 1% |
| | Refrigeration | 6 | 1% |
| | Space heating | 58 | 14% |
| | Ventilation | 16 | 4% |
| | Water Heating | 21 | 5% |
| | Commercial Other* | 65 | 16% |
| | *All Sectors* | *416* | *100%* |

*Subsector does not have underlying stock rollover. Residential Other includes furnace fans, plug loads, secondary heating, fireplaces, and outdoor grills. Commercial Other includes plug loads, office equipment, fireplaces, and outdoor grills.

#### 2.4.2.2 Reference Scenario

The primary reference measure represented in buildings is the achievement of electric energy efficiency. Energy efficiency in buildings is implemented in the PATHWAYS model in one of four ways:

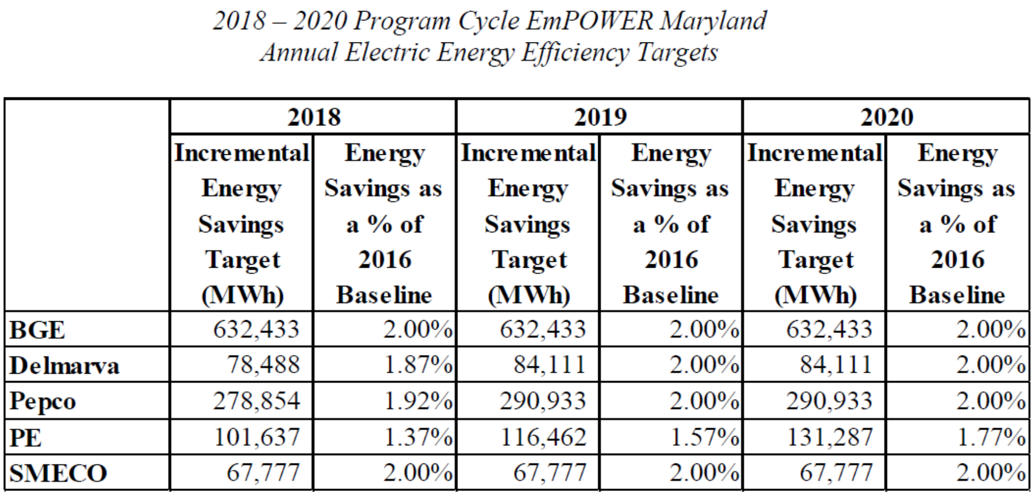
1. As new appliance or lighting end use technology used in the residential and commercial sectors (e.g., a greater share of high efficiency appliances is assumed to be purchased). New equipment is typically assumed to replace existing equipment “on burn-out”, e.g., at the end of the useful lifetime of existing equipment.
2. As a reduction in energy services demand, due to smart devices (e.g. programable thermostats), conservation, or behavior change, and
3. For the sectors that are not modeled using specific technology stocks (Residential Other and Commercial Other), energy efficiency is modeled as a reduction in total energy demand.
4. As a reduction in transmission and distribution losses through distribution system optimization (e.g. CVR).

*Table 2-7. Reference Scenario Assumptions for Building Energy Efficiency*

| **Category of Efficiency** | **Reference Scenario Assumption** |
|---|---|
| Building retrofits for high efficiency building shells | None |
| New technology sales | 50% of new sales of all electric appliances are assumed to be efficient (e.g. EnergyStar) from 2015-2023 to represent EmPOWER (0% sales starting in 2024). See Figure 2-3. |
| Building electrification | None |
| Behavioral conservation and smart devices | 5% reduction in energy services demand below Baseline Scenario in residential lighting, space heating, and water heating |
| Other non-stock sectors | 10% reduction in electric energy consumption below Baseline Scenario by 2023 |
| Distribution System Optimization | Reduction in transmission and distribution losses from 5.4% to 4.8%, to represent EmPOWER estimates |

Since the model is based on a bottom-up forecast of technology stock changes in the residential and commercial sectors, the model does not use a single load forecast or energy efficiency savings forecast as a model input. It's important to note that the modeling assumptions used in this plan may not reflect specific future energy efficiency programs or activities.

EmPOWER is represented through the range of bottom-up infrastructure and energy changes shown in Table 2-7. The total reductions in electricity demand from all subsectors were then calibrated to estimated reductions in utility EmPOWER filings relative to their 2016 weather-normalized sales baseline (see Figure 2-2).



*2018 – 2020 Program Cycle EmPOWER Maryland*
*Annual Electric Energy Efficiency Targets*

| | **2018** | | **2019** | | **2020** | |
|---|---|---|---|---|---|---|
| | **Incremental Energy Savings Target (MWh)** | **Energy Savings as a % of 2016 Baseline** | **Incremental Energy Savings Target (MWh)** | **Energy Savings as a % of 2016 Baseline** | **Incremental Energy Savings Target (MWh)** | **Energy Savings as a % of 2016 Baseline** |
| **BGE** | 632,433 | 2.00% | 632,433 | 2.00% | 632,433 | 2.00% |
| **Delmarva** | 78,488 | 1.87% | 84,111 | 2.00% | 84,111 | 2.00% |
| **Pepco** | 278,854 | 1.92% | 290,933 | 2.00% | 290,933 | 2.00% |
| **PE** | 101,637 | 1.37% | 116,462 | 1.57% | 131,287 | 1.77% |
| **SMECO** | 67,777 | 2.00% | 67,777 | 2.00% | 67,777 | 2.00% |

*Figure 2-2. Utility EmPOWER Efficiency Targets by Year*

Distribution system optimization was assumed to account for 32% of total EmPOWER electricity savings and end-use efficiency, new sales of efficient devices, and behavioral conservation and smart devices were assumed to account for 68% of savings.

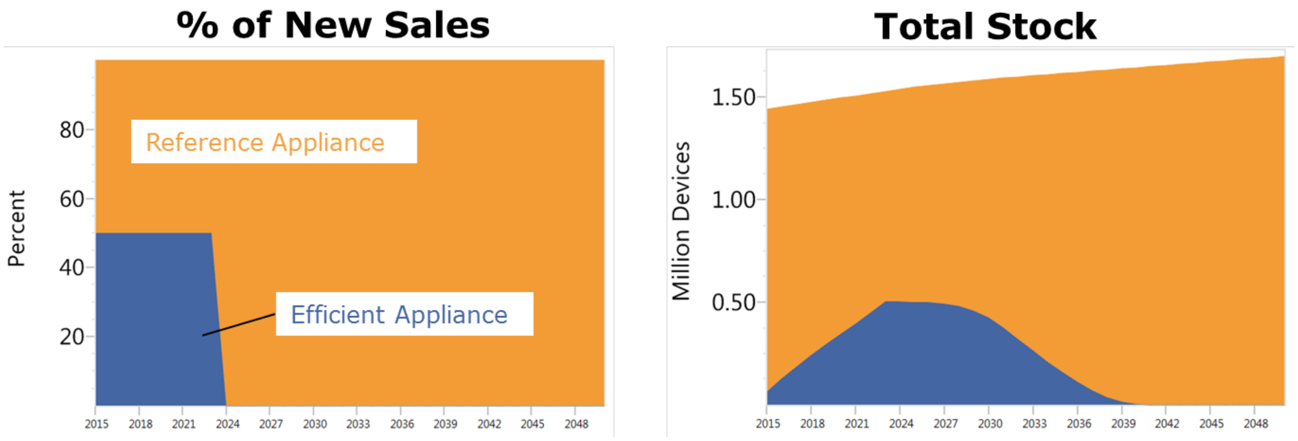


*Figure 2-3. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Reference Scenario*

### *2.4.2.3 Policy Scenario 1*

Policy Scenario 1 includes continued effort for energy efficiency in buildings. This effort builds on the EMPOWER annual savings targets from 2018-2023 but does not assume that the same annual savings will continue in perpetuity. Instead, we assume that the level of sales for efficient electric appliances will continue through 2050 as well as introducing sales of efficient natural gas appliances. See Table 2-8 for a full list of assumptions.

*Table 2-8. Policy Scenario 1 Assumptions for Building Energy Efficiency*

| **Category of Efficiency** | **Policy Scenario 1 Assumption** |
|---|---|
| Building retrofits for high efficiency building shells | None |
| New technology sales | 50% of new sales of all electric appliances are assumed to be efficient (e.g. EnergyStar) from 2015-2023 to represent EmPOWER, and continued from 2024-2050<br>25% of new sales of all natural gas appliances are assumed to be efficient by 2030 |
| Building electrification | 15% of new sales of electric heat pump by 2050, replacing natural gas furnaces and boiler sales |
| Behavioral conservation and smart devices | 10% reduction in energy services demand below Baseline Scenario in residential lighting, space heating, and water heating |
| Other non-stock sectors | 20% reduction in electric energy consumption below Baseline Scenario by 2050<br>10% reduction in all other energy consumption |

| | |
|---|---|
| | below Baseline Scenario by 2050 |
| Distribution System Optimization | Reduction in transmission and distribution losses from 5.4% to 4.8%, to represent EmPOWER estimates |

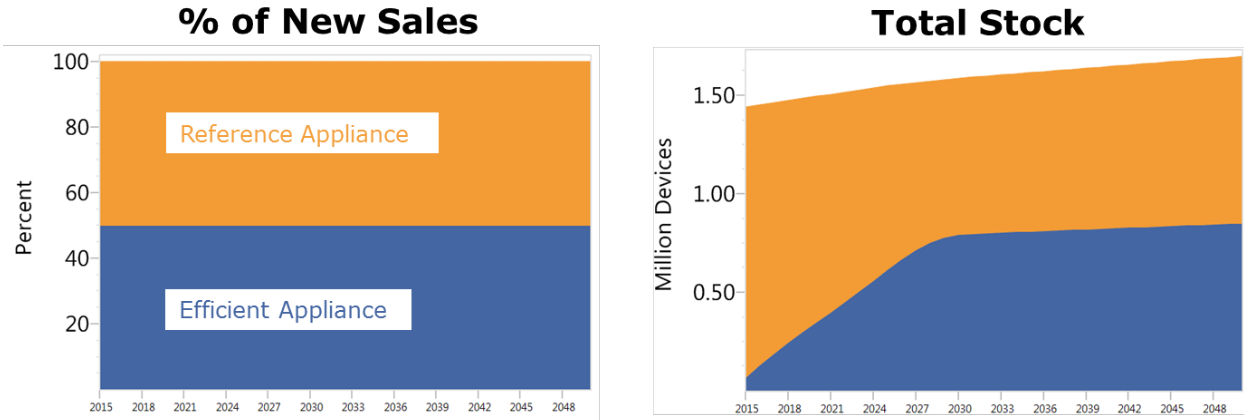


*Figure 2-4. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Policy Scenario 1*

### *2.4.2.4 Policy Scenario 2*

Policy Scenario 2 includes additional effort for energy efficiency in buildings and broad electrification of space heating and water heating. See Table 2-9 for a full list of assumptions.

*Table 2-9. Policy Scenario 2 Assumptions for Building Energy Efficiency*

| **Category of Efficiency** | **Policy Scenario 2 Assumption** |
|---|---|
| Building retrofits for high efficiency building shells | 100% of new construction and retrofitted residential buildings are assumed to have efficient shells by 2030, reducing the energy demand for space heating and cooling |
| New technology sales | 100% of new sales of all electric and natural gas appliance are assumed to be efficient (e.g. EnergyStar) by 2030. See Figure 2-5. |
| Building electrification | 95% of new sales of space heaters and water heaters are electric heat pump by 2050, replacing natural gas furnaces and boiler sales |
| Behavioral conservation and smart devices | 10% reduction in energy services demand below Baseline Scenario in residential lighting, space heating, and water heating |
| Other non-stock sectors | 30% reduction in all energy consumption below Baseline Scenario by 2050 |
| Distribution System Optimization | Reduction in transmission and distribution losses from 5.4% to 4.8%, to represent EmPOWER |

| | |
|---|---|
| | estimates |

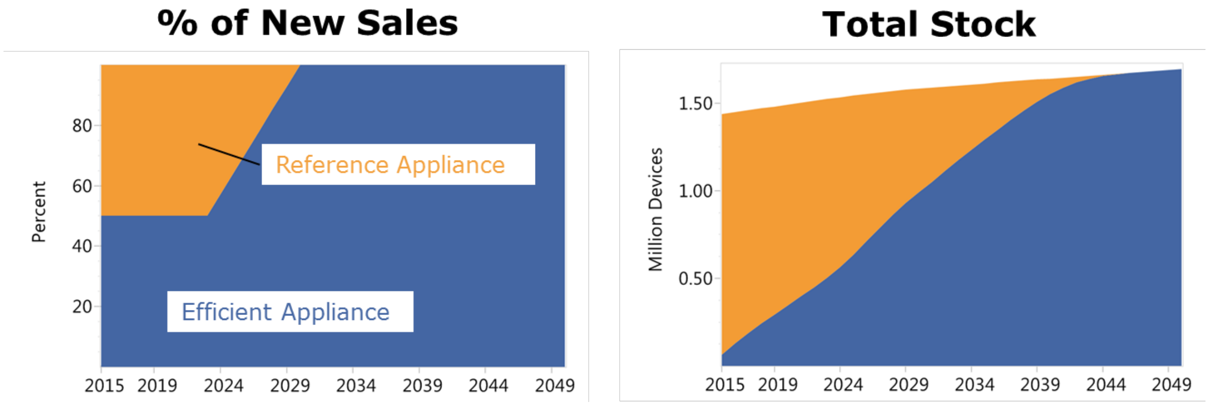


*Figure 2-5. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Policy Scenario 2*

### *2.4.2.5 Policy Scenario 3*

The assumptions for Policy Scenario 3 were specified by the Maryland Commission on Climate Change and are therefore not a policy proposal or recommendation by MDE. Policy Scenario 3 includes a carbon pricing mechanism on top of the measures and actions included in Policy Scenario 1. The carbon pricing mechanism has multiple effects on buildings. The first effect is the direct impact of higher fuel prices on energy consumption, which is represented through price elasticities. In other words, as carbon-intensive fuel prices increase, consumption is reduced. The elasticities used are described in Appendix G. The second effect is the use of revenue from the program to fund additional mitigation measures. Based on conversations with stakeholders, MDE, MDOT, and Towson University, we assumed that electric heat pump adoption would be incentivized by a portion of these revenues, meaning that our building electrification assumptions from Policy Scenario 2 were also adopted in Policy Scenario 3.

*Table 2-10. Policy Scenario 3 Assumptions for Building Energy Efficiency*

| **Category of Efficiency** | **Policy Scenario 3 Assumption** |
|---|---|
| Building retrofits for high efficiency building shells | None |
| New technology sales | 50% of new sales of all electric appliances are assumed to be efficient (e.g. EnergyStar) from 2015-2023 to represent EmPOWER, and continued from 2024-2050<br>25% of new sales of all natural gas appliances are assumed to be efficient by 2030 |
| Building electrification | 95% of new sales of space heaters and water heaters are electric heat pump by 2050, replacing natural gas furnaces and boiler sales |
| Behavioral conservation and smart devices | 10% reduction in energy services demand below Baseline Scenario in residential lighting, space |

| | |
|---|---|
| | heating, and water heating |
| Other non-stock sectors | 20% reduction in electric energy consumption below Baseline Scenario by 2050<br>10% reduction in all other energy consumption below Baseline Scenario by 2050 |
| Distribution System Optimization | Reduction in transmission and distribution losses from 5.4% to 4.8%, to represent EmPOWER estimates |

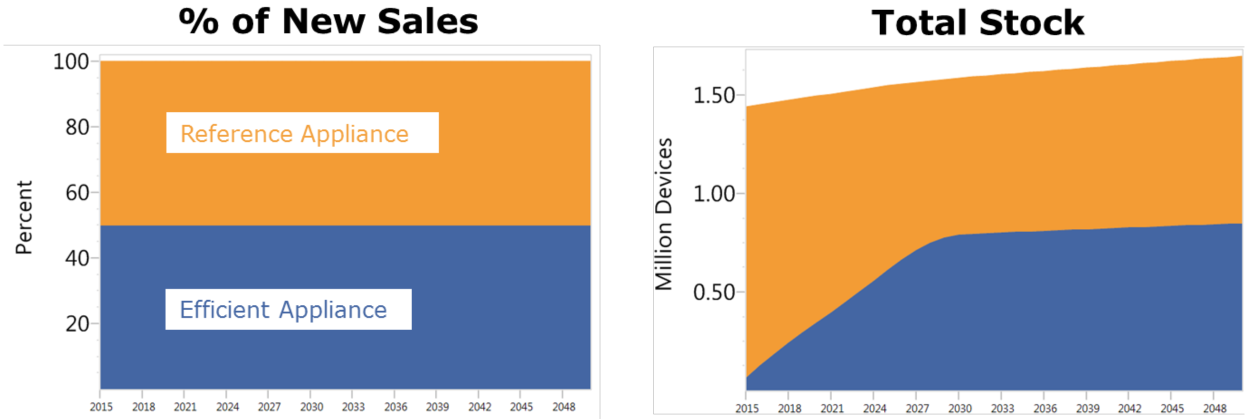


*Figure 2-6. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Policy Scenario 3 (identical assumption to Policy Scenario 1)*

### 2.4.2.6 Policy Scenario 4

Policy Scenario 4 adopts the same energy efficiency and building electrification assumptions as Policy Scenario 1.

*Table 2-11. Policy Scenario 4 Assumptions for Building Energy Efficiency*

| **Category of Efficiency** | **Policy Scenario 4 Assumption (same as Policy Scenario 1)** |
|---|---|
| Building retrofits for high efficiency building shells | None |
| New technology sales | 50% of new sales of all electric appliances are assumed to be efficient (e.g. EnergyStar) from 2015-2023 to represent EmPOWER, and continued from 2024-2050<br>25% of new sales of all natural gas appliances are assumed to be efficient by 2030 |
| Building electrification | 15% of new sales of electric heat pump by 2050, replacing natural gas furnaces and boiler sales |

| | |
|---|---|
| Behavioral conservation and smart devices | 10% reduction in energy services demand below Baseline Scenario in residential lighting, space heating, and water heating |
| Other non-stock sectors | 20% reduction in electric energy consumption below Baseline Scenario by 2050<br>10% reduction in all other energy consumption below Baseline Scenario by 2050 |
| Distribution System Optimization | Reduction in transmission and distribution losses from 5.4% to 4.8%, to represent EmPOWER estimates |

#### *2.4.2.7 Building Electrification Assumptions in all Scenarios*

A key assumption across our scenarios is the adoption of high efficiency electric heat pumps for space heating and water heating. Currently in Maryland electric heat pumps make up about 14% of Residential Space heaters, 4% of commercial space heaters, 0% of residential water heaters, and 2% of commercial water heaters.

In the Reference Scenario we assume a moderate displacement of existing electric space heaters with heat pumps. In Policy Scenario 1 we assume heat pump space heater adoption increases to about 25% in 2030, beginning to displace sales of natural gas systems as well (i.e. a portion of households with natural gas furnaces will replace their system with a heat pump when their furnace breaks). Policy Scenarios 2 and 3 assume significant adoption of heat pumps for both space heating and water heating, reducing sales of natural gas and existing electric systems. Policy Scenario 4 assumes the same adoption as Policy Scenario 1. The annual sales percentage and resulting stocks of residential heat pump space heaters are shown in Figure 2-7 and Figure 2-8.

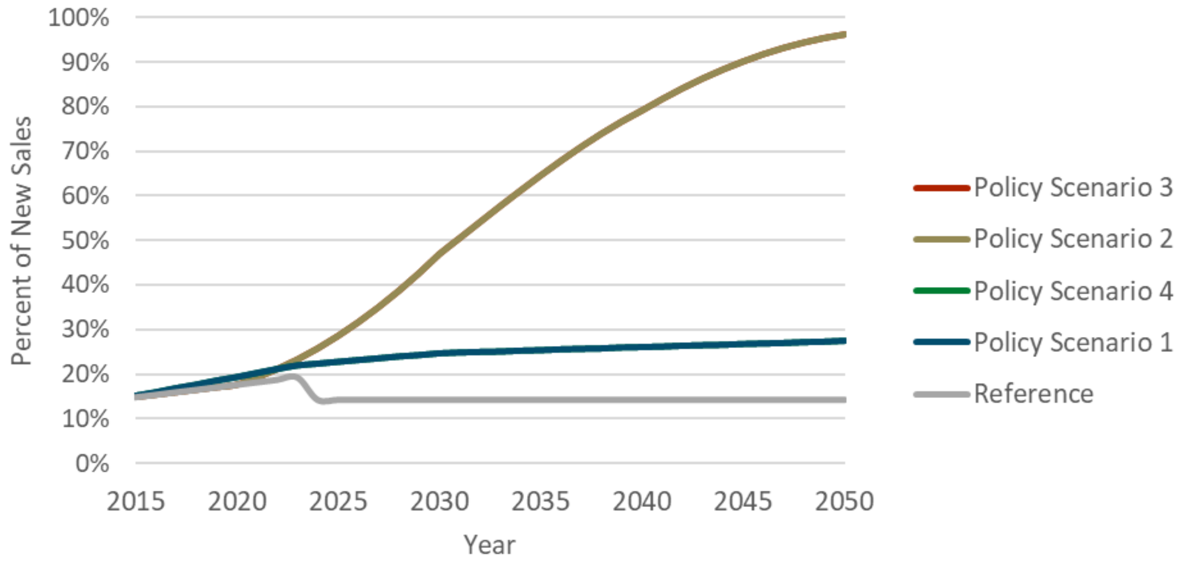


*Figure 2-7. Percent of annual new sales of residential electric heat pump space heaters in all four policy scenarios. Policy Scenario 3 has the same sales as Policy Scenario 2. Policy Scenario 4 has the same sales as Policy Scenario 1.*

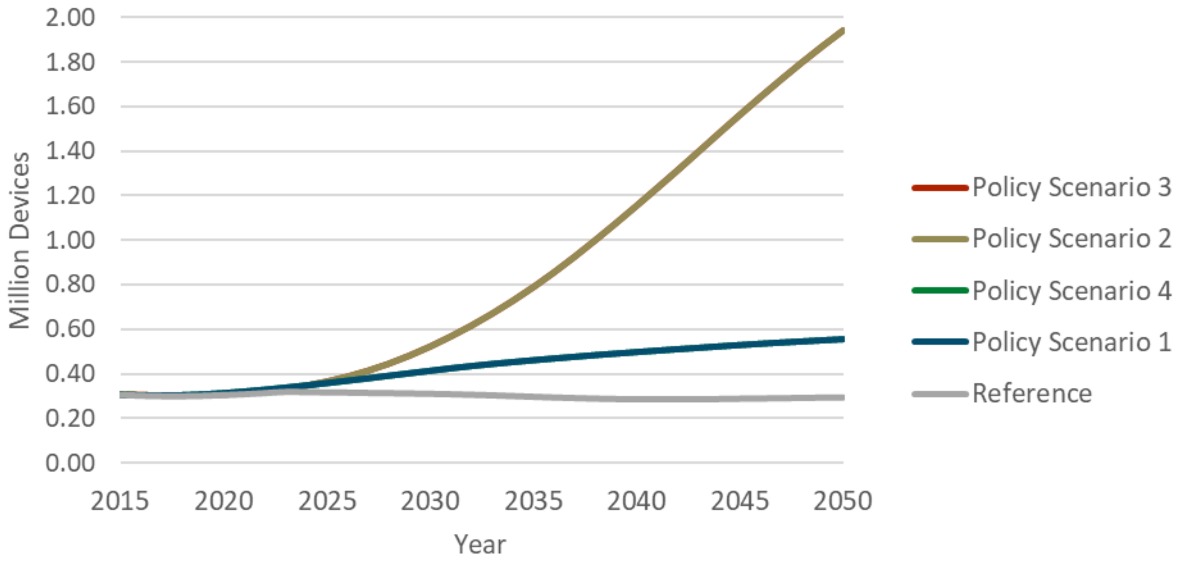


*Figure 2-8. Total number of residential electric heat pump space heaters in all four policy scenarios. Policy Scenario 3 has the same stock of electric heat pumps as Policy Scenario 2. Policy Scenario 4 has the same stock as Policy Scenario 1.*

## 2.4.3 INDUSTRY SECTOR REPRESENTATION

### *2.4.3.1 Base Year*

The Maryland LEAP model does not disaggregate the industry sector into additional subsectors as there was not sufficient data to do so. All industrial energy consumption is represented as total annual energy consumption by fuel, as shown in Table 2-12.

*Table 2-12. Industry 2014 Energy Consumption by Fuel in Maryland*

| Sector | Fuel | Energy Use in 2014 [Tbtu] | % of 2014 Energy Use [%] |
|---|---|---|---|
| Industry (All Subsectors) | Coal | 15.6 | 27% |
| | Diesel | 6.7 | 11% |
| | Renewable Diesel | - | 0% |
| | Electricity | 13.0 | 22% |
| | Natural Gas | 15.1 | 26% |
| | Biogas | - | 0% |
| | LPG | 0.4 | 1% |
| | Gasoline | 4.3 | 7% |
| | Misc. Petroleum Products | 0.3 | 0% |
| | Special Napthas | 3.0 | 5% |
| | Residual Fuel Oil | 0.2 | 0% |
| | *All Sectors* | *58.6* | *100%* |

#### *2.4.3.2 Reference Scenario*

In the Baseline Scenario, all energy is assumed to grow at the fuel-specific industrial growth rates from EIA AEO 2017 Reference Scenario shown in Table 2-13. In the Reference Scenario, industrial electricity use is reduced by 10% below the Baseline scenario by 2023, representing moderate efficiency gains in industry due to EmPOWER.

*Table 2-13. Baseline and Reference Scenario compound annual growth rates by fuel for Maryland's Industry Sector, 2015-2050*

| Fuel | Baseline Energy Growth [%] | Reference Energy Growth [%] |
|---|---|---|
| Coal | -2.8% | -2.8% |
| Diesel | 0.9% | 0.9% |
| Renewable Diesel | - | - |
| Electricity | 0.4% | 0.1% |
| Natural Gas | 0.7% | 0.7% |
| Biogas | - | - |
| LPG | 2.1% | 2.1% |
| Gasoline | 0.4% | 0.4% |
| Misc. Petroleum Products | 0.2% | 0.2% |
| Special Napthas | - | - |
| Residual Fuel Oil | -0.2% | -0.2% |

Industrial energy consumption in the Reference Scenario is driven largely by growth rates for each fuel consumed from EIA AEO projections. The Reference Scenario trend, shown in Figure 2-9, shows a modest switch from coal in industrial applications to natural gas, as well as small reductions in electricity consumption relative to Baseline Scenario growth.

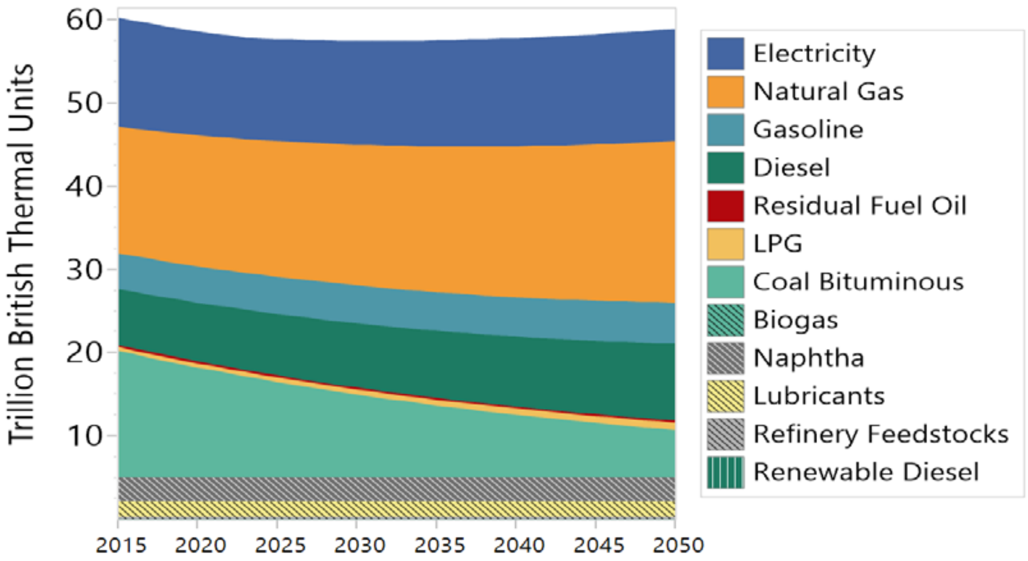


*Figure 2-9. Total Industrial Energy Consumption in the Reference Scenario*

#### 2.4.3.3 Policy Scenario 1

In Policy Scenario 1, industrial electricity use is reduced by 13% by 2030 based on economic potential of efficiency gains in industrial facilities, pumps and ventilation systems[6]. Continued moderate effort is assumed to reduce industrial electricity use by 20% and industrial natural gas use by 10% by 2050.

#### 2.4.3.4 Policy Scenario 2

In Policy Scenario 2, industrial electricity and natural gas use are assumed to decrease by 10% by 2023 due to EMPOWER and continued aggressive energy efficiency gains reduce all industrial fuel use by 30% by 2050 below Baseline levels. Policy Scenario 2 also includes blending of advanced biofuels into pipeline natural gas and diesel, discussed further in Section 2.4.6.

#### 2.4.3.5 Policy Scenario 3

In Policy Scenario 3, industrial energy efficiency measures are the same as Policy Scenario 1. Moderate efficiency gains are assumed to reduce industrial electricity use by 20% and industrial natural gas use by 10% by 2050. In addition to the level of efficiency assumed in Policy Scenario 1, a small reduction in electricity consumption was assumed due to demand elasticities from the increasing carbon price.

#### 2.4.3.6 Policy Scenario 4

In Policy Scenario 4, industrial efficiency measures are the same as in Policy Scenario 1.

#### 2.4.3.7 Industry Assumptions Summary

Based on the assumptions detailed in the preceding sections, the calculated annual growth rates for each fuel are shown in Table 2-14. Total annual energy consumption by fuel is shown in Figure 2-10 for each Policy Scenario.

*Table 2-14. Policy Scenario compound annual growth rates by fuel for Maryland's Industry Sector (2015-2050)*

| Fuel | Policy Scenario 1 | Policy Scenario 2 | Policy Scenario 3 | Policy Scenario 4 |
|---|---|---|---|---|
| Coal | -2.8% | -3.8% | -2.8% | -2.8% |
| Diesel | 0.9% | -3.9% | 0.9% | 0.9% |
| Renewable Diesel | - | 2.9 TBtu by 2050 | - | - |
| Electricity | -0.2% | -0.6% | -0.2% | -0.2% |
| Natural Gas | 0.4% | -1.0% | 0.4% | 0.4% |
| Biogas | - | 2.1 TBtu by 2050 | - | - |
| LPG | 2.3% | 1.2% | 2.3% | 2.3% |
| Gasoline | 0.4% | -0.7% | 0.4% | 0.4% |
| Misc. Petroleum Products | 0.0% | -1.0% | 0.0% | 0.0% |
| Special Napthas | 0.0% | -1.0% | 0.0% | 0.0% |

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[6] Assumed based on EPRI (2017), "State Level Electric Energy Efficiency Potential Estimates"

| | | | | |
|---|---|---|---|---|
| Residual Fuel Oil | 0.0% | 0.0% | 0.0% | 0.0% |

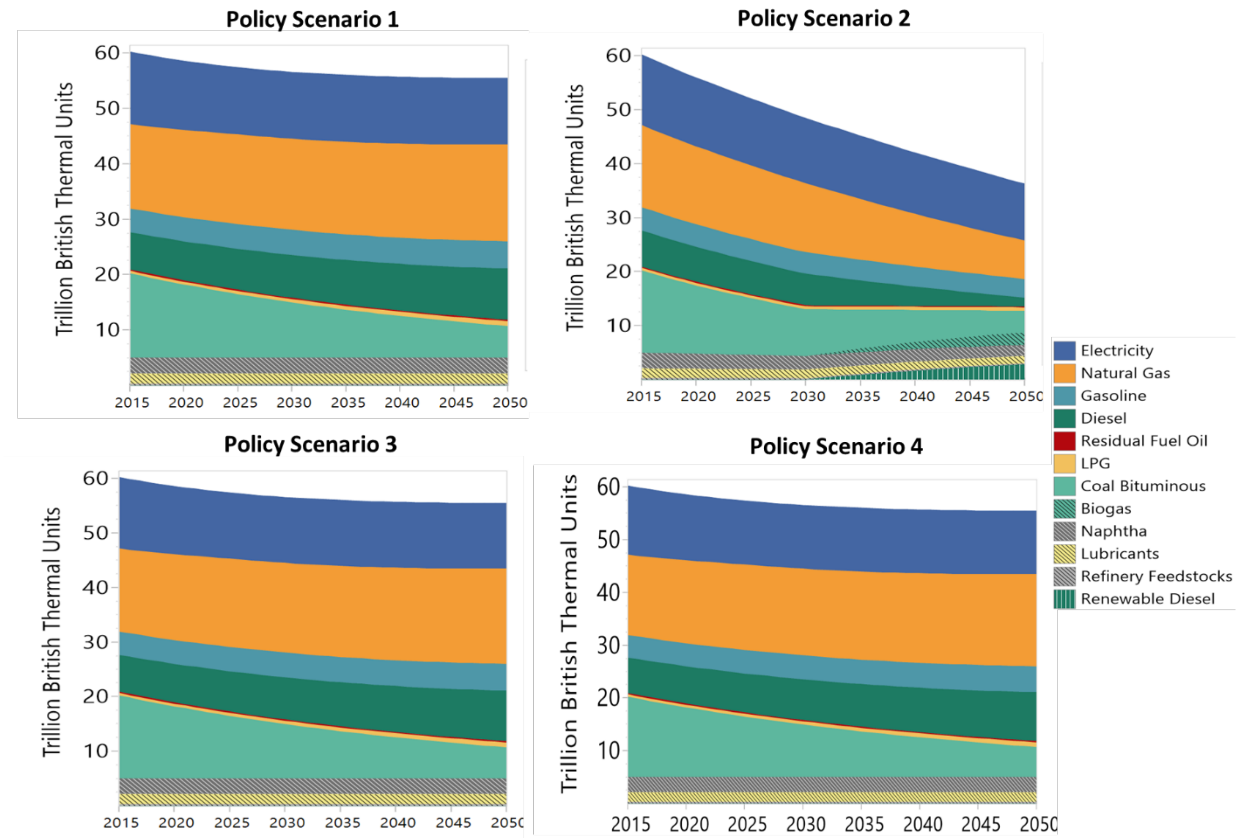

*Figure 2-10. Total Industrial Energy Consumption in All Policy Scenarios*

## 2.4.4 TRANSPORTATION SECTOR REPRESENTATION

### *2.4.4.1 Base Year*

The Maryland LEAP model includes a stock-rollover representation of 3 transportation sectors and an energy representation of 9 subsectors. Sectoral energy demand is benchmarked to energy consumption by fuel from the Maryland GHG inventory for 2014 and is disaggregated by subsector based on the EIA National Energy Modeling System (NEMS) technology characterization. All subsectors represented in the transportation sector are listed in Table 2-15.

*Table 2-15. Transportation 2014 Subsector Energy Consumption in Maryland*

| **Sector** | **Subsector** | **Energy Use in 2014 [Tbtu]** | **% of 2014 Energy Use [%]** |
|---|---|---|---|
| Light duty vehicles | Light Duty Autos | 123 | 28% |
| | Light Duty Trucks | 169 | 38% |
| Heavy Duty Vehicles | Heavy Duty Trucks | 78 | 18% |
| Transportation Other | Aviation* | 11 | 3% |
| | Rail* | 4 | 1% |
| | Bunker Fuels* | 2 | 0% |
| | Farm* | 2 | 0% |
| | Construction* | 42 | 9% |
| | Marine* | 3 | 1% |
| | Motorcycle* | 2 | 0% |
| | Other* | 4 | 1% |
| | Bus* | 4 | 1% |
| | *All Sectors* | *444* | *100%* |

*Subsector does not have underlying stock rollover.

### 2.4.4.2 Reference Scenario

Two key policies were represented in the Maryland PATHWAYS Reference Scenario: (1) Federal Light Duty Vehicle (LDV) Corporate Average Fuel Economy (CAFE) Standards, and (2) the zero emission vehicle (ZEV) Memorandum of Understanding (MOU). LDV CAFE Standards are represented in the marginal fuel economy of new gasoline vehicles sold in addition to an increased share of ZEVs sold. Increasing marginal fuel economy assumed is shown in Figure 2-11.

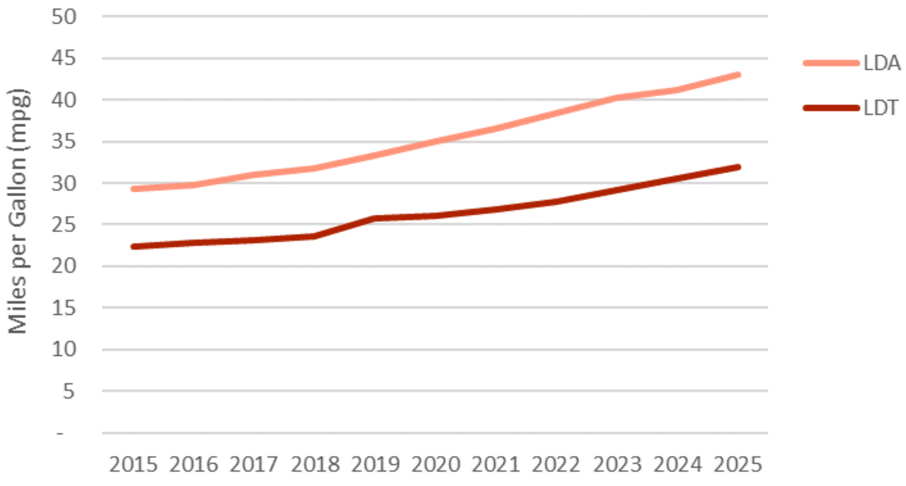

*Figure 2-11. Marginal Fuel Economy for Gasoline LDVs in Maryland*

The second key policy, the ZEV MOU, is represented through increasing sales of plug-in hybrid vehicles (PHEVs) and battery electric vehicles (EVs) over time. We assume that new sales increase linearly to be 20% ZEV sales by 2020. In our stock rollover methodology, this means that of all the cars that are purchased in 2020 (either due to retirement or new growth), 15% will be battery electric vehicles (EVs) and 5% will be plug-in hybrid electric vehicles (PHEVs). This assumption is shown for light duty autos (LDAs) and light duty trucks (LDTs) in Figure 2-12. No changes were assumed in the heavy-duty fleet.

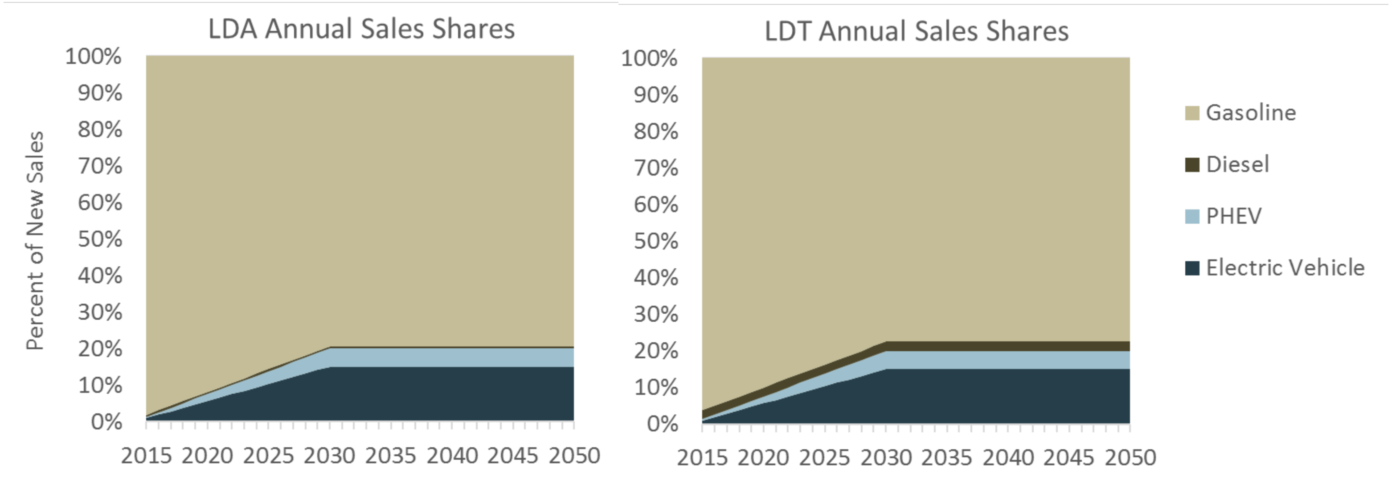

*Figure 2-12. New Sales Rates for LDAs and LDTs in Reference Scenario*

In other subsectors of transportation, total energy consumption in Table 2-15 was assumed to grow at the Maryland population growth rate of 0.76% per year.

### 2.4.4.3 Policy Scenario 1

Policy Scenario 1 has the same adoption of ZEVs as the Reference Scenario through 2030 (20% of new sales) and then grows to 35% of sales by 2050. Growth in on-road vehicle miles traveled are assumed to be reduced to 1.4% annually and light-duty vehicle miles are assumed to be reduced further through smart transit measures such as compact development, transportation demand management, and public and intercity transit.

*Table 2-16. Policy Scenario 1 Assumptions for Transportation*

| **Category of Transportation Measures** | **Policy Scenario 1 Assumption** |
|---|---|
| Vehicle Miles Traveled (VMT) reductions | Annual VMT growth rate is reduced to 1.4% (1.7% in Reference) based on 2018 the Metropolitan Planning Organizations (MPO) plans & programs for smart growth |
| Zero-emission Light Duty Vehicle (LDV) sales | Meet the Zero-Emission Vehicle (ZEV) mandate by 2025 (270,000 ZEVs), and continue to grow new ZEV sales to 35% by 2050 to reach 1.4 million ZEVs |
| Zero-emission Heavy Duty Vehicle (HDV) sales | None |
| Transportation Other | AEO 2017 reference scenario growth rates by fuel |

#### 2.4.4.4 Policy Scenario 2

Policy Scenario 2 includes aggressive adoption of zero emission vehicles and ramps up to 50% of new sales by 2030 and 100% by 2050. Significant VMT reductions are achieved in both light duty and heavy duty vehicles as estimated by MDOT. In addition, electric vehicles are integrated into heavy duty vehicles, construction vehicles, and buses.

*Table 2-17. Policy Scenario 2 Assumptions for Transportation*

| **Category of Transportation Measures** | **Policy Scenario 2 Assumption** |
|---|---|
| Vehicle Miles Traveled (VMT) reductions | Annual LDV VMT is reduced to 11% below Policy Scenario 1 by 2030 and continued to 2050 based on Maryland Department of Transportation (MDOT) emerging and innovative strategies for highway management, smart transit, etc.<br>Annual HDV VMT is reduced to 4% below Reference by 2030 and continued to 2050 based on MDOT strategies for freight stop electrification, truck corridors, etc |
| Zero-emission Light Duty Vehicle (LDV) sales | 50% new sales of ZEVs (electric vehicle and plug-in hybrid) in LDVs by 2030 and 100% by 2050 assuming aggressive ZEV adoption |
| Zero-emission Heavy Duty Vehicle (HDV) sales | 40% new sales of combined electric vehicle and diesel hybrid by 2030 and 95% by 2050 to assuming aggressive ZEV adoption |
| Transportation Other | Electrification of 50% of construction vehicles by 2050, electrification of 50% of transit buses by 2050 (equal to 28% of total buses), AEO 2017 reference scenario growth rates by fuel for all other subsectors |

#### 2.4.4.5 Policy Scenario 3

Policy Scenario 3 includes a carbon pricing mechanism on top of the measures and actions included in Policy Scenario 1. The carbon pricing mechanism has multiple effects on transportation. The first effect is the direct impact of higher fuel prices on energy consumption, which is represented through price elasticities. In other words, as carbon-intensive fuel prices increase, consumption of gasoline and diesel is reduced. The elasticities used are described in Appendix G. The second effect is the use of revenue from the program to fund additional mitigation measures. Based on conversations with stakeholders, MDE, MDOT, and Towson University, we assumed that the following mitigation programs would be funded:

- Light-duty vehicle electrification
- 50% EV Transit bus fleet by 2030

- Expanded bike/pedestrian system development,
- Truck stop electrification
- Expanded Transportation Demand Management (TDM) strategies, including telecommute and non-work policies
- MARC (Maryland's commuter rail system) growth and investment plan
- Zero-emission trucks and truck corridors

These measures are translated to scenario assumptions as shown in Table 2-18.

*Table 2-18. Policy Scenario 3 Assumptions for Transportation*

| **Category of Transportation Measures** | **Policy Scenario 3 Assumption** |
|---|---|
| Vehicle Miles Traveled (VMT) reductions | Annual LDV VMT reduction of 3% below Policy Scenario 1 by 2030 and continued effort to 9% reduction by 2050 based on Maryland Department of Transportation (MDOT) strategies for transit capacity expansion, expanded transportation demand management and commuter rail system expansion, etc. |
| Zero-emission Light Duty Vehicle (LDV) sales | 50% new sales of ZEVs (electric vehicle and plug-in hybrid) in LDVs by 2030 and 100% by 2050 assuming aggressive ZEV adoption |
| Zero-emission Heavy Duty Vehicle (HDV) sales | Truck stop electrification and zero-emission truck corridors |
| Transportation Other | Electrification of 50% of transit buses by 2050 (equal to 28% of total buses), AEO 2017 reference scenario growth rates by fuel for all other subsectors |

### 2.4.4.6 Policy Scenario 4

Policy Scenario 4 looks very similar to Policy Scenario 2 for transportation. Annual VMT reductions were estimated by the Maryland Department of Transportation.

*Table 2-19. Policy Scenario 4 Assumptions for Transportation*

| **Category of Transportation Measures** | **Policy Scenario 4 Assumption** |
|---|---|
| Vehicle Miles Traveled (VMT) reductions | Annual LDV VMT is reduced to 11% below Policy Scenario 1 by 2030 and continued to 2050 based on Maryland Department of Transportation (MDOT) emerging and innovative strategies for highway management, smart transit, etc.<br>Annual HDV VMT is reduced to 4% below |

| | |
|---|---|
| | Reference by 2030 and continued to 2050 based on MDOT strategies for freight stop electrification, truck corridors, etc. |
| Zero-emission Light Duty Vehicle (LDV) sales | 50% new sales of ZEVs (electric vehicle and plug-in hybrid) in LDVs by 2030 and 100% by 2050 assuming aggressive ZEV adoption |
| Zero-emission Heavy Duty Vehicle (HDV) sales | Truck stop electrification and zero-emission truck corridors |
| Transportation Other | Electrification of 50% of transit buses by 2050 (equal to 28% of total buses), AEO 2017 reference scenario growth rates by fuel for all other subsectors |

### *2.4.4.7 Transportation Assumptions Summary*

All scenarios include the same assumptions about ZEV sales through 2025, but then sales assumptions diverge, with Policy Scenario 2 and 3 assuming aggressive adoption, while Policy Scenario 2 assumes continued moderate increases in adoption. Assumptions for total new sales of ZEVs and resulting total stocks is shown in Figure 2-13.

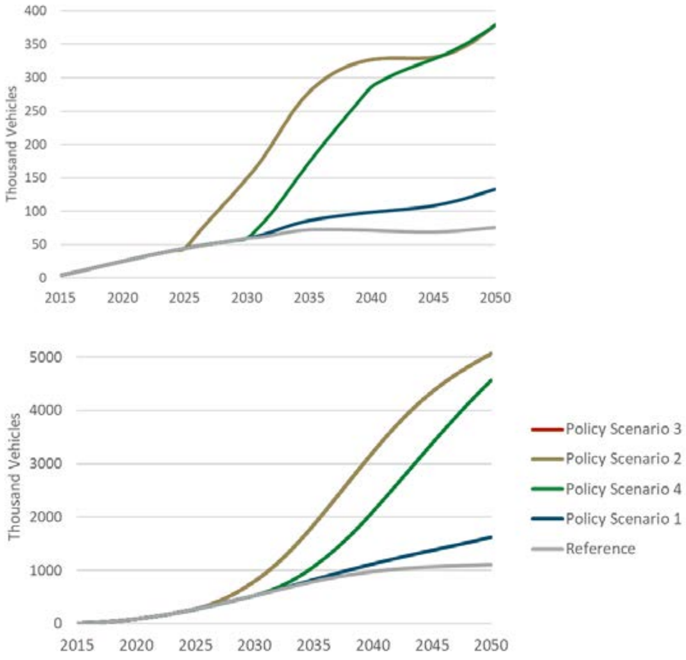

*Figure 2-13. Annual new sales (left) and stock (right) of Light-Duty ZEVs (electric vehicle and plug-in hybrid) for all scenarios, 2015-2050. Policy Scenario 3 has the same ZEV sales and stocks as Policy Scenario 2*

Each scenario meets the state ZEV Memorandum of Understanding (MOU) by reaching 270,000 ZEVs by 2025. Total ZEV stocks are reported in Table 2-20.

*Table 2-20. Total Stock of Zero Emission Vehicles, Reference Scenario and all four policy scenarios*

**Reference Scenario**

| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| EVs | 3,115 | 65,062 | 203,789 | 395,805 | 591,606 | 732,592 | 799,992 | 828,496 |
| PHEVs | 1,038 | 21,687 | 67,930 | 131,935 | 197,202 | 244,197 | 266,664 | 276,165 |
| **Total ZEVs** | **4,153** | **86,749** | **271,718** | **527,739** | **788,808** | **976,789** | **1,066,656** | **1,104,662** |

**Policy Scenario 1**

| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| EVs | 3,115 | 65,062 | 203,789 | 395,805 | 620,737 | 842,799 | 1,034,197 | 1,219,415 |
| PHEVs | 1,038 | 21,687 | 67,930 | 131,935 | 206,912 | 280,933 | 344,732 | 406,472 |
| **Total ZEVs** | **4,153** | **86,749** | **271,718** | **527,739** | **827,649** | **1,123,732** | **1,378,930** | **1,625,887** |

**Policy Scenario 2**

| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| EVs | 3,115 | 65,062 | 203,789 | 597,195 | 1,418,842 | 2,535,752 | 3,542,468 | 4,292,743 |
| PHEVs | 1,038 | 21,687 | 67,930 | 199,065 | 436,222 | 682,482 | 807,898 | 775,073 |
| **Total ZEVs** | **4,153** | **86,749** | **271,718** | **796,260** | **1,855,064** | **3,218,233** | **4,350,366** | **5,067,816** |

**Policy Scenario 3**

| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| EVs | 3,115 | 65,062 | 203,789 | 597,195 | 1,418,842 | 2,535,752 | 3,542,468 | 4,292,743 |
| PHEVs | 1,038 | 21,687 | 67,930 | 199,065 | 436,222 | 682,482 | 807,898 | 775,073 |
| **Total ZEVs** | **4,153** | **86,749** | **271,718** | **796,260** | **1,855,064** | **3,218,233** | **4,350,366** | **5,067,816** |

**Policy Scenario 4**

| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| EVs | 3,115 | 65,062 | 203,789 | 395,805 | 818,098 | 1,667,763 | 2,776,306 | 3,888,676 |
| PHEVs | 1,038 | 21,687 | 67,930 | 131,935 | 251,769 | 436,172 | 603,672 | 676,935 |
| **Total ZEVs** | **4,153** | **86,749** | **271,718** | **527,739** | **1,069,866** | **2,103,935** | **3,379,978** | **4,565,611** |

Many policy measures and mitigation actions impact total vehicle miles traveled. The total number of vehicles owned and driven is consistent between all scenarios modeled, but each policy scenario included measures that reduce total miles traveled per passenger and freight vehicle. The resulting total VMT for each scenario is shown in Figure 2-14 and Table 2-21.

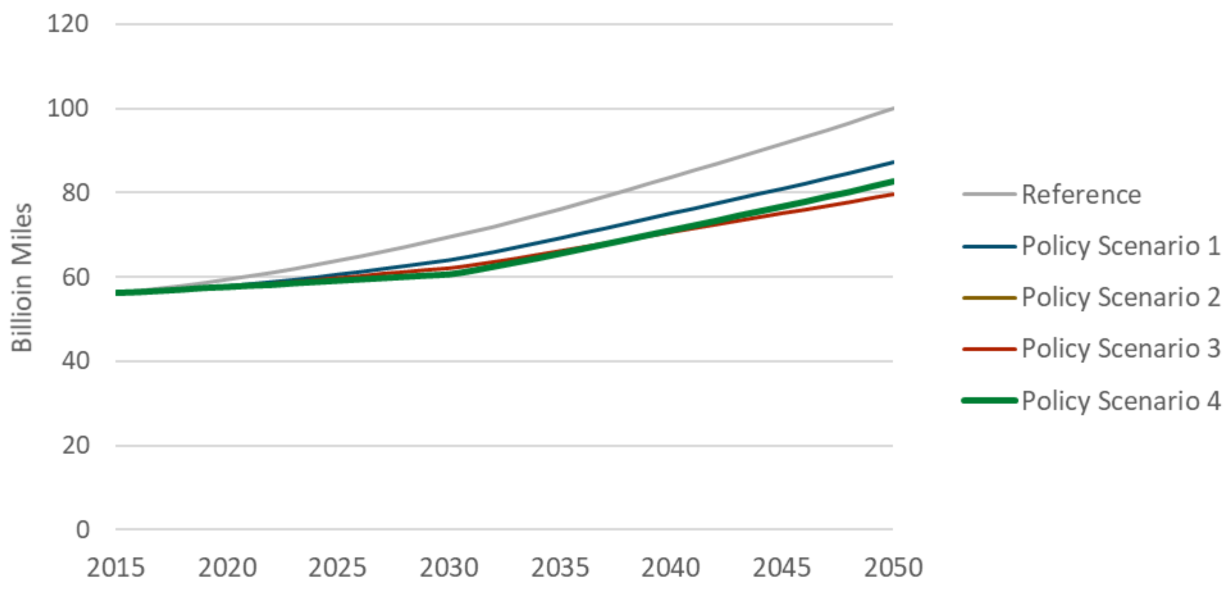

*Figure 2-14. Total Vehicle Miles Traveled (VMT) for all scenarios, 2015-2050, Policy Scenario 2 and Policy Scenario 4 have the same VMT.*

*Table 2-21 Total Vehicle Miles Traveled, Reference Scenario and all four policy scenarios. Units: Billion Miles*

| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Reference | 56.3 | 59.5 | 64 | 69.6 | 76.2 | 83.8 | 91.7 | 100.1 |
| Policy Scenario 1 | 56.3 | 57.9 | 60.7 | 64.1 | 69.3 | 75.2 | 81 | 87.3 |
| Policy Scenario 2 | 56.3 | 57.7 | 59.2 | 60.7 | 65.6 | 71.1 | 76.7 | 82.6 |
| Policy Scenario 3 | 56.3 | 57.8 | 59.9 | 62.2 | 66.3 | 70.8 | 75.3 | 79.8 |
| Policy Scenario 4 | 56.3 | 57.7 | 59.2 | 60.7 | 65.6 | 71.1 | 76.7 | 82.6 |

### 2.4.5 ELECTRICITY SECTOR REPRESENTATION

LEAP contains a dedicated branch for modeling the operations of the electricity sector, which we populated with the best available data from Maryland and supplemented with data and insights from other sources. Operations in the electricity sector are modeled on an hourly basis throughout the year, based on existing load shapes and current and projected resources in Maryland.

#### *2.4.5.1 Existing Generation Resources in Maryland*

In-state generation capacity for Maryland resources is based on modeling done for the Regional Greenhouse Gas Initiative ("RGGI") and provided to E3 by the Maryland Department of the Environment. The RGGI results contain 2017 installed capacity by generator type, which we used as our starting point for determining the resource mix in Maryland.

*Table 2-22. Maryland Installed Capacity in 2017 (RGGI)*

| Capacity Type | MW |
|---|---|
| Biomass | 265 |
| Coal (Without CCS) | 4,718 |
| Combined Cycle (Gas) | 230 |
| Combustion Turbine (Gas) | 2,725 |
| Nuclear | 1,841 |
| Oil/Gas Steam | 2,039 |
| Hydro | 566 |
| Solar | 311 |
| Wind | 190 |
| Other Renewable | 29 |
| **Total** | 12,915 |

We supplemented the generation information available from the RGGI modeling with the more detailed look at Maryland renewable generation available from PJM's Generation Attribute Tracking System (GATS), as well as the sources of out-of-state Renewable Energy Credits (RECs) used to meet Maryland's existing RPS obligations.

### 2.4.5.2 *Reference Scenario*

These baseline resources are supplemented with the "Resource Additions" generated by ICF in their "2017 RGGI Model Rule Policy Scenario (No National Program)" RGGI case. This output provides Maryland's incremental capacity changes between 2017 and 2031 by resource type. The ICF analysis projects that Maryland will add a net total of 4,156 MW of generation by 2031 (including the retirement of 670 MW of coal resources). A summary of these resource additions is shown below.

*Table 2-23. Cumulative Installed Capacity in Maryland in the Reference Scenario*

| Capacity Type | Cumulative MW | | | | | |
|---|---|---|---|---|---|---|
| | 2017 | 2020 | 2023 | 2026 | 2029 | 2031 |
| Coal (Without CCS) | - | (135) | (670) | (670) | (670) | (670) |
| Combined Cycle (Gas) | 1,725 | 3,355 | 3,355 | 3,355 | 3,355 | 3,702 |
| Combustion Turbine (Gas) | 135 | 135 | 135 | 135 | 135 | 135 |
| Wind | 30 | 130 | 130 | 130 | 130 | 130 |
| Solar | 326 | 579 | 682 | 785 | 848 | 852 |
| Other Renewable | - | 7 | 7 | 7 | 7 | 7 |

We supplemented the capacity expansion shown in the table above with information from the Maryland Department of the Environment about two planned offshore wind projects scheduled for construction over the next 5 years. The U.S. Wind project is expected to provide 248 MW (913,845 MWh / year) with an in-service date of January 2020, while the Skipjack project is expected to provide 120 MW (455,482 MWh / year) with an in-service date of November 2022.

One of the advantages of the LEAP modeling software is the ability to do an hourly dispatch of electricity resources to meet a shaped load over the course of the year. For this analysis, we dispatch the generation capacity described in the previous section according to a merit order, adjusting the availability of each resource type to benchmark to the annual generation numbers in the ICF RGGI analysis. The in-state capacity is supplemented with imports into Maryland from the rest of the PJM system, consistent with historical levels. The results of the ICF RGGI analysis are shown in Table 2-24.

*Table 2-24. Net Generation by Generator Type*

| Generator Type | Net Generation (GWh) | | | | | |
|---|---|---|---|---|---|---|
| | 2017 | 2020 | 2023 | 2026 | 2029 | 2031 |
| Biomass | 1,698 | 2,122 | 2,141 | 2,191 | 2,210 | 2,242 |
| Coal (Without CCS) | 12,100 | 8,177 | 7,901 | 8,072 | 8,264 | 7,505 |
| Combined Cycle (Gas) | 9,976 | 15,572 | 16,143 | 13,923 | 13,237 | 12,903 |
| Combustion Turbine (Gas) | 2,348 | 833 | 929 | 777 | 747 | 668 |
| Nuclear | 15,365 | 15,365 | 15,365 | 15,365 | 15,365 | 15,365 |
| Oil/Gas Steam | 5,819 | 2,532 | 2,949 | 1,490 | 1,017 | 929 |
| *Conventional Generation Total* | *47,306* | *44,601* | *45,430* | *41,818* | *40,841* | *42,274* |
| Hydro | 1,620 | 1,620 | 1,620 | 1,620 | 1,620 | 1,620 |
| Solar | 398 | 441 | 441 | 441 | 441 | 441 |
| Wind | 472 | 654 | 654 | 654 | 654 | 654 |
| Other Renewable | 204 | 250 | 250 | 250 | 250 | 250 |
| *Renewable Generation Total* | *3,022* | *3,643* | *3,812* | *3,982* | *4,085* | *4,092* |
| **Total** | **50,328** | **48,245** | **49,242** | **45,800** | **44,926** | **46,366** |

The hourly dispatch capability in LEAP allows us to examine the resource balance on any given day, which is especially useful in understanding the system conditions that lead to renewable overgeneration.

To determine the desired availability of resources throughout the year for benchmarking, we used AURORA, an economic dispatch model developed by EPIS. Where the ICF modeling done for the RGGI process provided information about the total amount of generation by resource type over the course of the year, the AURORA modeling provided information about the monthly distribution of the generation throughout the year. For example, the AURORA modeling indicated that while for most of the year, natural gas units are active, high natural gas prices during the winter months (due to competing demand for space heating) improve the relative economics of coal generation. To reflect this, E3 reduces the availability of natural gas units in the winter months and puts coal units ahead of them in the dispatch order. Nuclear generation, meanwhile, is running at full capacity for most of the year in the AURORA runs, apart from some light downtime for maintenance in the spring and fall.

Solar and wind generation is not dispatchable in the model, but rather produces energy based on an hourly shape obtained from the National Renewable Energy Laboratory (the National Solar Radiation Data Base for solar resources and the Wind Prospector for wind resources). We generated composite shapes for both utility and rooftop PV installations based on the statewide technical potential estimated by Daymark Energy Advisors in the report on “Benefits and Costs of Utility Scale and Behind the Meter

Solar Resources in Maryland"[7]. If there is not sufficient load to absorb the output from renewable and baseload resources in Maryland, the surplus is exported to PJM.

Existing levels of in-state and out-of-state RPS-eligible generation (i.e. black liquor, landfill gas, etc.) were included in the state's renewable portfolio going forward, based on the amounts listed in the PJM GATS system[8] and the 2016 *Renewable Energy Portfolio Standard Report* from the Public Service Commission of Maryland[9]. Landfill gas resources have an emissions rate of 0.11 Mtonnes / MWh, consistent with guidance from MDE. Renewable output from in-state generators is counted toward the state's 25% Renewable Portfolio Standard requirements, with the remainder of the requirement satisfied by out-of-state RECs.

Large hydroelectric resources (30 MW and greater) are eligible to contribute to the RPS as Tier 2 resources until 2018, after which they no longer count towards the RPS requirements but continue to serve the state's energy needs.

The Calvert Cliffs nuclear facility represents a significant baseload resource for Maryland during the early years of the analysis, with nuclear licenses that expire in August 2034 (Unit 1) and August 2036 (Unit 2). Based on feedback from stakeholders, we assume that the licenses are renewed and Calvert Cliffs remains online for the duration of the analysis.

Figure 2-15, below, shows the breakdown of generation by resource type coming out of the LEAP model.

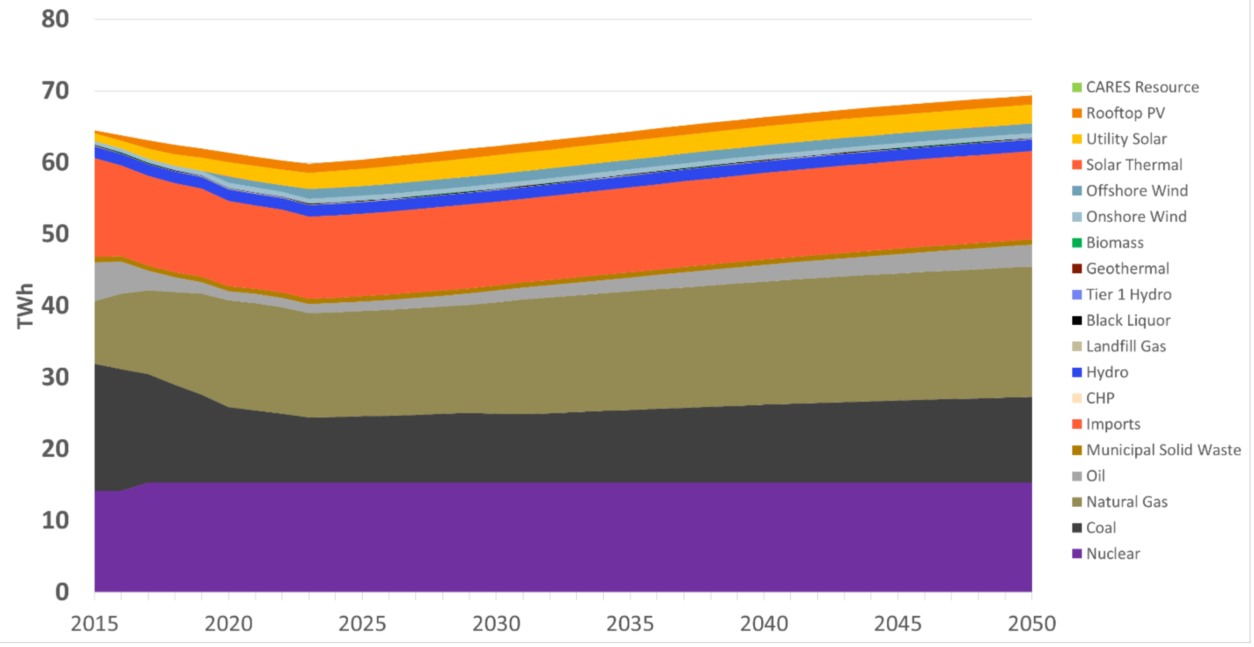

*Figure 2-15. Annual Generation by Resource Type – Reference Case*

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[7] Available at https://www.psc.state.md.us/wp-content/uploads/MD-Costs-and-Benefits-of-Solar-Draft-for-stakeholder-review.pdf. Appendices to the report can be found at https://www.psc.state.md.us/transforming-marylands-electric-grid-pc44/

[8] We incorporated information from the "Renewable Generators Registered in GATS", "RPS Retired Certificates (Reporting Year)", and "RPS Eligible Certificates (Reporting Year)" reports available at https://www.pjm-eis.com/reports-and-events/public-reports.aspx

[9] The report can be found at https://www.psc.state.md.us/wp-content/uploads/CY16-RPS-Annual-Report-1.pdf

### 2.4.5.3 Policy Scenario 1

The primary difference between Policy Scenario 1 and the Reference scenario is the expansion of the RPS to a 50% goal by 2030, consistent with the program laid out in the Clean Energy Jobs Act of 2018[10]. This 50% RPS goal includes resource-specific carveouts for Tier 1 Solar and Offshore Wind (14.5% and 10%, respectively, by 2030), while also eliminating MSW as an RPS-eligible resource in 2021. Wind RECs are purchased from PJM

The Maryland Department of Energy provided us guidance regarding the resources to be ramped down to make room for the increase in renewable energy generated within the state. New renewable resources constructed within the state (Tier 1 Solar PV, including Rooftop PV, and Offshore Wind) result in a decrease in imported generation rather than displacing in-state generation.

Beyond 2030, the RPS requirements (including the resource-specific carveouts) are held constant until the end of the analysis. This results in limited additional renewable build to maintain the legislated 2030 shares of generation as load increases to 2050.

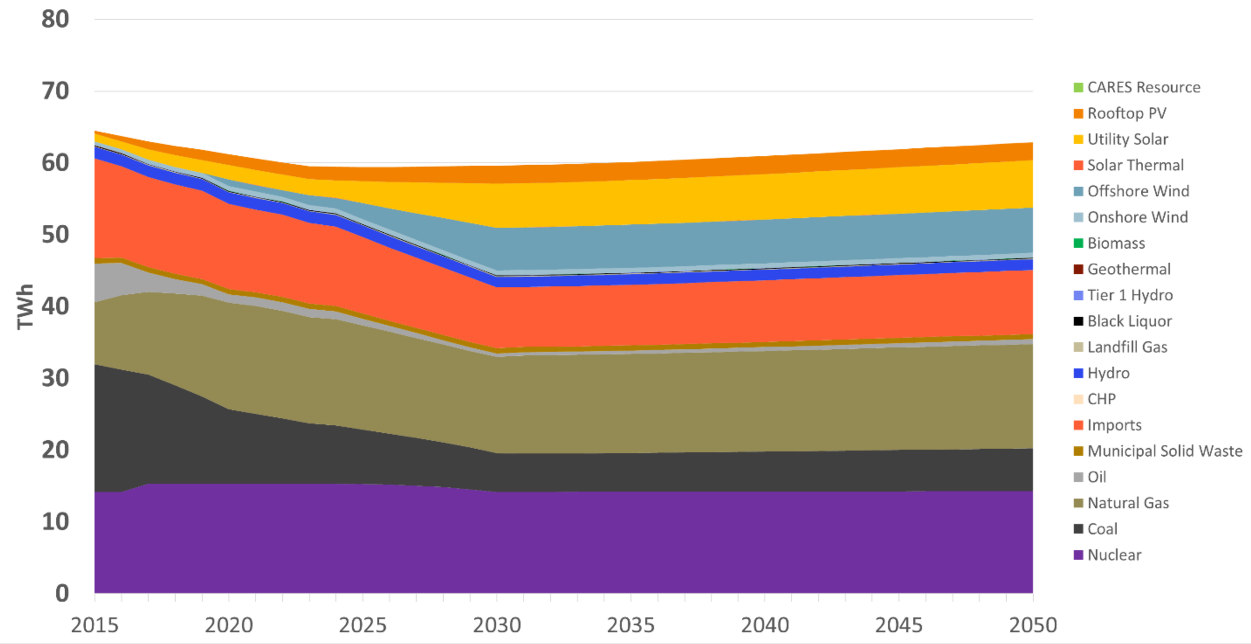

*Figure 2-16. Annual Generation by Resource Type – Policy Scenario 1*

### 2.4.5.4 Policy Scenario 2

Policy Scenario 2 replaces the 50% RPS by 2030 (modeled in Policy Scenario 1) with a 50% Clean and Energy Standard (CARES) by 2030 and a 100% CARES by 2040, while also tightening the RGGI emissions cap between 2030 and 2050.[11]

The CARES expands eligibility to low-carbon resources beyond the Tier 1 renewables that are used to meet the RPS in the remaining scenarios. While Tier 2 Hydro is no longer eligible to satisfy the RPS after

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[10] The text of the bill can be found here http://mgaleg.maryland.gov/2018RS/bills/hb/hb1453F.pdf

[11] This analysis represents an illustrative first cut at a 100% CARES target for the State and additional work will be required to determine exact eligibility and compliance mechanisms.

2018 in the other Policy Scenarios, it counts as a CARES resource for the duration of the analysis in Policy Scenario 2.

Electricity generated from Combined Heat and Power (CHP) is also eligible to meet the CARES, with the assumption that the emissions from CHP generation is counted against the industrial and commercial sectors (which use the heat produced) rather than the electricity sector. We based our deployment of CHP on a Department of Energy (DOE) study titled *The State of CHP in Maryland*[12], which provided estimates of the technical potential for CHP of different sizes across both the industrial and commercial sectors. CHP is modeled as a supply side resource in the MD PATHWAYS model and is not explicitly linked to energy efficiency in building or industrial sectors. The table below shows the total potential estimated by the DOE by size and sector.

*Table 2-25. Technical Potential for CHP in Maryland, by Sector and Plant Size (MW)*

| Size | Industrial | Commercial / Institutional | Total |
|---|---|---|---|
| Small (<1 MW) | 135 | 679 | 814 |
| Medium (1 - 5 MW) | 142 | 323 | 465 |
| Large (>5 MW) | 424 | 941 | 1365 |
| **Total** | **701** | **1943** | **2644** |

CHP is expected to be an attractive option for satisfying the CARES requirements, as cost projections indicate that medium and large CHP installations are cost-competitive with market power when CHP units are given a thermal credit for the heat they supply[13]. Our analysis assumes that the CARES leads to the development of 80% of all Industrial technical potential (roughly 560 MW) and large Commercial and Institutional technical potential (roughly 750 MW). Due to less favorable economics, development of small and medium Commercial / Institutional CHP installations is assumed to occur at rates that yield an average CHP plant size of 1.5 MW across all installations (10.5% of technical potential, or roughly 105 MW). Across all installation, these assumptions lead to 28% of technical potential installed by 2030 and 54% by 2050.

The CARES includes carveouts for offshore wind and solar (7.5% by 2030 and 12.5% by 2040 for each), as well as a minimum of 25% of generation from other Tier 1 renewable resources in both 2030 and 2040. Existing Tier 1 resources count toward this 25% requirement, and any shortfall is made up by purchasing of out-of-state wind RECs.

In the early years of the analysis (until 2030), we assume that any shortfall in CARES resources relative to the requirements will result in the construction of additional utility scale solar until the requirement is satisfied. Past 2030, however, we assume the availability of a generic "CARES Resource" that is used to close any gap that remains after all carveouts are met and CHP is built. This generic resource could be natural gas plants with carbon capture and sequestration, small modular nuclear reactors, or solar PV (subject to the availability of suitable sites).

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[12] This report can be found at https://www.energy.gov/sites/prod/files/2017/11/f39/StateOfCHP-Maryland.pdf

[13] See the DOE's *Maryland Combined Heat and Power Market Assessment*, available at https://energy.maryland.gov/Documents/MarylandCHPMarketAnalysis.pdf

Policy Scenario 2 also assumes a tightening of the RGGI emissions cap both within Maryland and across PJM. Within Maryland, the cap declines an additional 60% between 2030 and 2050, on top of the 30% decline between 2020 and 2030 that is assumed in Policy Scenarios 1 and 3. This results in the shutdown of all coal and oil generation within the state by 2040, replaced primarily by imports from out-of-state (not covered by the RGGI caps). Due to tightening RGGI caps throughout PJM and adoption of RGGI or comparable programs in additional PJM states, the emissions intensity of imported electricity is also assumed to decrease over time, decreasing a total of 40% between 2025 and 2045.

The resulting generation mix for Policy Scenario 2 is shown in Figure 2-17.

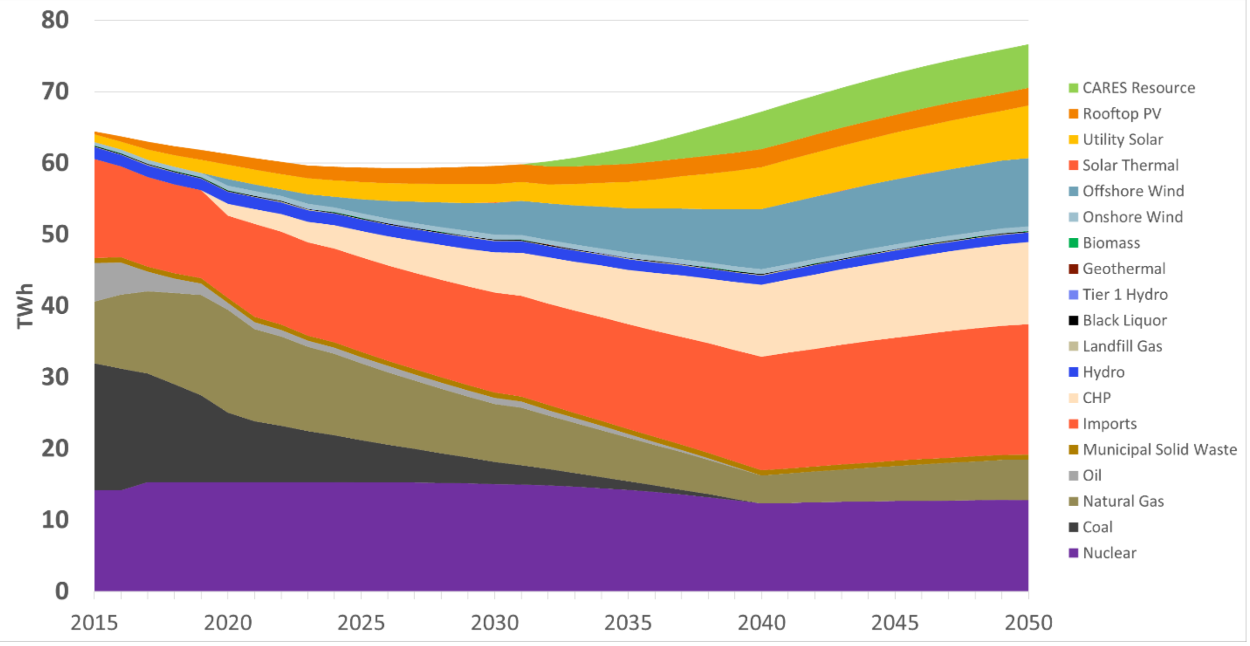

*Figure 2-17. Annual Generation by Resource Type – Policy Scenario 2*

### *2.4.5.5 Policy Scenario 3*

Policy Scenario 3 has the same RPS requirements and carveouts as Policy Scenario 1, but assumes that the imposition of a carbon fee leads to a decline in carbon-intensive generation due to the additional cost of generation. We assume that coal and oil generation shut down as the variable costs of generation exceeded those from natural gas, which occurs in the mid-2020s at a carbon tax of roughly $30 per tonne. Unlike Policy Scenario 2, where the coal is phased out over time to reflect a tightening RGGI cap, the assumption in Policy Scenario 3 is that the increased cost of generation will lead coal plants within Maryland to shut down as their economics become unfavorable, eliminating in-state coal generation by the late 2020s.

The imposition of a carbon fee also improves the relative economics of solar PV resources, suggesting that these resources may be constructed as a cost-effective means of serving load rather than simply to meet the carveouts in the RPS legislation. To reflect these changing economics, we continued to add solar until the total amount of solar and offshore wind reached 30% of load, consistent with PJM estimates of the amount of intermittent renewable energy that the system can accommodate without issue[14].

The resulting generation mix for Policy Scenario 4 is shown in Figure 2-18 below.

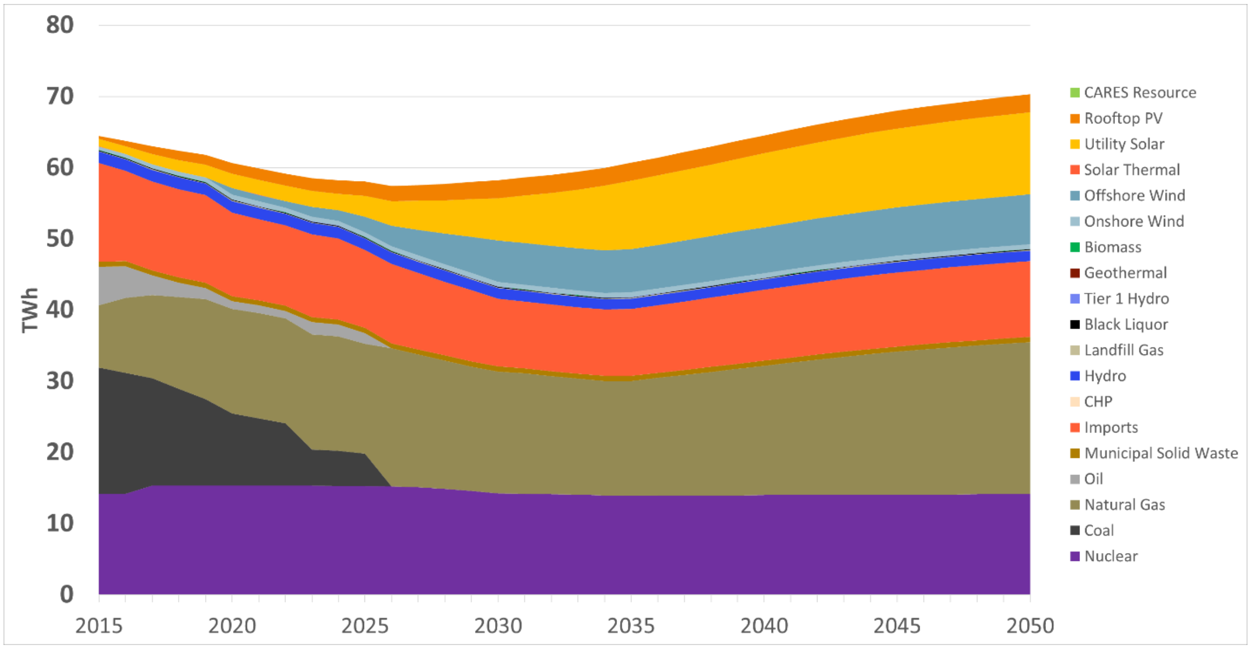

*Figure 2-18. Annual Generation by Resource Type – Policy Scenario 3*

### 2.4.5.6 Policy Scenario 4

Policy Scenario 4 has similar requirements for the electricity sector as Policy Scenario 2: Maryland meets the existing 2020 RPS of 25%, and then adopts a 50% CARES target for 2030 and 100% CARES target for 2040, with carveouts for in-state solar, offshore wind, and CHP.[15] The CHP carveouts in the Policy Scenario 4 CARES remain the same as those in Policy Scenario 2, the in-state solar carveout was set to 10% in 2030 and 15% in 2040, the offshore wind requirement was set to 7.5% in 2030 and 10% in 2040. The Tier 1 REC requirement has been set at 20% in both 2030 and 2040 for this scenario. Additional clean energy resources will need to be added to meet the 100% CARES requirement, which will depend on technologies available at that time.

While Policy Scenario 2 explicitly ramps down coal and oil CTs until they are retired in 2040 (reflecting continued tightening of the RGGI caps), Policy Scenario 4 reduces the capacity of these resources along the same schedule to 2030 but leaves them available at 2030 levels for the remainder of the analysis. As Figure 2-19. below indicates, however, the resources added to satisfy the increasing CARES requirements end up displacing generation from these generators anyway.

As in Policy Scenario 2, this scenario assumes RGGI continues to expand throughout PJM, lowering the deemed emissions rate for imported power.

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[14] See https://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pris-executive-summary.ashx

[15] This analysis represents an illustrative first cut at a 100% CARES target for the State and additional work will be required to determine exact eligibility and compliance mechanisms.

The resulting generation mix for Policy Scenario 4 is shown Figure 2-19.

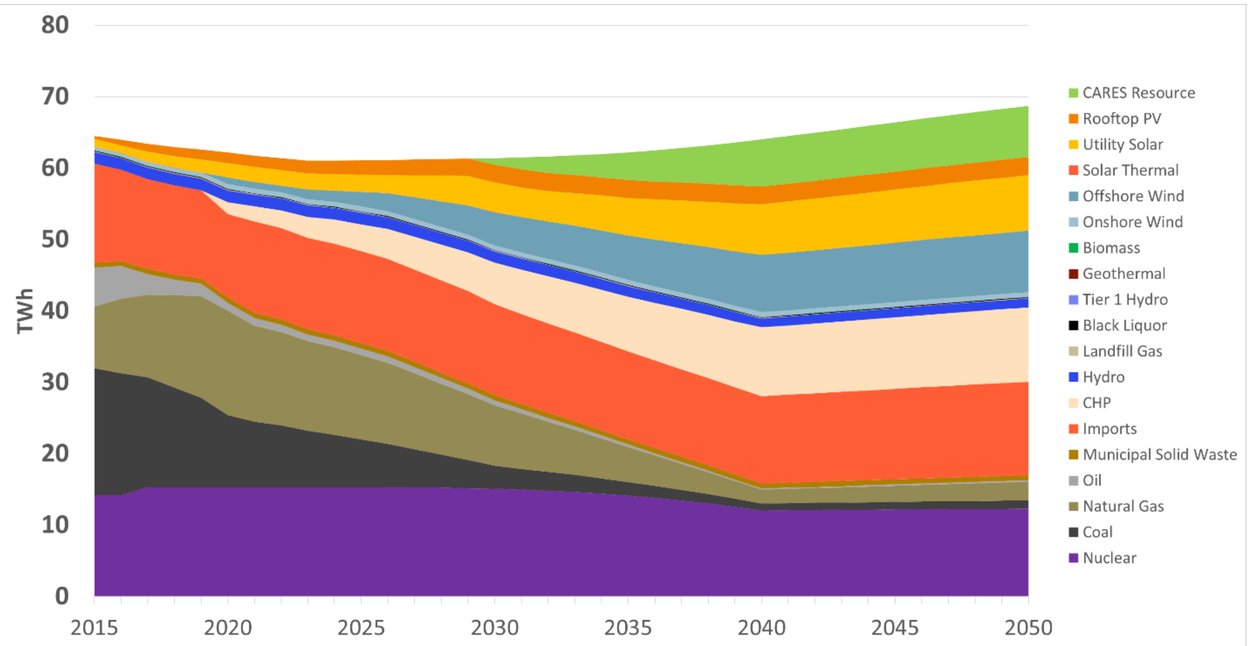

*Figure 2-19. Annual Generation by Resource Type – Policy Scenario 4*

### 2.4.6 BIOFUEL SUPPLY

We define biofuels as fuel derived from sustainably harvested biomass. Examples of biomass products that are used to produce biofuels include corn, soybeans, sugar cane, forest products and wood, manure, switch grass and other agricultural waste products, such as corn stover. As long as biomass feedstocks are sustainably harvested, we define the resulting biofuel products as renewable and zero-carbon fuel types. Conventional biofuels include ethanol blended into motor gasoline and biodiesel, while advanced biofuels include renewable gasoline, renewable diesel, and renewable natural gas, which are chemically equivalent to their fossil counterparts.

Only Policy Scenario 2 explores the development and use of advanced biofuels for consumption in Maryland. All other scenarios assume the Federal Renewable Fuel Standard (RFS) continues but no additional biofuels are introduced.

#### *2.4.6.1 Reference Scenario*

The Reference Scenario assumes that the Federal RFS continues but no additional increase in biomass or biofuel consumption.

#### *2.4.6.2 Policy Scenario 1*

Policy Scenario 1 assumes that the Federal RFS continues but no additional increase in biomass or biofuel consumption.

### 2.4.6.3 Policy Scenario 2

The decarbonization transition will require very strategic use of limited biomass and careful screening of sustainable feedstocks to ensure that bioenergy is truly renewable and produces no adverse land-use impacts.

Initial biomass feedstock assessments are taken from the 2016 DOE Billion Ton Study (BTS) Update[16], which estimates sustainable yield of a variety of raw biomass sources, including agricultural (including dedicated energy crops), forestry (including new forests and residues), and waste streams (including municipal waste and forest residues). For the purposes of this study, we have assumed a conservative biofuel supply, where any regional supplies are limited to residues and waste streams.

To determine total biomass supply, we assumed that Maryland would have access to its population-weighted share of the total national feedstock supply, which is about 2% of the total supply. This approach assumes that all US states begin to transition to developing advanced biofuels with these resources.

Figure 2-20 shows the national estimated biomass feedstock supply. Policy Scenario 2 has assumed Maryland can purchase 2% of the national "Residue" categories: agricultural residues, food waste, forest residues, municipal solid waste, and manure. The residues have fewer concerns about land-use constraints and competition with food crops.

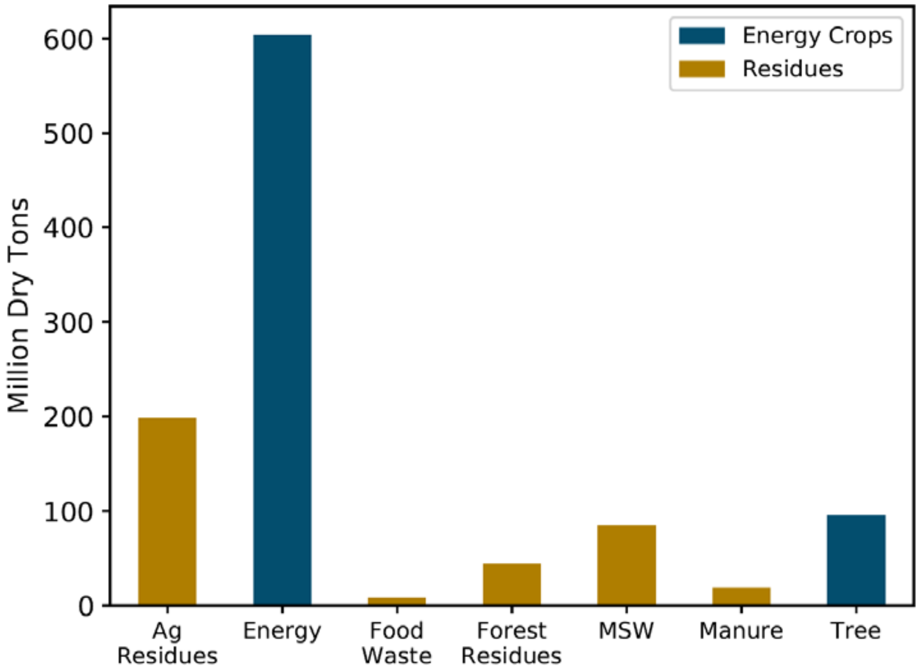

*Figure 2-20. National Biomass Feedstock Supply by 2040 by Resource Category*

To calculate the optimal portfolio of biofuels, E3 has developed a model which generates biofuel supply curves that determine the availability and cost of renewable liquid and gaseous fuels. The model optimizes the selection of combinations of feedstocks and conversion pathways. The model adds

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[16] DOE, 2016 Billion-Ton Report. Available online: https://www.energy.gov/eere/bioenergy/2016-billion-ton-report

preparation, process, transportation, and delivery costs to BTS feedstock cost curves to achieve supply curves by feedstock and conversion pathway. To obtain biofuel demand, we apply the percentage biofuel penetration targets to aggregate calculated final energy demand.

Figure 2-21 shows the total resulting advanced biofuel consumption by sector and fuel.

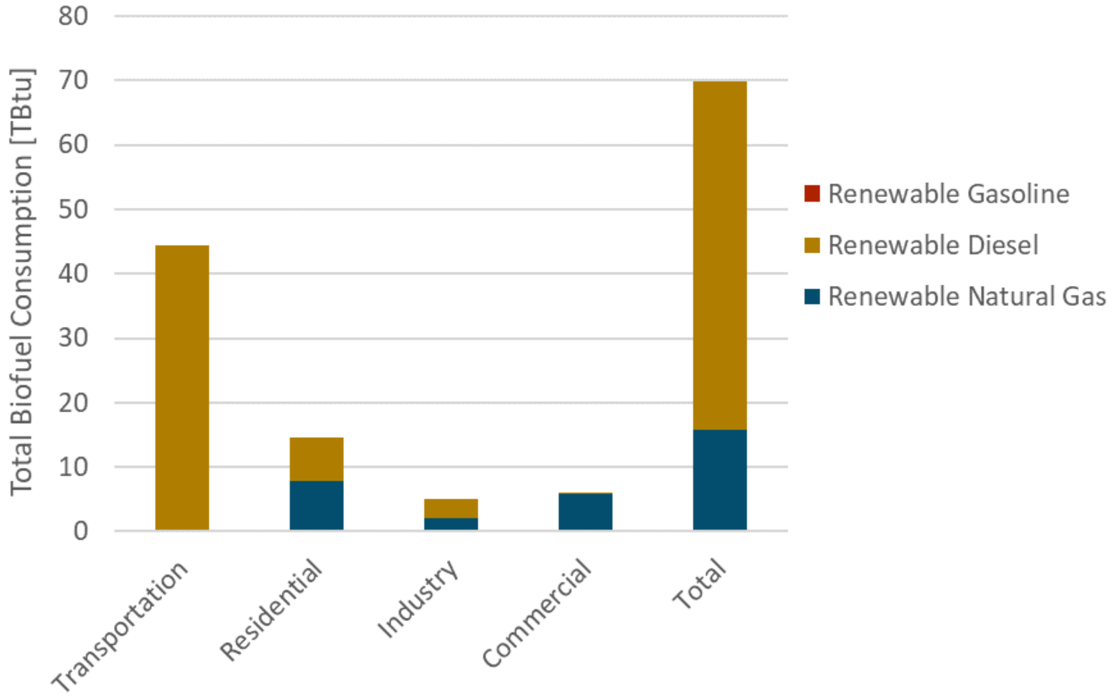

*Figure 2-21. Total Advanced Biofuel Production by Sector and Biofuel in 2050, Policy Scenario 2*

Figure 2-22 highlights a different view of the same result, showing total consumption of gasoline, diesel, and natural gas by the share that is blended biofuel (and therefore zero-carbon) and the remaining share that is fossil.

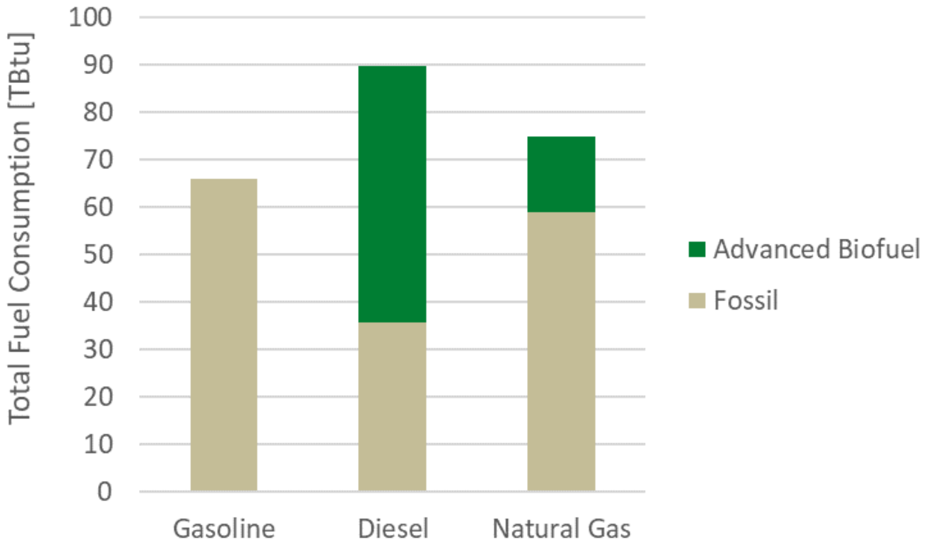

*Figure 2-22. Total Fuel Consumption for Gasoline, Diesel, and Natural Gas by Primary Fuel Composition in 2050, Policy Scenario 2*

#### 2.4.6.4 Policy Scenario 3

Policy Scenario 3 assumes that the Federal RFS continues but no additional increase in biomass or biofuel consumption.

#### 2.4.6.5 Policy Scenario 4

Policy Scenario 4 assumes that the Federal RFS continues but no additional increase in biomass or biofuel consumption.

### 2.4.7 NON-COMBUSTION

#### 2.4.7.1 Base Year

Non-combustion GHG emissions include methane (primarily from agriculture, waste and fugitive gas pipeline emissions), ozone depleting substance (ODS) substitutes, i.e. fluorinated gases (primarily from refrigeration and air conditioning units) and nitrogen oxides, primarily from agriculture. Maryland also has land-use emissions sinks in soils, forested landscape, and urban forestry. The emissions sinks are accounted for in state GHG goals after calculating percent reductions below gross emissions.

Table 2-26 shows non-combustion emissions taken directly from the MDE 2014 GHG Inventory.

*Table 2-26. Non-Combustion Emissions and Emissions sinks in Maryland, 2014*

| Sector | Subsector | 2014 [MMT CO2e] |
|---|---|---|
| Agriculture | Agricultural Burning | 0.24 |
| | Agricultural Soils | 0.99 |
| | Enteric Fermentation | 0.34 |
| | Manure Management | 0.32 |
| | Urea Fertilizer Usage | 0.01 |
| Emissions Sinks and Land Use | Agricultural Soils | -0.05 |
| | Forest Fires | 0.05 |
| | Forested Landscape | -10.45 |
| | Urban Forestry and Land Use | -1.20 |
| Fossil Fuel Industry | Coal Mining | 0.14 |
| | Natural Gas Industry | 0.58 |
| Industrial Processes | Ammonia and Urea Production | 0.00 |
| | Cement Manufacture | 1.58 |
| | Electric T and D Systems | 0.05 |
| | Limestone and Dolomite Use | 0.14 |
| | ODS Substitutes | 2.97 |
| | Soda Ash | 0.04 |
| Waste Management | Landfills | 1.11 |
| | Residential Open Burning | 0.03 |
| | Waste Combustion | 1.30 |
| | Wastewater Management | 0.57 |
| Total Non-Combustion Emissions | | 10.41 |
| Total Non-Combustion Emissions Sinks | | -11.65 |
| Total Net Non-Combustion Emissions | | -1.24 |

#### 2.4.7.2 Reference Scenario

No specific measures were assumed in any non-combustion subsectors in the reference scenario. Small changes over time were assumed for waste management, soil sequestration, and forests based on estimates from UMD and DNR.

#### 2.4.7.3 Policy Scenario 1

Policy Scenario 1 assumes moderate reductions in GHGs through additional forested landscape and agricultural soils initiatives, as indicated in Table 2-27.

*Table 2-27. Policy Scenario 1 Assumptions for Non-Combustion Emissions*

| **Category of Non-Combustion** | **Policy Scenario 1 Assumption** |
|---|---|
| Agriculture | None |

| | |
|---|---|
| Emissions Sinks and Land Use | Additional acreage in forest management and healthy soils conservation practices |
| Fossil Fuel Industry | None |
| Industrial Processes | None |
| Waste Management | None |

### 2.4.7.4 Policy Scenario 2

Policy Scenario 2 assumes more aggressive reductions in agriculture, forests, soils, natural gas industry, and refrigerant use, as indicated in Table 2-28.

*Table 2-28. Policy Scenario 2 Assumptions for Non-Combustion Emissions*

| **Category of Non-Combustion** | **Policy Scenario 2 Assumption** |
|---|---|
| Agriculture | Reductions in Enteric Fermentation: 16% below 2014 levels by 2030<br>Reductions in Manure Management: 65% below 2014 levels by 2030 |
| Emissions Sinks and Land Use | Additional acreage in forest management and healthy soils conservation practices (beyond levels achieved in Policy Scenario 1. |
| Fossil Fuel Industry | Reductions in Natural Gas Industry: 45% reduction below 2014 levels by 2030 (equivalent to California's Short-Lived Climate Pollutant Strategy), 60% by 2050 |
| Industrial Processes | Reductions in ODS substitutes: 23% below 2014 levels by 2030 (SNAP), and 85% below 2014 levels by 2050 (Kigali) |
| Waste Management | None |

### 2.4.7.5 Policy Scenario 3

Policy Scenario 3 has the same assumptions as Policy Scenario 1 as the carbon price is not expected to have any additional effect on emissions from non-energy and non-combustion categories, as shown in Table 2-29.

*Table 2-29. Policy Scenario 3 Assumptions for Non-Combustion Emissions*

| **Category of Non-Combustion** | **Policy Scenario 3 Assumption** |
|---|---|
| Agriculture | None |
| Emissions Sinks and Land Use | Additional acreage in forest management and |

| | |
|---|---|
| | healthy soils conservation practices |
| Fossil Fuel Industry | None |
| Industrial Processes | None |
| Waste Management | None |

#### 2.4.7.6 Policy Scenario 4

Policy Scenario 4 includes the enhanced sinks measure from Policy Scenario 2 as well as the SNAP reductions in ODS substitutes, but does not include the other waste, agriculture, and fossil fuel measures that do not currently have a policy mechanism in Maryland.

*Table 2-30. Policy Scenario 4 Assumptions for Non Combustion Emissions*

| Category of Non Combustion | Policy Scenario 4 Assumption |
|---|---|
| Agriculture | None |
| Emissions Sinks and Land Use | Additional acreage in forest management and healthy soils conservation practices |
| Fossil Fuel Industry | None |
| Industrial Processes | Reductions in ODS substitutes: 23% below 2014 levels by 2030 (SNAP) |
| Waste Management | None |

# 3 Results

## 3.1 GHG Emissions

Based on the assumptions outlined in Section 2 above, net GHG emissions are calculated for Maryland as shown in Figure 3-1. In the Reference Scenario, emission reductions are achieved in the initial years due to energy efficiency in buildings and transportation, as well as cleaner electricity generation. Emissions begin to rise after current policies no longer have an incremental effect and increased population and economic activity continues to increase energy use.

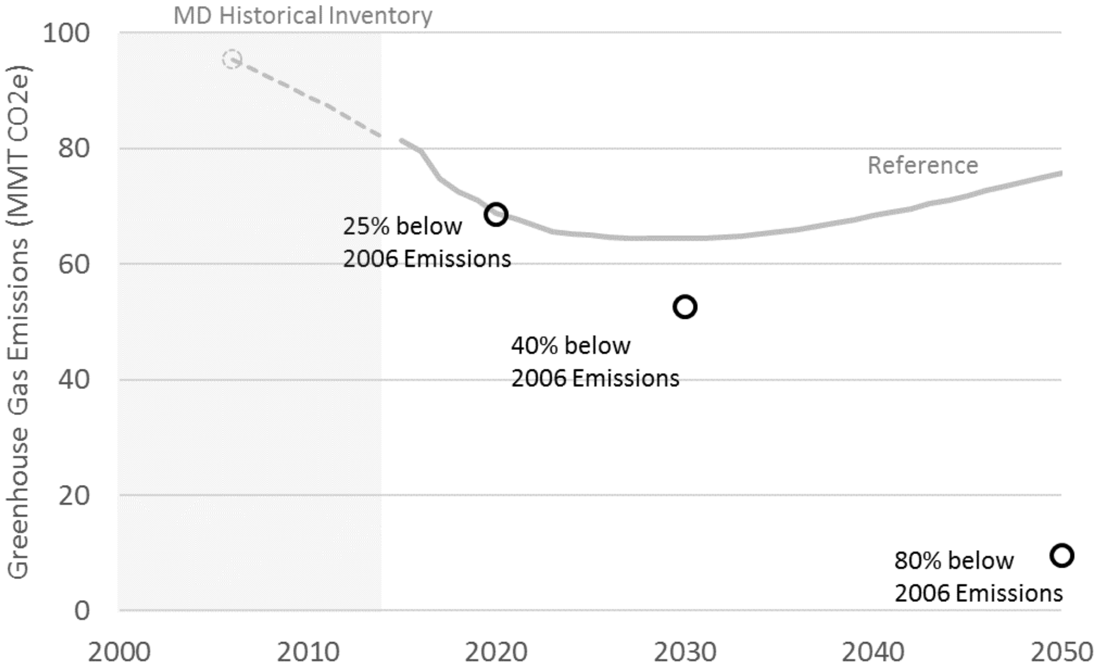

*Figure 3-1. Maryland Net GHG Emissions Results for Reference Scenario, 2015-2050*

Emissions for each modeled sector are shown over time in Figure 3-2 in the Reference Scenario. The largest direct reductions are in electricity generation, due to the retirement of in-state coal units and reduced demand due to efficiency, and transportation, due to federal CAFE standards and increased sales of ZEVs.

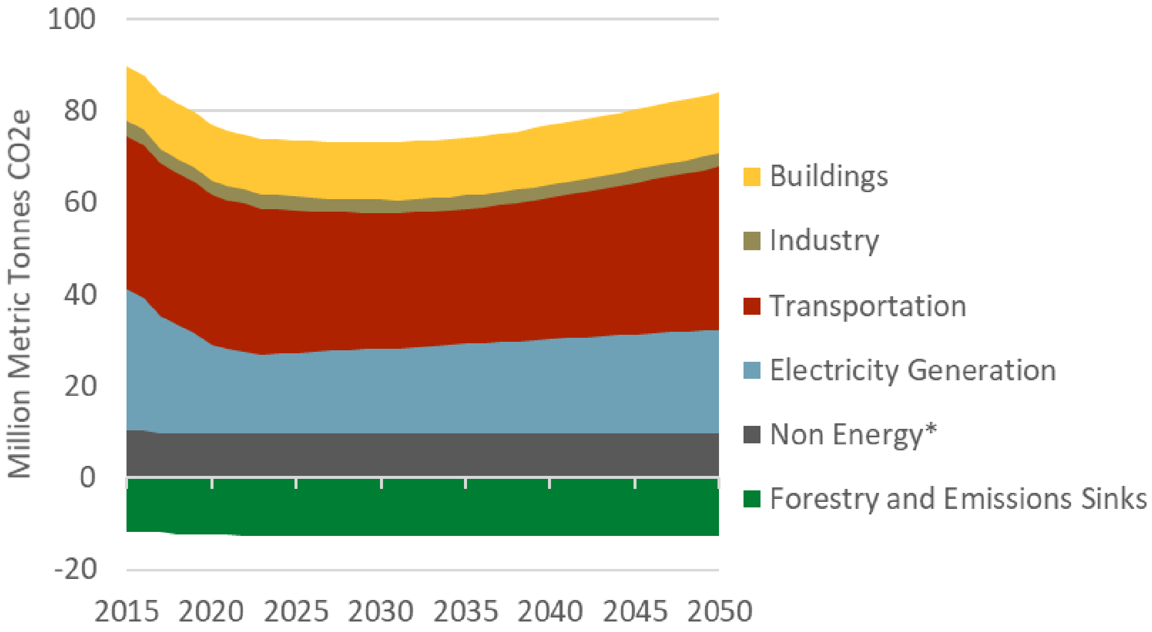

*Figure 3-2. Maryland Gross GHG Emissions by Sector in the Reference Scenario, 2015-2050*[17]

Policy Scenario 1, which represents an extension of existing efforts, including building efficiency and the state's RPS get close but falls short of the 2030 goal. Policy Scenarios 2 and 3 both meet the 2030 goal. Policy Scenario 3's included carbon pricing mechanism has the most effect between 2020 and 2030, after which the reductions taper off and the scenario falls short of the 2050 goal. Policy Scenario 2 very nearly meets the 2050 GHG target by including targeted complementary policies and measures to reduce GHGs in all sectors of Maryland's economy.

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[17] *Non Energy includes Agriculture, Waste Management, Industrial Processes and Fossil Fuel Industry emissions

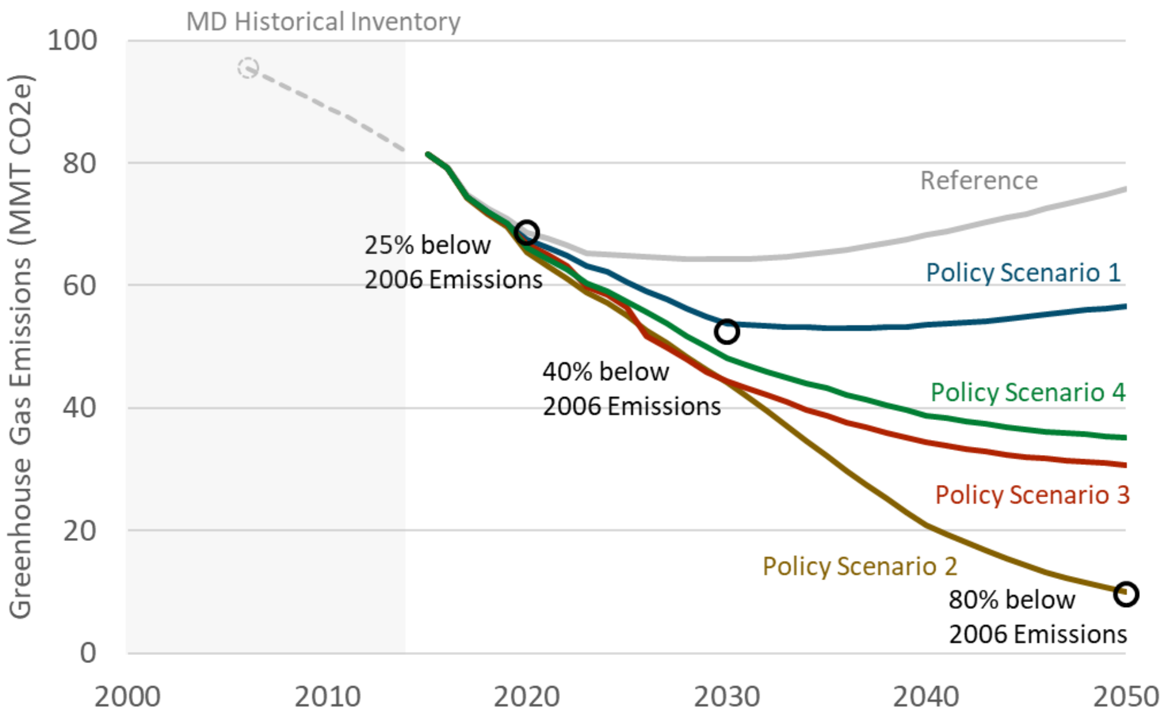

*Figure 3-3. Total Net GHG Emissions by Scenario Relative to Policy Targets*

Figure 3-4 shows total emissions by sector in each Policy Scenario. The largest reductions in Policy Scenario 1 are in buildings, transportation, and electricity generation, offsetting growth in emissions after 2030 relative to the Reference Scenario. Policy Scenario 2 achieves significant reductions in all sectors, but most notably in transportation and electricity generation. Policy Scenario 3 has the most emission reductions in transportation and electricity generation due to the carbon price.

*Table 3-1. Total Net GHG Emissions by Policy Scenario*

| [MMT CO2e] | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Policy Scenario 1 | 67.5 | 53.9 | 53.5 | 56.6 |
| Policy Scenario 2 | 65.4 | 44.1 | 21.0 | 9.9 |
| Policy Scenario 3 | 66.7 | 44.4 | 34.5 | 30.7 |
| Policy Scenario 4 | 66.2 | 48.1 | 38.7 | 35.2 |
| GHG Goals | 68.6 | 52.5 | 31.1 | 9.7 |

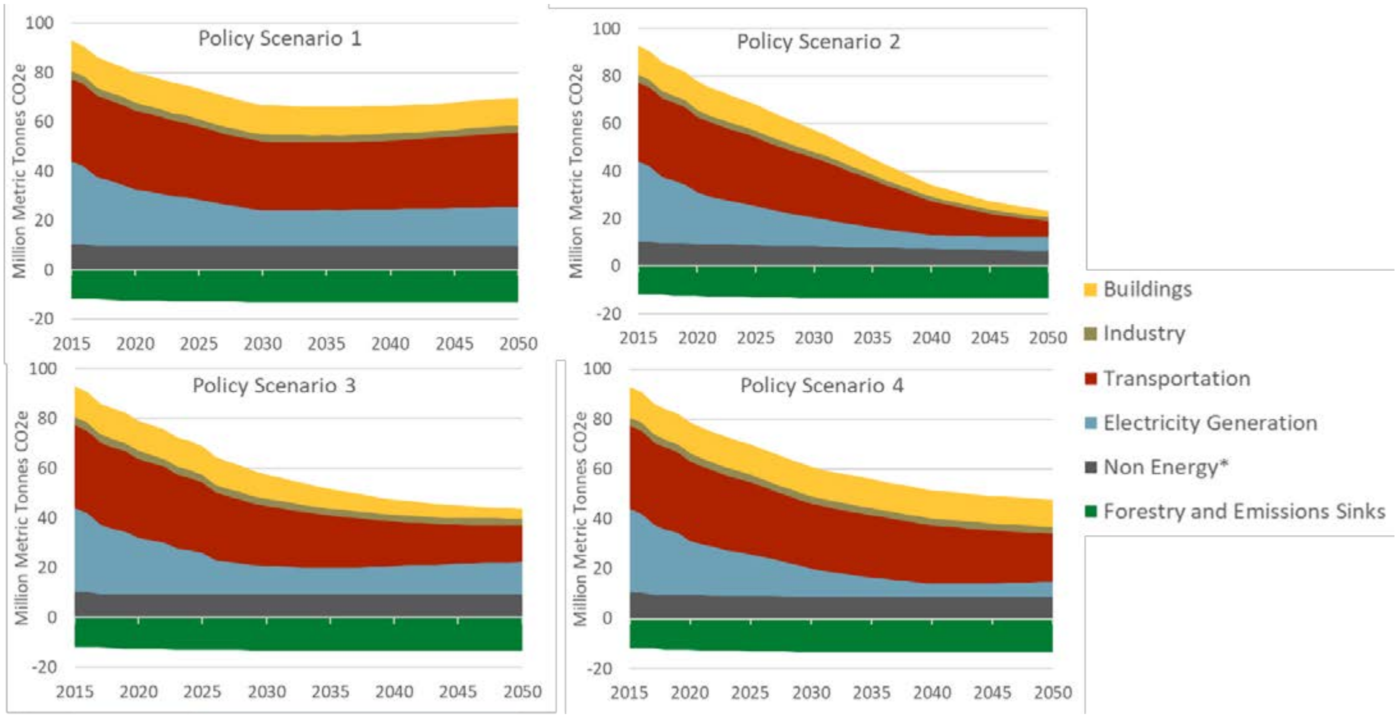

*Figure 3-4. Maryland Gross GHG Emissions by Sector in the four policy scenarios, 2015-2050*[18]

## 3.2 Sectoral Findings

### 3.2.1 BUILDINGS

The focus of measures in buildings is on energy efficiency and electrification. Increased sales of more efficient appliances and devices result in increased stock of those devices over time as old devices retire. Increased sales of efficient devices along with behavioral conservation and reductions in non-stock energy consumption results in significant reductions in total energy consumption and associated emissions as shown in Figure 3-5. Any emissions associated with electricity consumption in buildings is represented as direct emissions in the electricity generation sector, but emissions benefits associated with biofuel consumption are reflected here.

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[18] *Non Energy includes Agriculture, Waste Management, Industrial Processes and Fossil Fuel Industry emissions

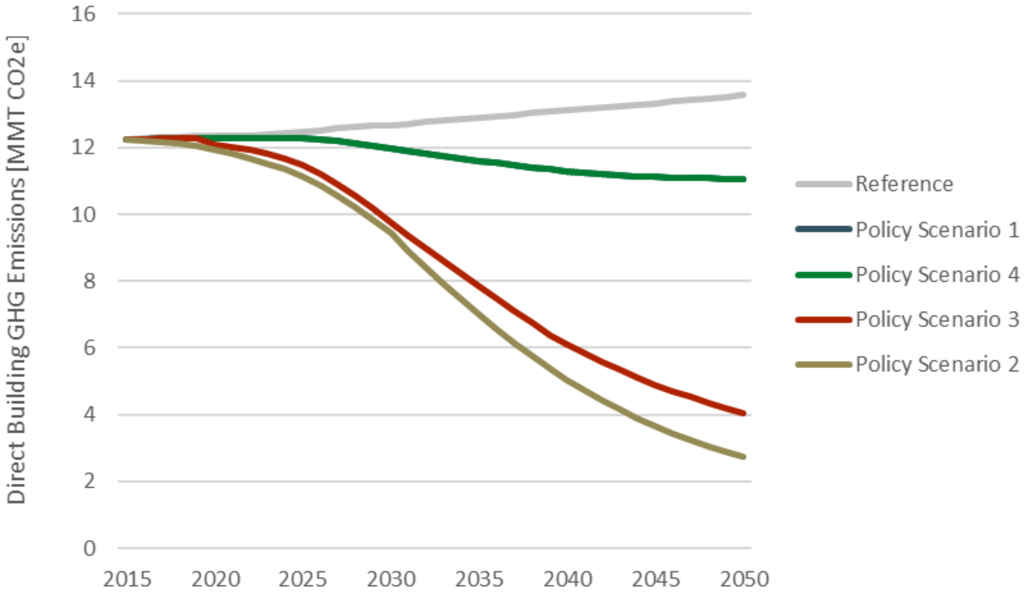

*Figure 3-5. Total Direct Emissions by Scenario in Buildings. Policy Scenario 4 has the same direct emissions in Buildings as Policy Scenario 1.*

### 3.2.2 INDUSTRY

The focus of measures in industry is on energy efficiency. Increased efficiency in Maryland's industrial sector results in reductions in total energy consumption and associated emissions as shown in Figure 3-6. Any emissions associated with electricity consumption in industry is represented as direct emissions in the electricity generation sector, but emissions benefits associated with biofuel consumption are reflected here.

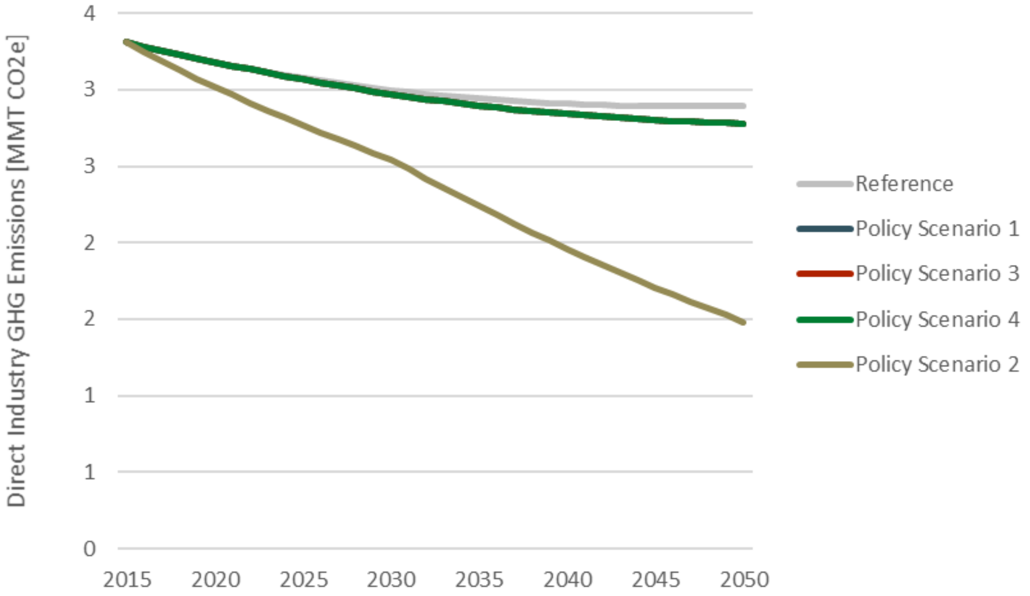

*Figure 3-6. Total Direct Emissions by Scenario in Industry. Policy Scenarios 1 and 3 have the same emissions. Policy Scenario 3 and Policy Scenario 4 have same direct emissions in Industry as Policy Scenario 1.*

### 3.2.3 TRANSPORTATION

Reductions in emissions in the transportation sector are achieved through efficiency, electrification, and biofuels. Energy efficiency is included in two forms: (1) federal CAFÉ standards for new vehicle sales, and (2) VMT reductions due to transit and smart growth measures. New sales of vehicles with more efficient electric drive trains achieve significant efficiency and the potential to reduce emissions further by consuming cleaner electricity. Benefits of displacing fossil diesel with renewable diesel further reduces emissions within the transportation sector.

The impact of LDV CAFÉ Standards and the ZEV MOU can be seen in the aggregate energy consumption by transportation sector as shown in Figure 3-7.

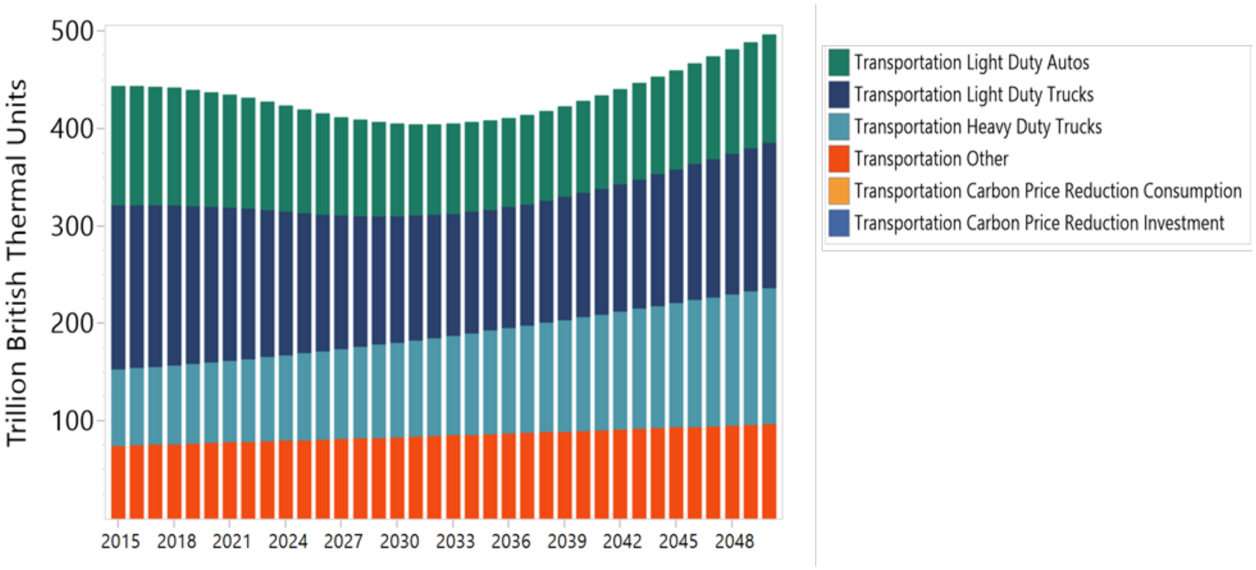

*Figure 3-7. Total Energy Consumed in Transportation by Subsector, Reference Scenario*

Additional electric vehicle sales and VMT reductions reduce energy consumption further in Policy Scenarios 1 and 2, while Policy Scenario 3 also sees reductions from carbon price response, as shown in Figure 3-8.

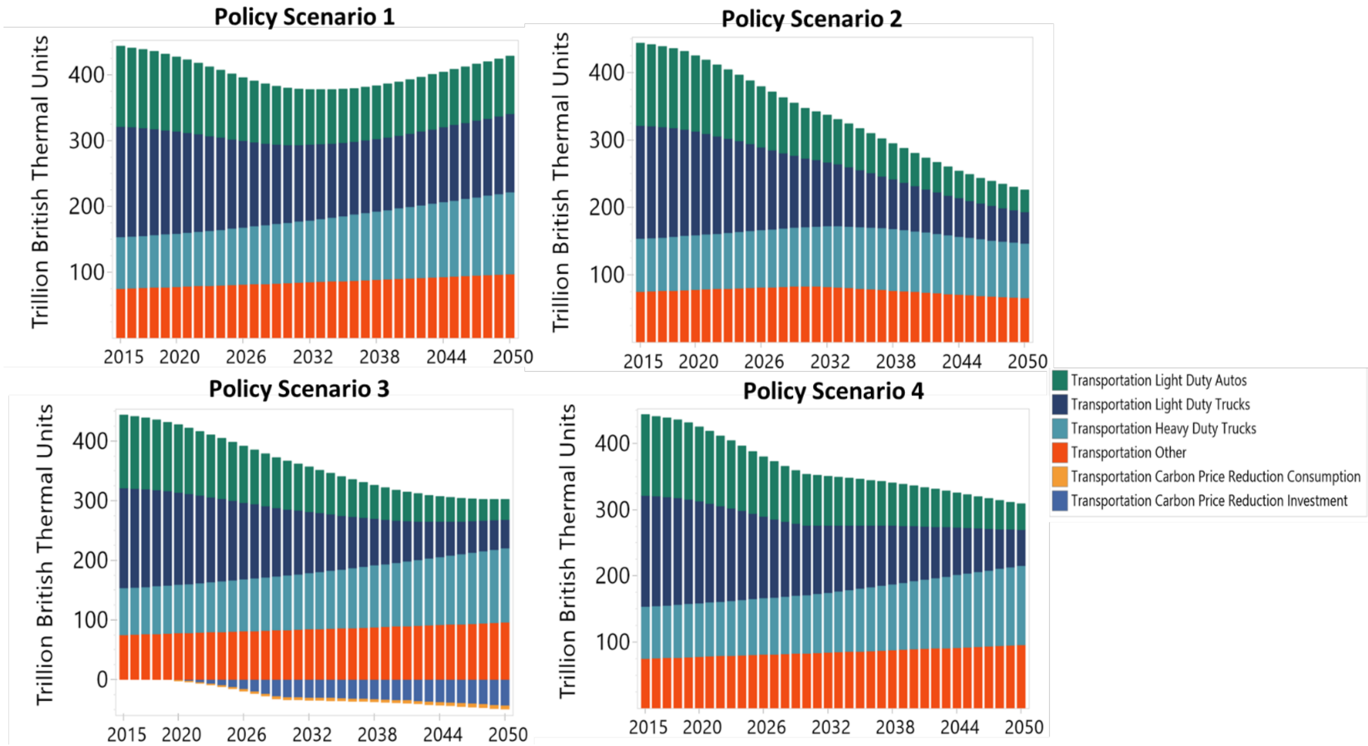

*Figure 3-8. Total Energy Consumed in Transportation by Subsector, all four policy scenarios*

The resulting emissions for Transportation sectors are shown in Figure 3-9.

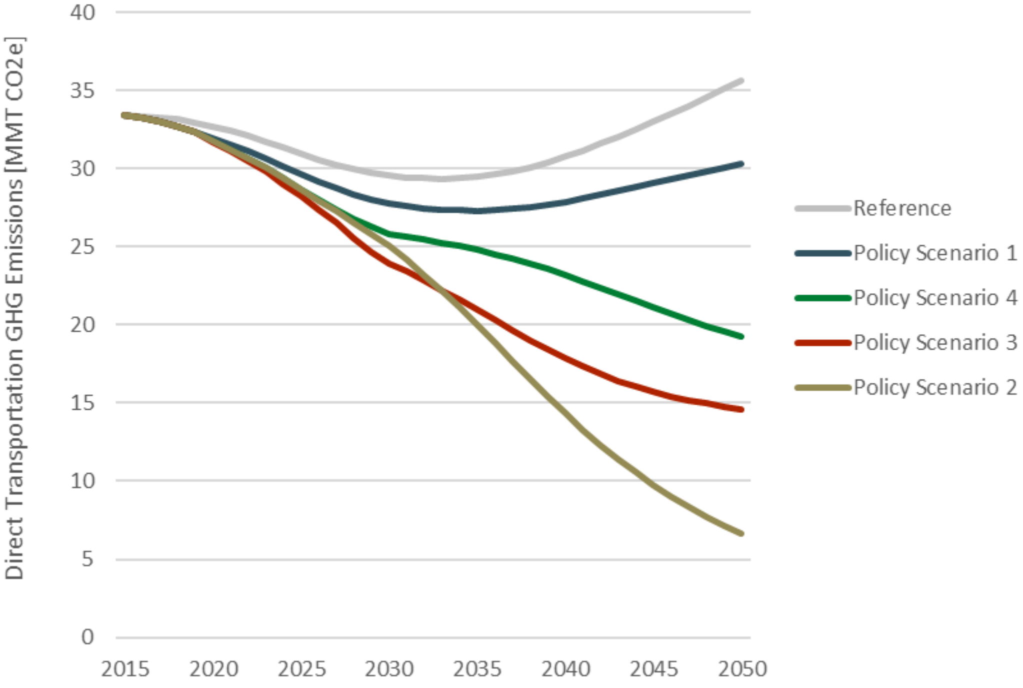

*Figure 3-9. Total Direct GHG Emissions in Transportation by Scenario*

#### 3.2.3.1 Total Electric Loads

Total electricity demands feed into the requirements for electricity generation within the Pathways model. Total electric load due in the Reference Scenario is shown in Figure 3-10.

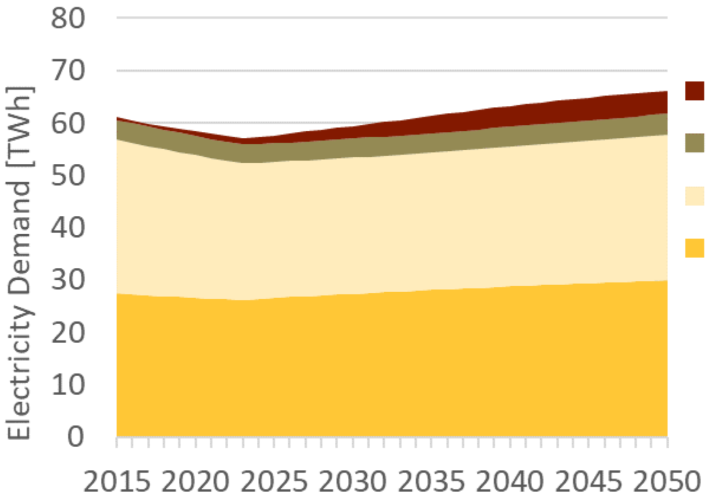

*Figure 3-10. Total Electric Load by Sector, Reference Scenario*

In each of the Policy Scenarios both electric efficiency and electrification impacts total electricity demand in buildings. Transportation electrification is the most apparent in Figure 3-11.

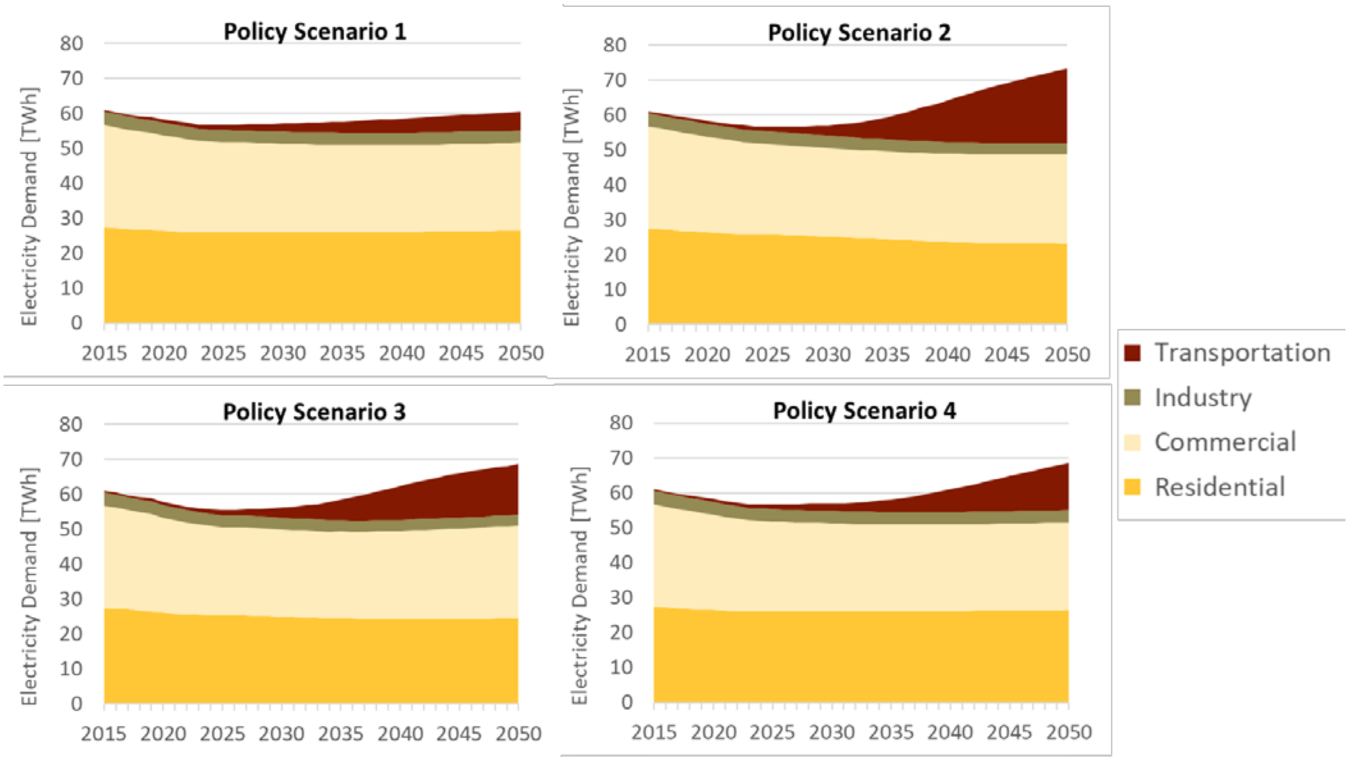

*Figure 3-11. Total Electric Load by Sector and Policy Scenario*

### 3.2.4 ELECTRICITY GENERATION

Emissions results for the electricity sector in the Reference case are largely pre-determined by our attempts to benchmark to the ICF RGGI modeling efforts. These efforts produced projections of the generation by resource type, which determines the emissions profile of the electricity mix in Maryland. Based on these modeling runs, along with the information on the two offshore wind facilities that were not included in the RGGI modeling, Figure 3-12 shows the emissions from the electricity sector declining rapidly until 2023 as coal generation is displaced by natural gas and renewable generation. After 2023, load growth and slowing renewable deployment cause emissions to slowly climb.

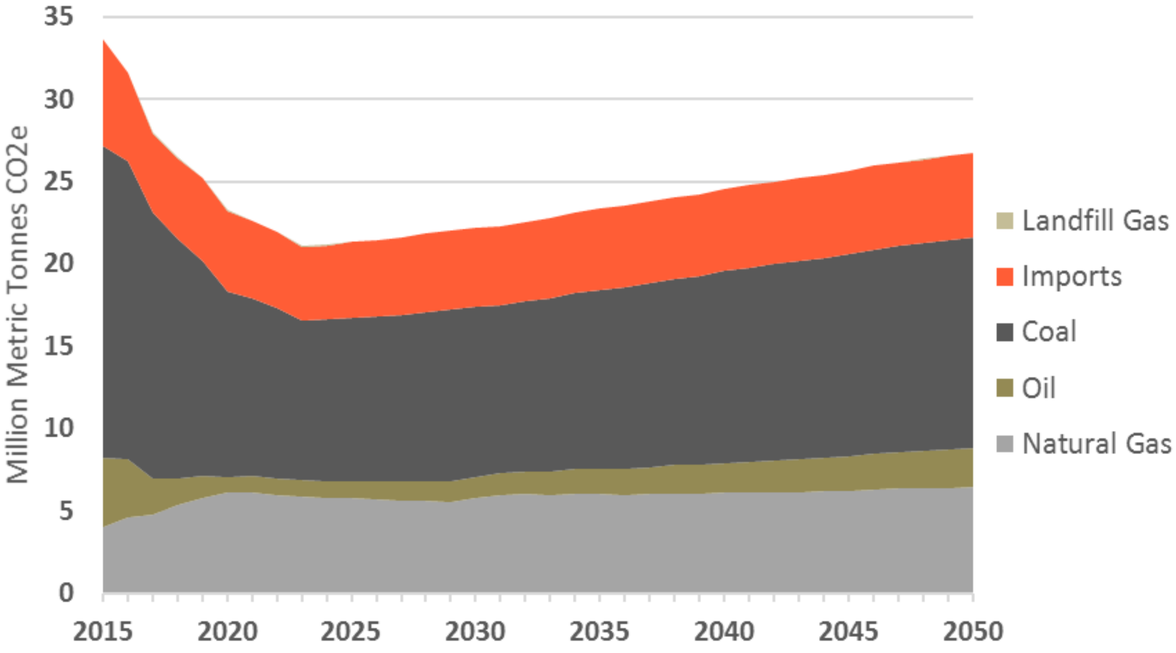

*Figure 3-12. Annual Electricity Emissions by Resource Type, Reference Scenario*

Emissions from the electricity sector decline sharply in all three Policy Scenarios, due to the increasing RPS and CARES requirements, which displace coal and natural gas generation. Policy Scenario 1 has the highest emissions of the three cases due to the continued use of coal generation within the state, which is ramped down in Policy Scenarios 2, 3, and 4 due to RGGI requirements and carbon fees, respectively. Increased electrification loads in these scenarios offset some of the reductions, especially in Policy Scenario 3.

Policy Scenarios 2 and 4 have lower electricity sector emissions than Policy Scenario 3 due to two factors: first, CHP emissions are not allocated to the electricity sector, which allows CHP generation to displace similar natural gas generators without impacting electricity sector emissions; and second, the declining emissions intensity of imports from PJM due to tightening RGGI caps regionwide.

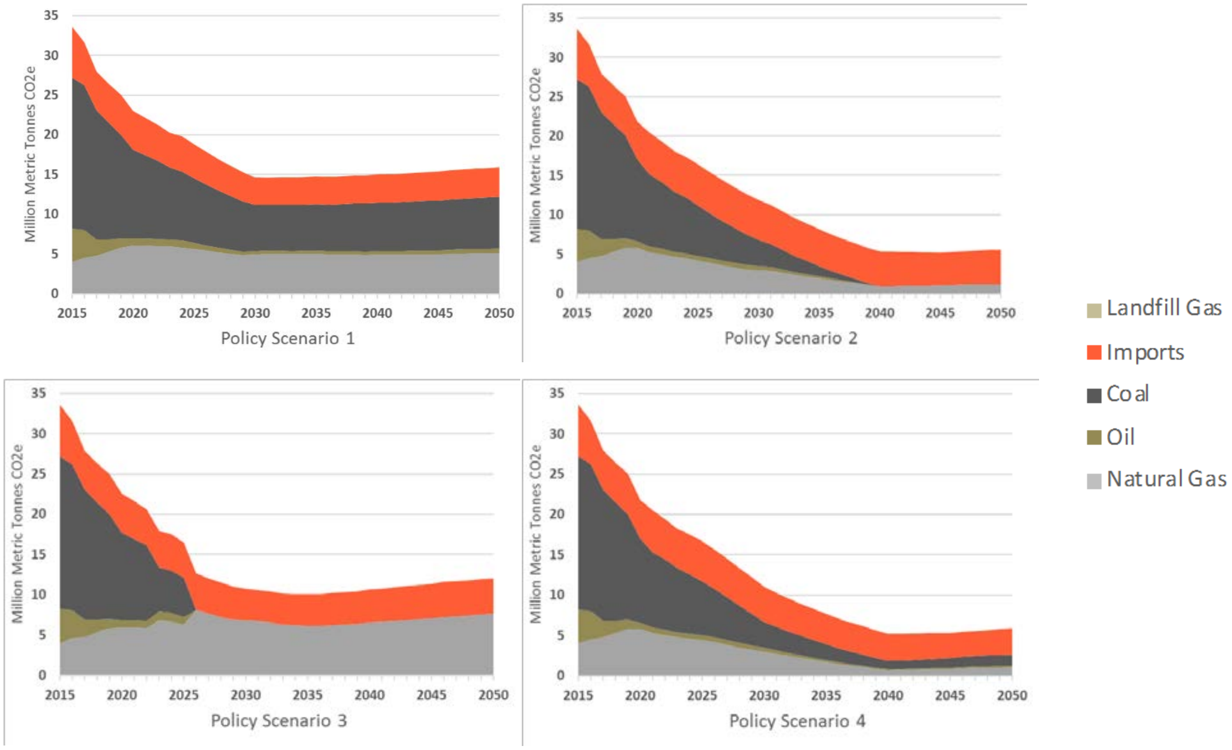

*Figure 3-13. Annual Electricity Emissions by Resource Type and Policy Scenario*

## 3.2.5 NON-COMBUSTION

Non-combustion emissions in the Reference Scenario are shown in Figure 3-14. Near term reductions are embedded in the Reference projection and then held constant.

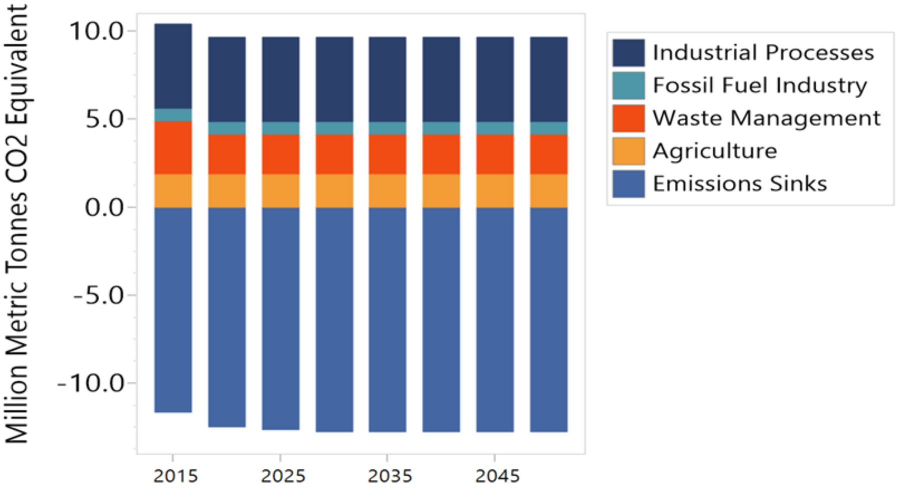

*Figure 3-14. Non-Combustion Emissions in the Reference Scenario*

Policy Scenarios 1 and 3 include modest reductions in forestry and soils. Policy Scenario 2 achieves broad reductions in forestry, soils, waste, and ozone depleting substances (ODS) substitutes.

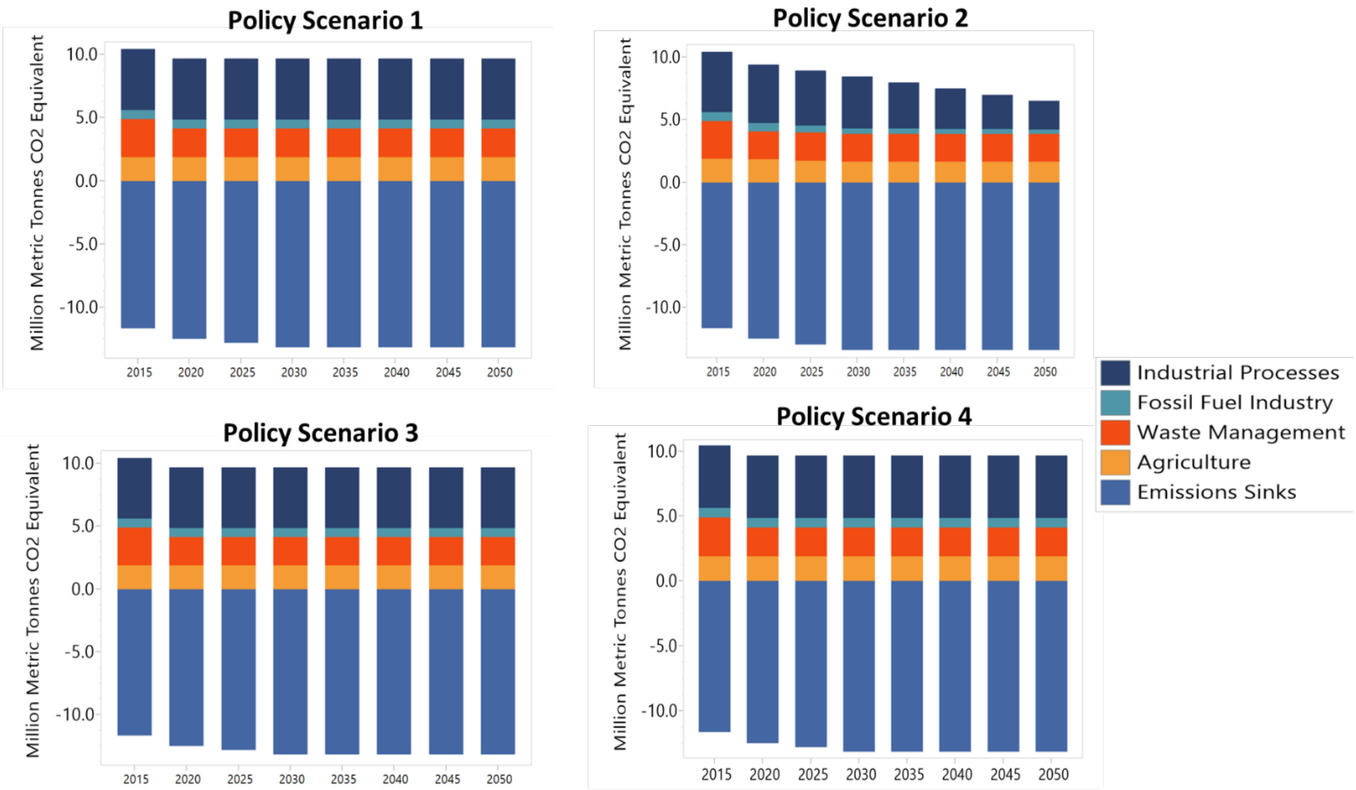

*Figure 3-15. Non-Combustion Emissions in all four policy scenarios*

## 3.3 Sensitivity Analysis Results

Figure 3-16 shows the results of three sensitivities on Policy Scenario four, designed to evaluate the impact of federal policies and consumer adoption. The Low CAFE Standard sensitivity has a larger impact in 2030 than 2050 because of the increased share of electric vehicles at the end of the study period. The Low Adoption sensitivity has a small impact in 2030, but a significant impact by 2050 when Policy Scenario 4 has 30 years of compounded adoption of electric heat pumps, electric vehicles, and efficient appliances.

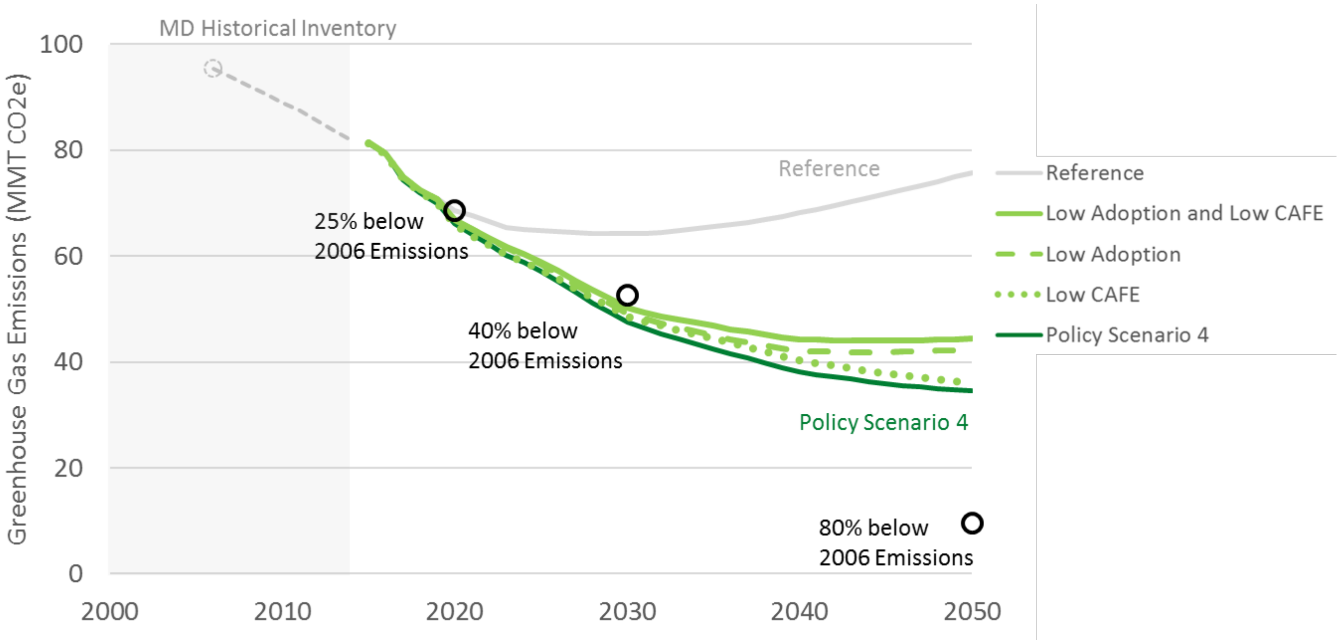

*Figure 3-16. Maryland Net GHG Emissions for Sensitivities on Policy Scenario 4, 2015-2050*

Figure 3-16 highlights the fact that even with more conservative assumptions on consumer adoption of devices and federal action on fuel economy standards, the measures and actions in Policy Scenario 4 are sufficient to meet Maryland's 2030 GHG target. By 2050, however, the lower levels of consumer adoption creates a significant emissions gap as the state tries to reach its 2050 GHG goal. The combined impact of lower adoption and lower CAFE standards result in an additional emissions gap of 9.7 MMT CO2e in 2050.

*Table 3-2. Maryland Net GHG Emissions of Policy Scenario 4 Sensitivities*

| [MMT CO2e] | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Policy Scenario 4 | 66.2 | 48.1 | 38.7 | 35.2 |
| Low Adoption | 67.1 | 49.7 | 42.6 | 42.9 |
| Low CAFE | 66.0 | 49.2 | 40.8 | 36.6 |
| Low Adoption and Low CAFE | 67.1 | 50.8 | 44.8 | 44.9 |
| GHG Goals | 68.6 | 52.5 | 31.1 | 9.7 |

All scenarios include Calvert Cliffs Nuclear Power Plant running through 2050, which assumes it is relicensed in 2034 and 2036. We ran one sensitivity to test the emissions impact of retiring Calvert Cliffs at the end of its current license, which is shown in Figure 3-17.

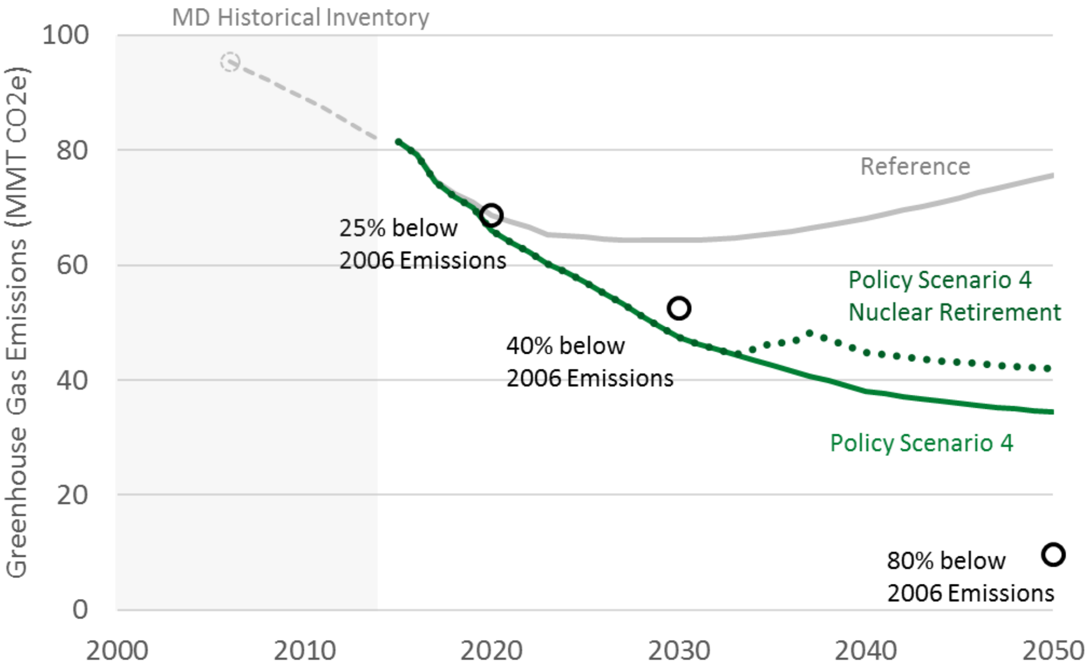

*Figure 3-17. Maryland Net GHG Emissions for Policy Scenario 4 with and without Nuclear Retirement*

The impact of Calvert Cliffs retiring is about 7.4 million metric tonnes CO2e in 2050, widening the gap to reach the state's GHG target.

*Table 3-3. Maryland Net GHG Emissions for Policy Scenario 4 with and without Nuclear Retirement*

| [MMT CO2e] | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Policy Scenario 4 | 66.1 | 48.1 | 38.7 | 35.2 |
| Policy Scenario 4 with Nuclear Retirement | 66.1 | 48.7 | 45.4 | 42.6 |
| GHG Goals | 68.6 | 52.5 | 31.1 | 9.7 |

# 4 Appendix

## 4.1 Maryland Department of Transportation (MDOT) Strategies

Estimates of measures and actions to decarbonize the transportation sector were provided by MDOT as inputs to the scenario modeling described in this report. This appendix documents those original assumptions and the translation to the PATHWAYS model.

### 4.1.1 POLICY SCENARIO 1

Table 4-1 shows the original measures and actions quantified from MDOT for Policy Scenario 1. Two types of measures are represented: (1) measures that directly reduce vehicle-miles traveled (VMT) and (2) measures that directly reduce fuel consumption of gasoline or diesel vehicles. In E3's bottom-up model of transportation and vehicles, both types of measures were translated into effective VMT reductions within the PATWHAYS model.

*Table 4-1 2030 annual reductions of VMT and transportation fuel in Policy Scenario 1 (provided by MDOT)*

| Strategy | VMT Reduction | VMT type | Fuel reduction (g gasoline) | Fuel reduction (g diesel) |
|---|---|---|---|---|
| **2018 MPO Plans & Programs yield lower annual VMT growth (1.4%/yr)** | 3,158,758,638 | On-road fleet | - | - |
| **EV/PHEV sales grow to 15%/5% by 2025** | - | - | - | |
| **On-Road Technology (CHART, Traveler Information)** | - | - | 16,165,665 | 1,326,297 |
| **Freight and Freight Rail Programs (National Gateway and MTA rail projects including new locomotive technologies)** | 26,431,915 | HDV only | - | - |
| **Public Transportation (new capacity, improved operations/ frequency, BRT)** | 84,137,696 | LDV only | - | - |

| | | | | |
|---|---|---|---|---|
| **Public Transportation (fleet replacement / technology)** | - | - | - | 2,367,995 |
| **Intercity Transportation Initiatives (Amtrak NE Corridor, Intercity bus)** | 47,806,157 | LDV only | - | |
| **Transportation Demand Management** | 486,499,923 | LDV only | - | - |
| **Pricing Initiatives (Electronic Tolling)** | - | - | 2,241,454 | 209,554 |
| **Bicycle and Pedestrian Strategies (Provision of non-motorized infrastructure including sidewalks and bike lanes)** | 79,504,966 | LDV only | - | - |
| **Land-Use and Location Efficiency** | 979,733,809 | LDV only | - | - |
| **Drayage Track Replacements** | - | - | - | 590,523 |
| **BWI Airport parking shuttle bus replacements** | - | - | - | 150,000 |

*Table 4-2 Description of MDOT strategies in Policy Scenario 1*

| **Strategy** | **Description** |
|---|---|
| **2018 MPO Plans & Programs yield lower annual VMT growth (1.4%/yr)** | Modeled VMT and emissions outcomes (through MOVES2014a) from implementation of MPO fiscally constrained long-range transportation plans and cooperative land use forecasts. |
| **EV/PHEV sales grow to 15%/5% by 2025** | EV market share analysis within reference case already assumes 15%/5% sales growth by 2030. |
| **On-Road Technology (CHART, Traveler Information)** | A range of increase in coverage shall be assumed based on a low and high deployment scenario. Under on the books scenario, 35% of urban unrestricted access roadways and 15% of rural restricted access roadways are assumed to be included under CHART's coverage. |

| | |
|---|---|
| **Freight and Freight Rail Programs (National Gateway and MTA rail projects including new locomotive technologies)** | Implementation of the CSX National Gateway provides new capacity and eliminates bottlenecks for access to the Port of Baltimore and across MD for rail access westward toward PA and OH and south toward VA and NC. |
| **Public Transportation (new capacity, improved operations/ frequency, BRT)** | This strategy includes projects designed to increase public transit capacity, improve operations and frequency, and new BRT corridors. Projects include dedicated bus lanes/TSP, bus rapid transit (US 29), and MARC service/capacity improvements. |
| **Public Transportation (fleet replacement / technology)** | This strategy includes MTA planned fleet replacement to Clean Diesel and WMATA planned fleet replacement based on current replacement strategy. |
| **Intercity Transportation Initiatives (Amtrak NE Corridor, Intercity bus)** | Northeast corridor analysis - Assumption of growth in annual ridership by 2030 for Amtrak consistent with addressing growing demand. Assume primarily SOGR investments only through 2030. |
| **Transportation Demand Management** | The following programs are included for consideration towards reduction in VMT: Commuter Connections Transportation Emission Reduction Measures (MWCOG), Guaranteed Ride Home, Employer Outreach , Integrated Rideshare, Commuter Operations and Ridesharing Center, Telework Assistance, Mass Marketing, MTA Transportation Emission Reduction Measures, MTA College Pass, MTA Commuter Choice Maryland Pass, Transit Store in Baltimore |
| **Pricing Initiatives (Electronic Tolling)** | Ongoing Conversion to All-Electronic Tolling |
| **Bicycle and Pedestrian Strategies (Provision of non-motorized infrastructure including sidewalks and bike lanes)** | Assumes VMT reductions due to availability of Bike/Ped facility lane miles (assuming connectivity is maintained and incrementally added to the existing network). Trend of VMT reductions based on data available for 2015, 2017 and 2025 for Bike/Ped facility lane miles. |
| **Land-Use and Location Efficiency** | MDP projection of 75% compact development/redevelopment (10% OF CURRENT BUILT ENVIRONMENT) through 2030. Compact development is assumed to reduce VMT by 30% relative to standard density/mix development. This strategy partially captures MDOT/MDP commitment to TOD. |
| **Drayage Track Replacements** | Emission benefit of estimated 600 total dray trucks replaced through 2030. |
| **BWI Airport parking shuttle bus replacements** | Emission benefit of replacing 50 diesel buses with clean diesel buses and CNG buses for expansion. |

Figure 4-1 shows the effective VMT reductions from measures that directly reduce vehicle-miles traveled and incremental measures that directly reduce fuel consumption of gasoline or diesel vehicles, but that are modeled as VMT.

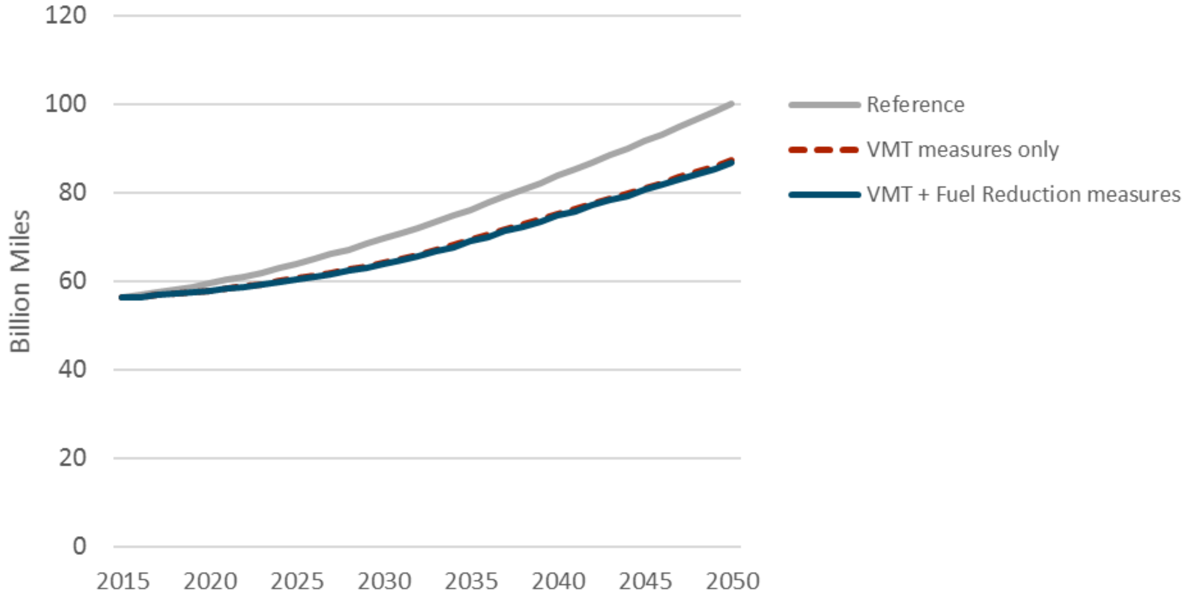

*Figure 4-1. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 1*

### 4.1.2 POLICY SCENARIO 2

Table 4-3 shows the original measures and actions quantified from MDOT for Policy Scenario 2. All measures were incorporated as effective VMT reduction measures within PATHWAYS.

*Table 4-3 2030 annual reductions of VMT and transportation fuel in Policy Scenario 2 (provided by MDOT)*

| "Emerging Strategies" | | | | |
|---|---|---|---|---|
| **Strategy** | **VMT Reduction** | **VMT type** | **Fuel reduction (g gasoline)** | **Fuel reduction (g diesel)** |
| Freeway Management/Integrated Corridor Management (I-270 example, SHA I-95/MD 295 pilot) | - | Urban Restricted Access VMT - On-road fleet | 5,209,998 | 427,449 |
| Arterial System Operations and Management (expanded signal coordination, extend CHART coverage) | - | Urban Unrestricted Access VMT - On-road fleet | 5,546,896 | 402,247 |
| Limited Access System Operations and Management (other management technologies including ramp metering) | - | Urban Restricted Access VMT - On-road fleet | 2,319,544 | 190,305 |
| Managed Lanes (Traffic Relief Plan Implementation) | - | LDV only | 5,231,211 | 429,189 |
| Intermodal Freight Centers Access Improvement (Strategic Goods Movement Plan) | - | HDV only | - | 415,997 |

| | | | | |
|---|---|---|---|---|
| Commercial Vehicle Idle Reduction (Maryland's Idling Law) | - | HDV only | 1,676,878 | 137,578 |
| Medium/Heavy Duty Vehicle Low-Carbon Fleet/Fueling Incentives and Programs (inc. dray trucks) | - | HDV only | - | 42,823 |
| Eco-Driving (informal implementation underway) | - | LDV and HDV | 4,136,469 | 339,373 |
| Lead by example - Alternative Fuel Usage in State/Local Govt Fleet | - | MDOT Fleet Only | 10,301 | 374,635 |
| Truck Stop Electrification | - | HDV only | - | 150,000 |
| Transit capacity/service expansion (fiscally unconstrained) | 251,126,400 | LDV only | - | - |
| Expanded TDM strategies (dynamic), telecommute, non-work strategies | 1,142,326,291 | LDV only | - | - |

|  |  |  |  |  |
|---|---|---|---|---|
| Expanded bike/pedestrian system development | 293,542,659 | LDV only | - | - |
| Freight Rail Capacity Constraints/Access (Howard St. Tunnel) | 46,253,740 | HDV only | - | - |
| MARC Growth and Investment Plan / Cornerstone Plan completion | 206,630,615 | LDV only | - | - |
| EV scenario + additional 100k ramp-up (total of 704,840 EVs by 2030) | - | LDV only | 32,012,646 | - |
| 50% EV Transit Bus Fleet | - | HDV only | - | 3,563,423 |
| **“Innovative Strategies"** |  |  |  |  |
| **Strategy** | **VMT Reduction** | **VMT type** | **Fuel reduction (g gasoline)** | **Fuel reduction (g diesel)** |
| Autonomous/Connected Vehicle Technologies (Transit/Passenger/Freight Fleet) | - | On-road fleet | 72,765,759 | 5,276,787 |
| Speed Management on Freeways (increased levels of enforcement) | - | Urban Restricted - On-road fleet | 9,353,658 | 678,303 |
| Zero-Emission Trucks/Truck Corridors | - | HDV only | - | 482,152 |

| | | | | |
|---|---|---|---|---|
| Ridehailing / Mobility as a Service (MaaS) | 995,937,400 | LDV only | - | - |
| Pay-As-You-Drive (PAYD) Insurance | 223,902,645 | LDV only | - | - |
| Freight Villages/Urban Freight Consolidation Centers | - | HDV only | - | 186,396 |

*Table 4-4 Description of MDOT strategies in Policy Scenario 2*

| **"Emerging Strategies"** | |
|---|---|
| **Strategy** | **Description** |
| Freeway Management/Integrated Corridor Management (I-270 example, SHA I-95/MD 295 pilot) | This strategy assumes integrated corridor management, intelligent transportation systems, or advanced traffic management systems for the three corridors listed. |
| Arterial System Operations and Management (expanded signal coordination, extend CHART coverage) | This strategy assumes corridor management, intelligent transportation systems, or advanced traffic management systems are in place on all urban arterials. |
| Limited Access System Operations and Management (other management technologies including ramp metering) | This strategy assumes corridor management (including ramp metering), intelligent transportation systems, or advanced traffic management systems are in place on all urban restricted access facilities and all urban principal and minor arterials. All urban limited access facilities are assumed to be covered. |
| Managed Lanes (Traffic Relief Plan Implementation) | $9 billion plan to add express toll lanes to the routes of three of Maryland’s most congested highways — the Interstate 495 Capital Beltway, the I-270 spur connecting Frederick to D.C., and the Baltimore-Washington Parkway. |

| | |
|---|---|
| Intermodal Freight Centers Access Improvement (Strategic Goods Movement Plan) | As noted in the Strategic Goods Movement Plan, reliability improvements and congestion mitigation that positively impact supply chain costs associated with driver and truck delay and fuel consumption is a desired outcome. The strategy to achieve this includes SHA and MDTA continuing to advance appropriate measures to reduce or mitigate the effects of congestion on industry supply chains. |
| Commercial Vehicle Idle Reduction (Maryland's Idling Law) | Considers extended idling only and not short term idling (eg. At a delivery/pick-up point. Data requirements for short term idling are more extensive and might not be substantial compared to the extended idling emissions. It is assumed that APUs will be used to power the trucks during the time spent idling. |
| Medium/Heavy Duty Vehicle Low-Carbon Fleet/Fueling Incentives and Programs (inc. dray trucks) | Targeted fleet fuel incentives are geared more towards particulate matter/air quality benefits and not as much towards GHG emission reductions. 2x level of investment and overall replacement compared to continuation of dray truck replacement program. |
| Eco-Driving (informal implementation underway) | General marketing program with basic outreach and information brochure about the savings is assumed. Assumptions based on the extent of government led programs. Private sector programs not included. For example, fleet operators of trucks, logistical operation enterprises conduct eco-driving for their fleet separately and typically have a higher degree of focus and return on results from the programs. |
| Lead by example - Alternative Fuel Usage in State/Local Govt Fleet | Use MDOT Excellerator Data as a starting point and consider a range of deployment scenarios. |
| Truck Stop Electrification | Strategy assumes a range of deployment of electrification of truck stops throughout the state. Three scenarios of deployment (all public spaces, 50% of public spaces, and 10% of public spaces are considered). Average rates of truck stop utilization is set at 50%. It is assumed that the electricity source for powering the truck is similar to using an APU (without having to compute the power supplied for the duration and its source and its energy footprint). The three scenarios for deployment in 2030 - 100%, 50% and 10% of spaces available across the state are considered and presented as high/medium/and low cases. |

| | |
|---|---|
| Transit capacity/service expansion (fiscally unconstrained) | Projects in fiscally constrained LRTPs post-2030 or in needs based plan (unconstrained). These potential enhancements/expansions to Maryland's transit system are extensive, including extension of the Baltimore Metro Green Line and multiple bus rapid transit corridors in Montgomery, Prince Georges, Howard, and Anne Arundel Counties. Most of these projects are identified in the BMC and MWGOG LRTPs for implementation post-2030 or identified as a need for a corridor study. |
| Expanded TDM strategies (dynamic), telecommute, non-work strategies | TDM expansion programs are designed to reduce single-occupant vehicle trips and transfer trips to more efficient modes such as transit, carpool, vanpool, bike, and walk. Effective TDM can also reduce trips altogether through flexible work schedules or telecommuting. Expanded coverage of TDM strategy - two alternatives - coverage of existing programs by increased growth rates or funding levels. |
| Expanded bike/pedestrian system development | Determine whether and how higher low-stress bicycle network connectivity is correlated with a higher bicycle and pedestrian mode share by looking at the correlation between BNA (Bicycle Network Analysis) score and ped/bike mode share for a range of MD communities. The result of this analysis would be a BNA factor that could be used to compute VMT reductions, e.g., a 10 point increase in BNA results in a 20% increase in ped/bike mode share. |
| Freight Rail Capacity Constraints/Access (Howard St. Tunnel) | Build-out of National Gateway and Crescent Corridor plus other freight rail strategies |
| MARC Growth and Investment Plan / Cornerstone Plan completion | MARC Growth and Investment Plan completion accelerated to 2030. |
| EV scenario + additional 100k ramp-up (total of 704,840 EVs by 2030) | Additional 100K EV Ramp-Up Scenario by 2030. Outside of MDOTs control, would require transformational technology advancement and cost decrease to support market share. |
| 50% EV Transit Bus Fleet | 50% of MTA, WMATA, and LOTS fleets are BEV in 2030. |
| **“Innovative Strategies"** | |
| **Strategy** | **Description** |
| Autonomous/Connected Vehicle Technologies (Transit/Passenger/Freight Fleet) | Core assumptions regarding market penetration of AVs, change in VMT, and fuel savings have been adopted from an ENO study which lays out three scenarios of AV deployment, of which the low-end penetration of 10% by 2030 is considered in this analysis. |
| Speed Management on Freeways (increased levels of enforcement) | Speed Management coverage on MD highways is assumed to be at 100% urban restricted access roadways and only 50% of |

| | |
|---|---|
| | rural restricted access roadways. |
| Zero-Emission Trucks/Truck Corridors | Consider corridors in MD (port connections, etc.) in line with the I-710 Calstart Corridor. http://www.calstart.org/Projects/I-710-Project.aspx |
| Ridehailing / Mobility as a Service (MaaS) | Ridehailing services not only encourage cost-saving and emission reducing measures like carpooling (the price savings of serves like Uber pool and Lyft Line), but also as a first/last mile connection between users and other modes, reducing the needs for SOV ownership. Mobility as a Service deployment at scale will be the replacement of private auto trips with the use of ridehailing services either shared or SOV. Impacts on reduced vehicle ownership, reduced travel activity to be estimated based on national literature pointing to a range of anywhere between 10 to 20% adoption of carsharing by 2030. |
| Pay-As-You-Drive (PAYD) Insurance | Two cases of adoption of PAYD insurance assumed:<br>5% assumed by MIA by 2020. Low case, assumed same participation rate remains through 2030. In the high case, it doubles to 10% Only considering insured drivers. 12% of drivers uninsured. |
| Freight Villages/Urban Freight Consolidation Centers | Consolidated freight distribution centers to utilize cleaner last-mile delivery trucks for urban areas. (fleet or urban area approach) |

Figure 4-2 shows the effective VMT reductions from measures that directly reduce vehicle-miles traveled and incremental measures that directly reduce fuel consumption of gasoline or diesel vehicles, but that are modeled as VMT.

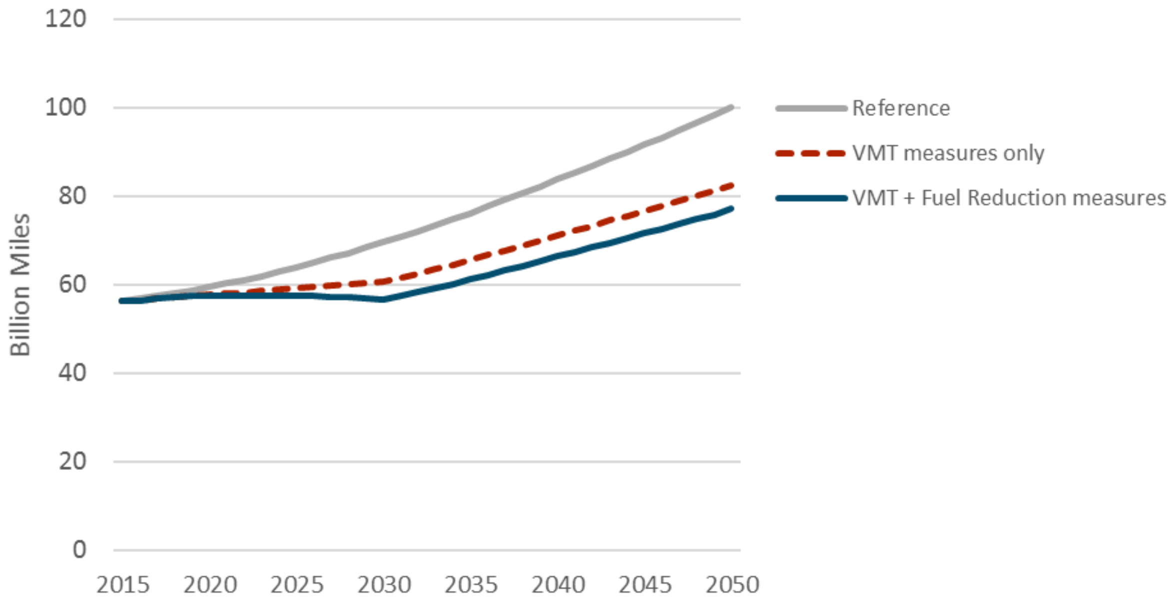

*Figure 4-2. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 2*

### 4.1.3 POLICY SCENARIO 3

Table 4-5 shows the original measures and actions quantified from MDOT for Policy Scenario 3. All measures were incorporated as effective VMT reduction measures within PATHWAYS.

*Table 4-5 2030 annual reductions of VMT and transportation fuel in Policy Scenario 3 (provided by MDOT)*

| **"Emerging Strategies"** | | | |
|---|---|---|---|
| **Strategy** | **VMT Reduction** | **VMT type** | **Fuel reduction (g diesel)** |
| Truck Stop Electrification | - | HDV only | 150,000 |

| | | | |
|---|---|---|---|
| Transit capacity/service expansion (fiscally unconstrained) | 251,126,400 | LDV only | - |
| Expanded TDM strategies (dynamic), telecommute, non-work strategies | 1,142,326,291 | LDV only | - |
| Expanded bike/pedestrian system development | 293,542,659 | LDV only | - |
| MARC Growth and Investment Plan / Cornerstone Plan completion | 206,630,615 | LDV only | - |
| **"Innovative Strategies"** | | | |
| **Strategy** | **VMT Reduction** | **VMT type** | **Fuel reduction (g diesel)** |
| Zero-Emission Trucks/Truck Corridors | - | HDV only | 482,152 |

*Table 4-6 Description of MDOT strategies in Policy Scenario 3*

| **"Emerging Strategies"** | |
|---|---|
| **Strategy** | **Description** |
| Truck Stop Electrification | Strategy assumes a range of deployment of electrification of truck stops throughout the state. Three scenarios of deployment (all public spaces, 50% of public spaces, and 10% of public spaces are considered). Average rates of truck stop utilization is set at 50%. It is assumed that the electricity source for powering the truck is similar to using an APU (without having to compute the power supplied for the duration and its source and its energy footprint). The three scenarios for deployment in 2030 - 100%, 50% and 10% of spaces available across the state are considered and |

| | |
|---|---|
| | presented as high/medium/and low cases. |
| Transit capacity/service expansion (fiscally unconstrained) | Projects in fiscally constrained LRTPs post-2030 or in needs based plan (unconstrained). These potential enhancements/expansions to Maryland's transit system are extensive, including extension of the Baltimore Metro Green Line and multiple bus rapid transit corridors in Montgomery, Prince Georges, Howard, and Anne Arundel Counties. Most of these projects are identified in the BMC and MWGOG LRTPs for implementation post-2030 or identified as a need for a corridor study. |
| Expanded TDM strategies (dynamic), telecommute, non-work strategies | TDM expansion programs are designed to reduce single-occupant vehicle trips and transfer trips to more efficient modes such as transit, carpool, vanpool, bike, and walk. Effective TDM can also reduce trips altogether through flexible work schedules or telecommuting. Expanded coverage of TDM strategy - two alternatives - coverage of existing programs by increased growth rates or funding levels. |
| Expanded bike/pedestrian system development | Determine whether and how higher low-stress bicycle network connectivity is correlated with a higher bicycle and pedestrian mode share by looking at the correlation between BNA (Bicycle Network Analysis) score and ped/bike mode share for a range of MD communities. The result of this analysis would be a BNA factor that could be used to compute VMT reductions, e.g., a 10 point increase in BNA results in a 20% increase in ped/bike mode share. |
| MARC Growth and Investment Plan / Cornerstone Plan completion | MARC Growth and Investment Plan completion accelerated to 2030. |
| **"Innovative Strategies"** | |
| **Strategy** | **Description** |
| Zero-Emission Trucks/Truck Corridors | Consider corridors in MD (port connections, etc.) in line with the I-710 Calstart Corridor. http://www.calstart.org/Projects/I-710-Project.aspx |

Figure 4-3 shows the effective VMT reductions from measures that directly reduce vehicle-miles traveled and incremental measures that directly reduce fuel consumption of gasoline or diesel vehicles, but that are modeled as VMT.

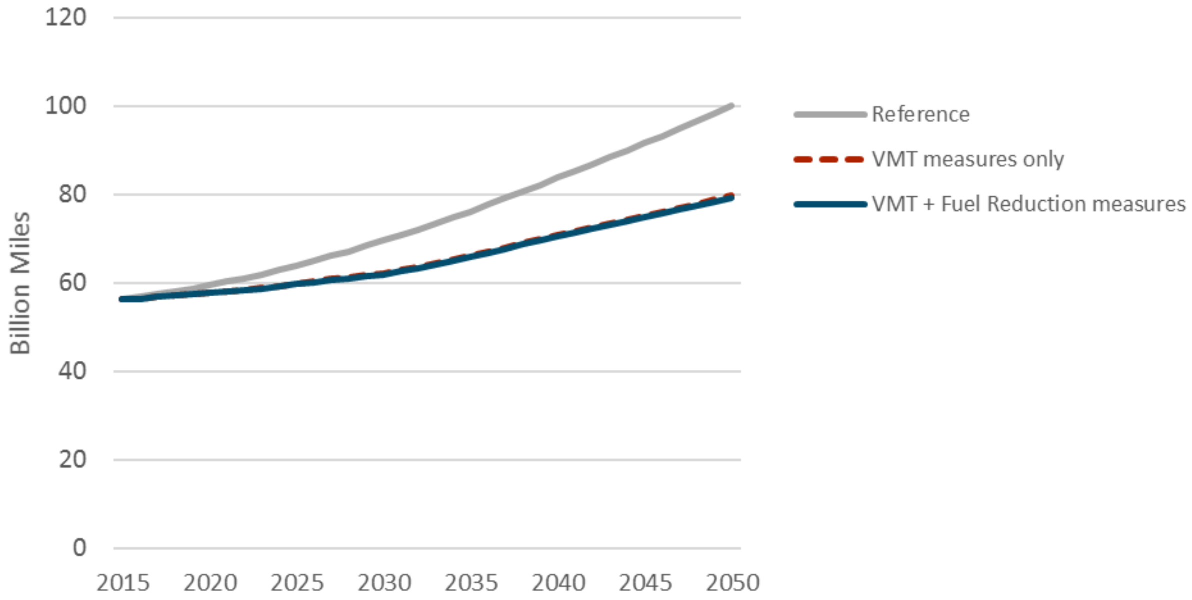

*Figure 4-3. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 3*

### 4.1.4 POLICY SCENARIO 4

Policy Scenario 4 includes the same MDOT measures as Policy Scenario 2. See Table 4-3 for a full list of measures included in Policy Scenario 4. Figure 4-4 shows the effective VMT reductions from measures that directly reduce vehicle-miles traveled and incremental measures that directly reduce fuel consumption of gasoline or diesel vehicles, but that are modeled as VMT.

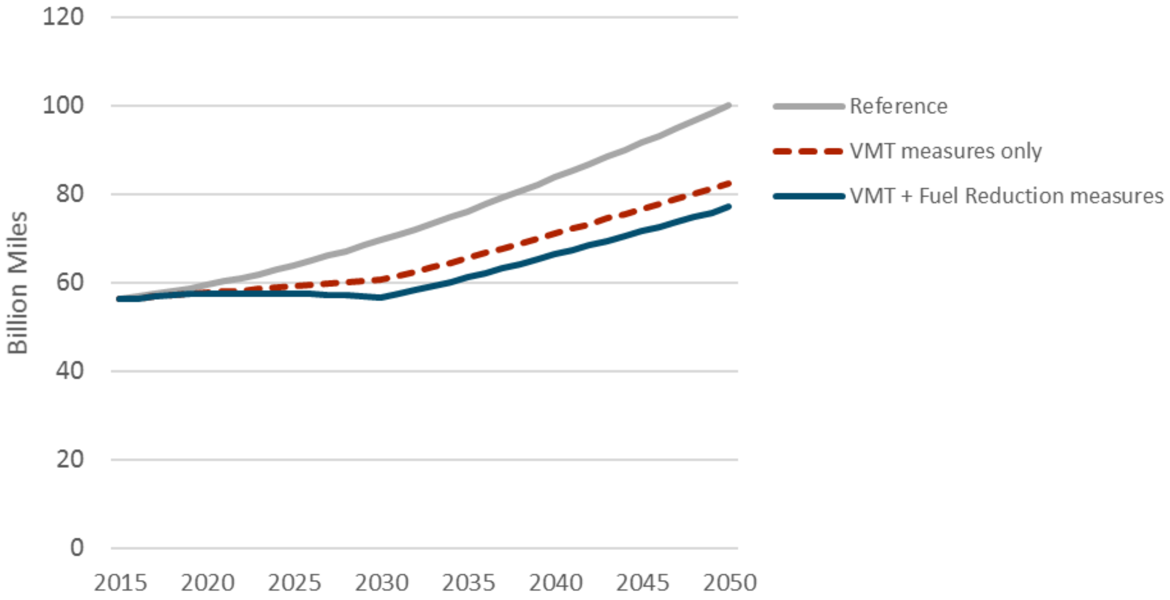

*Figure 4-4. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 4*

Maryland
Department of
the Environment

# Appendix G

## Economic Impacts

# 2019 GGRA Draft Plan

# Chapter 7: Economic Impacts

*Commissioned by*
Maryland Department of the Environment

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## Acronyms and Abbreviations

| | |
|---|---|
| AVERT | Avoided Emissions and Generation Tool |
| CES | Clean energy standard |
| CHP | Combined heat and power |
| CTAM | Carbon Tax Assessment Model |
| COBRA | CO-Benefits Risk Assessment |
| E3 | Energy and Environmental Economics, Inc. |
| EPA | U.S. Environmental Protection Agency |
| GGRA | Greenhouse Gas Emissions Reduction Act |
| GSP | Gross state product |
| HCUP | Healthcare Cost and Utilization Project |
| MCCC | Maryland Commission on Climate Change |
| MDE | Maryland Department of the Environment |
| MDOT | Maryland Department of Transportation |
| MMBTUs | Millions of British Thermal Units |
| MOU | Memorandum of understanding |
| MPG | Miles per gallon |
| MPO | Metropolitan Planning Organization |
| NAICS | North American Industrial Classification System |
| $NH_3$ | Ammonia |
| $NO_X$ | Nitrogen oxides |
| $PM_{2.5}$ | Fine particulate matter with a diameter less than 2.5 micrometers |
| Project Team | RESI and E3 |
| RCCI | Regional Cost Collection Initiative Bill |
| RESI | Regional Economic Studies Institute |
| RGGI | Regional Greenhouse Gas Initiative |
| RPS | Renewable portfolios standard |
| $SO_2$ | Sulfur Dioxide |
| SOC | Standard Occupational Classification |
| VMT | Vehicle miles traveled |
| VOCs | Volatile organic compounds |

## 7.1 Executive Summary

The Regional Economic Studies Institute (RESI) of Towson University was tasked by the Maryland Department of the Environment (MDE) to provide a coherent set of analyses to inform the development of its proposed plan to reduce statewide greenhouse gas emissions by 40 percent from 2006 levels by 2030, to satisfy MDE's obligations under the Greenhouse Gas Emission Reduction Act (GGRA) Reauthorization. RESI contracted with Energy and Environmental Economics, LLC (E3) to model changes in emissions arising from various policy bundles under consideration. The results of the emissions modeling, conducted using the Pathways model, are discussed in Chapter 6 of this report, while the current chapter contains the results of the economic modeling, which the Project Team completed using REMI PI+ (REMI).[1]

The REMI model is a high-end dynamic modeling tool used by various federal and state government agencies in economic policy analysis. The REMI model is calibrated to the specific demographic features of Maryland as a whole and five regions of the state:

- **Central Maryland**: Baltimore City and Harford, Baltimore, Carroll, Anne Arundel, and Howard Counties
- **Southern Maryland**: St. Mary's, Charles, and Calvert Counties
- **Capital Maryland**: Frederick, Montgomery, and Prince George's Counties
- **Western Maryland**: Garrett, Allegany, and Washington Counties
- **Eastern Shore**: Cecil, Kent, Queen Anne's, Talbot, Caroline, Dorchester, Wicomico, Somerset, and Worcester Counties

To model economic impacts, the team synthesized data from a number of sources, including Pathways output and estimates of program costs from state agencies. Additionally, the team conducted public health modeling to estimate the economic impact associated with improved air quality under each policy scenario.

### 7.1.1 Criteria for Evaluating the Economic Impact of Policy Scenarios

In addition to satisfying emission requirements through 2030, the policies selected by the State of Maryland to reduce carbon emissions must provide a net benefit to the Maryland economy. To determine whether each policy scenario meets this mandate and qualifies as meeting the economic goals of the GGRA, the team used the following set of indicators:

- Average positive job growth through 2030;
- Positive cumulative personal income growth through 2030 with a 3 percent discount rate; and
- Positive cumulative gross state product (GSP) growth through 2030 with a 3 percent discount rate.

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[1] All analyses were conducted using REMI Version 2.2.

In addition to these three metrics, the team considered other measures of economic well-being, including:

- The impact across different sectors of Maryland's economy, including manufacturing;
- The impact on consumer prices;
- Distributional impacts in terms of income, education and training, and race/ethnicity; and
- The regional distribution of jobs.

Reducing carbon emissions and ensuring net benefits to Maryland's economy are not mutually exclusive goals. The following sections will outline the various policy bundles that the Project Team considered, as well as the results of the analysis.

### 7.1.2 Overview of Policy Scenarios One, Two, and Three

In evaluating policies to reduce carbon emissions in Maryland and achieve the goals set forward in the GGRA plan, the Project Team evaluated a total of four policy scenarios. This section provides an overview of the first three scenarios. The results of these three policy bundles were then examined, and feedback was solicited from policy makers to arrive at the final policy scenario, highlighted here in Section 7.1.4 and discussed fully in Section 7.6.

#### 7.1.2.1 Policy Scenario One

Policy Scenario One represents a continuation of current policies. Under Policy Scenario One, energy efficiency is extended as EmPOWER investment continues through 2050, rather than ending in 2023. This corresponds with increased sales of efficient appliances and reductions in electricity usage through behavioral conservation. In addition to increased energy efficiency, Policy Scenario One contains extensions of the Zero Emissions Vehicle MOU, leading to increased sales of electric vehicles through 2050. This policy scenario results in 300,000 additional zero emissions vehicles (ZEVs) in 2050, relative to the reference scenario. Additionally, transportation policies proposed by the Maryland Department of Transportation (MDOT) will reduce vehicle miles traveled (VMT) for both heavy- and light-duty vehicles.

Policy Scenario One also contains an increase in the renewable portfolio standards (RPS) from 25 percent by 2020 to 50 percent by 2030. This increase is modeled after proposed state legislation.[2]

#### 7.1.2.2 Policy Scenario Two

Policy Scenario Two represents an extension of Policy Scenario One designed to achieve deeper reductions in carbon emissions. Instead of generally continuing existing policies, Policy Scenario Two also contains a number of new programs. For example, Policy Scenario Two replaces the RPS with a 75 percent clean energy standard (CES) goal by 2040. The CES encompasses other sources of generation beyond renewable energy, including combined heat and power (CHP) and nuclear power.

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[2] The increase in Maryland's RPS is consistent with HB1435 and SB0732 proposed in the 2018 legislative session.

Additionally, Policy Scenario Two models rapid adoption of zero emission vehicles. Zero emission vehicles are assumed to be 50 percent of new sales by 2030 and 100 percent of light-duty vehicle sales by 2050. In addition to these sales of light-duty vehicles, the team assumed that 95 percent of heavy-duty vehicle sales in the state would be electric vehicles or diesel hybrids by 2050. Regarding energy efficiency, the team modeled 100 percent of electric and natural gas appliance sales in Maryland as high-efficiency by 2030.

#### 7.1.2.3 Policy Scenario Three

While the other policy scenarios were developed by MDE, Policy Scenario Three was developed by the Mitigation Working Group of the Maryland Commission on Climate Change. Similar to Policy Scenario Two, Policy Scenario Three uses Policy Scenario One as a foundation. In addition to the measures discussed in Section 7.1.2.1, Policy Scenario Three contains carbon pricing as a strategy to reduce carbon emissions instead of regulations. The carbon price for this scenario was modeled as starting at $20 per metric ton in 2020, rising to the social cost of carbon in 2030 and beyond.

Revenue from the carbon pricing scheme is allocated based on the Regional Cost Collection Initiative (RCCI) bill, or House Bill 939, introduced in the Maryland General Assembly in 2018, with modifications:

- $10 million each year is allocated towards administration of the program;
- 50 percent of total revenue, less $10 million, is rebated to consumers in lower income brackets;
- 30 percent of total revenue each year is allocated to additional carbon mitigation measures beyond those modeled in Policy Scenario One;
- 10 percent of total revenue is allocated to adaptation and resilience policies, which help vulnerable communities to prepare for and react to climate change; and
- 10 percent of total revenue is allocated to just transition efforts, which provide job retraining efforts and assistance for workers and communities impacted by the transition away from fossil fuels.[3]

### 7.1.3 Results of Policy Scenarios One Through Three

Overall, as summarized in Figure 1, the first three policy scenarios all achieve the 2030 economic goal. Additionally, Policy Scenario Two and Policy Scenario Three meet both the 2020 and 2030 emissions goals.

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[3] H.B. 939, Session of 2018 (Mar. 2018), p.1, http://mgaleg.maryland.gov/2018RS/fnotes/bil_0009/hb0939.pdf.

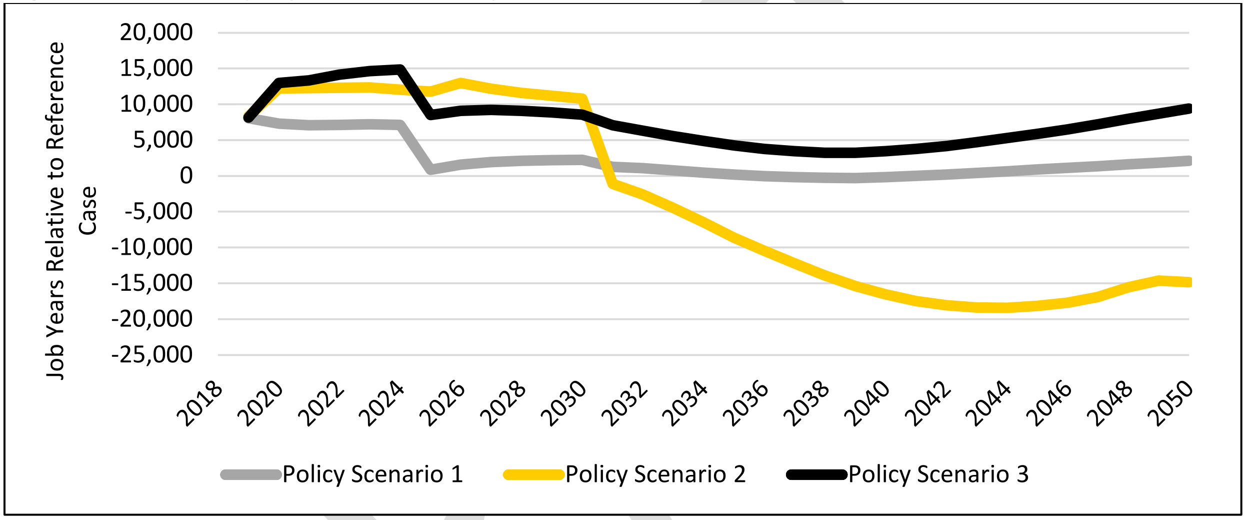
**Figure 1: Summary of Policy Scenarios**

| Policy Scenario | Achieve 2020 Emissions Goal? | Achieve 2030 Emissions Goal? | Achieve 2030 Economic Goal? |
|---|---|---|---|
| Policy Scenario One | Yes | No | Yes |
| Policy Scenario Two | Yes | Yes | Yes |
| Policy Scenario Three | Yes | Yes | Yes |

Source: RESI

In terms of employment, as illustrated in Figure 2, all three policy scenarios exhibit average positive job growth through 2030.

**Figure 2: Total Employment for Policy Scenarios One, Two, and Three**



Sources: REMI PI+, E3, MDE, MDOT, RESI

Policy Scenario Two produces the most jobs between 2019 and 2030, averaging 11,665 jobs, while Policy Scenario One produces the least at 4,564 jobs. By 2050, these numbers are significantly lower across all policy scenarios, with Policy Scenario Two losing an average of 3,811 jobs between 2019 and 2050, but Policy Scenarios One and Three still maintaining positive job growth.

To summarize, these results are due to a number of aspects contained in each bundle of policies:

- **Transportation infrastructure spending**
  Policy Scenario Two, in particular, shows large near-term employment increases due to the I-495 and I-270 lane expansion projects. Both Policy Scenarios One and Three begin the same, but the divergence in 2020 is due to the presence of the carbon fee as a funding source for infrastructure projects.
- **Carbon fee and dividend**
  The carbon fee plays a pivotal role in boosting employment numbers for Policy Scenario Three in the long run. The revenue from this fee is able to mitigate some of the negative

effects of Policy Scenario One by providing rebates to consumers for increased energy prices, as well as the provision of funding for additional job-creating mitigation measures. The rationale behind this job-creating policy is that the fee acts as a filter—redirecting funds that would have previously flowed out of the state towards job creation activities within the state.

- **In-state wind and solar generation**
  Because Maryland is traditionally a net importer of energy, increasing the percentage of self-supplied energy enables money that would have been spent out of the state, to stay within the state.

Although the employment impacts displayed in Figure 2 appear large, they in fact represent a very small proportion of Maryland's total economy. Employment impacts, both positive and negative, do not vary more than one percentage point beyond the levels forecast in the reference case. Even under Policy Scenario Two, which contains aggressive policies aimed at reducing carbon emissions in the state, employment is expected to decline by less than 0.5 percent at its most extreme point. Given the scale of the spending occurring under each policy as described later in Section 7.5.1, employment impacts are relatively muted.

### 7.1.4 Policy Scenario Four

After the emissions and economic impacts associated with Policy Scenarios One through Three were estimated and analyzed, Policy Scenario Four was constructed both to achieve the emissions requirements laid forth in the GGRA and provide a blueprint for future efforts to reduce greenhouse gas emissions. Policy Scenario Four uses Policy Scenario One as its foundation. Policy Scenario One represents a collection of policies that are either a continuation or extension of current programs. In addition to these measures, Policy Scenario Four consists of new programs explored in Policy Scenario Two. For example, as in Policy Scenario Two, Policy Scenario Four includes a 75 percent Clean and Renewable Energy Standards (CARES) goal by 2040 instead of the RPS modeled in Policy Scenario One.[4] Other policies modeled similarly to Policy Scenario Two include bus electrification, transportation programs, and forest management and healthy soils initiatives.

Similar to Policy Scenario One, Policy Scenario Two, and Policy Scenario Three, Policy Scenario Four meets the economic goals outlined in Section 7.3.7. Notably, Policy Scenario Four achieves these goals with low levels of spending. As illustrated in Figure 3, in every year in Policy Scenario Four, consumers and businesses spend less on capital costs and fuel costs relative to the reference case.

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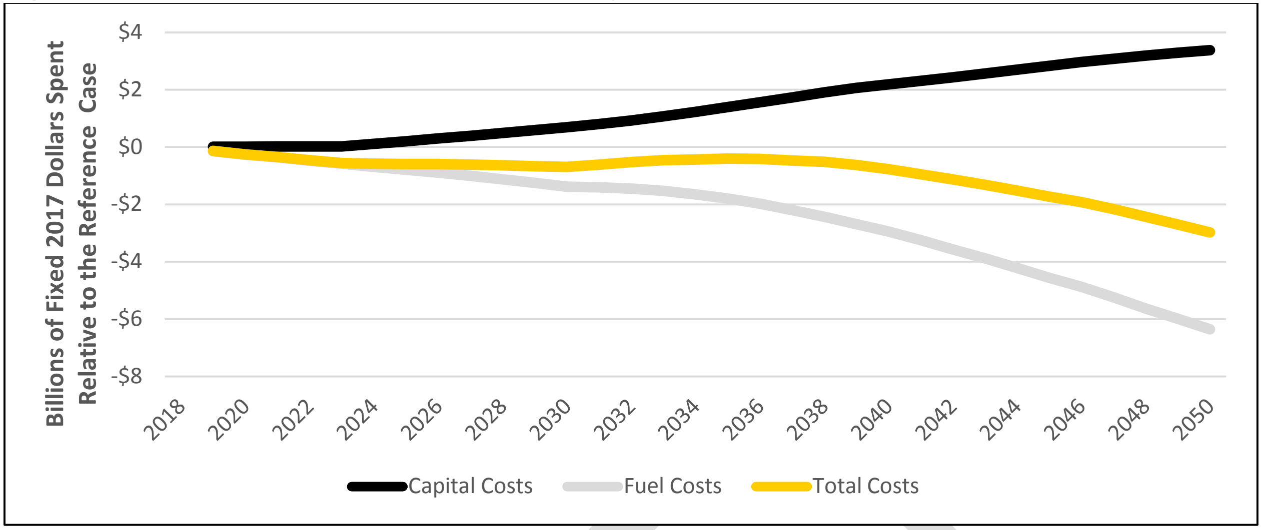
[4] However, the CARES program modeled in Policy Scenario Four contains different carveouts than the CARES program modeled in Policy Scenario Two. In Policy Scenario Two, carveouts include 12.5 percent for in-state solar, 12.5 percent for offshore wind, and 25 percent for tier one renewables. In Policy Scenario Four, the carveouts include 15 percent for in-state solar, 10 percent for offshore wind, and 20 percent for tier one renewables.

**Figure 3: Total Costs from PATHWAYS in Policy Scenario Four Relative to the Reference Case**



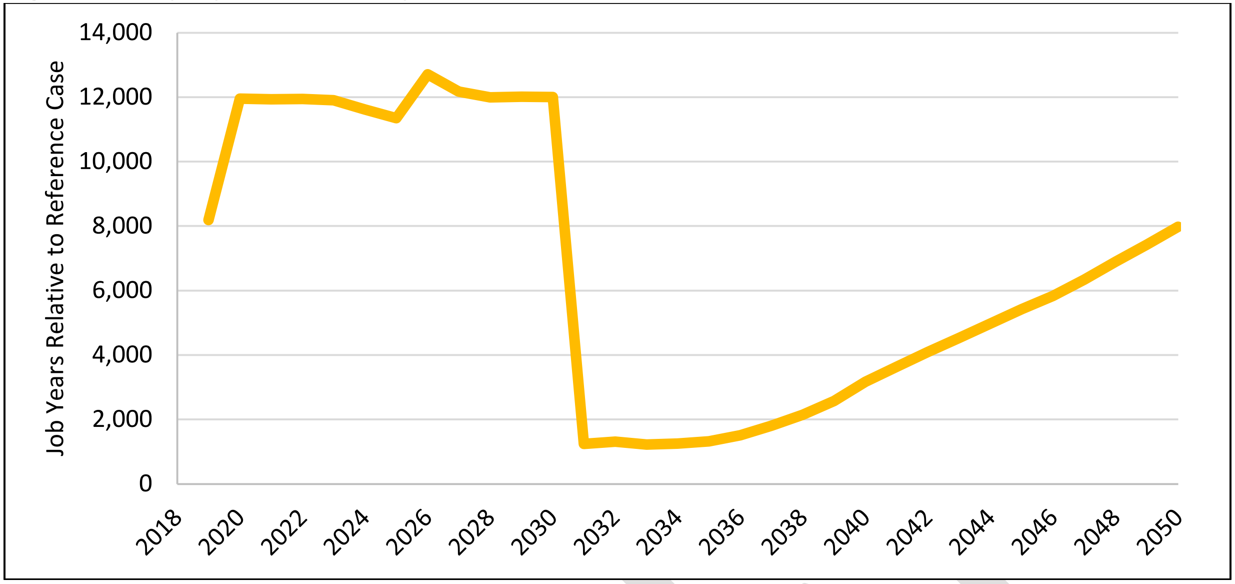
Sources: E3, MDE, RESI

As seen in Figure 3, although consumers and businesses are spending more on capital costs (e.g., new energy-efficient appliances or new electric vehicles) in Policy Scenario Four than in the reference case, fuel savings exceed this amount every year. This is in contrast to the other policy scenarios and is attributable to two general trends:

- Spending on transportation infrastructure projects is high in Policy Scenario Four. These projects are generally due to policies aimed at reducing fuel usage through behavioral changes (e.g., increased mass transit usage or increased use of bike lanes) as well as more direct capital outlays (e.g., truck stop electrification or bus electrification). The level of spending on these projects is equal to the level in Policy Scenario Two, which is the highest level modeled.
- Capital costs are generally low. Through 2025, capital costs in Policy Scenario Four are equal to those in Policy Scenario One, the scenario with the lowest spending on capital costs. Although capital expenditures after 2025 are higher in Policy Scenario Four than in Policy Scenario One, they never approach those in Policy Scenario Two or Policy Scenario Three.

The impacts of infrastructure spending and capital costs can both be seen when examining the economic impacts of Policy Scenario Four. As seen in Figure 4, Policy Scenario Four supports an average of 11,649 jobs each year through 2030 relative to the reference case.

**Figure 4: Employment in Policy Scenario Four Relative to the Reference Case**

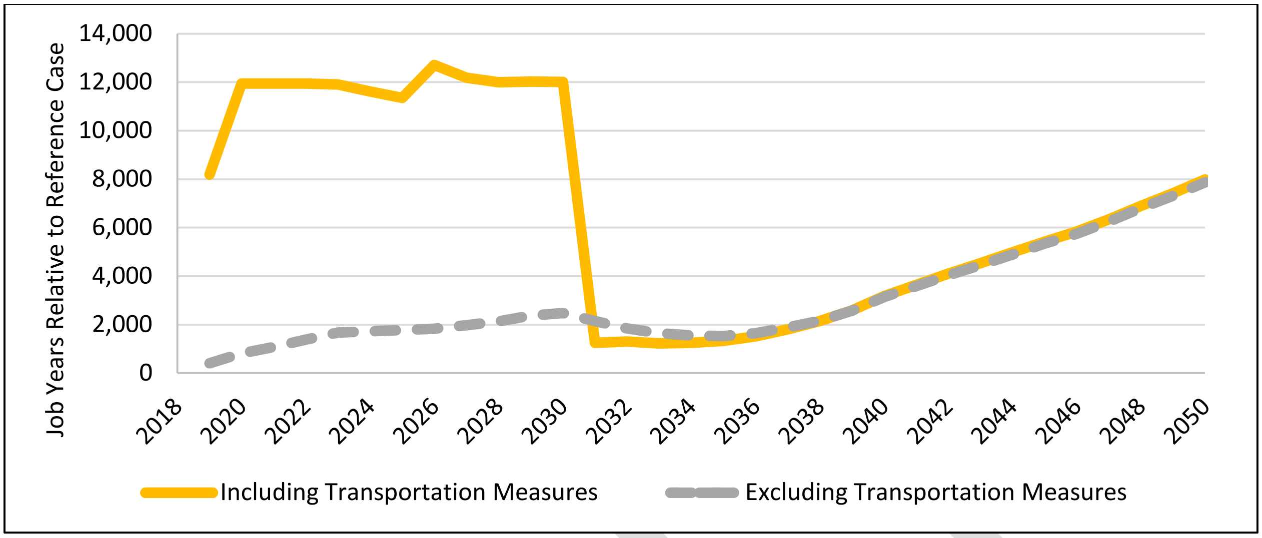


Sources: E3, MDE, REMI PI+, RESI

Through 2030, these employment impacts are driven by transportation infrastructure projects, as seen in other policy scenarios. After 2030, employment impacts remain positive relative to the reference case. The steady increase in employment after 2030 is due in part to the relatively low capital costs seen in Policy Scenario Four. Because spending on capital is lower, consumers have more money to spend on other goods and services, and businesses are more profitable. These positive impacts, coupled with reductions in spending on fuel, result in a slow albeit steady increase in jobs supported relative to the reference case.

To visualize the impact of spending on transportation infrastructure on the economic impact results for Policy Scenario Four, Figure 5 below shows employment differences in Policy Scenario Four with and without this spending.

**Figure 5: Employment in Policy Scenario Four With and Without Transportation Spending Relative to the Reference Case**



Sources: E3, MDE, REMI PI+, RESI

The impact of transportation spending in Policy Scenario Four is similar to the impacts in the other three policy scenarios. On average through 2030, transportation infrastructure measures support 10,013 more jobs compared to the scenario without this spending. This is illustrated above as the difference between the two lines. Regardless of the status of the transportation spending, however, employment impacts are steadily positive for Policy Scenario Four.

In sum, as shown in Figure 6, all four policy scenarios achieve the 2030 economic goals and three policy scenarios meet both the 2020 and 2030 emissions targets as well.

**Figure 6: Summary of Policy Scenarios**

| Policy Scenario | Achieve 2020 Emissions Goal? | Achieve 2030 Emissions Goal? | Achieve 2030 Economic Goal? |
|---|---|---|---|
| Policy Scenario One | Yes | No | Yes |
| Policy Scenario Two | Yes | Yes | Yes |
| Policy Scenario Three | Yes | Yes | Yes |
| Policy Scenario Four | Yes | Yes | Yes |

Source: RESI

Sensitivity analyses were performed for Policy Scenario 4 under a number of difference scenarios, including:

1. A decrease in future renewable energy credit (REC) prices.
2. A rollback of the federal level Corporate Average Fuel Economy (CAFE) program. Removing the CAFE standards for fuel efficiency means an increase in emissions from vehicles and less pressure for consumers to purchase zero emissions vehicles.
3. Reduced consumer adoption of energy efficient appliances and zero emission vehicles. Under this sensitivity, consumer purchases of efficient appliances and zero emission

vehicles are 50 percent lower than originally modeled, leading to increased emissions, reduced capital costs, and reduced fuel savings.

4. A sensitivity analysis combining the rollback of the CAFE standards with the reduced consumer adoption sensitivity.

The results indicate that the economic outcomes of Policy Scenario 4 are robust to large changes in policies, consumer behavior deviations, and an uncertain economic environment. Under all the sensitivity analyses, the economic goals are still met.[WND1]

## 7.2 Introduction

The Regional Economic Studies Institute (RESI) of Towson University was tasked by the Maryland Department of the Environment (MDE) to provide a coherent set of analyses to inform the development of its proposed plan to reduce statewide greenhouse gas emissions by 40 percent from 2006 levels by 2030, to satisfy MDE's obligations under the Greenhouse Gas Emission Reduction Act (GGRA) Reauthorization. RESI contracted with Energy and Environmental Economics, LLC (E3) to model changes in emissions arising from various policy bundles under consideration. The results of the emissions modeling, conducted using the Pathways model, are discussed in Chapter 6 of this report, while the current chapter contains the results of the economic modeling.

## 7.3 Economic Modeling Methodology

As discussed in Chapter 6 of the draft GGRA Plan, the Project Team used the Pathways model to estimate the impact of each policy scenario on greenhouse gas emissions in Maryland. To estimate the economic impacts of each policy scenario, the Project Team used REMI PI+.[5]

The REMI model is a high-end dynamic modeling tool used by various federal and state government agencies in economic policy analysis. The REMI model is calibrated to the specific demographic features of Maryland as a whole and five regions of the state:

- **Central Maryland**: Baltimore City and Harford, Baltimore, Carroll, Anne Arundel, and Howard Counties
- **Southern Maryland**: St. Mary's, Charles, and Calvert Counties
- **Capital Maryland**: Frederick, Montgomery, and Prince George's Counties
- **Western Maryland**: Garrett, Allegany, and Washington Counties
- **Eastern Shore**: Cecil, Kent, Queen Anne's, Talbot, Caroline, Dorchester, Wicomico, Somerset, and Worcester Counties

A map of these regions is found in Figure 7.

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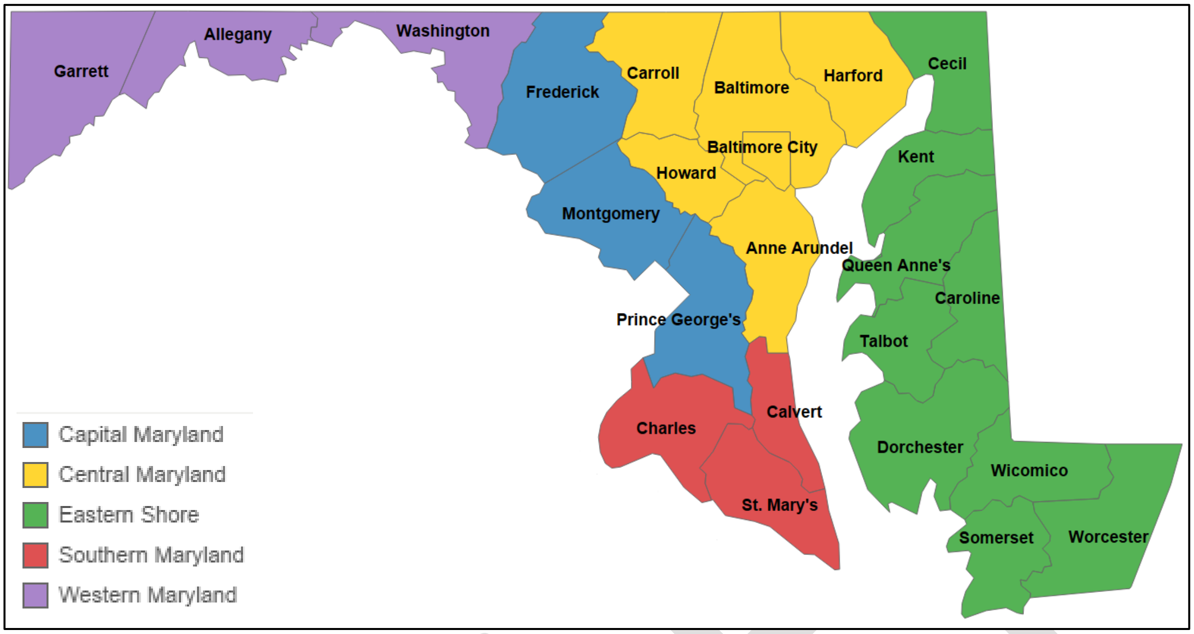
[5] All analyses were conducted using REMI Version 2.2.

**Figure 7: Maryland Counties and Corresponding Region within REMI PI+**



Sources: RESI, Tableau

REMI contains a baseline model of the economy for each of the five regions within Maryland. When a scenario is evaluated, REMI calculates the direct impact of the economic event (for example the sales made to a new business), as well as secondary effects (the new business' payments to vendors and the money spent in the local economy by workers in the new business). The effects of these effects on the baseline REMI forecast are estimated, allowing researchers to see both the impacts on their own but also in the context of the state's economy. Unlike simpler economic impact analysis models, such as IMPLAN, REMI is a dynamic model, which means that the model also considers economic and demographic shifts between regions (within Maryland and across state lines) in response to the economic scenario. For example, if a new business opens in Maryland, some workers may move from Virginia or Delaware to be closer to their new employer. The dynamic nature of REMI is important for this analysis, as proposed polices to reduce carbon emissions will lead to changes in consumer prices, salaries, and government spending priorities. Additionally, REMI PI+ has a time component which makes it especially useful in evaluating the long-term impact of policies in the future.

### 7.3.1 Translating Pathways Output to REMI PI+ Input

To ensure that estimates of economic impacts and emissions impacts for each policy scenario were consistent, the Project Team first modeled each policy scenario within Pathways. In addition to calculating changes in emissions for each policy scenario, Pathways also calculates changes in costs for four main sectors of the economy:

- Residential,
- Commercial,

- Industrial, and
- Transportation.

Across these four sectors, Pathways estimates capital costs associated with 35 distinct subsectors, such as commercial air conditioning, residential clothes washing, transportation light duty automobiles, and residential water heating. Additionally, Pathways produces fuel consumption and fuel cost estimates for a total of 45 different subsectors, such as residential electricity, commercial solar, transportation diesel, and industrial natural gas.

To calculate the economic impact of each policy scenario, the Project Team first translated cost estimates from Pathways into inputs appropriate for REMI PI+. Each cost estimate from Pathways is associated with at least one transfer of funds from one entity to another. For example, if a policy scenario results in increased purchases of residential washing machines, several positive impacts are felt in the economy, including:

- Retail stores experience higher sales and
- Manufacturers of washing machines experience increased demand and higher sales.

These impacts would generally be associated with job gains, as increased sales may allow stores and manufacturers to hire additional workers. However, in this example, there are also negative impacts to the economy of consumers purchasing additional washing machines. If consumers spend more of their income on washing machines, they will have less income available to spend on all other goods and services. If consumers forego eating out in order to balance their budget, the economy could experience job losses at restaurants. In other words, it is important to consider not just economic benefits accruing from a given policy, but also the opportunity cost of the new spending.

Therefore, each cost from Pathways is generally entered into REMI twice: once as a change in spending patterns or production costs from the group bearing the cost of the new policy and once as a change in demand to the industry and group providing the particular good.

Within REMI, there are several ways of modeling the benefits to any given industry. Using the previous example, economic benefits to appliance manufacturers can be modeled through methods such as increased employment in the industry, increased sales, or an increase in consumer/business demand. For this project, benefits are generally modeled as a change in consumer/business demand. One advantage of this method is that REMI allows for some portion of the new demand to be satisfied by producers outside of Maryland, which allows for more conservative and accurate estimates than assuming all new production occurs in state.[6]

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[6] When using consumer/business demand, the percent of new demand estimated to be satisfied by in-state sources is estimated to be the same as the percent of local demand satisfied by Maryland producers. For example, if 30 percent of current automobile manufacturing demand is satisfied by in-state sources, 30 percent of all new automobile manufacturing would be satisfied by in-state producers.

In addition to modeling benefits, the team also modeled the economic costs associated with each policy, beginning with Pathways output. Pathways categorizes costs as capital costs and fuel costs, both of which correspond to input variables within REMI. An increase in costs increases businesses' production costs, making it more expensive to produce goods in Maryland as opposed to other states where businesses would not need to invest in the same technologies.

For capital costs and fuel costs impacting households, the Project Team changed REMI's baseline estimates of household spending patterns. For example, if a policy led to consumers spending $30 less on gasoline, the team adjusted household demand for gasoline spending down by $30, and then allowed consumers to spend the $30 on all other goods and services.

### 7.3.2 Modeling Policy Costs Not Captured Within Pathways

Although the economic impact modeling used Pathways output in order to be as consistent as possible with the emissions modeling, not all policies are able to be explicitly modeled within Pathways. Economic data from Pathways are incomplete because the model is limited to generating cost estimates for items that have a physical stock (e.g., automobiles, appliances, HVAC systems) or that are related to fuels (e.g., electricity, natural gas, diesel). Many policies include investment decisions and benefits not associated with a physical stock.

For example, many policies implemented by the Maryland Department of Transportation (MDOT) would correspond with reduced vehicle miles traveled, and thus emissions, but not a change in the stock of automobiles. Emissions reductions from these policies are still calculated, even though no costs are captured within Pathways. If no cost data were entered separately into REMI, emissions reductions would be achieved for free. Therefore, it is important to capture many changes by state agencies separately instead of relying on Pathways data alone.

One of the largest sources of data to be modeled separately was spending data from MDOT. MDOT data represented a range of different policies across the various policy scenarios, including:

- Public transportation projects,
- Transportation demand management,
- Additional toll roads, and
- More efficient busses.

MDOT policies are modeled within REMI as an increase in the demand for the industry most closely associated with the policy. For example, public transportation projects are generally modeled as an increase in the demand for construction, while updates to the bus fleet are modeled as an increase in demand for motor vehicle manufacturing. By increasing the baseline demand values with REMI, REMI assumes some production will be satisfied by out-of-state sources.

Generally, funding for future MDOT projects will come from three general sources:

- Federal government,
- State government, and
- Private investment.

Funding from the federal government and from private sources was treated as funding that would not be allocated to Maryland otherwise. That is, if the federal government does not provide grant funding to complete a given Maryland project, the team assumed those grant funds would go to another state. Therefore, projects funded by the federal government and private investors represent a positive shock to Maryland's economy.

However much of the funding needed for transportation projects would originate with the state budget. For these projects, MDOT did not specify the funding source(s) to support the new initiatives. To avoid making broad judgements about which state services would need to be reduced or eliminated to pay for an increase in transportation budgets, the Project Team estimated that state income taxes would change each year by the amount necessary to cover the cost of each project. In instances where spending decreases, particularly due to fuel savings, the team modeled a decrease in state income taxes equal to the savings.[7]

### 7.3.3 Updating the REMI Baseline

REMI evaluates policy changes in the context of current and forecasted economic conditions, referred to as the standard regional control. Changes to the REMI control model will impact how policies are evaluated in the model. Similarly, policy scenarios within Pathways are evaluated relative to a reference scenario, as described in more detail in Chapter 6. For consistency across models, the REMI standard regional control was adjusted to more closely match the reference case in the Pathways model.

The reference case within Pathways assumes the implementation of a variety of policies that are not fully accounted for in REMI's standard regional control. For example, the reference case accounts for Maryland's most recent EmPOWER goals between 2015 and 2023, the most current projections regarding rooftop solar, current renewable portfolio standards (RPS), and changes to the Regional Greenhouse Gas Initiative (RGGI).

Therefore the team created a new regional control model within REMI that accounts for all policies included in the reference case. To do so, the team followed the methodology outlined in Section 7.3.1, increasing capital costs and fuel costs across different sectors of the state economy to more accurately reflect the economy. Once established within REMI, all policy scenarios were run against this new control, rather than the standard regional control.

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[7] An alternative approach to the one taken by the Project Team would consist of modeling an increase in demand for the most relevant industry (e.g., construction) and a decrease in general state spending. However, modeling this approach within REMI led to decreases in the employment of teachers and law enforcement personnel. Losses in these occupations are not expected, given the nature of employment contracts for these occupations.

### 7.3.4 Custom Industries Within REMI

One shortcoming of the REMI model used in this analysis is that all firms producing electric power are aggregated into a single utilities sector, regardless of if the power is generated by a renewable source, such as wind, or by fossil fuels, such as coal. This aggregation structure can lead to unintuitive indirect impacts. With the baseline model, an increase in sales of wind energy would be treated the same as an increase in sales of coal power. Because REMI uses one set of economic multipliers to estimate how utility firms spend their revenues on support products and services, an increase in revenue for a wind plant would lead to an increase in purchases of coal or petroleum products within the model.

Therefore, the Project Team separated electric power generation into three categories:

- Wind electric power generation,
- Solar electric power generation, and
- General electric power generation.

General electric power generation uses the same multipliers as the baseline electric power generation sector within REMI. To create the other two custom industries, the Project Team customized REMI using industry multipliers from IMPLAN, another input-output economic modeling software.

To populate the REMI output multipliers, RESI crosswalked IMPLAN industry classifications to REMI. Because IMPLAN uses a more granular set of industry codes than REMI, some IMPLAN industries were combined. The results were then input into REMI as custom industries.

The solar and wind power generation industries look substantially different than the general electric power generation industry, as illustrated in Figure 8. These industries have a higher value-added component at 0.82 and 0.90, for solar and wind respectively, compared to the base utilities industry, which has a value-added component of 0.79. Because much of the value-added component is due to earnings, on average, it can be expected that jobs in the base utilities industry will be lower paying than those in the solar and wind industries. In terms of intermediate demand, the base utilities industry relies heavily on fossil fuel intensive industries such as oil and gas extraction, petroleum and coal products manufacturing, and mining (except oil and gas). Solar and wind, on the other hand, rely more heavily on services (both professional and support services), construction, and real estate.

**Figure 8: Top Five Intermediate Demand Industries for Utilities and the Solar and Wind Custom Industries**

| | Intermediate Demand Industry | Multiplier |
|---|---|---|
| Base Utilities | Oil and gas extraction | 0.046 |
| | Petroleum and coal products manufacturing | 0.033 |
| | Professional, scientific, and technical services | 0.019 |
| | Mining (except oil and gas) | 0.013 |
| | Scenic and sightseeing transportation; Support activities for transportation | 0.012 |
| Solar Power Generation | Professional, scientific, and technical services | 0.035 |
| | Scenic and sightseeing transportation; Support activities for transportation | 0.019 |
| | Construction | 0.016 |
| | Administrative and support services | 0.015 |
| | Real estate | 0.010 |
| Wind Power Generation | Professional, scientific, and technical services | 0.019 |
| | Scenic and sightseeing transportation; Support activities for transportation | 0.010 |
| | Construction | 0.009 |
| | Administrative and support services | 0.008 |
| | Real estate | 0.006 |

Source: REMI PI+, RESI

### 7.3.5 Estimating Health Impacts

Health impacts and their subsequent economic effects were also evaluated by the Project Team. A reduction in carbon emissions corresponds with increased air quality, which will lead to a number of health benefits for Maryland residents. These factors include reduced hospital visits, fewer days missed of work, improved quality of life, and decreased mortality. To estimate these effects, the Project Team used the U.S. Environmental Protection Agency's (EPA) CO-Benefits Risk Assessment (COBRA) model to measure the impacts of reduced emissions on health. The COBRA model is intended to assist state and local governments that are estimating the costs and benefits of clean energy policies. Originally developed by Abt Associates in 2002, and most recently updated in 2017, COBRA is designed to "estimate the economic value of the health benefits associated with clean energy policies and programs" so these values can be weighed against the economic costs of a proposed policy.[8,9]

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[8] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 3, accessed August 9, 2018, https://www.epa.gov/sites/production/files/2018-05/documents/cobra_user_manual_may2018_508.pdf.

COBRA utilizes emission estimates for five different forms of air pollution: fine particulate matter ($PM_{2.5}$), sulfur dioxide ($SO_2$), nitrogen oxides ($NO_X$), ammonia ($NH_3$), and volatile organic compounds (VOCs).[10,11] Baseline emission estimates are included for both 2017 and 2025, allowing users to change emissions in either year.[12] Once the emission estimates for the policy are determined, the user can then input any corresponding emission increases or decreases from the baseline into the model. These changes can be input as either percentage changes from the baseline or as a specific quantity of emissions in tons.

To model health impacts through 2050, emission changes from each policy scenario were run for five different years: 2017, 2025, 2030, 2040, and 2050. Since COBRA only contains pre-made baseline emissions for 2017 and 2025, the baseline was increased to adapt for increased emission reductions in the later years of the model.[13]

Except for emissions from electric utilities, all of the COBRA inputs were derived from PATHWAYS using the change in final fuel demand (measured in millions of British Thermal Units, or MMBTU) for every sector between the reference scenario and the policy scenario being modeled. The formula for estimating changes in emissions varied by sector.

For example, gasoline and diesel use, particularly in vehicles, makes up the largest portion of emission changes in the policy scenarios, outside of electric utilities. To determine emissions for gasoline and diesel fuels, the change in MMBTUs provided by Pathways was converted into gallons of fuel using conversions rates provided by the U.S. Energy Information Administration.[14] These gallons of fuel were converted into miles traveled using average mileage of 30 miles per gallon (mpg) for gasoline vehicles and 10 mpg for diesel. Finally, miles were converted into emissions using emissions factors prepared for the Project Team by MDE's Mobile Sources Control Program.[15]

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[9] "CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool," U.S. Environment Protection Agency, accessed August 9, 2018, https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool.

[10] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 18.

[11] According to the U.S. Environmental Protection Agency, fine particulate matter, or $PM_{2.5}$, typically has a diameter of 2.5 micrometers or less.

[12] COBRA also contains the ability to import a custom emissions baseline for any other year, however this functionality was not used for this analysis.

[13] The baseline emissions were increased using a multiplier on the 2025 baseline so that proportional emissions between counties in Maryland would be preserved. Test runs using various COBRA baselines revealed that the size of the baseline does not have an effect on health impacts as long as proportional emissions between counties remains constant.

[14] "British Thermal Units (BTU)," U.S. Energy Information Administration, accessed January 20, 2019, https://www.eia.gov/energyexplained/index.php?page=about_btu.

[15] Private correspondence with MDE, September 24, 2018.

Emissions for natural gas sectors were calculated using emissions factors for greenhouse gases published by the EPA.[16] These EPA figures allow for a direct conversion from MMBTUs as modeled by PATHWAYS into tons of emissions for $PM_{2.5}$, $NO_x$, $SO_2$, and VOCs. The EPA's emissions factors also allow for differentiation in $NO_X$ emissions between commercial/industrial and residential natural gas furnaces.

Certain policy scenarios model the introduction and subsequent increase in use of biogas as a fuel source in Maryland. Emissions created by the use of biogas are calculated using emissions factors made available by the California Air Resources Board.[17] As with natural gas, emissions for $PM_{2.5}$, $NO_x$, $SO_2$, and VOCs are calculated directly using the factors provided.

Emission changes due to shifts in electric utilities are calculated by first using the EPA's Avoided Emissions and Generation Tool (AVERT) modeling program to estimate the change in emissions for each pollutant.[18] Additionally, AVERT is used to estimate emissions reductions resulting from increased generation of wind and solar energy. These emissions shifts are then input into COBRA.

COBRA output consists of a number of different impacts, including:

- Changes in mortality and infant mortality;
- Changes in instances of non-fatal heart attacks;
- Changes in hospital admissions for asthma, chronic lung disease, and all other respiratory issues; and
- Changes in days of work missed due to sickness or days of work with inhibited productivity.

All outputs from COBRA were translated into inputs appropriate for use in REMI. Health impact figures output by COBRA are represented in the COBRA model through an increase in the survival rate, the cost of hospitalization, an increase in the amenity value, a change in productivity, and increased consumer income.[19]

In the REMI model, changes to adult mortality and infant mortality are represented through a change in the survival rate, which represents the percentage of a given population expected to die in a single year. To determine the change in the survival rate, RESI compared the decreased mortality from the COBRA model to the population size of each Maryland region. An

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[16] U.S. Environment Protection Agency, "Natural Gas Combustion," 6, accessed January 20, 2019, https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf.

[17] Marc Carreras-Sospedra and Robert Williams, "Assessment of the Emissions and Energy Impacts of Biomass and Biogas Use in California," University of California and California Biomass Collaborative (January 14, 2015): 63 accessed January 20, 2019, https://www.arb.ca.gov/research/rsc/1-30-15/item6dfr11-307.pdf.

[18] "Avoided Emissions Factors Generated from AVERT," U.S. Environment Protection Agency, accessed January 20, 2019, https://www.epa.gov/statelocalenergy/avoided-emission-factors-generated-avert.

[19] The amenity value measures non-economic improvements to quality of life in a region, which has an effect on migration patterns.

adjustment to the COBRA output was also required in order to accurately adjust the survival rate for each year. While most health impacts in COBRA are limited to occurrences within a single year, impacts on premature mortality are determined using a 20-year lag structure. For any change in premature deaths resulting from a single year of emissions, 30 percent of those deaths are assumed to occur in the first year, 50 percent occurs evenly from years two to five after the emissions year, and the final 20 percent occurs over years six to 20.[20] Mortality changes for each year in the COBRA model were adjusted so that the REMI input reflected the change in mortality that occurs within a given year, rather than the change in mortality caused by a single year of emissions.

Six of the health impacts measured by COBRA involve admittance or visitation to a hospital. To determine the cost of hospitalization for these issues, RESI relied on health data from HCUPnet, an online system which uses data from the Healthcare Cost and Utilization Project (HCUP). Using HCUPnet, RESI obtained average hospital charges in Maryland for each of the relevant conditions.[21] For each reduced incidence of hospital admittance in the COBRA model, RESI decreased medical revenue in the REMI model by an amount equal to the average hospital charge for that condition, and reallocated the revenue to consumers, government, and private insurance in proportion to their contribution to the medical bill based on payer data also provided by HCUPnet.[22]

In many cases, a health incident involving hospital admission will result in an absence from work and decreased productivity. COBRA additionally measures missed work days and restricted activity days not directly resulting from one of the other measured health impacts.[23] RESI utilized HCUPnet data to determine the average length of stay for each of the hospital admissions. The productivity gained from a reduction in missed work days was input into REMI as an equivalent increase in employment. RESI calculated the increase in employment by measuring the total reduction in missed work days against the number of active working days in a calendar year.[24]

The change to the amenity value is based on four additional health impacts in the COBRA model: acute bronchitis, upper respiratory symptoms, lower respiratory symptoms, and asthma exacerbation. Since these impacts do not involve hospital admission or missed work days, they are reflected in the REMI model using a change in the amenity value for each region. The values entered into the model are taken directly from COBRA's valuation of each of the four health impacts.

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[20] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," F-6.
[21] "HCUPnet, Healthcare Cost and Utilization Project," Agency for Healthcare Research and Quality, accessed August 15, 2018, https://hcupnet.ahrq.gov/.
[22] Revenue was reallocated in the REMI model to insurance carriers, federal, state, and local government, and consumer spending.
[23] For RESI's model, a single restricted activity day is treated as 0.5 missed work days.
[24] Active working days exclude weekends and non-working holidays.

### 7.3.6 Estimating the Impact of Carbon Pricing

Policy Scenario Three, discussed in more detail in Section 7.4.3, used carbon pricing as a strategy to reduce carbon emissions. A carbon price is a market-based approach to reduce greenhouse gas emissions by, generally, imposing a fee on each unit of carbon dioxide (or other emissions) produced. In this way, the polluting firm must internalize the negative externality that results from the firm's behavior.[25] The revenue collected from this fee is then used to compensate consumers for increased energy costs and/or fund additional reductions in greenhouse gas emissions.

In Policy Scenario Three, the price of carbon begins at $20 per metric ton in 2020 and rises to the social cost of carbon in 2030. The social cost of carbon is a price determined by the EPA, to fully account for the negative externalities associated with carbon emissions. The price for one metric ton of carbon emissions each year between 2020 and 2050 is displayed in Figure 9.

**Figure 9: Carbon Price Escalation**

| Year | Carbon Price ($2017) | Year | Carbon Price ($2017) |
|---|---:|---|---:|
| 2020 | $19.61 | 2036 | $68.35 |
| 2021 | $23.75 | 2037 | $69.57 |
| 2022 | $27.89 | 2038 | $70.79 |
| 2023 | $32.04 | 2039 | $72.01 |
| 2024 | $36.18 | 2040 | $73.24 |
| 2025 | $40.32 | 2041 | $74.33 |
| 2026 | $44.46 | 2042 | $75.43 |
| 2027 | $48.61 | 2043 | $76.53 |
| 2028 | $52.75 | 2044 | $77.63 |
| 2029 | $56.89 | 2045 | $78.73 |
| 2030 | $61.03 | 2046 | $79.83 |
| 2031 | $62.25 | 2047 | $80.93 |
| 2032 | $63.47 | 2048 | $82.03 |
| 2033 | $64.69 | 2049 | $83.13 |
| 2034 | $65.91 | 2050 | $84.23 |
| 2035 | $67.13 | | |

Source: RESI

Policy Scenario Three represents an extension of Policy Scenario One with the addition of a carbon pricing scheme. However, to estimate revenues generated by carbon pricing, the Project Team could not simply multiply the carbon price by the emission levels for each year in Policy Scenario One. Carbon pricing makes carbon-intensive fuels more expensive, thus altering consumer and business behavior. For example, if the price of gasoline increases, consumers may choose to drive less or carpool to use less gas. If the price increase is not seen as a

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[25] Kevin A. Hasset, Aparna Mathur, and Gilbert Metcalf, "The Incidence of a U.S. Carbon Tax: A Lifetime and Regional Analysis," 2009. *The Energy Journal, International Association for Energy Economics* 30 no. 2 (2009): 155-178.

temporary shock, consumers may make longer-term decisions, such as buying an electric vehicle. To measure the amount consumption of carbon-intensive fuels changes in response to price shocks, the team used a model based on Washington State's Carbon Tax Assessment Model (CTAM).[26]

CTAM is considered an industry standard in estimating the impact of various carbon pricing programs, and has been used in conjunction with REMI on several similar analyses.[27] However, the base CTAM model does have limitations. For one, the base CTAM model assumes the carbon price will increase by a constant amount each year, up to a maximum cap. However, for Policy Scenario Three, the carbon price has two rates of change:

- One rate of change between 2020 and 2030, where the carbon price starts at $20 and climbs to the social cost of carbon in 2030; and
- One rate of change between 2030 and 2050, where the carbon price rises in line with the social cost of carbon.

Another limitation of the base CTAM model in this analysis is that the emissions and consumption categories used do not directly match with the categories within Pathways. A third limitation is that the CTAM model does not distinguish between short-term consumption responses and long-term investment responses to price shocks. For example, in the prior example regarding the cost of gasoline, the consumer reducing unnecessary trips is a consumption response and does not have an associated cost to capture. If the same consumer perceives the price change as long-term and purchases a new electric vehicle in response, this is a cost that should be fully captured in economic models. Both responses will lead to reductions in emissions, but investment responses are accompanied by additional investments. This differentiation is not possible within the base CTAM model.

Therefore, the Project Team adapted the methodology behind the CTAM model to fit the needs of this analysis. First, the applicable price adjustment for each fuel source was calculated by taking the carbon emission rate for each fuel source and multiplying it by the carbon price for each year. Then, total elasticity values (the effect of both consumption and investment responses to increased price) were gathered from CTAM and applied to relevant Pathways categories. The short-run consumption effect was estimated by analyzing literature, including published sources from the EPA. The investment response is estimated as the difference between the consumption effect and the total elasticity. Within the model, investment

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[26] "Carbon Policy and Strategies—Washington State Department of Commerce," Washington State Department of Commerce, accessed September 19, 2018, https://www.commerce.wa.gov/growing-the-economy/energy/washington-state-energy-office/carbon-tax/.

[27] Scott Nystrom, Katie O'Hare, and Ken Ditzel, "The Economic, Fiscal, and Emissions Impacts of a Revenue-Neutral Carbon Tax," (July 2018): 1, accessed January 14, 2019, https://www.fticonsulting.com/~/media/Files/us-files/insights/reports/impacts-revenue-neutral-carbon-tax.pdf.

elasticities are phased in over ten to twenty years in order to more accurately depict how consumers and businesses make long-term decisions.[28]

The consumption response for a given fuel each year is calculated as the product of the baseline consumption of that fuel, the consumption elasticity, and the percentage the price of that fuel changes as a result of the carbon pricing. The investment response is calculated in a similar manner, except using the relevant investment elasticities instead of consumption elasticities. After calculating the consumption and investment response, the adjusted consumption for each Pathways sector is calculated as the baseline consumption less the consumption and investment responses.

To generate the revenue associated with a carbon pricing scheme, the adjusted consumption levels for each fuel are multiplied by the carbon price for the given year and by the emission value associated with that fuel.

Once collected, revenue in Policy Scenario Three are distributed through the economy in several different ways as determined by the Mitigation Working Group of the Maryland Commission on Climate Change and described in Section 7.4.3. Thirty percent of all funds will be spent on mitigation activities. Mitigation activities will reduce the amount of carbon, therefore reducing the revenue raised in future years. The team used an iterative approach to modeling revenues from a carbon pricing scheme. Reductions in emissions as a result of mitigation measures were calculated, and then revenue was re-estimated. The revenues generated each year with and without mitigation reinvestment are displayed below in Figure 10.

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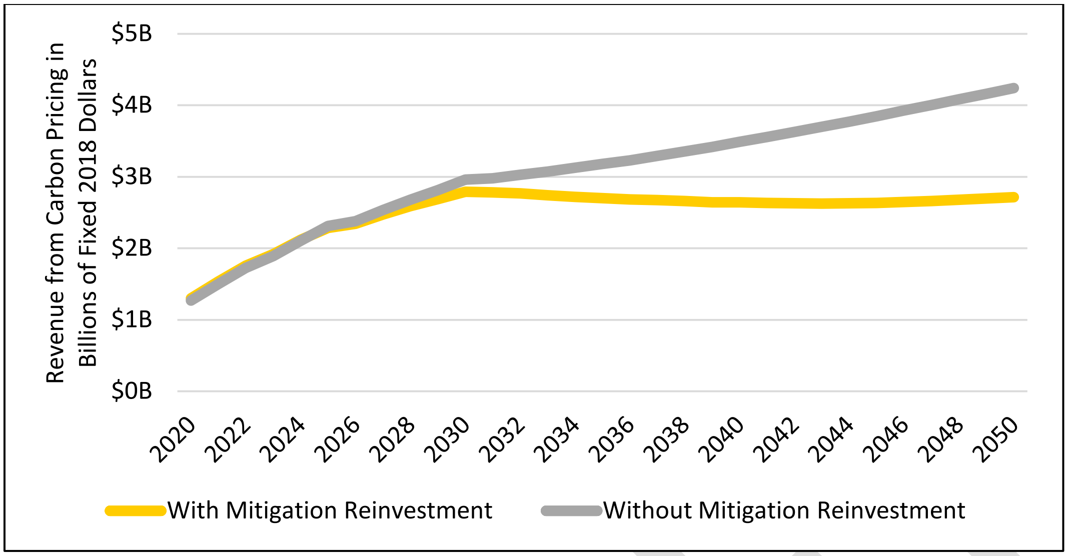
[28] The timeframe for phasing in the investment elasticity for each fuel and sector combination is derived from the base CTAM model.

**Figure 10: Revenue from Carbon Pricing With and Without Reinvestment in Mitigation Measures**



Sources: E3, MDE, RESI

In addition to investing in mitigation efforts, the team modeled 50 percent of generated revenue as redistributed to lower-income households. However, a limitation of REMI is that household spending cannot be increased for consumers in given income brackets. Therefore, the Project Team modeled the increase in household spending as an increase in spending on consumption categories that are necessities within REMI (e.g., food, transportation, rent/mortgage) to model how consumers in lower-income brackets would spend rebates.

One limitation of integrating carbon pricing into REMI is that the default REMI model does not assume policies will impact farms unless explicitly modeled. However, carbon pricing applied in a single state could generally lead to negative impacts for farms in the absence of exemptions, given the industry's reliance on energy as an input. The team used estimates of reduced farm output under potential carbon pricing schemes as a guide for estimates within REMI.[29] These estimates were adjusted based on the makeup of Maryland's farming industry.

### 7.3.7 Criteria for Evaluating the Economic Impact of Policy Scenarios

In addition to satisfying emission requirements through 2030, the policies selected by the State of Maryland to reduce carbon emissions must provide a net benefit to the Maryland economy. To determine whether each policy scenario meets this mandate and qualifies as meeting the economic goals of the GGRA, the team used the following set of indicators:

- Average positive job growth through 2030;

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[29] Ronald Sands and Paul Westcott, "Impacts of Higher Energy Prices on Agriculture and Rural Economies," Economic Research Service, Economic Research Report Number 123 (August 2011): 21, accessed November 19, 2018, https://www.ers.usda.gov/webdocs/publications/44894/6814_err123_1_.pdf?v=41432.

- Positive cumulative personal income growth through 2030 with a 3 percent discount rate; and
- Positive cumulative gross state product (GSP) growth through 2030 with a 3 percent discount rate.[30]

In addition to these three metrics, the team considered other measures of economic well-being, including:

- The impact across different sectors of Maryland's economy, including manufacturing;
- The impact on consumer prices;
- Distributional impacts in terms of income, education and training, and race/ethnicity; and
- The regional distribution of jobs.

Reducing carbon emissions and ensuring net benefits to Maryland's economy are not mutually exclusive goals. The following sections will outline the various policy bundles that the Project Team considered, as well as the results of the analysis. Emissions results are presented in Chapter 6 of this report.

## 7.4 Overview of Policy Scenarios One, Two, and Three

In evaluating policies to reduce carbon emissions in Maryland and achieve the goals set forward in the GGRA plan, the Project Team evaluated a total of four policy scenarios. This section provides an overview of the first three scenarios. The results of these three policy bundles were then examined, and feedback was solicited from policy makers to arrive at the final policy scenario, presented in Section 7.6. For more detail on individual assumptions and policies in all policy scenarios, please see Appendix A.

### 7.4.1 Policy Scenario One

Policy Scenario One represents a continuation of current policies. Under Policy Scenario One, energy efficiency is extended as EmPOWER investment continues through 2050, rather than ending in 2023. This corresponds with increased sales of efficient appliances and reductions in electricity usage through behavioral conservation. In addition to increased energy efficiency, Policy Scenario One contains extensions of the Zero Emissions Vehicle memorandum of understanding (MOU), leading to increased sales of electric vehicles through 2050. This policy scenario results in 300,000 additional zero emissions vehicles in 2050, relative to the reference scenario. Additionally, transportation policies proposed by MDOT will reduce vehicle miles traveled (VMT) for both heavy duty and light duty vehicles.

Policy Scenario One also contains an increase in the renewable portfolio standards (RPS) from 25 percent by 2020 to 50 percent by 2030. This increase is modeled after proposed State legislation.[31]

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[30] GSP is the sum of consumption, investment, government expenditures, and net exports from the state.

### 7.4.2 Policy Scenario Two

Policy Scenario Two represents an extension of Policy Scenario One designed to achieve deeper reductions in carbon emissions. Instead of generally continuing existing policies, Policy Scenario Two also contains a number of new programs. For example, Policy Scenario Two replaces the RPS with a 75 percent clean energy standard (CES) goal by 2040. A CES encompasses other sources of generation beyond renewable energy, including combined heat and power (CHP) and nuclear power.

Additionally, Policy Scenario Two models rapid adoption of zero emission vehicles. Zero emission vehicles are assumed to be 50 percent of new sales by 2030 and 100 percent of light duty sales by 2050. In addition to these sales of light duty vehicles, the team assumed that 95 percent of heavy-duty vehicle sales in the state would be electric vehicles or diesel hybrids by 2050. Regarding energy efficiency, the team modeled 100 percent of electric and natural gas appliance sales in Maryland would be high efficiency by 2030.

### 7.4.3 Policy Scenario Three

While the other policy scenarios were developed by MDE, Policy Scenario Three was developed by the Mitigation Working Group (MWG) of the Maryland Commission on Climate Change (MCCC). Similar to Policy Scenario Two, Policy Scenario Three uses Policy Scenario One as a foundation. In addition to the measures discussed in Section 7.4.1, Policy Scenario Three contains carbon pricing as a strategy to reduce carbon emissions instead of regulations. The carbon price for this scenario was modeled as starting at $20 per metric ton in 2020 rising to the social cost of carbon in 2030 and beyond.

Revenue from the carbon pricing scheme is allocated based on the Regional Cost Collection Initiative (RCCI) bill, or House Bill 939, introduced in the Maryland General Assembly in 2018, with modifications: [32]

- $10 million each year is allocated towards administration of the program;
- 50 percent of total revenue, less $10 million, is rebated to consumers in lower income brackets;
- 30 percent of total revenue each year is allocated to additional carbon mitigation measures beyond those modeled in Policy Scenario One;
- 10 percent of total revenue is allocated to adaptation and resilience policies, which help vulnerable communities prepare for and react to climate change; and
- 10 percent of total revenue is allocated to just transition efforts, which provide job retraining efforts and assistance for workers and communities impacted by the transition away from fossil fuels.[33]

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[31] The increase in Maryland's RPS is consistent with HB1435 and SB0732 proposed in the 2018 legislative session.
[32] H.B. 939, Session of 2018 (Mar. 2018), p.1, http://mgaleg.maryland.gov/2018RS/fnotes/bil_0009/hb0939.pdf.
[33] Regional Carbon Cost Collection Initiative, H.B. 939, Maryland General Assembly 2018 Session, 1, (2018), http://mgaleg.maryland.gov/2018RS/fnotes/bil_0009/hb0939.pdf.

## 7.5 Results of Policy Scenarios One, Two, and Three

There are multiple avenues through which policies to reduce Maryland's carbon emissions may impact the state's economy. For example, the construction and installation of solar panels and windmills on the Eastern Shore or construction of additional public transportation infrastructure in Montgomery County would boost employment. On the other hand, if policies lead to more expensive electricity costs for consumers and businesses, employment growth may be hampered. The following section contains the economic results of Policy Scenario One, Policy Scenario Two, and Policy Scenario Three. As summarized in Figure 11, all three policy scenarios achieved the economic goals described in Section 7.3.7. However, impacts on employment, personal income, and gross state product (GSP) varied.[34]

**Figure 11: Summary of Policy Scenarios**

| Policy Scenario | Achieve 2020 Emissions Goal? | Achieve 2030 Emissions Goal? | Achieve 2030 Economic Goal? |
|---|---|---|---|
| Policy Scenario One | Yes | No | Yes |
| Policy Scenario Two | Yes | Yes | Yes |
| Policy Scenario Three | Yes | Yes | Yes |

Source: RESI

### 7.5.1 Spending in Policy Scenarios One, Two, and Three

Within each policy scenario, there are two broadly competing forces: capital costs and fuel savings. Generally, the price of fuel increases across policy scenarios, as relatively cheap but carbon-intensive fuels are replaced by more-expensive alternatives. To offset rising prices and comply with new regulations, consumers and businesses make investments in new technologies. The hope is that the initial cost of these investments will be outweighed by future fuel savings. For example, if a consumer purchases an electric vehicle, that purchase may be considered cost-effective if fuel savings outweigh the initial purchase price. However, if fuel savings are not enough to compensate for the initial capital expenditure (above and beyond what would have been spent on a gasoline-powered car), the vehicle is not considered cost-effective.

Pathways data can broadly illustrate this effect. Ideally, savings on fuel will outweigh the cost of switching to more energy-efficient technologies, and the total cost for each policy scenario will be lower than in the reference case. As seen in Figure 12, the total spending in each policy scenario is very different.

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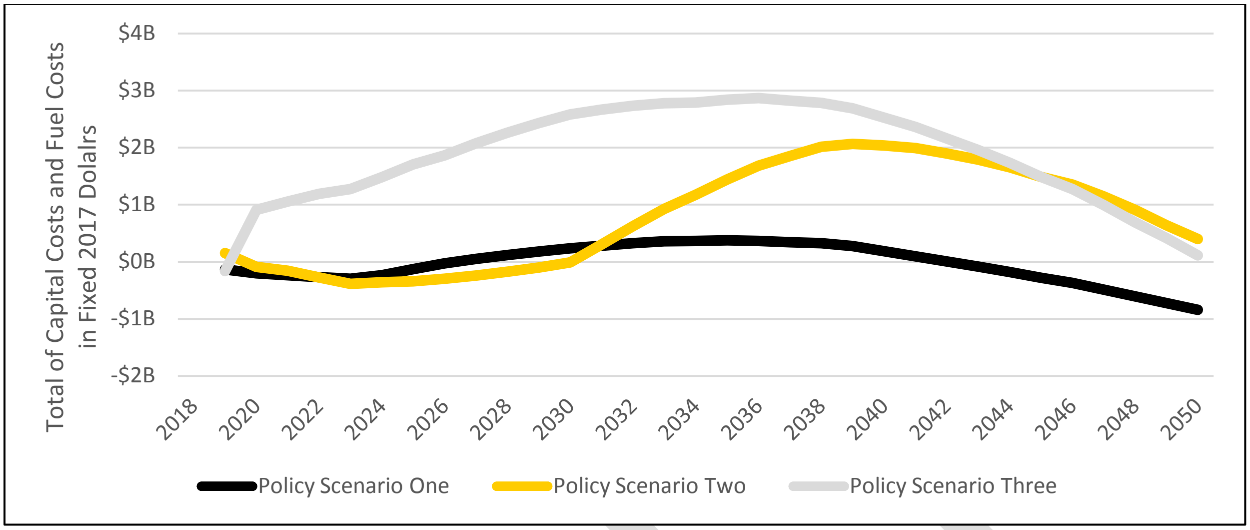
[34] GSP is the sum of consumption, investment, government expenditures, and net exports from the state.

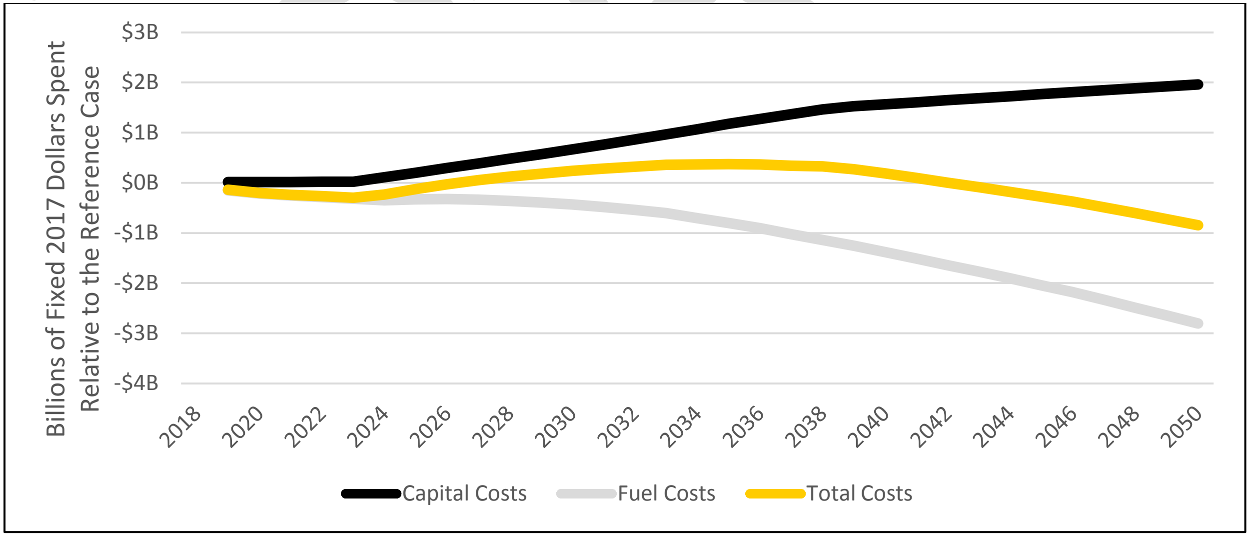
**Figure 12: Total Costs from Pathways for Policy Scenario One, Policy Scenario Two, and Policy Scenario Three Relative to the Reference Case**



Sources: E3, MDE, RESI

Figure 13, below, illustrates the total amount spent on fuel costs and capital costs (e.g., new energy-efficient appliances or new electric vehicles) in Policy Scenario One, relative to the reference case.

**Figure 13: Total Costs from Pathways in Policy Scenario One Relative to the Reference Case**

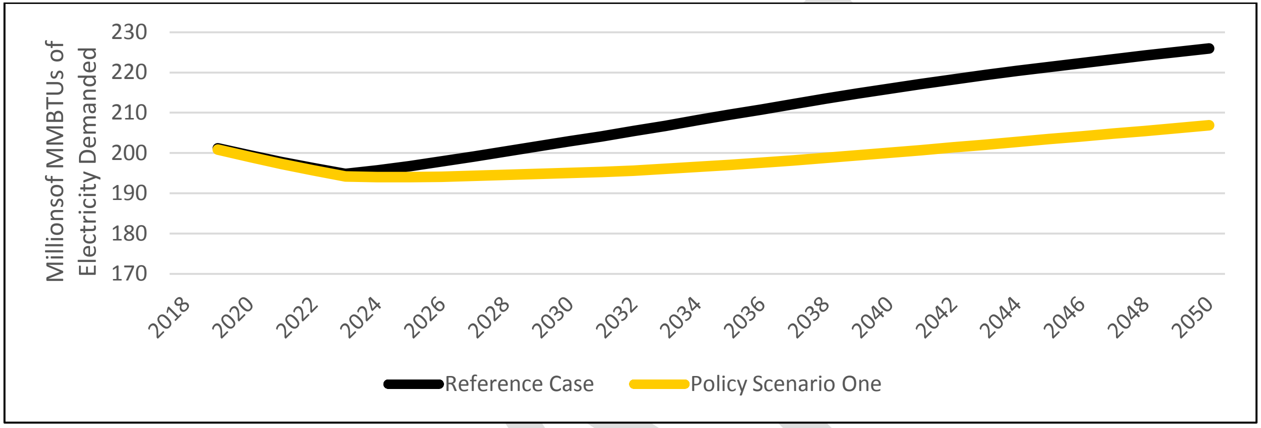


Sources: E3, MDE, RESI

As seen in Figure 13, fuel costs in Policy Scenario One are lower than in the reference case, indicating that consumers and businesses are spending less money on electricity, natural gas, and other fuel sources. This is generally due to reductions in consumption outweighing rising prices. In the short-term, the fuel savings are large enough that the total costs in Policy Scenario One are lower than in the reference case. This is largely because near-term infrastructure projects lead to reductions in vehicle miles traveled and reductions in consumption. However, as consumers and businesses purchase more energy-efficient appliances and systems, total costs rise and remain higher than in the reference case through 2045. At this point, fuel savings from new technologies are large enough that total costs are less than in the reference case.

Figure 14 illustrates how electricity demand specifically in Policy Scenario One differs from electricity demand in the reference case.

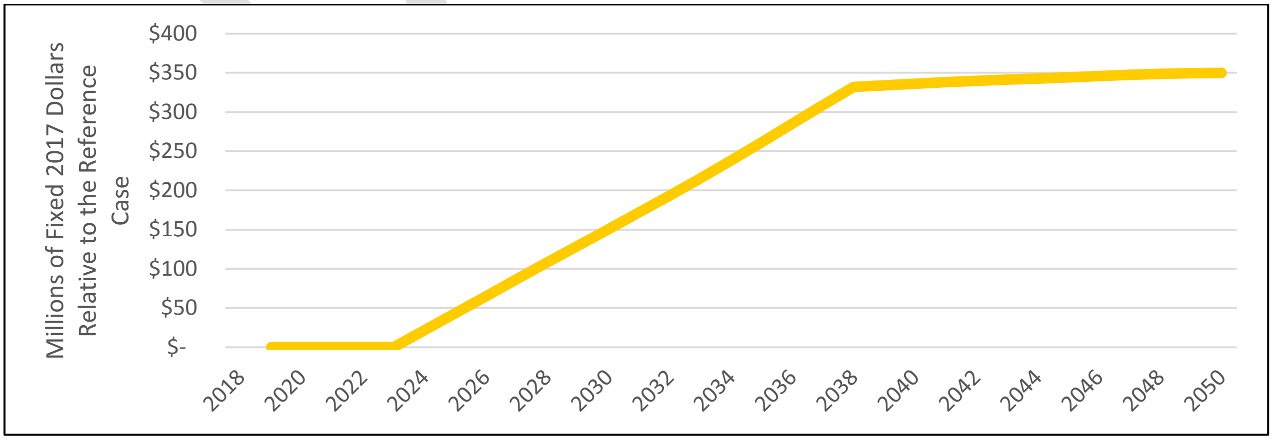
**Figure 14: Electricity Demand in the Reference Case and Policy Scenario One**



Sources: E3, MDE, RESI

As illustrated in Figure 14, total electricity demand declines in the reference case until 2023. At this point, the current iteration of EmPOWER expires, causing consumers and businesses to purchase less energy-efficient technologies. However, Policy Scenario One contains an extension of EmPOWER, which leads to a continuation of reduced demand for electricity after 2023. The impact of EmPOWER can be seen looking at purchasing patterns of more energy-efficient residential air conditioning units, shown in Figure 15.

**Figure 15: Capital Costs for Residential Air Conditioning Units in Policy Scenario One Relative to the Reference Case**

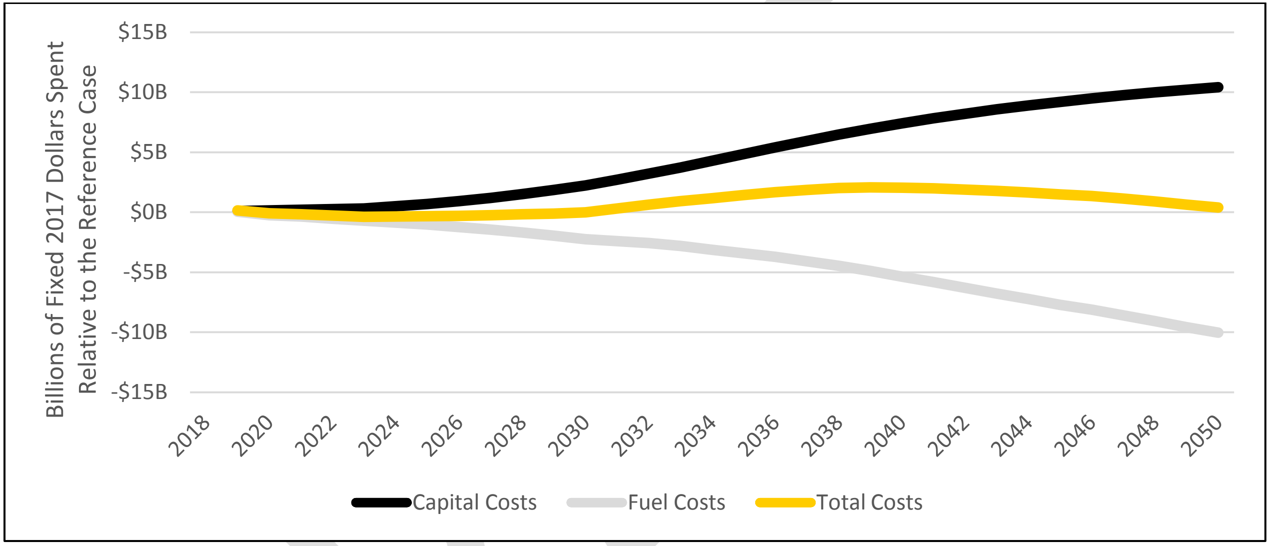


Sources: E3, MDE, RESI

As shown in Figure 15, residential spending on energy-efficient air conditioning units under Policy Scenario One is not different than in the reference case through 2023. However, starting in 2024, when the new EmPOWER extension is enacted, consumers steadily spend more on new appliances through 2038. Between 2038 and 2050, new sales of efficient appliances remains relatively constant.

Policy Scenario Two exhibits a similar overall pattern of spending on fuel costs and capital costs as in Policy Scenario One, illustrated in Figure 16.

**Figure 16: Total Costs from Pathways in Policy Scenario Two Relative to the Reference Case**

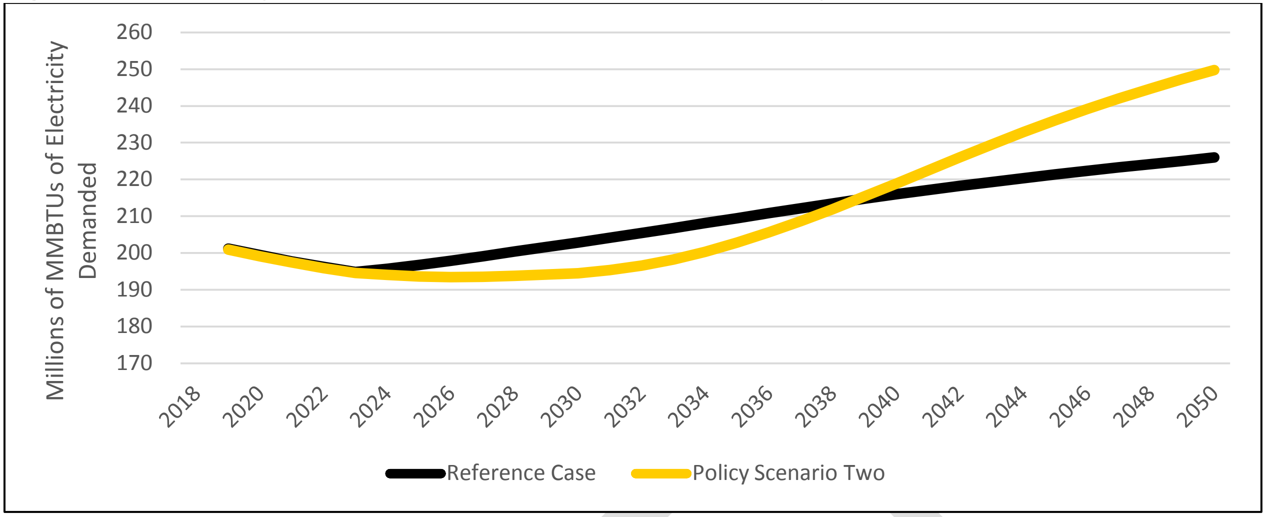


Sources: E3, MDE, RESI

Similar to Policy Scenario One, fuel savings in the near-term period help keep total costs to consumers and businesses lower than in the reference case. However, as aggressive policies encouraging sales of zero emission vehicles and energy-efficient appliances come into effect, thus increasing capital costs, total costs in Policy Scenario Two increase relative to the reference case, peaking in 2039. After 2039, total costs decrease and approach zero. However, unlike in Policy Scenario One, fuel savings in later years are not enough to create savings in the economy.

One interesting pattern in Policy Scenario Two concerns the demand for electricity, as shown in Figure 17.

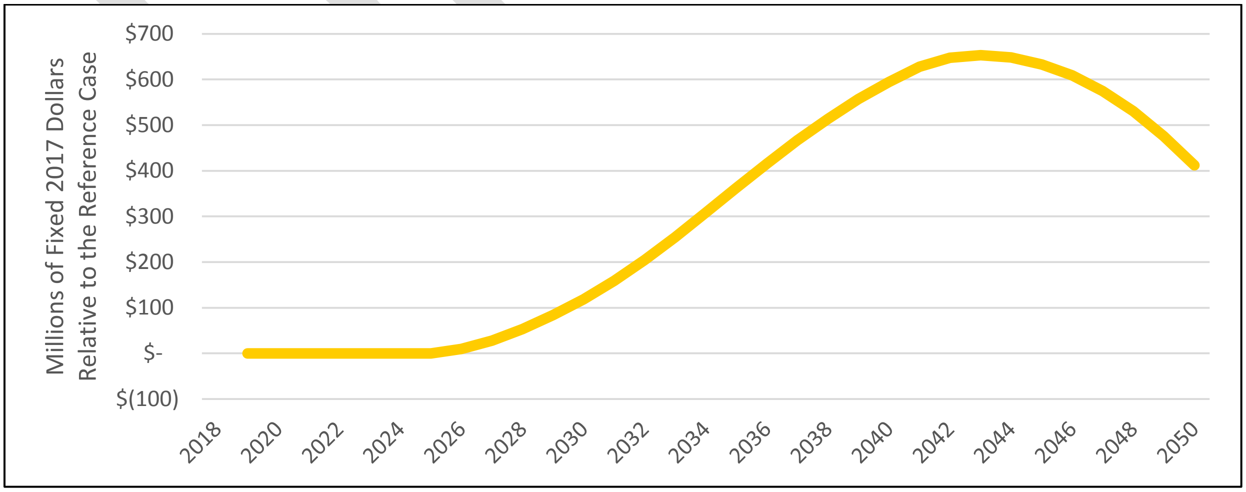
**Figure 17: Electricity Demand in the Reference Case and Policy Scenario Two**



Sources: E3, MDE, RESI

Similar to Policy Scenario One, demand for electricity in Policy Scenario Two is lower than in the reference case in the near term. Although Policy Scenario Two does contain measures that reduce consumer demand for electricity before the current 2023 EmPOWER end-date, the difference is not substantial until the EmPOWER extension goes into effect. The main difference between Policy Scenario Two and Policy Scenario One is that demand for electricity is higher in Policy Scenario Two than in the reference case in the later years of the study period. This increase in demand is due to an aggressive transfer of light-duty and heavy-duty vehicles to run on electricity rather than traditional gasoline or diesel. Capital costs associated with light-duty vehicles under Policy Scenario Two are presented below.

**Figure 18: Capital Costs Spent on Light Duty Automobiles in Policy Scenario Two Relative to the Reference Case**

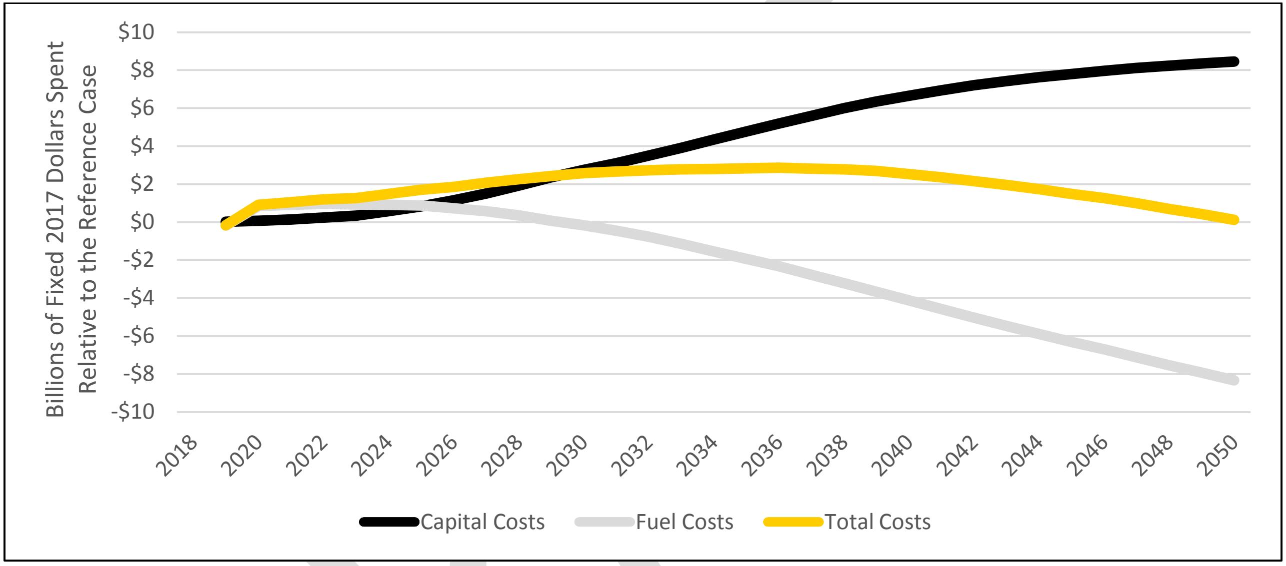


Sources: E3, MDE, RESI

As seen in Figure 18, purchases of new electric vehicles are substantial, with large increases starting in 2026 relative to the reference case. These changes reflect programs that incentive the use of electric vehicles. Spending on new purchases of efficient vehicles peaks in 2043 at roughly $650 million in purchases before declining to approximately $400 million in purchases by 2050.

Overall, the cost patterns in Policy Scenario Two are very similar to that of Policy Scenario Three, as illustrated in Figure 19.

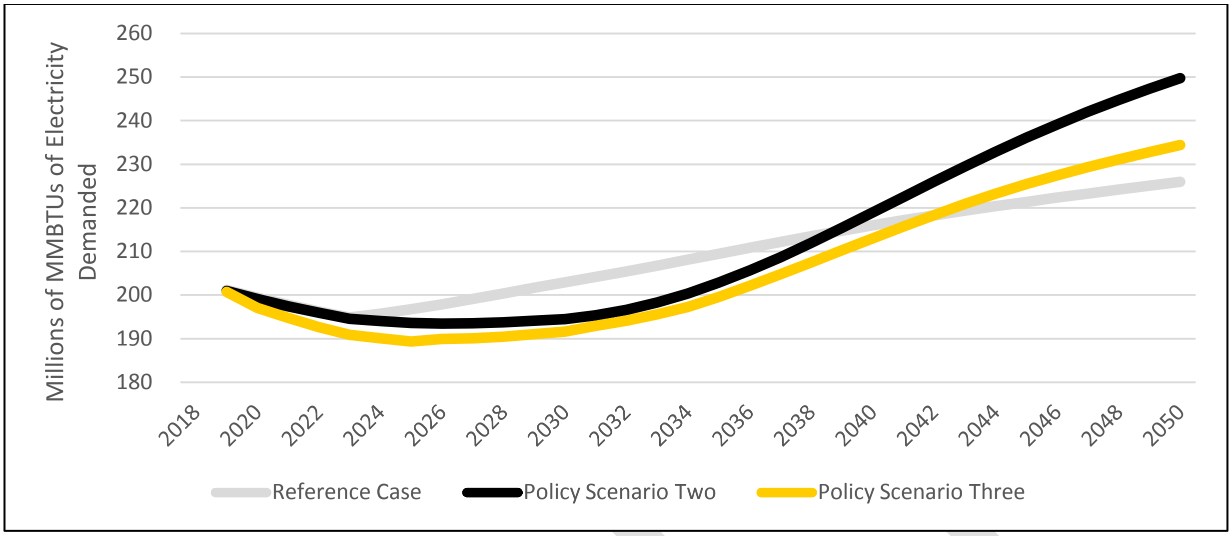
**Figure 19: Total Costs from Pathways in Policy Scenario Three Relative to the Reference Case**



Sources: E3, MDE, RESI

As seen in Figure 19, total costs in Policy Scenario Three never fall below levels of the reference case between 2020 and 2050. In the short term, spending on fuel is actually higher in Policy Scenario Three than in the reference case. This is due to the modeled carbon price increasing the cost of carbon-intensive fuels, an effect which outweighs reduced consumption by consumers and businesses. In the long term, a pattern similar to Policy Scenario Two emerges, where heightened levels of spending on capital costs outweigh the fuel savings from those purchases. The similarities between Policy Scenario Two and Policy Scenario Three with respect to electricity demand are represented in Figure 20.

**Figure 20: Electricity Demand in the Reference Case, Policy Scenario Two, and Policy Scenario Three**



Sources: E3, MDE, RESI

Policy Scenario Two and Policy Scenario Three both contain strategies to aggressively reduce carbon emissions in Maryland. However, the two scenarios contain very different policies, as Policy Scenario Two contains a more traditional mix of programs while Policy Scenario Three relies on carbon pricing. As shown in Figure 20, although these two policies pursue carbon reductions through different tactics, they lead to very similar patterns in energy consumption. Noticeable differences in electricity consumption between policy scenarios only emerge around 2038, with Policy Scenario Three not exhibiting the same increase in demand for electricity as seen in Policy Scenario Two, mostly in transportation.

### 7.5.2 Employment

To meet the economic goals as described in Section 7.3.7, policy scenarios must achieve positive job growth, on average, through 2030. This section presents detailed employment results for each policy scenario. In addition to the total employment trends, the following aspects will also be addressed for each policy scenario:

- Sensitivity analyses,
- Regional distribution of job impacts,
- Employment impacts by industry,
- Employment impacts by occupation,
- Employment impacts by job zone,
- Employment impacts by income levels, and
- Employment impacts from improved health outcomes.

Sensitivity analyses were conducted by evaluating employment impacts both with and without MDOT transportation measures. This was done due to the magnitude of the job impacts that resulted from this spending, and to provide a range of expected employment effects if funding levels vary from the initial projections.

Employment impacts were evaluated for the five-region Maryland model described in Section 7.3, and includes:

- **Central Maryland**: Baltimore City and Harford, Baltimore, Carroll, Anne Arundel, and Howard Counties;
- **Southern Maryland**: St. Mary's, Charles, and Calvert Counties;
- **Capital Maryland**: Frederick, Montgomery, and Prince George's Counties;
- **Western Maryland**: Garrett, Allegany, and Washington Counties; and
- **Eastern Shore**: Cecil, Kent, Queen Anne's, Talbot, Caroline, Dorchester, Wicomico, Somerset, and Worcester Counties.

Industries were defined using North American Industrial Classification System (NAICS) codes.[35] NAICS categorizes industries into two- to six-digit codes, with two-digit codes representing the broadest industry definitions, and six-digit codes representing specific industries on a more granular level. For employment results shown within this section, jobs were categorized into two-digit NAICS codes.

Jobs were categorized into professions using the Standard Occupational Classification (SOC) system. Similar to the structure of NAICS codes, this system organizes jobs from broad major groups to more detailed occupations.[36] For employment results shown within this section, occupations were categorized into major SOC groups.

Job zones were developed by O*NET as a way to categorize jobs based on their similarities in regard to education, related experience, and on-the-job training requirements.[37] These zones range from one through five, with Job Zone 1 requiring little to no preparation (e.g., dishwashers), and Job Zone 5 requiring many years of preparation (e.g., attorneys). Employment effects within this section are classified as follows.

- Job Zone 1: Some occupations may require a high school diploma or equivalent, and training would be expected to take several days to several months.
- Job Zone 2: Most occupations require a high school diploma or equivalent, and training would be expected to take several months to a year.
- Job Zone 3: Occupations typically require some additional education, such as vocational school or an associate degree, with training expected to take one to two years.
- Job Zone 4: Often require a bachelor's degree, with several years of training expected.

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[35] "North American Industry Classification System," U.S. Census Bureau, accessed February 14, 2019, https://www.census.gov/eos/www/naics/.

[36] "Standard Occupational Classification," U.S. Bureau of Labor Statistics, accessed February 14, 2019, https://www.bls.gov/soc/home.htm.

[37] "O*NET OnLine Help: Job Zones," O*NET OnLine, accessed February 13, 2019, https://www.onetonline.org/help/online/zones.

- Job Zone 5: Most occupations require an advanced degree, such as a master's degree or Ph. D., and may require additional training for specialization following degree attainment.[38]

The jobs supported by Policy Scenario One were further examined based on wage group. Each occupation was categorized into one of three groups based on median earnings for Maryland. These groups were categorized based on the following annual wages:

- Low-wage jobs: less than $35,000;
- Medium-wage jobs: between $35,000 and $65,000; and
- High-wage jobs: more than $65,000.[39]

Improved health outcomes affect employment through a number of avenues. First, because mortality is reduced due to cleaner air, the population survival rate increases. This subsequently causes the number of available workers in the labor pool to rise. Second, a reduction in morbidity will increase the labor productivity of workers as fewer sick days are taken. Third, while hospitals will receive less revenue from treating fewer patients, this money will be cycled back to consumers, insurance companies, and federal and state governments. The net employment effects depend upon on the structure of the economy and magnitude of the medical expenditures. Employment effects shown in this section consider each of these components when generating a net impact.

### 7.5.2.1 Employment in Policy Scenario One

Policy Scenario One, representing a continuation of existing and planned programs, achieves the economic goal of positive job growth through 2030. As seen in Figure 21, Policy Scenario One supports an average of 4,564 jobs each year through 2030 relative to the reference case.

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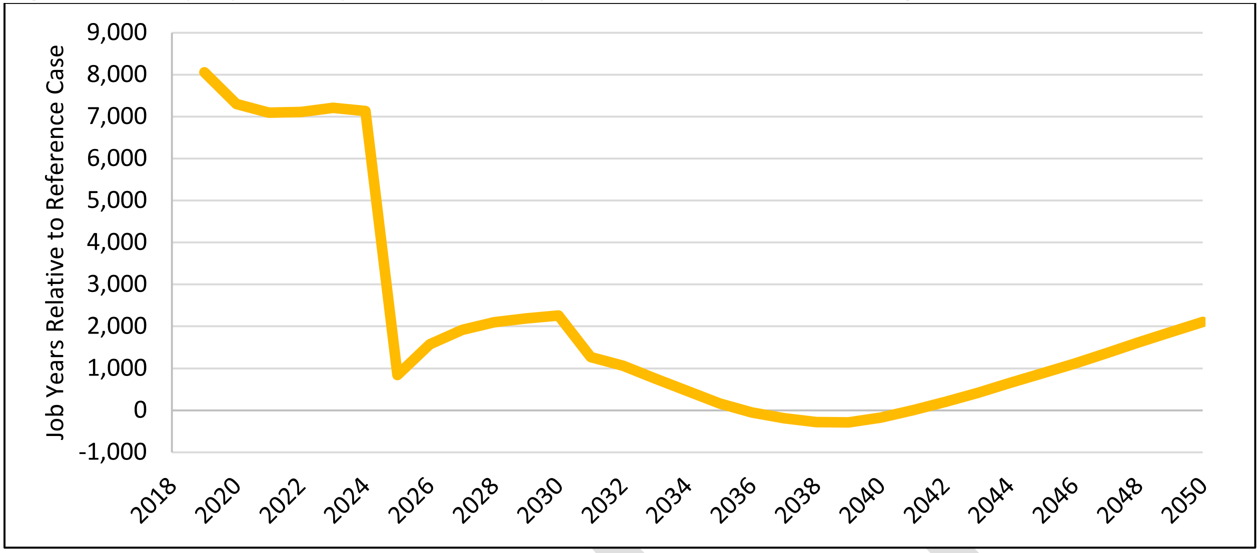
[38] "O*NET OnLine Help: Job Zones," O*NET OnLine.

[39] Wage categories were selected which roughly categorize Maryland's workforce into three equal groups. Therefore, if jobs are distributed equally across income levels, we would expect to see an equal number of jobs in all three groups.

**Figure 21: Employment by Year for Policy Scenario One, 2019 Through 2050**



Sources: REMI PI+, E3, MDE, MDOT, RESI

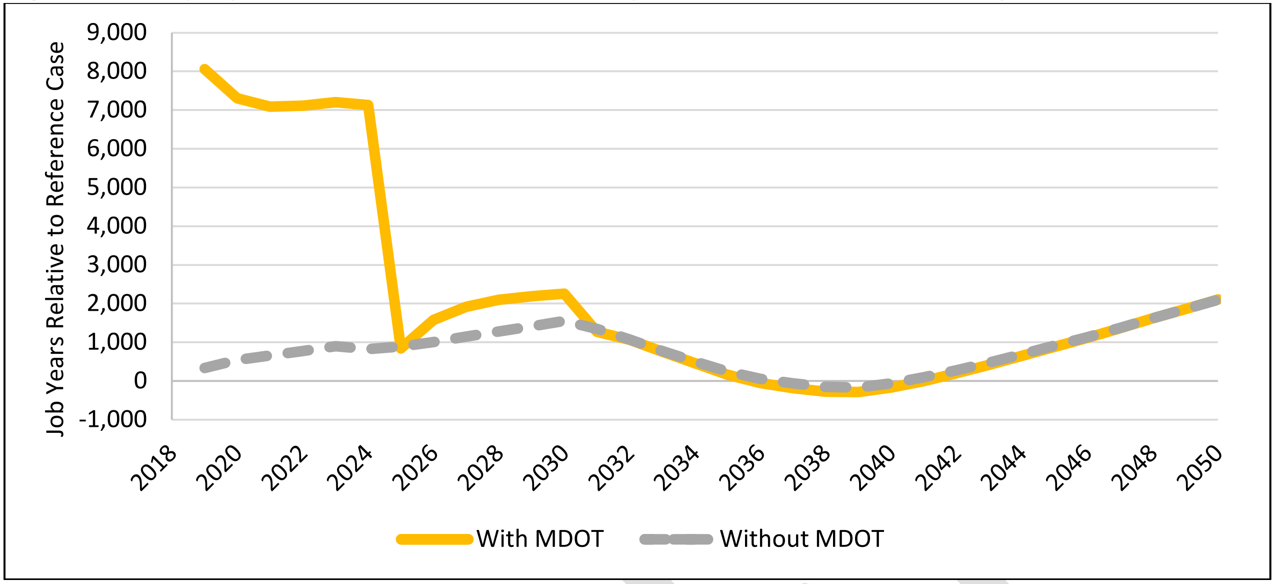
In the short term, employment gains are relatively high, due to spending on a variety of infrastructure projects, including new funding for Metropolitan Planning Organization (MPO) plans and programs. Many of these infrastructure projects are set to be completed by 2025, corresponding with the decrease in job growth seen at this time.

After 2030, job growth relative to the reference case slows and approaches zero. During this time, capital expenditures significantly outweigh reductions in energy consumption, as discussed in Section 7.5.1. One reason for this is the extension of EmPOWER, which begins in 2024 and extends through 2050. Additionally, new sales of zero emission vehicles in the later years of the study period are captured as increased capital costs. The fuel savings from these policies is seen in later years. After 2045, fuel savings outweigh capital costs and lead to higher growth relative to the reference case.

Another driver behind the employment patterns seen in Figure 21 is the increase of in-state renewable energy production. As Maryland's energy mix shifts from out-of-state fossil fuel and towards in-state wind and solar generation, new jobs are created in Maryland.

Although transportation spending in the near term constitutes a large percentage of the employment impacts, Figure 22 shows that job growth is dominantly positive relevant to the reference case, even after removing transportation spending from the model. Transportation spending in Policy Scenario One consists of two main phases as seen in the graph below.

**Figure 22: Employment with and without Transportation Measures in Policy Scenario One**



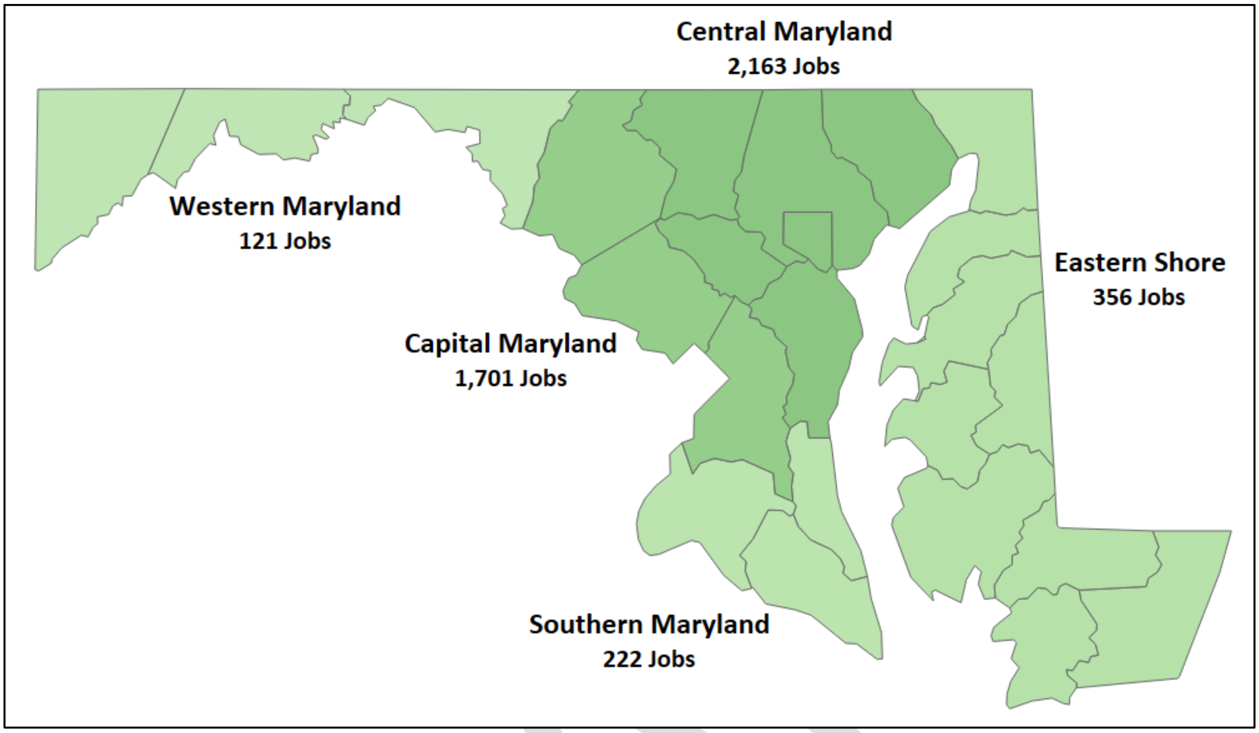
Sources: E3, MDE, MDOT, RESI

The majority of spending and associated jobs impacts occurs prior to 2025. A number of smaller projects extend through 2030, representing the smaller, yet significant difference between the employment estimates with and without MDOT measures. On average through 2030, the scenario without MDOT spending supports 3,620 fewer jobs annually compared to the scenario with MDOT spending.

As with each policy scenario evaluated, these employment effects will not be uniformly distributed across the various regions of the state. Each region of Maryland has a unique local economy that will respond differently to the policies outlined in each scenario, based on the composition of industries within the area. For example, Capital Maryland, which is heavily reliant on the on government and services industries, would be impacted differently by policies primarily affecting these industries than the Eastern Shore, where farming and natural resources industries are dominant.

As shown in Figure 23, no region within the state experiences job losses on average through 2030, relative to the reference case. Central Maryland has the largest gains with 2,163 jobs while the smallest gains of 121 jobs are found in Western Maryland. In terms of percentage growth, job gains are roughly distributed in line with Maryland's workforce; each of the regions experiences a 0.1 percent increase in employment on average between 2019 and 2030.

**Figure 23: Average Annual Employment Impacts by Region for Policy Scenario One, 2019 - 2030**



Sources: E3, MDE, RESI

Figure 24 outlines the composition of employment gains by industry.

**Figure 24: Average Annual Employment by Industry for Policy Scenario One, 2019 - 2030**

| NAICS | Industry | Average Annual Jobs Through 2030 |
|---|---|---:|
| 11 | Agriculture, Forestry, Fishing and Hunting | 72 |
| 21 | Mining, Quarrying, and Oil and Gas Extraction | -21 |
| 22 | Utilities | 245 |
| 23 | Construction | 5,156 |
| 31-33 | Manufacturing | 47 |
| 42 | Wholesale Trade | -2 |
| 44-45 | Retail Trade | -557 |
| 48-49 | Transportation and Warehousing | 3 |
| 51 | Information | -12 |
| 52 | Finance and Insurance | -58 |
| 53 | Real Estate and Rental and Leasing | -44 |
| 54 | Professional, Scientific, and Technical Services | 89 |
| 55 | Management of Companies and Enterprises | -7 |
| 56 | Administrative and Support and Waste | 6 |

| NAICS | Industry | Average Annual Jobs Through 2030 |
|---|---|---:|
| | Management and Remediation Services | |
| 61 | Educational Services | -16 |
| 62 | Health Care and Social Assistance | -174 |
| 71 | Arts, Entertainment, and Recreation | -42 |
| 72 | Accommodation and Food Services | -104 |
| 81 | Other Services (except Public Administration) | -169 |
| 92 | Public Administration | 153 |
| **Total** | | **4,564** |

Sources: E3, MDE, REMI PI+, RESI, U.S. Census

As detailed above, the vast majority of these jobs are estimated to be in the construction industry, and is likely reflective of the transportation infrastructure projects. Conversely, Retail Trade posts the largest declines of 557 jobs, followed by Health Care and Social Assistance (loss of 174 jobs) and Other services (decrease of 169 jobs). A significant proportion of retail job losses are likely attributed to projected declines in gas station use, as consumers shift from gasoline-fuel vehicles to electric and hybrid vehicles. Notably, however, these impacts may be lessened if gas stations shift with market demand to repurpose as charging stations. The REMI model assumes a relatively consistent structure of the Maryland economy over time, and would not account for these dynamic or innovative industry changes.

Figure 25 below shows the distribution of employment impacts by occupation. Please note that the total average number jobs may not match the industry total due to rounding.

**Figure 25: Employment by Occupation for Policy Scenario One**

| SOC Code | SOC Description | Average Jobs Through 2030 |
|---|---|---:|
| 11 | Management Occupations | 308 |
| 13 | Business and Financial Operations Occupations | 170 |
| 15 | Computer and Mathematical Occupations | 25 |
| 17 | Architecture and Engineering Occupations | 95 |
| 19 | Life, Physical, and Social Science Occupations | 8 |
| 21 | Community and Social Service Occupations | -8 |
| 23 | Legal Occupations | 8 |
| 25 | Education, Training, and Library Occupations | 36 |
| 27 | Arts, Design, Entertainment, Sports, and Media Occupations | -8 |
| 29 | Healthcare Practitioners and Technical Occupations | -52 |
| 31 | Healthcare Support Occupations | -40 |
| 33 | Protective Service Occupations | 15 |

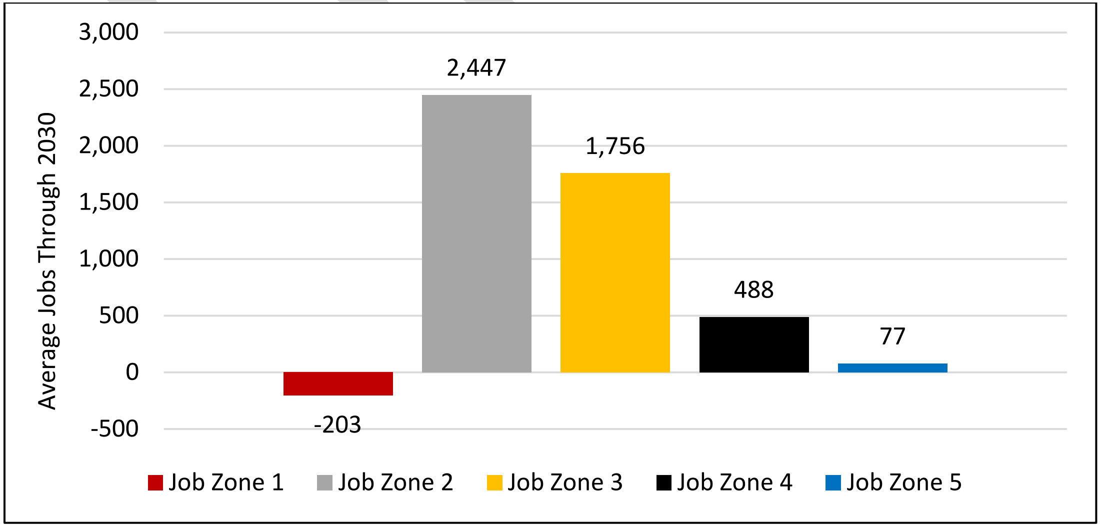
| SOC Code | SOC Description | Average Jobs Through 2030 |
|---|---|---|
| 35 | Food Preparation and Serving Related Occupations | -108 |
| 37 | Building and Grounds Cleaning and Maintenance Occupations | 7 |
| 39 | Personal Care and Service Occupations | -99 |
| 41 | Sales and Related Occupations | -211 |
| 43 | Office and Administrative Support Occupations | 368 |
| 45 | Farming, Fishing, and Forestry Occupations | 41 |
| 47 | Construction and Extraction Occupations | 3,245 |
| 49 | Installation, Maintenance, and Repair Occupations | 494 |
| 51 | Production Occupations | 131 |
| 53 | Transportation and Material Moving Occupations | 140 |
| **Total** | | **4,564** |

Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

The greatest employment gains are projected to be in Construction and Extraction Occupations with an estimated 3,245 jobs, and are likely supported by the marked increase in construction activity. The second-highest increase is shown in Installation, Maintenance, and Repair Occupations (494 jobs), driven by the increase in self-supplied renewable energy production. Additionally, workers in Office and Administrative Support Occupations (368); Management Occupations (308); and Business and Financial Operations Occupations (170) are also expected to have significant job gains.

Figure 26 below shows the distribution of employment changes by job zone, as previously defined in Section 7.5.2.

**Figure 26: Employment by Job Zone for Policy Scenario One**

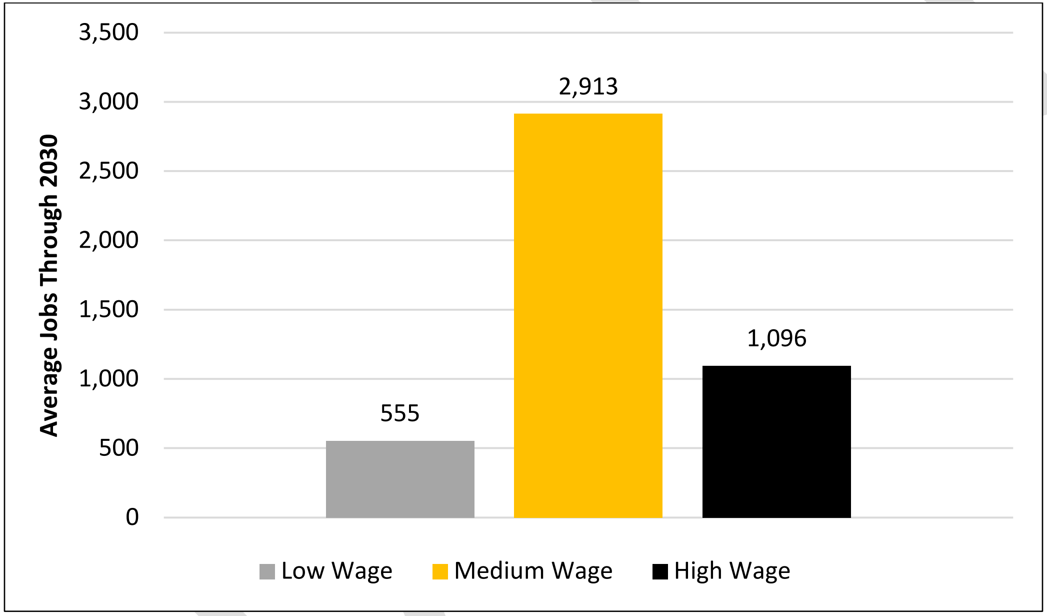


Sources: E3, MDE, O*Net, REMI PI+, RESI

Simulations for Policy Scenario One indicate robust job growth for occupations in Job Zones 2 and 3, with small losses occurring in Job Zone 1, generally representing a loss of cashiers associated with gas stations. This indicates that while jobs requiring the lowest levels of preparation are lost, the most-substantial increases are in jobs that typically require modest preparation (typically ranging from a high school diploma or equivalent to vocational school or an associate degree).[40] These results are largely being driven by the transportation projects and the growing wind and solar power generation sectors. The growth in jobs in job zones 2 and 3 mean that retraining and repositioning workers for the new economy in Maryland will be less burdensome than if jobs were created that required extensive training or education. In that case, Maryland would likely fill the job openings through recruiting talent from out-of-state, as opposed to boosting employment of current residents.

Figure 27 illustrates employment results by wage group, as previously outlined in Section 7.5.2.

**Figure 27: Employment by Wage Group for Policy Scenario One**



Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

The graph above indicates that the jobs supported by Policy Scenario One are largely medium-wage jobs, but there are also significant gains in high-wage jobs as well. Low-wage jobs represent the smallest proportion of employment gains. These shifts are likely due to the slightly increased preparation required for new employment opportunities, as shown in the distribution of occupations by Job Zone.

Figure 28 details the expected employment impacts resulting from changes in health outcomes, as described in Section 7.5.2.

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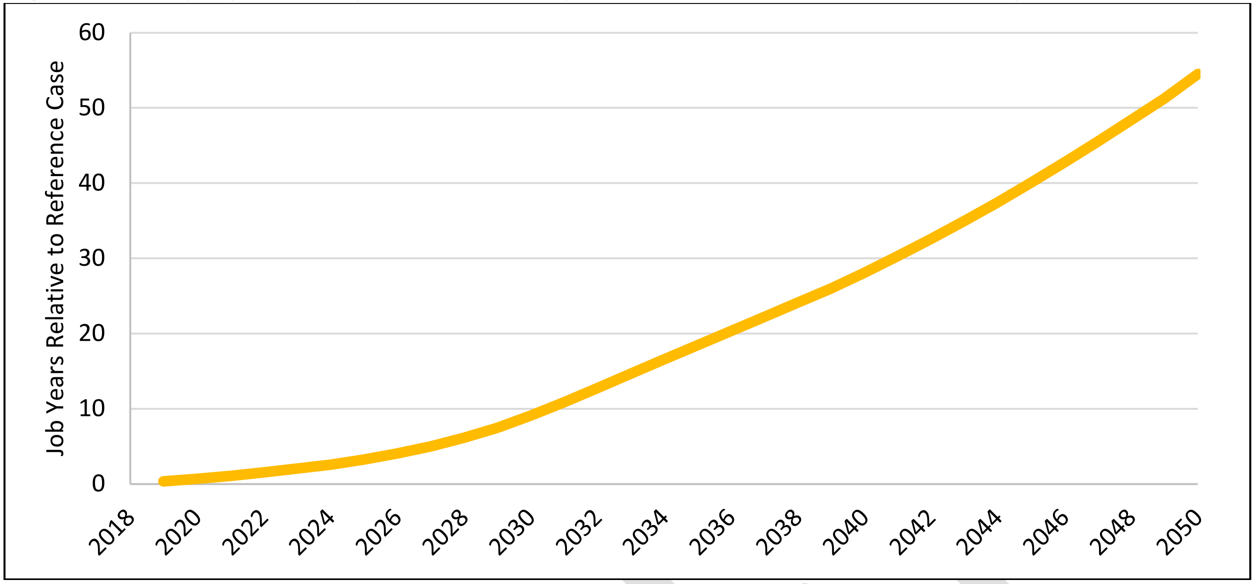
[40] "O*NET OnLine Help: Job Zones," O*NET OnLine.

**Figure 28: Employment Impacts Due to Improved Health Outcomes for Policy Scenario One**



Sources: E3, MDE, MDOT, RESI, U.S. EPA

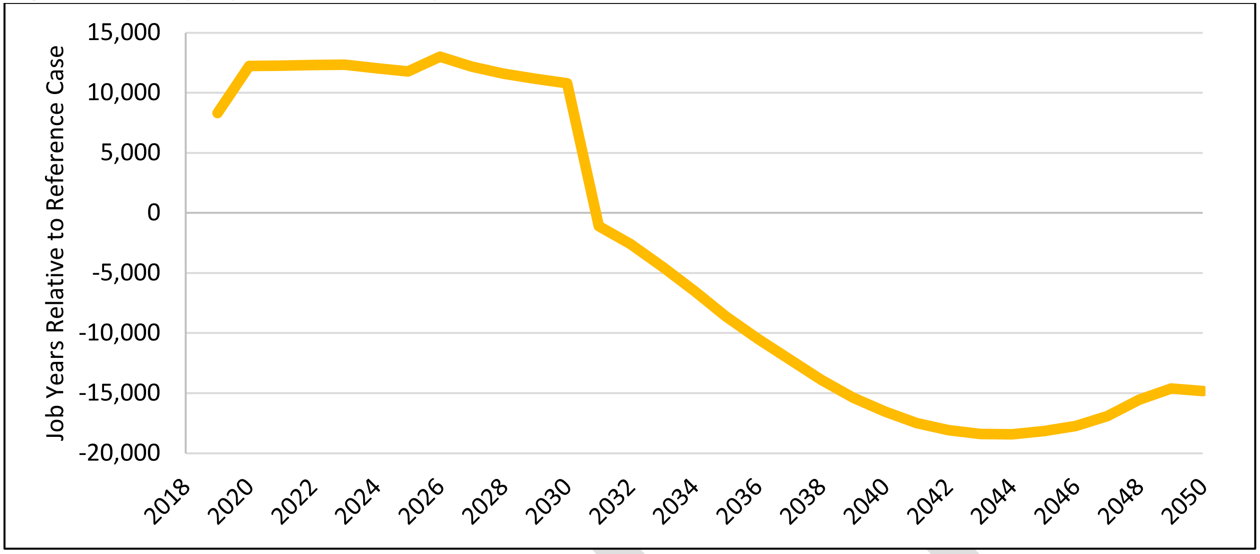
As illustrated above, the number of jobs due to improved health outcomes from Policy Scenario One grows exponentially, averaging approximately 4 jobs per year through 2030 and 20 jobs per year through 2050. This exponential growth is due to the cumulative effects of air pollution reduction. Detailed results for health impacts are found in Appendix C.5.

### 7.5.2.2 Employment in Policy Scenario Two

Total employment in Policy Scenario Two follows a similar trend as in Policy Scenario One, but with more extreme highs and more extreme lows. On average, Policy Scenario Two supports approximately 11,665 jobs annually through 2030, with these impacts largely resulting from transportation strategies implemented by MDOT. Specifically, the Traffic Relief Plan Implementation, Intermodal Freight Centers Access Improvement, and Transit Capacity/Service Expansion are responsible for most of the near-term transportation-related jobs.

Figure 29 shows employment changes in Policy Scenario Two, with declines observed around 2025 and 2030. These drops in employment correspond with MDOT project timelines, most of which are forecasted to be completed by 2025, with some projects having an estimated completion date of 2030.

**Figure 29: Employment for Policy Scenario Two**

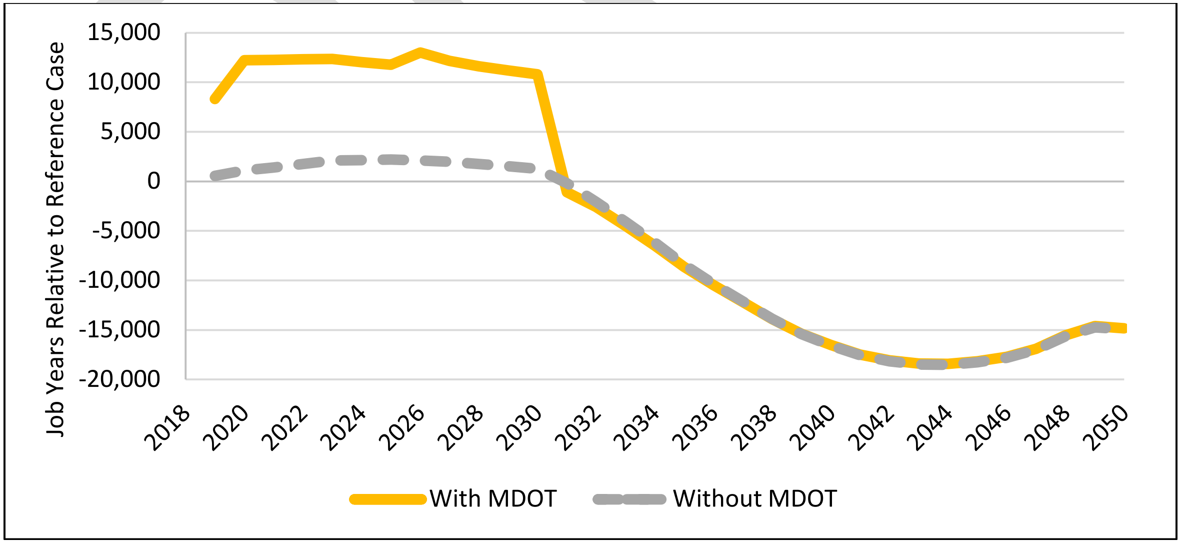


Sources: REMI PI+, E3, MDE, MDOT, RESI

In the years beyond 2030, employment levels drop relative to the reference case. This is mainly due to the more aggressive emissions assumptions for Policy Scenario Two. Consumers and businesses are spending more on capital relative to their fuel savings, producing a net cost to the economy. However, this divergence becomes less pronounced in the long-term as the total costs (referenced in Section 7.5.1) approach zero.

Figure 30 shows the difference in employment effects with and without funding directed towards transportation measures.

**Figure 30: Employment Impacts due to Transportation Measures for Policy Scenario Two**

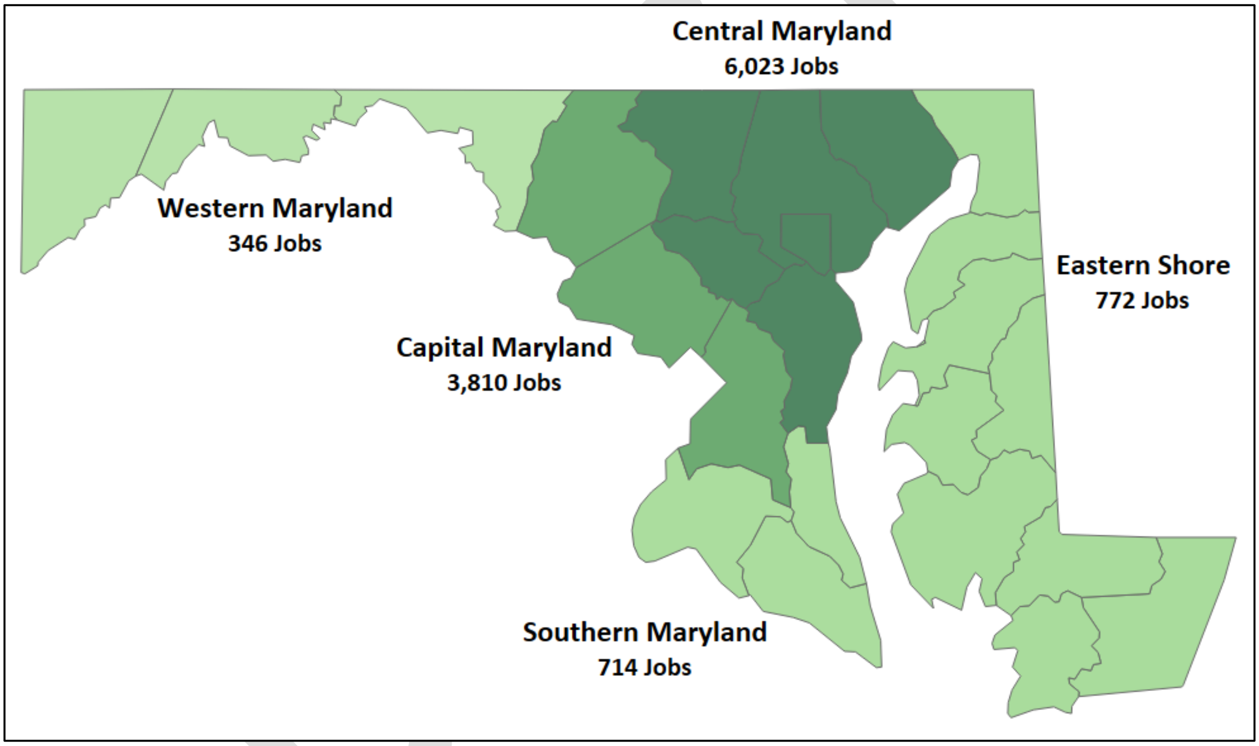


Sources: REMI PI+, E3, MDE, MDOT, RESI

Similar to Policy Scenario One, there is a large divergence in the near-term between the scenarios with and without MDOT projects, with the effects becoming virtually identical after 2030 as the MDOT measures are set to expire. On average through 2030, the scenario without MDOT spending supports 10,013 fewer jobs annually compared to the scenario with MDOT spending. Compared to Policy Scenario One and Three, this is the greatest difference between MDOT spending scenarios.

As was the case for Policy Scenario One, no region of Maryland loses jobs on average through 2030 under Policy Scenario Two. Figure 31 shows the regional distribution of jobs under Policy Scenario Two, with darker-shaded areas having greater average employment gains.

**Figure 31: Average Annual Employment Impacts by Region for Policy Scenario Two, 2019-2030**



Sources: E3, MDE, RESI

Central Maryland continues to show the largest gains with 6,023 jobs, followed by Capital Maryland with 3,810 jobs. However, on a percentage basis, Southern Maryland experiences the highest levels of growth, with employment increasing by 0.4 percent. Job gains in other regions are similarly modest, ranging from a 0.2 percent increase in Western Maryland to 0.3 percent in the other three regions of the state. Figure 31 illustrates that even in the most aggressive policy scenario with regards to reducing carbon emissions, all regions of Maryland benefit, not just urban centers or rural areas.

Employment distributions by major NAICS industries are outlined in Figure 32. As shown below, Construction is responsible for almost three quarters of the jobs supported by Policy Scenario Two, creating an average of 8,331 jobs through 2030. Significant gains are also observed in Public Administration with an increase of 700 jobs, and Transportation and Warehousing with 574 additional positions.

**Figure 32: Employment Impacts by Industry for Policy Scenario Two, 2019-2030**

| NAICS | Industry | Annual Average Number of Jobs, 2019-2030 |
|---|---|---|
| 11 | Agriculture, Forestry, Fishing and Hunting | 131 |
| 21 | Mining, Quarrying, and Oil and Gas Extraction | -39 |
| 22 | Utilities | 154 |
| 23 | Construction | 8,331 |
| 31-33 | Manufacturing | 210 |
| 42 | Wholesale Trade | 98 |
| 44-45 | Retail Trade | 47 |
| 48-49 | Transportation and Warehousing | 574 |
| 51 | Information | 17 |
| 52 | Finance and Insurance | 30 |
| 53 | Real Estate and Rental and Leasing | 297 |
| 54 | Professional, Scientific, and Technical Services | 286 |
| 55 | Management of Companies and Enterprises | 22 |
| 56 | Administrative and Support and Waste Management and Remediation Services | 231 |
| 61 | Educational Services | 41 |
| 62 | Health Care and Social Assistance | 278 |
| 71 | Arts, Entertainment, and Recreation | 2 |
| 72 | Accommodation and Food Services | 183 |
| 81 | Other Services (except Public Administration) | 73 |
| 92 | Public Administration | 700 |
| **Total** | | **11,665** |

Sources: E3, MDE, REMI PI+, RESI, U.S. Census

In contrast to Policy Scenario One, only one industry experiences job losses relative to the reference case. Those losses that do occur are in Mining, Quarrying, and Oil and Gas Extraction, with a decrease of 39 jobs, and reflect the aggressive push to lower dependency on fossil-fuel generated energy.

The occupational distributions of employment changes within Policy Scenario Two are detailed in Figure 33.

**Figure 33: Employment Impacts by Occupation for Policy Scenario Two**

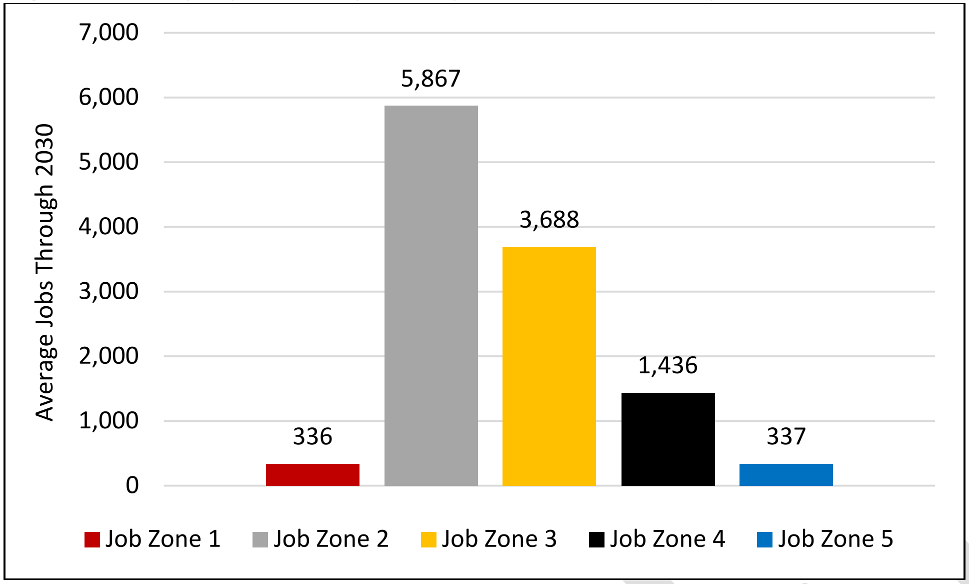
| SOC Code | SOC Description | Annual Average Number of Jobs, 2019-2030 |
|---|---|---|
| 11 | Management Occupations | 703 |
| 13 | Business and Financial Operations Occupations | 434 |
| 15 | Computer and Mathematical Occupations | 114 |
| 17 | Architecture and Engineering Occupations | 169 |
| 19 | Life, Physical, and Social Science Occupations | 30 |
| 21 | Community and Social Service Occupations | 46 |
| 23 | Legal Occupations | 34 |
| 25 | Education, Training, and Library Occupations | 278 |
| 27 | Arts, Design, Entertainment, Sports, and Media Occupations | 38 |
| 29 | Healthcare Practitioners and Technical Occupations | 143 |
| 31 | Healthcare Support Occupations | 63 |
| 33 | Protective Service Occupations | 114 |
| 35 | Food Preparation and Serving Related Occupations | 195 |
| 37 | Building and Grounds Cleaning and Maintenance Occupations | 185 |
| 39 | Personal Care and Service Occupations | 101 |
| 41 | Sales and Related Occupations | 351 |
| 43 | Office and Administrative Support Occupations | 1,232 |
| 45 | Farming, Fishing, and Forestry Occupations | 76 |
| 47 | Construction and Extraction Occupations | 5,258 |
| 49 | Installation, Maintenance, and Repair Occupations | 963 |
| 51 | Production Occupations | 315 |
| 53 | Transportation and Material Moving Occupations | 825 |
| **Total** | | **11,665** |

Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

On average, no major occupational group experiences losses in Policy Scenario Two. Construction and Extraction Occupations post the largest gains at 5,258 jobs on average through 2030, followed by Office and Administrative Support Occupations with average increases of 1,232 positions. Life, Physical, and Social Science Occupations and Legal Occupations show the smallest gains of 30 and 34 jobs, respectively. A substantial portion of the jobs in the Life, Physical, and Social Science Occupations are in the Chemical Manufacturing or Oil and Gas Extraction industries. Given this, gains to these occupations resulting from the push towards renewable energy generation will likely be diminished by losses in those industries.

As illustrated in Figure 34, no occupations in any of the five job zones experience losses on average through 2030.

**Figure 34: Employment Impacts by Job Zone for Policy Scenario Two**

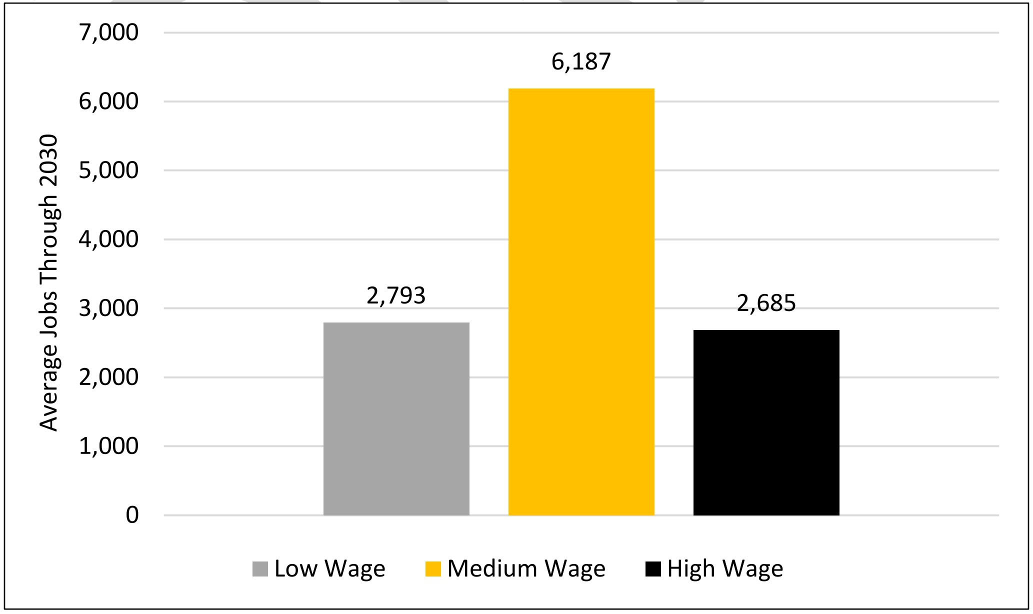


Sources: E3, MDE, O*Net, REMI PI+, RESI

Similar to the results for Policy Scenario One, the simulation results for Policy Scenario Two show that the largest employment gains will be in Job Zone 2 and Job Zone 3. Job gains in zones that require less education or training may work to increase the labor force participation rate in the state, as these jobs have fewer barriers to entry.

Employment distributions by wage group for Policy Scenario Two are illustrated in Figure 35 below.

**Figure 35: Employment Impacts by Wage Group for Policy Scenario Two**

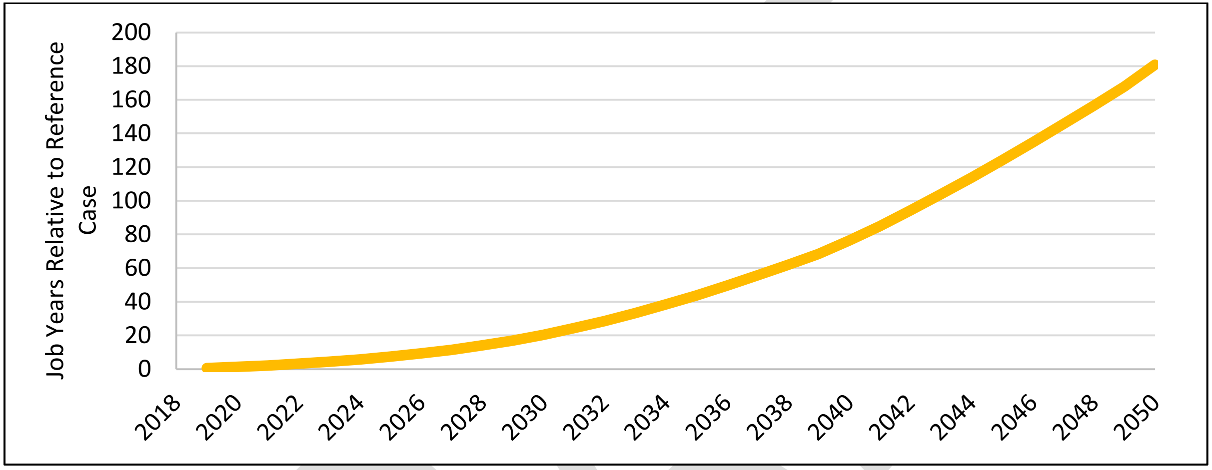


Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

As in Policy Scenario One, medium-wage occupations show the largest gains under Policy Scenario Two. However, unlike in Policy Scenario One, low-wage jobs are estimated to form a slightly higher proportion of the supported occupations relative to high-wage jobs. This is likely due to the larger proportion of jobs in Office and Administrative Support occupations. These occupations are likely supported by the strong job gains in the construction industry.

The employment impacts due to improved health outcomes for Policy Scenario Two, illustrated in Figure 36, show a similar pattern as in Policy Scenario One.

**Figure 36: Employment Impacts of Improved Health Outcomes for Policy Scenario Two**



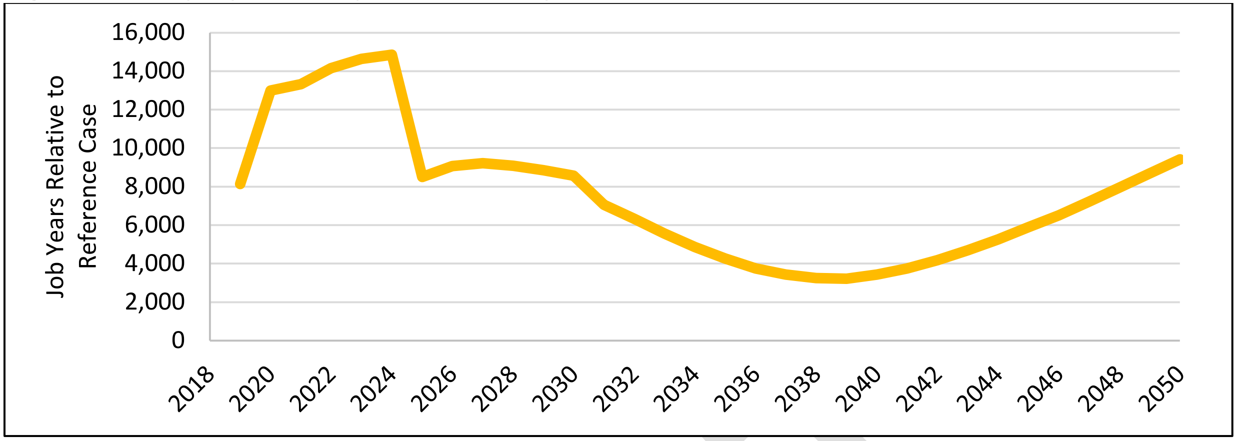
Sources: E3, MDE, MDOT, RESI, U.S. EPA

Notably, because emissions reductions are more substantial in Policy Scenario Two as compared to Policy Scenario One, the magnitude of job gains are larger—supporting an average of 8 jobs through 2030 and 59 jobs through 2050. Detailed results for health impacts are found in Appendix C.5.

### 7.5.2.3 Employment in Policy Scenario Three

Policy Scenario Three supports, on average, 10,950 jobs through 2030 relative to the reference case. The general trends remain similar to the other two policy scenarios, with the increase in the near-term but then leveling out over the long-term. The spike in employment before 2025, shown in Figure 37 below, is due to the transportation infrastructure projects as well as additional mitigation measures funded by carbon fee revenues.

**Figure 37: Employment Impacts for Policy Scenario Three**

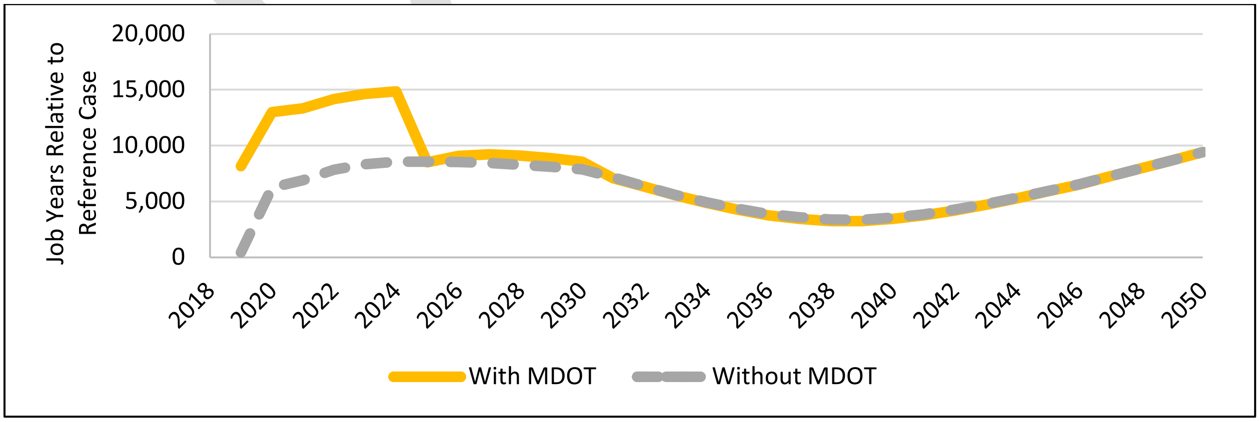


Sources: REMI PI+, E3, MDE, MDOT, RESI

The carbon fee in this policy scenario effectively acts as a transfer mechanism. Because Maryland is a net importer of energy, revenue is generally derived from out-of-state businesses. The revenue is then spent mostly within Maryland, either through rebates to consumers, job training programs, additional mitigation measures, or on adaptation and resilience funds for local governments. If employment outside of Maryland were considered in this report, job gains would likely be more modest. However, Maryland's unique structure enables the pattern illustrated in Figure 37. This transfer effect due to the carbon fee may also be visualized by comparing employment impacts between Policy Scenario Two and Policy Scenario Three. While in Policy Scenario Two there was a dip in employment after 2030, the carbon fee revenue is able to boost employment in the long-run for Policy Scenario Three through the mechanisms described above.

Figure 38 shows how the incorporation of the MDOT transportation measures impacts the simulation results.

**Figure 38: Employment Impacts With and Without Transportation Measures for Policy Scenario Three**

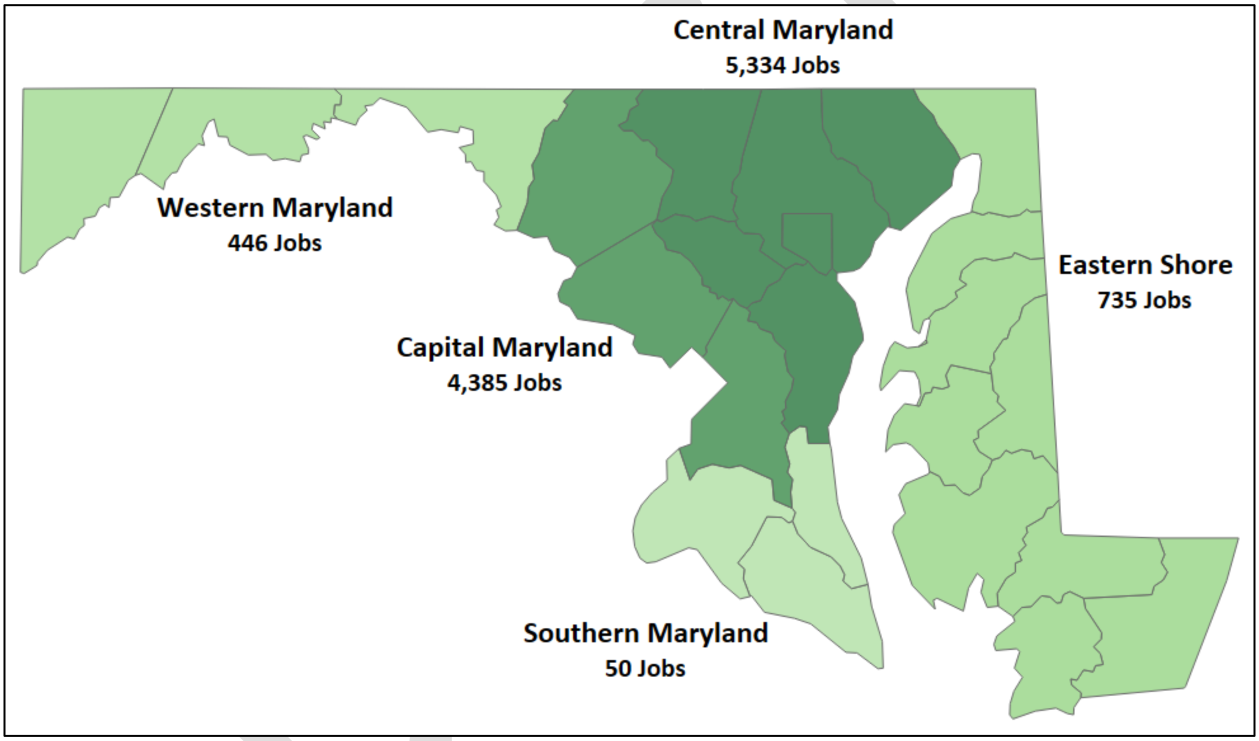


Sources: REMI PI+, E3, MDE, MDOT, RESI

Compared to the other two scenarios, the MDOT spending impacts are similar to Policy Scenario One with these measures supporting, on average, 3,614 more jobs through 2030 compared to the scenario without MDOT spending. This is illustrated above in Figure 38 as the difference between the two lines. Once again, the employment changes are observed between the two spending scenarios as the majority of MDOT projects are completed in 2025, with additional projects being completed in 2030.

On average, as seen in Figure 39, no region of Maryland experiences job losses relative to the reference case through 2030 for Policy Scenario Three. As with the other two policy scenarios, Central Maryland sustains the largest gains at 5,334 jobs.

**Figure 39: Employment Impacts by Region for Policy Scenario Three**



Sources: E3, MDE, RESI

Significant employment increases are also observed in Capital Maryland, with 4,385 jobs. On a percentage basis, job gains are very similar in all regions except for Southern Maryland. All other regions experience a 0.3 percent increase in employment through 2030 under Policy Scenario Three, while employment in Southern Maryland remains more or less constant, only seeing an increase of 50 jobs. Notably, while average job gains are generally comparable between Policy Scenario Two and Policy Scenario Three through 2030, job gains differ slightly regionally. Capital Maryland, consisting of the Washington, D.C. suburbs, experiences higher rates of job growth in Policy Scenario Three than in Policy Scenario Two (4,385 jobs compared to 3,810). The Eastern Shore and Southern Maryland experience declines, largely due to the effect of carbon pricing on the farming industry. As noted in Section 7.3.6, the farming industry is impacted by changes in the price of gasoline and diesel applied only in Maryland, making rural areas of Maryland more impacted by this policy bundle.

Employment changes by major industry are shown below in Figure 40. The Construction industry, which captures an average of 7,534 annual jobs, represents nearly 69 percent of the jobs supported by Policy Scenario Three.

**Figure 40: Employment Impacts by Industry for Policy Scenario Three**

| NAICS | Industry | Annual Average Number of Jobs, 2019-2030 |
|---|---|---:|
| 11 | Agriculture, Forestry, Fishing and Hunting | -171 |
| 21 | Mining, Quarrying, and Oil and Gas Extraction | -77 |
| 22 | Utilities | -312 |
| 23 | Construction | 7,534 |
| 31-33 | Manufacturing | -13 |
| 42 | Wholesale Trade | 108 |
| 44-45 | Retail Trade | 995 |
| 48-49 | Transportation and Warehousing | -73 |
| 51 | Information | 14 |
| 52 | Finance and Insurance | 18 |
| 53 | Real Estate and Rental and Leasing | 127 |
| 54 | Professional, Scientific, and Technical Services | 229 |
| 55 | Management of Companies and Enterprises | 2 |
| 56 | Administrative and Support and Waste Management and Remediation Services | 117 |
| 61 | Educational Services | 30 |
| 62 | Health Care and Social Assistance | 1,196 |
| 71 | Arts, Entertainment, and Recreation | -2 |
| 72 | Accommodation and Food Services | 88 |
| 81 | Other Services (except Public Administration) | 35 |
| 92 | Public Administration | 1,106 |
| **Total** | | **10,950** |

Sources: E3, MDE, REMI PI+, RESI, U.S. Census

The increase in Construction jobs are due not only to the transportation measures by MDOT, but also the additional mitigation measures funded by the carbon fee revenues. Notable increases are also found in the Health Care and Social Assistance industry and Public Administration industry, with increases of 1,196 and 1,106 jobs, respectively. Relative to the reference case, Utilities; Agriculture, Forestry, Fishing, and Hunting; and Transportation and Warehousing industries experience the largest declines, on average, through 2030. While the previous two scenarios showed increases to Agriculture, Forestry, Fishing, and Hunting, the employment losses in Policy Scenario Three are due to the effect of the carbon fee on farming. As discussed earlier, the increase in the cost of gasoline and diesel as a result of the carbon pricing impacts the price-sensitive farming industry, but its application only in Maryland leaves farms in surrounding states unaffected, causing Maryland farms to lose business to competitors elsewhere in the region. Job losses in the broader Agriculture, Forestry, and Fishing sector as seen in Figure 40 are balanced out slightly by investments in adaptation and resilience programs funded by carbon fee revenues.

The occupational distribution of jobs follows a similar pattern to the effects by industry for Policy Scenario Three, as illustrated in Figure 41. Construction and Extraction Occupations post the largest gains of 4,720 jobs created on average through 2030, followed by Office and Administrative Support Occupations with 1,148 jobs.

**Figure 41: Employment Impacts by Occupation for Policy Scenario Three**

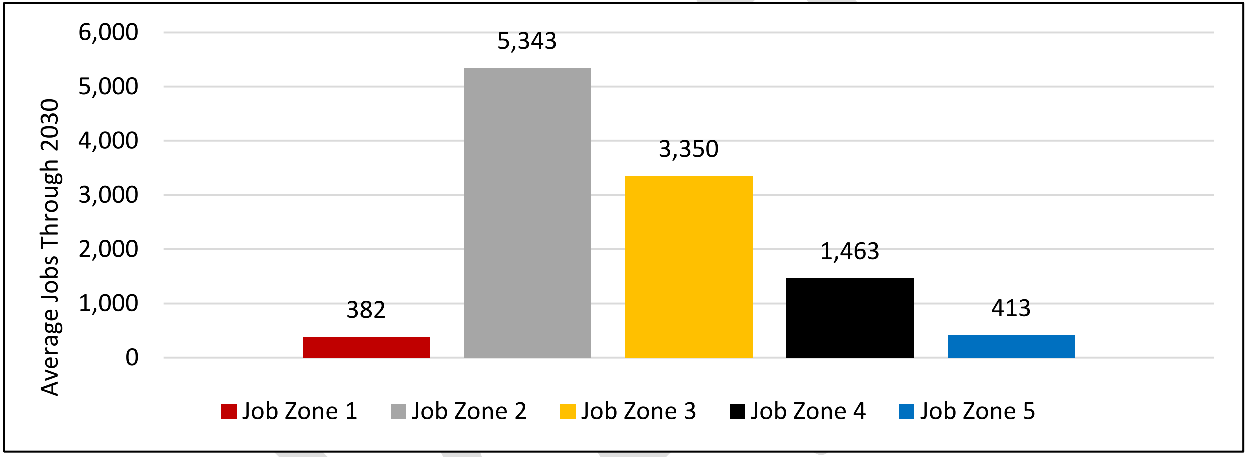
| SOC Code | SOC Description | Annual Average Number of Jobs, 2019-2030 |
|---|---|---:|
| 11 | Management Occupations | 589 |
| 13 | Business and Financial Operations Occupations | 337 |
| 15 | Computer and Mathematical Occupations | 72 |
| 17 | Architecture and Engineering Occupations | 86 |
| 19 | Life, Physical, and Social Science Occupations | 3 |
| 21 | Community and Social Service Occupations | 171 |
| 23 | Legal Occupations | 29 |
| 25 | Education, Training, and Library Occupations | 564 |
| 27 | Arts, Design, Entertainment, Sports, and Media Occupations | 41 |
| 29 | Healthcare Practitioners and Technical Occupations | 201 |
| 31 | Healthcare Support Occupations | 136 |
| 33 | Protective Service Occupations | 134 |
| 35 | Food Preparation and Serving Related Occupations | 169 |
| 37 | Building and Grounds Cleaning and Maintenance Occupations | 141 |
| 39 | Personal Care and Service Occupations | 458 |
| 41 | Sales and Related Occupations | 779 |
| 43 | Office and Administrative Support Occupations | 1,148 |
| 45 | Farming, Fishing, and Forestry Occupations | -39 |
| 47 | Construction and Extraction Occupations | 4,720 |
| 49 | Installation, Maintenance, and Repair Occupations | 721 |
| 51 | Production Occupations | 135 |
| 53 | Transportation and Material Moving Occupations | 354 |
| **Total** | | **10,950** |

Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

During this same period, Farming, Fishing, and Forestry occupations show the largest average annual declines of 39 jobs—the only major occupational group with an average negative impact. These 39 jobs being lost are largely due to the effect of the carbon fee on the farming industry. As described previously, these impacts are offset somewhat by investments in state forestry programs, as well as adaptation and resilience programs. Despite the offsets from these investments, the net effect in the broader industry are still negative, on average.

The employment impacts by job zone for Policy Scenario Three are similar in distribution to Policy Scenario Two, as illustrated in Figure 42.

**Figure 42: Employment Impacts by Job Zone for Policy Scenario Three**

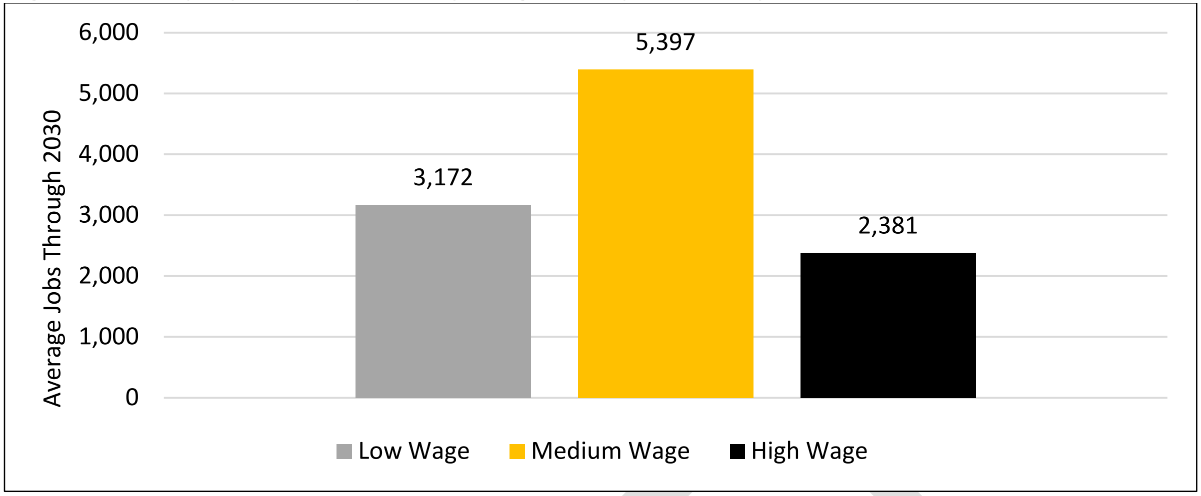


Sources: E3, MDE, O*Net, REMI PI+, RESI

Approximately 5,343 of the 10,950 jobs sustained in Policy Scenario Three will fall into Job Zone 2, which as previously described in Section 7.5.2, typically require a high school diploma or equivalent. The second- and third-highest increases are seen in Job Zones 3 and 4, respectively, which require increasing levels of preparation. On average, under Policy Scenario 3, no job zone is expected to have negative impacts through 2030.

Employment distributions for Policy Scenario Three by wage group are outlined in Figure 43 below.

**Figure 43: Employment Impacts by Wage Group for Policy Scenario Three**

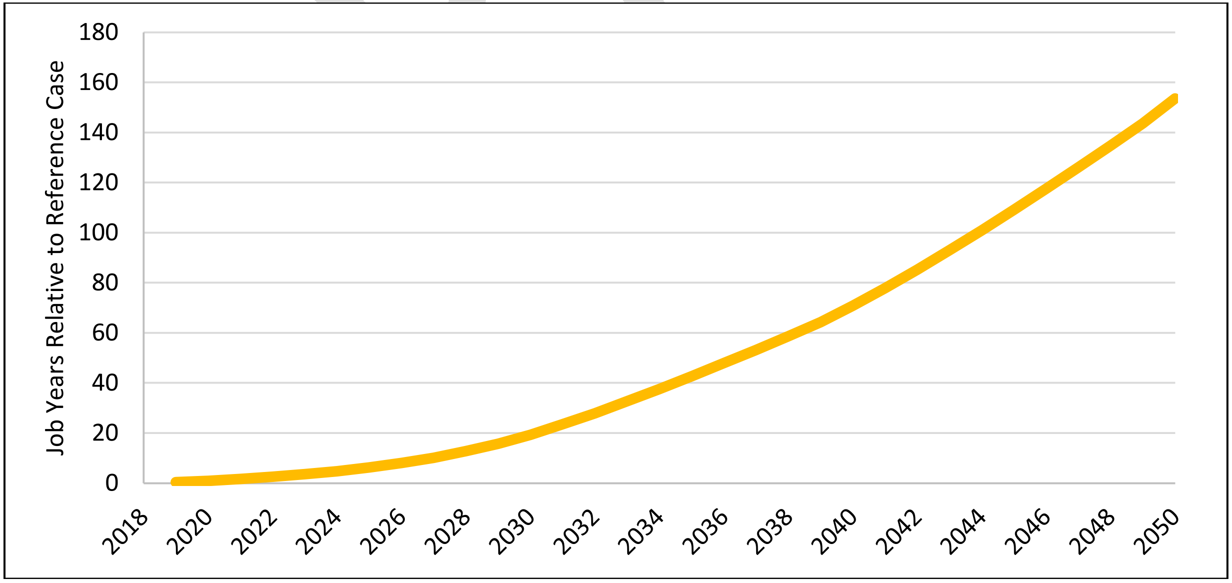


Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

The distribution of the jobs supported by Policy Scenario Three are also similar to those in Policy Scenario Two, with roughly half the jobs being in medium-wage occupations. Contrary to the results in Policy Scenario One, more jobs will be supported in the low-wage group than in the high-wage group.

The effects of improved health outcomes on employment for Policy Scenario Three are illustrated in Figure 44.

**Figure 44: Employment Impacts from Improved Health Outcomes for Policy Scenario Three**



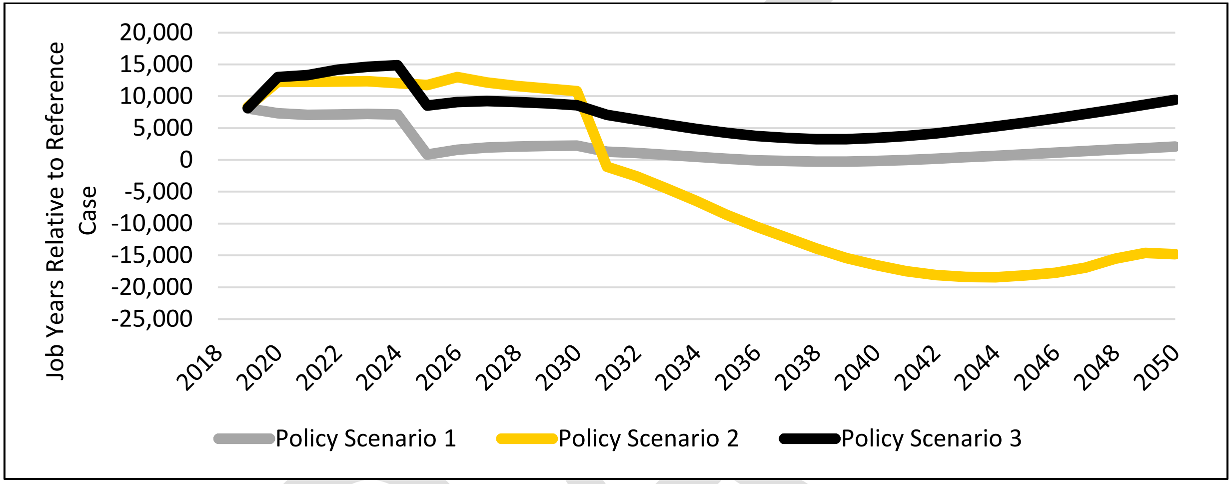
Sources: E3, MDE, MDOT, RESI, U.S. EPA

On average, between 2019 and 2030 Policy Scenario Three will sustain seven jobs. By 2050 this figure increases to nearly 53 jobs annually. The magnitudes of the employment impacts vary with the levels of emissions reductions. Thus, Policy Scenario One, which has the lowest emission reductions, supports the least amount of jobs while Policy Scenario Two, which aggressively targets emissions, supports the most. Policy Scenario Three falls in the middle of these two scenarios.

### 7.5.2.4 Comparison of Employment Levels Across Policy Scenarios

Overall, as illustrated in Figure 45, all three policy scenarios exhibit average positive job growth through 2030.

**Figure 45: Total Employment for Policy Scenarios One, Two, and Three**



Sources: REMI PI+, E3, MDE, MDOT, RESI

Policy Scenario Two produces the most jobs between 2019 and 2030, averaging 11,665 jobs while Policy Scenario One produces the least at 4,564 jobs. By 2050, these numbers are significantly lower across all policy scenarios, with Policy Scenario Two losing an average of 3,811 jobs between 2019 and 2050, but Policy Scenarios One and Three still maintaining positive job growth.

To summarize, these results are due to a number of aspects contained in each bundle of policies:

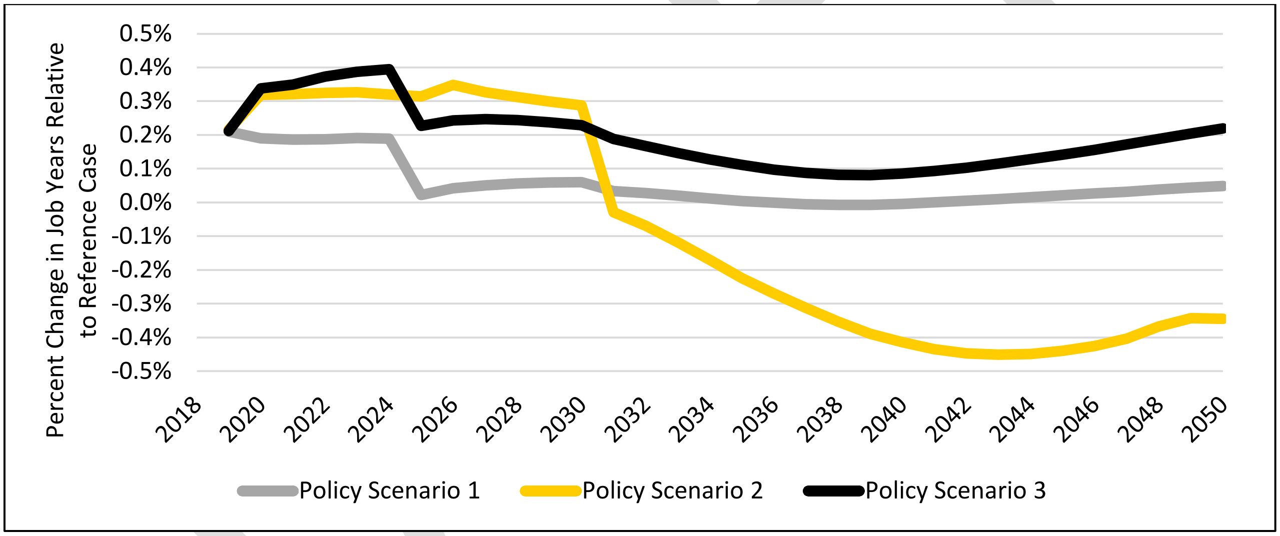
- **Transportation infrastructure spending**
  Policy Scenario Two, in particular, shows large near-term employment increases due to the I-495 and I-270 lane expansion projects. Both Policy Scenario One and Three begin the same, but the divergence in 2020 is due to the presence of the carbon fee as a funding source for infrastructure projects.
- **Carbon fee and dividend**
  The carbon fee plays a pivotal role in boosting employment numbers for Policy Scenario Three in the long run. The revenue from this fee is able to mitigate some of the negative effects of Policy Scenario One by providing rebates to consumers for increased energy prices, as well as the provision of funding for additional job-creating mitigation measures. The rationale behind this job-creating policy is that the fee acts as a filter—

redirecting funds that would have previously flowed out of state towards job creation activities within the state.

- **In-state wind and solar generation**
  Because Maryland is traditionally a net importer of energy, increasing the percentage of self-supplied energy enables money that would have been spent out of the state, to stay within the state.

Although the employment impacts displayed in Figure 45 appear large, they in fact represent a very small proportion of Maryland's total economy. As seen in Figure 46, employment impacts, both positive and negative, do not vary more than one percentage point beyond the levels forecast in the reference case. Even under Policy Scenario Two, which contains aggressive policies aimed at reducing carbon emissions in the state, employment is expected to decline by less than 0.5 percent at its most extreme point. Given the scale of the spending occurring under each policy as described in Section 7.5.1, employment impacts are relatively muted.

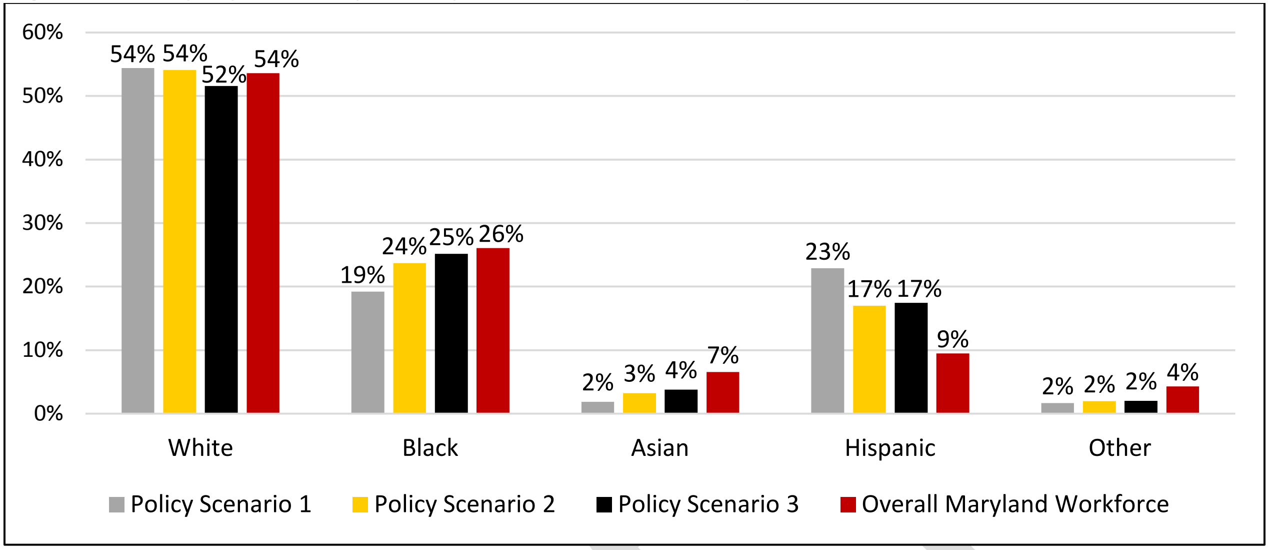
**Figure 46: Percent Change in Employment Under Policy Scenarios One, Two, and Three Relative to the Reference Case**



Sources: E3, MDE, REMI PI+, RESI

In addition to considering distribution of jobs across regions of the state, education and training requirements, and wage levels, the Project Team also considered the potential racial and ethnic distributions of jobs under each policy scenario. Estimated distributions are calculated using existing racial and ethnic composition by occupation as sourced from U.S. Census data. However, it should be stressed that these estimates, as presented below in Figure 47, are based off of current trends in the racial composition of Maryland's workforce. They are intended only to serve as a guide to see whether job gains will be in occupations that have traditionally experienced higher levels of segregation, or if job gains are more equitable.

**Figure 47: Employment Impacts by Race Across All Policy Scenarios**



Sources: REMI PI+, E3, MDE, MDOT, RESI, U.S. Census

As seen in Figure 47, Policy Scenario Two and Policy Scenario Three generally represent the most racially equitable scenarios, meaning employment shares in these scenarios are most similar to the distribution of jobs in Maryland's workforce overall. In Policy Scenario Three, jobs are projected to go to workers that are 52 percent White, 24 percent Black, 4 percent Asian, and 2 percent Other. Those of Hispanic origin account for 17 percent of the supported jobs. It is worth reiterating that this is only a forecast based on current trends in the racial composition of the workforce.

### 7.5.3 Personal Income

In addition to employment, it is also important to consider how personal income will be affected. Personal income within REMI is calculated as the sum of the total wages and salaries, supplements to these wages and salaries, property income, and personal current transfer receipts. Of these, wages and salaries represent the majority of personal income in Maryland.

Relative to the reference case, changes to personal income remain positive through 2030 across all three scenarios. Policy Scenario Three posts the largest increases, averaging $2.0 billion between 2019 and 2030, while Policy Scenario One shows the smallest gains at $0.3 billion.[41] As illustrated in Figure 48, the trends over time vary considerably by policy scenario. Because Policy Scenario One is generally a continuation of current policies, it is expected that very little change from the reference case would be observed. Policy Scenario Three, while exhibiting a similar temporal distribution, is boosted largely due to the household rebates from the carbon fee revenue. Policy Scenario Two shows a large decrease after 2030, due to a

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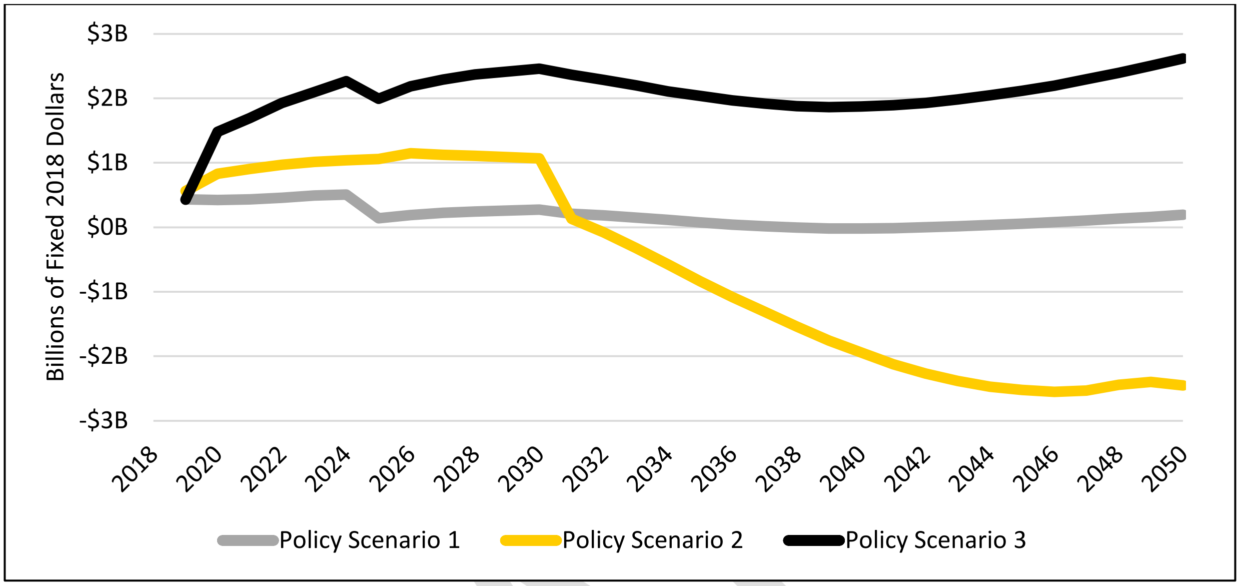
[41] Figures represent scenarios that include MDOT project spending.

combination of the expiration of MDOT transportation projects as well as the increased expenditures on capital relative to fuel savings.

**Figure 48: Personal Income in Policy Scenario One, Policy Scenario Two, and Policy Scenario Three Relative to the Reference Case**



Source: E3, MDE, REMI PI+, RESI

Total wages and salaries, the largest components of personal income, are expected to rise across all three policy scenarios. In Policy Scenario Two and Policy Scenario Three, total wages and salaries rise by an average of 0.3 percent per year through 2030, compared to a 0.1 percent increase under Policy Scenario One.

### 7.5.4 Gross State Product (GSP)

The Project Team considered impacts to Maryland's economy across all three policy scenarios. These impacts are measured in terms of changes to Maryland's gross state product (GSP), which totaled nearly $400 billion dollars in 2017.[42] GSP is the sum of consumption, investment, government expenditures, and net exports for the state. The Project Team considered impacts to 2030 as well as between 2030 and 2050. To capture impacts over time, the Project Team measured dollars over time using cumulative net present value, a common way of comparing the return on investment when looking at the financial viability of multiple projects or policies. For this analysis, the Project Team used a discount rate of 3 percent.

**Figure 49: Cumulative Net Present Value**

| | Policy Scenario One | Policy Scenario Two | Policy Scenario Three |
|---|---|---|---|
| 2030 | $5,938,647,263 | $10,180,593,369 | $7,213,211,643 |
| 2050 | $8,205,244,837 | -$7,666,122,560 | $964,374,703 |

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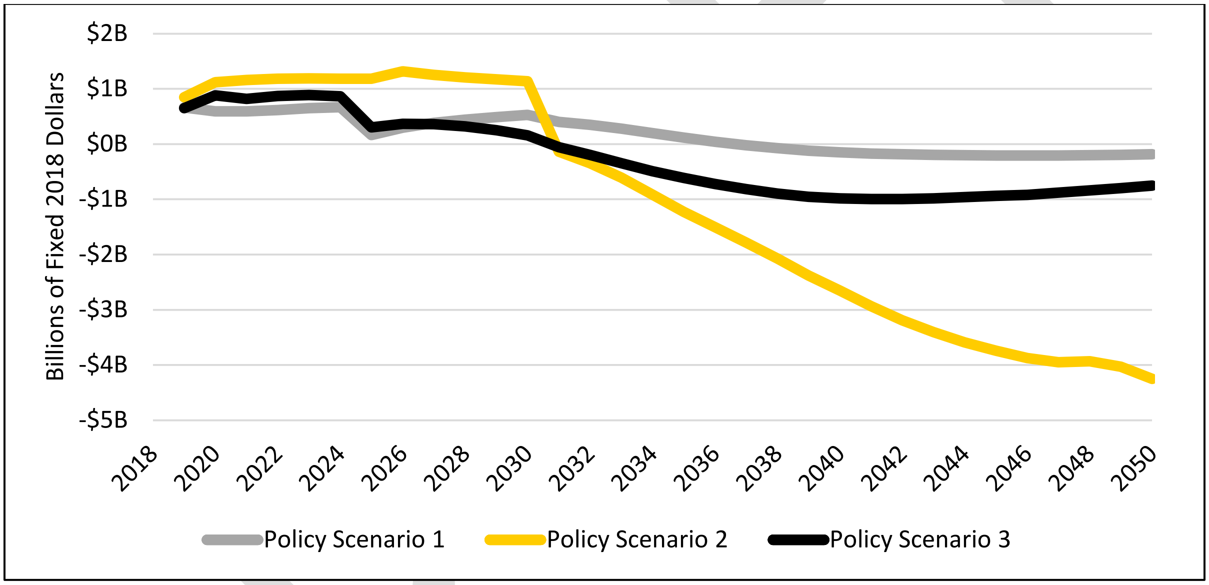
[42] "Total Gross Domestic Product for Maryland (MDNGSP)," FRED Federal Reserve Bank of St. Louis, last modified November 19, 2018, accessed February 14, 2019, https://fred.stlouisfed.org/series/MDNGSP.

Sources: E3, MDE, REMI, RESI

Across all three policy scenarios, contributions to GSP remain positive through 2030.[43] Policy Scenario Two shows the largest gains, adding an additional $10.2 billion to the state's GSP, while Policy Scenario One sees the smallest gains at $5.9 billion. Policy Scenario Three sees an increase of $7.2 billion. The large increases seen for Policy Scenario Two are due to near-term spending on transportation infrastructure projects as well as additional mitigation measures. Policy Scenario One, on the other hand, is largely a continuation of current policies, so smaller increases to the GSP should be expected. While Policy Scenario Three begins the same as Policy Scenario One, the divergence seen is due to the additional mitigation measures and household rebates funded by the carbon revenues.

Figure 50 below details changes to Maryland's GSP under the three policy scenarios through 2050.

**Figure 50: Gross State Product in Policy Scenarios One, Two, and Three Relative to the Reference Case**



Sources: E3, MDE, REMI PI+, RESI

While changes to Maryland's GSP are forecasted to be positive through 2030, this trend is not expected to continue through 2050. The large declines seen after 2030 for Policy Scenario Two reflect decreased exogenous final demand in the Utilities and Petroleum and Coal Products Manufacturing industries.

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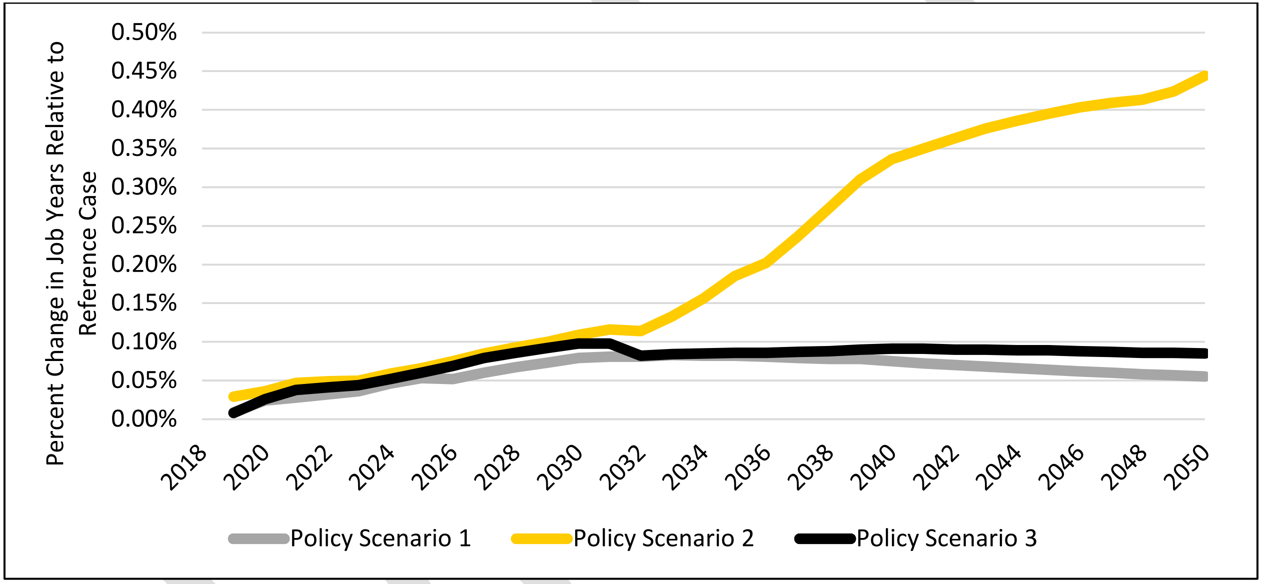
[43] Figures represent scenarios that include MDOT project spending.

### 7.5.5 Consumer Prices

The Project Team also considered how the policy scenarios could impact prices that Maryland residents would pay for goods and services. To do so, price changes were analyzed using the Personal Consumption Expenditure (PCE) Price Index relative to the reference case. The PCE Price Index, similar to the Consumer Price Index (CPI), measures the change in prices for a basket of goods. While the CPI asks consumers directly how much they spend, the PCE Price Index uses sales data from businesses to construct the index.

On average, as illustrated in Figure 51, Policy Scenarios One through Three show similar price increases through 2030, ranging from 0.05 percent to 0.08 percent, relative to the reference case through 2030.[44] After 2030, Policy Scenario One and Three plateau, rising by 0.06 percent and 0.12 percent, respectively, between 2019 and 2050. Policy Scenario Two sees a larger increase, averaging a 0.21 percent increase through 2050.

**Figure 51: Percent Change in the PCE Price Index in Policy Scenarios One, Two, and Three**



Sources: E3, MDE, REMI PI+, RESI

In addition to considering the impacts on overall prices to consumers resulting from the policy scenarios, the Project Team considered how the policy scenarios could affect the total cost of fuel for residential customers. A number of policies in each scenario will affect the price and consumption of various fuels, leading to changes in total costs. Figure 52 details the projected change in residential fuel costs until 2050 for Policy Scenarios One, Two, and Three.

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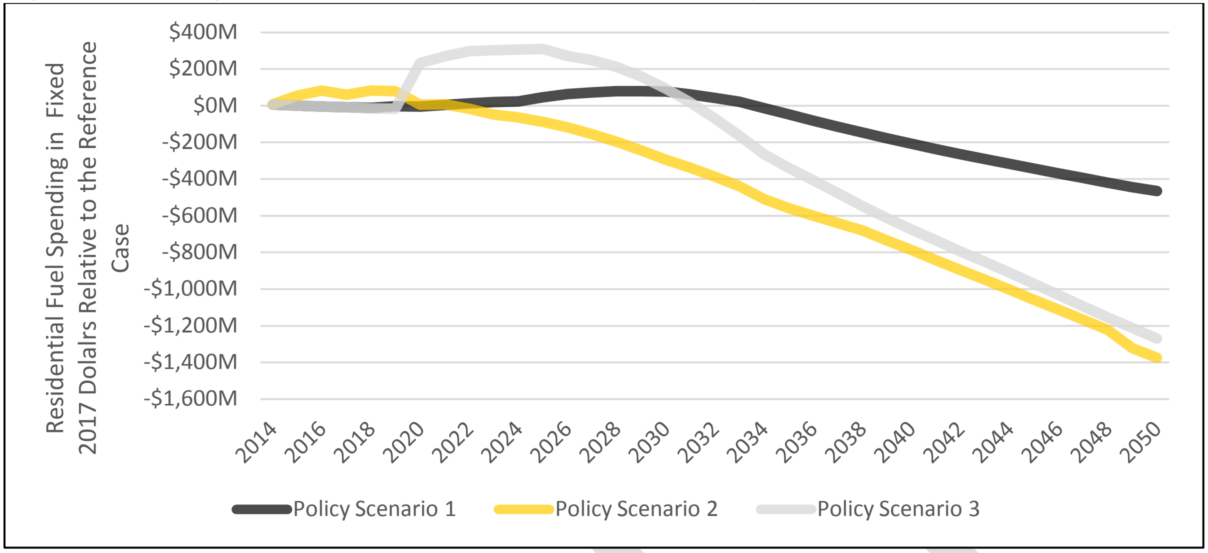
[44] Figures represent scenarios that include MDOT project spending.

**Figure 52: Change in Total Residential Fuel Costs in Policy Scenarios One, Two, and Three**



Source: E3, MDE, REMI PI+, RESI

In 2030, residential spending on non-transportation utilities is lower than in the reference case only in Policy Scenario Two. However, by 2050, residential spending is lower than the reference case for all scenarios. In all scenarios, spending on electricity increases, due to the increased cost of generation as well as increased usage of electricity instead of other fuels. Usage of electricity increases as consumers convert to using more energy efficient appliances. In Policy Scenario Three, increased fuel costs, especially between 2020 and 2030, are primarily due to carbon pricing, which raises the price of all fuel types. However, under this policy, almost fifty percent of all revenue raised by the carbon pricing is returned to consumers in the form of rebate, resulting in a mitigation of costs that is not captured by the chart.

## 7.6 Policy Scenario Four

After the emissions and economic impacts associated with Policy Scenario One, Policy Scenario Two, and Policy Scenario Three were estimated and analyzed, Policy Scenario Four was constructed both to achieve the emissions requirements laid forth in the GGRA and provide a blueprint for future efforts to reduce greenhouse gas emissions. Policy Scenario Four uses Policy Scenario One, discussed in Section 7.4.1, as its foundation. Policy Scenario One represents a collection of policies that are either a continuation or extension of current programs. In addition to these measures, Policy Scenario Four consists of new programs explored in Policy Scenario Two, as discussed in Section 7.4.2. For example, as in Policy Scenario Two, Policy Scenario Four includes a 75 percent Clean and Renewable Energy Standards (CARES) goal by 2040 instead of the renewable portfolio standard (RPS) modeled in Policy Scenario One.[45] Other policies modeled similarly to Policy Scenario Two include bus electrification, transportation programs, and forest management and healthy soils initiatives.

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[45] However, the CARES program modeled in Policy Scenario Four contains different carveouts than the CARES program modeled in Policy Scenario Two. In Policy Scenario Two, carveouts include 12.5 percent for in-state solar,

### 7.6.1 Policy Scenario Four Results

Similar to Policy Scenario One, Policy Scenario Two, and Policy Scenario Three, Policy Scenario Four meets the economic goals outlined in Section 7.3.7. As shown in Figure 53, all four policy scenarios achieve the 2030 economic goals and three policy scenarios meet both the 2020 and 2030 emissions targets as well.

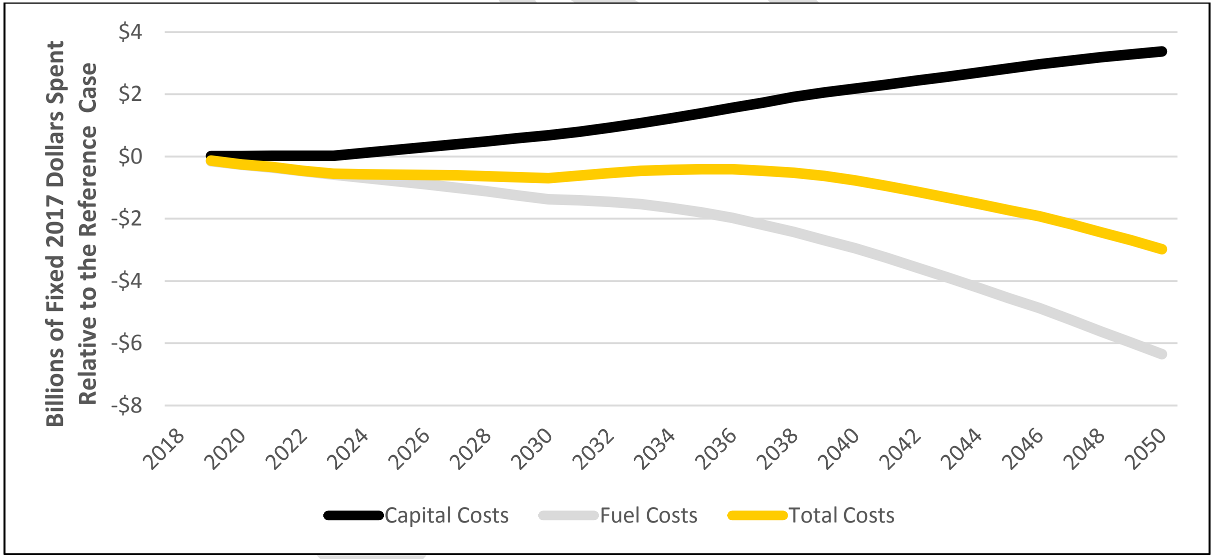
**Figure 53: Summary of Policy Scenarios**

| Policy Scenario | Achieve 2020 Emissions Goal? | Achieve 2030 Emissions Goal? | Achieve 2030 Economic Goal? |
|---|---:|---:|---:|
| Policy Scenario One | Yes | No | Yes |
| Policy Scenario Two | Yes | Yes | Yes |
| Policy Scenario Three | Yes | Yes | Yes |
| Policy Scenario Four | Yes | Yes | Yes |

Source: RESI

Notably, Policy Scenario Four achieves these goals with low levels of spending. As illustrated in Figure 54, in every year in Policy Scenario Four, consumers and businesses spend less on capital costs and fuel costs relative to the reference case.

**Figure 54: Total Costs from Pathways in Policy Scenario Four Relative to the Reference Case**



Sources: E3, MDE, RESI

As seen in Figure 54, although consumers and businesses are spending more on capital costs (e.g., new energy-efficient appliances or new electric vehicles) in Policy Scenario Four than in the reference case, fuel savings exceed this amount every year. This is in contrast to the other policy scenarios as discussed in Section 7.5.1. This result is attributable to two general trends:

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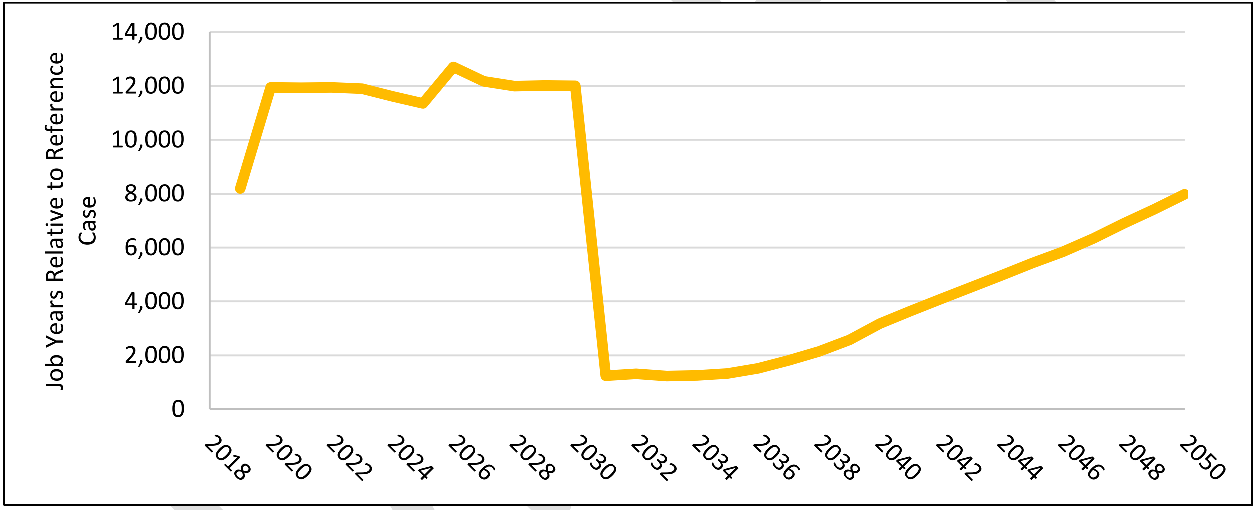
12.5 percent for offshore wind, and 25 percent for tier one renewables. In Policy Scenario Four, the carveouts include 15 percent for in-state solar, 10 percent for offshore wind, and 20 percent for tier one renewables.

- Spending on transportation infrastructure projects is high in Policy Scenario Four. These projects are generally due to policies aimed at reducing fuel usage through behavioral changes (e.g., increased mass transit usage or increased use of bike lanes) as well as more direct capital outlays (e.g., truck stop electrification or bus electrification). The level of spending on these projects is the highest in Policy Scenario Four, and is equal to the level in Policy Scenario Two.
- Capital costs are generally low. Through 2025, capital costs in Policy Scenario Four are equal to those in Policy Scenario One, the scenario with the lowest spending on capital costs. Although capital expenditures after 2025 are higher than in Policy Scenario One, they never approach those in Policy Scenario Two or Policy Scenario Three.

### 7.6.1.1 Employment in Policy Scenario Four

The impacts of infrastructure spending and capital costs can both be seen when examining the economic impacts of Policy Scenario Four. As seen in Figure 55, Policy Scenario Four supports an average of 11,649 jobs each year through 2030 relative to the reference case.

**Figure 55: Employment in Policy Scenario Four Relative to the Reference Case**

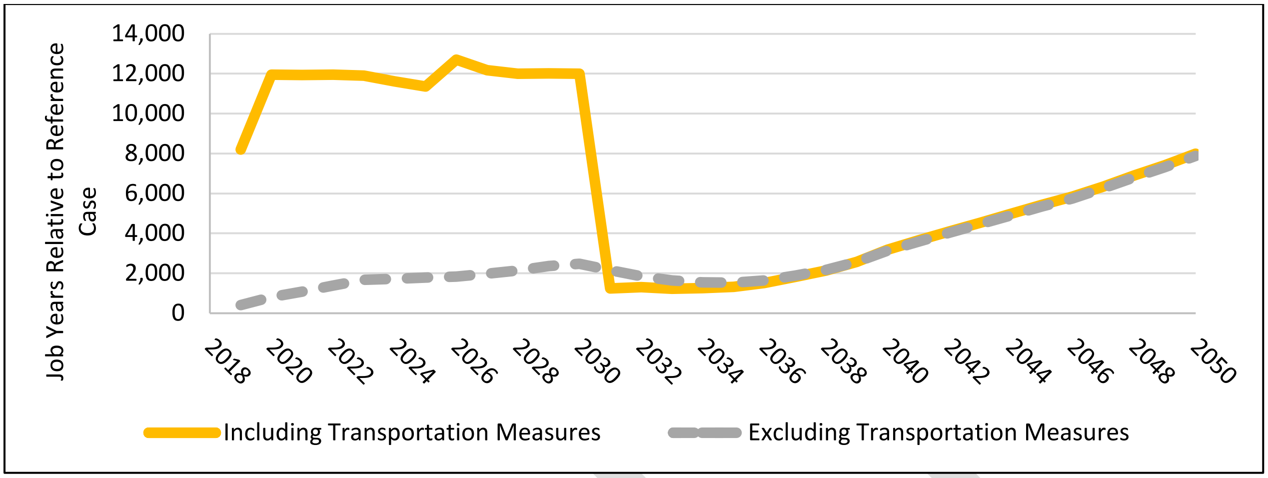


Sources: E3, MDE, REMI PI+, RESI

Through 2030, these employment impacts are driven by transportation infrastructure projects, as seen in other policy scenarios. After 2030, employment impacts remain positive relative to the reference case. The steady increase in employment after 2030 is due in part to the relatively low capital costs seen in Policy Scenario Four. Because spending on capital is lower, consumers have more money to spend on other goods and services, and businesses are more profitable. These positive impacts, coupled with reductions in spending on fuel, result in a slow albeit steady increase in jobs supported relative to the reference case.

To visualize the impact of spending on transportation infrastructure on the economic impact results for Policy Scenario Four, Figure 56 below shows employment differences in Policy Scenario Four with and without this spending.

**Figure 56: Employment in Policy Scenario Four With and Without Transportation Spending Relative to the Reference Case**

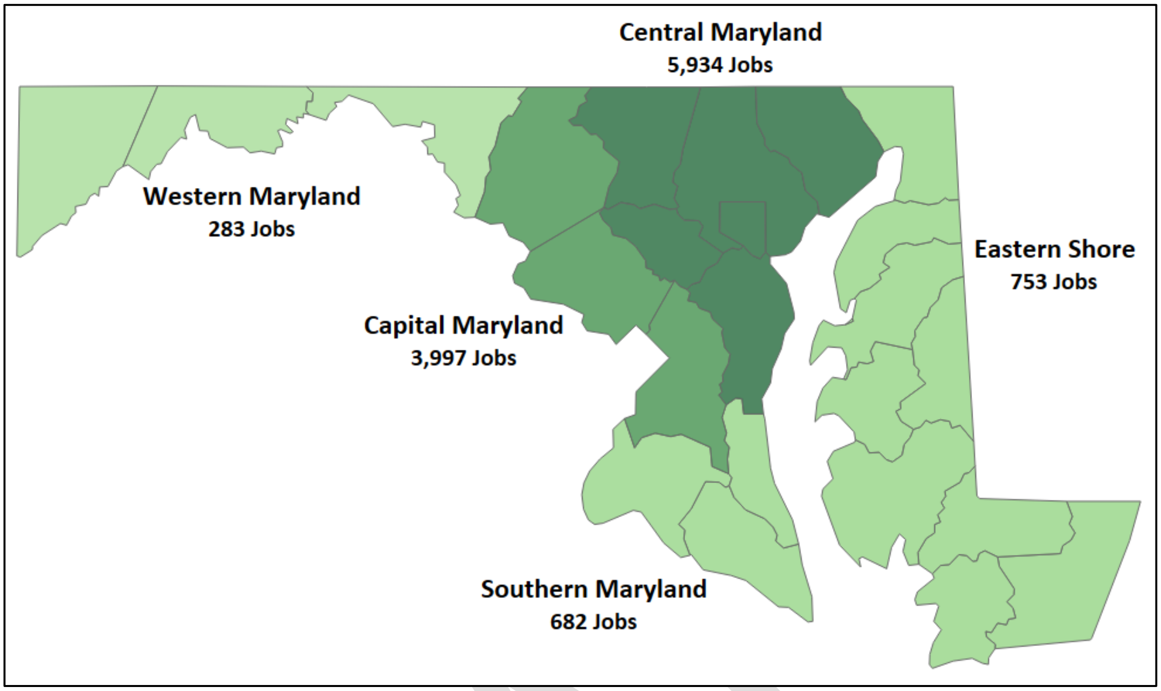


Sources: E3, MDE, REMI PI+, RESI

The impact of transportation spending in Policy Scenario Four is similar to the impacts in the other three policy scenarios. On average through 2030, transportation infrastructure measures support 10,013 more jobs compared to the scenario without this spending. This is illustrated above as the difference between the two lines. Regardless of the status of the transportation spending, however, employment impacts are steadily positive for Policy Scenario Four.

As shown in Figure 57, all regions of Maryland experience positive job growth relative to the reference case through 2030 for Policy Scenario Four.

**Figure 57: Employment Impacts by Region for Policy Scenario Four**



Sources: E3, MDE, REMI PI+, RESI

Following a similar pattern as with the other policy scenarios, Central Maryland sustains the largest employment gains of 5,934 jobs. The Capital Maryland region also shows significant employment increases of 3,997 jobs. However, as with other policy scenarios, these large gains are primarily due to the large workforce already existing within the regions. When considered in terms of percentage changes, job gains are similarly modest, ranging between a 0.2 percent in Western Maryland to a 0.4 percent increase in Southern Maryland.

Figure 58 below details employment impacts under Policy Scenario Four through 2030 by industry. Of the annual average of 11,649 jobs, the Construction industry comprises 8,456 positions, or nearly 73 percent, and is driven largely by spending on transportation infrastructure policies during this period.

**Figure 58: Employment Impacts by Industry for Policy Scenario Four, 2019 Through 2030**

| NAICS | Industry | Annual Average Number of Jobs, 2019-2030 |
|---|---|---|
| 11 | Agriculture, Forestry, Fishing and Hunting | 131 |
| 21 | Mining, Quarrying, and Oil and Gas Extraction | -27 |
| 22 | Utilities | 173 |
| 23 | Construction | 8,456 |
| 31-33 | Manufacturing | 126 |
| 42 | Wholesale Trade | 84 |
| 44-45 | Retail Trade | -169 |
| 48-49 | Transportation and Warehousing | 99 |
| 51 | Information | 27 |
| 52 | Finance and Insurance | 107 |
| 53 | Real Estate and Rental and Leasing | 162 |
| 54 | Professional, Scientific, and Technical Services | 311 |
| 55 | Management of Companies and Enterprises | 21 |
| 56 | Administrative and Support and Waste Management and Remediation Services | 216 |
| 61 | Educational Services | 63 |
| 62 | Health Care and Social Assistance | 573 |
| 71 | Arts, Entertainment, and Recreation | 45 |
| 72 | Accommodation and Food Services | 303 |
| 81 | Other Services (except Public Administration) | 279 |
| 92 | Public Administration | 671 |
| **Total** | | **11,649** |

Sources: E3, REMI PI+, RESI, U.S. Census Bureau

Under Policy Scenario Four, the Public Administration industry and Health Care and Social Assistance industry have the second- and third-highest gains of 671 and 573 jobs, respectively. Moderate employment increases are also estimated in Professional, Scientific, and Technical Services (311 jobs), Accommodation and Food Services (303 jobs), and Other Services (279 jobs). Employment decreases are seen in two industries; Retail Trade falls by 169 positions annually, while Mining, Quarrying, and Oil and Gas Extraction declines by an average of 27 positions.

No major occupational group is expected to have an annual decline under Policy Scenario Four, as shown in Figure 59 below. Once again, the greatest impacts are seen in Construction and Extraction Occupations, with an increase of 5,337 jobs estimated annually through 2030.

**Figure 59: Employment Impacts by Occupation for Policy Scenario Four**

| SOC | SOC Description | Average Jobs |
|---|---|---|

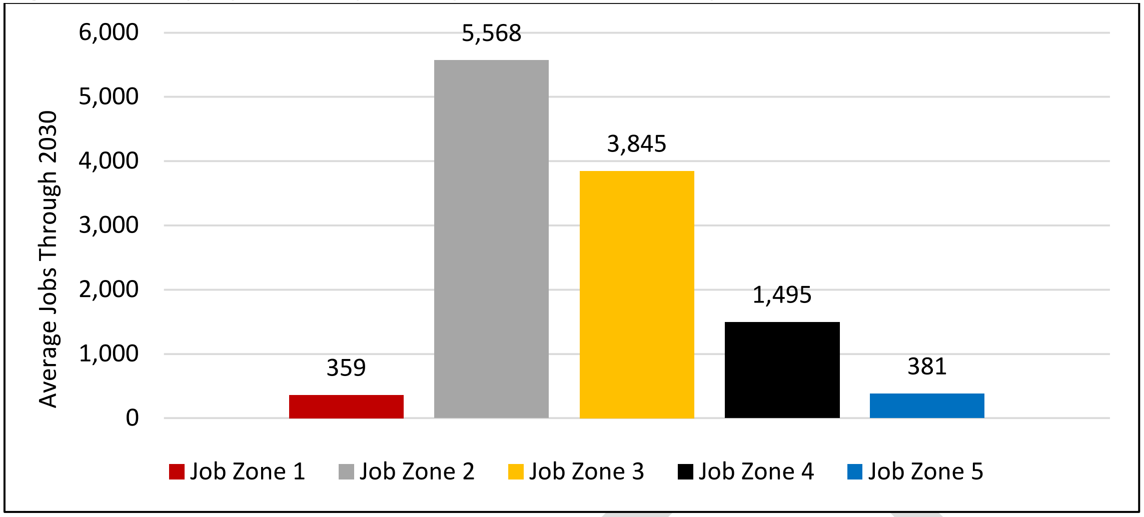
| Code | | Through 2030 |
|---|---|---|
| 11 | Management Occupations | 700 |
| 13 | Business and Financial Operations Occupations | 461 |
| 15 | Computer and Mathematical Occupations | 121 |
| 17 | Architecture and Engineering Occupations | 164 |
| 19 | Life, Physical, and Social Science Occupations | 33 |
| 21 | Community and Social Service Occupations | 66 |
| 23 | Legal Occupations | 36 |
| 25 | Education, Training, and Library Occupations | 292 |
| 27 | Arts, Design, Entertainment, Sports, and Media Occupations | 51 |
| 29 | Healthcare Practitioners and Technical Occupations | 221 |
| 31 | Healthcare Support Occupations | 128 |
| 33 | Protective Service Occupations | 105 |
| 35 | Food Preparation and Serving Related Occupations | 291 |
| 37 | Building and Grounds Cleaning and Maintenance Occupations | 187 |
| 39 | Personal Care and Service Occupations | 229 |
| 41 | Sales and Related Occupations | 233 |
| 43 | Office and Administrative Support Occupations | 1,215 |
| 45 | Farming, Fishing, and Forestry Occupations | 76 |
| 47 | Construction and Extraction Occupations | 5,337 |
| 49 | Installation, Maintenance, and Repair Occupations | 934 |
| 51 | Production Occupations | 289 |
| 53 | Transportation and Material Moving Occupations | 479 |
| **Total** | | **11,649** |

Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

Office and Administrative Support Occupations have the second-highest growth at 1,215 positions annually, followed by Installation, Maintenance, and Repair Occupations with 934 jobs. Significant gains are also seen in Management Occupations (700 jobs), Transportation and Material Moving Occupations (479 jobs), and Business and Financial Operations Occupations (461 jobs). Life, Physical, and Social Science Occupations and Legal Occupations have the lowest levels of growth at 33 and 36 jobs, respectively. Similar to findings in Policy Scenario Two, gains made in Life, Physical, and Social Science Occupations due to renewable energy generation are likely diminished by losses within the Chemical Manufacturing and Oil and Gas Extraction industries, resulting in a low net positive effect.

The estimated employment effects by job zone under Policy Scenario Four are shown in Figure 60. As illustrated below, the plurality of occupational growth occurs in in Job Zone 2, and represents nearly half of the jobs gained annually.

**Figure 60: Employment Impacts by Job Zone for Policy Scenario Four**

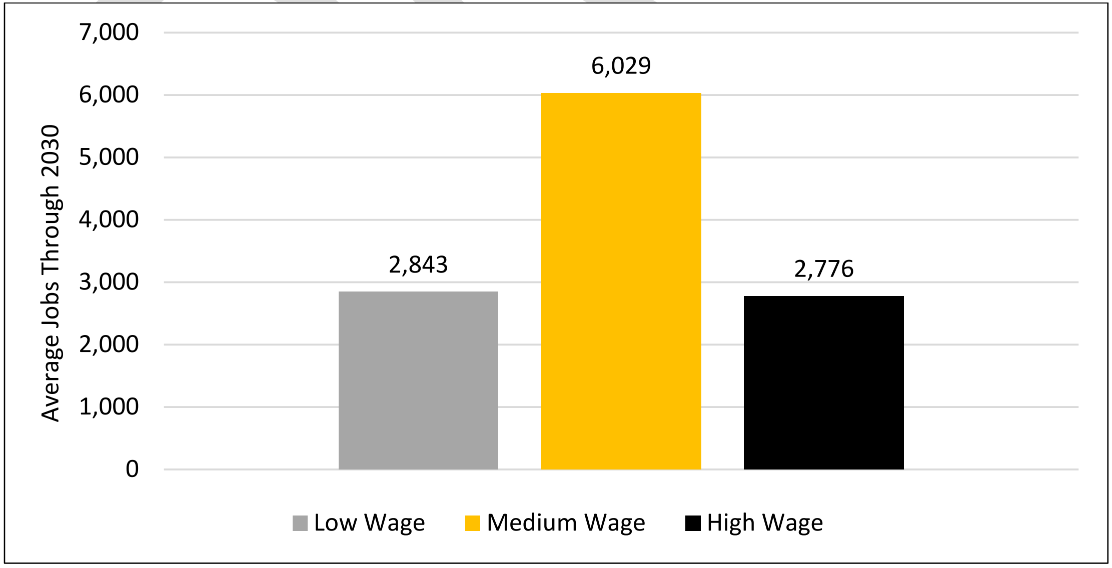


Sources: E3, MDE, O*Net, REMI PI+, RESI

The distribution of employment by job zone in Policy Scenario Four closely resembles that of Policy Scenarios Two and Three, with the most-substantial increases in jobs that typically require modest preparation and a high school diploma (Job Zone 2), followed by positions that generally require an associate degree or vocational training (Job Zone 3). This is beneficial in that retraining and educational needs are expected to be relatively less extensive and time consuming. No negative impacts are seen in any job zone under Policy Scenario Four, with the smallest annual increases represented in Job Zone 1.

Employment distribution by wage groups for Policy Scenario Four are shown in Figure 61 below.

**Figure 61: Employment Impacts by Wage Group for Policy Scenario Four**

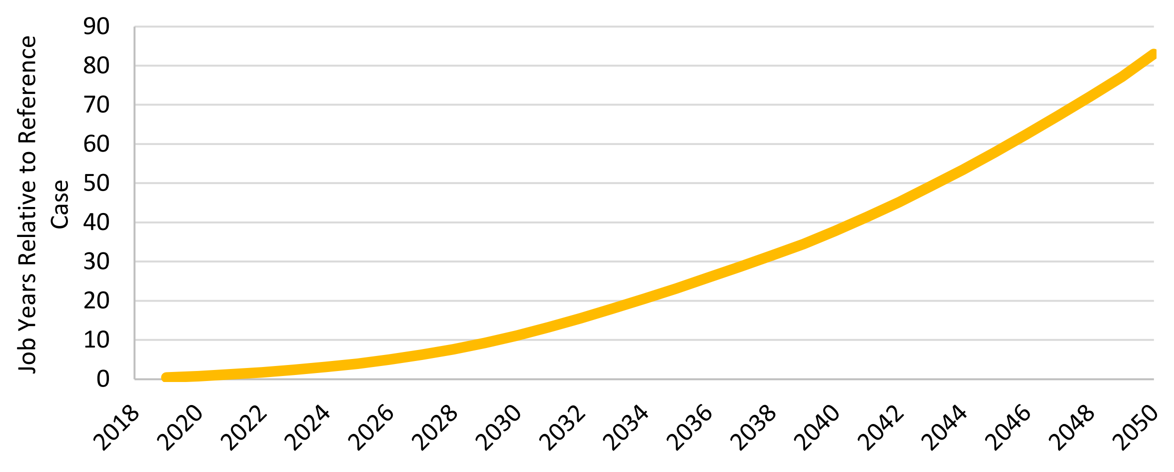


Sources: E3, MDE, REMI PI+, RESI, U.S. BLS

Over half of the employment impacts under Policy Scenario Four, 6,029 jobs, are found in medium-wage occupations earning between $35,000 and $65,000 annually. A slightly higher number of positions are found in low-wage jobs than high-wage jobs, though the difference between the two groups is less than 100 positions annually.

Figure 62 shows the employment impacts that result specifically from improved health outcomes in Policy Scenario Four.

**Figure 62: Employment Impacts of Improved Health Outcomes for Policy Scenario Four**



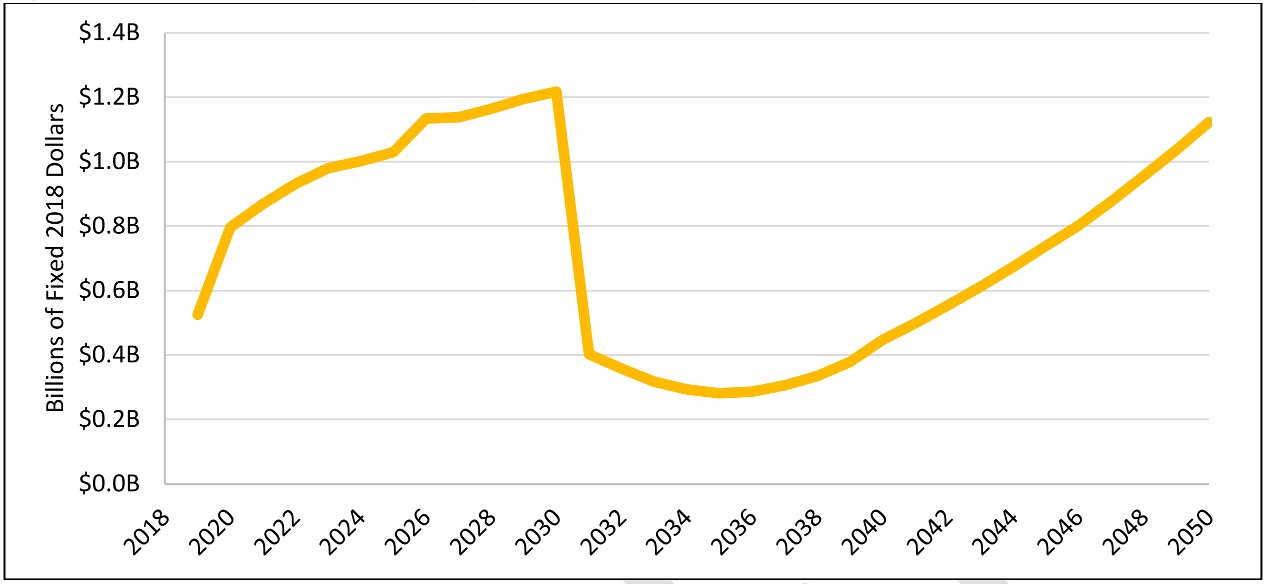
Sources: E3, MDE, MDOT, RESI, U.S. EPA

Between 2019 and 2030, improved health outcomes from Policy Scenario Four will support an average of four jobs annually. This average increases to 28 jobs when extended to 2050. Detailed results for health impacts are found in Appendix C.5.

### 7.6.1.2 Personal Income in Policy Scenario Four

As previously noted, personal income within REMI PI+ is calculated as the sum of total wages and salaries, supplements to these wages and salaries, property income, and personal current transfer receipts. Figure 63 below shows changes in personal income levels under Policy Scenario Four, which remain positive through 2030.

Figure 63: Personal Income in Policy Scenario Four Relative to the Reference Case



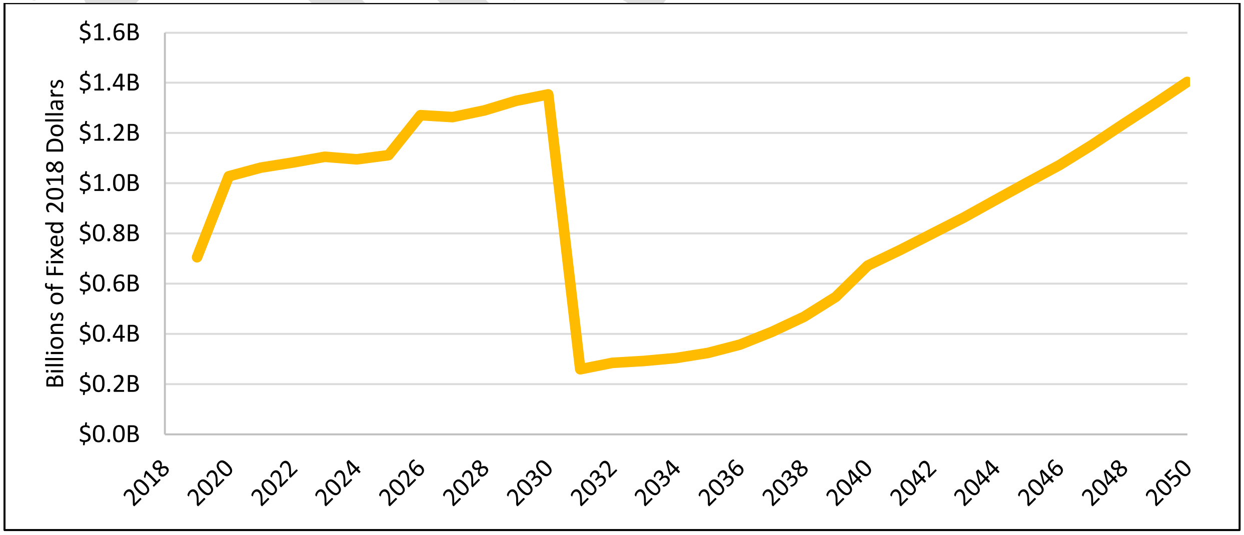
Sources: E3, MDE, REMI PI+, RESI

Personal income is expected to rise under Policy Scenario Four. Between 2019 and 2030, personal income exceeds the reference scenario by an average of $1.0 billion. A significant portion of this increase is due to spending on transportation infrastructure projects.

#### 7.6.1.3 Gross State Product in Policy Scenario Four

Gross state product (GSP) is the sum of consumption, investment, government spending, and net exports out of the state in a given year. Figure 64 shows the expected changes to Maryland's GSP under Policy Scenario Four, presented in billions of fixed 2018 dollars.

Figure 64: Gross State Product in Policy Scenario Four Relative to the Reference Case



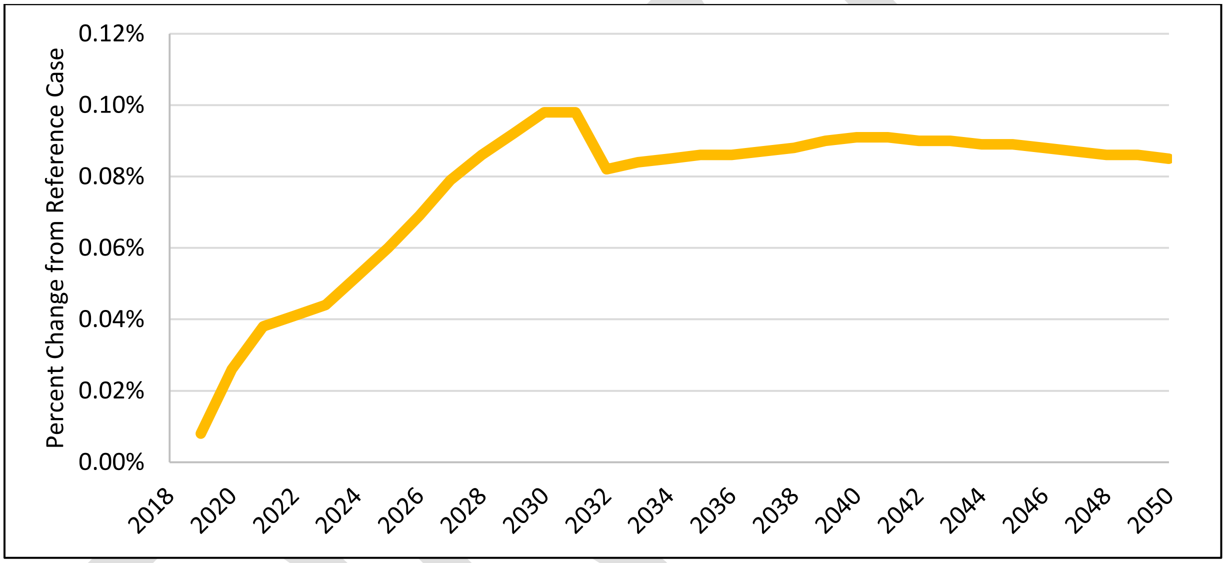
Sources: E3, MDE, REMI PI+, RESI

Under Policy Scenario Four, Maryland's GSP is forecasted to increase relative to the reference case in every year between 2019 and 2050. The change remains positive even after transportation infrastructure spending ends in 2030.

### 7.6.1.4 Consumer Prices in Policy Scenario Four

Consumer prices are only expected to rise modestly under Policy Scenario Four. As illustrated in Figure 65, on average--between 2019 and 2030--prices will rise 0.06 percent per year relative to the reference case. Through 2050, prices will rise 0.08 percent relative to the reference case. This implies that a good or service that costs $1.00 in 2019 will cost less than one additional penny per year above inflation through both 2030 and 2050.

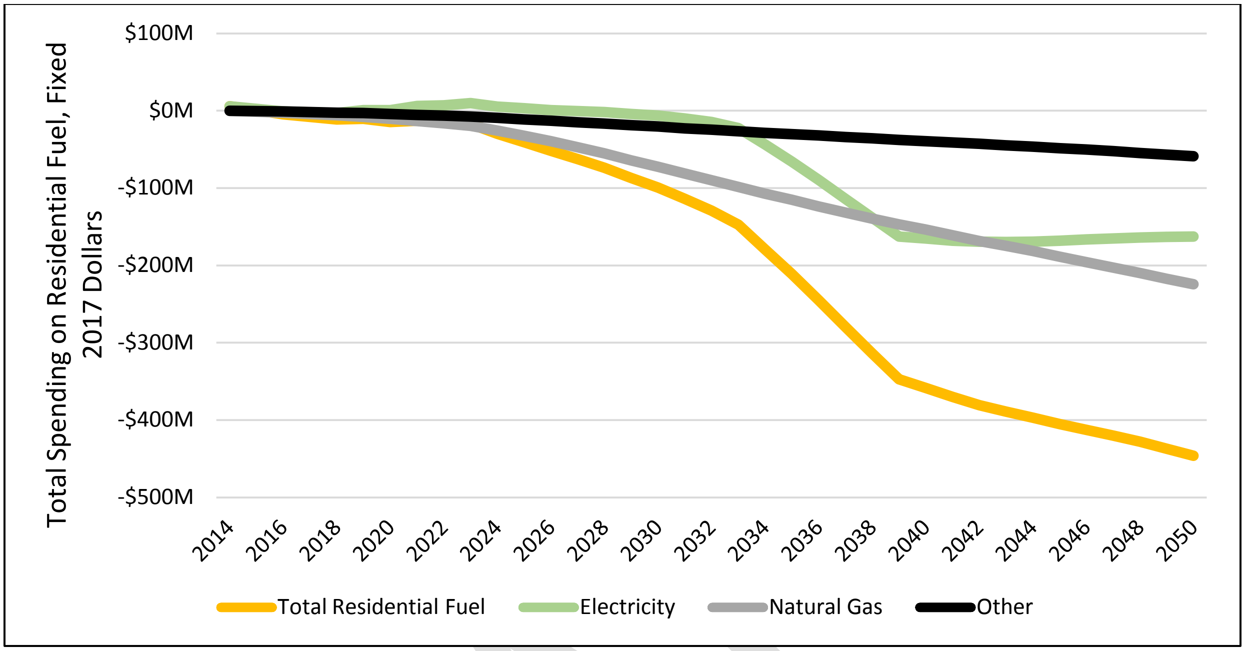
**Figure 65: Percent Change in Consumer Prices In Policy Scenario Four Relative to the Reference Case**



Sources: E3, MDE, REMI PI+, RESI

When considering policies to reduce greenhouse gas emissions, one of the most relevant spending categories for consumers is utilities. Figure 66 shows residential non-transportation fuel spending in Policy Scenario Four.

**Figure 66: Total Residential Spending on Non-Transportation Fuel By Fuel Type in Policy Scenario Four, Relative to the Reference Case**



Sources: E3, MDE, RESI

As seen in Figure 66, total non-transportation fuel spending declines over time. Before 2028, consumers generally spend slightly more for electricity, as consumers substitute from using natural gas and other fuels. However, this increase in spending is not enough to counteract the savings consumers experience. After 2028, policies designed to increase energy efficiency lead to consumers spending less on electricity relative to the reference case, even as they substitute away from other fuels into electricity.

### 7.6.2 Sensitivity Analyses

Any modeling of future policies involves uncertainty. A number of factors, including consumer adoption, changes in federal policy, and state or regional program shifts can greatly impact the policies considered in Policy Scenario Four. Given that Policy Scenario Four meets the emissions and economic goals, the Project Team modeled various sensitivities to understand the robustness of these results. In total, the Project Team modeled five different sensitivities:

1. A decrease in future renewable energy credit (REC) prices. This sensitivity does not impact overall emissions levels, and therefore is not captured in the chapter on emissions modeling.
2. A rollback of the federal level Corporate Average Fuel Economy (CAFE) program. Removing the CAFE standards for fuel efficiency means an increase in emissions from vehicles and less pressure for consumers to purchase zero emissions vehicles.
3. Reduced consumer adoption of energy efficient appliances and zero emission vehicles. Under this sensitivity, consumer purchases of efficient appliances and zero emission

vehicles are 50 percent lower than originally modeled, leading to increased emissions, reduced capital costs, and reduced fuel savings.

4. A sensitivity analysis combining the rollback of the CAFE standards with the reduced consumer adoption sensitivity.
5. A non-renewal of the Calvert Cliffs Nuclear Power Plant. This sensitivity, while considered in the emissions modeling, was not considered in the economic modeling.

A summary of the four sensitivities modeled are presented below in Figure 67.

**Figure 67: Summary of Sensitivity Analyses**

| Sensitivity | Achieve 2020 Emissions Goal? | Achieve 2030 Emissions Goal? | Achieve 2030 Economic Goal? |
|---|---|---|---|
| REC Price | Yes | Yes | Yes |
| Low CAFE | Yes | Yes | Yes |
| Low Adoption | Yes | Yes | Yes |
| Low CAFE and Adoption | Yes | Yes | Yes |

Sources: E3, MDE, REMI PI+, RESI

The difference in employment between the sensitivity results in this section and Policy Scenario Four should not be interpreted as the economic impact to Maryland of the policy in question. The economic modeling is done by considering all policies together. If one policy is removed, the change in economic impacts should only be interpreted relative to the original bundle, in this case Policy Scenario Four. Were the same sensitivity to be applied to the reference case, the economic impacts would be different, because the economic modeling is dynamic and captures the interactions between policies.

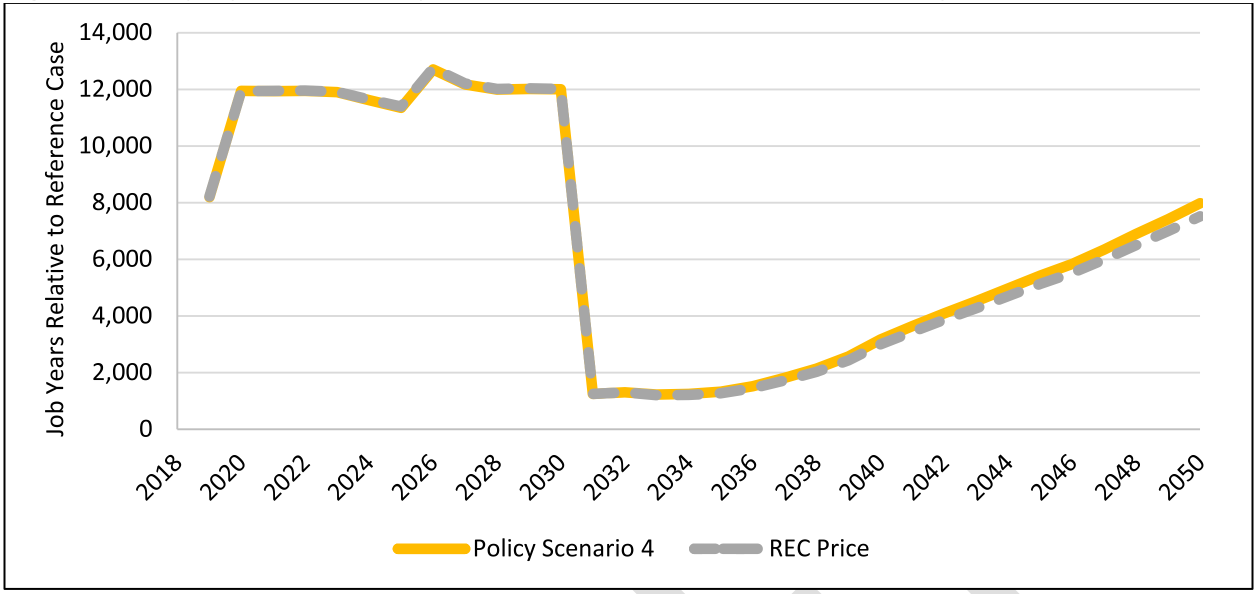
### Sensitivity 1: Decrease in Future Renewable Energy Credits (REC) Prices

The first sensitivity analyzed involved the altering of the price of renewable energy credits (RECs). For the reference case and Policy Scenario One, Two, Three, and Four, the REC price is modeled according to projections from ICF International. For this sensitivity, the REC price is modeled based on the futures market for REC prices. This change in forecasting on net leads to REC prices being lower than in Policy Scenario Four. This has two main effects:

- Producers of renewable energy receive less revenue and
- Consumers and businesses spend less on electricity.

The results of this analysis are presented below in Figure 68.

**Figure 68: Employment in Policy Scenario Four and REC Price Sensitivity**



Sources: E3, MDE, RESI

Overall, the change in REC prices leads to minimal changes in employment in the sensitivity relative to Policy Scenario Four. The reduced REC price sensitivity, on average, produces 17 more jobs through 2030, but loses 114 jobs through 2050. Under this sensitivity, the economic goals are still met.

**Sensitivity 2: Rollback of the Federal CAFE Standards**

The second sensitivity analysis conducted focuses on possible changes to the CAFE standards set forth by the National Highway Traffic Safety Administration (NHTSA). CAFE standards regulate the minimum number of miles per gallon (MPG) that new vehicles must adhere to.[46] In this sensitivity, continued advancements to the light-duty vehicle program standards are rolled back to current requirements. That is, instead of extending the CAFE standards through 2026, they are only modelled through 2021.

The primary channel through which the CAFE standards rollback affects economic outcomes is through an increase in fuel costs. On average, through 2030, fuel costs will increase three percent per year and 11 percent per year through 2050.

Figure 69 presents the results of this sensitivity analysis.

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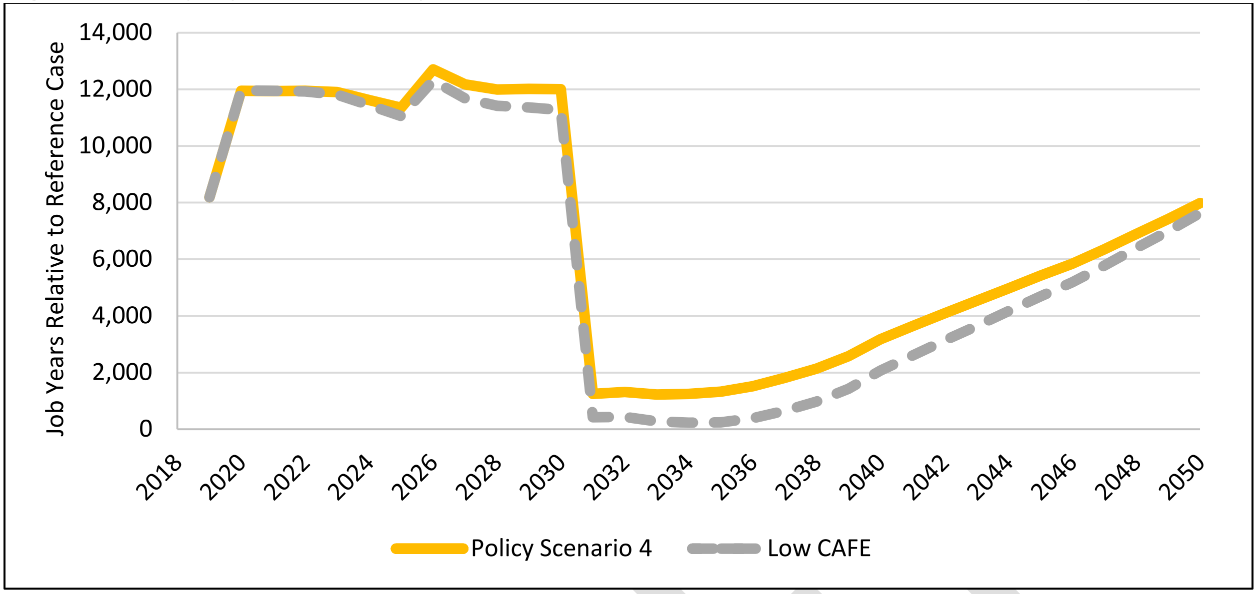
[46] "Corporate Average Fuel Economy," NHTSA, December 26, 2018, accessed May 13, 2019, https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy.

**Figure 69: Employment in Policy Scenario Four and Low CAFE Standards Sensitivity**



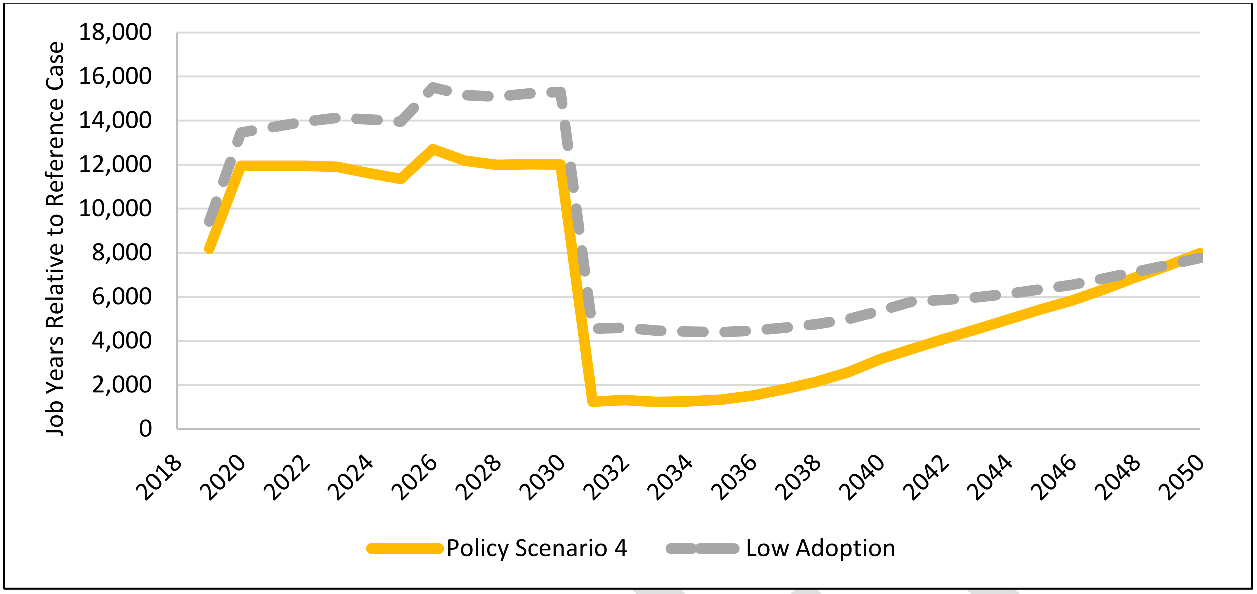
Sources: E3, MDE, RESI

As in the case of the REC price sensitivity, rolling back the CAFE standards has a very small effect on employment through 2030. Should the standards be rolled back, Maryland would still meet the economic goals, though, on average, producing 287 fewer jobs through 2030.

In the long-run, the lower CAFE standards sensitivity produces even fewer jobs. By 2050, Policy Scenario Four produces more than 650 additional job years compared to the sensitivity.

**Sensitivity 3: Reduced Consumer Adoption of Energy Efficient Appliances and ZEVs**
Under the Low Adoption sensitivity, instead of 50 percent high efficiency electric sales, 15 percent increase in sales of electric heat pumps, and 530,000 additional ZEV sales by 2030 as in Policy Scenario Four, these numbers are halved. Thus, in this analysis, only 25 percent high efficiency electric sales, 7.5 percent increase in electric heat pump sales, and 260,000 additional ZEV sales are modelled. The results are shown below in Figure 70.

**Figure 70: Employment in Policy Scenario Four and Low Adoption Sensitivity**



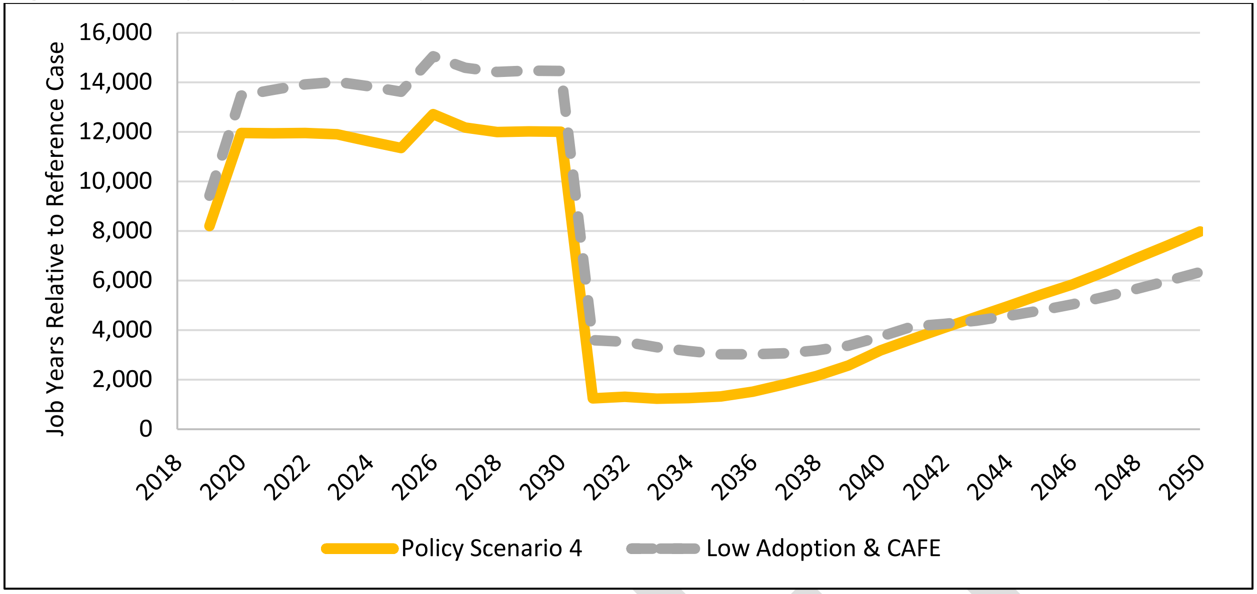
Sources: E3, MDE, RESI

Under these parameters, employment is expected to rise in the short-run relative to the reference case but then drop in the long-run. On average, through 2030, the Low Adoption sensitivity produces 2,425 more jobs. These results are largely being driven by the nature of capital investments. Lower employment numbers are present in the short-run because consumers are not spending more on high efficiency appliances and ZEVs. By 2050, after all fuel savings are realized economy-wide, Policy Scenario Four produces an additional 214 job years compared to the Low Adoption sensitivity.

### Sensitivity 4: Combination of the CAFE rollback and Reduced Consumer Adoption

The fourth sensitivity combines both the rollback in CAFE standards as well as the reduced consumer adoption of high efficiency appliances and ZEVs. These results are presented below in Figure 71.

**Figure 71: Employment in Policy Scenario Four and Low Adoption & CAFE Sensitivity**



Sources: E3, MDE, RESI

On average through 2030, 2,092 jobs are sustained above Policy Scenario Four levels in this sensitivity. However, in 2043, employment under Policy Scenario Four relative to the reference case exceeds levels under the sensitivity relative to the reference case. In 2050, Policy Scenario Four produces 1,648 more job years relative to the sensitivity case.

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## Appendix A—Detailed Assumptions by Policy Scenario

This appendix contains information regarding how the policy scenarios were constructed as well as a comparison between the four scenarios.

***EITHER INCLUDE TABLE FROM E3 TO ENSURE CONSISTENCY ACROSS CHAPTERS OR CREATE A SEPARATE APPENDIX REFERENCED BY BOTH CHAPTERS.***

## Appendix B—Methodology

This appendix contains more information regarding the methodology that the Project Team utilized for the economic analysis. For more detail regarding the emissions modeling that was used as the basis of the economic analysis, please see Chapter 6.

### B.1 REMI PI+

To quantify the economic impacts of economic events or policy changes, RESI uses the Regional Economic Models, Inc. (REMI) PI+ model version 2.2. The REMI PI+ model is a high-end dynamic modeling tool used by various federal and state government agencies in economic policy analysis. Utilization of REMI PI+ helps RESI to build a sophisticated model that is calibrated to the specific demographic features of the study area. This model enumerates the combined economic impacts of each dollar spent by the following: employees relating to the economic events, other supporting vendors (business services, retail, etc.), each dollar spent by these vendors on other firms, and each dollar spent by the households of the event's employees, other vendors' employees, and other businesses' employees. The REMI PI+ model reports economic impacts above the economic activity that would have occurred without the policy change or event.

As a dynamic model, REMI PI+ features the ability to capture price effects, wage changes, and behavioral effects through time. Another benefit of the model compared to traditional static models, such as IMPLAN, is the regional constraint is built in to account for limited resources over time. A situation like this is built into the model using current industry data and employment information from Bureau of Economic Analysis (BEA) data. The REMI PI+ model also allows RESI to capture the effects occurring between industries and minimize the potential for double-counting in employment, output, and wages. The ability to capture effects throughout a span of time provides a detailed representative of an economic event over time and its effects on the study area.

### B.2 COBRA

The EPA's CO-Benefits Risk Assessment (COBRA) model assists state and local governments with estimating the costs and benefits of clean energy policies. Originally developed by Abt Associates in 2002, and most recently updated in 2017, COBRA "estimate[s] the economic value of the health benefits associated with clean energy policies and programs" so that these values can be weighed against the economic costs of a proposed policy.[47,48]

To use the COBRA model, a user first needs to estimate the reduction in emissions that would occur as a result of the clean energy policy. COBRA utilizes emission estimates for five different forms of air pollution: particulate matter ($PM_{2.5}$), sulfur dioxide ($SO_2$), nitrogen oxides ($NO_X$),

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[47] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 3.

[48] "CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool," U.S. Environment Protection Agency.

ammonia ($NH_3$), and volatile organic compounds (VOCs).[49] Baseline emission estimates are included for both 2017 and 2025, allowing users to change emissions in either year.[50] Once the emission estimates for the policy are determined, the user can then input any corresponding emission increases or decreases from the baseline into the model. These changes can be input as either percentage changes from the baseline or as a specific quantity of emissions in tons.

Beyond year and pollutant type, emission changes can be further customized to specifically match the scenario being estimated through the model.[51] Changes can be entered at a national, state, or county level, including the 48 contiguous states and the District of Columbia. Changes can be further specified by the source of the emissions, with options such as highway vehicles or electric utility plants. COBRA allows the user to build a scenario with multiple changes across various locations and emissions, allowing a single scenario to contain variations in emission levels across different states or across different counties within the same state.

Regardless of the type(s) of air pollution input as changes into the model, COBRA will translate the changes in pollution into changes in ambient $PM_{2.5}$. In addition to changes to primary particles as a result of directly inputting changes in $PM_{2.5}$, changing one of the other emissions results in a change in secondary $PM_{2.5}$. Secondary $PM_{2.5}$ is formed by chemical reactions in the atmosphere involving other gaseous emissions.[52] For example, $SO_2$ will create sulfates in the atmosphere while $NO_x$ will form nitrates, both of which are forms of $PM_{2.5}$.[53]

The changes in ambient $PM_{2.5}$ are then further translated into health impacts, which cover a wide range of effects from mortality and non-fatal heart attacks to work days missed and minor restricted activity days (MRADs).[54] Finally, these various health impacts are assigned economic values in 2017 dollars.[55] Both a low and a high economic estimate are provided, based on "two sets of assumptions about the sensitivity of adult mortality and non-fatal heart attacks to changes in ambient $PM_{2.5}$."[56] Although the most significant health impacts will be seen in the geographic location where the emissions were changed, COBRA provides the impact to air pollution levels within every county in the model, since air pollution is not subject to state and

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[49] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 18.

[50] COBRA also contains the ability to import a custom emissions baseline for any other year, however this functionality was not used for this analysis.

[51] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 6-14.

[52] U.S. Environment Protection Agency, "Particulate Matter Emissions," accessed August 9, 2018, 1, https://cfpub.epa.gov/roe/indicator_pdf.cfm?i=19.

[53] U.S. Environment Protection Agency, "Particulate Matter Emissions," 1.

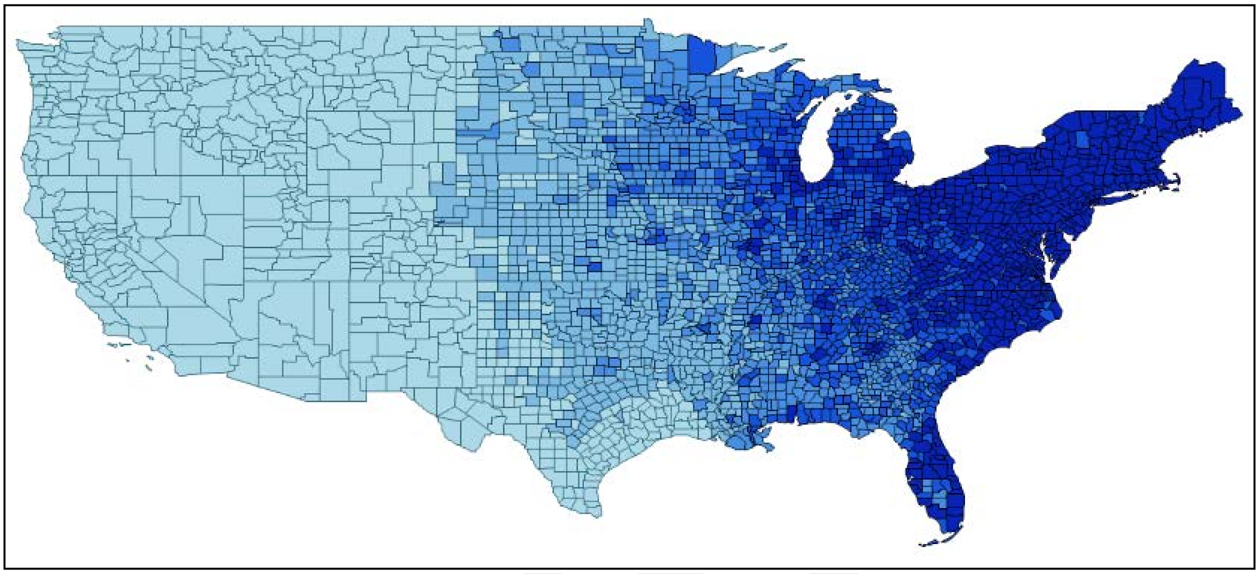
[54] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 43-44.

[55] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 7-8.

[56] U.S. Environment Protection Agency, "User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," 23.

county lines. Figure 63 below is a map produced by COBRA illustrating total economic benefits for each county in the United States following a reduction in Maryland emissions. Generally, greater economic benefits are seen in counties closer to the reductions and in counties with higher populations.

**Figure 72: Example of Emissions Result Map from COBRA**



Source: U.S. EPA

COBRA is an industry and academically recognized tool for quantifying health impacts related to emissions. In 2016, a paper in the *International Journal of Environmental Research and Public Health* used COBRA to estimate the health and economic effects of Volkswagen's violations of the Clean Air Act. Volkswagen had installed software onto its diesel-fueled passenger cars that deactivated the $NO_x$ emissions control system while driving, but would reactivate the system whenever the car underwent emissions testing.[57] This illegal software caused each car to emit $NO_x$ at a rate "10 to 40 times higher than the EPA's current Tier 2 vehicle emission standard."[58]

Using COBRA, the authors estimated that the additional $NO_x$ from Volkswagen vehicles resulted in economic losses ranging from$43 million to $423 million related to premature deaths and other negative health impacts.[59,60] The wide range of the impact is a result of running multiple scenarios covering the range of increased emissions reported by the EPA, in addition to reporting both the high and low economic estimates from COBRA for each of these scenarios.

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[57] Lifang Hou et al., "Public Health Impact and Economic Costs of Volkswagen's Lack of Compliance with the United States' Emission Standards," *International Journal of Environmental Research and Public Health* 13, no. 9 (2016): 1-2, accessed August 9, 2018, doi:10.3390/ijerph13090891.

[58] Hou et al., "Public Health Impact and Economic Costs of Volkswagen's Lack of Compliance with the United States' Emission Standards," 2.

[59] Hou et al., "Public Health Impact and Economic Costs of Volkswagen's Lack of Compliance with the United States' Emission Standards," 4.

[60] Values in this study are in 2010 dollars.

COBRA has also been previously used in studies specific to Maryland and the surrounding region. In 2016, the Chesapeake Climate Action Network used the tool to advocate for an increase in the renewable energy used by the District of Columbia. The organization estimated that the expansion of renewable energy could carry an economic benefit of up to $572 million annually from the resulting improvement in air quality.[61]

An extensive study was conducted by Abt Associates, the developers of COBRA, to examine the public health impacts and related economic benefits of the Regional Greenhouse Gas Initiative (RGGI) from 2009 to 2014. Using both COBRA and the more complex BenMAP tool, Abt Associates estimated that RGGI resulted in an economic benefit of $3.0 billion to $8.3 billion, stemming from the avoided negative health effects of air pollution over the six-year period.[62] Notably, Abt found significant health and economic benefits both in RGGI states and in neighboring states that did not participate in RGGI.[63]

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[61] Chesapeake Climate Action Network, “B21-0650—Renewable Portfolio Standard Expansion Amendment Act of 2016,” 2, May 23, 2016, accessed August 9, 2018, http://chesapeakeclimate.org/wp/wp-content/uploads/2016/05/CCAN_B21-0650_testimony_DC-RPS.pdf.

[62] Abt Associates, “Analysis of the Public Health Impacts of the Regional Greenhouse Gas Initiative, 2009-2014,” 2, January 2017, accessed August 9, 2018, https://www.abtassociates.com/sites/default/files/2018-06/Analysis%20of%20the%20public%20health%20impacts%20of%20regional%20greenhouse%20gas.pdf.

[63] Abt Associates, “Analysis of the Public Health Impacts of the Regional Greenhouse Gas Initiative, 2009-2014,” 32

# Appendix C—Detailed Results

## C.1 Employment

Figure 73: Total Employment Impacts by Policy Scenario without Transportation Measures by Year Relative to the Reference Case, 2019-2050

| Year | PS 1 | PS 2 | PS 3 | PS 4 |
|---|---|---|---|---|
| Average through 2030 | 944 | 1,652 | 7,336 | 1,636 |
| Average through 2050 | 794 | -7,515 | 6,188 | 3,002 |
| 2019 | 333 | 537 | 436 | 412 |
| 2020 | 541 | 1,096 | 6,231 | 810 |
| 2021 | 660 | 1,394 | 6,901 | 1,085 |
| 2022 | 774 | 1,750 | 7,827 | 1,380 |
| 2023 | 900 | 2,109 | 8,330 | 1,675 |
| 2024 | 822 | 2,147 | 8,545 | 1,723 |
| 2025 | 889 | 2,198 | 8,553 | 1,781 |
| 2026 | 1,008 | 2,118 | 8,514 | 1,828 |
| 2027 | 1,150 | 1,965 | 8,452 | 1,971 |
| 2028 | 1,276 | 1,742 | 8,279 | 2,136 |
| 2029 | 1,414 | 1,519 | 8,088 | 2,365 |
| 2030 | 1,555 | 1,252 | 7,873 | 2,470 |
| 2031 | 1,346 | -198 | 7,152 | 2,146 |
| 2032 | 1,073 | -2,053 | 6,350 | 1,847 |
| 2033 | 774 | -4,069 | 5,591 | 1,643 |
| 2034 | 505 | -6,181 | 4,924 | 1,552 |
| 2035 | 244 | -8,409 | 4,360 | 1,532 |
| 2036 | 56 | -10,347 | 3,860 | 1,648 |
| 2037 | -63 | -12,126 | 3,567 | 1,882 |
| 2038 | -152 | -13,866 | 3,378 | 2,166 |
| 2039 | -167 | -15,412 | 3,352 | 2,566 |
| 2040 | -60 | -16,569 | 3,557 | 3,139 |
| 2041 | 93 | -17,540 | 3,843 | 3,585 |
| 2042 | 278 | -18,152 | 4,257 | 4,027 |
| 2043 | 476 | -18,473 | 4,758 | 4,455 |
| 2044 | 690 | -18,508 | 5,314 | 4,895 |
| 2045 | 913 | -18,250 | 5,921 | 5,339 |
| 2046 | 1,129 | -17,823 | 6,528 | 5,750 |
| 2047 | 1,370 | -17,011 | 7,242 | 6,254 |
| 2048 | 1,620 | -15,648 | 7,953 | 6,797 |
| 2049 | 1,859 | -14,735 | 8,681 | 7,318 |
| 2050 | 2,101 | -14,944 | 9,409 | 7,872 |

Sources:

**Figure 74: Total Employment Impacts by Policy Scenario with Transportation Measures by Year Relative to the Reference Case, 2019-2050**

| Year | PS 1 | PS 2 | PS 3 | PS 4 |
|---|---:|---:|---:|---:|
| Average through 2030 | 4,564 | 11,665 | 10,950 | 11,649 |
| Average through 2050 | 2,116 | -3,811 | 7,504 | 6,703 |
| 2019 | 8,054 | 8,314 | 8,145 | 8,190 |
| 2020 | 7,303 | 12,236 | 12,985 | 11,949 |
| 2021 | 7,092 | 12,248 | 13,325 | 11,938 |
| 2022 | 7,113 | 12,318 | 14,159 | 11,947 |
| 2023 | 7,206 | 12,337 | 14,629 | 11,903 |
| 2024 | 7,130 | 12,043 | 14,852 | 11,618 |
| 2025 | 841 | 11,766 | 8,505 | 11,348 |
| 2026 | 1,574 | 12,998 | 9,074 | 12,707 |
| 2027 | 1,915 | 12,170 | 9,211 | 12,175 |
| 2028 | 2,095 | 11,596 | 9,090 | 11,990 |
| 2029 | 2,193 | 11,172 | 8,859 | 12,018 |
| 2030 | 2,256 | 10,785 | 8,565 | 12,004 |
| 2031 | 1,268 | -1,100 | 7,065 | 1,245 |
| 2032 | 1,061 | -2,592 | 6,329 | 1,309 |
| 2033 | 756 | -4,486 | 5,563 | 1,227 |
| 2034 | 457 | -6,482 | 4,868 | 1,252 |
| 2035 | 163 | -8,616 | 4,271 | 1,324 |
| 2036 | -51 | -10,479 | 3,745 | 1,515 |
| 2037 | -186 | -12,196 | 3,438 | 1,810 |
| 2038 | -279 | -13,887 | 3,244 | 2,143 |
| 2039 | -290 | -15,399 | 3,223 | 2,576 |
| 2040 | -171 | -16,529 | 3,441 | 3,174 |
| 2041 | -2 | -17,481 | 3,744 | 3,639 |
| 2042 | 201 | -18,080 | 4,176 | 4,093 |
| 2043 | 416 | -18,392 | 4,694 | 4,529 |
| 2044 | 646 | -18,421 | 5,266 | 4,976 |
| 2045 | 882 | -18,158 | 5,887 | 5,423 |
| 2046 | 1,110 | -17,729 | 6,506 | 5,836 |
| 2047 | 1,360 | -16,912 | 7,230 | 6,344 |
| 2048 | 1,617 | -15,545 | 7,947 | 6,892 |
| 2049 | 1,862 | -14,625 | 8,681 | 7,419 |
| 2050 | 2,107 | -14,826 | 9,413 | 7,981 |

Sources:

## C.2 Gross State Product (GSP)

**Figure 75: Gross State Product Impacts by Policy Scenario without Transportation Measures by Year Relative to the Reference Case, 2019-2050 (in Billions of 2018 Dollars)**

| Year | PS 1 | PS 2 | PS 3 | PS 4 |
|---|---|---|---|---|
| Average through 2030 | $0.21 | $0.25 | $0.27 | $0.23 |
| Average through 2050 | $0.06 | -$1.46 | -$0.36 | $0.56 |
| 2019 | $0.04 | $0.19 | $0.04 | $0.05 |
| 2020 | $0.05 | $0.17 | $0.35 | $0.08 |
| 2021 | $0.07 | $0.22 | $0.31 | $0.12 |
| 2022 | $0.09 | $0.25 | $0.35 | $0.15 |
| 2023 | $0.12 | $0.28 | $0.37 | $0.19 |
| 2024 | $0.12 | $0.29 | $0.33 | $0.20 |
| 2025 | $0.19 | $0.30 | $0.33 | $0.23 |
| 2026 | $0.26 | $0.30 | $0.33 | $0.26 |
| 2027 | $0.32 | $0.29 | $0.31 | $0.30 |
| 2028 | $0.38 | $0.26 | $0.25 | $0.35 |
| 2029 | $0.43 | $0.24 | $0.19 | $0.40 |
| 2030 | $0.47 | $0.20 | $0.11 | $0.42 |
| 2031 | $0.42 | $0.00 | -$0.03 | $0.40 |
| 2032 | $0.36 | -$0.25 | -$0.19 | $0.38 |
| 2033 | $0.29 | -$0.53 | -$0.33 | $0.37 |
| 2034 | $0.21 | -$0.85 | -$0.48 | $0.37 |
| 2035 | $0.14 | -$1.17 | -$0.59 | $0.38 |
| 2036 | $0.07 | -$1.46 | -$0.70 | $0.40 |
| 2037 | $0.00 | -$1.75 | -$0.79 | $0.44 |
| 2038 | -$0.05 | -$2.04 | -$0.88 | $0.50 |
| 2039 | -$0.10 | -$2.36 | -$0.93 | $0.57 |
| 2040 | -$0.13 | -$2.63 | -$0.96 | $0.69 |
| 2041 | -$0.15 | -$2.92 | -$0.98 | $0.75 |
| 2042 | -$0.17 | -$3.18 | -$0.98 | $0.81 |
| 2043 | -$0.18 | -$3.39 | -$0.97 | $0.88 |
| 2044 | -$0.19 | -$3.58 | -$0.95 | $0.94 |
| 2045 | -$0.20 | -$3.74 | -$0.93 | $1.01 |
| 2046 | -$0.20 | -$3.87 | -$0.91 | $1.08 |
| 2047 | -$0.20 | -$3.95 | -$0.88 | $1.16 |
| 2048 | -$0.20 | -$3.93 | -$0.84 | $1.24 |
| 2049 | -$0.19 | -$4.03 | -$0.79 | $1.32 |
| 2050 | -$0.18 | -$4.25 | -$0.75 | $1.40 |

Sources:

**Figure 76: Gross State Product Impacts by Policy Scenario with Transportation Measures by Year Relative to the Reference Case, 2019-2050 (in Billions of 2018 Dollars)**

| Year | PS 1 | PS 2 | PS 3 | PS 4 |
|---|---|---|---|---|
| Average through 2030 | $0.51 | $1.16 | $0.56 | $1.14 |
| Average through 2050 | $0.16 | -$1.14 | -$0.26 | $0.88 |
| 2019 | $0.66 | $0.85 | $0.65 | $0.71 |
| 2020 | $0.59 | $1.12 | $0.88 | $1.03 |
| 2021 | $0.59 | $1.16 | $0.82 | $1.06 |
| 2022 | $0.62 | $1.18 | $0.87 | $1.08 |
| 2023 | $0.65 | $1.19 | $0.89 | $1.11 |
| 2024 | $0.67 | $1.19 | $0.86 | $1.10 |
| 2025 | $0.16 | $1.19 | $0.30 | $1.11 |
| 2026 | $0.30 | $1.32 | $0.37 | $1.27 |
| 2027 | $0.38 | $1.25 | $0.36 | $1.26 |
| 2028 | $0.44 | $1.21 | $0.32 | $1.29 |
| 2029 | $0.49 | $1.17 | $0.25 | $1.33 |
| 2030 | $0.53 | $1.14 | $0.16 | $1.35 |
| 2031 | $0.40 | -$0.14 | -$0.05 | $0.26 |
| 2032 | $0.35 | -$0.35 | -$0.20 | $0.29 |
| 2033 | $0.28 | -$0.61 | -$0.35 | $0.29 |
| 2034 | $0.20 | -$0.91 | -$0.49 | $0.30 |
| 2035 | $0.12 | -$1.23 | -$0.61 | $0.32 |
| 2036 | $0.04 | -$1.50 | -$0.72 | $0.36 |
| 2037 | -$0.02 | -$1.78 | -$0.82 | $0.41 |
| 2038 | -$0.08 | -$2.07 | -$0.90 | $0.47 |
| 2039 | -$0.12 | -$2.38 | -$0.95 | $0.55 |
| 2040 | -$0.15 | -$2.65 | -$0.98 | $0.67 |
| 2041 | -$0.17 | -$2.94 | -$1.00 | $0.73 |
| 2042 | -$0.19 | -$3.19 | -$0.99 | $0.80 |
| 2043 | -$0.20 | -$3.40 | -$0.98 | $0.86 |
| 2044 | -$0.20 | -$3.59 | -$0.96 | $0.93 |
| 2045 | -$0.21 | -$3.74 | -$0.94 | $1.00 |
| 2046 | -$0.21 | -$3.87 | -$0.92 | $1.07 |
| 2047 | -$0.21 | -$3.95 | -$0.88 | $1.15 |
| 2048 | -$0.20 | -$3.93 | -$0.84 | $1.24 |
| 2049 | -$0.20 | -$4.03 | -$0.80 | $1.32 |
| 2050 | -$0.19 | -$4.25 | -$0.75 | $1.40 |

Sources:

### C.3 Personal Income

**Figure 77: Personal Income Impacts by Policy Scenario without Transportation Measures by Year Relative to the Reference Case, 2019-2050 (in Billions of 2018 Dollars)**

| Year | PS 1 | PS 2 | PS 3 | PS 4 |
|---|---:|---:|---:|---:|
| Average through 2030 | $0.11 | $0.15 | $1.74 | $0.15 |
| Average through 2050 | $0.09 | -$1.03 | $1.99 | $0.37 |
| 2019 | $0.02 | $0.07 | $0.03 | $0.03 |
| 2020 | $0.03 | $0.08 | $1.10 | $0.05 |
| 2021 | $0.05 | $0.11 | $1.32 | $0.08 |
| 2022 | $0.06 | $0.14 | $1.54 | $0.10 |
| 2023 | $0.08 | $0.17 | $1.69 | $0.13 |
| 2024 | $0.08 | $0.18 | $1.84 | $0.14 |
| 2025 | $0.10 | $0.19 | $1.96 | $0.16 |
| 2026 | $0.12 | $0.19 | $2.12 | $0.17 |
| 2027 | $0.15 | $0.18 | $2.22 | $0.20 |
| 2028 | $0.17 | $0.17 | $2.30 | $0.22 |
| 2029 | $0.19 | $0.15 | $2.35 | $0.25 |
| 2030 | $0.22 | $0.12 | $2.40 | $0.27 |
| 2031 | $0.20 | -$0.02 | $2.36 | $0.25 |
| 2032 | $0.17 | -$0.21 | $2.28 | $0.23 |
| 2033 | $0.15 | -$0.42 | $2.20 | $0.22 |
| 2034 | $0.11 | -$0.65 | $2.11 | $0.21 |
| 2035 | $0.08 | -$0.90 | $2.04 | $0.22 |
| 2036 | $0.05 | -$1.14 | $1.98 | $0.23 |
| 2037 | $0.03 | -$1.36 | $1.93 | $0.26 |
| 2038 | $0.01 | -$1.59 | $1.90 | $0.29 |
| 2039 | $0.00 | -$1.80 | $1.88 | $0.34 |
| 2040 | $0.00 | -$1.98 | $1.89 | $0.41 |
| 2041 | $0.00 | -$2.16 | $1.91 | $0.46 |
| 2042 | $0.01 | -$2.30 | $1.95 | $0.52 |
| 2043 | $0.03 | -$2.42 | $2.00 | $0.58 |
| 2044 | $0.05 | -$2.50 | $2.06 | $0.64 |
| 2045 | $0.07 | -$2.55 | $2.13 | $0.71 |
| 2046 | $0.09 | -$2.58 | $2.21 | $0.77 |
| 2047 | $0.11 | -$2.57 | $2.31 | $0.84 |
| 2048 | $0.14 | -$2.48 | $2.40 | $0.92 |
| 2049 | $0.17 | -$2.44 | $2.51 | $1.00 |
| 2050 | $0.20 | -$2.49 | $2.62 | $1.08 |

Sources:

Figure 78: Personal Income Impacts by Policy Scenario with Transportation Measures by Year Relative to the Reference Case, 2019-2050 (in Billions of 2018 Dollars)

| Year | PS 1 | PS 2 | PS 3 | PS 4 |
|---|---|---|---|---|
| Average through 2030 | $0.34 | $0.99 | $1.97 | $1.00 |
| Average through 2050 | $0.17 | -$0.67 | $2.06 | $0.73 |
| 2019 | $0.43 | $0.56 | $0.43 | $0.53 |
| 2020 | $0.42 | $0.83 | $1.48 | $0.80 |
| 2021 | $0.43 | $0.90 | $1.70 | $0.87 |
| 2022 | $0.46 | $0.97 | $1.93 | $0.93 |
| 2023 | $0.49 | $1.02 | $2.10 | $0.98 |
| 2024 | $0.51 | $1.04 | $2.27 | $1.00 |
| 2025 | $0.14 | $1.06 | $1.99 | $1.03 |
| 2026 | $0.19 | $1.15 | $2.19 | $1.13 |
| 2027 | $0.22 | $1.12 | $2.29 | $1.14 |
| 2028 | $0.25 | $1.11 | $2.37 | $1.16 |
| 2029 | $0.26 | $1.09 | $2.41 | $1.19 |
| 2030 | $0.28 | $1.07 | $2.46 | $1.22 |
| 2031 | $0.21 | $0.13 | $2.36 | $0.40 |
| 2032 | $0.18 | -$0.08 | $2.29 | $0.36 |
| 2033 | $0.15 | -$0.32 | $2.20 | $0.32 |
| 2034 | $0.11 | -$0.57 | $2.11 | $0.29 |
| 2035 | $0.08 | -$0.84 | $2.04 | $0.28 |
| 2036 | $0.04 | -$1.08 | $1.97 | $0.29 |
| 2037 | $0.02 | -$1.31 | $1.92 | $0.31 |
| 2038 | -$0.01 | -$1.54 | $1.88 | $0.34 |
| 2039 | -$0.02 | -$1.76 | $1.86 | $0.38 |
| 2040 | -$0.02 | -$1.94 | $1.87 | $0.45 |
| 2041 | -$0.01 | -$2.12 | $1.89 | $0.50 |
| 2042 | $0.00 | -$2.27 | $1.93 | $0.55 |
| 2043 | $0.02 | -$2.38 | $1.98 | $0.61 |
| 2044 | $0.03 | -$2.47 | $2.05 | $0.67 |
| 2045 | $0.06 | -$2.52 | $2.12 | $0.74 |
| 2046 | $0.08 | -$2.55 | $2.20 | $0.80 |
| 2047 | $0.11 | -$2.53 | $2.30 | $0.88 |
| 2048 | $0.13 | -$2.44 | $2.39 | $0.96 |
| 2049 | $0.16 | -$2.40 | $2.50 | $1.04 |
| 2050 | $0.19 | -$2.45 | $2.62 | $1.12 |

Sources:

## C.4 Producer Consumption Expenditures (PCE)

**Figure 79: PCE-Price Index (2009=100) Under Policy Scenario 4**

| Year | With Transportation Measures | Without Transportation Measures |
|---|---:|---:|
| Average through 2030 | 0.078 | 0.037 |
| Average through 2050 | 0.128 | 0.109 |
| 2019 | 0.010 | 0.004 |
| 2020 | 0.031 | 0.005 |
| 2021 | 0.046 | 0.010 |
| 2022 | 0.051 | 0.011 |
| 2023 | 0.056 | 0.014 |
| 2024 | 0.067 | 0.024 |
| 2025 | 0.079 | 0.035 |
| 2026 | 0.092 | 0.046 |
| 2027 | 0.108 | 0.057 |
| 2028 | 0.120 | 0.068 |
| 2029 | 0.132 | 0.079 |
| 2030 | 0.143 | 0.089 |
| 2031 | 0.145 | 0.100 |
| 2032 | 0.125 | 0.109 |
| 2033 | 0.130 | 0.118 |
| 2034 | 0.133 | 0.125 |
| 2035 | 0.138 | 0.132 |
| 2036 | 0.141 | 0.136 |
| 2037 | 0.146 | 0.142 |
| 2038 | 0.151 | 0.148 |
| 2039 | 0.157 | 0.154 |
| 2040 | 0.161 | 0.159 |
| 2041 | 0.164 | 0.162 |
| 2042 | 0.166 | 0.164 |
| 2043 | 0.169 | 0.167 |
| 2044 | 0.171 | 0.169 |
| 2045 | 0.173 | 0.172 |
| 2046 | 0.175 | 0.174 |
| 2047 | 0.177 | 0.176 |
| 2048 | 0.180 | 0.178 |
| 2049 | 0.182 | 0.180 |
| 2050 | 0.184 | 0.182 |

Sources:

## C.5 Health Impacts

**Figure 80: Jobs Due to Health Impacts by Policy Scenario**

| Year | Policy Scenario 1 | Policy Scenario 2 | Policy Scenario 3 | Policy Scenario 4 |
|---|---|---|---|---|
| Average Through 2030 | 3.60 | 8.10 | 7.15 | 4.38 |
| Average Through 2050 | 20.46 | 58.88 | 52.70 | 28.45 |
| 2019 | 0.36 | 0.63 | 0.41 | 0.37 |
| 2020 | 0.67 | 1.32 | 0.91 | 0.73 |
| 2021 | 1.07 | 2.20 | 1.63 | 1.21 |
| 2022 | 1.52 | 3.22 | 2.50 | 1.76 |
| 2023 | 2.02 | 4.40 | 3.53 | 2.38 |
| 2024 | 2.57 | 5.69 | 4.68 | 3.07 |
| 2025 | 3.25 | 7.41 | 6.24 | 3.96 |
| 2026 | 4.03 | 9.29 | 8.00 | 4.97 |
| 2027 | 4.97 | 11.50 | 10.13 | 6.17 |
| 2028 | 6.13 | 14.13 | 12.73 | 7.61 |
| 2029 | 7.47 | 16.98 | 15.69 | 9.22 |
| 2030 | 9.09 | 20.41 | 19.36 | 11.14 |
| 2031 | 10.88 | 24.28 | 23.49 | 13.27 |
| 2032 | 12.73 | 28.53 | 27.92 | 15.55 |
| 2033 | 14.66 | 33.28 | 32.70 | 18.01 |
| 2034 | 16.55 | 38.36 | 37.61 | 20.54 |
| 2035 | 18.43 | 43.78 | 42.64 | 23.16 |
| 2036 | 20.33 | 49.59 | 47.86 | 25.88 |
| 2037 | 22.20 | 55.64 | 53.18 | 28.66 |
| 2038 | 24.09 | 61.97 | 58.64 | 31.53 |
| 2039 | 25.98 | 68.48 | 64.20 | 34.44 |
| 2040 | 28.08 | 76.45 | 70.80 | 37.82 |
| 2041 | 30.27 | 85.01 | 77.80 | 41.39 |
| 2042 | 32.56 | 94.18 | 85.18 | 45.17 |
| 2043 | 34.96 | 103.90 | 92.97 | 49.21 |
| 2044 | 37.45 | 113.84 | 100.91 | 53.42 |
| 2045 | 40.05 | 124.11 | 109.09 | 57.84 |
| 2046 | 42.75 | 134.65 | 117.48 | 62.46 |
| 2047 | 45.54 | 145.54 | 126.08 | 67.25 |
| 2048 | 48.38 | 156.59 | 134.77 | 72.15 |
| 2049 | 51.28 | 167.89 | 143.63 | 77.19 |
| 2050 | 54.51 | 180.81 | 153.56 | 82.94 |

Sources: Sources: E3, MDE, REMI PI+, RESI, U.S. EPA

**Figure 81: Avoided Mortality and Estimated Value by Policy Scenario**

| Year | Policy Scenario 1 | | Policy Scenario 2 | | Policy Scenario 3 | | Policy Scenario 4 | |
|---|---|---|---|---|---|---|---|---|
| | Mortality Avoided | Value | Mortality Avoided | Value | Mortality Avoided | Value | Mortality Avoided | Value |
| Average Through 2030 | 6.27 | $62,361,822 | 14.07 | $139,947,620 | 13.38 | $133,137,885 | 7.68 | $76,455,728 |
| Average Through 2050 | 19.37 | $192,733,991 | 59.84 | $595,298,539 | 52.58 | $523,141,762 | 28.10 | $279,586,443 |
| 2019 | 1.47 | $14,575,643 | 3.04 | $30,293,325 | 2.34 | $23,256,339 | 1.67 | $16,610,412 |
| 2020 | 2.13 | $21,237,190 | 4.56 | $45,368,665 | 3.67 | $36,520,196 | 2.49 | $24,795,131 |
| 2021 | 2.80 | $27,836,131 | 6.13 | $61,034,769 | 5.15 | $51,228,051 | 3.34 | $33,256,082 |
| 2022 | 3.39 | $33,710,966 | 7.59 | $75,473,587 | 6.57 | $65,375,276 | 4.12 | $41,025,741 |
| 2023 | 3.99 | $39,695,156 | 9.06 | $90,184,099 | 8.02 | $79,792,111 | 4.92 | $48,941,437 |
| 2024 | 4.60 | $45,788,701 | 10.57 | $105,166,306 | 9.50 | $94,478,559 | 5.73 | $57,003,171 |
| 2025 | 5.68 | $56,473,849 | 13.56 | $134,924,965 | 12.26 | $121,962,592 | 7.23 | $71,895,059 |
| 2026 | 6.94 | $69,067,151 | 16.31 | $162,299,104 | 15.19 | $151,085,278 | 8.76 | $87,144,836 |
| 2027 | 8.40 | $83,608,742 | 19.34 | $192,363,644 | 18.50 | $184,093,004 | 10.48 | $104,253,535 |
| 2028 | 10.06 | $100,098,622 | 22.63 | $225,118,584 | 22.21 | $220,985,769 | 12.39 | $123,221,155 |
| 2029 | 11.75 | $116,868,400 | 25.65 | $255,164,931 | 25.84 | $257,100,384 | 14.23 | $141,559,719 |
| 2030 | 14.01 | $139,381,314 | 30.35 | $301,979,468 | 31.34 | $311,777,063 | 16.86 | $167,762,453 |
| 2031 | 15.58 | $155,034,649 | 34.67 | $344,898,965 | 35.58 | $354,009,968 | 18.98 | $188,788,218 |
| 2032 | 17.02 | $169,329,684 | 39.25 | $390,451,372 | 39.78 | $395,792,550 | 21.08 | $209,680,209 |
| 2033 | 18.32 | $182,266,419 | 44.09 | $438,636,688 | 43.94 | $437,124,809 | 23.16 | $230,438,424 |
| 2034 | 19.28 | $191,820,848 | 48.59 | $483,410,585 | 47.38 | $471,341,432 | 24.95 | $248,258,011 |
| 2035 | 20.25 | $201,503,312 | 53.17 | $528,938,514 | 50.87 | $506,095,384 | 26.77 | $266,357,008 |
| 2036 | 21.24 | $211,313,811 | 57.82 | $575,220,477 | 54.42 | $541,386,665 | 28.62 | $284,735,415 |
| 2037 | 22.24 | $221,252,345 | 62.54 | $622,256,474 | 58.02 | $577,215,275 | 30.50 | $303,393,231 |
| 2038 | 23.25 | $231,318,914 | 67.35 | $670,046,504 | 61.67 | $613,581,213 | 32.40 | $322,330,456 |

| Year | Policy Scenario 1 |  | Policy Scenario 2 |  | Policy Scenario 3 |  | Policy Scenario 4 |  |
|---|---|---|---|---|---|---|---|---|
|  | Mortality Avoided | Value | Mortality Avoided | Value | Mortality Avoided | Value | Mortality Avoided | Value |
| 2039 | 24.28 | $241,513,518 | 72.23 | $718,590,567 | 65.38 | $650,484,480 | 34.33 | $341,547,092 |
| 2040 | 26.04 | $259,109,344 | 82.07 | $816,529,541 | 72.80 | $724,275,900 | 37.75 | $375,596,895 |
| 2041 | 27.46 | $273,244,009 | 89.21 | $887,592,463 | 78.10 | $777,013,618 | 40.51 | $403,023,230 |
| 2042 | 28.93 | $287,778,998 | 96.46 | $959,719,317 | 83.44 | $830,127,671 | 43.36 | $431,390,147 |
| 2043 | 30.43 | $302,714,313 | 103.82 | $1,032,910,104 | 88.82 | $883,618,060 | 46.31 | $460,697,646 |
| 2044 | 31.70 | $315,342,711 | 109.46 | $1,089,059,609 | 92.87 | $923,954,200 | 48.80 | $485,528,495 |
| 2045 | 32.98 | $328,128,189 | 115.19 | $1,145,996,203 | 96.98 | $964,810,497 | 51.33 | $510,709,279 |
| 2046 | 34.28 | $341,070,745 | 120.99 | $1,203,719,887 | 101.14 | $1,006,186,949 | 53.90 | $536,239,997 |
| 2047 | 35.60 | $354,170,381 | 126.87 | $1,262,230,660 | 105.35 | $1,048,083,557 | 56.50 | $562,120,650 |
| 2048 | 36.93 | $367,427,096 | 132.83 | $1,321,528,522 | 109.61 | $1,090,500,322 | 59.14 | $588,351,237 |
| 2049 | 38.28 | $380,840,889 | 138.87 | $1,381,613,474 | 113.93 | $1,133,437,243 | 61.81 | $614,931,760 |
| 2050 | 40.60 | $403,965,667 | 150.45 | $1,496,831,881 | 122.01 | $1,213,841,956 | 66.86 | $665,180,052 |

Sources: E3, MDE, RESI, U.S. EPA

**END OF DOCUMENT**

Maryland
Department of
the Environment

# Appendix H

### Impact Analysis of the GGRA of 2009 on Manufacturing Industry in MD

# 2019 GGRA Draft Plan

# Impact Analysis of the Greenhouse Gas Reduction Act of 2009 on the Manufacturing Industry in Maryland

*Prepared for*
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# 1.0 Executive Summary

## 1.1 Overview

The Maryland Department of the Environment (MDE) tasked the Regional Economic Studies Institute (RESI) to complete an impact analysis of the policies from the *Greenhouse Gas Emissions Reduction Act (GGRA) 2012 Plan* on Maryland's manufacturing industry. RESI employed the REMI PI+ model using agency level data collected for the GGRA report to determine the impact on Maryland's Manufacturing industry. In this report, RESI assumed that all GGRA initiatives were implemented and results are reported for the Manufacturing industry by the four-digit North American Industry Classification System (NAICS) codes.

In addition to an economic impact analysis, RESI solicited feedback from regional manufacturers to include in the report. Manufacturer interviews included in this report are case studies of greenhouse gas reduction measures taken by these firms to remain compliant with government environmental mandates. RESI and representatives from MDE visited these manufacturers to witness their methods and interview them one on one in regard to the challenges faced with reducing greenhouse gas emissions, if any.

## 1.2 Historical Trend Analysis

To provide background for the economic impact analysis, RESI analyzed the current historical trends of Manufacturing in Maryland. RESI found the following:

- The average weekly wages in the Manufacturing industry increased from $933 in 2002 to $1,324 in 2012.
- Preliminary estimates indicate that average weekly wages increased by $16 between 2012 and 2013—an increase from $1,324 in 2012 to $1,340 in 2013.[1]
- The industry accounted for 5.9 percent of Maryland's total output in 2012.

The industry remains a vital component of Maryland's economic base, despite declines since the recent recession. Industry data indicates that the workforce is shifting to demand employees with middle skills and more training. Partnerships with state-based groups such as the Regional Manufacturing Institute (RMI) and state agencies such as Maryland Public Service Commission (PSC) and Maryland Energy Administration have assisted manufacturers through funding opportunities to meet energy efficiency goals.

National partnerships are also key in building the needed workforce, such as those with Manufacturing Extension Partnership (MEP) and the National Institute of Standards and Technology. This partnership seeks to build and establish training to meet the higher skill needs of employers by the local workforce. As the industry shifts towards a higher skill-based workforce, partnerships such as those between industry leaders, state agencies, and federal

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[1] "Quarterly Census of Employment and Wages," Bureau of Labor Statistics, accessed April 9, 2014, http://data.bls.gov/pdq/SurveyOutputServlet.

agencies will be vital to producing the workforce needed to implement the policies outlined in the GGRA.

## 1.3 Economic Impact Findings

RESI analyzed the GGRA initiatives outlined in the GGRA to determine the economic impacts on the manufacturing industry. Using agency-provided data along with external research, RESI found the following:

- The manufacturing industry will create 113 total jobs by 2020 related to implementation of the policies between 2010 and 2020.
- Directly, policy implementation between 2010 and 2020 will result in 104 direct jobs created to support the greenhouse gas reduction policies under the GGRA.
- The *Computer and electronic product manufacturing* sector will experience the greatest gains in employment between 2010 and 2020.
- The industry's wages will increase to $10.7 million by 2020.
- The industry's output will increase to $26.5 million by 2020.

RESI's economic impact analysis confirms historical and current trend analyses. To implement the strategies outlined in the GGRA, Maryland will create an additional 113 jobs in the Manufacturing industry by 2020. Of these 113 jobs, nearly 54 percent will be created within higher skilled sectors, such as *Computer and electronic product manufacturing* and *Electrical equipment and appliance manufacturing*. Some sectors, such as *Food Manufacturing* and *Textile mills; Textile product mills* will see minimal job declines between 2010 and 2020 as the industry shifts to a higher-skilled workforce demand to meet policy implementation associated with the GGRA. Despite all the change in Maryland's Manufacturing industry, there is no conclusive evidence that any closures or relocations outside Maryland are directly attributable to the GGRA or climate change planning. Based on the analysis provided within this report, RESI finds no discernible impacts on the manufacturing sector as a result of the GGRA programs. Furthermore, RESI recommends based on this analysis that Maryland not adopt any manufacturing specific GHG regulations in the future.

# 2.0 Introduction

The Maryland Department of the Environment (MDE) tasked the Regional Economic Studies Institute (RESI) to complete an impact analysis of the policies from the *Greenhouse Gas Emissions Reduction Act (GGRA) 2012 Plan* on Maryland's manufacturing industry. RESI employed the REMI PI+ model using agency-level data collected for the GGRA report to determine the impact on Maryland's Manufacturing industry. In this report, RESI assumed that all GGRA initiatives were implemented and results are reported for the Manufacturing industry by the four-digit North American Industry Classification System (NAICS) codes.

In addition to an economic impact analysis, RESI solicited feedback from regional manufacturers to include in the report. Manufacturer interviews included in this report are case studies of greenhouse gas reduction measures taken by these firms to remain compliant with government environmental mandates. RESI and representatives from MDE visited these manufacturers to witness their methods and interview them one on one in regard to the challenges faced with reducing greenhouse gas emissions, if any.

# 3.0 Literature Review

## 3.1 Trends in Manufacturing in Maryland

Since 2002 employment in Manufacturing in Maryland has steadily declined. In 2002 average annual employment in the manufacturing sector reached nearly 157,000 but dropped to approximately 109,000 in 2012.[2] Manufacturing as a percent of total Maryland employment has seen a less drastic change than employment within the manufacturing sector alone. In 2002 Manufacturing encompassed more than 6 percent of Maryland's total employment; by 2012 that share decreased slightly to 4 percent.[3] Despite employment declines, average weekly wages per worker have steadily increased. According to the Department of Labor, Licensing and Regulation (DLLR), average wages increased from $933 to $1,324 between 2002 and 2012. Average wages in Manufacturing have remained greater than average wages for Maryland industries overall.[4]

As seen in Figure 1, preliminary data for 2013 support the existing employment and wage trends. Employment in Manufacturing in Maryland decreased to fewer than 107,000 workers in 2013. [5] Preliminary figures for 2013 show that average weekly wages continue to increase; average weekly wages rose to approximately $1,340 in 2013, a $16 increase from 2012.[6]

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[2] "Employment and Payrolls - Industry Series – Maryland," Department of Labor, Licensing and Regulation, September 30, 2013, accessed October 24, 2013, http://www.dllr.state.md.us/lmi/emppay/tab1md.shtml.

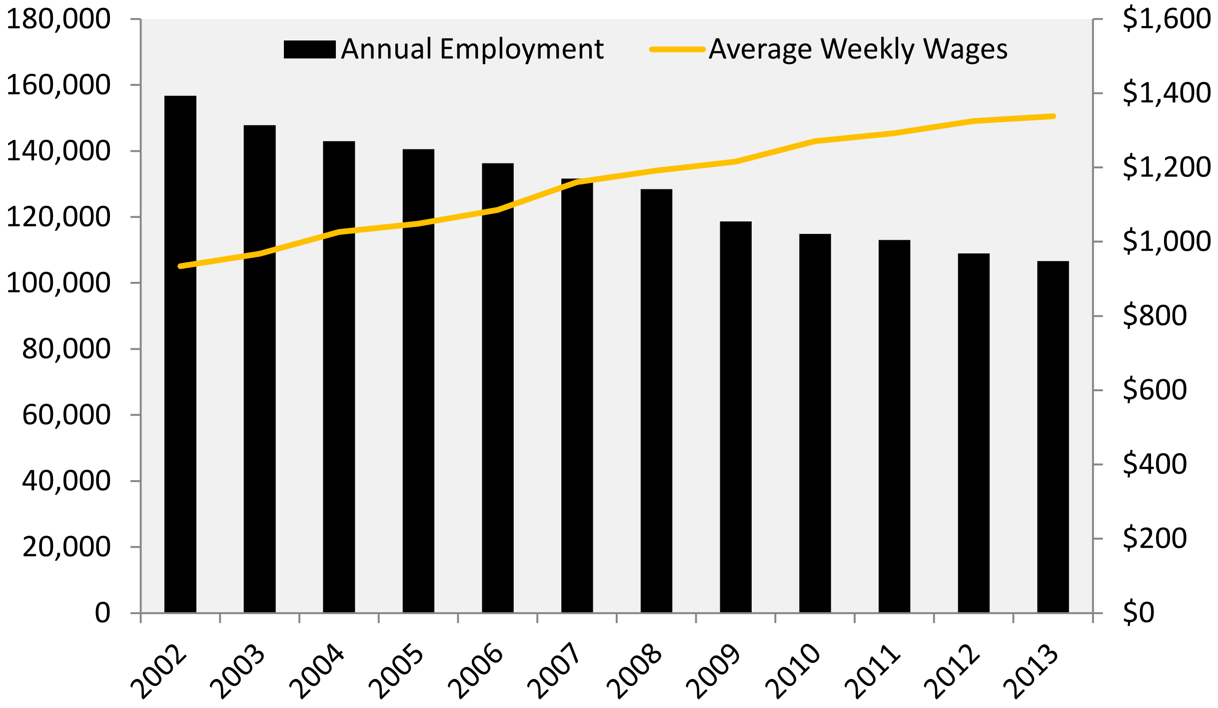
[3] Ibid.

[4] Ibid.

[5] "Quarterly Census of Employment and Wages," Bureau of Labor Statistics.

[6] Ibid.

**Figure 1: Manufacturing Employment and Wages for Maryland**[7]



Sources: BLS, QCEW

Regardless of employment declines, the manufacturing industry remains a vital enterprise for Maryland. In 2012 the manufacturing industry in Maryland

- Accounted for 5.9 percent of the total output in the state,
- Comprised 4.3 percent of the state's total employed workforce,
- Produced output of $18.7 billion, and
- Exported nearly $11 billion worth of goods.[8]

According to the 2014 report "Impact of the Manufacturing Renaissance from Energy Intensive Sources" prepared for the U.S. Conference of Mayors and the Council on Metro Economies and the New American City, the manufacturing industry has been a "keystone of economic growth" since the end of the recession—specifically, in the nation's metropolitan areas, such as the Baltimore-Columbia-Towson metropolitan statistical area (MSA), and in regard to industries that are energy intensive, such as Manufacturing.[9] Metropolitan areas encompass a vast

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[7] QCEW wages and employment data reported here are seasonally adjusted.

[8] "Maryland Manufacturing Facts," National Association of Manufacturers, 1-2, 2012, accessed October 24, 2013, http://www.nam.org/~/media/40D1B093FBD64A17BCC68940B5A7F167/Maryland.pdf.

[9] "U.S. Metro Economies Report on Impact of Manufacturing Renaissance from Energy Intensive Sectors," Global Insight and iHS, 1, 2013, accessed April 10, 2014, http://www.usmayors.org/pressreleases/uploads/2014/0320-report-MetroEconomiesManufacturing.pdf.

amount of the nation's total employment. In 2012 metropolitan areas encompassed nearly 80 percent of the nation's total employment and more than 80 percent of "real sales" that resulted from energy-intensive manufacturing industry components.[10] The report forecasts that employment within energy-intensive manufacturing industry components will expand at the same rate as that expected on the national level through 2020. At 72 percent, the majority of projected expansion will occur in metropolitan areas.[11]

Maryland has multiple organizations that support and/or promote the manufacturing industry. Since 1990 the Regional Manufacturing Institute (RMI) of Maryland has acted as an advocate for Maryland manufacturers.[12] With the help of a recent $3 million grant, provided by the Maryland Public Service Commission and the Maryland Energy Administration, RMI aims to assist Maryland manufacturers in targeting energy efficiency opportunities.[13] Maryland is also home to one of the nation's centers of the Manufacturing Extension Partnership (MEP) and the Maryland World Class Manufacturing Consortium.

Through partnerships with other MEP centers nationwide, as well as the National Institute of Standards and Technology, the Maryland MEP facilitates the growth of manufacturers.[14] These partnerships allow the Maryland MEP to offer training in "Lean, Innovation Engineering, Advanced Manufacturing and Marketing." [15] Additional Manufacturing support comes from the Maryland World Class Manufacturing Consortium. The Consortium aids manufacturers in meeting international demand and standards.[16]

### 3.2 Maryland's Manufacturing Industry and Greenhouse Gas Reduction

Under the Greenhouse Gas Reduction Act (GGRA) of 2009, the State of Maryland is required to produce the 25 percent reduction from 2006 levels by 2020. The bill also states that Manufacturing can only be regulated at a federal level, and the industry is therefore excluded from the GGRA.[17] Greenhouse gas (GHG) emissions resulting from the state's Manufacturing

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[10] "U.S. Metro Economies Report on Impact of Manufacturing Renaissance from Energy Intensive Sectors," Global Insight and iHS, 1.

[11] Ibid.

[12] "About RMI," Regional Manufacturing Institute of Maryland, accessed October 24, 2013, http://rmiofmaryland.com/about-rmi/.

[13] "Join the RMI's Next-Gen-M Energy Efficiency Program," Regional Manufacturing Institute of Maryland, October 14, 2013, accessed October 24, 2013, http://rmiofmaryland.com/join-the-rmis-next-gen-m-energy-efficiency-program/.

[14] "Maryland Direct Financial Incentives 2014," Area Development, 2014, accessed April 10, 2014, http://www.areadevelopment.com/stateResources/maryland/MD-Direct-Financial-Incentives-2014-124356.shtml.

[15] Ibid.

[16] Ibid.

[17] "Facts About The Greenhouse Gas Reduction Act of 2009," Maryland Department of the Environment, 1, accessed October 24, 2013, http://www.mde.state.md.us/assets/document/Air/ClimateChange/GGRA_factsheet.pdf.

industry make up a relatively small portion, only 4 percent, of the state's total GHG emissions—this percent is not expected to change significantly by 2020.[18]

**Regulation Impacts on Competitiveness**
Maryland manufacturers must contend with regional, national, and international competitors. Due to this competitiveness, the industry's GHG emissions are thought to be best regulated on a national level.[19] State regulations cannot require the manufacturing industry to reduce GHG emissions nor can such regulations place higher financial burden on Maryland manufacturers unless required at the federal level.[20] Doing so would place Maryland's Manufacturing sector at a competitive disadvantage.

While Manufacturing is currently excluded from GHG emissions reduction requirements, the GGRA encourages the manufacturing industry to reduce emissions voluntarily. In the future, it is possible that Manufacturing will be subject to reduction requirements; any GHG emissions reductions accomplished in Manufacturing in the short term will be applied to future reduction requirements. [21] With the GGRA of 2009, Maryland continues to advocate for a strong federal GHG reduction program. [22]

**Energy Efficiency Investments**
Across the U.S., companies have committed to at least a 25 percent reduction in energy intensity associated with manufacturing within 10 years—these companies are recognized by the Department of Energy's as Better Plants Program Partners.[23] Some of these companies have already reached the 25 percent reduction goal, while others have accepted the Better Buildings, Better Plants Challenge and strive to obtain "enhanced levels of transparency and innovation" and have "agreed to make a significant near-term investment in energy efficiency at a chosen facility." [24]

On a more local level, progress is evident throughout the state. For example, in 2012 seasoning company McCormick & Company announced that its distribution center based in Belcamp, Maryland, reached "net-zero" through energy conservation measures—in other words, the

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[18] Facts About The Greenhouse Gas Reduction Act of 2009," Maryland Department of the Environment.
[19] "Chapter 172 (Senate Bill 278)," Maryland General Assembly, 2, 2009, accessed October 24, 2013, http://mgaleg.maryland.gov/2009rs/chapters_noln/Ch_172_sb0278E.pdf.
[20] Ibid, 7.
[21] "Facts About The Greenhouse Gas Reduction Act of 2009," Maryland Department of the Environment, 2.
[22] Ibid.
[23] Office of Energy Efficiency & Renewable Energy, "Better Plants Program Partners," U.S. Department of Energy, accessed January 7, 2015, http://www.energy.gov/eere/amo/better-plants-program-partners.
[24] Ibid.

distribution center uses less electricity that it produces.[25] To achieve net-zero status at its Belcamp location, McCormick installed "energy-efficient interior and exterior lighting, occupancy sensors, HVAC upgrades, and energy efficient pallet conveyors," with a solar array generating the surplus energy.[26]

The Regional Manufacturing Institute of Maryland (RMI), in partnership with the Maryland Energy Administration, is using a recently obtained $3 million grant "to help target energy efficiency opportunities with Maryland manufacturers in the BGE service territory." [27] Those firms that meet program criteria can receive business services, such as a comprehensive energy audit and energy efficiency training, at minimal out-of-pocket cost (services that could cost more than $30,000). [28] These services have the potential to reduce energy costs by 15 to 25 percent. [29] Current participants include the following:

- Chesapeake Specialty Chemical (Building Materials),
- Danko Arlington (pattern shop, foundry, and machine shop),
- Ellicott Dredge (Dredging Equipment Sector),
- Green Bay Packaging (Packaging Sector),
- GM Baltimore Operations (Automotive Sector),
- Maritime Applied Physics Corporation (Shipping Sector),
- Maryland Thermoform (Plastics Sector),
- Medifast (Dietary Meals/Snacks),
- Northrop Grumman Electronic Systems (Defense Electronics Sector),
- Sun Automation (Machinery Motors),
- U.S. Gypsum (Construction Materials), and
- Zentech Manufacturing (Electronics Sector).[30]

Firms that have seen production increases due to previous energy efficiency measures, such as Hunt Valley's Green Bay Packaging, have spoken out in favor of improved energy efficiency.[31] Other programs, such as BGE's Smart Energy Savers program, are aiding Maryland's journey toward energy efficiency. BGE's "success stories" include El Andariego, Mars Supermarkets, Pet

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[25] "McCormick Distribution Center Achieves Net-Zero Energy Status," Environmental Leader, April 17, 2012, accessed January 7, 2015, http://www.environmentalleader.com/2012/04/17/mccormick-distribution-center-achieves-net-zero-energy-status/.

[26] Ibid.

[27] Energy Solutions Center, "About the RMI Energy Efficiency Program," Regional Manufacturing Institute of Maryland, accessed January 7, 2015, http://rmienergysolutions.com/about-us/.

[28] Ibid.

[29] Ibid.

[30] Ibid.

[31] Jamie Smith Hopkins, "A bid to lower manufacturers' energy bills," The Baltimore Sun, April 21, 2014, accessed January 7, 2015. http://articles.baltimoresun.com/2014-04-21/business/bs-bz-manufacturers-energy-efficiency-20140414_1_energy-efficiency-energy-bills-manufacturers.

Depot, Ski Haus, and Under Armour.[32] Under Armour operates two 300,000-plus-squarefoot distribution centers in Baltimore. Working with BGE, for a nearly 50 percent savings in retrofit costs, Under Armour recently installed nearly 900 new lighting fixtures between the two distribution centers. [33] These projects both aligned with the company's UA Green corporate mission, while producing a 28 percent reduction in kilowatt-hour (kWh) use per year and, therefore, generating ongoing energy savings in the future.[34]

Others, such as Gaithersburg's MedImmune have "been able to achieve savings in such an aggressive way due to its partnerships with DOE's Industrial Assessment Center program and the Maryland Energy Administration, as well as energy efficiency rebates available via its electric utility, Pepco."[35] MedImmune aims to reduce energy intensity by 25 percent by 2020, and as of 2013 MedImmune has achieved an energy intensity reduction of 19.2 percent.[36]

### 3.3 Greenhouse Gas Emissions Reduction Guidelines for Manufacturing

In the U.S., the greatest sources of GHG emissions include electricity production, transportation, industry, commercial and residential, agriculture, and land use and forestry.[37] Worldwide, electricity production followed by industry activity and forestry are the greatest sources of GHG emissions.[38] In 2006, the baseline year, industrial activity was responsible for approximately 7 percent of the total GHG emissions in Maryland.[39] In 2011 industrial activity was responsible for 20 percent of the total GHG emissions in the U.S. [40] To reduce GHG emissions, manufacturers and other industrial producers could increase energy efficiency, consider fuel switching, recycling, and institute training and awareness programs.[41] Many of these options have been successfully implemented both nationally and worldwide.

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[32] "Success Stories," BGE, accessed January 7, 2015, http://www.bge.com/waystosave/business/bizlearnmore/bizsuccessstories/Pages/default.aspx.

[33] "Under Armour," BGE, accessed January 7, 2015, http://www.bge.com/waystosave/business/bizlearnmore/bizsuccessstories/Pages/Under-Armour.aspx.

[34] Ibid.

[35] MedImmune, "Maryland Manufacturer Pursues Energy Efficiency Improvements for Operational Savings," Maryland Energy Administration, accessed January 7, 2015, http://energy.maryland.gov/SEN/pdfs/MedImmune%20One%20Pager-042513.pdf.

[36] Ibid.

[37] "Sources of Greenhouse Gas Emissions Overview," United States Environmental Protection Agency, September 9, 2013, accessed October 24, 2013, http://www.epa.gov/climatechange/ghgemissions/sources.html.

[38] "Global Greenhouse Gas Emissions Data," United States Environmental Protection Agency, September 9, 2013, accessed April 18, 2014, http://www.epa.gov/climatechange/ghgemissions/global.html.

[39] "Maryland's Plan to Reduce Greenhouse Gas Emissions," Maryland Department of the Environment, 8, December 31, 2011, accessed October 28, 2013. http://www.mde.state.md.us/programs/Air/ClimateChange/Documents/2011%20Draft%20Plan/2011GGRADRAFTPlan.pdf.

[40] "Sources of Greenhouse Gas Emissions Overview," United States Environmental Protection Agency.

[41] "Sources of Greenhouse Gas Emissions Industry Sector Emissions," United States Environmental Protection Agency, October 30, 2013, accessed October 30, 2013, http://www.epa.gov/climatechange/ghgemissions/sources/industry.html.

**Alabama**

In Alabama, national policy affecting reduction of GHG emissions will impact a variety of industries, such as coal mining, energy, and manufacturing. These industries all have strong representation in the state.[42] To mitigate GHG emissions, the recommended policy options for the state include the following:

- Increased energy efficiency,
- Waste reduction and increased recycling,
- Increased use of methane/natural gas,
- Transportation changes, and
- Sequestration.[43]

**California**

Assembly Bill 32 passed in California in 2006. The bill included requirements that will help California meet GHG emissions reduction goals.[44] Specific requirements related to industrial activity include the adoption of required reporting regarding the level of greenhouse gas emissions as well as the adoption of set emissions limits.[45]

**Pennsylvania**

While climate change will impact Pennsylvania's energy industry, activities associated with renewable energy, such as manufacturing activities, will provide new jobs and revenue growth.[46] Coal, which has the highest carbon content when compared to other fossil fuels, will remain the major fuel source in the state, creating the challenge of managing GHG emissions associated with coal.[47] [48] In 2000, Pennsylvania's base year, coal production and use was responsible for 93 percent of the state's total energy-related emissions. [49] Due to the relatively controversial nature of coal and other fossil fuels, and Pennsylvania's abundance of such fuels, the state must seek viable uses of these natural resources.[50]

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[42] Robert A. Griffin, William D. Gunther, and William J. Herz, "Policy Planning to Reduce Greenhouse Gas Emissions in Alabama Final Report," The University of Alabama, 16, December 1997, accessed October 28, 2013, http://www.epa.gov/statelocalclimate/documents/pdf/Alabama_action_plan.pdf.

[43] Ibid, 16-20.

[44] "Assembly Bill 32: Global Warming Solutions Act," California Environmental Protection Agency, accessed October 28, 2013, http://www.arb.ca.gov/cc/ab32/ab32.htm.

[45] Ibid.

[46] "Final Climate Change Action Plan," Pennsylvania Environmental Protection Agency, 2-3, December 18, 2009, accessed October 29, 2013, http://www.dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_001957.pdf.

[47] "Coal," Center for Climate and Energy Solutions, accessed April 18, 2014, http://www.c2es.org/energy/source/coal.

[48] "Final Climate Change Action Plan," Pennsylvania Environmental Protection Agency, 2-3.

[49] "Final Climate Change Action Plan," Pennsylvania Environmental Protection Agency, 4-3.

[50] Ibid, 2-3.

## Comparative International Findings

Efforts to reduce GHG emissions are not limited to the U.S.; nations and organizations worldwide are working toward GHG emissions reductions. Canada, for instance, is committed to reducing GHG emissions—primarily through regulations pertaining to Canada's high emissions producing industries, like transportation and electricity.[51] Canada has seen a decrease in emissions of 5.1 percent from 2005 to 2012; this decrease did not hinder economic growth, which increased by 10.1 percent during the same period. [52] Other regulations implemented by Canada's climate change plan are performance standards for the major sources of emissions, with a focus on oil and gas, and other industrial emitters.[53]

A multitude of well-known global corporations, such as Unilever, Avon, SC Johnson, and Whirlpool, have all moved toward processes to reduce the GHG emissions created during the manufacturing process. Unilever aims to reduce emissions to or below 2008 levels by 2020 (a reduction of 40 percent per tonne of production), to increase its use of renewable energy to 40 percent of total energy with a long-term goal of using 100 percent renewable energy.[54] In 2012 Unilever's emission reductions were equivalent to that of reducing roadway congestion by approximately 200,000 cars.[55] As of 2012, all of Unilever's sites located in the U.S., Canada, and European Union utilized certified renewable electricity sources.[56]

Avon joined the Green Lights program, run by the U.S. Environmental Protection Agency, in 1994. At this time, Avon retrofitted many of its U.S.-based manufacturing and distribution locations with energy-efficient lighting.[57] Avon hoped to reduce GHG emissions created during operations by 20 percent compared to 2005 levels by 2020—a goal Avon exceeded in 2012 when reductions from the 2005 baseline reached 41 percent.[58] In the future, Avon hopes to switch to 100 percent clean energy, therefore eliminating emissions entirely.[59]

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[51] "Canada's Action on Climate Change," Government of Canada, April 11, 2014, accessed April 18, 2014, http://www.climatechange.gc.ca/default.asp?lang=En&n=72F16A84-1.

[52] "Reducing Greenhouse Gases," Government of Canada, April 11, 2014, accessed April 18, 2014, http://www.climatechange.gc.ca/default.asp?lang=En&n=4FE85A4C-1.

[53] Ibid.

[54] "Reducing GHG from Manufacturing," Unilever, 2014, accessed April 10, 2014, http://www.unilever.com/sustainable-living/greenhousegases/reducingghgfrommanufacturing/.

[55] Ibid.

[56] Ibid.

[57] "Energy & Greenhouse Gas Emissions Reduction Efforts," Avon, the Company for Women, 2014, accessed April 10, 2014, http://www.avoncompany.com/corporatecitizenship/corporateresponsibility/sustainability/minimizingoperationalfootprint/energy-greenhouse-gas-reduction.html.

[58] "Energy & Greenhouse Gas Emissions Reduction Efforts," Avon.

[59] Ibid.

In 2000 SC Johnson established benchmarks for its largest plants, five in total at the international level, regarding GHG emissions.[60] In 2002 the corporation implemented additional reduction guidelines covering all operations in the U.S.; these goals were surpassed in 2005.[61] Over the past several years, SC Johnson has repeatedly set new reduction goals and continued to meet them. Most recently, SC Johnson began working toward an emissions reduction from global manufacturing of 48 percent compared to 2000 levels by 2016. [62] As of 2012, emissions from global sites compared at 40.2 percent of 2000 levels, with preliminary 2013 figures moving SC Johnson even closer to its 2016 goal. [63]

In 2003 Whirlpool stated its aim to accomplish a three percent emissions reduction from the 1998 base year by 2008.[64] Between 2003 and 2006, Whirlpool reduced GHG emissions by 4.1 million metric tons—the equivalent of planting nearly 1.4 million acres of trees.[65] In 2007 Whirlpool announced that it would further reduce GHG emissions by 6.6 percent by 2012; this announcement was made in support of Whirlpool's commitment to environmentally-sound business practices.[66] Whirlpool hopes to meet its overall reduction goals through the introduction of energy efficient models to its product line to reduce the impact of these products, as well as implementing improvements in both manufacturing and freight operations.[67]

Policies around the world are having vast impacts, and it is clear that successful policies regarding GHG emissions reduction have several key components in common. A 2003 Organization for Economic Co-Operation and Development report found three factors for success with greenhouse gas mitigation policies. Policies must be environmentally effective (i.e., reduce rather than reallocate), economically efficient (i.e., flexible options with minimal cost options), and have support.[68] These factors are also necessary if manufacturers worldwide are to remain competitive.

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[60] "Reducing Greenhouse Gas Emissions," SC Johnson, A Family Company, 2013, accessed April 10, 2014, http://www.scjohnson.com/en/commitment/focus-on/conserving/reducing.aspx.
[61] Ibid.
[62] Ibid.
[63] Ibid.
[64] "Reducing Greenhouse Gas Emissions," Whirlpool Corporation, accessed April 10, 2014, http://www.whirlpoolcorp.com/responsibility/environment/performance/reducing_greenhouse_gas_emissions.aspx.
[65] Ibid.
[66] Ibid.
[67] Ibid.
[68] "Policies to Reduce Greenhouse as Emissions in Industry - Successful Approaches and Lessons Learned: Workshop Report," Organisation for Economic Co-operation and Development International Energy Agency, 10, 2003, accessed March 12, 2014, http://www.oecd.org/env/cc/2956442.pdf.

### 3.4 The Effect of Greenhouse Gas Emissions Reduction

**Energy Costs**

A 2014 Boston Consulting Group study finds that manufacturers in the U.S. are poised to benefit from the rising production of natural gas nationwide. [69] The lower electricity prices have already spurred investment in energy-intensive industries—even in industries that are less energy-intensive, low cost natural gas is estimated to shave "1 to 2 percent off of U.S. manufacturing costs as the benefits eventually flow downstream through the value chain."[70] BCG estimates that soon natural gas and electricity will account for just 2 percent and 1 percent, respectively, of average U.S. manufacturing costs—compared to the combined 7 to 13 percent energy costs seen in Japan and in the European Union. [71] Low energy costs will further narrow the cost gap between the manufacturers in the U.S. and in China. [72]

**Transportation**

Since 2010, following new greenhouse gas emissions standards implemented by the Obama administration, upfront vehicle prices have slightly increased (by approximately $1,000) yet lifetime fuel savings have surpassed that—coming in at $4,000 over the lifetime of the vehicle.[73] These estimates reflect a fuel efficiency of 35.5 miles per gallon required for standard cars and light trucks by model year 2016.[74] Since then, hybrid and electric vehicles have become increasingly popular—with the availability of electricity overweighing the availability of natural gas, vehicles of this type require less investment when compared to natural gas vehicles.[75] Alternatively, "the greatest opportunity to reduce greenhouse gas emissions…is through fuel substitution in fleets and heavy-duty vehicles." [76]

In some states, such as California, new transportation fuel policies benefit drivers and communities; however, trucking companies are not fairing as well—the EPA Regulations are putting some trucking companies out of business.[77] [78] The same regulations implemented by

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[69] "Nearly Every Manufacturer in the U.S. Will Benefit from Low-Cost Natural Gas," The Boston Consulting Group, February 13, 2014, accessed January 7, 2015, http://www.bcg.com/media/PressReleaseDetails.aspx?id=tcm:12-154623.

[70] Ibid.

[71] Ibid.

[72] Ibid.

[73] Juliet Eilperin, "Emissions limits, greater fuel efficiency for cars, light trucks made official," The Washington Post, April 2, 2010, accessed January 7, 2015, http://www.washingtonpost.com/wp-dyn/content/article/2010/04/01/AR2010040101412.html.

[74] Ibid.

[75] "Leveraging Natural Gas to Reduce Greenhouse Gas Emissions," Center for Climate and Energy Solutions, June 2013, accessed January 7, 2015, http://www.c2es.org/publications/leveraging-natural-gas-reduce-greenhouse-gas-emissions.

[76] Ibid.

[77] Erica Morehouse, "Transportation fuel policies continue to benefit drivers and communities across California," Environmental Defense Fund, May 16, 2014, accessed January 7, 2015,

the California Air Resources Board (CARB) that will save drivers money will also put an "overwhelming burden for businesses, especially small businesses." [79] [80] As of January 1, 2015, "trucks weighing 14,000 pounds to 26,000 pounds will be forced to install PM retrofits;" retrofits cost are generally between $10,000 and $20,000.[81]

**Growth Opportunities**

Natural gas exploration has taken place in more than 30 states nationwide, creating local jobs in its wake.[82] Since the beginning of the Great Recession, states undergoing shale exploration have added nearly 1.4 million jobs; conversely states without shale exploration have lost more than 400,000 jobs.[83] According to 2014 study by the Perryman Group, natural gas exploration generates more than 9.3 million jobs and nearly $1.2 trillion in annual gross product.[84] Moreover, a PricewaterhouseCoopers study, done on the behalf of the National Association of Manufacturers, estimated that natural gas will generate an additional 1 million U.S. manufacturing jobs by 2025.[85]

### 3.5 Workforce Redevelopment

Manufacturing in Maryland and the U.S. as a whole has seen steady employment declines since 2002. The industry's average per capita weekly wage, however, has increased. This trend indicates a shift in the type of Manufacturing jobs available. According to the Manufacturing Institute, due in part to the increased "technological sophistication" of manufacturing, the industry now requires "more process-oriented, team-oriented workers."[86] As the industry evolves and the technical knowledge required of industry workers increases, the quality of available jobs is also increasing. Manufacturing jobs now require a higher level of training and education compared to traditional Manufacturing jobs. In 2000, 22 percent of the

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http://blogs.edf.org/californiadream/2014/05/16/transportation-fuel-policies-continue-to-benefit-drivers-and-communities-across-california/.

[78] Wesley Coopersmith, "California EPA Regulation Puts Trucking Companies Out of Business," June 20, 2012, access January 7, 2015, http://www.freedomworks.org/content/california-epa-regulation-puts-trucking-companies-out-business.

[79] Morehouse, "Transportation fuel policies continue to benefit drivers and communities across California."

[80] Coopersmith, "California EPA Regulation Puts Trucking Companies Out of Business."

[81] Ibid.

[82] "Jobs," America's Natural Gas Alliance, accessed January 7, 2015, http://anga.us/why-natural-gas/jobs#.VKbsOyvF9yw.

[83] Tyler Durden, "Jobs: Shale States vs Non-Shale States," Zero Hedge, December 3, 2014, accessed January 7, 2015, http://www.zerohedge.com/news/2014-12-03/jobs-shale-states-vs-non-shale-states.

[84] Mella McEwen, "Study: Oil & Gas Industry Creates 9.3 Million Jobs in U.S.," Midland Reporter-Telegram, August 31, 2014, accessed January 7, 2015, http://www.cpapracticeadvisor.com/news/11674995/study-oil-gas-industry-creates-93-million-jobs-in-us.

[85] "Jobs," America's Natural Gas Alliance.

[86] "Percent of Manufacturing Workforce by Education Level," Manufacturing Institute, April 2014, accessed June 2, 2014, http://www.themanufacturinginstitute.org/Research/Facts-About-Manufacturing/Workforce-and-Compensation/Workforce-by-Education/Workforce-by-Education.aspx.

Manufacturing workforce in the U.S. held a Bachelor's degree or higher; this figure rose to approximately 29 percent in 2012.[87]

Having evolved to a new level of technological sophistication, Manufacturing now requires the use of "precision machinery, computer modeling and high-tech tooling."[88] According to the National Association of Manufacturers (NAM), the industry needs employee development, lifelong learning, and adult education, and many think it is necessary to develop these aspects well before beginning a career.[89] [90]

In recent years, many states have adopted a Common Core (CC) curriculum for K-12 grade levels. The CC curriculum focuses on higher universal standards in regard to literacy and mathematics, focuses which help prepare students "for these higher-skilled, internationally competitive jobs."[91] Beyond improvements made to the K-12 school system, many students who go on to earn a college degree often remain at a disadvantage. The industry lacks a standardized credentialing system, a limitation which creates an inadequate pool of desirable college graduates for employers in the industry.[92]

The aim of the newly launched Skills for America's Future program is to "provide 500,000 community college students with standardized manufacturing credentials that will promise secure jobs within the sector." [93] Through the program, students can "earn valuable credentials that are portable and demanded by vast amounts of firms." [94] Partners of the for-credit program of study include the Gates Foundation, the Lumina Foundation, and several members involved in education and training such as individuals from the American Welding Society, the National Institute of Metalworking Skills, the Society of Manufacturing Engineers, and the Manufacturing Skills Standards Council.[95]

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[87] Ibid.

[88] Richard Haass and Klaus Kleinfeld, "Column: Lack of skilled employees hurting manufacturing," *USA Today News*, July 3, 2012, accessed June 2, 2014, http://usatoday30.usatoday.com/news/opinion/forum/story/2012-07-02/public-private-manufacuting/56005466/1.

[89] "Workforce Development and Training," National Association of Manufacturers, accessed June 2, 2014, http://www.nam.org/Issues/Employment-and-Labor/Manufacturing-Workforce-Development.aspx.

[90] "HRP-01 Education and the Workforce," National Association of Manufacturers, accessed June 2, 2014, http://www.nam.org/Issues/Official-Policy-Positions/Human-Resources-Policy/HRP-01-Education-and-the-Workforce.aspx#202.

[91] Haass and Kleinfeld, "Column: Lack of skilled employees hurting manufacturing."

[92] "President Obama and Skills for America's Future Partners Announce Initiatives Critical to Improving Manufacturing Workforce," Office of the Press Secretary, The White House, June 8, 2011, accessed June 2, 2014, http://www.whitehouse.gov/the-press-office/2011/06/08/president-obama-and-skills-americas-future-partners-announce-initiatives.

[93] Ibid.

[94] "President Obama and Skills for America's Future Partners Announce Initiatives Critical to Improving Manufacturing Workforce," Office of the Press Secretary.

[95] Ibid.

Skills for America's Future's partnerships also promote several other initiatives, such as the following:

- Helping manufacturers realize the need to implement credentials through "Boots on the Ground,"
- Building credentials into high school pathways,
- Providing new online tools for workers to earn and utilize these credentials,
- Improving awareness of such credentials through a Career Awareness Campaign,
- Increasing opportunities for at-risk youth to seek these careers and credentials, and
- Creating the next-generation engineering workforce.[96]

Locally, the Maryland Manufacturing Extension Partnership (MD MEP) has several programs designed to train the new manufacturing workforce. These programs include the Manufacturing Boot Camp and the Manufacturing Incumbent Workforce Training Partnership.[97] Both programs are made possible through the Employment Advancement Right Now (EARN) program. The Manufacturing Boot Camp, a six-week training program, aims to "increase the skills of potential workers and enhance their employability." [98] Following an assessment of trainee skills, individuals will undergo training for skills including but not limited to the following:

- Work ethic,
- Job readiness,
- Professionalism,
- Problem solving,
- Basic mathematics and English,
- Communication, and
- Basic manufacturing skills.[99]

An abbreviated version of this program was successfully piloted with Garrett Container Systems, Inc., a shipping and storage container manufacturer located in Western Maryland. Upon their completion of the program, ten of the program participants were hired by the company.[100]

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[96] Ibid.

[97] Courtney Gaddi, "Maryland Manufacturing Extension Partnership Works to Grow Manufacturing in Maryland," *Columbia Patch*, February 20, 2014, accessed June 2, 2014, http://columbia.patch.com/groups/business-updates/p/maryland-manufacturing-extension-partnership-works-to-grow-manufacturing-in-maryland.

[98] "EARN Maryland 2014 Planning Grant Strategic Industry Partnerships," Maryland Department of Labor, Licensing and Regulation, 7, accessed June 2, 2014, http://www.dllr.maryland.gov/earn/earnsipsummaries.pdf.

[99] Gaddi, "Maryland Manufacturing Extension Partnership Proves Manufacturing Bootcamp Program Successful With Pilot Program."

[100] Gaddi, "Maryland Manufacturing Extension Partnership Proves Manufacturing Bootcamp Program Successful With Pilot Program."

In addition to the Manufacturing Boot Camp, the MD MEP proposed the Manufacturing Incumbent Workforce Training Partnership**.** This proposal seeks to "address skills gaps in advanced machining, master craftsmen and other areas," while alleviating the "burden on individual employers of incumbent worker training, such as tuition costs, wages and lost production time."[101]

# 4.0 Relevant Maryland Case Studies

While Manufacturing is excluded from current state regulations that require a 25 percent reduction in GHG emissions from 2006 levels by 2020, impacts associated with reduction efforts are occurring in the industry. RESI reached out to manufacturers in Maryland to discuss the impacts that reduction requirements have made. To date, Redland Brick and General Motors Baltimore Operations are the two completed case studies.

## 4.1 Redland Brick

On Thursday, December 12, 2013, team members from RESI and MDE visited and toured Redland Brick, Inc., in Williamsport, Maryland. Barry Miller (Manager of Safety, Environmental, and Quality) met with team members to discuss the impacts that legislation has had on Redland Brick and to provide a guided tour of the Williamsport facilities.

A subsidiary of Belden Holding & Acquisition Company, Inc., Redland Brick has six brick manufacturing plants, including two in Maryland (Cushwa and Rocky Ridge) and one each in Pennsylvania (Harmar), Connecticut (KF), and Virginia (Lawrenceville). Redland Brick produces a wide range of brick products, including handmade, moulded, and extruded styles.[102] Redland Brick's two moulded brick plants, located in Maryland, "have established themselves as the premier moulded brick producers in the United States."[103] In 2001 Redland Brick commissioned Harmar, located in suburban Pittsburgh, Pennsylvania. This plant offers "a variety of products including fireclay, red shale, and sand coated bricks" and is completely automated.[104] Located in South Windsor, Connecticut, is Redland's KF plant. According to the company's website, this plant "is a modern extruded plant that supplies quality brick products for New England and the Mid-Atlantic markets."[105] Redland also owns the two plants of Lawrenceville Brick in Lawrenceville, Virginia. Redland Brick has the unique ability to limit waste resulting from manufacturing. If at any time during the brick making process a brick is deemed flawed, it can be cycled back through to the beginning of the brickmaking process.

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[101] "EARN Maryland 2014 Planning Grant Strategic Industry Partnerships," Maryland Department of Labor, Licensing and Regulation, 7.

[102] "Redland Brick Inc. – Brick Manufacturer," Redland Brick, 2011, accessed April 14, 2014, http://www.redlandbrick.com/aboutus.asp.

[103] Ibid.

[104] Ibid.

[105] "Redland Brick Inc. – Brick Manufacturer," Redland Brick.

To meet the Environmental Protection Agency's (EPA) Maximum Achievable Control Technology (MACT) requirements, in 2008 Redland Brick installed a new scrubber that cost approximately $1 million.[106] This particular scrubber uses high-quality, expensive limestone in the scrubbing process. In the interest of further reducing waste, Mr. Miller has worked with the Connecticut Agricultural Experiment Station to complete an analysis that shows that the limestone used by Redland Brick, and therefore the limestone waste resulting from the scrubbing process, provides a pH level comparable to the regular lime commonly used in farming when added to topsoil. After the expensive changes made by Redland Brick to meet the 2008 MACT requirements, the legislation was overturned. EPA is now finalizing a second MACT standard for the same emissions.

Depending upon the outcome, Redland Brick may need to replace that scrubber, continue to operate it, or have it determined that the scrubber was never necessary. The combination of regulatory requirements and the housing market crash has crippled the brick industry. Redland is not aware of technology available on the market today that can be used in a brick kiln to reduce greenhouse gas emissions. If forced to reduce greenhouse gas emissions, Redland would likely be forced to reduce production. Reducing production would lead to job losses and an additional sizable strain on Redland Brick's ability to operate.

### 4.2 General Motors Baltimore Operations

In June 2015, team members from RESI spoke with a representative from the General Motors (GM) Baltimore Operations. Michael Martinko, Senior Environmental Engineer, spoke with team members to discuss the impacts that legislation has had on GM's Baltimore Operations since the early 2000s.

GM is a dynamic motor vehicle manufacturer with operations worldwide.[107] GM's domestic brands include Buick, Cadillac, Chevrolet, and GMC. With nearly 400 facilities and more than 20,000 dealers, GM's wide spread activity encompasses 6 continents and 120 countries.[108] GM strives to create new vehicles and technology as well as engineer state-of-the-art plants.[109] Through innovative technology development, such as electric vehicles and fuel saving technology, GM is working to shape the automotive industry of the future.[110] The GM Baltimore Operations facility is located in White Marsh, Maryland.[111]

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[106] While MACT is not a GHG reduction requirement, it is aimed at criteria pollutants.
[107] "Our Company," General Motors, accessed June 22, 2015, http://www.gm.com/company/aboutGM/our_company.html.
[108] Ibid.
[109] Ibid.
[110] "Our Company," General Motors.
[111] "Baltimore Operations," GM News, accessed June 22, 2015, http://media.gm.com/media/us/en/gm/company_info/facilities/powertrain/baltimore.html.

Opened in December 2000, GM Baltimore Operations encompasses more than 580,000 square feet.[112] This plant houses 1.81 megawatts of rooftop solar arrays and is landfill-free, meaning it recycles, reuses, or converts to energy all waste created from daily operations.[113] In April 2011, the facility took first place in the *Baltimore Business Journal*'s Annual Green Business Award Event; that same year, the facility earned Wildlife Habitat Council certification.[114] In June 2012, the facility was included among the winners of the Maryland Green Registry Leadership Awards, and in 2013 Baltimore County honored Baltimore Operations in the Baltimore County Chamber of Commerce Business Hall of Fame for the facility's environmental efforts.[115] More recently, in June 2014, the facility was recognized with a Project of Distinction Award from PV America for a smart microgrid charging technology, which uses a solar array and solar EV charging canopy to charge Chevrolet Volts or stores energy in a system to support the grid.[116]

GM committed to reduce its facilities' carbon intensity globally by 20 percent by 2020. While the solar array generates approximately 6 percent of GM Baltimore Operation's electricity, natural gas used in heat treating remains the facility's key contributor to GHG emissions. However, the plant maintains its commitment to operating landfill-free by recycling or reusing 90 percent of waste in 2013. In addition to the solar array on site at the facility, GM Baltimore Operations strives to reduce power usage during lunch hours by shutting down lights and running at a 20 percent level of production on weekends. GM Baltimore Operations recently met the Environmental Protection Agency's ENERGY STAR® Challenge for Industry by reducing the energy intensity of its operations by 15.5 percent in just three years. The site has continued other initiatives to reduce energy costs, such as moving from single speed compressors to variable speed compressors, a change that helps to reduce both energy and maintenance costs. Although the upfront cost is greater, Mr. Martinko noted that the long-term costs are diminished, which balances the short-term investment. GM Baltimore Operations attributes much of its success in leading the way as a manufacturer to collaborative environmental efforts with companies like Constellation Energy and TimberRock. These partnerships help GM Baltimore Operations continue to reduce its impact on climate change.

# 5.0 Economic Impacts from the GGRA on Manufacturing

Maryland's Manufacturing industry was one of the hardest hit industries in the state during the recession from 2007 through 2009. Upon passage of the GGRA, concerns arose about Manufacturing's ability to remain competitive if more costs were added after the recession. However, RESI's analysis shows that there are no net discernible impacts on Manufacturing from GGRA implementation.

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[112] Ibid.
[113] Ibid.
[114] Ibid.
[115] Ibid.
[116] Ibid.

To determine the potential impacts associated with the GGRA, RESI used agency-specific data and external research to determine inputs for the analysis. These inputs included the following:

- Industry sales data,
- Energy consumption reduction estimates,
- Industry-level demand, and
- Tax credits.

Using these inputs, RESI ran the analysis using the REMI PI+ model, specifically calibrated to Maryland's economy, to determine impacts from 2010 through 2020. The following section discusses the impacts on employment, output, and wages.

### 5.1 Economic Impacts

To determine the level of impact on the Manufacturing industry, RESI ran all GGRA initiatives outlined in the GGRA from investment through operation. The following results are the impacts expected to occur in Maryland for the Manufacturing industry by 2020. Overall, RESI found no discernible impact on employment in the Manufacturing industry between 2010 and 2020. Figure 3 reports the findings for the 20 sectors that make up the industry at the four-digit NAICS level for employment in 2020.

**Figure 2: Manufacturing Employment Impacts from GGRA Initiatives, 2020**[117]

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 3.9 | -0.4 | 3.5 |
| Beverage and tobacco product manufacturing | 4.4 | -1.7 | 2.7 |
| Chemical manufacturing | 4.2 | -1.0 | 3.2 |
| Computer and electronic product manufacturing | 9.3 | 29.2 | 38.5 |
| Electrical equipment and appliance manufacturing | 23.0 | -0.4 | 22.6 |
| Fabricated metal product manufacturing | 16.3 | -0.5 | 15.8 |
| Food manufacturing | 5.3 | -13.7 | -8.4 |
| Furniture and related product manufacturing | -0.7 | 1.7 | 1 |
| Machinery manufacturing | -2.9 | 5.2 | 2.3 |
| Miscellaneous manufacturing | -1.1 | 3.4 | 2.3 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 0.2 | 1.0 | 1.2 |
| Nonmetallic mineral product manufacturing | 14.3 | -2.7 | 11.6 |
| Other transportation equipment manufacturing | -1.5 | -0.8 | -2.3 |
| Paper manufacturing | 2.7 | -1.5 | 1.2 |
| Petroleum and coal products manufacturing | 0.7 | -0.3 | 0.4 |
| Plastics and rubber product manufacturing | 6.2 | -2.2 | 4 |
| Primary metal manufacturing | 0.6 | -1.0 | -0.4 |
| Printing and related support activities | 14.1 | -0.7 | 13.4 |
| Textile mills; Textile product mills | 0.0 | -0.6 | -0.6 |
| Wood product manufacturing | 4.9 | -3.8 | 1.1 |

Sources: REMI PI+, RESI

As reported in Figure 2, the two greatest gaining sectors in terms of employment by 2020 from GGRA initiatives are *Computer and electronic product manufacturing* and *Electrical equipment and appliance manufacturing*. The sectors that are likely to experience minimal to no loss are *Food manufacturing*, *Other transportation equipment manufacturing*, and *Textile mills; Textile product mills.* Overall, most sectors are expect to see some minor increases in employment during that period.

In addition to an increase in employment, output for the industry is expected to grow through 2020. Impacts associated with the changes in output are reported in Figure 3.

**Figure 3: Manufacturing Output Impacts from GGRA Initiatives, 2020**[118]

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[117] The following impacts are those that are expected to occur in year 2020. Therefore, in year 2020, RESI expects that the *Apparel manufacturing; Leather and allied product manufacturing* sector will increase by 3.5 jobs.

**Impact Analysis of the GGRA of 2009 on Manufacturing in Maryland**
RESI of Towson University

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $213,645 | -$38,618 | $175,027 |
| Beverage and tobacco product manufacturing | $1,931,614 | -$423,644 | $1,507,970 |
| Chemical manufacturing | $6,739,902 | $1,829,887 | $8,569,789 |
| Computer and electronic product manufacturing | $1,836,413 | $2,108,593 | $3,945,006 |
| Electrical equipment and appliance manufacturing | $4,378,054 | -$128,919 | $4,249,135 |
| Fabricated metal product manufacturing | $2,347,909 | -$8,334 | $2,339,575 |
| Food manufacturing | $34,898,986 | -$35,919,825 | -$1,020,839 |
| Furniture and related product manufacturing | -$1,245,385 | $1,238,741 | -$6,644 |
| Machinery manufacturing | $1,222,865 | -$1,213,066 | $9,799 |
| Miscellaneous manufacturing | $1,214,402 | -$1,124,451 | $89,951 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $1,463,898 | -$1,647,134 | -$183,236 |
| Nonmetallic mineral product manufacturing | $1,766,294 | $410,368 | $2,176,662 |
| Other transportation equipment manufacturing | $1,775,479 | -$1,865,199 | -$89,720 |
| Paper manufacturing | $520,176 | $7,570 | $527,746 |
| Petroleum and coal products manufacturing | $2,934,225 | -$2,128,244 | $805,981 |
| Plastics and rubber product manufacturing | $3,420,268 | -$1,553,721 | $1,866,547 |
| Primary metal manufacturing | -$53,062 | $663,211 | $610,149 |
| Printing and related support activities | $1,597,468 | $178,777 | $1,776,245 |
| Textile mills; Textile product mills | $93,151 | -$75,113 | $18,038 |
| Wood product manufacturing | $1,238,096 | -$2,137,476 | -$899,380 |

Sources: REMI PI+, RESI

By 2020, the greatest increase in output will be associated with the *Computer and electronic production manufacturing* and the *Chemical Manufacturing* sectors. Smaller sectors such as *Other transportation equipment manufacturing* and *Textile mills; Textile product mills* are expected to see minimal gains during that period.

Finally, RESI found that wages are expected to rise through 2020 in the manufacturing industry if all GGRA initiatives are implemented. Figure 5 reports the wage impacts over the 20 sectors that comprise the Manufacturing industry.

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[118] The following impacts are those that are expected to occur in year 2020. Therefore, in year 2020, RESI expects that the *Apparel manufacturing; Leather and allied product manufacturing* sector will increase by $175,027 in output.

**Figure 4: Manufacturing Wage Impacts from GGRA Initiatives, 2020**[119]

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $67,541 | -$7,935 | $59,606 |
| Beverage and tobacco product manufacturing | $130,895 | $25,425 | $156,320 |
| Chemical manufacturing | $443,825 | $139,011 | $582,836 |
| Computer and electronic product manufacturing | $1,685,521 | $3,862,656 | $5,548,177 |
| Electrical equipment and appliance manufacturing | $1,825,196 | -$59,269 | $1,765,927 |
| Fabricated metal product manufacturing | $1,057,189 | -$59,759 | $997,430 |
| Food manufacturing | $663,109 | -$1,018,840 | -$355,731 |
| Furniture and related product manufacturing | -$262,103 | $284,368 | $22,265 |
| Machinery manufacturing | $268,869 | -$178,872 | $89,997 |
| Miscellaneous manufacturing | -$188,135 | $220,202 | $32,067 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $83,647 | -$44,139 | $39,508 |
| Nonmetallic mineral product manufacturing | $604,918 | $72,718 | $677,636 |
| Other transportation equipment manufacturing | $277,546 | -$166,669 | $110,877 |
| Paper manufacturing | $508,840 | -$420,837 | $88,003 |
| Petroleum and coal products manufacturing | $101,596 | -$79,035 | $22,561 |
| Plastics and rubber product manufacturing | -$228,819 | $536,758 | $307,939 |
| Primary metal manufacturing | -$41,682 | $74,578 | $32,896 |
| Printing and related support activities | $284,661 | $212,314 | $496,975 |
| Textile mills; Textile product mills | -$116,148 | $124,413 | $8,265 |
| Wood product manufacturing | $277,286 | -$352,867 | -$75,581 |

Sources: REMI PI+, RESI

According to Figure 4, the sectors with the greatest gain in wages through 2020 are *Computer and electronic product manufacturing* and *Electrical equipment and appliance manufacturing.* Smaller gains are likely to be recorded in the *Textile mills; Textile product mills* sector and the *Petroleum and coal products manufacturing* sector.

## 5.2 Discussion

According to RESI's analysis, manufacturing will experience no discernible impact on employment between 2010 and 2020 if all policies are implemented. Manufacturing sectors

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[119] The following impacts are those that are expected to occur in year 2020. Therefore, in year 2020, RESI expects that the *Apparel manufacturing; Leather and allied product manufacturing* sector will increase by $59.606 in wages.

associated with high and middle skilled labor, such as *Computer and electronic product manufacturing*, *Chemical manufacturing*, and *Electrical equipment and appliance manufacturing*, will experience the greatest impacts. Occupations within *Computer and electronic product manufacturing* include the following:

- Computer hardware engineers,
- Computer software engineers, applications,
- Computer software engineers, systems software,
- Electrical and electronic engineering technicians,
- Electrical and electronic equipment assemblers, and,
- Semiconductor processors.[120]

Some of the occupations within this sector, such as computer hardware engineers, require at least a Bachelor's degree.[121] This occupation pays a median salary of $100,920, which is well above the median income for a Bachelor's degree according to The National Center for Education Statistics.[122] [123] However, some occupations, such as electrical and electronic engineering technicians, require less additional education opening career pathways for non-college graduates. According to the BLS's Occupational Outlook Handbook, electrical and electronic engineering technician jobs require a minimum of an Associate's degree.[124]

Overall, RESI found that the GGRA's impact on Maryland may benefit Manufacturing for high- to middle-skilled labor. Although the workforce needed to meet this demand is likely to require additional education and training to meet specifics industry needs, Maryland is poised to provide this workforce to prospective employees. Continued partnerships, as discussed in Section 3.0, will provide the fundamental groundwork in meeting employer demand related to implementation and operation of GGRA initiatives. However, there is no conclusive evidence that any change in the Manufacturing industry operations has been directly attributable to the GGRA.

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[120] "Industries at a Glance: Computer and Electronic Product Manufacturing: NAICS 334," Bureau of Labor Statistics, date extracted on April 29, 2014, accessed April 29, 2014, http://www.bls.gov/iag/tgs/iag334.htm.

[121] "Occupational Outlook Handbook: Computer Hardware Engineers," Bureau of Labor Statistics, last modified on January 8, 2014, accessed April 29, 2014, http://www.bls.gov/ooh/architecture-and-engineering/computer-hardware-engineers.htm.

[122] Ibid.

[123] "Fast Facts: Income of Young Adults," National Center for Education Statistics, updated 2013, accessed April 30, 2014. http://nces.ed.gov/fastfacts/display.asp?id=77

[124] "Occupational Outlook Handbook: Electrical and Electronics Engineering Technicians," Bureau of Labor Statistics, last modified on January 8, 2014, accessed April 29, 2014, http://www.bls.gov/ooh/architecture-and-engineering/electrical-and-electronics-engineering-technicians.htm.

# 6.0 Conclusion

The reduction of greenhouse gas emissions is not only a statewide issue but one that extends internationally. Internationally recognizable companies such as Avon, Whirlpool, SC Johnson, and General Motors have worked with the industry to achieve reductions in greenhouse gas emissions domestically and abroad. Nationally, partnerships between industry leaders, and state and federal agencies continue to pursue greenhouse gas emissions. Regional partnerships such as those between RMI and PSC have assisted manufacturers in effectively reducing energy consumption through funding opportunities.

RESI's research indicates that the Manufacturing industry will see no discernible impacts from the greenhouse gas reduction strategies as outlined in the GGRA. In addition to this finding, RESI expects the following:

- The manufacturing industry will create 113 jobs by 2020 to meet the demand for greenhouse gas reduction.
- Sectors within the industry such as *Computer and electronic product manufacturing* and *Electrical equipment and appliance manufacturing* will see the greatest growth during this time.
- Lower skilled sectors such as *Food manufacturing* and *Textile mills* will see minimal declines in employment between 2010 and 2020.
- Wages for the industry will increase by $10.7 million and output for the industry will grow by $26.5 million by 2020.

Some manufacturers have implemented energy-efficient strategies as a method for reducing production costs rather than a method for achieving greenhouse gas reduction. As stated by Mr. Miller from Redland Brick, the brick industry sector has transformed its energy use over time. From wood to coal and finally to natural gas, these reductions have been more focused on reducing costs than reducing emissions. The use of natural gas rather than coal reduces emissions but also allows the producer to reduce production costs and remain competitive.

The EIA expects these energy costs to increase over the next five years. During this time, manufacturers will need to seek new methods of cost reduction to retain competitiveness. The expansion of new technologies, energy efficiency methods, and partnerships to achieve these goals at the least cost will be key in the success of the GGRA as well as the Manufacturing industry through 2020. RESI's findings indicate that workforce training will be crucial in meeting industry demand as more GGRA initiatives are implemented and fully operational by 2020.

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## Appendix A—Annual Employment Impacts for the Manufacturing Industry

The following tables highlight the employment impacts associated with the GGRA to the Manufacturing industry in Maryland between 2010 and 2020.

**Figure 5: Manufacturing Employment Impacts from GGRA Initiatives, 2010**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 1.3 | 0.0 | 1.3 |
| Beverage and tobacco product manufacturing | 1.6 | 0.0 | 1.6 |
| Chemical manufacturing | 10.1 | 0.6 | 10.7 |
| Computer and electronic product manufacturing | 3.7 | 2.5 | 6.2 |
| Electrical equipment and appliance manufacturing | 5.0 | 0.0 | 5 |
| Fabricated metal product manufacturing | 18.0 | -0.3 | 17.7 |
| Food manufacturing | 2.5 | -0.1 | 2.4 |
| Furniture and related product manufacturing | 2.2 | 0.2 | 2.4 |
| Machinery manufacturing | 1.8 | 0.3 | 2.1 |
| Miscellaneous manufacturing | 1.6 | 0.1 | 1.7 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 1.7 | 0.0 | 1.7 |
| Nonmetallic mineral product manufacturing | 14.1 | -0.4 | 13.7 |
| Other transportation equipment manufacturing | 0.5 | 0.1 | 0.6 |
| Paper manufacturing | 2.3 | -0.1 | 2.2 |
| Petroleum and coal products manufacturing | 0.8 | 0.0 | 0.8 |
| Plastics and rubber product manufacturing | 6.0 | -0.1 | 5.9 |
| Primary metal manufacturing | 0.6 | 0.2 | 0.8 |
| Printing and related support activities | 10.2 | -0.1 | 10.1 |
| Textile mills; Textile product mills | 0.2 | 0.0 | 0.2 |
| Wood product manufacturing | 6.2 | 1.2 | 7.4 |

Sources: REMI PI+, RESI

**Figure 6: Manufacturing Employment Impacts from GGRA Initiatives, 2011**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 3.0 | 0.0 | 3.0 |
| Beverage and tobacco product manufacturing | 3.0 | -0.1 | 2.9 |
| Chemical manufacturing | 15.7 | 1.2 | 16.9 |
| Computer and electronic product manufacturing | 21.7 | 22.0 | 43.7 |
| Electrical equipment and appliance manufacturing | 51.1 | -1.1 | 50.0 |
| Fabricated metal product manufacturing | 30.0 | 0.7 | 30.7 |
| Food manufacturing | 4.5 | -0.5 | 4.0 |
| Furniture and related product manufacturing | 2.1 | 1.6 | 3.7 |
| Machinery manufacturing | -1.8 | 5.5 | 3.7 |
| Miscellaneous manufacturing | 0.8 | 2.3 | 3.1 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 1.6 | 1.0 | 2.6 |
| Nonmetallic mineral product manufacturing | 23.8 | -0.7 | 23.1 |
| Other transportation equipment manufacturing | 0.1 | 0.7 | 0.8 |
| Paper manufacturing | 3.2 | -0.2 | 3.0 |
| Petroleum and coal products manufacturing | 1.4 | 0.0 | 1.4 |
| Plastics and rubber product manufacturing | 9.8 | 0.0 | 9.8 |
| Primary metal manufacturing | 1.0 | 0.3 | 1.3 |
| Printing and related support activities | 14.2 | 0.1 | 14.3 |
| Textile mills; Textile product mills | 0.2 | 0.0 | 0.2 |
| Wood product manufacturing | 10.4 | 0.8 | 11.2 |

Sources: REMI PI+, RESI

**Figure 7: Manufacturing Employment Impacts from GGRA Initiatives, 2012**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | 3.7 | -0.1 | 3.6 |
| Beverage and tobacco product manufacturing | 3.7 | -0.3 | 3.4 |
| Chemical manufacturing | 15.9 | 1.2 | 17.1 |
| Computer and electronic product manufacturing | 10.6 | 11.4 | 21.9 |
| Electrical equipment and appliance manufacturing | 19.8 | -0.2 | 19.6 |
| Fabricated metal product manufacturing | 32.6 | -0.2 | 32.4 |
| Food manufacturing | 5.4 | -1.1 | 4.3 |
| Furniture and related product manufacturing | 3.2 | 0.7 | 3.8 |
| Machinery manufacturing | 1.9 | 2.4 | 4.3 |
| Miscellaneous manufacturing | 2.5 | 1.0 | 3.5 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 2.2 | 0.4 | 2.7 |
| Nonmetallic mineral product manufacturing | 26.0 | -0.9 | 25.1 |
| Other transportation equipment manufacturing | 0.6 | 0.1 | 0.8 |
| Paper manufacturing | 3.4 | -0.4 | 3.1 |
| Petroleum and coal products manufacturing | 1.3 | 0.0 | 1.2 |
| Plastics and rubber product manufacturing | 11.2 | -0.3 | 10.9 |
| Primary metal manufacturing | 1.0 | 0.4 | 1.3 |
| Printing and related support activities | 16.5 | -0.2 | 16.3 |
| Textile mills; Textile product mills | 0.3 | -0.1 | 0.1 |
| Wood product manufacturing | 11.8 | 0.8 | 12.6 |

Sources: REMI PI+, RESI

**Figure 8: Manufacturing Employment Impacts from GGRA Initiatives, 2013**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 3.5 | -0.1 | 3.4 |
| Beverage and tobacco product manufacturing | 3.6 | -0.4 | 3.2 |
| Chemical manufacturing | 12.9 | 1.5 | 14.4 |
| Computer and electronic product manufacturing | 17.9 | 22.4 | 40.3 |
| Electrical equipment and appliance manufacturing | 44.1 | -0.8 | 43.3 |
| Fabricated metal product manufacturing | 35.1 | 0.2 | 35.3 |
| Food manufacturing | 5.0 | -3.2 | 1.8 |
| Furniture and related product manufacturing | 2.1 | 1.4 | 3.5 |
| Machinery manufacturing | -1.0 | 5.2 | 4.2 |
| Miscellaneous manufacturing | 0.6 | 2.2 | 2.8 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 1.6 | 0.9 | 2.5 |
| Nonmetallic mineral product manufacturing | 29.1 | -1.1 | 28.0 |
| Other transportation equipment manufacturing | 0.0 | 0.3 | 0.3 |
| Paper manufacturing | 3.5 | -0.5 | 3.0 |
| Petroleum and coal products manufacturing | 1.3 | -0.1 | 1.2 |
| Plastics and rubber product manufacturing | 11.3 | -0.4 | 10.9 |
| Primary metal manufacturing | 1.1 | 0.5 | 1.6 |
| Printing and related support activities | 15.6 | -0.1 | 15.5 |
| Textile mills; Textile product mills | 0.2 | -0.2 | 0.0 |
| Wood product manufacturing | 12.4 | -0.1 | 12.3 |

Sources: REMI PI+, RESI

**Figure 9: Manufacturing Employment Impacts from GGRA Initiatives, 2014**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 3.9 | -0.2 | 3.7 |
| Beverage and tobacco product manufacturing | 3.8 | -0.6 | 3.2 |
| Chemical manufacturing | 11.4 | 1.7 | 13.1 |
| Computer and electronic product manufacturing | 11.6 | 15.8 | 27.4 |
| Electrical equipment and appliance manufacturing | 24.7 | -0.3 | 24.5 |
| Fabricated metal product manufacturing | 27.0 | -0.2 | 26.8 |
| Food manufacturing | 4.9 | -4.9 | 0.0 |
| Furniture and related product manufacturing | 2.1 | 0.9 | 3.0 |
| Machinery manufacturing | 0.2 | 3.3 | 3.5 |
| Miscellaneous manufacturing | 1.2 | 1.3 | 2.6 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 1.6 | 0.6 | 2.2 |
| Nonmetallic mineral product manufacturing | 22.4 | -1.1 | 21.3 |
| Other transportation equipment manufacturing | 0.1 | -0.1 | 0.0 |
| Paper manufacturing | 3.2 | -0.7 | 2.5 |
| Petroleum and coal products manufacturing | 1.1 | -0.1 | 1.0 |
| Plastics and rubber product manufacturing | 9.6 | -0.4 | 9.1 |
| Primary metal manufacturing | 0.9 | 0.4 | 1.3 |
| Printing and related support activities | 15.6 | -0.4 | 15.2 |
| Textile mills; Textile product mills | 0.2 | -0.2 | -0.1 |
| Wood product manufacturing | 9.6 | -0.9 | 8.6 |

Sources: REMI PI+, RESI

**Figure 10: Manufacturing Employment Impacts from GGRA Initiatives, 2015**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 4.6 | -0.2 | 4.4 |
| Beverage and tobacco product manufacturing | 4.7 | -0.7 | 3.9 |
| Chemical manufacturing | 13.9 | 1.8 | 15.7 |
| Computer and electronic product manufacturing | 24.7 | 30.5 | 55.2 |
| Electrical equipment and appliance manufacturing | 53.0 | -1.0 | 52.0 |
| Fabricated metal product manufacturing | 37.4 | 0.3 | 37.7 |
| Food manufacturing | 5.8 | -6.6 | -0.9 |
| Furniture and related product manufacturing | 1.7 | 2.0 | 3.7 |
| Machinery manufacturing | -3.0 | 6.9 | 3.8 |
| Miscellaneous manufacturing | -0.5 | 3.2 | 2.7 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 1.3 | 1.2 | 2.4 |
| Nonmetallic mineral product manufacturing | 32.4 | -1.6 | 30.8 |
| Other transportation equipment manufacturing | -0.5 | 0.3 | -0.2 |
| Paper manufacturing | 3.9 | -0.9 | 3.1 |
| Petroleum and coal products manufacturing | 1.4 | -0.1 | 1.3 |
| Plastics and rubber product manufacturing | 12.6 | -0.6 | 12.0 |
| Primary metal manufacturing | 1.2 | 0.4 | 1.6 |
| Printing and related support activities | 19.8 | -0.3 | 19.5 |
| Textile mills; Textile product mills | 0.1 | -0.3 | -0.2 |
| Wood product manufacturing | 13.2 | -1.5 | 11.7 |

Sources: REMI PI+, RESI

**Figure 11: Manufacturing Employment Impacts from GGRA Initiatives, 2016**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 4.6 | -0.3 | 4.3 |
| Beverage and tobacco product manufacturing | 4.7 | -0.9 | 3.8 |
| Chemical manufacturing | 10.8 | 1.6 | 12.4 |
| Computer and electronic product manufacturing | 15.5 | 22.4 | 37.9 |
| Electrical equipment and appliance manufacturing | 29.1 | -0.4 | 28.7 |
| Fabricated metal product manufacturing | 27.7 | -0.3 | 27.4 |
| Food manufacturing | 5.5 | -8.3 | -2.8 |
| Furniture and related product manufacturing | 1.3 | 1.4 | 2.7 |
| Machinery manufacturing | -1.5 | 4.5 | 3.0 |
| Miscellaneous manufacturing | 0.3 | 2.1 | 2.4 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 1.2 | 0.8 | 2.0 |
| Nonmetallic mineral product manufacturing | 23.7 | -1.6 | 22.1 |
| Other transportation equipment manufacturing | -0.5 | -0.2 | -0.7 |
| Paper manufacturing | 3.5 | -1.1 | 2.4 |
| Petroleum and coal products manufacturing | 1.2 | -0.1 | 1.1 |
| Plastics and rubber product manufacturing | 10.1 | -0.9 | 9.2 |
| Primary metal manufacturing | 0.9 | 0.2 | 1.1 |
| Printing and related support activities | 18.0 | -0.6 | 17.4 |
| Textile mills; Textile product mills | 0.1 | -0.4 | -0.3 |
| Wood product manufacturing | 9.6 | -2.5 | 7.1 |

Sources: REMI PI+, RESI

**Figure 12: Manufacturing Employment Impacts from GGRA Initiatives, 2017**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 5.1 | 0.0 | 5.0 |
| Beverage and tobacco product manufacturing | 5.8 | -1.1 | 4.7 |
| Chemical manufacturing | 16.2 | 1.7 | 17.9 |
| Computer and electronic product manufacturing | 83.8 | 104.6 | 188.4 |
| Electrical equipment and appliance manufacturing | 145.8 | -3.4 | 142.4 |
| Fabricated metal product manufacturing | 57.8 | 4.5 | 62.4 |
| Food manufacturing | 7.0 | -9.9 | -2.9 |
| Furniture and related product manufacturing | -4.4 | 8.4 | 4.0 |
| Machinery manufacturing | -21.2 | 23.2 | 2.0 |
| Miscellaneous manufacturing | -13.3 | 14.7 | 1.4 |
| Motor vehicles, bodies and trailers, and parts manufacturing | -2.7 | 4.1 | 1.4 |
| Nonmetallic mineral product manufacturing | 56.5 | -2.6 | 53.9 |
| Other transportation equipment manufacturing | -4.8 | 3.3 | -1.4 |
| Paper manufacturing | 5.3 | -1.0 | 4.3 |
| Petroleum and coal products manufacturing | 2.1 | -0.2 | 1.9 |
| Plastics and rubber product manufacturing | 17.1 | -0.6 | 16.5 |
| Primary metal manufacturing | 1.7 | 0.0 | 1.7 |
| Printing and related support activities | 21.6 | 2.0 | 23.5 |
| Textile mills; Textile product mills | -0.2 | -0.2 | -0.5 |
| Wood product manufacturing | 20.0 | -2.1 | 17.9 |

Sources: REMI PI+, RESI

**Figure 13: Manufacturing Employment Impacts from GGRA Initiatives, 2018**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 4.4 | 0.0 | 4.4 |
| Beverage and tobacco product manufacturing | 5.4 | -1.4 | 4.1 |
| Chemical manufacturing | 11.3 | 1.0 | 12.3 |
| Computer and electronic product manufacturing | 82.0 | 113.4 | 195.5 |
| Electrical equipment and appliance manufacturing | 157.7 | -3.9 | 153.8 |
| Fabricated metal product manufacturing | 45.0 | 5.2 | 50.2 |
| Food manufacturing | 6.4 | -11.6 | -5.2 |
| Furniture and related product manufacturing | -7.3 | 9.4 | 2.2 |
| Machinery manufacturing | -23.0 | 23.2 | 0.2 |
| Miscellaneous manufacturing | -16.5 | 17.1 | 0.6 |
| Motor vehicles, bodies and trailers, and parts manufacturing | -3.7 | 4.3 | 0.7 |
| Nonmetallic mineral product manufacturing | 46.4 | -2.7 | 43.7 |
| Other transportation equipment manufacturing | -5.9 | 3.7 | -2.3 |
| Paper manufacturing | 4.3 | -1.1 | 3.2 |
| Petroleum and coal products manufacturing | 1.6 | -0.2 | 1.4 |
| Plastics and rubber product manufacturing | 13.2 | -0.8 | 12.4 |
| Primary metal manufacturing | 1.3 | -0.4 | 0.9 |
| Printing and related support activities | 17.5 | 2.7 | 20.2 |
| Textile mills; Textile product mills | -0.3 | -0.3 | -0.6 |
| Wood product manufacturing | 15.5 | -2.5 | 13.0 |

Sources: REMI PI+, RESI

**Figure 14: Manufacturing Employment Impacts from GGRA Initiatives, 2019**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 4.0 | -0.3 | 3.7 |
| Beverage and tobacco product manufacturing | 4.7 | -1.6 | 3.0 |
| Chemical manufacturing | 5.7 | -0.5 | 5.1 |
| Computer and electronic product manufacturing | 22.1 | 45.0 | 67.1 |
| Electrical equipment and appliance manufacturing | 47.7 | -1.1 | 46.7 |
| Fabricated metal product manufacturing | 26.6 | 0.5 | 27.1 |
| Food manufacturing | 5.2 | -13.0 | -7.7 |
| Furniture and related product manufacturing | -1.5 | 3.1 | 1.6 |
| Machinery manufacturing | -6.0 | 8.6 | 2.6 |
| Miscellaneous manufacturing | -4.0 | 6.0 | 2.0 |
| Motor vehicles, bodies and trailers, and parts manufacturing | -0.4 | 1.6 | 1.2 |
| Nonmetallic mineral product manufacturing | 24.9 | -2.7 | 22.2 |
| Other transportation equipment manufacturing | -2.2 | 0.0 | -2.2 |
| Paper manufacturing | 2.9 | -1.4 | 1.5 |
| Petroleum and coal products manufacturing | 1.0 | -0.2 | 0.7 |
| Plastics and rubber product manufacturing | 8.3 | -1.9 | 6.4 |
| Primary metal manufacturing | 0.8 | -0.8 | 0.0 |
| Printing and related support activities | 13.5 | 0.1 | 13.6 |
| Textile mills; Textile product mills | -0.1 | -0.5 | -0.6 |
| Wood product manufacturing | 8.3 | -3.3 | 4.9 |

Sources: REMI PI+, RESI

**Figure 15: Manufacturing Employment Impacts from GGRA Initiatives, 2020**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | 3.9 | -0.4 | 3.5 |
| Beverage and tobacco product manufacturing | 4.4 | -1.7 | 2.7 |
| Chemical manufacturing | 4.2 | -1.0 | 3.2 |
| Computer and electronic product manufacturing | 9.3 | 29.2 | 38.5 |
| Electrical equipment and appliance manufacturing | 23.0 | -0.4 | 22.6 |
| Fabricated metal product manufacturing | 16.3 | -0.5 | 15.8 |
| Food manufacturing | 5.3 | -13.7 | -8.4 |
| Furniture and related product manufacturing | -0.7 | 1.7 | 1.0 |
| Machinery manufacturing | -2.9 | 5.2 | 2.4 |
| Miscellaneous manufacturing | -1.1 | 3.4 | 2.3 |
| Motor vehicles, bodies and trailers, and parts manufacturing | 0.2 | 1.0 | 1.2 |
| Nonmetallic mineral product manufacturing | 14.3 | -2.7 | 11.6 |
| Other transportation equipment manufacturing | -1.5 | -0.8 | -2.3 |
| Paper manufacturing | 2.7 | -1.5 | 1.2 |
| Petroleum and coal products manufacturing | 0.7 | -0.3 | 0.5 |
| Plastics and rubber product manufacturing | 6.2 | -2.2 | 4.0 |
| Primary metal manufacturing | 0.6 | -1.0 | -0.4 |
| Printing and related support activities | 14.1 | -0.7 | 13.4 |
| Textile mills; Textile product mills | 0.0 | -0.6 | -0.6 |
| Wood product manufacturing | 4.9 | -3.8 | 1.1 |

Sources: REMI PI+, RESI

# Appendix B—Annual Output Impacts for the Manufacturing Industry

The following tables highlight the output impacts associated with the GGRA to the Manufacturing industry in Maryland between 2010 and 2020.

**Figure 16: Manufacturing Output Impacts from GGRA Initiatives, 2010**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $94,903 | -$2,525 | $92,378 |
| Beverage and tobacco product manufacturing | $672,766 | -$3,862 | $668,904 |
| Chemical manufacturing | $5,167,544 | $494,917 | $5,662,461 |
| Computer and electronic product manufacturing | $1,265,981 | $706,372 | $1,972,353 |
| Electrical equipment and appliance manufacturing | $738,830 | $8,609 | $747,439 |
| Fabricated metal product manufacturing | $1,686,367 | -$50,148 | $1,636,219 |
| Food manufacturing | $894,864 | $4,124 | $898,988 |
| Furniture and related product manufacturing | $364,258 | -$96,868 | $267,390 |
| Machinery manufacturing | -$122,588 | $403,682 | $281,094 |
| Miscellaneous manufacturing | $261,958 | $39,613 | $301,571 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $4,183,581 | -$3,708,946 | $474,635 |
| Nonmetallic mineral product manufacturing | $1,200,929 | -$35,060 | $1,165,869 |
| Other transportation equipment manufacturing | $165,602 | $40,459 | $206,061 |
| Paper manufacturing | $425,175 | -$21,491 | $403,684 |
| Petroleum and coal products manufacturing | $1,182,126 | -$48,639 | $1,133,487 |
| Plastics and rubber product manufacturing | $1,070,274 | $4,552 | $1,074,826 |
| Primary metal manufacturing | $229,859 | $148,953 | $378,812 |
| Printing and related support activities | $1,495,866 | -$17,480 | $1,478,386 |
| Textile mills; Textile product mills | $27,195 | -$2,692 | $24,503 |
| Wood product manufacturing | $491,313 | $64,966 | $556,279 |

Sources: REMI PI+, RESI

**Figure 17: Manufacturing Output Impacts from GGRA Initiatives, 2011**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $172,720 | -$6,734 | $165,986 |
| Beverage and tobacco product manufacturing | $1,341,575 | -$72,780 | $1,268,795 |
| Chemical manufacturing | $9,321,764 | $797,065 | $10,118,829 |
| Computer and electronic product manufacturing | $5,023,113 | $6,430,400 | $11,453,513 |
| Electrical equipment and appliance manufacturing | $8,321,291 | -$158,889 | $8,162,402 |
| Fabricated metal product manufacturing | $3,482,996 | -$75,425 | $3,407,571 |
| Food manufacturing | $2,170,760 | -$470,388 | $1,700,372 |
| Furniture and related product manufacturing | $440,802 | $6,320 | $447,122 |
| Machinery manufacturing | $466,451 | $137,517 | $603,968 |
| Miscellaneous manufacturing | $519,019 | $16,835 | $535,854 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $845,439 | -$122,041 | $723,398 |
| Nonmetallic mineral product manufacturing | $2,512,994 | -$85,010 | $2,427,984 |
| Other transportation equipment manufacturing | $227,670 | $159,257 | $386,927 |
| Paper manufacturing | $629,966 | $16,143 | $646,109 |
| Petroleum and coal products manufacturing | $2,380,733 | -$54,375 | $2,326,358 |
| Plastics and rubber product manufacturing | $2,035,651 | $3,682 | $2,039,333 |
| Primary metal manufacturing | $510,022 | $310,610 | $820,632 |
| Printing and related support activities | $2,264,693 | -$66,287 | $2,198,406 |
| Textile mills; Textile product mills | $71,719 | -$25,393 | $46,326 |
| Wood product manufacturing | $1,032,239 | $66,287 | $1,098,526 |

Sources: REMI PI+, RESI

**Figure 18: Manufacturing Output Impacts from GGRA Initiatives, 2012**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $227,653 | -$11,805 | $215,848 |
| Beverage and tobacco product manufacturing | $1,878,507 | -$164,235 | $1,714,272 |
| Chemical manufacturing | $11,264,988 | $1,216,700 | $12,481,688 |
| Computer and electronic product manufacturing | $3,340,246 | $3,315,252 | $6,655,498 |
| Electrical equipment and appliance manufacturing | $3,350,295 | -$3,581 | $3,346,714 |
| Fabricated metal product manufacturing | $5,084,786 | -$149,915 | $4,934,871 |
| Food manufacturing | $3,843,341 | -$1,681,702 | $2,161,639 |
| Furniture and related product manufacturing | $626,299 | -$44,096 | $582,203 |
| Machinery manufacturing | $1,002,100 | -$214,257 | $787,843 |
| Miscellaneous manufacturing | $918,073 | -$282,951 | $635,122 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $1,073,565 | -$237,684 | $835,881 |
| Nonmetallic mineral product manufacturing | $4,084,305 | -$144,965 | $3,939,340 |
| Other transportation equipment manufacturing | -$1,261,570 | $1,746,332 | $484,762 |
| Paper manufacturing | $822,222 | -$36,180 | $786,042 |
| Petroleum and coal products manufacturing | $2,277,876 | -$36,635 | $2,241,241 |
| Plastics and rubber product manufacturing | $2,882,450 | -$11,457 | $2,870,993 |
| Primary metal manufacturing | $654,863 | $495,259 | $1,150,122 |
| Printing and related support activities | $2,734,350 | -$125,457 | $2,608,893 |
| Textile mills; Textile product mills | $100,785 | -$41,163 | $59,622 |
| Wood product manufacturing | $1,731,956 | $50,679 | $1,782,635 |

Sources: REMI PI+, RESI

**Figure 19: Manufacturing Output Impacts from GGRA Initiatives, 2013**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $251,512 | -$17,333 | $234,179 |
| Beverage and tobacco product manufacturing | $2,081,966 | -$295,504 | $1,786,462 |
| Chemical manufacturing | $12,530,887 | $828,774 | $13,359,661 |
| Computer and electronic product manufacturing | $4,957,832 | $6,140,568 | $11,098,400 |
| Electrical equipment and appliance manufacturing | $7,418,773 | -$100,402 | $7,318,371 |
| Fabricated metal product manufacturing | $5,125,728 | -$166,124 | $4,959,604 |
| Food manufacturing | $854,583 | $961,703 | $1,816,286 |
| Furniture and related product manufacturing | $605,173 | -$22,969 | $582,204 |
| Machinery manufacturing | $1,197,037 | -$409,985 | $787,052 |
| Miscellaneous manufacturing | $2,730,851 | -$2,106,407 | $624,444 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $991,605 | -$219,685 | $771,920 |
| Nonmetallic mineral product manufacturing | $4,137,489 | -$182,907 | $3,954,582 |
| Other transportation equipment manufacturing | $1,395,170 | -$962,520 | $432,650 |
| Paper manufacturing | $913,107 | -$101,149 | $811,958 |
| Petroleum and coal products manufacturing | $2,295,401 | -$96,267 | $2,199,134 |
| Plastics and rubber product manufacturing | $3,076,228 | -$26,078 | $3,050,150 |
| Primary metal manufacturing | $1,007,213 | $493,876 | $1,501,089 |
| Printing and related support activities | $2,807,574 | -$186,850 | $2,620,724 |
| Textile mills; Textile product mills | $278,954 | -$214,447 | $64,507 |
| Wood product manufacturing | $1,674,523 | -$281,708 | $1,392,815 |

Sources: REMI PI+, RESI

**Figure 20: Manufacturing Output Impacts from GGRA Initiatives, 2014**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $274,139 | -$22,913 | $251,226 |
| Beverage and tobacco product manufacturing | $2,451,365 | -$564,339 | $1,887,026 |
| Chemical manufacturing | $16,168,286 | -$1,837,320 | $14,330,966 |
| Computer and electronic product manufacturing | $2,689,489 | $5,463,488 | $8,152,977 |
| Electrical equipment and appliance manufacturing | $4,232,302 | $18,281 | $4,250,583 |
| Fabricated metal product manufacturing | $4,016,429 | -$206,809 | $3,809,620 |
| Food manufacturing | $2,702,260 | -$1,126,998 | $1,575,262 |
| Furniture and related product manufacturing | $718,091 | -$155,215 | $562,876 |
| Machinery manufacturing | $1,024,614 | -$405,242 | $619,372 |
| Miscellaneous manufacturing | $482,114 | $110,122 | $592,236 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $1,269,548 | -$578,387 | $691,161 |
| Nonmetallic mineral product manufacturing | $3,359,083 | -$203,029 | $3,156,054 |
| Other transportation equipment manufacturing | $128,712 | $266,106 | $394,818 |
| Paper manufacturing | $966,832 | -$215,261 | $751,571 |
| Petroleum and coal products manufacturing | $1,732,295 | -$105,705 | $1,626,590 |
| Plastics and rubber product manufacturing | $2,953,533 | $6,613 | $2,960,146 |
| Primary metal manufacturing | $1,083,521 | $606,923 | $1,690,444 |
| Printing and related support activities | $2,905,159 | -$389,393 | $2,515,766 |
| Textile mills; Textile product mills | $57,431 | $15,206 | $72,637 |
| Wood product manufacturing | $1,286,665 | -$522,494 | $764,171 |

Sources: REMI PI+, RESI

**Figure 21: Manufacturing Output Impacts from GGRA Initiatives, 2015**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $327,851 | -$29,535 | $298,316 |
| Beverage and tobacco product manufacturing | $2,336,665 | -$112,266 | $2,224,399 |
| Chemical manufacturing | $3,781,011 | $13,596,312 | $17,377,323 |
| Computer and electronic product manufacturing | $9,685,559 | $5,504,631 | $15,190,190 |
| Electrical equipment and appliance manufacturing | $9,128,097 | -$91,949 | $9,036,148 |
| Fabricated metal product manufacturing | $4,881,700 | -$283,430 | $4,598,270 |
| Food manufacturing | $2,965,177 | -$1,274,888 | $1,690,289 |
| Furniture and related product manufacturing | $980,659 | -$339,686 | $640,973 |
| Machinery manufacturing | $1,791,360 | -$1,106,106 | $685,254 |
| Miscellaneous manufacturing | $1,606,052 | -$961,202 | $644,850 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $2,151,327 | -$1,613,560 | $537,767 |
| Nonmetallic mineral product manufacturing | $4,149,767 | -$308,118 | $3,841,649 |
| Other transportation equipment manufacturing | -$163,474 | $560,612 | $397,138 |
| Paper manufacturing | $1,258,261 | -$400,506 | $857,755 |
| Petroleum and coal products manufacturing | $2,197,149 | -$231,220 | $1,965,929 |
| Plastics and rubber product manufacturing | $3,749,117 | -$83,596 | $3,665,521 |
| Primary metal manufacturing | $1,270,825 | $781,611 | $2,052,436 |
| Printing and related support activities | $2,900,178 | $213,412 | $3,113,590 |
| Textile mills; Textile product mills | $108,233 | -$23,820 | $84,413 |
| Wood product manufacturing | $1,564,820 | -$738,303 | $826,517 |

Sources: REMI PI+, RESI

**Figure 22: Manufacturing Output Impacts from GGRA Initiatives, 2016**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $271,255 | -$37,494 | $233,761 |
| Beverage and tobacco product manufacturing | $2,530,208 | -$698,599 | $1,831,609 |
| Chemical manufacturing | $9,954,553 | $2,585,322 | $12,539,875 |
| Computer and electronic product manufacturing | $3,816,454 | $5,520,227 | $9,336,681 |
| Electrical equipment and appliance manufacturing | $5,106,054 | -$55,186 | $5,050,868 |
| Fabricated metal product manufacturing | $4,078,895 | -$504,299 | $3,574,596 |
| Food manufacturing | $3,694,064 | -$2,976,505 | $717,559 |
| Furniture and related product manufacturing | $205,647 | $146,930 | $352,577 |
| Machinery manufacturing | $1,234,626 | -$748,723 | $485,903 |
| Miscellaneous manufacturing | $27,626 | $366,605 | $394,231 |
| Motor vehicles, bodies and trailers, and parts manufacturing | -$233,556 | $452,424 | $218,868 |
| Nonmetallic mineral product manufacturing | $3,521,037 | -$435,120 | $3,085,917 |
| Other transportation equipment manufacturing | $100,828 | $84,907 | $185,735 |
| Paper manufacturing | $1,383,137 | -$734,514 | $648,623 |
| Petroleum and coal products manufacturing | $1,853,499 | -$424,105 | $1,429,394 |
| Plastics and rubber product manufacturing | $1,880,853 | $876,775 | $2,757,628 |
| Primary metal manufacturing | $1,068,608 | $447,144 | $1,515,752 |
| Printing and related support activities | $1,594,898 | $683,873 | $2,278,771 |
| Textile mills; Textile product mills | $259,256 | -$200,131 | $59,125 |
| Wood product manufacturing | $1,133,600 | -$929,972 | $203,628 |

Sources: REMI PI+, RESI

**Figure 23: Manufacturing Output Impacts from GGRA Initiatives, 2017**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $261,522 | -$28,729 | $232,793 |
| Beverage and tobacco product manufacturing | $3,127,804 | -$1,273,199 | $1,854,605 |
| Chemical manufacturing | $10,116,640 | $1,525,363 | $11,642,003 |
| Computer and electronic product manufacturing | $18,668,643 | $22,807,428 | $41,476,071 |
| Electrical equipment and appliance manufacturing | $25,481,266 | -$607,122 | $24,874,144 |
| Fabricated metal product manufacturing | $4,110,311 | -$549,557 | $3,560,754 |
| Food manufacturing | $2,467,082 | -$2,208,642 | $258,440 |
| Furniture and related product manufacturing | $183,264 | -$194,912 | -$11,648 |
| Machinery manufacturing | $7,054,717 | -$7,470,977 | -$416,260 |
| Miscellaneous manufacturing | $12,324,903 | -$12,438,817 | -$113,914 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $7,346,827 | -$8,691,142 | -$1,344,315 |
| Nonmetallic mineral product manufacturing | $3,726,945 | -$737,582 | $2,989,363 |
| Other transportation equipment manufacturing | -$1,489,072 | $1,463,004 | -$26,068 |
| Paper manufacturing | $3,217,563 | -$2,536,655 | $680,908 |
| Petroleum and coal products manufacturing | $2,062,788 | -$708,029 | $1,354,759 |
| Plastics and rubber product manufacturing | $2,571,846 | $68,910 | $2,640,756 |
| Primary metal manufacturing | $2,390,261 | -$1,128,463 | $1,261,798 |
| Printing and related support activities | $2,056,315 | $502,472 | $2,558,787 |
| Textile mills; Textile product mills | -$71,767 | $85,215 | $13,448 |
| Wood product manufacturing | $996,381 | -$1,064,055 | -$67,674 |

Sources: REMI PI+, RESI

**Figure 24: Manufacturing Output Impacts from GGRA Initiatives, 2018**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $252,357 | -$32,177 | $220,180 |
| Beverage and tobacco product manufacturing | $2,922,896 | -$1,284,659 | $1,638,237 |
| Chemical manufacturing | $5,734,817 | $4,290,684 | $10,025,501 |
| Computer and electronic product manufacturing | $17,370,557 | $22,369,824 | $39,740,381 |
| Electrical equipment and appliance manufacturing | $28,036,356 | -$703,219 | $27,333,137 |
| Fabricated metal product manufacturing | $1,514,875 | $1,343,401 | $2,858,276 |
| Food manufacturing | $5,959,473 | -$6,153,599 | -$194,126 |
| Furniture and related product manufacturing | $5,271,158 | -$5,522,391 | -$251,233 |
| Machinery manufacturing | -$103,083,527 | $102,230,974 | -$852,553 |
| Miscellaneous manufacturing | -$186,036,880 | $185,575,972 | -$460,908 |
| Motor vehicles, bodies and trailers, and parts manufacturing | -$47,911,394 | $46,142,299 | -$1,769,095 |
| Nonmetallic mineral product manufacturing | $16,466,157 | -$13,932,561 | $2,533,596 |
| Other transportation equipment manufacturing | -$1,251,104 | $1,048,773 | -$202,331 |
| Paper manufacturing | -$934,274 | $1,541,811 | $607,537 |
| Petroleum and coal products manufacturing | $2,061,569 | -$1,047,719 | $1,013,850 |
| Plastics and rubber product manufacturing | $2,436,338 | -$235,389 | $2,200,949 |
| Primary metal manufacturing | -$421,842 | $1,361,164 | $939,322 |
| Printing and related support activities | $1,617,420 | $609,151 | $2,226,571 |
| Textile mills; Textile product mills | -$56,346 | $43,389 | -$12,957 |
| Wood product manufacturing | $593,083 | -$1,025,069 | -$431,986 |

Sources: REMI PI+, RESI

**Figure 25: Manufacturing Output Impacts from GGRA Initiatives, 2019**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $227,381 | -$38,499 | $188,882 |
| Beverage and tobacco product manufacturing | $1,861,513 | -$371,444 | $1,490,069 |
| Chemical manufacturing | $8,628,825 | -$545,061 | $8,083,764 |
| Computer and electronic product manufacturing | $4,271,675 | $6,064,376 | $10,336,051 |
| Electrical equipment and appliance manufacturing | $8,697,316 | -$245,073 | $8,452,243 |
| Fabricated metal product manufacturing | $346,863 | $1,838,945 | $2,185,808 |
| Food manufacturing | $9,154,797 | -$9,893,362 | -$738,565 |
| Furniture and related product manufacturing | $1,452,869 | -$1,496,097 | -$43,228 |
| Machinery manufacturing | $2,210,542 | -$2,359,087 | -$148,545 |
| Miscellaneous manufacturing | $1,872,284 | -$1,944,182 | -$71,898 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $2,755,307 | -$3,275,326 | -$520,019 |
| Nonmetallic mineral product manufacturing | $1,497,307 | $536,369 | $2,033,676 |
| Other transportation equipment manufacturing | $329,684 | -$462,086 | -$132,402 |
| Paper manufacturing | -$311,302 | $770,491 | $459,189 |
| Petroleum and coal products manufacturing | $3,137,543 | -$2,559,628 | $577,915 |
| Plastics and rubber product manufacturing | $2,781,636 | -$1,075,439 | $1,706,197 |
| Primary metal manufacturing | -$293,527 | $998,181 | $704,654 |
| Printing and related support activities | $1,315,287 | $177,773 | $1,493,060 |
| Textile mills; Textile product mills | $61,414 | -$48,362 | $13,052 |
| Wood product manufacturing | $503,621 | -$1,282,048 | -$778,427 |

Sources: REMI PI+, RESI

**Figure 26: Manufacturing Output Impacts from GGRA Initiatives, 2020**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $213,645 | -$38,618 | $175,027 |
| Beverage and tobacco product manufacturing | $1,931,614 | -$423,644 | $1,507,970 |
| Chemical manufacturing | $6,739,902 | $1,829,887 | $8,569,789 |
| Computer and electronic product manufacturing | $1,836,413 | $2,108,593 | $3,945,006 |
| Electrical equipment and appliance manufacturing | $4,378,054 | -$128,919 | $4,249,135 |
| Fabricated metal product manufacturing | $2,347,909 | -$8,334 | $2,339,575 |
| Food manufacturing | $34,898,986 | -$35,919,825 | -$1,020,839 |
| Furniture and related product manufacturing | -$1,245,385 | $1,238,741 | -$6,644 |
| Machinery manufacturing | $1,222,865 | -$1,213,066 | $9,799 |
| Miscellaneous manufacturing | $1,214,402 | -$1,124,451 | $89,951 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $1,463,898 | -$1,647,134 | -$183,236 |
| Nonmetallic mineral product manufacturing | $1,766,294 | $410,368 | $2,176,662 |
| Other transportation equipment manufacturing | $1,775,479 | -$1,865,199 | -$89,720 |
| Paper manufacturing | $520,176 | $7,570 | $527,746 |
| Petroleum and coal products manufacturing | $2,934,225 | -$2,128,244 | $805,981 |
| Plastics and rubber product manufacturing | $3,420,268 | -$1,553,721 | $1,866,547 |
| Primary metal manufacturing | -$53,062 | $663,211 | $610,149 |
| Printing and related support activities | $1,597,468 | $178,777 | $1,776,245 |
| Textile mills; Textile product mills | $93,151 | -$75,113 | $18,038 |
| Wood product manufacturing | $1,238,096 | -$2,137,476 | -$899,380 |

Sources: REMI PI+, RESI

## Appendix C—Annual Wage Impacts for the Manufacturing Industry

The following tables highlight the wage impacts associated with the GGRA to the Manufacturing industry in Maryland between 2010 and 2020.

**Figure 27: Manufacturing Wage Impacts from GGRA Initiatives, 2010**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $31,752 | -$795 | $30,957 |
| Beverage and tobacco product manufacturing | $83,802 | -$2,003 | $81,799 |
| Chemical manufacturing | $814,488 | $46,336 | $860,823 |
| Computer and electronic product manufacturing | $1,049,388 | $26,216 | $1,075,605 |
| Electrical equipment and appliance manufacturing | $259,106 | -$191 | $258,915 |
| Fabricated metal product manufacturing | $480,081 | -$13,961 | $466,120 |
| Food manufacturing | $238,633 | -$32,827 | $205,806 |
| Furniture and related product manufacturing | $89,403 | -$19,512 | $69,891 |
| Machinery manufacturing | $30,828 | $95,365 | $126,193 |
| Miscellaneous manufacturing | $87,557 | $7,880 | $95,437 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $349,847 | -$282,522 | $67,325 |
| Nonmetallic mineral product manufacturing | $288,208 | -$8,711 | $279,497 |
| Other transportation equipment manufacturing | $153,438 | -$40,440 | $112,998 |
| Paper manufacturing | $104,224 | -$5,350 | $98,874 |
| Petroleum and coal products manufacturing | $41,244 | -$1,708 | $39,536 |
| Plastics and rubber product manufacturing | $238,722 | -$3,532 | $235,190 |
| Primary metal manufacturing | $52,826 | $5,895 | $58,721 |
| Printing and related support activities | $458,069 | -$4,255 | $453,814 |
| Textile mills; Textile product mills | $17,083 | -$4,494 | $12,589 |
| Wood product manufacturing | $80,160 | $11,322 | $91,483 |

Sources: REMI PI+, RESI

**Figure 28: Manufacturing Wage Impacts from GGRA Initiatives, 2011**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $64,359 | -$2,295 | $62,064 |
| Beverage and tobacco product manufacturing | $199,135 | -$17,359 | $181,776 |
| Chemical manufacturing | $1,603,562 | $18,648 | $1,622,210 |
| Computer and electronic product manufacturing | $641,910 | $6,137,928 | $6,779,839 |
| Electrical equipment and appliance manufacturing | $2,935,886 | -$64,804 | $2,871,082 |
| Fabricated metal product manufacturing | $1,021,080 | -$21,033 | $1,000,047 |
| Food manufacturing | $839,280 | -$379,045 | $460,236 |
| Furniture and related product manufacturing | $140,174 | -$3,684 | $136,490 |
| Machinery manufacturing | $231,776 | $73,895 | $305,670 |
| Miscellaneous manufacturing | $174,238 | $18,682 | $192,919 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $129,324 | $360 | $129,683 |
| Nonmetallic mineral product manufacturing | $602,113 | -$21,510 | $580,603 |
| Other transportation equipment manufacturing | -$45,140 | $304,882 | $259,742 |
| Paper manufacturing | $187,954 | -$13,206 | $174,748 |
| Petroleum and coal products manufacturing | $83,397 | -$1,965 | $81,432 |
| Plastics and rubber product manufacturing | $507,421 | -$14,708 | $492,713 |
| Primary metal manufacturing | $195,630 | -$63,163 | $132,467 |
| Printing and related support activities | $761,471 | -$19,592 | $741,879 |
| Textile mills; Textile product mills | $99,382 | -$69,535 | $29,848 |
| Wood product manufacturing | $172,940 | $13,094 | $186,035 |

Sources: REMI PI+, RESI

**Figure 29: Manufacturing Wage Impacts from GGRA Initiatives, 2012**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $92,201 | -$4,413 | $87,787 |
| Beverage and tobacco product manufacturing | $311,118 | -$45,527 | $265,591 |
| Chemical manufacturing | $2,109,066 | -$60,226 | $2,048,840 |
| Computer and electronic product manufacturing | $1,722,385 | $2,302,458 | $4,024,843 |
| Electrical equipment and appliance manufacturing | $1,203,645 | -$15,924 | $1,187,720 |
| Fabricated metal product manufacturing | $1,520,733 | -$42,919 | $1,477,814 |
| Food manufacturing | $1,764,470 | -$1,098,482 | $665,988 |
| Furniture and related product manufacturing | $220,929 | -$21,802 | $199,127 |
| Machinery manufacturing | $449,929 | -$43,545 | $406,383 |
| Miscellaneous manufacturing | $358,362 | -$103,245 | $255,117 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $175,464 | -$6,091 | $169,373 |
| Nonmetallic mineral product manufacturing | $976,182 | -$36,222 | $939,960 |
| Other transportation equipment manufacturing | $422,206 | -$40,990 | $381,216 |
| Paper manufacturing | $257,729 | -$26,235 | $231,494 |
| Petroleum and coal products manufacturing | $92,157 | -$1,430 | $90,727 |
| Plastics and rubber product manufacturing | $765,000 | -$37,196 | $727,805 |
| Primary metal manufacturing | $293,844 | -$96,805 | $197,039 |
| Printing and related support activities | $970,864 | -$38,938 | $931,926 |
| Textile mills; Textile product mills | $88,722 | -$43,439 | $45,283 |
| Wood product manufacturing | $290,657 | $11,004 | $301,661 |

Sources: REMI PI+, RESI

**Figure 30: Manufacturing Wage Impacts from GGRA Initiatives, 2013**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $106,737 | -$6,850 | $99,887 |
| Beverage and tobacco product manufacturing | $387,835 | -$73,467 | $314,368 |
| Chemical manufacturing | $2,448,878 | -$387,237 | $2,061,641 |
| Computer and electronic product manufacturing | $2,857,241 | $4,366,951 | $7,224,192 |
| Electrical equipment and appliance manufacturing | $2,749,000 | -$66,157 | $2,682,843 |
| Fabricated metal product manufacturing | $1,608,243 | -$49,273 | $1,558,970 |
| Food manufacturing | -$383,121 | $1,091,305 | $708,184 |
| Furniture and related product manufacturing | $383,856 | -$179,546 | $204,310 |
| Machinery manufacturing | $527,382 | -$73,750 | $453,632 |
| Miscellaneous manufacturing | $1,490,033 | -$1,200,321 | $289,712 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $188,051 | -$16,418 | $171,633 |
| Nonmetallic mineral product manufacturing | $1,029,939 | -$48,020 | $981,919 |
| Other transportation equipment manufacturing | -$302,310 | $734,632 | $432,322 |
| Paper manufacturing | $316,737 | -$47,027 | $269,710 |
| Petroleum and coal products manufacturing | $100,578 | -$3,826 | $96,752 |
| Plastics and rubber product manufacturing | $825,178 | -$48,105 | $777,073 |
| Primary metal manufacturing | $112,662 | $125,801 | $238,463 |
| Printing and related support activities | $1,100,932 | -$54,790 | $1,046,142 |
| Textile mills; Textile product mills | $175,818 | -$125,176 | $50,642 |
| Wood product manufacturing | $297,513 | -$26,262 | $271,251 |

Sources: REMI PI+, RESI

**Figure 31: Manufacturing Wage Impacts from GGRA Initiatives, 2014**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $106,349 | -$9,232 | $97,118 |
| Beverage and tobacco product manufacturing | $505,962 | -$209,843 | $296,119 |
| Chemical manufacturing | $3,418,328 | -$1,397,168 | $2,021,161 |
| Computer and electronic product manufacturing | $1,019,198 | $4,274,849 | $5,294,047 |
| Electrical equipment and appliance manufacturing | $1,587,013 | -$4,494 | $1,582,520 |
| Fabricated metal product manufacturing | $1,342,349 | -$56,843 | $1,285,506 |
| Food manufacturing | $1,718,509 | -$1,225,305 | $493,204 |
| Furniture and related product manufacturing | $302,418 | -$106,144 | $196,274 |
| Machinery manufacturing | $594,195 | -$193,904 | $400,291 |
| Miscellaneous manufacturing | $19,434 | $211,600 | $231,034 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $173,974 | -$18,667 | $155,307 |
| Nonmetallic mineral product manufacturing | $1,068,040 | -$55,146 | $1,012,893 |
| Other transportation equipment manufacturing | -$33,623 | $451,464 | $417,841 |
| Paper manufacturing | $290,903 | -$62,464 | $228,439 |
| Petroleum and coal products manufacturing | $85,647 | -$4,268 | $81,379 |
| Plastics and rubber product manufacturing | $803,884 | -$78,018 | $725,866 |
| Primary metal manufacturing | $364,144 | -$130,554 | $233,589 |
| Printing and related support activities | $1,118,724 | -$92,237 | $1,026,486 |
| Textile mills; Textile product mills | -$170,856 | $218,552 | $47,696 |
| Wood product manufacturing | $305,658 | -$61,100 | $244,558 |

Sources: REMI PI+, RESI

**Figure 32: Manufacturing Wage Impacts from GGRA Initiatives, 2015**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $124,804 | -$11,574 | $113,230 |
| Beverage and tobacco product manufacturing | $30,042 | $305,639 | $335,680 |
| Chemical manufacturing | $332,876 | $2,113,835 | $2,446,711 |
| Computer and electronic product manufacturing | $7,477,982 | $2,738,498 | $10,216,481 |
| Electrical equipment and appliance manufacturing | $3,526,396 | -$87,249 | $3,439,147 |
| Fabricated metal product manufacturing | $1,614,689 | -$80,532 | $1,534,156 |
| Food manufacturing | -$3,118,075 | $3,624,845 | $506,770 |
| Furniture and related product manufacturing | $457,740 | -$238,171 | $219,570 |
| Machinery manufacturing | $1,449,639 | -$1,042,140 | $407,499 |
| Miscellaneous manufacturing | $229,597 | $37,771 | $267,368 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $212,601 | -$40,342 | $172,259 |
| Nonmetallic mineral product manufacturing | $1,266,581 | -$79,868 | $1,186,713 |
| Other transportation equipment manufacturing | -$101,389 | $588,141 | $486,752 |
| Paper manufacturing | $370,471 | -$97,694 | $272,777 |
| Petroleum and coal products manufacturing | $115,520 | -$9,440 | $106,080 |
| Plastics and rubber product manufacturing | $990,006 | -$146,413 | $843,593 |
| Primary metal manufacturing | $208,227 | $57,343 | $265,570 |
| Printing and related support activities | $1,273,313 | -$86,342 | $1,186,971 |
| Textile mills; Textile product mills | -$54,213 | $105,942 | $51,729 |
| Wood product manufacturing | $294,595 | -$92,612 | $201,982 |

Sources: REMI PI+, RESI

**Figure 33: Manufacturing Wage Impacts from GGRA Initiatives, 2016**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $124,331 | -$20,503 | $103,828 |
| Beverage and tobacco product manufacturing | $317,091 | -$8,093 | $308,998 |
| Chemical manufacturing | $1,192,499 | $306,794 | $1,499,293 |
| Computer and electronic product manufacturing | $2,385,912 | $4,483,764 | $6,869,676 |
| Electrical equipment and appliance manufacturing | $1,978,879 | -$15,403 | $1,963,476 |
| Fabricated metal product manufacturing | $1,396,050 | -$162,590 | $1,233,459 |
| Food manufacturing | -$1,038,027 | $1,384,149 | $346,122 |
| Furniture and related product manufacturing | -$972,187 | $1,122,941 | $150,754 |
| Machinery manufacturing | $355,852 | -$36,040 | $319,812 |
| Miscellaneous manufacturing | -$1,081,302 | $1,286,830 | $205,528 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $63,431 | $51,299 | $114,730 |
| Nonmetallic mineral product manufacturing | $919,502 | -$116,847 | $802,655 |
| Other transportation equipment manufacturing | $72,820 | $314,831 | $387,651 |
| Paper manufacturing | $364,107 | -$169,172 | $194,935 |
| Petroleum and coal products manufacturing | $91,412 | -$18,107 | $73,306 |
| Plastics and rubber product manufacturing | $580,696 | $175,869 | $756,565 |
| Primary metal manufacturing | $58,837 | $136,284 | $195,121 |
| Printing and related support activities | $757,136 | $229,042 | $986,178 |
| Textile mills; Textile product mills | -$864 | $43,809 | $42,945 |
| Wood product manufacturing | $289,822 | -$132,844 | $156,978 |

Sources: REMI PI+, RESI

**Figure 34: Manufacturing Wage Impacts from GGRA Initiatives, 2017**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $131,969 | -$30,523 | $101,445 |
| Beverage and tobacco product manufacturing | $376,986 | -$71,920 | $305,067 |
| Chemical manufacturing | -$1,343,875 | $2,772,524 | $1,428,649 |
| Computer and electronic product manufacturing | $15,191,860 | $19,468,494 | $34,660,353 |
| Electrical equipment and appliance manufacturing | $10,234,696 | -$262,523 | $9,972,173 |
| Fabricated metal product manufacturing | $1,408,095 | -$135,992 | $1,272,103 |
| Food manufacturing | -$225,199 | $394,257 | $169,058 |
| Furniture and related product manufacturing | $214,010 | -$123,043 | $90,967 |
| Machinery manufacturing | $1,759,791 | -$1,694,346 | $65,445 |
| Miscellaneous manufacturing | $1,809,360 | -$1,702,714 | $106,646 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $374,788 | -$342,461 | $32,328 |
| Nonmetallic mineral product manufacturing | $961,687 | -$170,015 | $791,672 |
| Other transportation equipment manufacturing | -$87,697 | $354,217 | $266,519 |
| Paper manufacturing | $563,713 | -$361,925 | $201,788 |
| Petroleum and coal products manufacturing | $96,682 | -$28,808 | $67,874 |
| Plastics and rubber product manufacturing | $877,685 | -$149,252 | $728,433 |
| Primary metal manufacturing | $274,622 | -$100,232 | $174,390 |
| Printing and related support activities | $943,180 | $149,102 | $1,092,282 |
| Textile mills; Textile product mills | -$10,725 | $40,876 | $30,152 |
| Wood product manufacturing | $218,977 | -$166,301 | $52,675 |

Sources: REMI PI+, RESI

**Figure 35: Manufacturing Wage Impacts from GGRA Initiatives, 2018**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $83,577 | $284 | $83,861 |
| Beverage and tobacco product manufacturing | $459,797 | -$203,421 | $256,375 |
| Chemical manufacturing | -$14,341 | $1,214,995 | $1,200,654 |
| Computer and electronic product manufacturing | $15,625,723 | $21,405,361 | $37,031,084 |
| Electrical equipment and appliance manufacturing | $11,619,208 | -$280,979 | $11,338,229 |
| Fabricated metal product manufacturing | $157,290 | $912,446 | $1,069,736 |
| Food manufacturing | $568,696 | -$557,249 | $11,447 |
| Furniture and related product manufacturing | $2,832,442 | -$2,808,608 | $23,834 |
| Machinery manufacturing | -$24,052,933 | $23,970,090 | -$82,843 |
| Miscellaneous manufacturing | -$26,803,351 | $26,815,836 | $12,485 |
| Motor vehicles, bodies and trailers, and parts manufacturing | -$1,836,745 | $1,844,798 | $8,053 |
| Nonmetallic mineral product manufacturing | $1,594,329 | -$922,408 | $671,921 |
| Other transportation equipment manufacturing | -$232,763 | $416,471 | $183,708 |
| Paper manufacturing | $58,451 | $116,360 | $174,811 |
| Petroleum and coal products manufacturing | $98,266 | -$44,091 | $54,175 |
| Plastics and rubber product manufacturing | $580,499 | $40,301 | $620,800 |
| Primary metal manufacturing | $11,762 | $131,162 | $142,924 |
| Printing and related support activities | $395,754 | $584,606 | $980,360 |
| Textile mills; Textile product mills | -$5,992 | $24,579 | $18,587 |
| Wood product manufacturing | $157,413 | -$142,374 | $15,039 |

Sources: REMI PI+, RESI

**Figure 36: Manufacturing Wage Impacts from GGRA Initiatives, 2019**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---:|---:|---:|
| Apparel manufacturing; Leather and allied product manufacturing | $75,067 | -$8,216 | $66,850 |
| Beverage and tobacco product manufacturing | $87,359 | $110,338 | $197,697 |
| Chemical manufacturing | $9,378,203 | -$8,610,795 | $767,409 |
| Computer and electronic product manufacturing | $4,089,844 | $7,439,774 | $11,529,618 |
| Electrical equipment and appliance manufacturing | $3,657,725 | -$115,540 | $3,542,185 |
| Fabricated metal product manufacturing | $807,662 | $262,704 | $1,070,366 |
| Food manufacturing | -$167,261 | -$45,717 | -$212,978 |
| Furniture and related product manufacturing | -$43,186 | $72,353 | $29,167 |
| Machinery manufacturing | $483,898 | -$416,258 | $67,640 |
| Miscellaneous manufacturing | $356,165 | -$300,913 | $55,252 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $142,040 | -$92,235 | $49,805 |
| Nonmetallic mineral product manufacturing | $594,689 | $116,894 | $711,583 |
| Other transportation equipment manufacturing | $151,113 | -$6,566 | $144,547 |
| Paper manufacturing | -$75,143 | $190,334 | $115,192 |
| Petroleum and coal products manufacturing | $178,536 | -$145,228 | $33,308 |
| Plastics and rubber product manufacturing | $1,208,731 | -$817,855 | $390,876 |
| Primary metal manufacturing | -$66,626 | $135,495 | $68,869 |
| Printing and related support activities | $474,823 | $137,616 | $612,439 |
| Textile mills; Textile product mills | $10,272 | $2,947 | $13,219 |
| Wood product manufacturing | $170,706 | -$202,718 | -$32,012 |

Sources: REMI PI+, RESI

**Figure 37: Manufacturing Wage Impacts from GGRA Initiatives, 2020**

| Manufacturing Sector | Direct | Indirect/Induced | Total |
|---|---|---|---|
| Apparel manufacturing; Leather and allied product manufacturing | $67,541 | -$7,935 | $59,606 |
| Beverage and tobacco product manufacturing | $130,895 | $25,425 | $156,321 |
| Chemical manufacturing | $443,825 | $139,011 | $582,837 |
| Computer and electronic product manufacturing | $1,685,521 | $3,862,656 | $5,548,178 |
| Electrical equipment and appliance manufacturing | $1,825,196 | -$59,269 | $1,765,927 |
| Fabricated metal product manufacturing | $1,057,189 | -$59,759 | $997,431 |
| Food manufacturing | $663,109 | -$1,018,840 | -$355,731 |
| Furniture and related product manufacturing | -$262,103 | $284,368 | $22,265 |
| Machinery manufacturing | $268,869 | -$178,872 | $89,997 |
| Miscellaneous manufacturing | -$188,135 | $220,202 | $32,067 |
| Motor vehicles, bodies and trailers, and parts manufacturing | $83,647 | -$44,139 | $39,508 |
| Nonmetallic mineral product manufacturing | $604,918 | $72,718 | $677,636 |
| Other transportation equipment manufacturing | $277,546 | -$166,669 | $110,877 |
| Paper manufacturing | $508,840 | -$420,837 | $88,003 |
| Petroleum and coal products manufacturing | $101,596 | -$79,035 | $22,561 |
| Plastics and rubber product manufacturing | -$228,819 | $536,758 | $307,939 |
| Primary metal manufacturing | -$41,682 | $74,578 | $32,896 |
| Printing and related support activities | $284,661 | $212,314 | $496,975 |
| Textile mills; Textile product mills | -$116,148 | $124,413 | $8,266 |
| Wood product manufacturing | $277,286 | -$352,867 | -$75,581 |

Sources: REMI PI+, RESI

**END OF DOCUMENT**

Maryland
Department of
the Environment

# Appendix I

## Just Transition

# 2019 GGRA Draft Plan

# Chapter 17: Just Transition

*Commissioned by*
Maryland Department of the Environment

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## 17.0 Executive Summary

As Maryland considers transitioning its energy mix away from fossil fuels and towards less carbon-intensive fuel sources, it is important to consider the impact of this transition on workers in fossil-fuel reliant industries. Some workers involved in aspects of the fossil fuel supply chain may lose their job and find it difficult to switch industries or occupations. The Maryland Department of the Environment (MDE) tasked the Regional Economic Studies Institute of Towson University (RESI) with evaluating economic dislocations resulting from potential carbon mitigation strategies. These economic dislocations included direct impacts to fossil-fuel-reliant workers, fiscal impacts resulting from industry changes at the local level, and other related disparities associated with the State's efforts to reduce GHG emissions. Additionally, to meet objectives set in the State's 40 by 30 Plan, MDE requested strategies for transitioning impacted fossil-fuel-reliant workers and mitigating other economic dislocations resulting associated with greenhouse gas reduction efforts. To meet the project objectives, RESI utilized a five-fold methodology:

- Identified major fossil-fuel-reliant industries within the state, focusing on industries related to the fossil-fuel supply chain;
- Estimated fiscal impacts to state and local governments resulting from a single firm closure within each major industry of focus;
- Determined key threatened occupations within the industries of focus;
- Analyzed related job opportunities for displaced employees; and
- Researched typical employment requirements and training opportunities within the state.

Major findings for each aspect are summarized below.

The fossil-fuel-reliant industries of focus identified through the analysis are illustrated in Figure 1 below. Data reflect 2017 annual averages.

**Figure 1: Industries of Focus**

| NAICS | Industry | Maryland Employment | Total Wages |
|---|---|---:|---:|
| 221112 | Fossil Fuel Electric Power Generation | 2,298 | $388,125,553 |
| 4471 | Gasoline Stations | 11,476 | $261,048,950 |
| 3241 | Petroleum and Coal Products Manufacturing | 848 | $70,113,044 |
| 2212 | Natural Gas Distribution | 587 | $50,083,767 |
| 3312 | Steel Product Manufacturing from Purchased Steel | 169 | $10,645,755 |
| 2121 | Coal Mining | 80 | $5,145,469 |

Sources: RESI, U.S. Bureau of Labor Statistics

As shown above, total Maryland employment in the industries of focus ranged from 80 to 11,476 workers. In sum, these six industries employ over 15,000 Maryland residents who earn just over $397 million in wages each year. However, as a proportion of total employment in the state, these six industries are relatively small, constituting 0.7 percent of the state's workforce.

Figure 2 below shows a summary of annual fiscal revenue losses estimated if a single Maryland firm in each industry of focus were to close. Inputs were based on the most recently available 2017 data, while impacts are shown in 2019 dollars.

**Figure 2: Summary of Fiscal Impacts per Average Industry Firm**

| Industry | State Taxes | Local Taxes | Total |
|---|---|---|---|
| Fossil Fuel Electric Power Generation | $7,203,040 | $6,288,787 | $13,491,826 |
| Gasoline Stations | $57,020 | $47,939 | $104,959 |
| Petroleum and Coal Products Manufacturing | $147,973 | $116,210 | $264,181 |
| Natural Gas Distribution | $1,036,774 | $906,343 | $1,943,118 |
| Steel Product Manufacturing from Purchased Steel | $314,372 | $249,786 | $564,160 |
| Coal Mining | $1,123,723 | $988,172 | $2,111,896 |

Sources: IMPLAN, RESI, U.S. Bureau of Labor Statistics, U.S. Census

Estimated total annual fiscal losses to state and local governments had a considerable range, with a low of $104,959/year per Gasoline Station to $13,491,826/year per Fossil Fuel Electric Power Generation firm.

Figure 3 below shows five key threatened occupations identified within the six industries of focus. Threatened occupations are those with the most workers in fossil-fuel-reliant industries. Employment figures include both total Maryland employment and the proportion of workers in these occupations who work in fossil-fuel-reliant industries. For example, of the 79,000 cashiers employed across Maryland, an estimated 10 percent work in fossil fuel reliant industries.

**Figure 3: Key Threatened Occupations in Maryland**

| Occupation | SOC Code | Total Maryland Employment | Employment in Fossil-Fuel-Reliant Industries |
|---|---|---|---|
| Cashiers | 41-2011 | 79,000 | 7,545 |
| Machinists | 51-4041 | 2,820 | 626 |
| First-Line Supervisors of Production and Operating Workers | 51-1011 | 6,780 | 257 |
| Petroleum Pump System Operators, Refinery Operators, and Gaugers | 51-8093 | 140 | 140 |
| Inspectors, Testers, Sorters, Samplers, and Weighers | 51-9061 | 4,060 | 168 |

Sources: RESI, U.S. Bureau of Labor Statistics

As detailed above, the occupation with greatest number of workers in fossil-fuel-reliant industries are cashiers, with 7,545 workers. The greatest proportion of potentially affected employees were in the petroleum pump system operators, refinery operators, and gaugers occupation with all employees working in fossil-fuel-reliant industries.

For each threated occupation, related occupations were identified based on skill transfers, existing patterns of employment changes, growth projections, and salary expectations. The related occupations identified are listed in Figure 4 below.

**Figure 4: Related Occupations**

| Related Occupation | Associated Threatened Occupation |
|---|---|
| Nursing Assistants | Cashiers |
| Receptionists and Information Clerks | Cashiers |
| Computer Numerically Controlled Machine Tool Programmers of Metal and Plastic | Machinists |
| Heavy and Tractor-trailer Truck Drivers | Machinists; Petroleum Pump System Operators, Refinery Operators, and Gaugers |
| First-line Supervisors of Construction Trades and Extraction Workers | First-Line Supervisors of Production and Operating Workers |
| First-line Supervisors of Mechanics, Installers, and Repairers | First-Line Supervisors of Production and Operating Workers |
| Engineering Technicians, Except Drafters | First-Line Supervisors of Production and Operating Workers and Machinists; Petroleum Pump System Operators, Refinery Operators, and Gaugers |
| Operating Engineers and Other Construction Equipment | Petroleum Pump System Operators, Refinery Operators, and Gaugers |
| Life, Physical, and Social Science Technicians, All Other | Inspectors, Testers, Sorters, Samplers, and Weighers |
| Stationary Engineers and Boiler Operators | Inspectors, Testers, Sorters, Samplers, and Weighers; Petroleum Pump System Operators, Refinery Operators, and Gaugers |

Sources: Maryland Workforce Exchange, O*Net, RESI, U.S. Bureau of Labor Statistics

For each related occupation above, typical requirements for entry into the profession were researched including educational attainment and on-the-job training needed. Additionally, a survey of available training opportunities within the state was conducted.

For example, cashiers, the occupation with the most jobs within a fossil-fuel-reliant industry, could be transitioned to become nursing assistants or receptionists and information clerks. Both alternative occupations have strong projected growth and higher median wages than cashiers. Becoming a nursing assistant typically requires a postsecondary nondegree award, and there are over 100 certified CNA (certified nursing assistant) training programs offered in colleges, nursing homes, and freestanding institutions in the state.

Certification and degree opportunities exist at Maryland’s colleges and universities for most of the occupations examined in greater detail in this report. Additionally, apprenticeship and less formal training programs exist to help prepare workers for new careers in the absence of formal programs. Partnering with local institutions and private employers can help to ensure workers in fossil-fuel-reliant occupations statewide find high-quality, high-paying jobs to help support their families and their communities.

While the industries and occupations evaluated do not represent an exhaustive list of all those that may be affected by the State’s 40 by 30 Plan, they provide a solid framework for evaluating potential economic and regional dislocations that may be incurred. Given the flexibility of job training and certification programs, scaling initiatives to respond to economic conditions is viable. Understanding the impacts and challenges related to greenhouse gas reduction policies enables the State to be better equipped when addressing these changes and taking steps to ensure an equitable and fair outcome for those affected.

## 17.1 Introduction

As Maryland considers transitioning its energy mix away from fossil fuels and towards less carbon-intensive fuel sources, it is important to consider the impact of this transition on workers in fossil-fuel reliant industries. Some workers involved in aspects of the fossil fuel supply chain may lose their job and find it difficult to switch industries or occupations. The Maryland Department of the Environment (MDE) tasked the Regional Economic Studies Institute of Towson University (RESI) with evaluating economic dislocations resulting from potential carbon mitigation strategies. These economic dislocations included direct impacts to fossil-fuel-reliant workers, fiscal impacts resulting from industry changes at the local level, and other related disparities associated with the State’s efforts to reduce GHG emissions. Additionally, to meet objectives set in the State’s 40 by 30 Plan, MDE requested strategies for transitioning impacted fossil-fuel-reliant workers and mitigating other economic dislocations resulting associated with greenhouse gas reduction efforts. To meet the project objectives, RESI utilized a five-fold methodology:

- Identified major fossil-fuel-reliant industries within the state, focusing on industries related to the fossil-fuel supply chain;
- Estimated fiscal impacts to state and local governments resulting from a single firm closure within each major industry of focus;
- Determined key threatened occupations within the industries of focus;
- Analyzed related job opportunities for displaced employees; and
- Researched typical employment requirements and training opportunities within the state.

This report will continue as follows. Section 17.2 provides a brief overview of Just Transition models and best practices observed in other regions. Section 17.3 outlines the methodology used to determine the industries of focus, threatened occupations, related occupations, estimated fiscal impacts, and available training opportunities in the state. Section 17.4 provides an overview of each industry of focus and a summary of the estimated fiscal losses that would be incurred by state and local governments resulting from a single firm closure in each industry. Section 17.5 highlights the threatened occupations identified within the industries of focus. This section also provides information on more stable positions related to the threatened occupations into which workers could transfer, typical employment requirements, and available job training opportunities in the state. Additionally, this section presents anecdotal evidence of alternative employment strategies that have been pursued to transition workers from fossil-fuel-reliant industries (primary coal mining) into alternative occupations. Section 17.6 concludes the report.

## 17.2 Just Transition Overview and Best Practices

The following section will provide an overview of the Just Transition framework, including how the model has been implemented in several countries as they move away from reliance on fossil-fuel-reliant power generation. Additionally, this section will outline several best practice strategies that have emerged from evaluations of transition efforts in other areas.

### 17.2.1 Overview of Just Transition

Just Transition is a developmental model that is intended to guide the phasing out of high-pollutant industries, while simultaneously introducing and utilizing new and alternative sources (i.e., green/clean/renewable) of energy production.[1] Just Transition approaches are also expected to provide job opportunities and job security to those workers affected by new environmental strategies and policies. In the United States, a transition to alternative energy sources has the potential to significantly impact traditional energy sector workers. The Just Transition framework stresses that that policies should be implemented in advance of major transitions to cushion the impacts and support these workers by providing them with new skills and job opportunities.[2]

The term Just Transition was first used in the late 1990s when North American unions began developing a program to support workers that had lost their jobs due to environmental protection policies.[3] Over time, the meaning of the term has broadened and is used to describe a "deliberate effort to plan for and invest in a transition to environmentally and socially sustainable jobs, sectors and economies."[4] Later, the phrase Just Transition was used again, this time by the International Trade Union Confederation (ITUC) during the 2015 Paris Climate Agreement Conference.[5]

After the Paris Agreement, the UN's International Labor Organization (ILO) produced a definitive definition and implementation plan for Just Transition. According to the ILO, Just Transition is a "bridge from where we are today to a future where all jobs are green and decent, poverty is eradicated, and communities are thriving and resilient."[6] Their approach to Just Transition includes "measures to reduce the impact of job losses and industry phase-out on workers and communities, and measure to produce new, green and decent jobs, sectors and healthy communities."[7]

The Just Transition model will be a crucial component in supporting both existing and developing industries as a new, cleaner energy future is realized. However, these adjustments in energy production will inevitably have an impact on existing industries. In 2017 there were 1.1 million U.S. workers directly employed in the traditional (i.e. coal, oil, gas) Electric Power

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[1] Samantha Smith, "Just Transition: A Report for the OECD," Just Transition Centre (May 2017): 1, accessed October 25, 2018, https://www.oecd.org/environment/cc/g20-climate/collapsecontents/Just-Transition-Centre-report-just-transition.pdf.

[2] Robert Pollin and Brian Callaci, "A Just Transition for U.S. Fossil Fuel Industry Workers," *American Prospect*, July 6, 2016, accessed October 25, 2018, http://prospect.org/article/just-transition-us-fossil-fuel-industry-workers.

[3] Smith, "Just Transition: A Report for the OECD,"2.

[4] Ibid.

[5] Sean Sweeney and John Treat, "Trade Unions and Just Transition," Trade Unions for Energy Democracy (April 2018): 1, accessed October 25, 2018, http://www.rosalux-nyc.org/wp-content/files_mf/tuedworkingpaper11_web.pdf.

[6] Smith, "Just Transition: A Report for the OECD,"3.

[7] Ibid.

Generation and Fuels technologies.[8] The cost for the Just Transition framework in the U.S. has been estimated to be around $500 million per year—only about 1 percent of the total annual investment needed to support climate stabilization policies.[9] The costs includes income subsidies, retraining, and relocation support for fossil-fuel impacted workers and should coincide with the growth of the clean energy industry.[10] Two major components of the Just Transition framework will be the guarantee of clean energy-related jobs for younger workers in affected industries and an expansion of employment opportunities through clean energy investments for individuals and communities that will face the brunt of the transition.[11]

### 17.2.2 Just Transition Best Practices

As countries around the world have begun to transition away from reliance on fossil fuels, examples of Just Transition models have emerged. These transitions vary in size and scope, depending upon the degree to which fossil fuels are integrated into the economy and the size of the industry. In a review of multiple case studies from economies transitioning away from coal, the IDDRI, an independent policy institute, noted several best practices when undertaking Just Transition initiatives.[12] These insights included aspects involving employee transitions, building successful policies to support Just Transition, and regional strategies for areas that are heavily fossil-fuel reliant. The following subsection highlights several best practice suggestions for each of these factors.

Employees of fossil-fuel-reliant industries are a central focus of Just Transition efforts. A fair transition into new employment opportunities for individuals and their families is crucial to a successful Just Transition effort. The IDDRI notes several aspects that should be considered when formulating a transition effort, including:

- Receiving input from workers early in planning stages,[13]
- Responding to questions from workers,
- Providing a timeline for the phase-out of activities, and
- Creating worker training programs that facilitate the transfer of employees to new jobs.[14]

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[8] National Association of State Energy Officials and Energy Futures Initiative, "2018 U.S. Energy and Employment Report," 13, accessed February 8, 2019, https://static1.squarespace.com/static/5a98cf80ec4eb7c5cd928c61/t/5afb0ce4575d1f3cdf9ebe36/1526402279839/2018+U.S.+Energy+and+Employment+Report.pdf.

[9] Pollin and Callaci, "A Just Transition for U.S. Fossil Industry Workers."

[10] Ibid.

[11] Ibid.

[12] "IDDRI, A Think Tank to Facilitate the Transition Towards Sustainable Development," IDDRI, accessed January 12, 2019, https://www.iddri.org/en/about-iddri.

[13] O. Sartor, "Insights from Case Studies of Major Coal-Consuming Economies," IDDRI and Climate Strategies (2018): 27, accessed January 4, 2019, https://coaltransitions.files.wordpress.com/2018/09/coal_synthesis_final.pdf.

[14] Ibid., 27-29.

The actions listed above help to ensure that employees are heard during the planning and transition, and also provide a framework for expectations around the process. Questions that should be addressed from workers include how they will be ensured a transition to a new career or retirement, how their compensation will be impacted during this transition period, and how the efforts will be funded.[15] Additionally, it is important to gain input through social dialogue from community members who are also impacted by the transition process.[16,17] The provision of a timeline surrounding activities allows workers to determine whether they will likely be transferring to a new career, or whether they are close enough to retirement that they would be exiting the workforce.[18] For those who will be seeking new employment, job retraining programs should match the existing skills of workers with local employment alternatives.[19] Additionally, job training programs with a focus on direct job placement have been found to be more effective than more general retraining initiatives.[20]

Policies surrounding Just Transition plans should also be designed to consider the needs of a successful program. These factors include:

- Providing a transition oversight body,
- Funding of the transition, and
- Facilitating the creating of a job retraining program.[21]

To ensure that the Just Transition framework is implemented more smoothly, a dedicated oversight body should be created that contains stakeholders in the process.[22] This group would be involved in outlining the timeline associated with the transition, creating plans for the implementation and monitoring of the transition, and providing policy suggestions to support a successful transition.[23] Plans to adequately finance the Just Transition effort should also be considered when developing supporting policies.[24,25,26] These may include the creation of a dedicated fund to provide workforce retraining or transition out of the labor force, or potentially involving companies directly involved in the funding of a labor transition.[27] The structure of the job retraining program should be considered in conjunction with how the program would be funded.[28] As previously mentioned, ideally, the program will focus on direct

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[15] Sartor, “Insights from Case Studies of Major Coal-Consuming Economies,” 27.
[16] Smith, “Just Transition A Report for the OECD,” 7.
[17] United Nations, “Just Transition of the Workforce, and the Creation of Decent Work and Quality Jobs,” 50, accessed January 11, 2019, https://unfccc.int/sites/default/files/resource/Just%20transition.pdf.
[18] Sartor, “Insights from Case Studies of Major Coal-Consuming Economies,” 28.
[19] Ibid., 29.
[20] Ibid.
[21] Ibid., 29-30.
[22] Ibid., 29.
[23] Ibid.
[24] Ibid., 30.
[25] United Nations, “Just Transition of the Workforce, and the Creation of Decent Work and Quality Jobs,” 55.
[26] Smith, “Just Transition A Report for the OECD,” 17-18.
[27] Sartor, “Insights from Case Studies of Major Coal-Consuming Economies,” 30.
[28] Ibid.

worker placement into alternative industries rather than providing a more generic or general skill training program.[29] This may involve providing subsidies for on-the-job (OTJ) training once an appropriate employment opportunity is found for affected workers.[30]

The economies of areas in which Just Transition strategies are implemented can vary significantly. For this reason, the unique attributes of the regional economy should be considered when designing a plan for transitioning away from fossil-fuel reliance. According to findings from the IDDRI, these regional strategies should include:

- Expanding regional industries that are not fossil-fuel reliant,
- Leveraging the area's advantages when diversifying industries,
- Supporting local entrepreneurial networks, and
- Strengthening regional expansion of alternative clean energy.[31]

Economic planning for Just Transition efforts should evaluate the area's existing related activities which are not directly reliant upon fossil-fuel industries, known as "related diversification."[32] Similarly, these diversification efforts should consider the region's unique strengths and leverage these attributes when determining which industries to expand upon.[33] This concept of "smart [specialization]" could include aspects of infrastructure, skills of the existing workforce, local growth industries, property availability, or other comparative advantages within the affected region.[34] If the strengths of an area affected by the transition away from fossil fuels are not clear, partnerships with regional higher educational institutions can be used to help identify these attributes.[35] Entrepreneurial networks can also be a useful tool to start or expand industries with growth potential, and can be facilitated and supported through higher education institutions and their partners, including local businesses and governmental organizations.[36] Through these measures, existing industries in the area with growth potential, or industries that could utilize the region's unique attributes to their advantage, can be identified and bolstered to diversify the local economy.

For regions with significant ties to energy production, and that also have the required infrastructure to support these projects, the expansion of renewable energy in the area may be a strong option in a Just Transition plan.[37][38] The nature of the project—wind, solar, hydropower, or other pilot projects—would depend in part upon the region's available

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[29] Sartor, "Insights from Case Studies of Major Coal-Consuming Economies," 30.
[30] Ibid., 30.
[31] Ibid, 31.
[32] Ibid.
[33] Ibid.
[34] Ibid.
[35] Ibid.
[36] Ibid.
[37] Anna Zinecker, et al., "Real People, Real Change: Strategies for Just Energy Transitions," International Institute for Sustainable Development and Global Subsidies Initiative (December 2018): 7, accessed January 11, 2019, https://www.iisd.org/sites/default/files/publications/real-people-change-strategies-just-energy-transitions.pdf.
[38] Sartor, "Insights from Case Studies of Major Coal-Consuming Economies," 31.

resources.[39] Additionally, these projects would require a business plan that shows a sustainable model for long-term and commercial-scale activity to be used as a substitute for fossil-fuel-reliant power generation.[40]

The best practices outlined above provide multiple examples of how Just Transition models can be designed to bolster a successful shift away from fossil-fuel-reliant industries. While the transition to cleaner energy has numerous societal, economic, and environmental benefits, the impact to existing industries and communities must not be overlooked.[41] By incorporating affected employees and stakeholders into program planning, providing clear policy guidance and funding, and considering unique regional and economic attributes that impact a program's success, Just Transition framework can be strengthened and increase the likelihood of a smooth transition. Successful execution of a Just Transition model can be an integral step in not only mitigating climate change opposition, but also ensuring that all share in the economic benefits of the transition.[42]

## 17.3 Methodology

This section will outline the methodology used to identify industries that would likely be impacted by the State's plan to reduce GHG emissions, as well as the identification of the specific threatened occupations within these industries. The process of identifying alternative occupations related to these threatened occupations is also discussed, as well as the methods of estimating potential fiscal impacts resulting from reduced activity in fossil-fuel-reliant industries. Lastly, the process by which training opportunities in the state were obtained is also reviewed.

### 17.3.1 Identification of Industries of Focus

To determine which industries would be most impacted by the State's GHG reduction strategies, RESI first identified industries related to the supply chain for energy derived from coal, oil, and gas. Broadly, these core industries were coal mining, power plant operation, heavy manufacturing, pipeline transport, coal transport (rail), and gas stations. RESI defined these industries using North American Industry Classification System (NAICS) codes. For two industries of interest—Pipeline Transportation of Crude Oil (NAICS 4861) and Pipeline Transportation of Natural Gas (NAICS 4862)—industry data were suppressed and unavailable at the state level. Data suppression often occurs when there are a limited number of establishments in the industry and data disclosure could enable identification of unique companies. For Rail Transportation (NAICS 4821), data were not available due to reporting

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[39] Sartor, "Insights from Case Studies of Major Coal-Consuming Economies," 31.
[40] Ibid.
[41] Arjin Makhijani, "Beyond a Band-Aid: A Discussion Paper on Protecting Workers and Communities in the Great Energy Transition," Institute for Energy and Environmental Research (June 10, 2016): 2-3, accessed October 2, 2018, https://ieer.org/wp/wp-content/uploads/2016/06/beyond-a-band-aid-just-energy-transition_2016_LNS-IEER.pdf.
[42] Makhijani, "Beyond a Band-Aid: A Discussion Paper on Protecting Workers and Communities in the Great Energy Transition," 2-3.

limitations related to the railroad unemployment insurance system.[43] After evaluating data availability and relevance for detailed industries within the broader coal supply chain industries, six industries for further evaluation were determined:

- Fossil Fuel Electric Power Generation,
- Gasoline Stations,
- Petroleum and Coal Products Manufacturing,
- Natural Gas Distribution,
- Steel Product Manufacturing from Purchased Steel, and
- Coal Mining.

In addition to the six core industries of focus that were identified, RESI also utilized 2016 input-output tables from the U.S. Bureau of Economic Analysis (BEA) to identify additional related industries. The BEA's input-output tables show the interactions of industries through the inputs to, and outputs from, one another.[44] RESI used these tables to consider additional industries that would likely be negatively impacted by decreased operations. After evaluating these relationships, detailed NAICS within the industries of nonmetallic mineral products, primary metals, fabricated metal products, and chemical products were also included in the data analysis to identify threatened occupations.

### 17.3.2 Identification of Threatened Occupations

RESI then utilized an industry to occupation crosswalk obtained from the U.S. Bureau of Labor Statistics (BLS).[45] This file shows the national-level distribution of specific occupations by industry, allowing for an estimation of an approximate industry-specific occupational proportion. Because standard occupational codes (SOCs) are spread across numerous industries in varying concentrations, RESI needed to more specifically identify the proportion of employees in each occupation that work in the identified threatened industries. As a hypothetical example, although there may be a total of 100 workers within the human resources managers occupation for a specific geographical area, these managers could be spread throughout a number of industries such as retail trade, manufacturing, or healthcare.

Using these national-level proportions, RESI then applied the estimated employment percentage for each occupation to 2017 Maryland-level industry data from the BLS Quarterly Census of Employment of Wages (QCEW).[46] This resulted in a file that estimated the number of employees by occupation for each industry within Maryland. The file was subsequently restricted to those industries which were identified to be fossil-fuel dependent. Employment

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[43] "QCEW Overview," U.S. Bureau of Labor Statistics, last modified July 18, 2018, accessed October 15, 2018, https://www.bls.gov/cew/cewover.htm.

[44] "Input-Output Accounts Data," U.S. Bureau of Economic Analysis, accessed October 15, 2018, https://www.bea.gov/industry/input-output-accounts-data.

[45] "May 2017 National Industry-Specific Occupational Employment and Wage Estimates," U.S. Bureau of Labor Statistics, accessed October 15, 2018, https://www.bls.gov/oes/2017/may/oessrci.htm#00.

[46] "Quarterly Census of Employment and Wages: Private, All Industry Aggregations, Maryland," U.S. Bureau of Labor Statistics, accessed October 15, 2018, http://www.bls.gov/cew/data/api/2017/a/area/24000.csv.

figures relevant to each threatened industry of focus were then aggregated and sorted, which produced a list of key threatened occupations in the state. To avoid only focusing on only a small subgroup of occupations, jobs with common three-and four-digit SOCs were grouped together. Occupations of focus were selected from these groups based on the number of employees within the profession, relevance to the threatened industry, and to represent a broad mix of occupations. A full list of considered occupations can be found in Appendix A.

### 17.3.3 Identification of Related Occupations

After identifying the threatened occupations of focus, RESI evaluated alternative options for individuals currently working in these jobs. The related occupations were chosen based on several factors, including skill transfers, existing patterns of employment changes, growth projections, and salary expectations.

RESI created an occupational matrix that included employment changes obtained from resume and occupational data through Maryland Workforce Exchange (MWE).[47] Resume data included jobs which workers had moved to or from, and the number of individuals making this job change. In addition to identifying related occupations through resume data, the Occupational Information Network (O*Net) database was also utilized to determine related jobs based on employment characteristics.[48] Occupational data through MWE included skills, certifications, and technologies associated with job postings. These data were merged with occupational growth projections from the BLS, as well as typical education and training requirements needed for entry into the occupation.[49,50] State-level wage data were also obtained from the BLS; for most occupations the most recent year available was 2017.[51] For several occupations, however, 2016 figures were the most recently available at the state level.[52]

For each threatened occupation, the related professions were sorted based on projected growth levels. Those jobs with projected negative growth were eliminated, as well as those with significantly lower median annual wages compared to the threatened occupation or that were also in fossil-fuel-reliant industries. Education and training requirements were considered, with those jobs requiring education levels close to that of the threatened occupation, or slightly above, being the most desirable. Using these criteria, the most relevant jobs were retained and

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[47] "Occupational Summary," Maryland Workforce Exchange, accessed November 19, 2018, https://mwejobs.maryland.gov/vosnet/lmi/default.aspx?pu=1&plang=E.

[48] "About O*Net," O*Net Resource Center, accessed November 19, 2018, https://www.onetcenter.org/overview.html.

[49] "Employment Projections," U.S. Bureau of Labor Statistics, last modified January 30, 2018, accessed October 16, 2018, https://www.bls.gov/emp/tables/emp-by-detailed-occupation.htm.

[50] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics, last modified October 24, 2017, accessed October 16, 2018, https://www.bls.gov/emp/tables/education-and-training-by-occupation.htm.

[51] "May 2017 State Occupational Employment and Wage Estimates: Maryland," U.S. Bureau of Labor Statistics, last modified March 30, 2018, accessed October 16, 2018, https://www.bls.gov/oes/current/oes_md.htm.

[52] "May 2016 State Occupational Employment and Wage Estimates: Maryland," U.S. Bureau of Labor Statistics, last modified March 31, 2017, accessed October 16, 2018, https://www.bls.gov/oes/2016/may/oes_md.htm#19-0000.

focused on as potential alternative employment opportunities for each threatened occupation.

### 17.3.4 Estimating Fiscal Impacts

In order to estimate the potential fiscal impacts resulting from industry closures, RESI first collected data on each industry of interest within the state of Maryland. Using 2017 annual averages from BLS QCEW, RESI evaluated the number of firms in each industry of focus, as well as the number of employees and total wages.[53] The average figures per firm were then calculated to provide an approximate reference for the size of each establishment.

The IMPLAN input/output model was then used to calculate the expected fiscal impacts resulting from a closure of an 'average' firm for each industry type within the state of Maryland. The IMPLAN model has the ability to enumerate the economic and fiscal impact of each dollar earned and spent by the following: employees of the firm, other supporting vendors (business services, retail, etc.), each dollar spent by these vendors on other firms, and each dollar spent by the households of the firm's employees, other vendors' employees, and other businesses' economic impacts that result from households increasing their purchases at local businesses.

Economists measure three types of economic impacts: direct, indirect, and induced impacts. The direct economic effects are generated as the event creates jobs and hires workers to support the event's activities. The indirect economic impacts occur as vendors purchase goods and services from other firms. In either case, the increases in employment generate an increase in household income, as new job opportunities are created and income levels rise. This drives the induced economic impacts that result from households increasing their purchases at local businesses.

The fiscal impacts generated by IMPLAN include direct, indirect, and induced impacts. As noted in Section 17.4, fiscal impacts for each standalone industry cannot be combined due to the potential for double counting.[54] To more clearly differentiate state and local taxes, beyond the categories provided (e.g., property taxes, payroll taxes, etc.) RESI evaluated tax structures from the U.S. Census, to obtain approximate breakdowns between state and local tax revenues.[55] Using these approximations, RESI applied ratios to the fiscal impacts estimated by IMPLAN for each industry.

RESI's analysis includes the following modeling assumptions.

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[53] "Quarterly Census of Employment and Wages: 2017, Annual Averages," U.S. Bureau of Labor Statistics, last modified March 7, 2017, accessed December 19, 2018, https://data.bls.gov/cew/apps/data_views/data_views.htm#tab=Tables.

[54] Fiscal impacts include not only direct effects, but also indirect and induced effects which often overlap over different industries. For example, a coal mining firm may be considered an input or supplier to a fossil fuel electric power generation firm. The fiscal impacts resulting from the closure of a fossil fuel electric power generation firm would include impacts from the coal mining firm. Because of this, fiscal impacts should be interpreted independently by industry and not combined, because doing so could show impacts that are artificially large.

[55] "State and Local Government Finances by Level of Government and by State: 2015," U.S. Census Bureau, American Factfinder, last updated October 19, 2017, accessed January 10, 2019, https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk.

- Economic impact multipliers are developed from IMPLAN input/output software.
- IMPLAN data are based on the North American Industrial Classification System (NAICS).
- IMPLAN employment multipliers are adjusted for inflation using the Bureau of Labor Statistic's CPI-U.
- Impacts are based on 2016 IMPLAN data for the state of Maryland.
- Impacts are represented in 2019 dollars.

### 17.3.5 Training Opportunities

RESI utilized a number of sources to gain information on job training for related occupations. Sources included career planning websites, local training finder websites, industry group information pages, and occupational databases such as O*Net. More specific information on programs and courses was obtained through college or training institution websites. For some occupations, such as nursing assistants, State requirements were also considered in training research. To provide additional employment context, data were also obtained on the number of job postings through Maryland Workforce Exchange to specify the areas within the state where positions were available as of November 2018.

## 17.4 Industries of Focus

As described in Section 17.3, six fossil-fuel-reliant industries were chosen for further analysis, based on relevance to the coal, oil, and gas supply chains. The following section will briefly describe each industry within Maryland and the estimated state and local fiscal impacts associated with potential firm reductions. Note that fiscal impacts presented for each industry include direct, indirect, and induced impacts. Because of this, fiscal impacts for standalone industries cannot be combined due to the potential for double counting.[56]

A summary of each fossil-fuel-reliant industry of focus is shown below in Figure 5 below. Data reflect 2017 annual averages.

**Figure 5: Industries of Focus**

| NAICS | Industry | Maryland Employment | Total Wages |
|---|---|---:|---:|
| 221112 | Fossil Fuel Electric Power Generation | 2,298 | $388,125,553 |
| 4471 | Gasoline Stations | 11,476 | $261,048,950 |
| 3241 | Petroleum and Coal Products Manufacturing | 848 | $70,113,044 |
| 2212 | Natural Gas Distribution | 587 | $50,083,767 |
| 3312 | Steel Product Manufacturing from Purchased Steel | 169 | $10,645,755 |
| 2121 | Coal Mining | 80 | $5,145,469 |

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[56] Fiscal impacts include not only direct effects, but also indirect and induced effects which often overlap over different industries. For example, a coal mining firm may be considered an input or supplier to a fossil fuel electric power generation firm. The fiscal impacts resulting from the closure of a fossil fuel electric power generation firm would include impacts from the coal mining firm. Because of this, fiscal impacts should be interpreted independently by industry and not combined, because doing so could show impacts that are artificially large.

Sources: RESI, U.S. Bureau of Labor Statistics

As detailed above, the six industries of focus vary considerably in both employment and total wages. The following subsections provide a more detailed breakdown of each industry, including the total number of firms, average employment per firm, and wages per firm. Additionally, estimated fiscal losses associated with the closure of an average firm are shown for each industry.

### 17.4.1 Fossil Fuel Electric Power Generation

Figure 6 below shows the industry summary for Fossil Fuel Electric Power Generation in Maryland during 2017.

**Figure 6: Fossil Fuel Electric Power Generation, 2017 Maryland Industry Summary**

| Metric | Total |
|---|---:|
| Total Firms | 27 Firms |
| Total Workers | 2,298 Employees |
| Total Wages | $388,125,553 |
| Average Workers Per Firm | 85 Employees |
| Average Wages Per Firm | $14,375,020 |

Sources: RESI, U.S. Bureau of Labor Statistics

As detailed above, a total of 2,298 employees worked in the industry in 2017 with total Maryland wages of $388.1 million. There were approximately 27 firms in the state within the Fossil Fuel Electric Power Generation industry, having an average of 85 employees per firm. Of the six industries evaluated, fossil fuel electric power plants have the most average employees per firm. This reflects the nature of modern power plants (and utility companies in general) which possess economies of scale—larger facilities with high entry costs and a relatively limited number of firms.

Figure 7 below provides an estimated fiscal impact summary for a Fossil Fuel Electric Power Generation firm in Maryland. These figures provide a hypothetical example of fiscal losses that would be attributed to the closing of a single firm within the industry. While input data reflects the most recently available 2017 figures from the BLS, impact dollars are represented in 2019 dollars.

**Figure 7: Fossil Fuel Electric Power Generation – Fiscal Impacts, Average Firm**

| Type | State | Local | Total |
|---|---:|---:|---:|
| Property | $426,054 | $4,966,037 | $5,392,091 |
| Income | $548,419 | $320,046 | $868,465 |
| Sales | $5,092,518 | $517,129 | $5,609,647 |
| Payroll | $32,027 | $6,589 | $38,616 |
| Other | $1,104,023 | $478,985 | $1,583,007 |

| | | | |
|---|---|---|---|
| **Total** | **$7,203,040** | **$6,288,787** | **$13,491,826** |

Sources: IMPLAN, RESI, U.S. Bureau of Labor Statistics, U.S. Census

Of the total $13.5 million in estimated annual taxes paid by each firm, approximately $7.2 million would be allocated to the State while $6.3 million would be paid to local governments. Combined, State sales tax and Local property tax account for $10.1 million—roughly 75 percent of all taxes paid by each Maryland Fossil Fuel Electric Power Generation firm. Individual plant closures would have the most significant effect on tax revenue of any of the industries evaluated—total fiscal impacts from the closing of one Fossil Fuel Electric Power Generation plant are equivalent to the closure of roughly 133 gas stations for example.

### 17.4.2 Gasoline Stations

Figure 8 below shows the industry summary for Gasoline Stations in Maryland during 2017.

**Figure 8: Gasoline Stations, 2017 Maryland Industry Summary**

| Metric | Total |
|---|---|
| Total Firms | 1,397 Firms |
| Total Workers | 11,476 Employees |
| Total Wages | $261,048,950 |
| Average Workers Per Firm | 8 Employees |
| Average Wages Per Firm | $186,864 |

Sources: RESI, U.S. Bureau of Labor Statistics

As illustrated above, a total of 11,476 employees worked in Gasoline Stations in 2017 with total Maryland wages of $261.0 million. There were approximately 1,397 firms in the state within the industry, having an average of eight employees per firm. Of the six industries evaluated, Gasoline Stations had the fewest average employees and, by far, the lowest average wages per firm. Further, while the five other industries evaluated each had less than 100 firms each, there were 1,397 Gasoline Stations within the state.

Figure 9 below provides an estimated fiscal impact summary for an average Gasoline Station in Maryland. These figures represent the estimated revenue losses to state and local governments resulting from the closure of a single station.

**Figure 9: Gasoline Stations – Fiscal Impacts, Average Firm**

| Type | State | Local | Total |
|---|---|---|---|
| Property | $2,831 | $32,999 | $35,830 |
| Income | $12,280 | $7,166 | $19,446 |
| Sales | $33,689 | $3,421 | $37,110 |
| Payroll | $469 | $97 | $566 |
| Other | $7,751 | $4,256 | $12,007 |
| **Total** | **$57,020** | **$47,939** | **$104,959** |

Sources: IMPLAN, RESI, U.S. Bureau of Labor Statistics, U.S. Census

Of the total $0.1 million in estimated annual taxes paid by each firm, approximately $57,020 would be allocated to the State while $47,939 would be paid to local governments. Sales and property taxes comprise the largest components of total fiscal revenues, at $37,110 and $35,830, respectively. Although an individual firm closure will have notably less-pronounced economic consequences with regard to taxes compared to the other industries examined, there are significantly more total firms across the state.

### 17.4.3 Petroleum and Coal Products Manufacturing

Figure 10 below illustrates the industry summary for Petroleum and Coal Products Manufacturing in Maryland during 2017.

**Figure 10: Petroleum and Coal Products Manufacturing, 2017 Maryland Industry Summary**

| Metric | Total |
|---|---:|
| Total Firms | 55 Firms |
| Total Workers | 848 Employees |
| Total Wages | $70,113,044 |
| Average Workers Per Firm | 15 Employees |
| Average Wages Per Firm | $1,274,783 |

Sources: RESI, U.S. Bureau of Labor Statistics

As detailed above, a total of 848 employees worked in the industry in 2017 with total Maryland wages of $70.1 million. There were approximately 55 firms in the state within the Petroleum and Coal Products Manufacturing industry, having an average of 15 employees per firm. Compared to the other five industries examined, this industry had both the second-lowest wages per firm and second-lowest average workers per firm.

Figure 11 below shows an estimated fiscal impact summary for the average Petroleum and Coal Products Manufacturing firm in Maryland.

**Figure 11: Petroleum and Coal Products Manufacturing – Fiscal Impacts, Average Firm**

| Type | State | Local | Total |
|---|---:|---:|---:|
| Property | $6,005 | $69,999 | $76,004 |
| Income | $46,028 | $26,861 | $72,889 |
| Sales | $71,112 | $7,221 | $78,333 |
| Payroll | $2,749 | $566 | $3,315 |
| Other | $22,078 | $11,564 | $33,640 |
| **Total** | **$147,973** | **$116,210** | **$264,181** |

Sources: IMPLAN, RESI, U.S. Bureau of Labor Statistics, U.S. Census

Of the nearly $0.3 million in total estimated annual taxes paid by an average firm, over $0.1

million each would be allocated to both the state and local governments, respectively. Sales, property, and income taxes comprise the largest components of total fiscal revenues, respectively. Overall, the Petroleum and Coal Products Manufacturing industry would represent the second-lowest revenue losses to state and local governments, per firm, compared to the other industries evaluated.

### 17.4.4 Natural Gas Distribution

Figure 12 below details the industry summary for Natural Gas Distribution in Maryland during 2017.

**Figure 12: Natural Gas Distribution, 2017 Maryland Industry Summary**

| Metric | Total |
|---|---:|
| Total Firms | 19 Firms |
| Total Workers | 587 Employees |
| Total Wages | $50,083,767 |
| Average Workers Per Firm | 31 Employees |
| Average Wages Per Firm | $2,635,988 |

Sources: RESI, U.S. Bureau of Labor Statistics

As shown above, a total of 587 employees worked in the industry in 2017 with total Maryland wages of $50.1 million. There were approximately 19 firms in the state within the Natural Gas Distribution industry, having an average of 31 employees per firm.

Figure 13 below provides an estimated fiscal impact summary for an average Natural Gas Distribution firm in Maryland. These figures represent the estimated losses that would be incurred by state and local governments resulting from the closure of a single firm.

**Figure 13: Natural Gas Distribution – Fiscal Impacts, Average Firm**

| Type | State | Local | Total |
|---|---:|---:|---:|
| Property | $58,270 | $679,195 | $737,465 |
| Income | $139,992 | $81,697 | $221,689 |
| Sales | $695,357 | $70,611 | $765,968 |
| Payroll | $7,009 | $1,442 | $8,451 |
| Other | $136,146 | $73,398 | $209,545 |
| **Total** | **$1,036,774** | **$906,343** | **$1,943,118** |

Sources: IMPLAN, RESI, U.S. Bureau of Labor Statistics, U.S. Census

Of the more than $1.9 million in total estimated annual taxes paid by each firm, approximately $1.0 million would be received by the State while $0.9 million would be paid to local governments. Sales and property taxes comprise the largest components of total fiscal revenues, at approximately $0.8 million and $0.7 million, respectively.

### 17.4.5 Steel Product Manufacturing from Purchased Steel

Figure 14 below shows the industry summary for Steel Product Manufacturing from Purchased Steel in Maryland during 2017.

**Figure 14: Steel Product Manufacturing, 2017 Maryland Industry Summary**

| Metric | Total |
|---|---:|
| Total Firms | 5 Firms |
| Total Workers | 169 Employees |
| Total Wages | $10,645,755 |
| Average Workers Per Firm | 34 Employees |
| Average Wages Per Firm | $2,129,151 |

Sources: RESI, U.S. Bureau of Labor Statistics

As detailed above, a total of 169 employees worked in the industry in 2017 with total Maryland wages of $10.7 million. There were approximately five firms in the state within the Steel Product Manufacturing industry, having an average of 34 employees per firm. This industry accounted for the second-lowest total wages of those industries evaluated and was tied with the Coal Mining industry as having the fewest number of firms in the state.

Figure 15 below shows a summary of the estimated fiscal losses from the closure of an average Steel Product Manufacturing firm in Maryland.

**Figure 15: Steel Product Manufacturing – Fiscal Impacts, Average Firm**

| Type | State | Local | Total |
|---|---:|---:|---:|
| Property | $13,691 | $159,579 | $173,270 |
| Income | $83,773 | $48,888 | $132,661 |
| Sales | $162,486 | $16,500 | $178,986 |
| Payroll | $5,300 | $1,091 | $6,391 |
| Other | $49,122 | $23,728 | $72,852 |
| **Total** | **$314,372** | **$249,786** | **$564,160** |

Sources: IMPLAN, RESI, U.S. Census

Of the nearly $0.6 million in total estimated annual taxes paid by each firm, over $0.3 million would be allocated to the State while more than $0.2 million would be paid to local governments. Sales and property taxes comprise the largest components of total fiscal revenues, at roughly $0.2 million each.

### 17.4.6 Coal Mining

Figure 16 below shows the industry summary for Coal Mining in Maryland during 2017.

**Figure 16: Coal Mining, 2017 Maryland Industry Summary**

| Metric | Total |
|---|---:|
| Total Firms | 5 Firms |
| Total Workers | 80 Employees |
| Total Wages | $5,145,469 |
| Average Workers Per Firm | 16 Employees |
| Average Wages Per Firm | $1,029,094 |

Sources: RESI, U.S. Bureau of Labor Statistics

In 2017, a total of 80 employees worked in the Coal Mining industry in Maryland with combined wages of $5.1 million. There were approximately five firms in the state within this industry, having an average of 16 employees per firm. Among the six industries evaluated, the Coal Mining industry in Maryland had the lowest total wages, and was tied with Steel Product Manufacturing as having the fewest number of firms.

Figure 17 below shows the estimated fiscal impact summary for an average Coal Mining firm in Maryland. These results represent the estimated revenue losses to state and local governments resulting from the closure of a single firm.

**Figure 17: Coal Mining – State and Local Fiscal Impacts, Average Firm**

| Type | State | Local | Total |
|---|---:|---:|---:|
| Property | $68,110 | $793,886 | $861,996 |
| Income | $63,832 | $37,251 | $101,083 |
| Sales | $814,523 | $82,712 | $897,235 |
| Payroll | $3,560 | $733 | $4,293 |
| Other | $173,698 | $73,590 | $247,289 |
| **Total** | **$1,123,723** | **$988,172** | **$2,111,896** |

Sources: IMPLAN, RESI, U.S. Bureau of Labor Statistics, U.S. Census

A total of $2.1 million in estimated annual taxes is generated by each firm, with approximately $1.1 million allocated to the State and $1.0 million paid to local governments. Sales and property taxes comprise the largest components of total fiscal revenues, at approximately $0.9 million each. The revenue losses from a single coal mining firm represent the second-highest of the industries evaluated.

As shown throughout this section, the size and scope of the evaluated industries vary substantially, with total Maryland employment ranging from 80 to 11,476. Estimated fiscal losses to state and local governments also had a considerable range, with a low of $0.1 million per Gasoline Station to $13.5 million per Fossil Fuel Electric Power Generation firm. These figures provide an estimate of the employment and fiscal impacts that would result from decreased operations within these industries of focus.

## 17.5 Occupational Transitions

RESI evaluated key threatened occupations resulting from State climate change mitigation strategies, as determined in the methodology outlined in Section 17.3. This section will provide a summary of these occupations, as well as related professions to each threatened occupation. For several of these related occupations, the requirements and opportunities for entry are discussed in greater detail. In addition, alternative strategies for transitioning fossil-fuel-reliant workers that have been explored are also described.

These five key threatened occupations are summarized in Figure 18 below.

**Figure 18: Key Threatened Occupations**

| Occupation | SOC Code | Total Maryland Employment | Employment in Fossil-Fuel-Reliant Industries |
|---|---|---|---|
| Cashiers | 41-2011 | 79,000 | 7,545 |
| Machinists | 51-4041 | 2,820 | 626 |
| First-Line Supervisors of Production and Operating Workers | 51-1011 | 6,780 | 257 |
| Petroleum Pump System Operators, Refinery Operators, and Gaugers | 51-8093 | 140 | 140 |
| Inspectors, Testers, Sorters, Samplers, and Weighers | 51-9061 | 4,060 | 168 |

Sources: RESI, U.S. Bureau of Labor Statistics

As detailed above, of the five key threatened occupations, four fall under major SOC code 51, Production Occupations. The most-heavily impacted of these professions is petroleum pump system operators, refinery operators, and gaugers, for which all Maryland positions are estimated to be affected. While the greatest number of employees potentially displaced from fossil-fuel-reliant occupations are cashiers, the number of affected workers represents approximately 9.6 percent of all workers in Maryland within this position.

The following subsection will detail occupations that are related to each of the threatened occupations shown in Figure 18 above.

### 17.5.1 Related Occupations

In 2017, there were approximately 79,000 cashiers in Maryland; of these, an estimated 7,545 would potentially be impacted by State climate change mitigation strategies. Figure 19 below outlines occupations related to cashiers, as well as entry requirements, growth projections, and 2017 median wages. Please note that in the following tables abbreviations are used for high school diploma or equivalent (HS/Equivalent) and on-the-job (OTJ) training.

**Figure 19: Related Occupations, Cashiers**

| Occupation | Code | Minimum Education | On-the-Job Training | Projected Growth 2016-2026 | Maryland Employment | Median Maryland Wage |
|---|---|---|---|---|---|---|
| **Cashiers** | **41-2011** | **No formal credential** | **Short-term OTJ** | **-0.9%** | **79,000** | **$20,363** |
| Combined food preparation and serving workers, including fast food | 35-3021 | No formal credential | Short-term OTJ | 16.8% | 53,330 | $20,738 |
| **Nursing assistants** | **31-1014** | **Postsecondary non-degree award** | **None** | **11.5%** | **28,250** | **$29,640** |
| **Receptionists and information clerks** | **43-4171** | **HS/Equivalent** | **Short-term OTJ** | **9.1%** | **18,640** | **$35,984** |
| Laborers and freight, stock, and material movers, hand | 53-7062 | No formal credential | Short-term OTJ | 7.6% | 42,370 | $27,456 |
| Waiters and waitresses | 35-3031 | No formal credential | Short-term OTJ | 7.0% | 41,630 | $19,843 |
| Maids and housekeeping cleaners | 37-2012 | No formal credential | Short-term OTJ | 6.1% | 16,640 | $23,483 |
| Counter and rental clerks | 41-2021 | No formal credential | Short-term OTJ | 5.5% | 10,260 | $30,326 |
| Stock clerks and order fillers | 43-5081 | HS/Equivalent | Short-term OTJ | 5.0% | 38,150 | $23,962 |

Sources: Maryland Workforce Exchange, O*Net, RESI, U.S. Bureau of Labor Statistics

As shown above, the majority of positions related to cashiers require a limited amount of education and training, such as short-term on-the job and a high school diploma or less. One of the highlighted occupations, nursing assistants, does require a postsecondary non-degree award. This position also has a significantly higher median wage than cashiers ($29,738 for nursing assistants vs. $20,363 for cashiers), and a high projected growth rate of 11.5 percent. The other highlighted occupation, receptionists and information clerks, has significant projected growth of 9.1 percent and a median wage in 2017 of $35,984. Training opportunities for each of these professions are discussed in Section 17.5.2.

Figure 20 below details several occupations related to machinists, as well as entry requirements, growth projections, and 2017 median wages. Of the 2,820 machinists in the state, 626 are estimated to be potentially impacted by State climate change mitigation strategies.

**Figure 20: Related Occupations, Machinists**

| Occupation | Code | Minimum Education | On-the-Job Training | Projected Growth 2016-2026 | Maryland Employment | Median Maryland Wage |
|---|---|---|---|---|---|---|
| **Machinists** | **51-4041** | **HS/Equivalent** | **Long-term OTJ** | **2.0%** | 2,820 | $43,306 |
| **Computer numerically controlled machine tool programmers, metal and plastic** | **51-4012** | **Postsecondary non-degree award** | **Moderate-term OTJ** | **16.3%** | **270** | **$54,829** |
| Construction laborers | 47-2061 | No formal credential | Short-term OTJ | 12.4% | 19,640 | $32,822 |
| Maintenance and repair workers, general | 49-9071 | HS/Equivalent | Moderate-term OTJ | 7.9% | 21,590 | $41,101 |
| **Heavy and tractor-trailer truck drivers** | **53-3032** | **Postsecondary non-degree award** | **Short-term OTJ** | **5.8%** | **23,640** | **$45,594** |
| Computer-controlled machine tool operators, metal and plastic | 51-4011 | HS/Equivalent | Moderate-term OTJ | 1.1% | 1,060 | $43,306 |

Sources: Maryland Workforce Exchange, O*Net, RESI, U.S. Bureau of Labor Statistics

Educational requirements for occupations related to machinists have more variation, ranging from no formal education to postsecondary non-degree awards. Similarly, on-the-job training needed for these positions range from short-term to moderate-term. The first highlighted occupation, computer numerically controlled machine tool programmers, metal and plastic, typically requires a postsecondary non-degree award and moderate-term on-the-job training. This position has a substantially higher median wage compared to machinists ($43,306 for machinists vs. $54,829 for computer numerically controlled machine tool programmers), and projected growth of 16.3 percent. The second highlighted occupation, heavy and tractor-trailer truck drivers, also requires a postsecondary non-degree award but only short-term on-the-job training. This occupation has projected growth of 5.8 percent and a median wage in 2017 of $45,594. Training opportunities for each of these professions are discussed in Section 17.5.2.

Figure 21 below details several occupations related to first-line supervisors of production and operating workers. Of the 6,780 individuals employed in this occupation within the state, 257 are estimated to be potentially impacted by State climate change mitigation strategies.

**Figure 21: Related Occupations, First-Line Supervisors of Production and Operating Workers**[57]

| Occupation | Code | Minimum Education | On-the-Job Training | Projected Growth 2016-2026 | Maryland Employment | Median Maryland Wage |
|---|---|---|---|---|---|---|
| **First-line supervisors of production and operating workers** | **51-1011** | **HS/Equivalent** | **None** | **-0.30%** | **6,780** | **$59,946** |
| **First-line supervisors of construction trades and extraction workers** | **47-1011** | **HS/Equivalent** | **None** | **12.6%** | **15,520** | **$67,330** |
| General and operations managers | 11-1021 | Bachelor's degree | None | 9.1% | 47,360 | $119,434 |
| First-line supervisors of helpers, laborers, and material movers, hand | 53-1021 | HS/Equivalent | None | 8.5% | 3,720* | $47,278* |
| **First-line supervisors of mechanics, installers, and repairers** | **49-1011** | **HS/Equivalent** | **None** | **7.1%** | **10,180** | **$65,728** |
| First-line supervisors of transportation and material-moving machine and vehicle operators | 53-1031 | HS/Equivalent | None | 6.6% | 4,790* | $60,674* |
| Aircraft cargo handling supervisors | 53-1011 | HS/Equivalent | None | 5.9% | 190 | $42,827 |
| **Engineering technicians, except drafters, all other** | **17-3029** | **Associate degree** | **None** | **5.2%** | **1,730** | **$86,445** |

Sources: Maryland Workforce Exchange, O*Net, RESI, U.S. Bureau of Labor Statistics

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[57] Note that figures marked with an asterisk (*) represent employment and wage estimates from 2016, the most recent available at the state level.

For the occupations related to first-line supervisors of production and operating workers, all are estimated by the BLS to require no on-the-job training. This is likely because supervisors will have knowledge of the requirements for their supervisees due to prior experience. Educational requirements for these positions vary, however, ranging from a high school diploma to bachelor's degree. Two highlighted occupations, first-line supervisors of construction trades and extraction workers, and first-line supervisors of mechanics, installers, and repairers, typically require a high school diploma or equivalent and no on-the-job training. These positions both have higher median wages compared to first-line supervisors of production and operating workers ($67,330 and $65,728 vs. $59,946 for first-line supervisors of production and operating workers), and have projected growth rates of 12.6 percent and 7.1 percent, respectively. The third highlighted occupation, engineering technicians, except drafters, typically requires an associate degree yet has a substantially higher median wage of $86,445. Moderate growth is projected for engineering technicians at 5.2 percent. Training opportunities for each of these professions are discussed in Section 17.5.2.

Figure 22 outlines several occupations related to petroleum pump system operators, refinery operators, and gaugers. This occupation is estimated to have the greatest proportion of workers potentially impacted by State climate change mitigation strategies, with all 140 individuals in the position potentially affected.

**Figure 22: Related Occupations, Petroleum Pump System Operators, Refinery Operators, and Gaugers**

| Occupation | Code | Minimum Education | On-the-Job Training | Projected Growth 2016-2026 | Maryland Employment | Median Maryland Wage |
|---|---|---|---|---|---|---|
| **Petroleum pump system operators, refinery operators, and gaugers** | **51-8093** | **HS/Equivalent** | **Moderate-term OTJ** | **2.8%** | **140** | **$48,838** |
| Pile-driver operators | 47-2072 | HS/Equivalent | Moderate-term OTJ | 14.6% | 90 | $49,317 |
| **Operating engineers and other construction equipment operators** | **47-2073** | **HS/Equivalent** | **Moderate-term OTJ** | **12.3%** | **4,610** | **$47,070** |
| Transportation vehicle, equipment and systems inspectors, except aviation | 53-6051 | HS/Equivalent | Moderate-term OTJ | 5.9% | 290 | $53,102 |
| **Heavy and tractor-trailer truck drivers** | **53-3032** | **Postsecondary non-degree award** | **Short-term OTJ** | **5.8%** | **23,640** | **$45,594** |
| **Engineering technicians, except drafters, all other** | **17-3029** | **Associate degree** | **None** | **5.2%** | **1,730** | **$86,445** |
| Mechanical engineering technicians | 17-3027 | Associate degree | None | 5.0% | 670 | $57,366 |
| **Stationary engineers and boiler operators** | **51-8021** | **HS/Equivalent** | **Long-term OTJ** | **5.0%** | **1,160** | **$56,410** |
| Control and valve installers and repairers, except mechanical door | 49-9012 | HS/Equivalent | Moderate-term OTJ | 4.9% | 1,280 | $56,035 |

Sources: Maryland Workforce Exchange, O*Net, RESI, U.S. Bureau of Labor Statistics

Occupations related to petroleum pump system operators, refinery operators, and gaugers show significant variation in estimated training and educational requirements for entry. The first highlighted occupation, Operating engineers and other construction equipment operators, generally requires a high school diploma or equivalent for entry and moderate-term on-the-job training. This profession has the highest projected growth rate of the three highlighted positions, at 12.3 percent, and a median wage comparable to that of petroleum pump system operators, refinery operators, and gaugers. Heavy and tractor-trailer truck drivers is again highlighted, requiring a postsecondary non-degree award and short-term on-the-job training. This occupation had a slightly lower median wage than petroleum pump system operators in 2017 ($45,594 and $48,838, respectively), though also has substantial employment opportunities in the state with 23,640 workers in 2017. Engineering technicians, except drafters are also highlighted again, which typically requires an associate degree. This position does offer a substantially higher median wage compared to petroleum pump system operators. Moderate growth is projected for both heavy and tractor-trailer truck drivers and engineering technicians at 5.8 percent and 5.2 percent, respectively. The final highlighted occupation, stationary engineers and boiler operators, most often requires a high school diploma only but long-term on-the-job training. This occupation has projected growth of 4.8 percent and had a median wage of $56,410 in 2017. Training opportunities for each of these highlighted professions are discussed in Section 17.5.2.

Positions related to the final threatened occupation, inspectors, testers, sorters, samplers, and weighers, are shown in Figure 23. Of the 4,060 individuals employed in this profession in Maryland, 168 workers are estimated to potentially be impacted by State climate change mitigation strategies.

**Figure 23: Related Occupations, Inspectors, Testers, Sorters, Samplers, and Weighers**

| Occupation | Code | Minimum Education | On-the-Job Training | Projected Growth 2016-2026 | Maryland Employment | Median Maryland Wage |
|---|---|---|---|---|---|---|
| **Inspectors, Testers, Sorters, Samplers, and Weighers** | **51-9061** | **HS/Equivalent** | **Moderate-term OTJ training** | **-10.7%** | **4,060** | **$46,363** |
| **Life, physical, and social science technicians, all other** | **19-4099** | **Associate degree** | **None** | **9.7%** | **3,150** | **$55,598** |
| Aviation/Transportation Inspectors | 53-6051 | HS/Equivalent | Moderate-term OTJ training | 5.9% | 290 | $53,102 |
| Welders, cutters, solderers, and brazers | 51-4121 | HS/Equivalent | Moderate-term OTJ training | 5.6% | 2,080 | $45,885 |
| **Stationary engineers and boiler operators** | **51-8021** | **HS/Equivalent** | **Long-term OTJ training** | **4.8%** | **1,160** | **$56,410** |

Sources: Maryland Workforce Exchange, O*Net, RESI, U.S. Bureau of Labor Statistics

For most of the occupations related to inspectors, testers, sorters, samplers, and weighers, a high school diploma plus moderate-term to long-term on-the-job training is required for entry. However, for the first highlighted occupation, life, physical, and social science technicians (all other), an associate degree is typically needed. Jobs in this field include quality control analysts, precision agriculture technicians, and remote sensing technicians.[58] These occupations have strong projected growth of 9.7 percent and a median annual wage of $55,598, higher than that of inspectors, testers, sorters, samplers, and weighers ($46,363). The second highlighted occupation, stationary engineers and boiler operators, requires a high school diploma only but long-term on-the-job training. This occupation has projected growth of 4.8 percent and had a median wage of $56,410 in 2017. Training opportunities for each of these professions are discussed in Section 17.5.2.

While the threatened occupations discussed in this subsection represent a cross section of those likely to be affected by the State's climate change mitigation strategies, they are not an exhaustive list. Rather, identifying these threatened occupations and related occupations into which workers could transition show examples of how displaced individuals could transfer skills and knowledge into new occupations with a more positive outlook. Often, these transitions could be facilitated with very feasible training, such as obtaining a postsecondary non-degree award or associate degree, and result in higher wages.

The following subsection will detail specific training and apprenticeship programs within the state for each of the related occupations that have been highlighted.

### 17.5.2 Job Training Programs

The following subsection outlines training requirements and opportunities in Maryland for the highlighted occupations in Section 17.5.4. These career preparation opportunities include apprenticeships, training programs, and formal degree programs. While other pathways to these professions exist, this section offers potential entry strategies for those seeking to transition from fossil-fuel-dependent jobs.

#### Nursing Assistants (31-1014)

Becoming a nursing assistant typically requires a postsecondary nondegree award.[59] To obtain this position in Maryland, the State requires a minimum of 100 training hours and 40 clinical hours for certified nursing assistant (CNA) certification.[60] In general, most CNA programs take approximately four to twelve weeks to complete.[61] Courses typically cover a broad range of patient care including taking vital signs, personal care, nutrition requirements, promotion of exercise and activity, identification of respiratory issues, basic diabetes management, and

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[58] "19-4099," My Next Move, accessed December 27, 2018, https://www.mynextmove.org/find/search?s=19-4099.
[59] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.
[60] "Nursing Assistant Training Requirements by State," PHI, accessed December 27, 2018, https://phinational.org/advocacy/nurse-aide-training-requirements-state-2016/.
[61] "Here's What You'll Study in a CNA Degree Program," All Nursing Schools, accessed February 7, 2019, https://www.allnursingschools.com/certified-nursing-assistant/degrees/.

caring for individuals with cognitive impairment.[62] Over 100 certified CNA training programs are offered in colleges, nursing homes, and freestanding institutions in the state.[63] These include community colleges located in 16 Maryland counties, serving a broad area within Maryland.[64]

Advertised skills for individuals in this profession include customer service, providing personal care, flexibility, and recording vital signs.[65] The most-common certifications requested in job postings on Maryland Workforce Exchange (MWE) for nursing assistants include Certification in Cardiopulmonary Resuscitation (CPR), CNA, Basic Life Support (CPR), Emergency Medical Technician (EMT), and Advanced Cardiac Life Support Certification (ACLS). There are also a number of certifications beyond a CNA certification. Some of these require a CNA certification as a base, but others, such as the Certified Patient Care Technician certificate, do not have this prerequisite. These additional certifications include Certified Wound Care Associate, National Nurse Aide Assessment Program, Certified Hospice and Palliative Nursing Assistant, and Certified Alzheimer Caregiver.[66]

In November of 2018, the Maryland counties with the highest numbers of job postings for nursing assistants were Baltimore City (107), Anne Arundel County (100), Montgomery County (84), Howard County (53), Baltimore County (52), and Prince George's County (52).[67]

### Receptionists and Information Clerks (43-4171)

Entry into the profession of receptionists and information clerks usually requires short-term on-the-job (OTJ) training and possessing a high school diploma or equivalent.[68] To further education, an associate degree in administrative assistant or secretarial science may be obtained.[69] These degree programs typically require one to two years of academic coursework.[70] Maryland has a wide range of degree programs that offer specialty options dependent on occupational field. Program curriculum can be field specific in areas such as healthcare, legal and business, or general for positions in corporate or government offices.[71] These options include but are not limited to software application specialist, executive

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[62] "Online CNA Classes: What You'll Need to Know," All Nursing Schools, accessed February 7, 2019, https://www.allnursingschools.com/certified-nursing-assistant/cna-classes/.

[63] Maryland Board of Nursing, "2018 Approved CNA Training Programs," 1-5, accessed December 27, 2018, https://mbon.maryland.gov/Documents/approved-na-training-programs.pdf.

[64] Maryland Board of Nursing, "2018 Approved CNA Training Programs," 2.

[65] "Occupational Summary," Maryland Workforce Exchange.

[66] "Find Training," CareerOneStop, accessed January 23, 2018, https://www.careeronestop.org/FindTraining/find-training.aspx.

[67] "Job Search," Maryland Workforce Exchange, accessed December 20, 2018, https://mwejobs.maryland.gov/jobbanks/default.asp?p=0&session=jobsearch&geo= .

[68] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.

[69] "Local Training Finder – Secretaries and Administrative Assistants," My Next Move, accessed December 27, 2018, https://www.mynextmove.org/profile/ext/training/43-6014.00?s=MD.

[70] Ibid.

[71] "Administrative Professional – A.A.S. Degree (Career), Howard Community College, accessed February 8, 2019, http://howardcc.smartcatalogiq.com/2018-2019/Catalog/Areas-of-Study-By-Academic-Division/Business-and-Computer-Systems-Division-Areas-of-Study/Administrative-Professional-AAS-Degree-Career.

administrative assistant, medical office administration, and legal office administration.[72] Programs may also be located at a local community college or university.[73]

Receptionists must possess strong customer service and time management skills.[74] In addition, knowledge of Microsoft Office programs are typically required.[75] Skills needed for this profession can be built by local courses in office administration and online training for office software.[76] Software skills learned are also dependent upon occupation field. Jobs in the medical field may require skills in medical coding software while jobs in business may require bookkeeping software skills.[77] The Maryland counties with the highest numbers of job postings for receptionist and information clerks in November 2018 were Montgomery County (70), Prince George's County (48) and Anne Arundel County (38).[78]

**Computer Numerically Controlled Machine Tool Programmers, Metal and Plastic (51-4012)**
Positions as a computer numerically controlled machine tool programmers of metal and plastic typically require a postsecondary non-degree award and moderate OTJ training.[79] Training for this profession can generally be completed in under two years.[80]

The Community College of Baltimore County offers a short-term training program that combines both manual and computer numerical control technology.[81] This program is certified through the National Institute of Metalworking skills (NIMS) and requires six months of educational training.[82] The Community College of Baltimore County also offers two other computer numerical control (CNC) certifications that differ in length and requirements. The CNC machinist certification prepares students for roles as a machine operator, machinist and/or a set-up person and requires 35 credit hours.[83] The CNC programming certificate is the shortest

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[72] "Office Administration (Executive Administrative Assistant Option)," Community College of Baltimore County, accessed February 8, 2019, http://catalog.ccbcmd.edu/preview_program.php?catoid=16&poid=7859&returnto=984.
[73] "Local Training Finder – Secretaries and Administrative Assistants," My Next Move.
[74] "Occupational Summary," Maryland Workforce Exchange.
[75] Ibid.
[76] "Become a Receptionist: Educations and Career Roadmap," Study.com, accessed December 27, 2018, https://study.com/become_a_receptionist.html.
[77] "Summary Report for: 43-4171.00," O*Net Online, accessed December 27, 2018, https://www.onetonline.org/link/summary/43-4171.00.
[78] "Job Search," Maryland Workforce Exchange.
[79] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.
[80] "Local Training Finder – Computer Numerically Controlled Machine Tool Programmers, Metal and Plastic," My Next Move, accessed December 27, 2018, https://www.mynextmove.org/profile/ext/training/51-4012.00?s=MD&g=Go.
[81] "CNC Machine Tool, Continuing Education Certificate," Community College of Baltimore County, accessed December 27, 2018, http://www.ccbcmd.edu/Programs-and-Courses-Finder/ConED-Program/cnc-machine-tool.
[82] Ibid.
[83] "CNC Machinist Certificate, Credit Certificate," Community College of Baltimore County, accessed December 27, 2018, http://www.ccbcmd.edu/Programs-and-Courses-Finder/program/cnc-machinist-certificate.

in length as it only requires 24 credit hours.[84] This certification is designed to prepare students for employment as a CNC programmer.[85]

Essential skills for this position include programming, operation monitoring, and complex problem solving.[86] Software programs used by computer numerically controlled machine tool programmers include computer-aided design (CAD), computer-aided manufacturing (CAM), object- or component-oriented software, and Microsoft Excel.[87]

**Heavy and Tractor Trailer Truck Drivers (53-3032)**

Becoming a heavy and tractor-trailer truck driver typically requires a postsecondary nondegree award and short-term OTJ training.[88] Potential truck drivers may attend a professional truck driving school to gain experience operating large vehicles, learn about federal regulations and laws, and earn the required commercial driver's license (CDL).[89] Additionally, drivers can add endorsements to their CDLs, such as the hazardous materials endorsement, which will enable them to drive a specialized type of vehicle.[90]

In Maryland, CDL programs provide instruction for both the written exam and driving training, and typically take between six to eight weeks for completion.[91] Currently, there are 16 programs in the state with an average tuition of $4,966, though individuals seeking this training may be eligible for federal financial aid.[92] Local schools offering this training include Anne Arundel Community College, College of Southern Maryland, Hagerstown Community College, All-State Career, and North American Trade Schools.[93] Classes are often held on both weekdays and weekends, enabling more flexible training schedules.[94,95,96] Some programs, such as the one offered through Hagerstown Community College, provide students with both job

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[84] "CNC Machinist Certificate, Credit Certificate," Community College of Baltimore County.

[85] Ibid.

[86] "Summary Report for 51-4012.00," O*Net Online, accessed January 4, 2019, https://www.onetonline.org/link/summary/51-4012.00.

[87] "Summary Report for 51-4012.00," O*Net Online.

[88] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.

[89] "Occupational Outlook Handbook: Heavy and Tractor-trailer Truck Drivers," U.S. Bureau of Labor Statistics, last modified April 13, 2018, accessed February 7, 2019, https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm.

[90] "Occupational Outlook Handbook: Heavy and Tractor-trailer Truck Drivers," U.S. Bureau of Labor Statistics.

[91] "Truck Driving Schools in Maryland," All Trucking.com, accessed December 27, 2018, http://www.alltrucking.com/schools/maryland/truck-driving/.

[92] Ibid.

[93] Ibid. .

[94] Hagerstown Community College, "Commercial Vehicle Transportation: Truck Driver Training at HCC," 1-2, accessed February 7, 2019, http://www.hagerstowncc.edu/sites/default/files/documents/13619%20B%20Lyle%20CVT%20brochure%20UPDATE.PDF.

[95] "Truck Driving: Commercial Driver's License," Anne Arundel Community College, accessed February 8, 2019, https://www.aacc.edu/programs-and-courses/job-training/truck-driving/.

[96] "Commercial Driver's License (CDL) Class A," College of Southern Maryland, accessed February 8, 2019, https://www.csmd.edu/programs-courses/non-credit/career-development/transportation/CDL-Class-A.

placement assistance through local and national employers.[97]

Heavy and tractor trailer truck drivers must be in good health.[98] Federal regulations can prohibit those with medical conditions such as high blood pressure or epilepsy from becoming truck drivers.[99] Potential truck drivers will also need to pass vision and hearing tests.[100] Additionally, CDL drivers must have a clean driving record and be willing to take random drug tests.[101]

In Maryland, the number of heavy and tractor-trailer truck driver jobs is expected to grow with an average of 2,440 annual job openings.[102] In November of 2018, the Maryland counties with the highest numbers of job postings for heavy and tractor-trailer truck drivers were Baltimore City (188), Howard County (137), Prince George's County (108), Baltimore County (101), and Anne Arundel County (91).[103]

**First-line Supervisors of Construction Trades and Extraction Workers (47-1011)**
Jobs for first-line supervisors of construction trades and extraction workers most-often require a high school diploma or equivalent.[104] Many positions also require training from a vocational school, related work experience, or an associate degree.[105] Training is offered in building and construction site management at multiple Maryland colleges, including Community College of Baltimore County, Prince George's Community College, and Frederick Community College.[106] Community College of Baltimore offer programs of varying lengths and required credit hours, such as the Construction Project Controls Certificate (12 credits), Construction Management Certificate (39 credits), First-Line Supervisor Continuing Education Certificate (six months), and an associate of applied science in construction management (60 credits). [107,108,109,110]

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[97] Hagerstown Community College, "Commercial Vehicle Transportation: Truck Driver Training at HCC," 1-2.
[98] "Occupational Outlook Handbook: Heavy and Tractor-trailer Truck Drivers," U.S. Bureau of Labor Statistics, last modified April 13, 2018, accessed February 7, 2019, https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm.
[99] "Occupational Outlook Handbook: Heavy and Tractor-trailer Truck Drivers," U.S. Bureau of Labor Statistics.
[100] Ibid.
[101] Ibid.
[102] "Long Term Occupational Projections (2016-2026): Maryland, Heavy and Tractor-Trailer Truck Drivers," Projections Central - State Occupational Projections, accessed February 7, 2019, http://www.projectionscentral.com/Projections/LongTerm.
[103] "Job Search," Maryland Workforce Exchange.
[104] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.
[105] "Summary Report for: 47-1011.00," My Next Move, accessed February 7, 2019, https://www.mynextmove.org/profile/ext/online/47-1011.00.
[106] "Local Training Finder – First-Line Supervisors of Construction Trades and Extraction Workers," My Next Move, accessed December 27, 2018, https://www.mynextmove.org/profile/ext/training/47-1011.00?s=MD&g=Go.
[107] "Construction Project Controls Certificate, Credit Certificate," Community College of Baltimore County, accessed February 7, 2019, http://www.ccbcmd.edu/Programs-and-Courses-Finder/program/construction-project-controls-certificate.
[108] "Construction Management Certificate, Credit Certificate," Community College of Baltimore County, accessed February 7, 2019, http://www.ccbcmd.edu/Programs-and-Courses-Finder/Program/construction-management-certificate.

Advertised job skills for this profession include customer service, problem solving, and the ability to stand for long periods of time.[111] Proficiency in project management software, data base user interface and query software, and calendar and scheduling software may be required in this role.[112] Specific programs cited for this profession include Microsoft Project and Oracle Primavera Enterprise Project Portfolio Management.[113] Job postings were most plentiful in November 2018 in Baltimore City (11), Prince George's County (7), Allegany County (4), Howard County (4), and Montgomery County (4).[114]

**First-line Supervisors of Mechanics, Installers, and Repairers (49-1011)**

To become a first-line supervisor of mechanics, installers, and repairers, individuals typically need a high school diploma or equivalent.[115] According to MWE, employees also typically need about two years of training, consisting of both on the job and informal training.[116,117] Operations management and supervision programs are offered by Johns Hopkins University, Morgan State University, and the University of Maryland-University College.[118] These programs can be completed in less than one year.[119] Other job titles associated with this occupation include facilities manager, facility maintenance supervisor, and maintenance manager.[120] The International Facility Management Association (IFMA) is an association of facility management professionals which offers a number of facility-related credential and professional

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[109] "First-Line Supervisor, Continuing Education Certificate," Community College of Baltimore County, accessed February 7, 2019, http://www.ccbcmd.edu/Programs-and-Courses-Finder/program/first-line-supervisor.

[110] "Construction Management, Associate of Applied Science," Community College of Baltimore County, accessed February 7, 2019, http://www.ccbcmd.edu/Programs-and-Courses-Finder/Program/construction-management.

[111] "First-Line Supervisors of Construction Trades and Extraction Workers," Maryland Workforce Exchange, accessed February 7, 2019, https://mwejobs.maryland.gov/vosnet/lmi/profiles/profileSummary.aspx?session=occdetail&valueName=occupation.

[112] "First-Line Supervisors of Construction Trades & Extraction Workers," My Next Move, accessed February 7, 2019, https://www.mynextmove.org/profile/summary/47-1011.00.

[113] Ibid.

[114] "Job Search," Maryland Workforce Exchange.

[115] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.

[116] "First-Line Supervisors of Mechanics, Installers, and Repairers: Description," Maryland Workforce Exchange, accessed February 7, 2019, https://mwejobs.maryland.gov/vosnet/lmi/profiles/profileDetails.aspx?session=occdetail&valueName=occupation&section=description.

[117] This OTJ varies from the minimum requirements provided by the U.S. BLS, which indicates that no OTJ training is required.

[118] "Local Training Finder: First-Line Supervisors of Mechanics, Installers, and Repairers, Maryland," CareerOneStop, accessed on February 8, 2019, https://www.careeronestop.org/Credentials/Toolkit/find-local-training.aspx?keyword=First-Line%20Supervisors%20of%20Mechanics%2C%20Installers%2C%20and%20Repairers&location=maryland&ajax=occ&post=y.

[119] "Local Training Finder: First-Line Supervisors of Mechanics, Installers, and Repairers, Maryland," CareerOneStop.

[120] "Summary Report for: 49-1011.00," O*Net Online, accessed February 8, 2019, https://www.onetonline.org/link/summary/49-1011.00.

qualifications, and may be useful in obtaining training.[121,122] In Maryland, Prince George's Community College and Community College of Baltimore County have partnered with the Chesapeake chapter of IFMA to offer the Facilities Management Professional certification program.[123,124] At Community College of Baltimore, it is a four-month program with day classes that are typically held on Fridays and Saturdays.[125]

These positions may utilize project management software, data base user interface and query software, and enterprise resource planning software.[126] Advertised job skills include (but are not limited to) customer service, welding, and preventative, general, building, and grounds maintenance.[127]

As recently as November 2018, Baltimore City (31), Prince George's County (21), Montgomery County (19), Howard County (14), and Baltimore County (13) were among the leaders in the most positions offered.[128]

### Engineering Technicians, Except Drafters, All Other (17-3029)

Those seeking positions as engineering technicians, except drafters, would typically need to acquire an associate degree.[129] Associate degree programs in engineering are offered through multiple Maryland community colleges including Carroll Community College, College of Southern Maryland, Community College of Baltimore County, Howard Community College, and Prince George's Community College.[130,131,132] Along with others, Howard Community College

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[121] "Empowering Facility Professionals Worldwide," International Facility Management Association, accessed February 8, 2019, http://www.ifma.org/.

[122] "Credentials and Continuing Education," International Facility Management Association, accessed February 7, 2019, https://www.ifma.org/professional-development/credentials.

[123] "Facility Management Credential Programs (FMP)," Prince George's Community College, accessed February 7, 2019, http://www.pgcc.edu/Programs_and_Courses/Noncredit/Continuing_Education_Program_Detail.aspx?id=6442462730.

[124] "Facility Management Professional, Continuing Education Certificate," Community College of Baltimore County, accessed February 7, 2019, http://www.ccbcmd.edu/Programs-and-Courses-Finder/ConED-Program/facility-management-professional.

[125] "Facility Management Professional, Continuing Education Certificate," Community College of Baltimore County.

[126] "First-Line Supervisors of Mechanics, Installers, & Repairers," Federal Student Aid, accessed February 7, 2019, https://studentaid.ed.gov/sa/prepare-for-college/students/career-search/profile/summary/49-1011.00.

[127] "First-Line Supervisors of Mechanics, Installers, and Repairers: Skills," Maryland Workforce Exchange, accessed February 7, 2019, https://mwejobs.maryland.gov/vosnet/lmi/profiles/profileDetails.aspx?session=occdetail&valueName=occupation&section=skillstools.

[128] "Job Search," Maryland Workforce Exchange.

[129] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.

[130] "Electronic Engineering Technology Courses in Maryland," Study.com, accessed December 27, 2018, https://study.com/electronic_engineering_technology_courses_in_maryland.html.

[131] "Engineering Technology," Community College of Baltimore County, accessed December 27, 2018, http://www.ccbcmd.edu/Programs-and-Courses/Schools-and-Academic-Departments/School-of-Technology-Art-and-Design/Engineering-Department/Engineering-Technology.aspx.

offers engineering degrees with various specializations, such as computer, electrical, and biomedical.[133] Additionally, programs in energy management and systems technology; hydraulics and fluid power technology; and heating, ventilation, air conditioning, and refrigeration engineering offer technician career preparation and are available at Maryland colleges.[134] Vocational and technical schools also offer programs for engineering technicians, such as the Lincoln College of Technology in Columbia, MD.[135,136] A certification through the National Institute for Certification in Engineering Technologies, though not required, may make prospective employees more competitive.[137]

It may be important to learn C++ programming, either through coursework or a certificate program.[138] Since many employers look for candidates with previous work experience, when starting off in the field individuals often pursue entry-level jobs.[139] If a candidate has difficulty obtaining one, he or she may consider a job involving electrical equipment, programming, or power systems to gain the experience they need to break into the field.[140] Counties hiring the most engineering technicians in late 2018 were St. Mary's County (15), Montgomery County (3), Harford County (2), and Washington County (2).[141]

### Operating Engineers and Other Construction Equipment Operators (47-2073)

Entry into the profession of operating engineers and other construction equipment operators typically requires a high school diploma or equivalent and moderate-term OTJ training.[142] OTJ training can be facilitated through apprenticeships, which typically take several years to complete.[143] Many apprenticeship programs take four years to complete and include 6,000 hours of on the job training.[144] Local apprenticeship programs include Operating Engineers

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[132] "Engineering Associate of Science," Prince George's Community College, accessed February 8, 2019, https://www.pgcc.edu/Programs_and_Courses/Program_Detail.aspx?programID=6442462394.

[133] "Search Results: Engineering," Howard Community College, accessed February 8, 2019, https://www.howardcc.edu/search-results.html?q=engineering.

[134] "Local Training Finder: 17-3029.00, MD," CareerOneStop, accessed February 8, 2019, https://www.careeronestop.org/Credentials/Toolkit/find-local-training.aspx?keyword=17-3029.00&persist=true&location=MD&ajax=0&post=y.

[135] Beatrice Harrison, "How To Become an Engineering Technician," College Mouse, August 4, 2014, accessed February 8, 2019, https://www.collegemouse.com/how-to-become-an-engineering-technician/.

[136] "Local Training Finder: 17-3029.00, MD," CareerOneStop.

[137] Dawn Rosenberg Mckay, "Engineering Technician Career," The Balance Careers, updated February 6, 2019, accessed February 8, 2019, https://www.thebalancecareers.com/engineering-technician-526012.

[138] "How To Become an Electronics Engineering Technician: Career Roadmap," Study.com, accessed February 8, 2019,
https://study.com/articles/How_to_Become_an_Electronics_Engineering_Technician_Career_Roadmap.html.

[139] "How To Become an Electronics Engineering Technician: Career Roadmap," Study.com.

[140] Ibid.

[141] "Job Search," Maryland Workforce Exchange.

[142] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.

[143] "Be an Operating Engineer: Education and Career Roadmap," Study.com, accessed December 27, 2018, `https://study.com/be_an_operating_engineer.html.

[144] "Operating Engineer Training Programs and Requirements," Study.com, accessed February 8, 2019, https://study.com/operating_engineer_training.html.

Local 37 Apprentice Training School and International Union of Operating Engineers Local 99.[145,146] The Operating Engineers Local 37 Apprenticeship is approximately a two-year program, comprised of 40-hour work weeks for a total length of 4,500 hours.[147] This apprenticeship is based in Sparrows Point, requires a high school diploma or GED, and offers a starting wage of $14.38 per hour.[148,149] The apprenticeship offered by Miller & Long lasts 8,000 hours, also requires a high school diploma or GED, and has a starting wage of $24.86 an hour.[150]

The International Union of Operating Engineers offers a four-year apprenticeship program consisting of 8,000 hours of OTJ experience and 576 classroom hours.[151] The Maryland Apprenticeship and Training Program (MATP) also lists operating engineers on their website, and directs applicants to available apprenticeship opportunities.[152] For individuals seeking jobs with certain skills such as operation of heavy construction equipment, certifications are offered.[153] For example, numerous crane certifications are offered through the National Commission for the Certification of Crane Operators.[154,155]

License requirements vary by state, but may be required to operate large machinery such as cranes and bulldozers.[156] Knowledge of Microsoft Office is frequently mentioned in job postings.[157] Facilities management software may also be necessary.[158]

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[145] "Operating Engineer Apprenticeship," Train Baltimore, accessed December 27, 2018, http://trainbaltimore.org/Training/Program-Details.aspx?pid=89&pn=0.

[146] "Welcome," International Union of Operating Engineers Local 99, accessed December 27, 2018, http://www.iuoelocal99.org/.

[147] "Maryland Apprenticeship Locator: Operating Engineers: Operating Engineer Details," Maryland Department of Labor, Licensing and Regulation, accessed February 8, 2019, http://www.dllr.state.md.us/Apprenticeship/Details.aspx?user=A&access=1&results=1&details=1&sessionGUID=94cd4cd4-cda2-405e-8b80-687c8f61146a.

[148] "Maryland Apprenticeship Locator: Operating Engineers: Operating Engineer Details," Maryland Department of Labor, Licensing and Regulation.

[149] "Operating Engineer Apprenticeship," Train Baltimore.

[150] "Maryland Apprenticeship Locator: Miller & Long Concrete Construction: Operating Engineer Details," Maryland Department of Labor, Licensing and Regulation, accessed February 8, 2019, http://www.dllr.state.md.us/Apprenticeship/Details.aspx?user=A&access=1&results=1&details=1&sessionGUID=94cd4cd4-cda2-405e-8b80-687c8f61146a.

[151] "Our Apprenticeship Program," International Union of Operating Engineers, accessed February 8, 2019, http://www.iuoelocal99.org/apprenticeships.htm#one.

[152] "Explore Registered Occupations - Maryland Apprenticeship and Training Program (MATP)," Maryland Department of Labor, Licensing, and Regulation, accessed December 27, 2018, https://www.dllr.state.md.us/employment/approcc/approcc.shtml.

[153] "Be an Operating Engineer: Education and Career Roadmap," Study.com, accessed December 27, 2018, https://study.com/be_an_operating_engineer.html.

[154] "Be an Operating Engineer: Education and Career Roadmap," Study.com.

[155] "News Headlines," National Commission for the Certification of Crane Operators (NCCCO), accessed February 8, 2019, http://nccco.org/.

[156] "Be an Operating Engineer: Education and Career Roadmap," Study.com.

[157] "Summary Report for: 47-2073.00," O*Net Online, accessed February 8, 2019, https://www.onetonline.org/link/summary/47-2073.00.

The best Maryland counties for operating engineers and other construction equipment operators opportunities are Prince George's County, which posted 19 job openings in November 2018, followed by eight in Baltimore City and seven in Anne Arundel County.[159]

**Life, Physical, and Social Science Technicians, All Other (19-4099)**

Jobs falling under life, physical, and social science technicians, all other, most often require obtaining an associate degree.[160] As noted in the previous subsection, occupations in this field include quality control analysts, precision agriculture technicians, and remote sensing technicians.[161] Several Maryland community colleges offer related associate degrees, including Baltimore City Community College, Community College of Baltimore County, and Harford Community College.[162]

Life, physical, and social science technicians positions usually require knowledge of analytical or scientific software.[163,164,165] Specifically, quality control analyst positions may use additional program testing software and data base user interface and query software such as Selenium and Structured Query Language (SQL).[166] Precision agriculture technicians and remote sensing technicians may also need knowledge of map creation software such as ESRI ArcGIS software.[167,168]

The counties offering the most job postings in November of 2018 were Montgomery County (116), Frederick County (37), Howard County (31), and Baltimore City (13).[169]

**Stationary Engineers and Boiler Operators (51-8021)**

To become a stationary engineers and boiler operator, individuals typically need a high school diploma or equivalent combined with long-term OTJ training.[170] Training for becoming a stationary engineer or boiler operator is often completed through an apprenticeship

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[158] "Operating Engineers & Other Construction Equipment Operators," My Next Move, accessed February 8, 2019, https://www.mynextmove.org/profile/summary/47-2073.00.

[159] "Job Search," Maryland Workforce Exchange.

[160] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.

[161] "19-4099," My Next Move, accessed December 27, 2018, https://www.mynextmove.org/find/search?s=19-4099.

[162] "Local Training Finder – Life, Physical, and Social Science Technicians, All Other," My Next Move, accessed December 27, 2018, https://www.mynextmove.org.

[163] "Quality Control Analysts," My Next Move, accessed February 8, 2019, https://www.mynextmove.org/profile/summary/19-4099.01.

[164] "Precision Agriculture Technicians," My Next Move, accessed February 8, 2019, https://www.mynextmove.org/profile/summary/19-4099.02.

[165] "Remote Sensing Technicians," My Next Move, accessed February 8, 2019, https://www.mynextmove.org/profile/summary/19-4099.03.

[166] "Quality Control Analysts," My Next Move.

[167] "Precision Agriculture Technicians," My Next Move.

[168] "Remote Sensing Technicians," My Next Move.

[169] "Job Search," Maryland Workforce Exchange.

[170] "Education and Training Assignments by Detailed Occupation," U.S. Bureau of Labor Statistics.

program.[171] These apprenticeship programs are typically completed over a four-year period though work with experienced operators, as well as supplemental classroom instruction.[172] Certification preparation courses are offered through Maryland community colleges including Anne Arundel Community College, College of Southern Maryland, Community College of Baltimore County, and Prince George's Community College.[173,174,175,176]

At Anne Arundel Community College (AACC), a Maryland Stationary Engineer Certification consists of two courses and in addition to earning an AACC certificate, it will prepare students for the Maryland Board of Stationary Engineers licensing exam.[177] Courses include training in boiler construction, care, and operations; hydronic heating systems; refrigeration and HVAC systems, and basic electrical knowledge.[178]

Commonly cited skills for this occupation include preventative maintenance, customer service, building maintenance, maintenance mechanics, and problem solving.[179] Use of technologies such as facilities management software or database user interface and query software may also be required in this role.[180] Baltimore City had the most job openings posted for stationary engineers and boiler operators in November of 2018 (11), followed by Harford and Prince George's County (three each).[181] Anne Arundel County, Dorchester County, Frederick County, Howard County, and Montgomery County also each had two positions listed during this time.[182]

### 17.5.3 Alternative Strategies

While this report has largely focused on retraining efforts through matching of education and skills between occupations through occupational crosswalks, alternative strategies have been pursued in other areas. A significant number of these efforts have focused on teaching former

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[171] "Stationary Engineer Training," International Union of Operating Engineers, accessed December 27, 2018, https://www.iuoe.org/training/stationary-engineer-training.
[172] Ibid.
[173] "Maryland Stationary Engineer Certification," Anne Arundel Community College, accessed December 27, 2018, https://www.aacc.edu/programs-and-courses/job-training/stationary-engineer/.
[174] "Stationary Engineer," College of Southern Maryland, accessed December 27, 2018, https://www.csmd.edu/programs-courses/non-credit/career-development/construction-and-skilled-trades/Stationary-Engineer.
[175] "VOC 042 – Preparation for Maryland Stationary Engineer's Certificate," Community College of Baltimore County, accessed December 27, 2018, https://www.ccbcmd.edu/Migrate/ceed/syllabus/voc.html.
[176] "OCU-359-Stationary Engineering I," Prince George's Community College, accessed December 27, 2018, http://www.pgcc.edu/Programs_and_Courses/course_detail.aspx?courseID=6442455530&programID=6442462358.
[177] "Maryland Stationary Engineer Certification," Anne Arundel Community College, accessed February 8, 2019, https://www.aacc.edu/programs-and-courses/job-training/stationary-engineer/.
[178] Ibid.
[179] "Occupational Summary," Maryland Workforce Exchange.
[180] "Summary Report for 51-8021.00," O*Net Online, accessed February 8, 2019, https://www.onetonline.org/link/summary/51-8021.00.
[181] "Job Search," Maryland Workforce Exchange.
[182] "Job Search," Maryland Workforce Exchange.

fossil-fuel-reliant workers to write code, for applications including software and web design, in order to gain employment in the technology field.[183] These programs are more prominent in states including West Virginia and Kentucky, which have historically had substantial coal mining industries.[184,185] Although this transition may initially seem incongruent with mining skillsets, some individuals leading transition efforts have stated that technologies used in mining, such as robotics, facilitate entry into the coding field.[186]

In eastern Kentucky, a startup company called Bit Source offered 22-week training in coding to laid-off coal miners.[187] Although the company hired only a fraction of the applicants for the training positions, local leaders have stressed the importance of small companies in diversifying the area's economic landscape.[188] One significant challenge the project has encountered is internet infrastructure, though there is a project currently underway to increase broadband availability in the state.[189] Internet speeds in the area lower than many other regions, with a 2017 ranking placing the state 47th in the nation for broadband speed and capacity.[190]

The Louisville, Kentucky-based startup Interapt provides another example of an organization that was created to increase economic activity through 'insourcing' of technology jobs.[191] The company initially trained 35 of 800 applicants to program completion, with plans to expand training over the next two sessions to 90 and over 150 individuals, respectively.[192] Interapt received funding from the Appalachia Regional Commission to launch the training program, which also provides trainees with a $400 weekly stipend. [193] Additionally, the company's founder currently investing $4 million in a local warehouse renovation to house the organization.[194]

While none of the programs listed above are sufficient to completely offset the impacts from fossil-fuel industry employment losses, they do offer examples of alternative strategies to

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[183] ABC Radio, "Coal Miners in West Virginia Learn HTML Coding as Second Career," *WTOP*, May 7, 2018, accessed November 15, 2018, https://wtop.com/national/2018/05/coal-miners-being-taught-html-coding-as-a-second-career/.

[184] ABC Radio, "Coal Miners in West Virginia Learn HTML Coding as Second Career."

[185] Sheryl Gay Stolberg, "Beyond Coal: Imagining Appalachia's Future," *New York Times*, August 17, 2016, accessed November 16, 2018, https://www.nytimes.com/2016/08/18/us/beyond-coal-imagining-appalachias-future.html.

[186] Erica Peterson, "From Coal to Code: A New Path for Laid-off Miners in Kentucky," *NPR*, May 6, 2016, accessed November 15, 2018, https://www.npr.org/sections/alltechconsidered/2016/05/06/477033781/from-coal-to-code-a-new-path-for-laid-off-miners-in-kentucky.

[187] Peterson, "From Coal to Code: A New Path for Laid-off Miners in Kentucky."

[188] Ibid.."

[189] Ibid.

[190] "KentuckyWired FAQs," Kentucky Communications Network Authority, accessed February 8, 2019, https://kentuckywired.ky.gov/about/Pages/faq.aspx.

[191] Arlie Hochschild, "The Coders of Kentucky," *New York Times*, September 21, 2018, accessed November 15, 2018, https://www.nytimes.com/2018/09/21/opinion/sunday/silicon-valley-tech.html.

[192] Hochschild, "The Coders of Kentucky."

[193] Ibid.

[194] Ibid.

create economic opportunities for displaced workers. Software and application positions often have the benefit of being amenable to working remotely, enabling these displaced employees to work in a new profession yet stay in their current geographic location and generate economic activity. In addition to the related occupations generated though the occupational crosswalks, these in-demand technology jobs can also be considered as potential alternatives to fossil-fuel reliant positions as the State plans Just Transition strategies.

## 17.6 Conclusion

Throughout this report, RESI has addressed a broad range of topics related to the State's climate change mitigation strategies. These efforts include providing an overview of Just Transition models and how they have been successfully implemented in other regions, and a comprehensive evaluation of the predicted effects to Maryland's workforce and economy resulting from the State's 40 by 30 Plan. RESI completed this analysis by studying the industries of focus and their economic and fiscal footprints within the state, identifying key occupations likely to be impacted, and determining related occupations that provide alternative employment opportunities as the State transitions from fossil-fuel-reliant industries. The educational requirements for highlighted related occupations and training opportunities within the state of Maryland were also explored to provide greater transitional guidance. Additionally, the report provides strategies for mitigating these impacts though Just Transition models that have been successfully implemented in other regions, as well as alternative strategies that have been used in areas with declining coal mining industries.

While the industries and occupations evaluated throughout this report do not represent an exhaustive list of all those that may be affected by the State's 40 by 30 Plan, they provide a solid framework for evaluating potential economic and regional dislocations that may be incurred with this effort. Understanding the impacts and challenges related to greenhouse gas reduction policies enables the State to be better equipped when addressing these changes and taking steps to ensure an equitable and fair outcome for those affected.

It is clear that the transition to cleaner energy has numerous societal, economic, and environmental benefits—but it is also crucial to anticipate the impacts to existing industries, employees, communities, and regions that will be affected through this process. Through the information provided in this report, the State can take actions to build and strengthen policies that increase the likelihood of a smoother transition to Maryland's future of increased clean energy.

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## Appendix A—Industries of Consideration

**Figure 24: Occupations within Fossil-Fuel-Reliant Industries**

| Six-Digit SOC Code | Six-Digit SOC Title | Maryland Jobs in Fossil Fuel Dependent Industries | Occupation of Focus |
|---|---|---|---|
| 41-2011 | Cashiers | 7,545 | X |
| 41-1011 | First-Line Supervisors of Retail Sales Workers | 1,127 | |
| 51-4041 | Machinists | 626 | X |
| 35-3021 | Combined Food Preparation and Serving Workers, Including Fast Food | 586 | |
| 11-1021 | General and Operations Managers | 314 | |
| 53-6031 | Automotive and Watercraft Service Attendants | 275 | |
| 41-2031 | Retail Salespersons | 258 | |
| 51-1011 | First-Line Supervisors of Production and Operating Workers | 257 | X |
| 43-9061 | Office Clerks, General | 199 | |
| 49-3023 | Automotive Service Technicians and Mechanics | 191 | |
| 51-4011 | Computer-Controlled Machine Tool Operators, Metal and Plastic | 186 | |
| 51-9061 | Inspectors, Testers, Sorters, Samplers, and Weighers | 168 | X |
| 43-5081 | Stock Clerks and Order Fillers | 167 | |
| 51-8093 | Petroleum Pump System Operators, Refinery Operators, and Gaugers | 162 | X |
| 35-2021 | Food Preparation Workers | 148 | |
| 51-9011 | Chemical Equipment Operators and Tenders | 141 | |
| 49-9071 | Maintenance and Repair Workers, General | 134 | |
| 49-9041 | Industrial Machinery Mechanics | 132 | |
| 51-4121 | Welders, Cutters, Solderers, and Brazers | 115 | |
| 43-3031 | Bookkeeping, Accounting, and Auditing Clerks | 114 | |

Sources: RESI, U.S. Bureau of Labor Statistics

**END OF DOCUMENT**

Maryland
Department of
the Environment

# Appendix J

## MDOT GGRA Draft Plan

# 2019 GGRA Draft Plan

MARYLAND DEPARTMENT
OF TRANSPORTATION

# 2018 Draft Greenhouse Gas Reduction Act Plan

# 2018 Maryland Department of Transportation Draft Greenhouse Gas Reduction Act Plan

prepared for

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**April 2019**

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# Executive Summary

## MDOT's 2030 Draft Greenhouse Gas Reduction Act (GGRA) Plan

**This plan presents the Maryland Department of Transportation (MDOT) approach to meet the requirements of the GGRA. The GGRA requires the Maryland Department of Environment (MDE) to submit a proposed plan that reduces statewide greenhouse gas (GHG) emissions by 40 percent from 2006 levels by 2030 ("40 by 30").** In 2018, MDOT worked with MDE and other agency and stakeholder partners to develop and test strategies for the transportation sector to achieve the "40 by 30" goal.

Trends including growth in population, vehicle miles traveled, and congestion combined with less available revenue relative to needs creates a major challenge. Based on MDOT analysis accounting for these challenges and new opportunities, it is possible for Maryland's transportation sector to meet the "40 by 30" goal. The analysis considered three policy scenarios built from the Maryland Transportation Plan (MTP) and current Consolidated Transportation Program (CTP). Achieving the goal will not be easy, requiring an innovative and cost-effective approach that includes:

- An aggressive investment in transportation well beyond current projected funding,
- Supportive policy and new resources enabling MDOT to advance these needed investments,
- A commitment from MDOT partners to advance reliable, low cost, and low carbon technologies, and
- A best-case scenario for market penetration of electric vehicles into public and private fleets in Maryland.

## Background

**Why Are We Doing This?** In response to the threat and growing concern with climate change, the Maryland Commission on Climate Change (MCCC or the Commission) was established in April 2007. The Commission released its initial plan of action for addressing climate change in August 2008 and the GGRA was passed in 2009 representing the starting point of over a decade of climate change planning in Maryland. MDOT began working with stakeholders in 2009 to develop a comprehensive approach to reduce GHG emissions from the transportation sector through 2020. In 2016, the GGRA was reauthorized, refocusing on a new goal of reducing greenhouse gas emissions by 40% from 2006 emissions by 2030.

**What Is Maryland's Role in Mitigating Greenhouse Gas Emissions?** Maryland's transportation system is complex, with major international ports, a high proportion of through trips, and notable challenges related to congestion and access. It is also critical that our transportation system remains a safe and sustainable resource for the movement of goods and people throughout the Northeast Megaregion.

Maryland accounts for 1.08 percent of total U.S. GHG emissions and Maryland's transportation sector accounts for 0.41 percent of total U.S. GHG emissions. The focus of this report is on-road transportation, which represented 31 percent of total Maryland GHG emissions, including emission sinks, in 2015.

**How Does This Align with MDOT's Mission and the Maryland Transportation Plan?** Mitigating greenhouse gas emissions from transportation and investing in a transportation system that is resilient to climate impacts is a crosscutting objective within MDOTs mission and multiple goals of the MTP.
**71 percent of MDOT's planned investments in the 2018-2023 CTP (outside of system preservation projects) will facilitate GHG emission reductions from transportation.** MDOT's Excellerator and the

Annual Attainment Report track multiple performance measures that are indicators of a more efficient and multimodal transportation system – all positive steps toward GHG reductions.

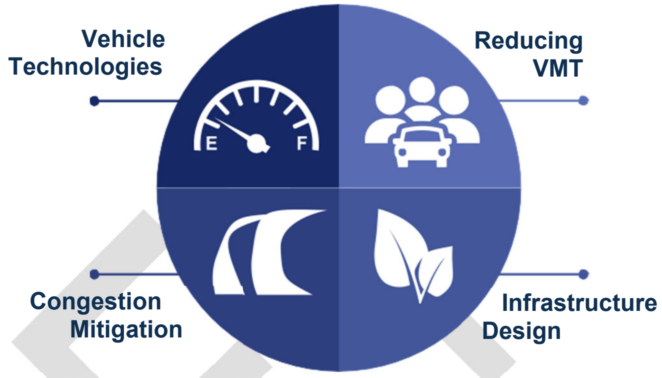
**What Are Key Examples of MDOT Actions that Support the GGRA?** Highlights of MDOT's ongoing actions to support GHG emission reductions through innovative delivery and operation of the transportation system and use of emerging technologies are presented below.

| MDOT Highlight | Implementation Details Supporting the GGRA |
|---|---|
| **Electric Vehicle Infrastructure Council (EVIC)**<br>MDOTs leadership of EVIC builds opportunities, financial incentives, and promotion of EVs, and the installation of electric vehicle supply equipment (EVSE) to support the State's EV goals. | ▪ EVIC produces annual reports on the progress of developing, evaluating and recommending strategies to facilitate the successful integration of EVs and EV infrastructure into Maryland's existing transportation infrastructure.<br>▪ EVIC supported the passage of the Clean Cars Act of 2017, which increased and extended funding that support rebates and incentives for electric vehicle purchases.<br>▪ MDOT is also working to complete an EV Signage Plan, focusing first on the acquisition, installation, and maintenance of EV signage on Maryland's ten FHWA designated alternative fuel corridors. |
| **Renewable Energy**<br>MDOT issued six Master Services Agreements (MSA) for qualified contractors to design, construct, commission, finance, operate, and maintain renewable energy facilities at MDOT locations throughout Maryland. | ▪ The program, one of the first of its kind by a state transportation agency, provides MDOT with the flexibility of developing renewable energy systems quickly and efficiently. The MSA is also available to any Maryland local government or non-profit organization.<br>▪ Phase 1 of the program deployed renewable energy sources at 35 sites across Maryland, including seven EV charging stations. In total, these sites will help reduce over 15,000 metric tons of $CO_2$ emissions.<br>▪ MDOT owns or controls more than 874 facilities, including buildings and parking lots that are eligible for renewable energy system development. |
| **Transit and Transportation Demand Management (TDM)**<br>MDOT continues to expand and diversify its commitment to improving transit service throughout Maryland while continuing to work to improve transportation demand management (TDM) programs available to Maryland commuters and students. | ▪ Construction on the Purple Line began in August 2017 through securing of $900 million from the Federal Transit Administration to match State, local, and private funding. The project will be delivered through a design/build/operate public-private partnership.<br>▪ Supported by two grants from US DOT, MDOT Maryland Transit Administration (MDOT MTA) is working with Baltimore City to deliver the North Avenue Rising project and Montgomery County to deliver the US 29 Bus Rapid Transit project.<br>▪ MDOT and MDOT MTA continue to work with Maryland's metropolitan planning organizations (MPOs), major employers, and universities, to expand TDM programs, aimed at providing commuters incentives and information to support ridesharing and transit use through Commuter Connections and Commuter Choice Maryland.<br>▪ The Maryland Metro/Transit Funding Act commits $167 million per year in additional, dedicated, funding for Metro from Maryland for the next 3 years. The bill also includes an additional $60 million annually for capital and operating funding to MDOT MTA. |
| **Connected and Automated Vehicles (CAV) and Integrated Corridor Management**<br>MDOT is developing Maryland's vision for a connected and automated vehicle future and deploying technologies to manage congestion. | ▪ MDOT is developing CAV strategic plans that document opportunities, challenges, priorities, strategies, and recommendations to help guide the State in planning and implementing CAV technology.<br>▪ MDOT State Highway Administration (MDOT SHA) is implementing Integrated Corridor Management (ICM), which uses real-time traffic conditions and artificial intelligence to adjust traffic signal timing.<br>▪ MDOT SHAs investment into a "progressive" design-build approach to improve reliability and reduce congestion in the I-270 corridor is an example of a project that will utilize technology to manage congestion. |

## Continuing Progress

**Where Are We Headed Through 2030?** According to projections by the Maryland Department of Planning, Maryland may grow to over 6.5 million people by 2030. Coupled with economic expansion and land use change, vehicle miles traveled could increase to over 71 billion by 2030, compared to 59 billion in 2017.

### What Drives Greenhouse Gas Emission Reductions from Transportation?

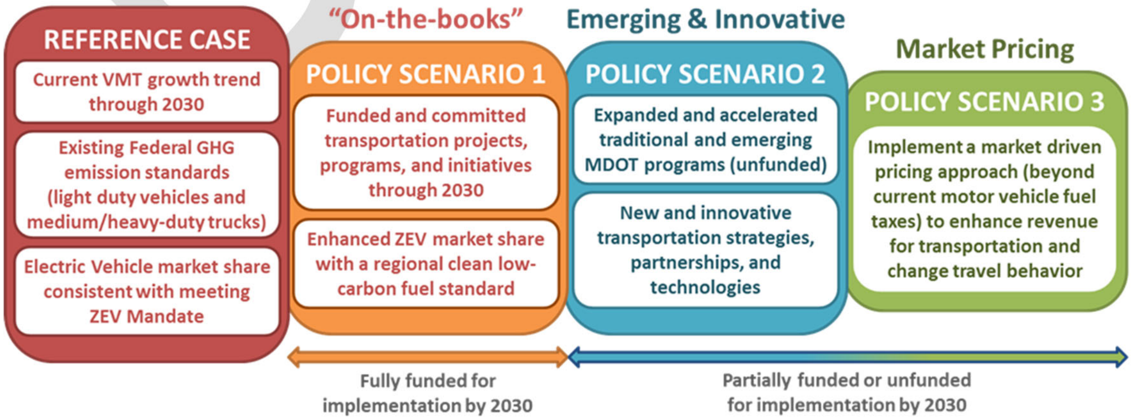


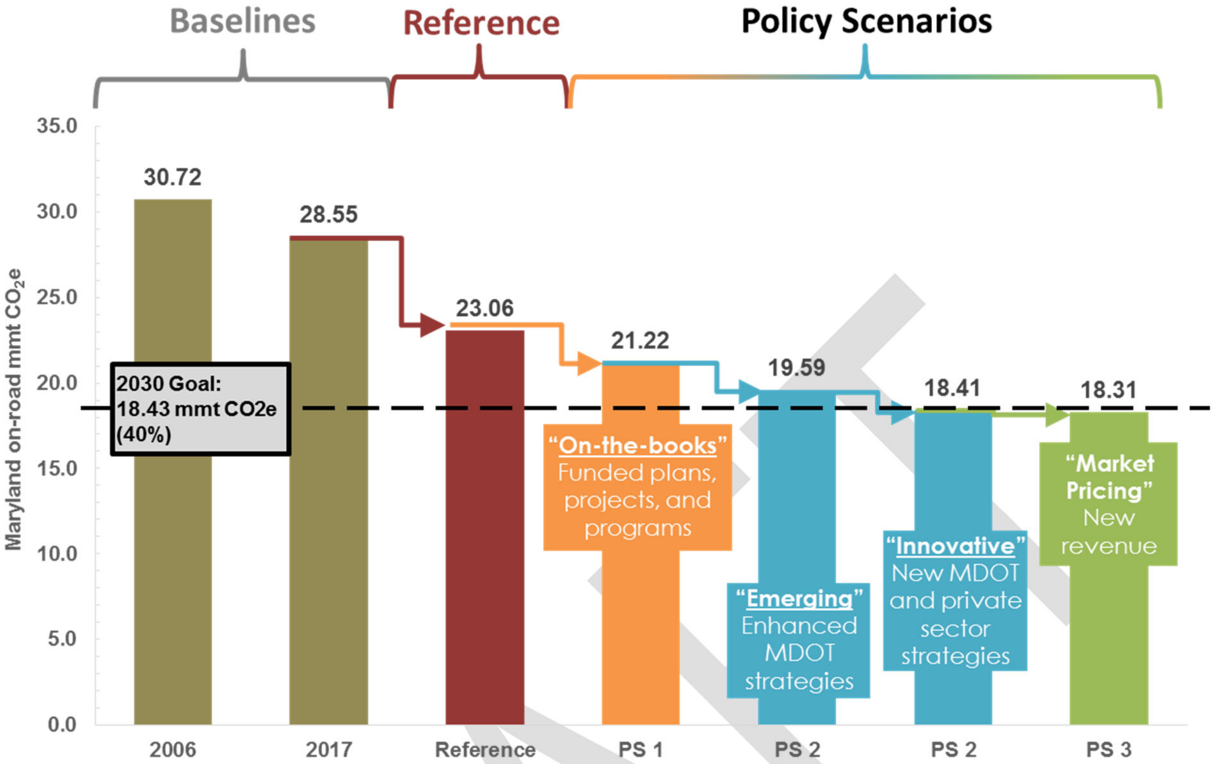
- **Vehicle Technologies** – New vehicle technologies could reduce average annual $CO_2$ emissions from each vehicle by 34 percent through 2030.
- **Congestion Mitigation** – Reducing congestion is a critical component of mitigating GHG emissions. A vehicle operating at 25 mph emits 25 percent more $CO_2$ per mile than one operating at 50 mph.
- **Reducing Vehicle Miles Traveled (VMT)** – Mitigating the growth in VMT relative to population growth is critical to GHG emission reductions. The strategies to change traveler behavior are complex, with success contingent on other decisions like land use. As the fleet becomes more efficient, VMT strategies are also less effective at reducing GHGs.
- **Infrastructure Design** – MDOT is developing vulnerability assessments and resiliency plans to address the current and future impacts of climate change. Contractors also are competing to install, operate, and maintain solar systems on MDOT properties, resulting in reductions in energy use.

## The 2030 Approach and Outcomes

**What Is the 2030 Approach?** – While there is some certainty established with transportation funding over the next six years, there are projects in early planning stages, plus other technological changes that will affect the 2030 landscape. Working closely with MDE, MDOT developed a list of strategies, organized across three Policy Scenarios, to put Maryland's transportation sector on a path toward the "40 by 30" goal.

**How Far Could We Get by 2030?** – While the GGRA goal is "40 by 30" across all economic sectors in Maryland, MDOT analysis applies the same goal for the transportation sector as the projected largest contributor of GHG emissions in Maryland by 2030. The policy scenarios and results are presented below.





**Reference** – This scenario assumes a constant 1.7 percent annual VMT growth rate (the annual average since 1990) through 2030 combined with full implementation of current Federal emission and fuel standards and Maryland meeting the Zero Emissions Vehicle (ZEV) mandate target of over 600k ZEVs registered in Maryland by 2030 (11 percent of the light-duty vehicle fleet). **The result – 23.06 mmt CO$_2$e from on-road mobile sources in 2030, a 25 percent reduction from 2006**.

**Policy Scenario 1 "On-the-Books"** – As its name implies, this scenario evaluates the emission reductions from funded projects and programs. This includes projects and programs in the CTP, land development assumptions consistent with local plans and Maryland Department of Planning goals, and GHG reducing projects included in fiscally constrained MPO metropolitan transportation plans. **The result – 21.22 mmt CO$_2$e from on-road mobile sources in 2030, a 31 percent reduction from 2006**. In other words, this scenario represents a best-case outcome for implementation of all strategies on the books through 2030.

**Policy Scenario 2 "Emerging and Innovative"** – This scenario acknowledges that attaining the 2030 goal will require additional investments to expand or accelerate deployment of previously planned strategies, deployment of new best-practice strategies, and capitalizing on the opportunities created by new transportation technologies. All of the strategies in this scenario require additional funding and, in some cases, private sector commitment. The 25 strategies in this scenario (17 emerging and 8 innovative) represent a combination of approaches to reduce GHG emissions with varying levels of confidence and MDOT responsibility. **The result – 18.41 mmt CO$_2$e from on-road mobile sources in 2030, exactly a 40 percent reduction from 2006**. In other words, this scenario suggests that achieving the 40 percent reduction is possible; however, the transportation sector will need new revenues and partnerships to make this a reality.

**Policy Scenario 3 "Market Pricing"** – This scenario takes a look at possibilities for addressing the primary challenge associated with implementing Policy Scenario 2 – funding. A market pricing approach could include current revenue sources, or augment or replace some of these sources with a VMT or carbon pricing approach. Among these options, MDOT estimated the outcomes of a carbon pricing strategy based on potential as a more sustainable and equitable revenue source. **This analysis was conducted for the scenario planning purposes of this report and is in no way indicative of MDOT's policy position.**

**The result – 18.31 mmt $CO_2e$ from on-road mobile sources in 2030, just past a 40 percent reduction from 2006.** An equally critical outcome – a carbon price could generate an additional $4.3 to $10.7 billion in revenue, depending on the ultimate price and implementation timeline, for implementing GHG emission reduction strategies through 2030.

**What Other Benefits Do These Strategies Create?** – The scope of strategies within the 2030 scenarios represent an opportunistic and innovative approach to reducing GHG emissions from on-road transportation sources while respecting the vision and goals of the MTP. These strategies will create the opportunity for significant co-benefits beyond just reduced fuel consumption and GHG emissions, including improved air and water quality, public health benefits, more equitable transportation options and access to opportunity, and direct and indirect economic impacts for current and future Maryland workers and employers.

## What Would It Take?

The path to “40 by 30” for the transportation sector is beset with implementation challenges and uncertainties, while also having the potential to capitalize on known and unknown opportunities. MDOT’s approach takes a careful, fact and research-driven approach to gauge what is realistic by 2030.

**What Are the Implementation Challenges?** – There are three broad categories of challenges to successful implementation of the policy scenario strategies by 2030 – **financial, technological, and policy and resource feasibility**.

**What Are the Uncertainties? –** The major sources of uncertainty that may affect the effectiveness of the policy scenarios include – **economic futures, travel costs, and disruptive changes in travel choices induced by technology or public behavior**.

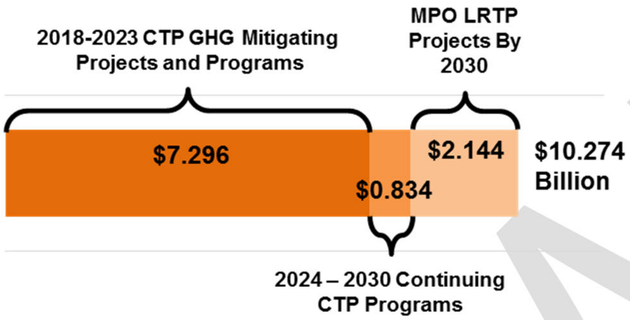
| Challenges | Uncertainties |
|---|---|
| **Financial** – The strategies in Policy Scenario 2 are partially funded or unfunded for implementation by 2030. Identifying new sources of funding is a major challenge. These new and creative sources of revenue will need to be prioritized relative to other needs, such as system preservation. | **Economic Futures** – Economic growth or decline and its impact on personal and commercial travel activity, choice, and vehicle ownership can influence emissions. Innovation in new technologies is often fostered in times of higher economic output, when increased investment in research and development are more typical. |
| **Technological** – Some pivotal strategies in the scenarios including electric vehicles (EVs), CAVs, and Mobility-as-a-Service, are at various points along their technological maturity for widespread adoption. For example, the EV technology is grappling with challenges like range anxiety, perceptions about availability of charging infrastructure, and cost parity. Similarly, CAV technologies are still undergoing a transition from the research realm to the real-world rollout scenario. If technology deployment slows, there is potential that meeting the “40 by 30” goal becomes nearly impossible for transportation. | **Travel Costs** – The most variable component of travel costs historically is fuel cost. Volatile fuel prices often result in more attention to alternative modes and more proactive strategies by logistics firms to reduce shipping costs. Sustained significant increases or decreases in gasoline and diesel costs relative to the norm could also affect vehicle ownership decisions and lead to declines in economic productivity, affecting other economic sectors beyond transportation. |

**Policy and Resource Feasibility** – Both the financial and technological challenges are manifested in public adoption of the strategies given that there are additional cost, behavioral, and regulatory challenges that need to be addressed for their implementation. Many transportation strategies require long lead times for engineering and environmental work, making accelerating key projects (even if the funding is available) a challenge.

**Disruptive Changes** – One major important source of uncertainty that is being seen across the transportation sector is the advent of disruptive technology that have already started to have a profound impact on travel choice and vehicle ownership among other factors. The shared mobility phenomenon has affected peoples' vehicle ownership and location choices thereby affecting travel patterns, mode choices and demand for services.

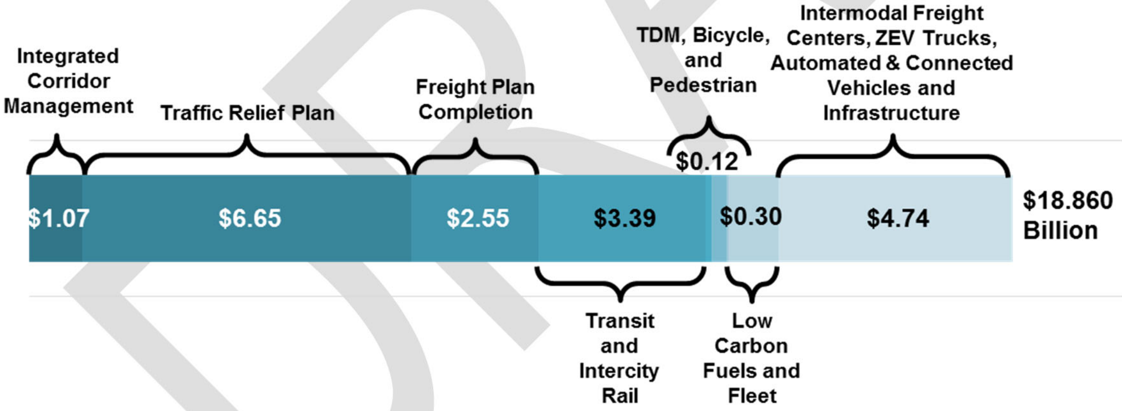
**What Are the Costs? –** A review of the strategies shows that a majority of them require an influx of capital funding for implementation. These include facility construction costs, cost of acquiring right of way, purchasing rolling stock or vehicles for transit, and technology costs for equipment and infrastructure.

### Policy Scenario 1 - FUNDED



**Policy Scenario 1** costs are based on CTP costs, ongoing investments in current MDOT programs from 2024 to 2030, and funded projects and programs in MPO MTPs planned for implementation by 2030. These programs are included within fiscally constrained plans based on projected revenue sources available to fund the programs for implementation.

### Policy Scenario 2 - UNFUNDED



**Policy Scenario 2** total estimated costs, not including potential investments in MAGLEV or Loop, ranges from $18.860 billion up to $26.174 billion (funding levels of 180 to 250 percent above current fiscally constrained plans). A balanced investment approach is needed to identify and prioritize strategies for funding based on cost effectiveness, reduction potential, and overall feasibility including readiness of policy adoption, public acceptance, and a supportive regulatory environment for rolling out new technologies.

A market-based pricing approach in **Policy Scenario 3**, could generate up to $10.7 billion in revenue to support strategies in Policy Scenario 2 through 2030. Combined with other innovative sources, including private commitments, the revenue generated could help implement many of the more cost-effective strategies in Policy Scenario 2. This approach does not completely address the funding shortfall in Policy Scenario 2, with potentially as high as $15.4 billion in unfunded strategies.

# 1.0 Background and Approach

This plan presents the Maryland Department of Transportation's (MDOT) draft blueprint for reducing greenhouse gas (GHG) emissions from the transportation sector through 2030, including information on estimated emission benefits, co-benefits, implementation considerations, and costs of each GHG reduction strategy and combination of strategies within different scenarios.

## 1.1 Greenhouse Gas Reduction Act and Maryland Commission on Climate Change

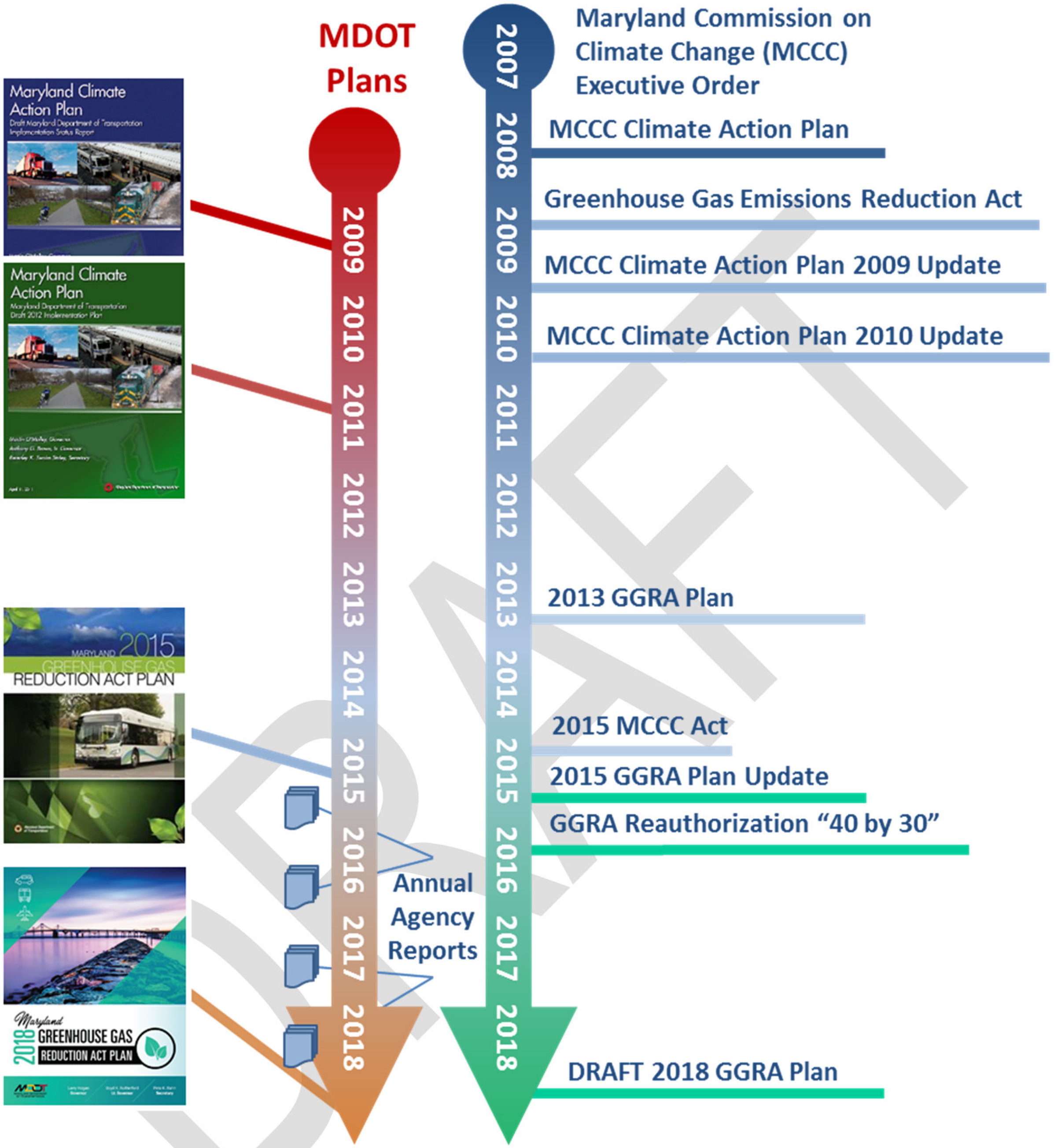
In response to the threat and growing concern with climate change, the Maryland Commission on Climate Change (MCCC or the Commission) was established in April 2007. The Commission released its initial plan of action for addressing climate change in August 2008, the starting point of over a decade of climate change planning in Maryland.

Maryland adopted the Greenhouse Gas Emission Reduction Act of 2009 (GGRA) in June 2009. Starting in 2009, MDOT began working with stakeholders to develop a comprehensive approach to reduce GHG emissions from the transportation sector through 2020 and beyond. This approach included careful planning, analysis, coordination, and outreach through the development of plans in 2009, 2011, and 2015 to highlight actions and progress toward achieving emission reduction goals. These efforts supported the Maryland Department of the Environment (MDE) and the MCCC in delivering regular reports to the Governor and General Assembly as required by the GGRA.

Maryland adopted the Maryland Commission on Climate Change Act in June 2015, which established a coordination and reporting protocol to institutionalize climate change planning across all Maryland agencies. Starting in 2015, MDOT supported MDE and the Commission through preparing Annual Agency Reports detailing progress and agency performance. MDOT has also been an active participant on workgroups and steering committees supporting the MCCC requirements.

In 2016, Maryland reauthorized the 2009 GGRA, refocusing efforts on a new goal of reducing greenhouse gas emissions by 40 percent of 2006 emissions by 2030 ("40 by 30"). This plan represents MDOT's draft approach toward achieving the 2030 goal, which will be finalized through development of the required 2019 GGRA Plan. An overview of the complete history, showing MDOT's role relative to the activities of the MCCC, is highlighted in Figure 1.1.

**Figure 1.1 MDOT's Contribution to Climate Change Planning in Maryland**



## 1.2 MDOT's Mission and Role in Addressing Climate Change

MDOT's mission statement communicates the importance of a customer-driven transportation system.

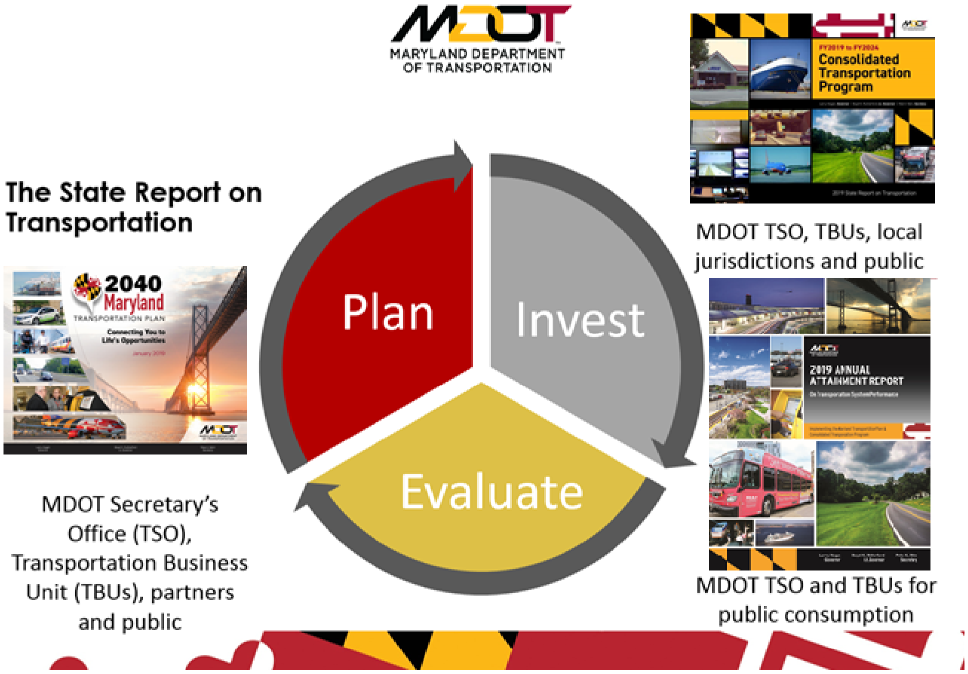
MDOT
MARYLAND DEPARTMENT
OF TRANSPORTATION

**MISSION STATEMENT**

"The Maryland Department of Transportation is a customer-driven leader that delivers safe, sustainable, intelligent, and exceptional transportation solutions in order to connect our customers to life's opportunities."

MDOT's strategic approach is presented through the State Report on Transportation (SRT), which is comprised of three documents:

1. The Maryland Transportation Plan (MTP): A 20-year vision document for the State's transportation system;
2. The Consolidated Transportation Program (CTP): The six-year budget for transportation projects statewide, produced annually; and
3. The MDOT Excellerator and the Annual Attainment Report on Transportation System Performance (AR): Recurring evaluations of the performance of Maryland's transportation system.



MDOT's mission communicates the importance of a customer-driven transportation system. The mission, along with the seven goals identified in the 2040 Maryland Transportation Plan (MTP), guides MDOT through statewide transportation planning, programming and coordination across its transportation business units (TBUs) to facilitate the strategic development of Maryland's intermodal transportation system. MDOT developed the goals, objectives, strategies, and performance measures in the 2040 MTP through an interactive outreach process. The goals of the plan are as follows:

- Ensure a Safe, Secure, and Resilient Transportation System;
- Maintain a High Standard and Modernize Maryland's Multimodal Transportation System;
- Improve the Quality and Efficiency of the Transportation System to Enhance the Customer Experience;
- Provide Better Transportation Choices and Connections;
- Facilitate Economic Opportunity and Reduce Congestion in Maryland through Strategic System Expansion;
- Ensure Environmental Protection and Sensitivity; and
- Promote Fiscal Responsibility.

MDOT is a leader in the development, tracking, and reporting of performance measures that drive MDOT and its business units to achieve and maintain exceptional standards while meeting the transportation demands of Maryland residents and users of the transportation system. This State Agency Report draws from three sources of performance and budgetary/financial reporting systems: 1.) The Annual AR, 2.) The MDOT Excellerator, and 3.) The annually updated, six-year, CTP.

**Attainment Report:** The Annual Attainment Report on System Performance assesses progress towards achieving the goals and objectives of the Maryland Transportation Plan (MTP). Several measures within the AR are indicators for GHG emissions, such as vehicle miles traveled (VMT), transit ridership, transit service reliability, roadway congestion, traffic safety, quality of the bicycle and pedestrian environment, and regional emissions. New measures were introduced as part of the 2018 AR goals and objectives update, including the number of formal or informal telework arrangements and the number of total electric vehicles (EVs) registered in Maryland.

**MDOT Excellerator:** In 2016, MDOT deployed the MDOT Excellerator, a performance management system which summarizes tangible results of MDOTs performance on a quarterly basis. This program is a living, evolving performance process that is in a constant state of evaluation, analysis, and action. The results represent critical data points that drive daily business decisions.

Like the AR, several measures within the MDOT Excellerator are indicators for GHG emissions, including percent of tolls collected by cash, reliability of highway travel, average highway incident duration, and peak hour congested VMT highway trends. In 2018, new, GHG-specific measures, were added to Tangible Result #9 within the Excellerator, “Be a Good Steward of the Environment.” MDOT is now tracking total EV registrations in Maryland as well as total publicly available electric vehicle supply equipment (EVSE). MDOT is also tracking the total GHG emissions from MDOT fuel consumption, by fuel type, and from MDOT’s electricity use.

**Consolidated Transportation Program:** The goals of the MTP and the associated measures that illustrate Maryland’s progress reflect the diversity of current and future transportation conditions, challenges, and needs. The Consolidated Transportation Program, the State’s six-year capital investment program for transportation, identifies funding for specific road, bridge, transit, aviation, port, pedestrian and bikeway projects based on the priorities established in the MTP. Many of the goal areas identified in the MTP include projects and programs in the CTP that directly or indirectly yield GHG emission reductions from transportation system users or the actual operation of the transportation system itself.

## 1.3 Recent and Ongoing MDOT Actions

Within the FY 2018 – 2023 CTP, MDOT estimates that 43 percent (approximately $6.401 billion) of Maryland’s $14.815 billion six-year program (excluding capital salaries, wages, and other costs) is associated with investments that could reduce GHG emissions through 2030 and beyond.

**When looking at total funding for major capital projects and programs only, MDOT is investing nearly three quarters of roughly $8.7 billion in funding for projects and programs that are expected to result in GHG emissions reductions.**

The successful maintenance, operation, and expansion of Maryland's transportation system requires extensive coordination between MDOT and a diversity of Federal, State, regional, and local partners. This coordination is critical given the shared approach between multiple government agencies as well as private entities in delivering Maryland's transportation system. Regulatory, financial, political, legal, and contractual matters, among others, create a complex framework within which MDOT manages Maryland's transportation system. This framework guides how MDOT, other transportation planning agencies, and transportation service providers function.

Captured within the CTP and many of MDOT's ongoing strategic planning and policy activities are a diverse suite of actions that will help keep Maryland's transportation sector on a sustained path toward GHG emission reduction goals. Highlights of some of these actions in 2017 and 2018 are detailed in Table 1.1.

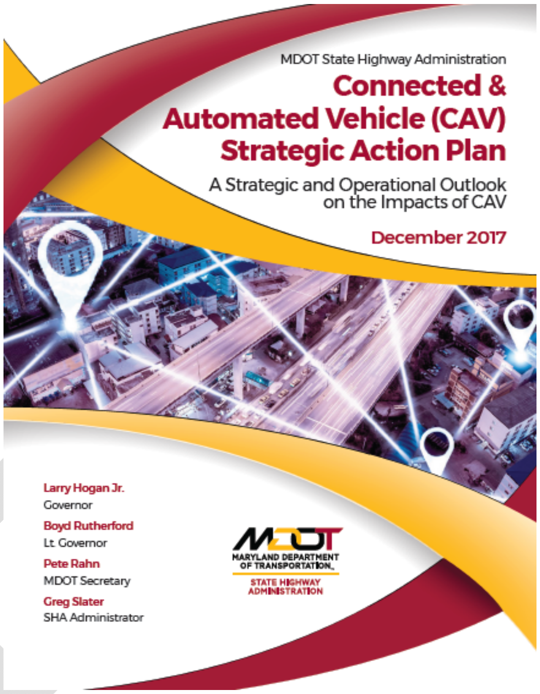
### Table 1.1 MDOT and MDOT TBU Accomplishments

| | 2018 Status Report Accomplishment Highlights |
|---|---|
| **Adaptation & Resilience** | MDOT SHA completed a statewide coastal vulnerability assessment with the best available climate projections and LiDAR data to help inform all aspects of planning, programming and design to ensure resilient and reliable transportation. |
| | MDOT MTA completed a climate change focused Vulnerability Plan in 2016 and is continuing to utilize the results in development of adaptation measures and resiliency planning. |
| **Transportation Technologies** | MDOTs leadership of the Electric Vehicle Infrastructure Council (EVIC) continues to build opportunities, financial incentives and promotion of the purchase of EVs and the installation of EVSE to support the State's EV goals. Total battery-electric and plug-in hybrid electric vehicles registered in Maryland is approaching 14,000 vehicles in 2018. |
| | MDOT SHAs Coordinated Highway Action Response Team (CHART) program continues to yield substantial GHG reductions associated with the efficient management of incidents, provision of traveler information, and deployment of other on-road infrastructure technologies. |
| **Public Transportation** | After launching in June 2017, BaltimoreLink has been providing improved transit service to existing customers as well as roughly 130,000 additional people within a ¼ mile of a bus route. |
| | Supported by two TIGER Grant awards from US DOT, MDOT MTA is working with Baltimore City to deliver the North Avenue Rising project and Montgomery County to deliver the US 29 Bus Rapid Transit project. Both projects will provide enhanced and more efficient transit options. |
| | Groundbreaking for the Purple Line in August 2017 through securing of $900 million from the Federal Transit Administration to match State, local, and private funding. |
| **Transportation Pricing** | MDOT and MDOT MTA continue to work with Maryland's metropolitan planning organizations (MPOs), major employers, and universities, to expand transportation demand management programs, aimed at providing commuters and student's access to financial incentives and information to support ridesharing and transit use. |
| | MDTA continues to update the technical capabilities and efficient operations of toll facilities, including strategic planning and procurement of new tolling hardware and software which supports an eventual shift to all-electronic tolling. |
| **Bicycle and Pedestrian** | In the FY2018—FY2023 CTP, there is over $175 million programmed to bicycle and pedestrian investments, including ongoing support of Maryland's bikeways and bikeshare programs. |

*Source: MDOT 2018 State Agency Report to the Maryland Commission on Climate Change*

MDOT and the TBUs are also taking innovative steps toward harnessing the potential benefits of emerging transportation technologies through research and development of new strategies including the use of renewable energy, connected and automated vehicles, and integrated corridor management.

- **Renewable Energy** - MDOT issued six Master Services Agreements (MSA) for qualified contractors to design, construct, commission, finance, operate, and maintain renewable energy facilities at MDOT locations throughout Maryland. The MSAs provide MDOT with the flexibility of developing renewable energy systems quickly and efficiently. The GHG benefit has increased by 10 percent over the last year and has already attributed to over 15 metric tons of $CO_2$ reductions.



MDOT State Highway Administration

**Connected & Automated Vehicle (CAV) Strategic Action Plan**

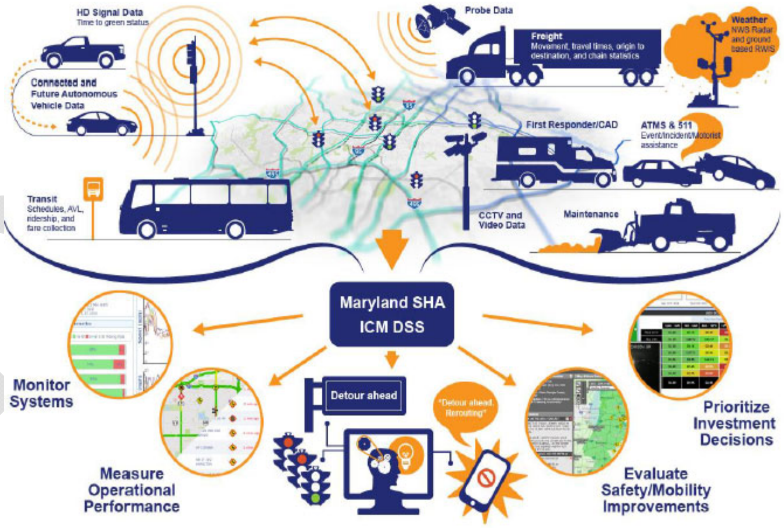
A Strategic and Operational Outlook on the Impacts of CAV

December 2017

Larry Hogan Jr.
Governor
Boyd Rutherford
Lt. Governor
Pete Rahn
MDOT Secretary
Greg Slater
SHA Administrator

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

- **Connected and Automated Vehicles (CAV)** - MDOT has established a CAV Working Group as the central coordination point for these emerging technologies. MDOT is developing Maryland's vision for a connected and automated vehicle future through extensive collaboration with MDOT's TBUs and planning partners. The Aberdeen Test Center has been recognized as a federal testing location for AV and US 1 was selected to pilot an innovative technology corridor. Maryland is emerging as a national leader in CAV technology and is building on this progress by developing CAV strategic plans that documents opportunities, challenges, priorities, strategies, and recommendations to help guide the State in planning and implementing CAV technology.



- **Integrated Corridor Management** – MDOT SHA is a recognized national leader in the testing and deployment of real time technologies to adjust signal operation to maximize throughput and reduce delay. The system uses real-time traffic conditions and artificial intelligence (AI) to adjust the timing of traffic signals and synchronize the entire corridor. These updates, associated with the Traffic Relief Plan, will improve traffic operations for 700,000 drivers per day on 14 major corridors across the state ($50.3 million in the FY 2018-2023 CTP).

## 1.4 Purpose and Process of This Plan

**The goal of this plan update is to present the progress the transportation sector has made in reducing GHG emissions, the trends affecting GHG emissions through 2030, and the anticipated benefits of planned MDOT strategies to support achieving the "40 by 30" goal.**

To meet this goal, the plan:

- Presents the transportation sector's accomplishments since 2009;

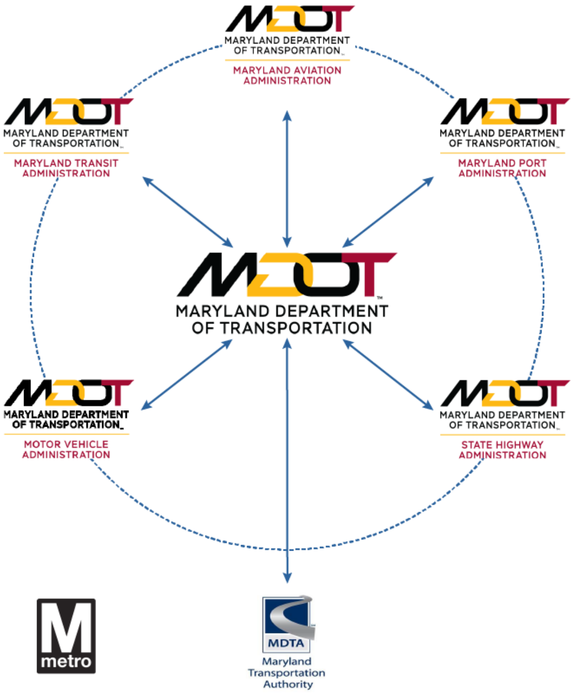
- Discusses broad trends impacting VMT, vehicle technology, and fuel use and details the emission outcomes of these trends;
- Identifies specific actions, including costs and benefits, for implementation through 2030; and
- Assesses the transportation sector’s contribution to the overall 2030 emission reduction goal.

### Technical Approach

The technical approach to analyzing GHG emission outcomes and co-benefits from transportation strategies is constantly evolving. New and updated tools and best practices require a rethinking of the analytical steps, data, and desired outputs for each iteration of transportation sector GHG emissions inventories and forecasts. In addition, with the focus on 2030, there are new assumptions for consideration including long-term economic growth, socioeconomic, vehicle and fuel technology, and transportation funding trends. As in prior analysis, the Environmental Protection Agency’s (EPA) MOVES (Motor Vehicle Emissions Simulator) model remains the primary tool for estimating on-road GHG emissions. This model has improved from previous MDOT analyses, as have the inputs from Maryland’s MPO metropolitan transportation plans and MDOT SHA’s new statewide transportation demand model.

### Coordination

Planning, implementation tracking, and emissions analysis within the transportation sector requires MDOT to coordinate regularly with MDE and other state and regional partners.



- MDOT is an organization comprised of five business units and one Authority. They are:
  The Secretary's Office (MDOT TSO), MDOT SHA, MDOT MTA, Motor Vehicle Administration (MDOT MVA), Maryland Port Administration (MDOT MPA), Maryland Aviation Administration (MDOT MAA), and MDTA.
- MDOT TSO works with the TBUs and the Washington Metropolitan Area Transit Authority (WMATA) to document operations and initiatives that are generating GHG emission reductions today and in the future.
- MDOT also coordinates with Maryland’s MPOs to support short and long-range transportation planning, and the transportation conformity process.
- MDOT chairs the Electric Vehicle Infrastructure Council (EVIC), working with MDE, the Maryland Energy Administration (MEA), and other public and private stakeholders to develop policy regarding EVs.
- MDOT also works with the Maryland Department of Planning (MDP), Sustainable Growth Commission, Smart Growth Subcabinet, and National Center for Smart Growth at University of Maryland regarding land use decisions and their connection to travel demand. Coordination with MDP includes planning to support transit-oriented development (TOD).

# 2.0 2030 Context – Transportation Drivers and Trends

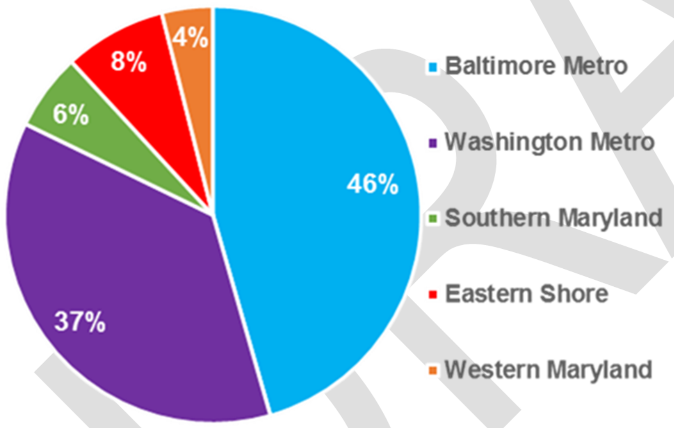
The last decade has seen shifts in Maryland's population and economy, and evolutions in how the transportation system provides mobility to Maryland's residents, and visitors, employers, and shippers. Ongoing development of the MTP has focused on these shifts to support creation of a new framework for transportation priorities and investments. In 2017 and early 2018, MDOT developed a Conditions, Trends, and Challenges Technical Memorandum that provides information that supported MDOT and stakeholder decisions regarding MTP goals, objectives, and strategies. Much of that work is summarized in this section.

## 2.1 Population

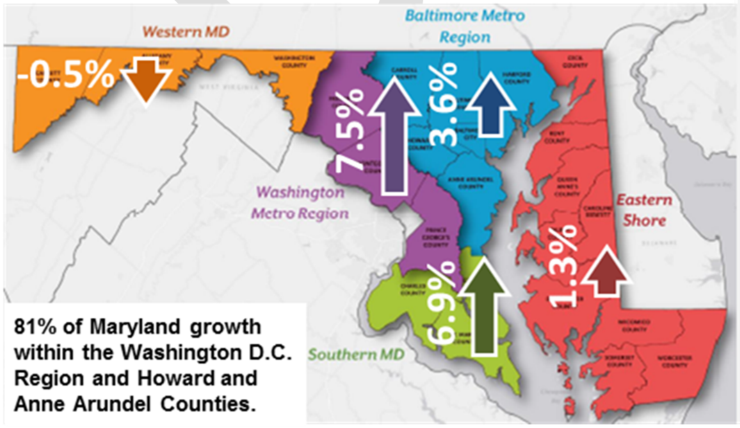
**Demand for travel in Maryland is tied to population growth, density, and demographics. In areas of the state with high population density, residents tend to rely more on mass transit and non-motorized transportation modes, while less populated areas remain reliant on motor vehicles.**

**6.05 million people** **#19 in US by population** **#5 in density**

**2017 Share by Region**



**2010 to 2017 Growth = 4.8%**



**81% of Maryland growth within the Washington D.C. Region and Howard and Anne Arundel Counties.**

**Aging Population** – The 65-and-older cohort grew 28 percent between 2010 and 2017, totaling 14.9 percent of Maryland's population. Much of this growth is occurring in rural locations, particularly on the Eastern Shore.

**Millenial Generation** – The 20-to-39 age cohort was the next highest rate of population growth. Most of this growth is occurring along the I-95 and I-270 corridor as well as in small city centers like Frederick.

**Auto Ownership** – 9.2 percent of Maryland's 2.17 million households do not own a car. Baltimore City has the highest share at over 29 percent, while Montgomery, Prince Georges, and Baltimore counties average 7.5 percent.

**Poverty** – Baltimore City faces a poverty rate (22.7 percent) more than double the statewide average of 9.9 percent. Outside of Baltimore City, poverty in Maryland tends to be concentrated in Western Maryland and the Eastern Shore.

## 2.2 Economic Growth and Diversity

A well-functioning transportation system is critical to Maryland's economic competitiveness and opportunities for its residents. Businesses seeking to relocate or open new facilities often consider transportation opportunities and efficiency as factors to ensure goods can be shipped on time and that employees can enjoy a high quality of life.

**3.23 million** civilian jobs in 2018 **5% growth** since 2010

**Maryland's Gross State Product increased from $242.3 billion in 2000 to $329.1 billion in 2015.** While Maryland has seen slower economic growth than the US since 2011, Maryland's economy did not contract as much during the Great Recession as peer states.

**41%** Finance/Insurance/ Real Estate, Professional/ Business, Information

**21%** Government

**17%** Trade, Construction Transportation

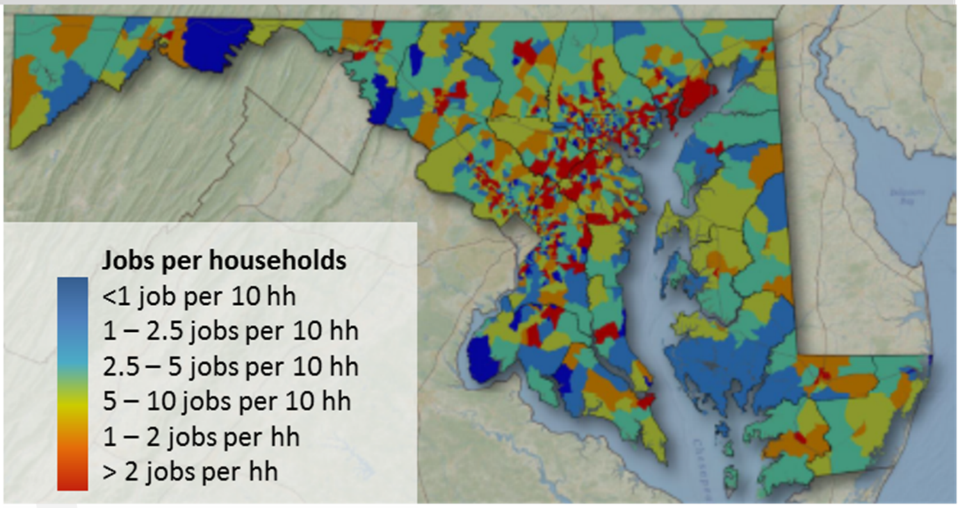
**8%** Education, Health

**8%** Manufacturing, Utilities

**5%** Entertainment, Recreation

**Maryland's labor force participation rate** has hovered between 65% and 70% since 2007. It currently stands at 68.4%, 5% above the national average.

**Jobs – Housing Balance:** There are relative imbalances between jobs and housing throughout Maryland. The map shows a concentration of jobs relative to housing units in central Maryland and an imbalance in other communities. This imbalance leads to longer commutes and congestion in the peak periods.



**Freight contributes to nearly every aspect of the lives of people living, visiting, and working in Maryland.** Freight goods include sensitive high-cost products, such as medicines and technology, household items purchased online, items found in grocery, convenience and retail stores, industrial goods, raw materials, finished goods, and even new vehicles. Industries in Maryland that compete on the global market, such as mining, agriculture, retail and wholesale trade, manufacturing, construction, and warehousing, depend on freight movement and account for over one million jobs in Maryland.

- Maryland's freight industry is a key driver of the economy employing over 1.5 million people and contributing over $123.0 billion (37 percent of the total) to the state's annual GDP.

- Truck, rail, water, and air modes moved nearly 631 million tons of freight, worth $835 billion, to, from, within, and through Maryland in 2012. By 2040, more than 1 billion tons of freight, worth close to $1.6 trillion, is expected to move within and through Maryland.
- **Over 95% of freight shipments (approximately 76% by tonnage) is moved by trucks on Maryland's Interstate highway and freight system,**
- The Port of Baltimore continues to see its investments in its facilities pay dividends as it is ranked as the **top port among all U.S. ports for handling autos and light trucks, farm and construction machinery, and imported sugar**. The Port of Baltimore handled **31.8 million tons of international cargo worth $49.9 billion in 2016** and is ranked ninth for the total dollar value of international cargo and 14th for international cargo tonnage for all U.S. ports.

## 2.3 Transportation Technology

Maryland is a leader in adopting strategies to advance cleaner vehicles and fuels, via the Maryland Clean Cars Program, which implemented California's low emissions vehicle (LEV) standards to vehicles purchased in Maryland starting in 2011. Since then, enhancements in Federal motor vehicle emissions standards have overlapped with this program, and further improvements in vehicle technologies and fuels are anticipated to play a key role in significantly improving air quality and reducing GHG emissions.

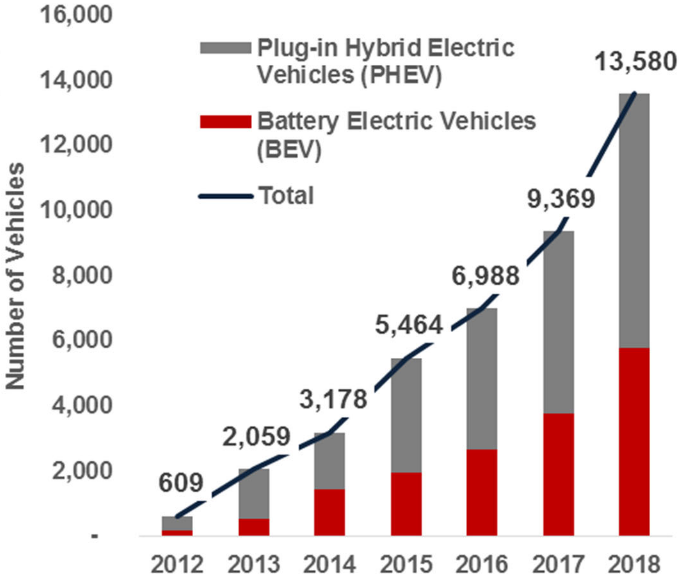
**National light-duty GHG and fuel economy program –**
These standards apply to passenger vehicles and light-duty trucks, and are projected to result in an average industry fleet level of 163 grams/mile of carbon dioxide in model year 2025, which is equivalent to 54.5 miles per gallon – **a more than doubling of fuel economy from 2010 model year vehicles.**

**National medium and heavy-duty vehicle GHG and fuel efficiency standards –**
Adopted Phase 1 and Phase 2 national standards for medium- and heavy-duty engines and vehicles through model year 2027 will result in reduced GHG emissions from trucks and other large vehicles traveling within and through Maryland.

**Zero-Emission Vehicle (ZEV) Mandate –**
The Maryland Clean Cars Program contains a ZEV mandate which requires that manufacturers make an increasing percentage of the vehicles available for sale in Maryland be ZEVs. **It is estimated that by 2025 this Program could result in approximately 300,000 ZEVs in Maryland.**

In 2012 there were two Battery Electric Vehicles (BEV) models available in Maryland - today, there are over 15 BEV models available for purchase in Maryland in addition to 20 plug-in hybrid vehicles.

As the number of electric vehicles increase, there is more need for charging stations. **Within Maryland there are 579 electric stations and 1,532 public charging outlets.**

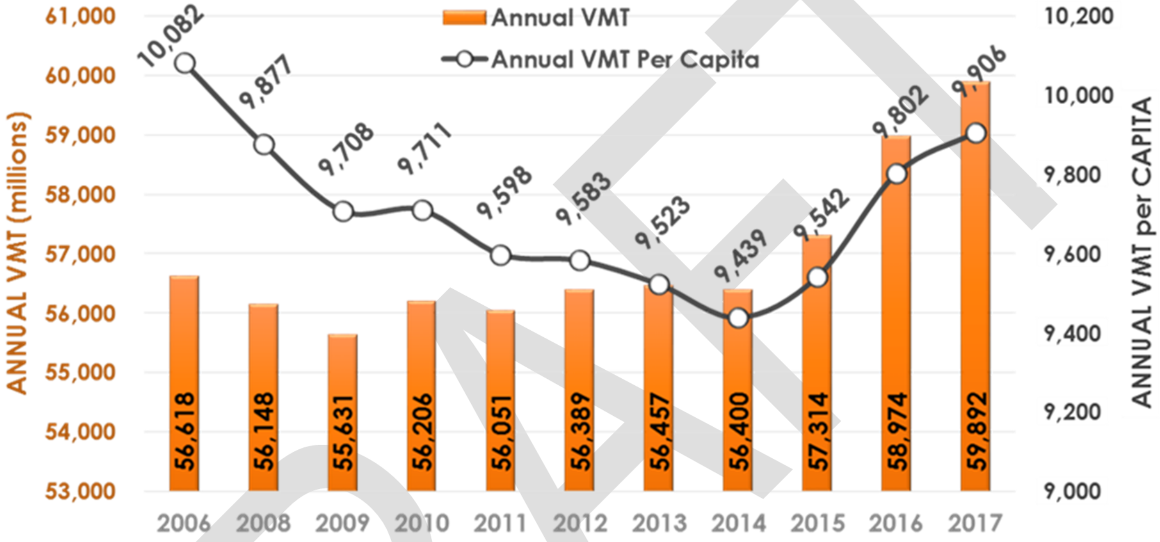


## 2.4 Transportation Mobility and Accessibility

Economic and population growth create more demand for mobility by residents, visitors, and companies conducting their business. As these demands increase, past trends indicate that it can be expected that total VMT will also increase, as will demand for all transportation services.

### Vehicle Miles Traveled

2017 Maryland VMT is expected to total around 59.6 billion, representing a 6 percent increase from 2010, outpacing population growth since 2010, resulting in increases in VMT per capita. While still lower than pre-recession VMT per capita, recent economic growth and comparatively low fuel costs have accelerated VMT growth in 2015 through 2017.



### Licensed Drivers and Registered Vehicles

The number of licensed drivers and registered vehicles relative to Maryland's population has remained generally constant since 2010.

**71%** of Maryland's population with a drivers license

**5.1 million** registered vehicles

### Commute Time

Based on U.S. Census data, Maryland has some of the longest commute times in the nation – **32.3 minutes**. Carroll, Frederick, Montgomery, Prince George's, Charles, and Calvert Counties all have average commute times greater than the State average, with both Charles and Calvert over 40 minutes. This pattern has remained fairly constant in Maryland since 2010. Commute trips represent about 1/3rd of total travel.

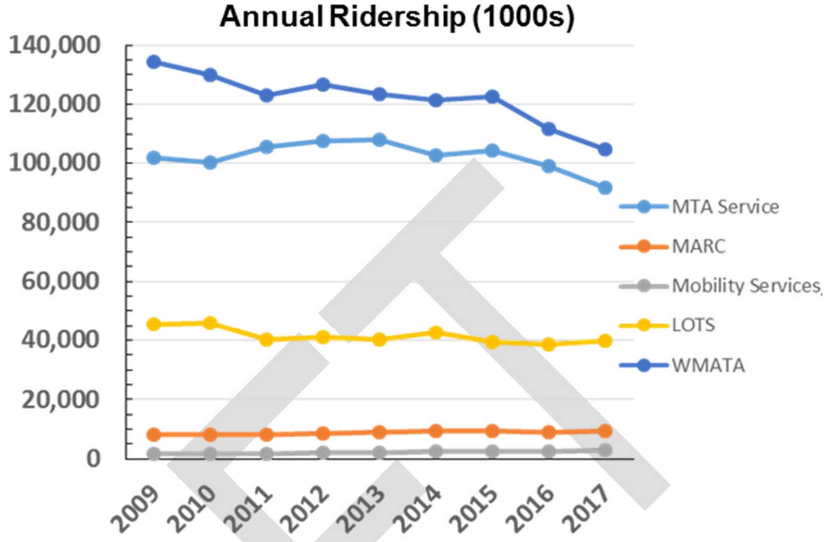
### Commute Mode Split

Based on U.S. Census data, commuting by mode has remained overall constant since 2010. **Drive alone has hovered around 74%**, while **carpool (9%)** and **transit (8.5%)** have decreased and been replaced by increases in work at home, walk, and other (including shared-ride). The highest non-drive alone mode shares are in Baltimore City (40%) and Montgomery and Prince George's Counties (35%).

## Transit Ridership

MDOT, MDOT MTA, WMATA, and local transit partners provide transit options for residents and visitors to urban and rural Maryland.

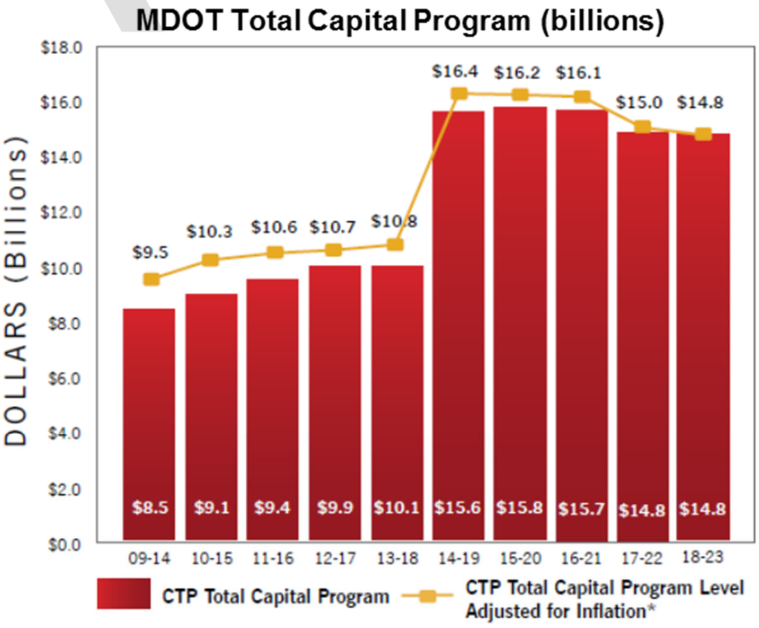
- Average annual growth rate in MTA service revenue vehicle miles from 2006 to 2017 was 3.1 percent, while ridership declined over that same period
- MD is #5 in transit commute mode share (9 percent) behind only IL, MA, NJ, NY
- Over the last 10 years, the share of the capital budget committed to MDOT MTA and WMATA has increased from 29.6 percent in 2006 to 33.1 percent in 2016



## 2.5 Transportation Policy and Funding

MDOT supports strategies across every mode of transportation – improving the customer experience on the transportation network by improving safety, reducing congestion, providing more and better non-motorized and transit options, increasing connections between modes, and improving the flow of goods. In the FY 2018–FY 2023 CTP, Maryland will invest $14.8 billion in transportation projects, ranging from connecting Maryland with transit options to addressing congestion to optimizing waterways for trade.

- **MDOT invests in the transportation system by applying all the resources it has available, the majority of which come from the Transportation Trust Fund (TTF).**
- **MDOT also engages private partners to minimize risk and maximize the efficiency of each dollar spent.** The Purple Line transit project is an example of a Public-Private- Partnership (P3). MDOT is also taking action to ease traffic on the state's most congested highways through a $9.0 billion P3 that will reduce congestion on three of Maryland's most congested highways – the Capital Beltway, I-270, and the Baltimore-Washington Parkway.

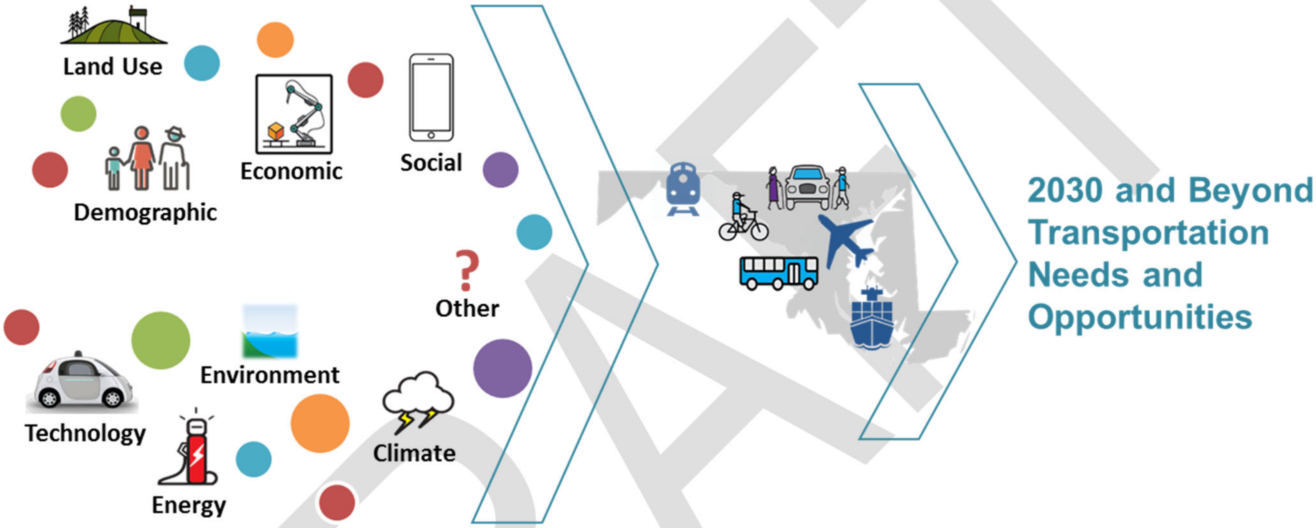


**43%** of the $14.8 billion 2018-2023 CTP support GHG emissions reductions.

This represents **73%** of major capital investments in the CTP.

## 2.6 What This Means for 2030 and Beyond

The performance of Maryland's transportation system, as well as MDOT's ability to maintain and enhance the system, is influenced by social, technological, and economic trends (including fuel prices, which have a significant impact on travel activity). Emerging trends toward a "sharing economy" in transportation, vehicle technology, fuel advancements including electric and connected / automated vehicles, and changing logistics and supply chain patterns will greatly influence the use of the transportation system. These trends will help shape Maryland's ability to reduce GHG emissions from the transportation sector over the coming decades. In many cases, MDOT has little control in how these trends will play out. Through the MTP and other long-range planning activities, MDOT and its partners will balance demand and available resources to accommodate current needs and create the 2030 and beyond transportation network.



**Climate**

The potential impacts of climate change on transportation infrastructure and operations are a growing concern, and Maryland's transportation infrastructure will be impacted by changes to the climate. For example, the Port is a water-dependent asset and since many of its facilities are within the flood plain, MDOT MPA has conducted a vulnerability assessment and implemented policies to increase resiliency. Rising sea level, increased flooding, changes in precipitation levels, and increased temperatures will stress infrastructure. Because those future factors are not always considered in the design specifications, infrastructure could meet today's standards, but fail in the future.

**Land Use**

As growth spreads from Maryland's economic centers, it becomes harder to provide efficient transportation options. As jobs and housing locate further from each other, demands on the transportation network increase. Land use is a local decision; however, provision of transportation access has State implications. Maryland's TOD program promotes TOD as a tool to support economic development, grow transit ridership, and maximize the efficient use of transportation infrastructure.

**Demographic**

As the Millennial generation continues to enter the workforce, Maryland's transportation system will face challenges associated with that generation's preferences. Maryland's population is also getting older, and the implications of this population shift are uncertain. Providing transportation for older Marylanders could impact public transportation agencies, non-profit transportation providers, and/or private providers.

**Social**

Ridesharing services, such as Uber and Lyft, substitute for traditional taxi services, providing a cheaper and immediate alternative. To date, ridesharing has been effective in large, dense urban areas with significant demand and a large number of drivers. It is uncertain how ridesharing, carsharing, and other mobility-on-demand providers like e-scooters will impact the number of vehicle registrations, licensed drivers, or transit riders. In addition, these services may be augmented or, conversely, reduced with the increase in automobile automation.

**Economic**

Retail in the United States is in the midst of a major shift and consolidation. The shift toward online shopping has reduced the number of individual shopping trips and increased the number of delivery trucks (or drones), leading to an overall reduction in vehicles on the road. An additional challenge for Maryland associated with online shopping is the tremendous growth in the development of very large warehouse and distribution centers. Technology in the manufacturing sector is also changing logistics patterns as distributed manufacturing, 3D printing, and other emerging tools may bring goods closer to market, increasing truck trips over marine, rail, or aviation.

These economic shifts might not unfold equally across Maryland. There are jobs and workers in other parts of the state, which also require transportation investments to ensure the continued growth of their economies. Striking a balance between the State's various transportation needs and economic shifts is an important policy challenge facing the State.

**Technology**

Connected and automated vehicles have the potential to both impact transportation system supply and demand. In a world where automation leads to lower auto ownership rates and transportation modes are interconnected through public and private providers though mobility-as-a-service, it is possible that VMT could increase as access to mobility is improved. Simultaneous to this, most, if not all of these vehicles will be electric, and presumably will make more efficient use of roadway capacity through new infrastructure technologies.

**Energy**

Technology changes in transportation are disruptive forces that could also create new challenges for transportation planning, including reduction in revenues from traditional motor vehicle fuel based taxes. Transition to an electric fleet will also have impacts on household and commercial electricity consumption, placing more pressure on the electric grid and Maryland's existing and future energy sources.

**Environment**

Population and economic growth will continue to stress Maryland's environment, particularly the Chesapeake Bay. How the expanding transportation system accommodates growing demand while mitigating impacts will remain a primary MDOT goal.

According to projections by the Maryland Department of Planning, **by 2030, Maryland is anticipated to grow to over 6.5 million people, nearly ½ million more people than in 2017**.

This growth, coupled with economic expansion and land use change could result in **statewide VMT over 71 billion by 2030**, compared to 59 billion in 2017.

This growth would lead to **significant challenges on the transportation system** – however, **emerging technology and proactive planning by MDOT** will help create opportunities and ensure a balanced transportation system providing equitable access for all and support Maryland's economy.

# 3.0 2030 Strategies and Scenarios

## 3.1 2030 Approach and Considerations

Prior MDOT GGRA Reports supporting requirements toward the 2020 goal relied on current trends and the suite of projects and programs fully funded within the CTP as the primary evidence for what 2020 may look like. Assumptions on potential new or expanded emission reduction strategies were tested as enhancements to MDOT's approach, with the recognition that additional funding or new policy would be required to make these a reality.

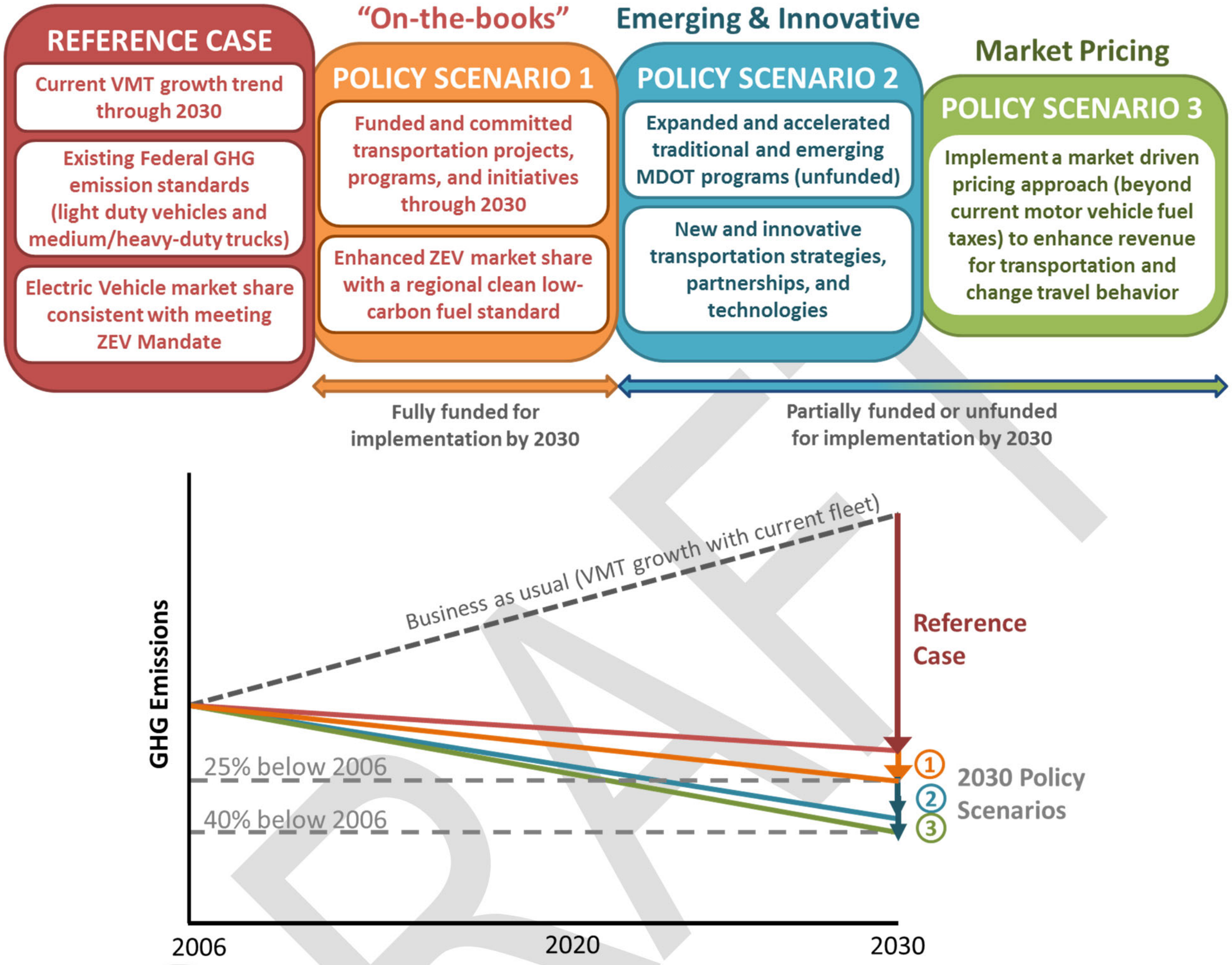
For the 2030 analysis, the opportunities and challenges within the transportation sector could greatly impact 2030 emission trends. As noted in the prior section, there are many forces creating disruptions and opportunities in transportation. While there is some certainty established with transportation funding over the next six years (2018 – 2023) through the CTP, there are significant projects and programs in early planning stages, plus other technological changes such as the shift to an electric fleet, automated and connected vehicles, and the rise of mobility-on-demand services that could greatly change the landscape through 2030. As a result, MDOT has developed a list of strategies and scenarios, consistent with the Draft goals, objectives, and strategies in the 2040 MTP, to put Maryland's transportation sector on a path toward the "40 by 30" goal.

Consistent with the GGRA, the development of emission reduction strategies and scenarios and the associated emissions analysis all pivot from the 2006 base year. Each 2030 scenario is modeled consistent with the assumptions of the prior scenario in order to account for synergies among scenario assumptions and avoid any double counting of emission benefits. MDOT followed the MCCC, Mitigation Work Group (MWG) scenario modeling organization, which covers all sectors, to inform development of transportation sector scenarios:

- **Reference Case:** "Business as usual" scenario incorporating effects of major policies as they currently exist on the books;
- **Policy Scenario 1:** Extension of the current policy and program framework within the Reference Case including funded plans, projects, and programs;
- **Policy Scenario 2:** New programs and policies beyond Policy Scenario #1;
- **Policy Scenario 3:** MWG driven scenario including market-based strategies; and
- **Policy Scenario 4:** Final 2018 Draft Plan scenario incorporating consensus findings from MWG

For the transportation sector, **Figure 3.1** depicts the overall strategy and high-level definitions for this scenario approach focused on the on-road transportation sector. Off-road transportation strategies and scenarios (e.g., aviation, marine, and rail) are developed and analyzed through a partnership approach between MDOT and MDE and presented separately.

## Figure 3.1 2030 Approach Overview



The MDOT approach to GHG reduction from the transportation sector balances continuing challenges with emerging opportunities, including:

- Communication technology advances – EVs, CAV, & Smart Mobility with private sector participation,
- Sustainable funding remaining a challenge,
- Changing generational preferences on transportation and development, and
- Economics and logistics shifts due to technology.

These factors require MDOT to advance more complex and multimodal projects, deliver improvements ultra-efficiently with more partners, rely more on system optimization, and use emerging technologies.

### *3.1.1 GHG Mitigation Strategy Development*

A comprehensive list of GHG mitigation strategies was compiled from previous MDOT GGRA plans, the MTP, other ongoing statewide and regional initiatives, and a review of national best practices. This preliminary list of strategies was qualitatively reviewed based on cost effectiveness, political feasibility, GHG reduction potential, MDOT's control over the strategy implementation, and the potential for strategy implementation by 2030. Based on these factors, strategies were grouped, and prioritized. Ultimately, very few strategies were removed from consideration for this analysis in the Draft 2018 GGRA Plan. Strategies that were excluded from consideration were likely those which had little or no chance of implementation under the current regulatory framework (for example, new post 2025 Federal fuel economy standards for light duty vehicles and renewed fuel economy standards for medium- and heavy-duty trucks beyond the current Phase 2 standards).

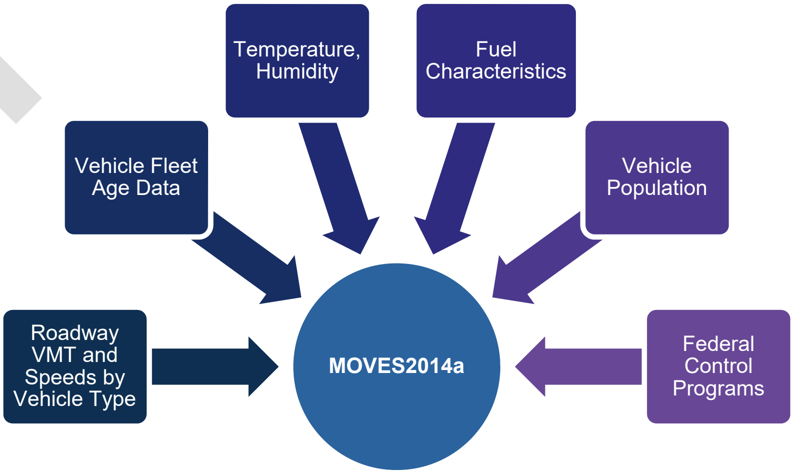
Some strategies were arranged or prioritized based on their likelihood of implementation by 2030 (for example, longer-term projects identified in the MARC Growth and Investment Plan or construction of Northeast Corridor High Speed Rail). In order to consider them in the strategy analysis, assumptions were made on enabling funding and policy changes that may be needed to promote implementation by 2030, particularly in Policy Scenario 2.

### *3.1.2 Technical Approach*

The on-road portion of the GHG emissions inventory were estimated with EPA's latest emissions model, version MOVES2014a, released in November 2016. With MOVES, greenhouse gases are calculated from vehicle energy consumption rates and vary by vehicle operating characteristics including speed, engine size, and vehicle age. As illustrated in **Figure 3.2**, the MOVES2014a model is integrated with local traffic, vehicle fleet, environmental data, fuel, and emission control programs to estimate statewide emissions.

The on-road transportation emissions inventory includes emissions of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) converted to carbon dioxide equivalents ($CO_2e$) that are measured in units of million metric tons (mmt $CO_2e$) based on each pollutant's global warming potential (GWP). Carbon dioxide represents about 97 percent of transportation sector GHG emissions. The data sets, input values, analysis tools and methodologies employed to conduct the on-road vehicle GHG emissions inventory were developed in consultation with MDE and are consistent with EPA guidance.

**Figure 3.2 Emissions Calculation Data Process**



The MOVES model is best suited to estimate emissions based on state-wide and jurisdiction level data that accounts for vehicle miles traveled trends and fleet characteristics. It is not well suited to analyze the impacts of individual strategies or scenarios. The MOVES model was used, along with post-processing techniques, to estimate emissions within the Reference and Policy Scenario 1. The combined emission outcomes of these scenarios informed spreadsheet level analysis outside of MOVES in Policy Scenario 2 and Policy Scenario 3 through best-practice GHG emission reductions estimates based on research, analysis, and observed benefits in Maryland and peer regions.

# 4.0 Baseline and Reference Scenarios

## 4.1 Description

Consistent with the GGRA, the development of emission reduction strategies and scenarios all pivot from the 2006 Base Year inventory. Each approach presented in this section is modeled consistently, but with the latest planning assumptions in place for the year of the inventory. MDOT refers to the 2006, 2014, 2017, and the 2030 Business as Usual scenarios as “Baseline Scenarios”.

**2006. The 2006 Baseline Inventory established the base conditions for the GHG reduction goals in the GGRA that include 25 percent by 2020 and 40 percent by 2030.** The on-road portion of the emissions inventory represents a “bottom-up” approach to estimating statewide GHG emissions based on roadway congestion levels and traffic volumes. This approach utilizes emission rates from EPA’s MOVES emissions model and Maryland reported VMT, combined with a robust forecasting process based on historic trends and regional population and employment forecasts.

**2014 and 2017.** MDOT annually reports on-road GHG emissions within the AR. GHG emission estimates for on-road transportation in 2014 and 2017 baselines reflect a “true up” of actual conditions based upon the process for developing EPAs National Emissions Inventory (NEI). The statewide inventories represent the traffic conditions (VMT, congestion and speeds) based on roadway segment counts, reported data from the Highway Performance Monitoring System (HPMS) developed by MDOT SHA and the vehicle technology standards in place for each inventory.

**2030 Business as Usual (BAU).** VMT trends show a total six percent growth from 2015 through 2017 compared to nearly no growth between 2006 and 2014. While the demand for the transportation system increases as a result of the economic recovery and other factors, GHG emissions continue to decline through 2017. The 2030 BAU scenario represents the expected forecast of GHG emissions and VMT projections based on existing fleet information and travel trends. This represents the future conditions without implementing any additional GHG reductions strategies or polices.

**The 2030 BAU is the starting point for GHG reduction needs to meet the 40% reduction goal.** The VMT forecast reflects the historic trends of 1990-2014 VMT growth. The average statewide annualized growth rate through 2030 for this scenario is 1.7 percent.

**2030 Reference.** The 2030 Reference scenario includes the Maryland and federal vehicle technology and GHG emissions standards, federal renewable fuels standards, and EV market share forecasts consistent with Maryland’s commitment to the ZEV Mandate.

**State and Federal Initiatives and Standards** – State and federal initiatives that affect fuel economy standards significantly contribute to the 2030 transportation sector GHG reductions. The technology advances are designed to improve vehicle fuel economy and reduce average GHG emissions per mile. The standards have been adopted through EPA Final Rulemakings and include light-duty vehicles, medium- and heavy-duty trucks, and fuel standards. These benefits represent the largest contributor to

GHG reductions in the transportation sector. The benefits will increase over time as the fleet turns over with newer vehicles and older vehicles are removed from the fleet. A summary of these standards is presented in **Table 4.1**.

**Table 4.1 2030 Approach Overview – Standards and Programs**

**Light-duty Vehicle (passenger cars and trucks) Standards**

- ***The Maryland Clean Car Program*** (Model Year 2011) – Implements California's Low-Emission Vehicle (LEV) standards to vehicles purchased in Maryland. The California LEV program also includes goals for the sale of electric vehicles (adopted 2007).
- ***Corporate Average Fuel Economy (CAFE) Standards (Model Years 2008-2011)*** – Vehicle model years through 2011 are covered under existing CAFE standards that will remain intact under the new national program.
- ***National Program (Model Years 2012-2016)*** – The light-duty vehicle fuel economy standards for model years between 2012 and 2016. The fuel economy improvements increase over time until an average 250 gram/mile $CO_2$ standard is met in the year 2016. This equates to an average fuel economy near 35 mpg (published May 2010).
- ***National Program Phase 2 (Model Years 2017-2025)*** – The light-duty vehicle fuel economy standards for model years between 2017 and 2025. The standards are phased-in and projected to result in an average 163 gram/mile of $CO_2$ by model year 2025. This equates to an average fuel economy of 54.5 mpg (published October 2012).

**Medium/Heavy-duty Vehicle (trucks and buses) Standards**

- ***Phase 1 National Medium and Heavy Vehicle Standards (Model Years 2014-2018)*** – Fuel efficiency and GHG standards for model years 2014 to 2018 medium- and heavy-duty vehicles. The new rulemaking adopted standards for three main regulatory categories: combination tractors, heavy-duty pickups and vans, and vocational vehicles. (published September 2011)
- ***Phase 2 National Medium and Heavy Vehicle Standards (2018 and Beyond)*** – The Phase 2 fuel efficiency and GHG standards for medium- and heavy-duty vehicles for model year 2018 and beyond. The standards apply to four categories of medium- and heavy-duty vehicles: combination tractors, heavy-duty pickups and vans, vocational vehicles and trailers to reduce greenhouse gas emissions and improve fuel efficiency. The standards phase in between model years 2021 and 2027 for engines and vehicles, and between model years 2018 and 2027 for trailers. (published October 2016)

**Fuel Standards**

- **Tier 3 vehicle and fuel standards** – The rule establishes more stringent vehicle emissions standards and will reduce the sulfur content of gasoline from current average level of 30 ppm to 10 ppm beginning in 2017. The gasoline sulfur standard will make emission control systems more effective for both existing and new vehicles and will enable more stringent vehicle emission standards. The vehicle standards will reduce both tailpipe and evaporative emissions from gasoline powered vehicles (published April 28, 2014)
- **The Federal Renewable Fuel Standard Program (RFS2) –** Mandates the use of 36 billion gallons of renewable fuel annually by 2022 (published March 2010). Based on an approach utilized by the Metropolitan Washington Council of Governments (MWCOG), the use of renewable fuels will represent a 2 percent reduction in total on-road gasoline $CO_2$ emissions in 2030.

**Electric Vehicles (EVs)** – Initiatives to encourage the use of electric and other low and zero-emitting vehicles are part of Maryland's efforts to reduce emissions of GHGs and other air pollutants from mobile sources by providing alternatives to conventional internal combustion engine vehicles. EVs include plug-in all-electric vehicles, battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs). Maryland has assumed a leadership role in facilitating the deployment of EVs and EV charging infrastructure in the State.

During the 2011 Maryland Legislative session, the General Assembly passed legislation creating EVIC, which was approved by the Governor in May 2011. MDOT chairs EVIC, working with MDE and MEA, as well as other public and private stakeholders to plan and develop policy regarding EVs. EVIC produces annual reporting on the progress of developing, evaluating and recommending strategies to facilitate the successful integration of EVs and EV infrastructure into Maryland's existing transportation infrastructure. In 2017, EVIC supported the passage of SB 393/HB 406, the Clean Cars Act of 2017, which Governor Hogan signed into law on May 4, 2017. This bill made the following changes:

- Extended the Electric Vehicle Recharging Equipment Rebate Program and authorization to issue motor vehicle excise tax credits for qualified PEV vehicles through fiscal year 2020.
- Increased the total amount of equipment rebates from up to $600,000 to a maximum of $1,200,000 per fiscal year, increasing the amount required to be transferred from the Strategic Energy Investment Fund to the Transportation Trust Fund (TTF).
- Increased the amount of motor vehicle excise tax credits that may be issued during a fiscal year. The credit value was reduced to $100 per kilowatt-hour (kWh) of battery capacity of the vehicle up to $3,000.
- Added additional eligibility requirements, capping qualifying vehicle purchase prices at $60,000, and requiring a minimum battery capacity of 5 kWh.
- Drivers of approved plug-in electric vehicles can use Maryland's high occupancy vehicle (HOV) lanes even if they are traveling solo.

Maryland's ZEV program is part of the California Clean Cars Program that Maryland adopted in 2007 and part of a seven-state memorandum of understanding (MOU) with auto manufacturers. The ZEV program requires an increasing number of ZEVs be made available for sale in the state. **The State goals for the number of registered EVs are – 60,000 by 2020, 300,000 by 2025, and 600,000 by 2030. These goals assume that 20 percent of the new passenger cars and truck sales are electric by 2025 and electric vehicle VMT represents 11 percent of the total VMT by 2030.**

## 4.2 2030 Emission Outcomes

The modeled Baseline Scenarios include the 2006 baseline that establishes the 2030 40 percent reduction goal and 2014 and 2017 baseline that reflects a true up of actual conditions and vehicle standards in place. The Baseline Scenarios also includes the 2030 BAU that assumes continued growth in vehicle travel and existing vehicle standards in 2030. **Table 4.2** summarizes annual VMT and GHG emissions for the Baseline Scenarios.

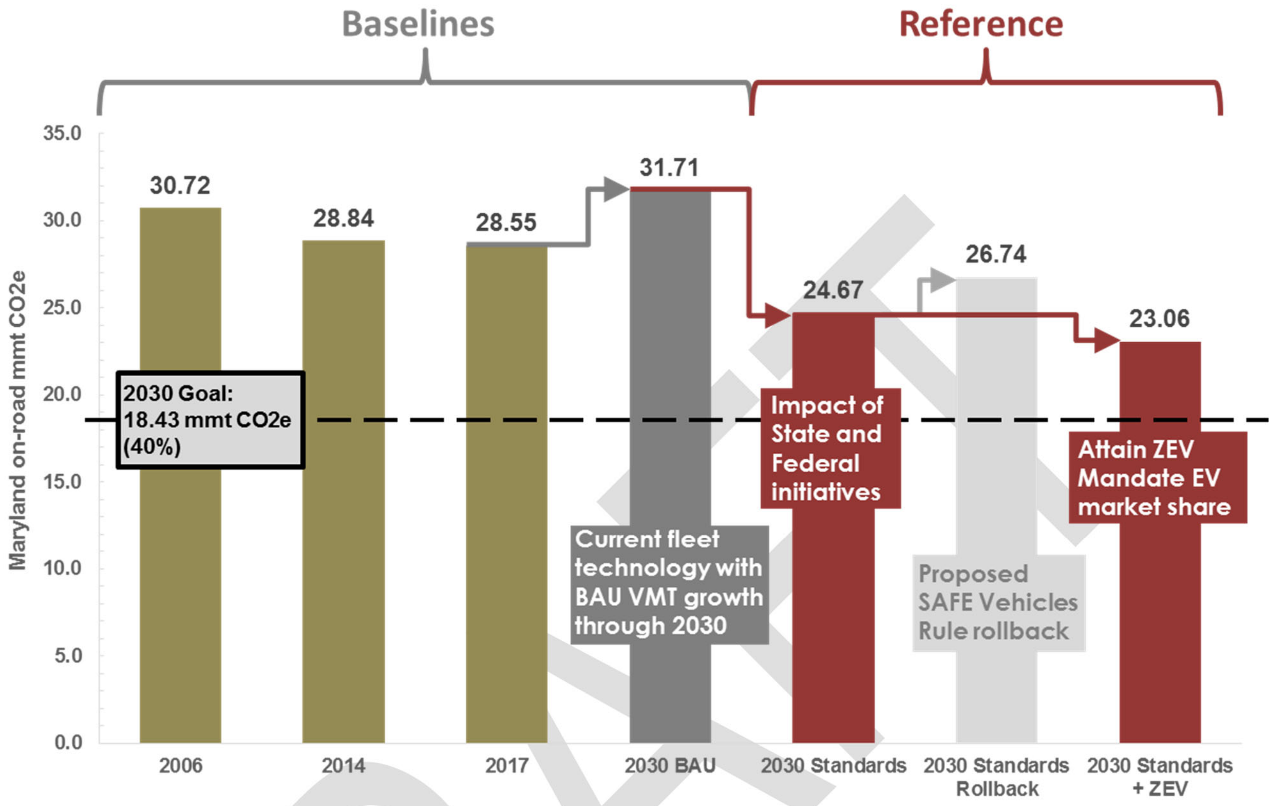
## Table 4.2 Maryland VMT and GHG Emissions for Baseline Scenarios

| Emissions Source | Measure | 2006 Baseline | 2014 Baseline | 2017 Baseline | 2030 Business as Usual |
|---|---|---|---|---|---|
| Light Duty Passenger Cars and Trucks | Annual VMT (millions) | 51,823 | 52,253 | 55,799 | 66,517 |
| | **Annual mmt $CO_2e$** | **23.34** | **22.49** | **22.45** | **24.35** |
| Medium/Heavy Duty Trucks & Buses | Annual VMT (millions) | 4,795 | 4,147 | 4,092 | 5,304 |
| | **Annual mmt $CO_2e$** | **7.38** | **6.35** | **6.10** | **7.36** |
| All On-road Vehicles | Annual VMT (millions) | 56,618 | 56,400 | 59,892 | 71,821 |
| | **Annual mmt $CO_2e$** | **30.72** | **28.84** | **28.55** | **31.71** |

Figure 4.1 presents each component of the Baseline Scenarios and the Reference Scenario.

- In 2017, GHG emissions from on-road sources is estimated at 7 percent below 2006 emissions.
- From 2017 to 2030, total on-road GHG emissions could increase 3.16 mmt $CO_2e$ to 31.71 mmt $CO_2e$ resulting from average annual VMT growth at 1.7 percent and only vehicle turnover accounting for current technology and standards. This represents the BAU Baseline Scenario.
- With the full implementation of final federal vehicle and fuel standards through 2030, **total on-road GHG emissions could decrease by 7.04 mmt $CO_2e$, bringing 2030 emissions 20 percent below 2006 emissions.**
- If the federal rulemaking of the SAFE Vehicles Rule for rolling back or freezing the federal light-duty vehicle standards to 2020 standards is approved, the GHG emissions for 2030 may increase by 2.07 mmt $CO_2e$. This result represents a potential worst-case scenario associated with the SAFE Vehicles Rule. Ultimately, the emissions impact of this potential standard change is highly uncertain given that auto manufacturers may choose to exceed Federal standards, particularly in state's like Maryland that are committed to the California standards.
- Presuming the current federal vehicle standards are fully implemented, and Maryland meets the ZEV mandate market share goals by 2030, **total on-road GHG emissions could decrease another 1.61 mmt $CO_2e$, bringing 2030 emissions to 25 percent below 2006 emissions.**

**Figure 4.1 Baseline and Reference Scenarios**



Utilizing a composite emissions factor, in 2014, a reduction of 1.96 billion VMT was required to reduce GHG emissions by 1 mmt $CO_2e$. As vehicles become cleaner, and the federal fuel economy standards begin to take hold, that figure increases in 2030 to 2.87 billion VMT required to reduce GHG emissions by 1 mmt $CO_2e$. **In other words, 2030 VMT would have to be reduced by 4 percent to achieve a 1 mmt $CO_2e$ reduction in on-road emissions.**

## 4.3 Implementation

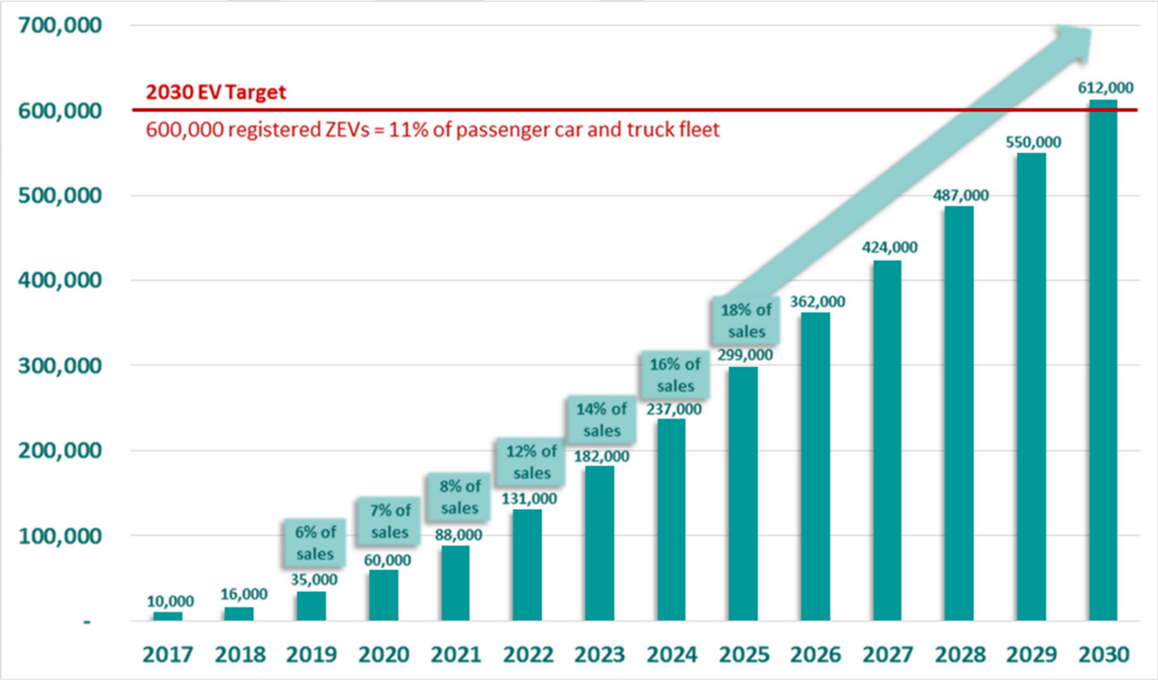
Implementation of the federal vehicle and fuel standards yields a significant GHG emissions benefit for on-road emissions from cars and trucks through 2030. Ultimately, vehicle turnover rates, vehicle purchase and operating costs, and other economic factors will impact exactly what the on-road fleet looks like in 2030. Taking these external forces into account, the forecasts developed through the robust analytical process within the MOVES model represents the state of the practice in estimating future emissions from on-road emission sources. The federal programs are managed by EPA and the National Highway Transportation Safety Administration (NHTSA) through partnerships with vehicle manufacturers.

For EVs, vehicle manufacturers will attain fleet-wide GHG emission requirements through a mix of different vehicle models and technologies. This will include traditional gasoline and diesel-powered vehicles, as well as hybrids, PHEVs, and BEVs, among other technologies. Achieving the goals within the ZEV mandate (300,000 EVs by 2025) reflects a commitment to a low-emissions fleet that well surpasses the federal standards. The path from nearly 10,000 PHEVs and BEVs registered in Maryland in 2017 to 300,000 vehicles by 2025 and 600,000 vehicles by 2030 requires a number of assumptions.

- ZEV sales and registrations have fallen well short of the original EV deployment goals. Implementation of the ZEV mandate as part of Maryland Clean Car Program starting in the year 2011 assumed a ramping up of ZEV sales until year 2018 when 16 percent of new light-duty vehicle (passenger cars, passenger trucks and light commercial trucks) sales are registered in Maryland are ZEVs. At this level of theoretical deployment, the total EV population in Maryland in the year 2017 was projected to be over 130,000 vehicles.
- To meet the goals, starting in 2018, EV deployment ramp-up is envisioned to start at a slower rate of 5 percent of sales in 2018, increased by a percentage point to 6 percent in 2019, which is then annually ramped up by two percentage points until hitting the Maryland Clean Car regulation of 16 percent of all new vehicles sold in the state by the year 2024. At this rate, Maryland would surpass 290,000 registered ZEVs by 2025.
- From 2025 to 2030, ZEV sales average 16 percent annually. With this rate of deployment, Maryland could reach over 600,000 registered ZEVs in 2030, which represents 11 percent of the light-duty fleet.
- Not all ZEVs are the same when considering GHG emission impacts. This approach assumes 75 percent of the ZEVs are PHEVs and the remaining 25 percent are BEVs. PHEVs are assumed to operate on electric power (no tailpipe emissions) for 55 percent of all vehicle miles traveled.

**Figure 4.2** presents the projected ZEV deployment curve through 2030. Maryland costs to facilitate this level of deployment includes up to $1.2 million annually through 2030 for the Electric Vehicle Recharging Equipment Rebate Program and other costs associated with matching Federal grants to expand public electric vehicle charging infrastructure throughout Maryland.

### Figure 4.2 Electric Vehicle Deployment Approach



# 5.0 Policy Scenario 1 (On-the-books)

## 5.1 Description

Policy Scenario 1 includes projects and programs funded for implementation within MDOT's 2018-2023 CTP, expected investments in continuing MDOT GHG emission reduction strategies included in future CTPs through 2030, and projects in fiscally constrained MPO metropolitan transportation plans identified for implementation by 2030.

### *5.1.1 2030 Plans and Programs*

MDOT continually takes steps to plan, invest in, and evaluate the transportation system to ensure it connects customers to key destinations–enabling a growing economy. MDOT sets a vision for the transportation system through the MTP, which is then implemented through the six-year budget for transportation, projects produced annually as the CTP.

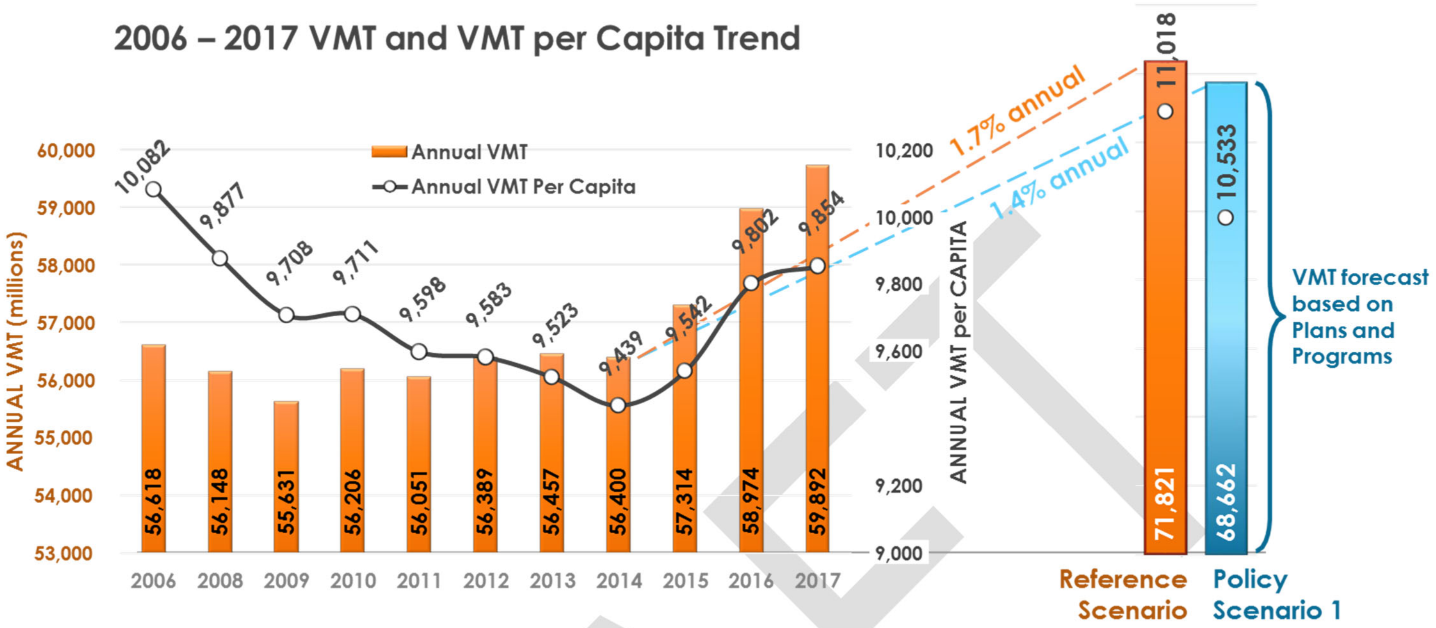
In coordination with MDOT, Maryland's MPOs develop federally required metropolitan transportation plans. These plans carefully combine locally driven projections of future land use with stakeholder input on transportation needs to develop fiscally constrained list of long-term transportation investments over the next 25 years.

The 2030 Plans and Programs uses information from the CTP, each MPO plan, and land use, population, and employment projections from MDP to estimate the emission trendline through 2030. The Plans and Programs are also referenced in this report as "on-the-books" (or Policy Scenario 1) to reflect that these actions are funded and programmed for implementation by MDOT. The primary benefit of the plans and programs relative to the Reference Scenario is the reduction in vehicle miles traveled and improved operational efficiency of the transportation system.

**The diversity of planned and programmed multimodal investments within the CTP and the MPO metropolitan transportation plans through 2030, matched with forecasted land use change consistent with local plans, results in an estimated reduction of 3.159 billion vehicle miles traveled (4.4 percent) through 2030.** This reduction is relative to the VMT growth trend through 2030 assumed within the Reference Scenario consistent with the average 1990 – 2014 trend of 1.7 percent annual growth. The key assumption for constructing this scenario is that the investment levels from the current MDOT CTP (FY 2018- FY 2023) continue at the same rate through 2030.

**Figure 5.1** presents Maryland's VMT trend since 2006 and the alternative VMT projections (Reference Case compared to Policy Scenario 1) for 2030. Note, both of these projections through 2030 anticipate VMT to continue to grow faster than Maryland's population, resulting in an increase in VMT per capita.

**Figure 5.1 VMT and VMT per Capita Trend and Forecasts**



## 5.1.2 Other "On-the-Books" Strategies

Along with the traditionally funded transportation programs and investments that have been included in the State and MPO planning documents, Policy Scenario 1 also assumes other "on-the-books" strategies that have been implemented with funding from Federal agencies (like the Department of Energy, EPA, and others) for improving air quality and reducing GHG emissions. Examples include Diesel Emissions Reduction Act (DERA) funding to replace or repower diesel engines, marine vessels, and cargo handling equipment. One such strategy includes MDOT MPA's help in replacing drayage trucks, which results in air quality benefits within the Port of Baltimore area where they operate.

Policy Scenario 1 also estimates the emissions impacts of current diesel transit bus replacement policies toward clean diesel and compressed natural gas for MDOT MTA, locally operated transit systems (LOTS), WMATA, and shuttle buses at BWI Airport. The emissions impact of a conversion to electric buses is included in Policy Scenario 2.

## 5.1.3 Strategy, Emissions, and Cost Summary

**Appendix B** lists each GHG mitigation strategy evaluated under the three policy scenarios, with strategy descriptions, underlying assumptions, summary of estimation methodology, and implementation caveats. **Table 5.1** lists the Policy Scenario 1 strategies, their estimated GHG reduction potential, and their estimated costs for implementation.

### Table 5.1 Policy Scenario 1 Strategies Summary

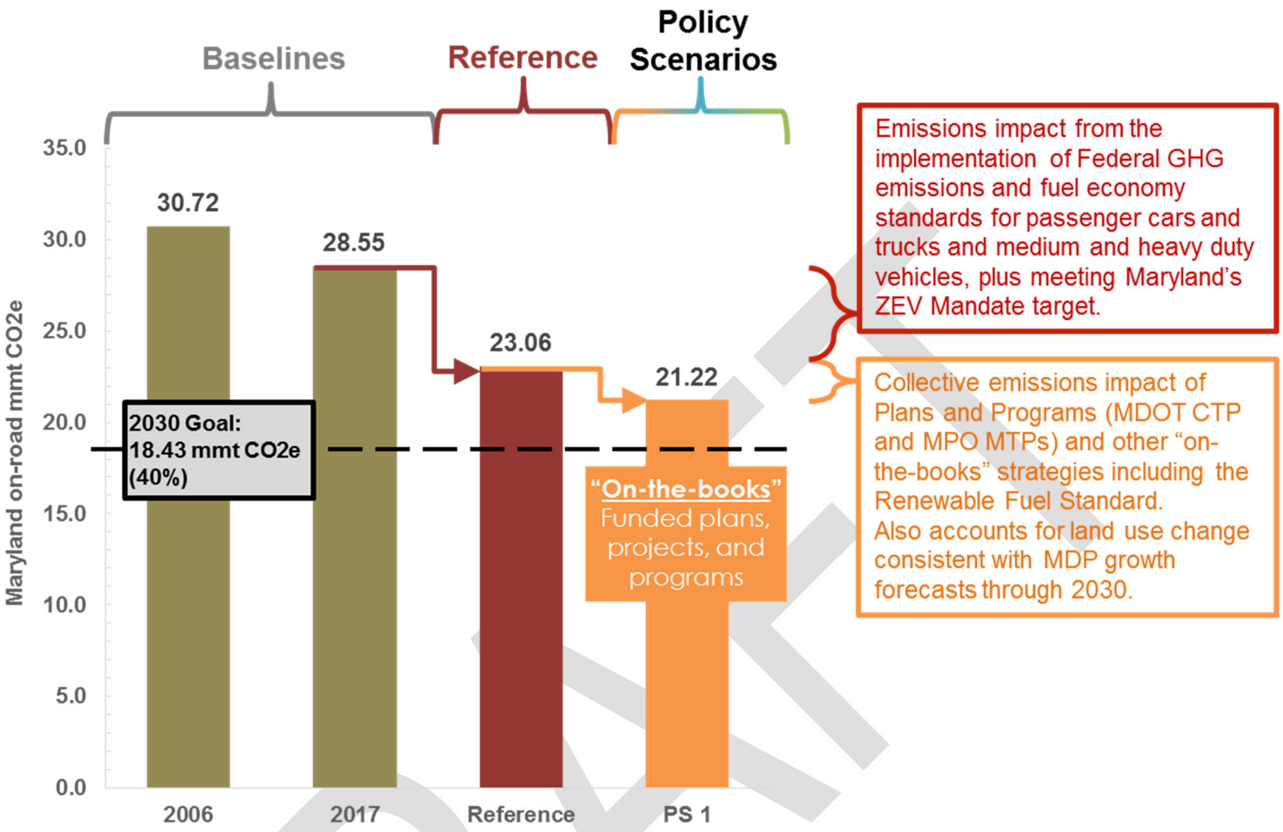
| Strategy | GHG Emission Reduction (mmt $CO_2e$) | Reduction Potential | Estimated Costs ($M) | Estimated Cost |
|---|---|---|---|---|
| Cumulative impact of the 2018 MPO Plans & Programs | 1.060 | ○○○ | $7,296 | $$$ |
| On-Road Technology (CHART, Traveler Information) | 0.163 | ○○ | $246 | $$ |
| Freight and Freight Rail Programs (MDOT MTA rail projects and National Gateway) | 0.072 | ○ | $31 | $ |
| Public Transportation (New capacity, improved operations, Bus Rapid Transit in MPO MTPs by 2030) | 0.033 | ○ | $2,144 | $$$ |
| Public Transportation (fleet replacement / technology based on current procurement) | 0.024 | ○ | $256 | $$ |
| TDM (Commuter Choice MD, Commuter Connections ongoing and expanding programs) | 0.142 | ○○○ | $30 | $ |
| Pricing Initiatives (conversion to All Electronic Tolling) | 0.018 | ○○ | $49 | $ |
| Bicycle and Pedestrian Strategies (program continuation and expansion through 2030) | 0.004 | ○ | $205 | $$ |
| Land-Use and Location Efficiency (MDP assumptions) | 0.318 | ○○○ | N/A | $ |
| Port of Baltimore Dray Track Replacements | 0.005 | ○ | $18 | $ |
| BWI Airport parking shuttle bus replacements | <0.001 | ○ | $52 | $ |
| **Total Policy Scenario #1 (30.9% reduction from 2006)** | **1.841** | | **$10,326** | |

## 5.2 Emission Outcomes

**Figure 5.2** presents the emission outcomes from Policy Scenario 1, compared to the 2030 Reference and the 2006 and 2017 Baselines.

- **The total estimated statewide reduction in 2030 is 1.825 mmt $CO_2e$.**
- Strategies that reduce VMT, including the Plans and Programs and other on-the-books strategies, result in a total reduction of 4.747 billion VMT in Maryland by 2030, equivalent to a 6.6 percent VMT reduction relative to business as usual VMT growth.
- Strategies that improve system operational efficiency and those that result in a cleaner fleet reduce fuel consumption by up to 18.0 million gallons of gasoline and 4.6 million gallons of diesel fuel in 2030 (in addition to fuel consumption reductions associated with the reduction of VMT).

**Figure 5.2 Policy Scenario 1 Emission Outcomes**



Emissions impact from the implementation of Federal GHG emissions and fuel economy standards for passenger cars and trucks and medium and heavy duty vehicles, plus meeting Maryland's ZEV Mandate target.

Collective emissions impact of Plans and Programs (MDOT CTP and MPO MTPs) and other "on-the-books" strategies including the Renewable Fuel Standard. Also accounts for land use change consistent with MDP growth forecasts through 2030.

## 5.3 Implementation

**Strategies listed as part of Policy Scenario 1 are funded in the six-year MDOT CTP (FY 2018-2023), MPO metropolitan transportation plans, or through Federal grants and funding sources. The total cost of Policy Scenario 1 totals $10.236 billion in capital investment through 2030**. This does not include additional operating costs for expanded transit or other services implemented by 2030.

The objective of constructing Policy Scenario 1 is to group programs and strategies that are completely funded or expected to be funded based on current funding levels and assumptions. In other words, the degree of confidence that the emission reductions from these strategies will materialize is tied to the assumption that the funding levels for these existing programs and strategies will continue through 2030.

The challenges for the continued implementation of Policy Scenario 1 strategies include widely acknowledged concerns such as diminishing fuel tax revenue, which is a primary funding mechanism for the Maryland TTF. Another related challenge is continued diminishing returns relative to needs from Federal sources, particularly formula funds provided through FHWA and FTA. MDOT and its partners also have to deliver this program, while at the same time maintaining and operating Maryland's multimodal transportation system.

This analysis assumes funding levels and shares across modes based on the CTP and the MPO metropolitan transportation plans. The projected scenario for funding is based on the best information we have at this time (over the next six years), which may be subject to change as MDOT and its partners respond to changes in mobility choices and travel patterns, and technological advancements that may alter some funding priorities and allocations. These assumptions are based on trends from the last few CTPs and are modeled on the latest version of the adopted CTP. They do not consider any potential major capital-intensive infrastructure initiatives that may need to be funded through 2030 to address new or emerging needs. This reinforces the characterization of Policy Scenario 1 as a trend or status quo scenario tied to current funding levels.

Major projects and programs within the $10.236 billion cost estimate for Policy Scenario 1 include:

- $405 million for Traffic Relief Plan implementation, including innovative congestion management (ICM) on the I-270 corridor, implementation of smart traffic signals on 14 corridors throughout Maryland, and implementation of peak hour shoulder use on I-695.
- $981 million in combined Federal, state, and local funding to match the $5.6 billion contract with the Purple Line Transit Partners (PLTP) to design, construct, financing, operate and maintain the Purple Line (not included in total Policy Scenario 1 costs).
- $1.16 billion through 2023 to support WMATA's capital improvement program
- Over $300 million for MDOT MTA bus procurement for fleet replacement and efficiency improvements
- $148 million for MARC service quality and reliability improvements on the Camden, Brunswick, and Penn corridors
- $111 million for MDOT SHA to improve, maintain and enhance the CHART program
- $63.6 million in funding to implement the next generation electronic tolling system which would represent the technology platform enabling a conversion to all-electronic tolling (AET)
- $175.4 million for bike and pedestrian projects and programs including 103 funded roadway expansion projects that include pedestrian and bicycle elements, in addition to the Bikeways Program and the Transportation Enhancements program, which focus on bicycle and pedestrian projects.

Cost information provided in these scenarios are all in present-day dollars. The costs presented in **Table 5.1** and highlighted in the list above include the total capital cost, including planning, preliminary engineering, right-of-way acquisition, and construction costs. Operations and maintenance costs were not included as part of the total costs presented in this report. Another point to note is regarding implementation costs for some of these strategies that may be administrative or regulatory costs, which are relatively modest and often times absorbed into the implementing agency budgets. Those costs have been presented in **Table 5.1** as "N/A" or "negligible".

# 6.0 Policy Scenario 2 (Emerging and Innovative)

## 6.1 Description

This scenario envisions implementing two distinct categories of GHG mitigating strategies – emerging and innovative strategies. The key distinction between the Policy Scenario 1 strategies and these strategies is the potential funding available for implementation. Funding sources for emerging and innovative strategies has not been finalized in any planning documents by Federal, State, local or private agencies. For a number of these strategies MDOT has limited control in their execution. Some of these strategies are driven by market forces that require MDOT to play the role of a facilitator enabling supportive policy and regulatory framework for their implementation.

### *6.1.1 Emerging Strategies*

Emerging strategies can be defined as logical next steps of strategies that are currently funded in the Policy Scenario 1, whose implementation requires one or more of the following:

- Full implementation of a strategy where current fiscally constrained plans have not identified the complete funding approach
- Expanded application of the strategy by enhancing its geographic scope, accelerated implementation of a strategy that would otherwise not be implemented before 2030, and implementation ramp-up of a strategy involving its intensity of application
- Strategies that have been implemented in peer states that could work in Maryland
- Expanded policy impetus and partnerships for a regional scale strategy application

Emerging strategies have a reasonably demonstrable record of mitigating emissions from both technological and practice adoption perspectives. Many of these strategies have been successfully implemented in peer states and to varying extents in Maryland. However, there is still some uncertainty as it relates to roll-out of some of these strategies as to the rate of adoption of new technologies by policymakers and the general public. Examples of such strategies include adoption of EVs by the public and transition to an electric bus fleet by transit agencies.

**Table 6.1** presents the list of emerging strategies, which consist of strategies that are extensions of Policy Scenario 1 strategies, and their associated emission reductions and cost estimate. The cost estimates indicate a range consistent with understanding on the potential low to high implementation cost associated with each strategy. These strategies acknowledge the potential to fully implement by 2030 and realize the benefits of more traditionally funded strategies in the event additional funding is made available or if there is considerable policy shift in the direction of funding some of those strategies through potential alternative financing mechanisms. Examples of such strategies include expanded bicycle and pedestrian projects, fiscally unconstrained transit capacity expansion, and expanded TDM coverage. Some strategies involve leveraging technology like CHART and expanding footprint in the areas of systems management including arterial, freeway, and access management systems. In addition, the emerging strategies assumes full implementation of the Traffic Relief Plan by 2030.

## Table 6.1 Policy Scenario 2 Strategies Summary (Emerging)

| Strategy | GHG Emission Reduction (mmt $CO_2e$) | Reduction Potential | Estimated Costs ($M) | Estimated Cost |
|---|---|---|---|---|
| Freeway Management/Integrated Corridor Management | 0.052 | ○○ | $506 to $760 | $$ |
| Arterial System Operations and Management | 0.049 | ○○ | $453 to $680 | $$ |
| Limited Access System Operations and Management | 0.023 | ○○ | $108 to $152 | $$ |
| Managed Lanes (I-270/I-495 Traffic Relief Plan Implementation) | 0.051 | ○○ | $6,650 to $9,840 | $$$ |
| Intermodal Freight Centers Access Improvement | 0.017 | ○○ | $2,240 to $3,136 | $$$ |
| Commercial Vehicle Idle Reduction, Low-Carbon Fleet | 0.055 | ○○ | Nominal § | $ |
| Eco-Driving (informal implementation underway) | 0.042 | ○○ | $3 to $5 | $ |
| Lead by example - Alternative Fuel Usage in State Fleet | 0.004 | ○ | Nominal § | $ |
| Truck Stop Electrification | 0.007 | ○ | $9 to $38 | $ |
| Transit capacity/service expansion (fiscally unconstrained) | 0.069 | ○○ | $2,307 to $2,659 | $$$ |
| Expanded TDM strategies (dynamic) | 0.314 | ○○○ | $15 to $30 | $ |
| Expanded bike/pedestrian system development | 0.081 | ○○ | $103 | $$ |
| Freight Rail Capacity Constraints/Access | 0.072 | ○○ | $300 | $$ |
| Regional Clean Fuel Standard | 0.382 | ○○○ | $148 | $$ |
| MARC Growth and Investment Plan / Cornerstone Plan | 0.052 | ○○ | $1,078 | $$$ |
| Additional 100K Ramp Up (total of 704,840 EVs) | 0.322 | ○○○ | $54 | $$$ |
| 50% EV Transit Bus Fleet | 0.036 | ○○ | $93 | $ |
| **Total Policy Scenario #2 "Emerging" (36.2% reduction from 2006)** | **1.628** | | **$14,068 - $19,077** | |

§ Nominal costs are program implementation, regulatory facilitation, and support costs for implementing emission reduction strategies, where MDOT has limited control.

### *6.1.2 Innovative Strategies*

Among the strategies grouped under innovative strategies in Policy Scenario 2 are those that are "disruptive" or undergoing breakthroughs in innovation, having impact on a significant user base and broad market reach, and having the potential to alter status quo in the way people make and execute their travel choices. These strategies are also characterized by uncertainty in the technological and policy maturity that is required for widespread adoption. Examples of strategies that require policy and technological maturity are CAV technologies, zero emission truck corridors, and SCMAGLEV or Loop.

Some strategies have been implemented on a controlled or limited scale by pioneering jurisdictions – for example, freight consolidation centers and variable speed management corridors.

MDOT's role in implementing some of these strategies is by playing the role of a facilitator and a policy regulator by providing a safe and conducive environment for Maryland residents and businesses to adopt the new technologies that are reshaping mobility choices and providing cleaner alternatives to single occupant vehicle travel. Challenges to implementing some of these strategies include technological maturity, MDOT's limited role in strategy facilitation or rolling out an enabling regulatory framework, partnerships with the private sector, transportation safety and data security and privacy, and concerns surrounding public acceptance (for example, speed management on freeways).

**Table 6.2** presents the list of innovative strategies, which consist of strategies that are extensions of Policy Scenario 1 strategies, and their associated emission reductions and cost estimate. The cost estimates indicate a range consistent with understanding on the potential low to high implementation cost associated with each strategy.

### Table 6.2 Policy Scenario 2 Strategies Summary (Innovative)

| Strategy | GHG Emission Reduction (mmt $CO_2e$) | Reduction Potential | Estimated Costs ($M) | Estimated Cost |
|---|---|---|---|---|
| Connected and Automated Vehicle Technologies | 0.647 | ○○○ | $43 - $62 | $ |
| Variable Speeds / Speed Management on Freeways | 0.083 | ○○ | $7 - $14 | $ |
| Zero-Emission Trucks/Truck Corridors | 0.059 | ○○ | $34 to $128 | $$ |
| Ride-hailing / Mobility-as-a-Service (MaaS) | 0.256 | ○○○ | Nominal § | $ |
| Pay-As-You-Drive (PAYD) Insurance | 0.062 | ○○ | Nominal § | $ |
| Freight Villages/Urban Freight Consolidation Centers * | 0.023 | ○○ | $4,705 - $ 6,893 | $$$ |
| SCMAGLEV/Loop ** | 0.056 | ○○ | $45,300 to $47,300 | $$$+ |
| **Total Policy Scenario #2 "Innovative" (40.3% reduction from 2006)** | **1.186** | | **$50,089 - $54,397** | |

§ Nominal costs are program implementation, regulatory facilitation, and support costs for implementing emission reduction strategies, where MDOT has limited control.

* Freight Villages/Urban Freight Consolidation Center costs represent a combination of private sector investment and Maryland commitment (potentially MDOT sponsored or other funding mechanisms) investing in access improvements and site circulation.

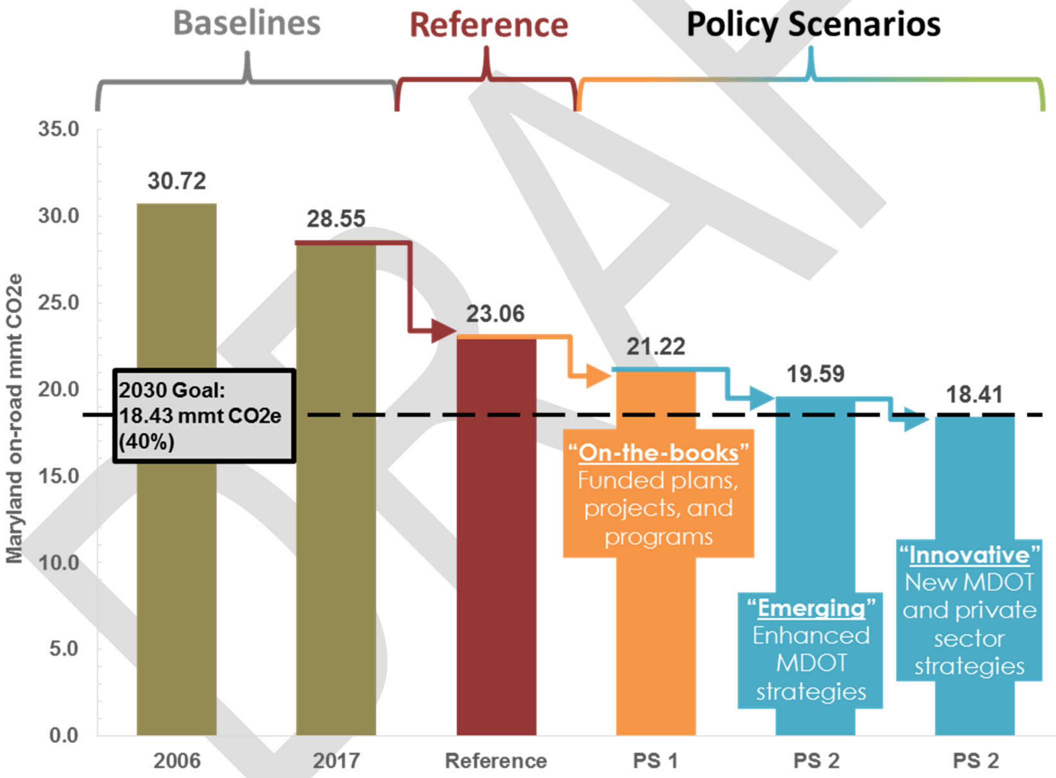
** High Speed Rail and SCMAGLEV costs include a majority of private costs and a mix of Federal and regional funding. Total funding estimate here reflects combined potential total of SCMAGLEV and Loop, but not implementation of the NEC Vision, which ultimately would be a Federal and regional funded effort.

## 6.2 Emission Outcomes

**Figure 6.1** presents the emission outcomes from Policy Scenario 2, compared to Policy Scenario 1, the 2030 Reference, and the 2006 and 2017 Baselines.

- **The total estimated statewide reduction in 2030 is 2.816 mmt $CO_2$e.**
- Strategies that reduce VMT, including the Plans and Programs and other on-the-books strategies, result in a total reduction of 3.629 billion VMT in Maryland by 2030, equivalent to an additional 5.1 percent VMT reduction relative to business as usual VMT growth. In total, the combination of Policy Scenario 1 and Policy Scenario 2 strategies reduce VMT by 11.7 percent in 2030.
- Strategies that improve system operational efficiency and those that result in a cleaner fleet reduce fuel consumption by up to 140.2 million gallons of gasoline and 13.4 million gallons of diesel fuel in 2030 (in addition to fuel consumption reductions associated with the reduction of VMT).

**Figure 6.1 Policy Scenario 2 Emission Outcomes**



## 6.3 Implementation

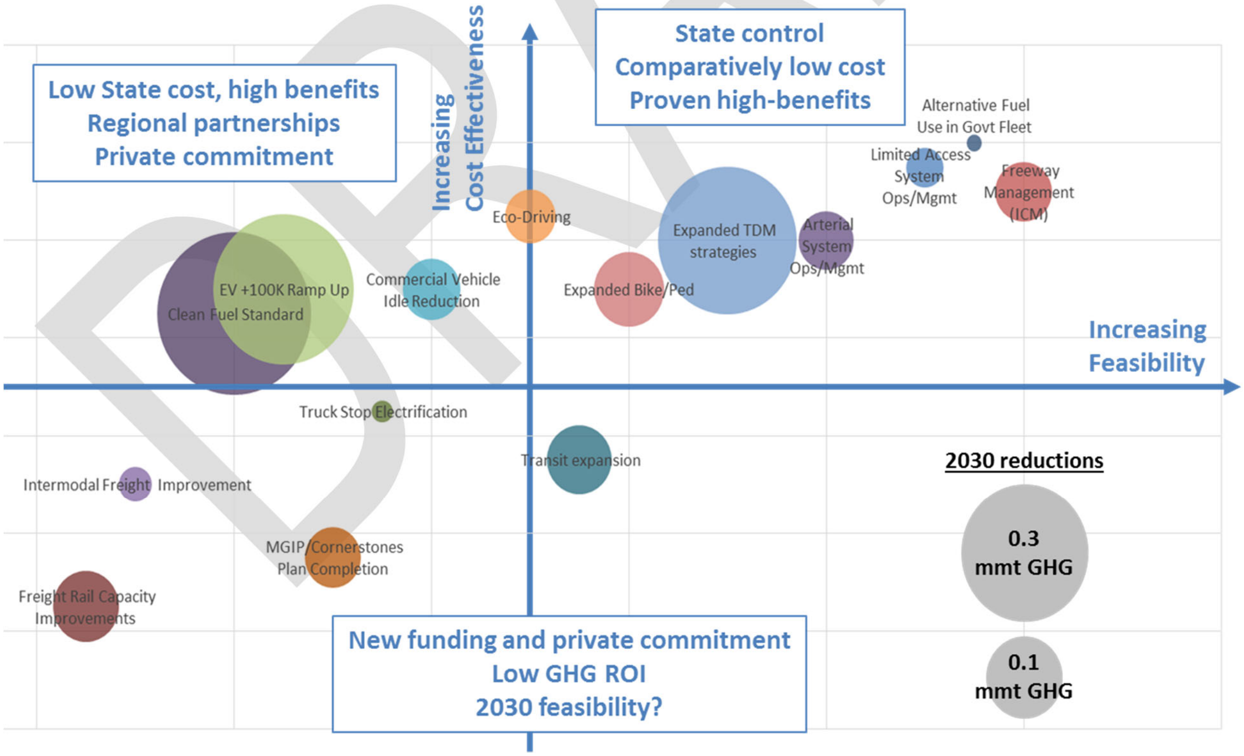
**Strategies listed as part of Policy Scenario 2 are currently not funded within MDOT's CTP or the MPO MTPs for implementation by 2030. Policy Scenario 2 total estimated costs, not including potential investments in MAGLEV or Loop, ranges from $18.860 billion up to $26.174 billion (funding levels of 180 to 250 percent above current fiscally constrained plans).**

The major underlying assumption for implementation of any of these strategies is that they require dedicated funding sources outside the current traditional investment sources and will require additional revenue to be generated for their implementation or necessitate funding from non-traditional sources of funding.  It should be noted that some these strategies require significant funding (comparable to the level of the State's entire CTP), which is indicative of challenges to their implementation. MDOT's role in implementation of these strategies is lower than that of the emerging strategies as the driving factors for the successful implementation of many of these strategies involve market forces and require significant share of private funding for execution.

The diverse suite of strategies in Policy Scenario 2 result in a wide spectrum of considerations regarding feasibility and cost effectiveness. **Figure 6.2** and **Figure 6.3** array each strategy in Policy Scenario 2 based on an objective look at feasibility and cost effectiveness relative to potential GHG reduction. For the purposes of this high-level scan, our definitions of feasibility and cost effectiveness are:

- **Feasibility** – Feasibility considers the extent of MDOT's level of control as it relates to strategy delivery and the engineering, technology, environmental, regulatory, and/or political hurdles to strategy implementation.
- **Cost Effectiveness** – Cost effectiveness considers the total implementation cost relative to the estimated GHG emission reduction while also considering the level of confidence in emission reductions as well as the potential for co-benefits.

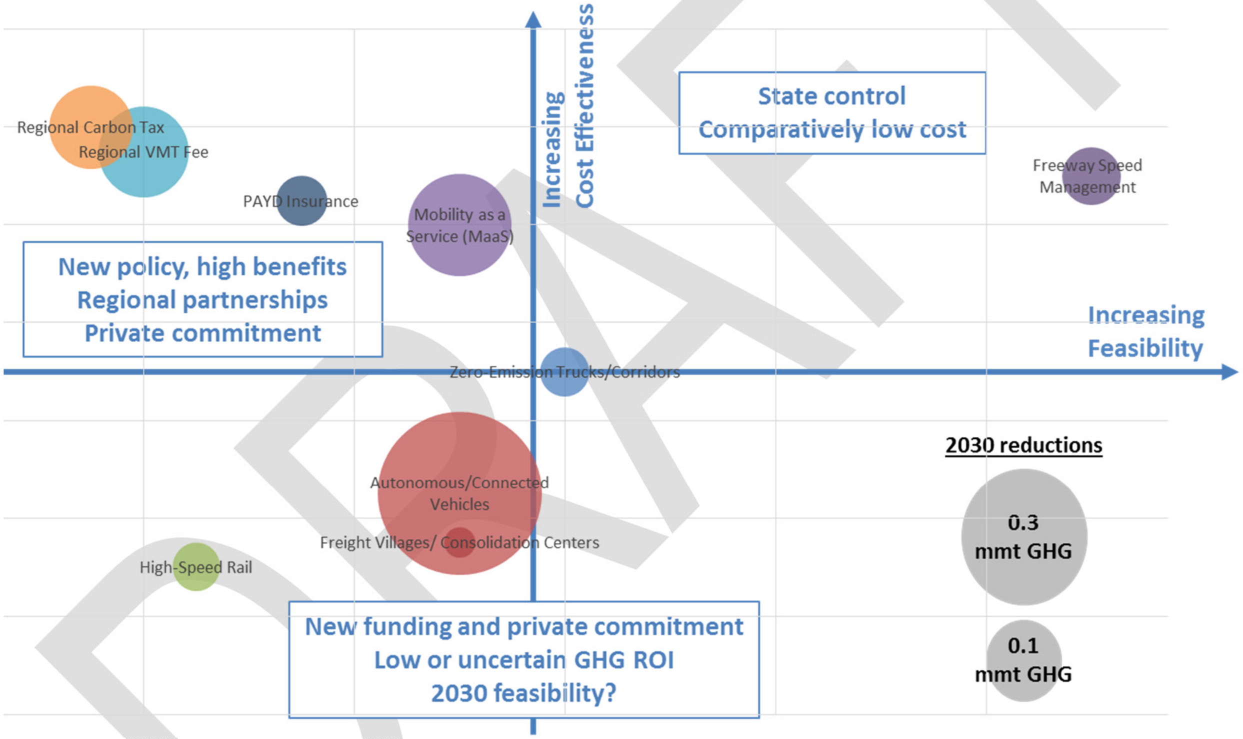
**Figure 6.2 Feasibility and Cost Effectiveness for "Emerging Strategies"**



Strategies in the upper right quadrant are those where MDOT is the primary strategy lead, costs are comparatively low relative to benefits, and the benefits are more reliable and less at risk to decrease because of external factors. Strategies in the upper left quadrant include some of the most cost effective and beneficial strategies from a GHG emission perspective, however, are less within MDOTs control or influence. In the case of a clean fuel standard and continued ramp-up of electric vehicle market share, MDOT may help facilitate implementation, but private commitment and market dynamics will impact long-term reductions. Strategies below the feasibility axis require significant capital investment (both public and private) and may yield significant economic and other transportation benefits (such as accessibility), they typically provide a low return in terms of cost relative to GHG emission reductions.

**Figure 6.3** presents the same graphic for the Innovative Strategies in Policy Scenario 2. As noted above, these strategies are predominantly less within MDOTs control (i.e., they require more partnerships with the private sector and across State lines) and show on average, higher cost effectiveness given the lower share of public funding involved in implementation.

### Figure 6.3 Feasibility and Cost Effectiveness for "Innovative Strategies"



# 7.0 Policy Scenario 3 (Pricing and Revenue)

## 7.1 Description

One potential policy mechanism for achieving the levels of reductions presented in Policy Scenario 2 would be to implement a transportation pricing policy, which could both achieve GHG reductions and generate revenue that could be used to fund clean and resilient transportation solutions. In the current transportation funding debate, mileage-based user fees, fuel fees indexed to inflation, carbon-content-based fees, and additional petroleum-based pricing policies have been discussed as potential options to reduce GHG emissions and raise proceeds for clean transportation policies. Policy Scenario 3 considers the potential effects of a hypothetical pricing policy on both GHG emissions and funding. The analysis considered a range of carbon-content-based fees, mileage-based user fees, and motor-fuel taxes. Ultimately, the emission impacts of these different policy approaches are comparable, while the potential revenue generated from each is subject to different external factors. For example:

- Carbon-content-based fees (or a carbon price) is based on a $ per unit of carbon. As the fleet moves toward lower carbon technologies (which in part may be encouraged by this policy), the revenue generated will decline relative to total VMT (although not as significantly as the motor vehicle fuels tax). The concept for a carbon price was drawn from the Transportation and Climate Initiative's (TCI) analysis supporting the *Reducing Greenhouse Gas Emissions from Transportation: Opportunities in the Northeast and Mid-Atlantic* report published in 2015.
- Mileage-based user fees (or a VMT fee) is based on $ per vehicle mile traveled. From a revenue perspective, this policy approach has no relationship to or impact on vehicle technology. It is strictly associated with total vehicle travel, which can have negative equity impacts on households unable to live close to where they work and on rural areas.
- Per the Code of Maryland, motor fuel tax rates are indexed for all fuels except aviation gasoline and turbine fuel to the annual change in the Consumer Price Index. The Transportation Infrastructure Investment Act of 2013 established this change in addition to imposing a sales and use tax equivalent on all motor fuel. Since 2013, the combined applicable tax rate has increased from $0.27 to $0.358 for gasoline and $0.2775 to $0.3605 for diesel. The continuing move toward a more efficient and electric fleet will decrease the revenue generating power of this tax relative to VMT growth.

Among these options, MDOT developed an estimation of a potential Carbon Pricing strategy based on its more sustainable revenue source, ability to encourage further transformation to a low-carbon or zero carbon fleet, and lower equity concerns. **This analysis was conducted for the MWG's scenario planning purposes and is in no way indicative of MDOT's policy position.**

At this phase of the GGRA planning effort, MDOT's support is limited to generating a high-level estimate of GHG emission reductions and potential for revenue generation from the Carbon Pricing strategy. MDOT analyzed four different Carbon Pricing tests based on the following assumptions:

- **Test 1** – $30 per ton $CO_2e$ (consistent with TCI analysis) applied to all on-road mobile source emissions starting in 2025 – **$4.3 billion cumulative revenue potential through 2030**

- **Test 2** – $30 per ton $CO_2e$ (consistent with TCI analysis) applied to all on-road mobile source emissions starting in 2021 – **$7.5 billion cumulative revenue potential through 2030**
- **Test 3** – Carbon price increasing annually from $20 per ton in 2020 to the social cost of carbon, $62.25 by 2030, applied to all on-road mobile source emissions starting in 2025 – **$7.4 billion cumulative revenue potential through 2030**
- **Test 4** – Carbon price increasing annually from $20 per ton in 2020 to the social cost of carbon, $62.25 by 2030, applied to all on-road mobile source emissions starting in 2021 – **$10.7 billion cumulative revenue potential through 2030**

As described in the TCI report, implementation of a pricing policy works best at the regional scale. There are risks associated with Maryland acting independently in the transportation sector that could result in economic disbenefits to the state, such as relocation of firms due to higher transportation costs.

## 7.2 Emission Outcomes

**The emissions reduction (0.098 mmt $CO_2e$) from carbon pricing only accounts for the potential of the price to reduce vehicle miles traveled through encouraging mode shift or less and/or shorter vehicle trips.** The indirect impact of the pricing policy on encouraging low or zero-emission vehicle purchases was not analyzed (Note: Policy Scenario 2 already assumes an aggressive share of electric vehicles in the Maryland fleet (12 – 14 percent).

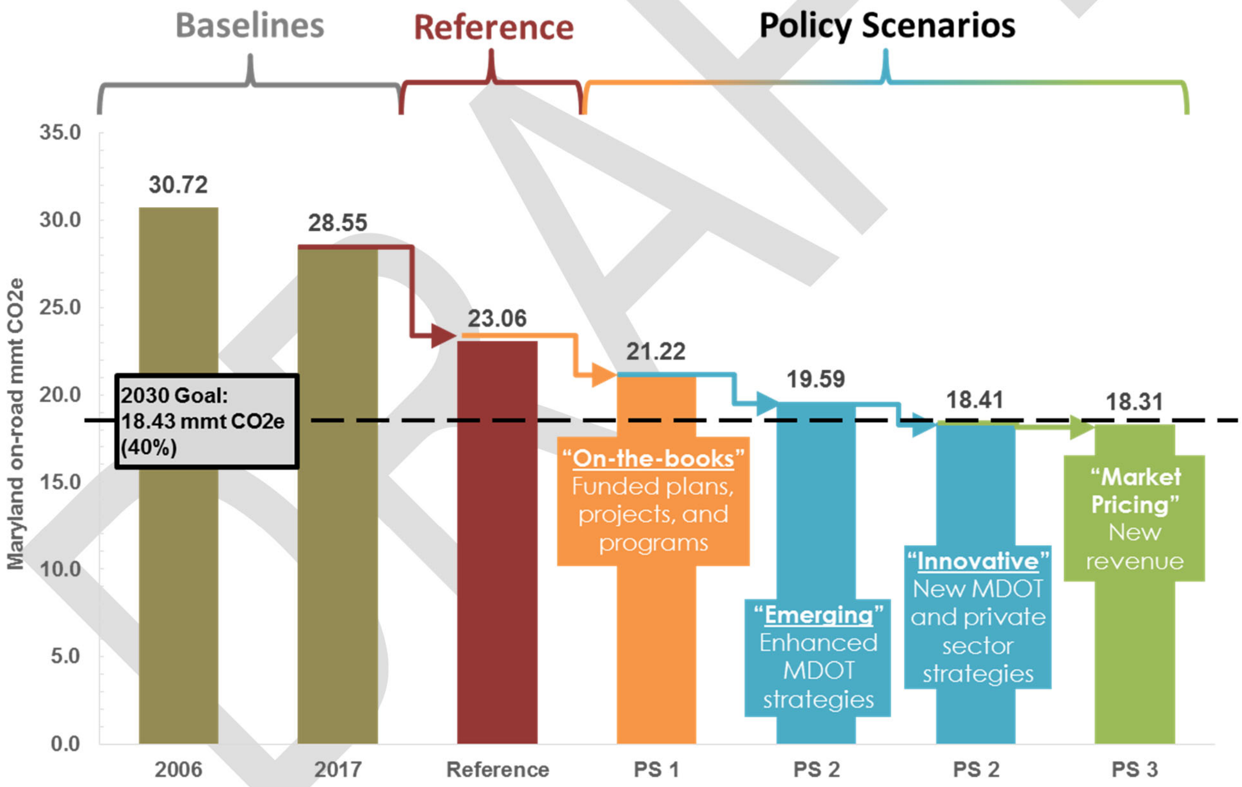
# 8.0 Findings Summary and Next Steps

## 8.1 Emission Outcomes

The on-road transportation sector in Maryland could achieve the "40 by 30" goal as highlighted by the results of the analysis presented in previous sections and summarized in **Figure 8.1**.

There is a multitude of approaches MDOT and its partners could take to facilitate achievement of the goal. These include substantial investments in multimodal options and new technologies to push more people and goods toward cleaner and more efficient modes, and to improve the efficiency of transportation system operations. However, many of the most significant GHG reduction strategies are mostly outside the control of MDOT, including for example, EV market penetration.

**Figure 8.1 2030 Draft Emission Results**



## 8.2 Implementation

Maryland's multimodal transportation network faces a number of challenges. Some are inherent to the network itself – continuing to maintain and modernize infrastructure and ensure the safe and efficient movement of people and goods – while others are related to changing transportation needs associated with technological, societal, demographic, land use, climate, and other environmental changes. An increasing number of residents and employers in the State will generate additional revenue, but they will also demand services, including transportation services, which could require increased spending. The impact of transportation-related technological changes such as CAVs, EVs, and the shared mobility economy is uncertain. MDOT maintains and delivers a transportation system that addresses these critical challenges to ensure that Maryland remains a great place to live, work, and do business. Across all of these challenges, Maryland faces the overarching uncertainty associated with the transportation-funding picture through 2030:

- Needs continue to far outweigh available resources and revenues;
- The federal funding picture continues to trend toward a competitive grant program, with less reliance on traditional formula-based funding; and
- Traditional revenue sources are producing less relative to growing demand, particularly as trends continue toward more efficient vehicle and lower ownership rates.

Maryland's transportation needs are comprised of the costs required to operate and maintain the current transportation system, and to expand services and infrastructure as needed. These costs include operation and maintenance (O&M) expenses, capital needs as provided by MDOT's six TBUs, and Maryland's share of the WMATA system. O&M expenses include the costs of service for 104 million annual transit trips, maintenance of highways and bridges, dredging for the Port of Baltimore, and operations for the BWI and MTN airports. Capital needs focus on existing assets and strategic expansion with the goal being to maintain and modernize.

### *8.2.1 Transportation Revenue Sources*

Transportation needs in Maryland are primarily funded from an integrated account called the Transportation Trust Fund (TTF) from sources including motor fuel tax, rental car sales tax, titling tax, corporate income tax, operating revenues, Federal aid, motor vehicle taxes and fees, and bond sales.

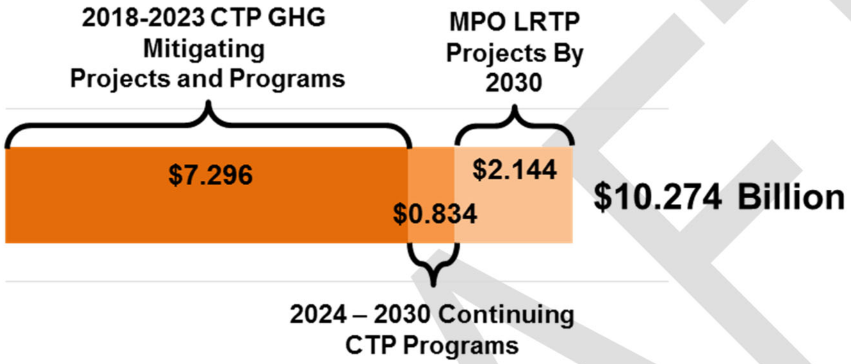
The Transportation Infrastructure Investment Act of 2013 (Transportation Act) substantially increased and advanced the TTF revenues. The changes included an increase in state motor fuel taxes; the indexing of principal revenue streams (e.g. motor fuel taxes and MDOT MTA passenger fares) to inflation; and restrictions on the transfer of funds from the Trust Fund to the State's General Fund. Funds from the TTF are not necessarily earmarked for specific agencies or programs. This approach affords Maryland tremendous flexibility to meet the varying service and infrastructure needs to support its diverse transportation system. With the exception of MDTA, which is funded primarily through tolls and concessions revenues, all activities of MDOT are supported by the TTF.

Though the Transportation Act provided a boost to the TTF over the past 5 years, MDOT's transportation infrastructure needs to maintain and preserve the extensive system, strategically expand the system, and modernize the system is projected to exceed MDOT's ability to fund all needed improvements. This coupled with the conservative assumptions about availability of future federal funds, highlights the importance of other project funding options including partnerships. Partnerships with other state and local agencies, and increasingly private entities are critical to ensuring the available funding to implement projects and meet the State's transportation needs.

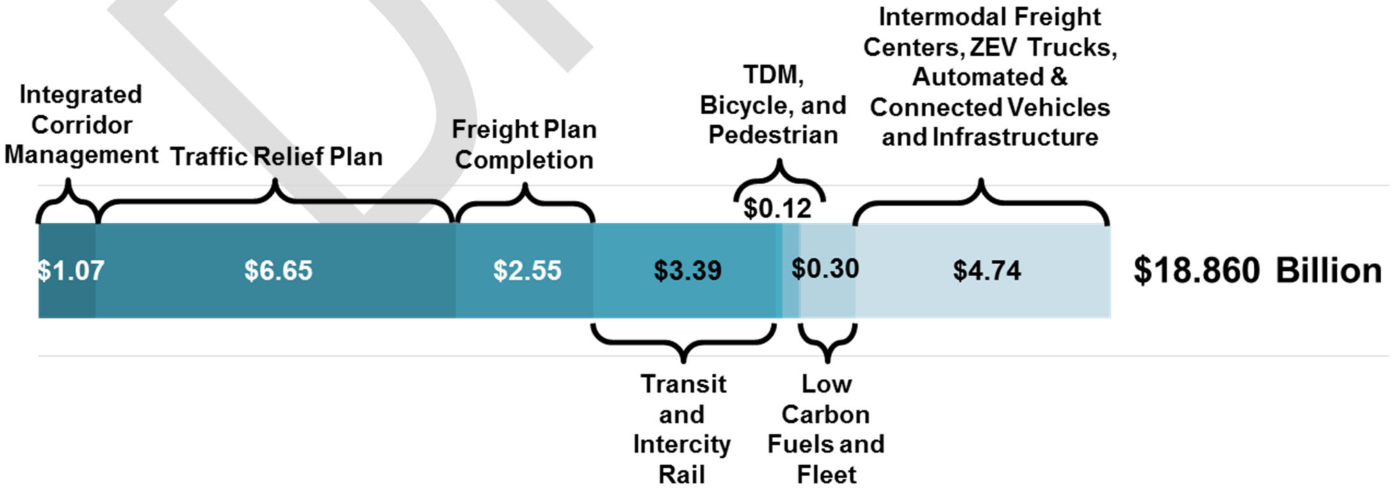
### 8.2.2 *Projected 2030 Scenario Costs*

The analysis of Policy Scenario 1, 2, and 3 included cost estimates for the complete implementation of strategies through 2030. These costs represent cumulative MDOT capital cost estimates in constant dollars through 2030.

- **Policy Scenario 1** includes total costs for all GHG mitigating project and programs funded in the 2018-2023 CTP, estimates of ongoing investments in current MDOT programs from 2024 – 2030 based on annual trendline investments in the CTP, and funded projects and programs in MPO MTPs planned for implementation by 2030. All of these programs are included within fiscally constrained plans, meaning that revenue sources are projected to be available to fully fund for implementation.



- **Policy Scenario 2** includes planning level cost estimates based on current cost information, where available, and other best practice data. Policy Scenario 2 strategies fall into two general buckets – emerging strategies and innovative strategies. The emerging strategies have more cost information as they generally represent expansion and evolution of current MDOT programs. The innovative strategies have minimal cost information and, in many cases, rely on a majority share of investment from the private sector for implementation. In both cases, these strategy cost estimates are for strategies not currently within fiscally constrained plans. In other words, either additional funding, reprioritization of investments, or new private partnerships would be required for implementation.



**Total estimated costs in Policy Scenario 2 not including potential investments in SCMAGLEV or Loop in Maryland ranges from $18.860 billion up to $26.174 billion**. The total cost of SCMAGLEV and/or Loop is estimated at an additional $45.3 billion based on publicly available information on cost per mile and anticipated corridor length and alignment in Maryland.

- **Policy Scenario 3** includes a pricing mechanism, for the purposes of this analysis tested as a $ per ton of carbon price, that will generate additional revenue for transportation investment and potentially impact travel behavior and electric vehicle market share. At this time, there is no policy or regulatory commitment to a carbon pricing approach in Maryland. **Four alternative pricing tests were analyzed by MDOT generating between $4.3 billion and $10.7 billion in additional revenue for transportation beyond traditional sources.**

Cost effectiveness of the Policy Scenarios is presented in **Table 8.1**, excluding the emission reductions and costs from the SCMAGLEV / Loop strategy. The table introduces the concept of net cost, in order to compare the revenue generated by the low and high carbon price options to the total implementation costs associated with Policy Scenario 1 and Policy Scenario 2 strategies. Ultimately, the cost per ton of $CO_2e$ reduced across the three policy scenarios ranges from $5,200 to $3,300 (exclusive of the costs and emission reductions from the SCMAGLEV / Loop strategy).

**Table 8.1 Policy Scenario Cost Effectiveness**

| Scenario | GHG Emission Reduction (mmt $CO_2e$) | Net Cost (millions) (Low Range) | Net Cost (millions) (High Range) | Cost Effectiveness (Low Range) ($ per ton $CO_2e$) | Cost Effectiveness (High Range) ($ per ton $CO_2e$) |
|---|---|---|---|---|---|
| Policy Scenario 1 | 1.825 | $10,236 | | $5,609 | |
| Policy Scenario 2 (Emerging) | 1.628 | $14,068 | $19,077 | $8,600 | $11,700 |
| Policy Scenario 2 (Innovative, excluding SCMAGLEV/Loop) | 1.130 | $4,789 | $7,097 | $4,200 | $6,300 |
| Policy Scenario 3 | 0.098 | - $4,280 | - $10,680 | - $43,700 | - $109,000 |
| **Total Across All Scenarios** | 4.998 | $24,813 | $15,494 | $5,300 | $3,300 |

## 8.3 Co-Benefits and Economic Impact

The scope of strategies within the 2030 scenarios presented in this Plan represent an integrated, multimodal, and innovative approach to reducing GHG emissions from on-road transportation sources throughout Maryland. These strategies will create the opportunity for significant co-benefits beyond just reduced fuel consumption and GHG emissions, including improved air and water quality, public health benefits, more equitable transportation options and access to opportunity, and direct and indirect economic impacts for current and future Maryland workers and employers.

### 8.3.1 Environmental Co-Benefits

Ensuring environmental protection and sensitivity is a goal of the 2040 MTP. The goal focuses on strategies to deliver sustainable transportation infrastructure improvements that protect and reduce impacts to Maryland's natural, historic, and cultural resources.

The MDOT Draft GGRA Plan's transportation scenarios strive to achieve the 40 percent GHG reduction goal. These strategies, policies and programs also achieve substantial reductions of the National Ambient Air Quality Standards (NAAQS) criteria pollutants, including ozone producing volatile organic compounds (VOC) and nitrogen oxides ($NO_x$), and fine particulates ($PM_{2.5}$). Transportation related control measures and improvements to vehicle technologies that reduce ozone and $PM_{2.5}$ have been included in State Implementation Plans (SIP) and transportation conformity determinations. These measures are major contributors to meeting the State's air quality goals and have proven to be effective in attaining the NAAQS for ozone and fine particulates.

The implementation of EPA's Tier 3 Motor Vehicle Emission and Fuel Standards represents one of the largest $NO_x$ control strategies that reduce emissions from passenger cars, light-duty trucks, medium-duty passenger vehicles, and some heavy-duty vehicles. The enhanced vehicle technology standards combined with fleet turnover to newer vehicles provide significant reductions to criteria pollutants in 2030 as compared to the 2014 Baseline. In addition, the Tier 3 gasoline sulfur standard will make emission control systems more effective for both existing and new vehicles and removing sulfur allows the vehicle's catalyst to work more efficiently for improved fuel economy.

The Tier 3 tailpipe standards are being phased-in with full implementation by 2025. The final gasoline fuels standard of not more than 10 parts per million (ppm) of sulfur on an annual average was implemented in January 2017.

Advanced vehicle and fuel technologies and the Draft GGRA Plan scenarios not only reduce criteria pollutant and GHG emissions, but also indirectly will reduce on-road transportation sources impact on Maryland's water quality and diverse and sensitive ecosystems.

Table 8.2 below provides the criteria pollutant co-benefits (in tons/year) for ozone and fine particulates from the implementation of Baseline, Reference, and Policy Scenarios. Starting with the 2014 Baseline scenario, the transportation technologies that include federal fuel economy standards for light- and heavy-duty vehicles and Tier 3 tailpipe and gasoline standards contribute 60 to 76 percent emissions reductions in 2030. The forecast of over 600,000 electric vehicles provide 844 tons of $NO_x$ and 1,124 of VOC benefit. Overall, the 2030 Reference Scenario contributes 69 to 78 percent emissions reductions in 2030.

Policy Scenario 1 contributes an additional one percent $NO_x$ benefit. Policy Scenarios 2 and 3 also yield an additional 1 percent benefit for $NO_x$ and PM. In 2030, the total criteria co-benefits contribute 65 percent VOC (22.4k tons), 79 percent $NO_x$ (58.8k tons) and 67 percent $PM_{2.5}$ (1.9k tons) of reductions from the 2014 Baseline.

## Table 8.2 Transportation Sector Criteria Pollutants Co-Benefits

| Pollutant | Scenario | Total Annual Emissions (tons) | Percent Reduction from 2014 (cumulative) |
|---|---|---|---|
| **VOC** | 2014 Statewide On-road Baseline | 28,513 | |
| | 2017 Statewide On-road Baseline | 22,366 | 22% |
| | 2030 Reference | 10,216 | 69% |
| | Policy Scenario 1 | 10,185 | 69% |
| | Policy Scenario 2 | 10,077 | 69% |
| | Policy Scenario 3 | 10,063 | 69% |
| **$NO_x$** | 2014 Statewide On-road Baseline | 70,290 | |
| | 2017 Statewide On-road Baseline | 48,342 | 31% |
| | 2030 Reference | 15,797 | 78% |
| | Policy Scenario 1 | 15,539 | 79% |
| | Policy Scenario 2 | 14,593 | 80% |
| | Policy Scenario 3 | 14,447 | 80% |
| **$PM_{2.5}$** | 2014 Statewide On-road Baseline | 2,520 | |
| | 2017 Statewide On-road Baseline | 1,999 | 21% |
| | 2030 Reference | 882 | 68% |
| | Policy Scenario 1 | 874 | 68% |
| | Policy Scenario 2 | 840 | 69% |
| | Policy Scenario 3 | 836 | 70% |

### *8.3.2 Public Health*

The criteria pollutant emission reductions highlighted above would improve public health. Reductions in these emissions could help prevent premature deaths and asthma cases in Maryland, translating to reductions in public health costs. Other associated public health benefits include:

- Travelers would spend less personal time in traffic due to reduced congestion, saving significant hours of delay, enabling time for other activities and improving employee satisfaction;
- Reduced vehicle travel would result in fewer traffic accidents, while new technologies, such as connected and automated vehicles could significantly reduce the frequency and severity of crashes; and
- Increased walking and cycling as a result of investments in pedestrian and bicycle infrastructure is also expected to result in public health improvements.

### *8.3.3 Equity*

The MTP includes goals regarding facilitating economic opportunity and improving quality of life. These goals recognize the importance of Maryland's transportation system in facilitating access for the aging population and supporting growth and diversification of economic activity in Maryland's distressed economic regions. The increase in older and non-working transportation users could change travel patterns and travel times and affect public transportation agencies, non-profit transportation providers, and/or private providers. While Maryland's largest employment centers are in the Baltimore and Washington regions, other parts of the State require transportation investments to ensure the continued growth of their economies. Striking a balance between congested and growing areas and slower growth areas in need of investment continues to be a key consideration within short- and long-range multimodal planning in Maryland. Strategies referenced in the Maryland Transportation Plan supporting equity in transportation include:

- Pursuing capital improvements to the transportation system that will improve access to jobs and tourism and leverage economic growth opportunities;
- Target infrastructure and incentive programs towards improving job access and reducing household transportation costs; and
- Assess productivity benefits through travel cost savings, reliability benefits of industry, delivery logistics and supply chain benefits, and agglomeration effects on access to specialized skills and services to facilitate business opportunities throughout Maryland.

### *8.3.4 Economic Vitality*

**Consumer Cost Savings** – The combination of all policy scenarios would likely lead to consumers initially experiencing cost increases as they purchase more advanced clean vehicles and pay the cost of the pricing policy. These increases would be more than offset in a short time by cost savings from reduced fuel use (because consumers are driving more fuel-efficient vehicles and driving less as a result of more and improved multimodal options), reduced vehicle maintenance costs (also because they are driving less), and incentives and discounts (to promote clean vehicles).

**Business Cost Savings** – The combination of all policy scenarios would likely lead to businesses experiencing initial cost increases due to higher vehicle prices and the pricing policy. Over time, savings from reduced fuel use and vehicle maintenance costs, as well as reductions in labor costs due to relieved congestion and the availability of more cost-effective freight options would quickly offset these increases.

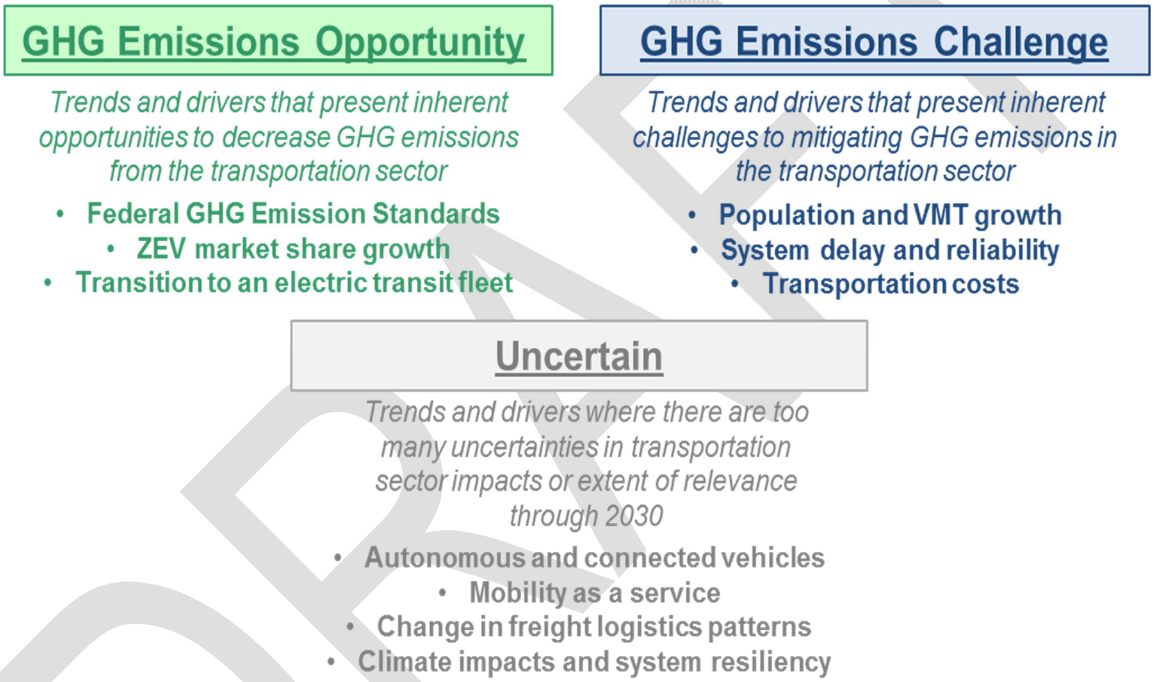
**Changes in Government Expenditures** – Maryland could receive an additional $4 to $10 billion in revenue for transportation investments through 2030 as a result of the pricing policy. The analysis assumes that the new funds would be reinvested in transportation strategies, resulting in direct benefits (construction jobs and logistics delivering materials) and indirect benefits (supporting retail and services).

**Net Macroeconomic Benefits** – Towson University, Division of Strategic Partnerships and Applied Research, is working with the MWG and MDE to assess the economic impacts of the GGRA policy scenarios. This analysis will report total job gains in Maryland and change in gross state product because of the combined effects of the carbon price and new infrastructure investments relative to the Reference Scenario.

## 8.4 Looking Toward 2050

As discussed in Section 2, through the MTP and other long-range planning activities, including those led by Maryland's MPOs, MDOT will continue to balance demand and available resources so that it can accommodate current needs as well as create the 2030 and beyond transportation network. Moving from 2030 to 2050, the extent of the impact of emerging trends and disrupters in the transportation sector and the relationship to GHG emissions is far more significant. **Figure 8.2** presents some high-level perspectives on the opportunities, challenges, and uncertainty facing the transportation sector through 2050. As further analysis in 2019 and beyond look at 2050, these general areas will represent a starting point for evaluating GHG emission trends and opportunities.

**Figure 8.2 2050 Perspective on Opportunities, Challenges, and Uncertainty**



**GHG Emissions Opportunity**

*Trends and drivers that present inherent opportunities to decrease GHG emissions from the transportation sector*

- **Federal GHG Emission Standards**
- **ZEV market share growth**
- **Transition to an electric transit fleet**

**GHG Emissions Challenge**

*Trends and drivers that present inherent challenges to mitigating GHG emissions in the transportation sector*

- **Population and VMT growth**
- **System delay and reliability**
- **Transportation costs**

**Uncertain**

*Trends and drivers where there are too many uncertainties in transportation sector impacts or extent of relevance through 2030*

- **Autonomous and connected vehicles**
- **Mobility as a service**
- **Change in freight logistics patterns**
- **Climate impacts and system resiliency**

# Appendix A. 2014 Baseline and 2030 BAU Emissions Inventory Documentation

This technical analysis report documents the methodology and assumptions used to produce the greenhouse gas (GHG) inventory for Maryland's on-road portion of the transportation sector. Statewide emissions have been estimated for the 2014 baseline and 2030 forecast business as usual (BAU) scenario based on the most recent traffic trends. The inventory was calculated by estimating emissions for carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$). Those emissions were then converted to carbon dioxide equivalents that are measured in the units of million metric tons (mmt $CO_2e$). Carbon dioxide represents about 97 percent of the transportation sector's GHG emissions.

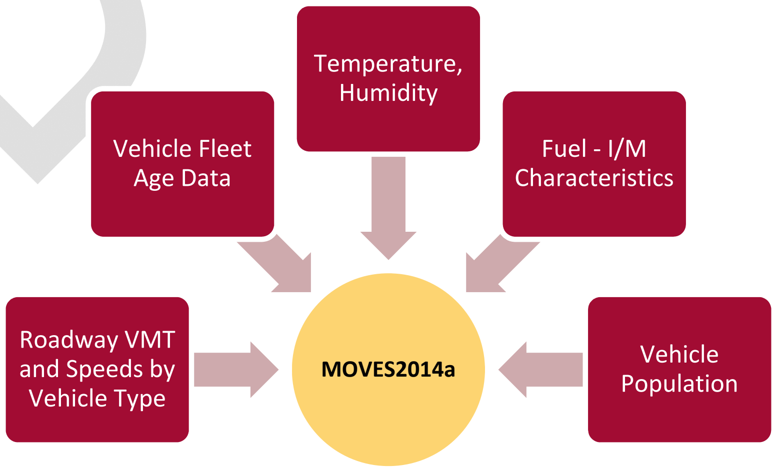
The on-road portion of the inventory was developed using EPA's latest emissions model MOVES2014a (Motor Vehicle Emissions Simulator) released in November 2016. The MOVES2014a model includes minor updates to the default fuel tables, corrects an error in MOVES2014 brake wear emissions, and add new options for the input of local VMT over the earlier version. With MOVES, greenhouse gases are calculated from vehicle energy consumption rates and vary by vehicle operating characteristics including speed, engine size, and vehicle age.

## On-Road Analysis Process

The data, tools and methodologies employed to conduct the on-road vehicle GHG emissions inventory were developed in close consultation with MDE and are consistent with the *MOVES2014 and MOVES2014a Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity, EPA-420-B-15-093, November 2015*. MOVES2014a incorporates all existing CAFE standards in place in 2014 plus: a) medium/heavy duty greenhouse gas standards for model years 2014-2018, b) light duty greenhouse gas standards for model years 2017-2025, and c) Tier 3 fuel and vehicle standards for model years 2017-2025.

As illustrated in Figure A.1, the MOVES2014a model has been integrated with local traffic, vehicle fleet, environmental, fuel, and control strategy data to estimate statewide emissions.

**Figure A.1 Emission Calculation Data Process**



The modeling assumptions and data sources were developed in coordination with MDE and are consistent with other SIP-related inventory efforts. The process represents a “bottom-up” approach to estimating statewide GHG emissions based on available roadway and traffic data. A “bottom-up” approach provides several advantages over simplified “top-down” calculations using statewide fuel consumption. These include:

- Addresses potential issues related to the location of purchased fuel. Vehicle trips with trip ends outside of the state (e.g. including “thru” traffic) create complications in estimating GHG emissions. For example, commuters living in Maryland may purchase fuel there but may spend much of their traveling in Washington D.C. The opposite case may include commuters from Pennsylvania working in Maryland. With a “bottom-up” approach, emissions are calculated for all vehicles using the transportation system.
- Allows for a more robust forecasting process based on historic trends of VMT or regional population and employment forecasts and their relationship to future travel. For example, traffic data can be forecasted using growth assumptions determined by the MPO through their analytic (travel model) and interagency consultation processes.

GHG emission values are reported as annual numbers for the 2014 baseline and 2030 BAU scenarios. The annual values were calculated based on annual MOVES runs as summarized in Figure A.2. Each annual run used traffic volumes, and speeds that represent an annual average daily traffic (AADT) condition, and temperatures and fuel input parameters representing an average day in each month.

**Figure A.2 Calculation of Annual Emissions**

For the 2014 and 2030 BAU emissions inventories, the traffic data was based on roadway segment data obtained from the Maryland State Highway Administration (SHA). This data does not contain information on congested speeds and the hourly detail needed by MOVES. As a result, post-processing software (PPSUITE) was used to calculate hourly-congested speeds for each roadway link, apply vehicle type fractions, aggregate VMT and VHT, and prepare MOVES traffic-related input files. The PPSUITE software and process methodologies are consistent with that used for state inventories and transportation conformity analyses throughout Maryland.

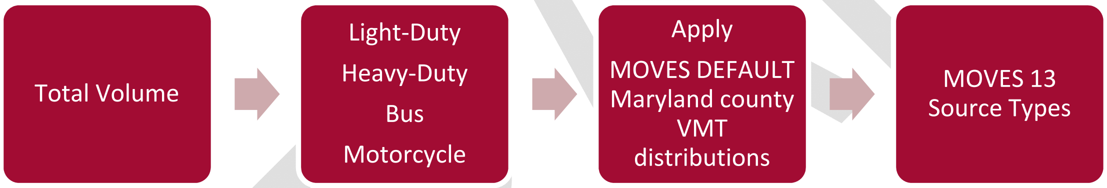
Other key inputs including vehicle population, temperatures, fuel characteristics and vehicle age were obtained from and/or prepared in close coordination with MDE staff. The following sections summarize the key input data assumptions used for the inventory runs.

## Summary of Data Sources

A summary of key input data sources and assumptions were developed in consultation with MDE and are consistent with the *MOVES2014 and MOVES2014a Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity, EPA-420-B-15-093,* *November 2015* and are provided in Table A.1. Many of these data inputs are consistent to those used for SIP inventories and conformity analyses. Several data items require additional notes:

- Traffic volumes and VMT are forecasted for the 2030 BAU analysis. A discussion of forecasted traffic volumes and vehicle miles of travel (VMT) is discussed in more detail in the following section.
- Vehicle population is a key input that has an important impact on start and evaporative emissions. The MOVES Model requires the population of vehicles by the thirteen source type categories. For light duty vehicles, vehicle population inputs were prepared and provided by MDE for base year (2014). For the analysis year 2030, the vehicle population was forecasted based on projected household and population growth obtained from state and MPO sources. For heavy-duty trucks, vehicle population was calculated from VMT using MOVES default estimates for the typical miles per vehicle by source type (e.g. vehicle type). The PPSUITE post processor automatically prepares the vehicle population file under this method.
- The vehicle mixes are another important file that is used to disaggregate total vehicle volumes and VMT to the 13 MOVES source types. The vehicle mix was calculated based on 2014 SHA vehicle type pattern percentages by functional class, which disaggregates volumes to four vehicle types: light-duty vehicles, heavy-duty vehicles, buses, and motorcycles. As illustrated in Figure A.3, from these four vehicle groups, MOVES default Maryland county VMT distributions by source type was used to divide the four groups into each of the MOVES 13 source types.

### Figure A.3 Defining Vehicle Types



### Table A.1 Summary of Key Data Sources

| Data Item | Source | Description | Difference between 2014 and 2030BAU |
|---|---|---|---|
| Roadway Characteristics | 2014 MDOT SHA Universal Database | Includes lanes, segment distance, facility type, speed limit | *Same Data Source* |
| Traffic Volumes | 2014 MDOT SHA Universal Database | Average Annual Daily Traffic Volumes (AADT) | Volumes forecasted for 2030 BAU |
| Seasonal Adjustments | SHA 2014 *ATR Station Reports in the Traffic Trends System Report Module* from the MDOT SHA website | Used to develop day and month VMT fractions as inputs to MOVES to disaggregate annual VMT to daily and monthly VMT | *Same Data Source* |
| VMT | Highway Performance Monitoring System 2014 | Used to adjust VMT to the reported 2014 HPMS totals by county and functional Class | VMT forecasted for 2030 BAU |

|  |  |  |  |
|---|---|---|---|
| Hourly Patterns | MDOT SHA 2014 *Traffic Trends System Report Module* from the SHA website | Used to disaggregated volumes and VMT to each hour of the day | *Same Data Source* |
| Vehicle Type Mix | 2014 MDOT SHA vehicle pattern and hourly distribution data; MOVES default Maryland county VMT distributions | Used to split traffic volumes to the 13 MOVES vehicle source types | *Same Data Source* |
| Ramp Fractions | MOVES Defaults | MOVES Defaults | *Same Data Source* |
| Vehicle Ages | 2014 Maryland Registration data;<br>MOVES2014 national default age distribution data | Provides the percentage of vehicles by each model year age | *Used 2014 registration data for light duty vehicles and MOVES2014 national default data for trucks (source types 52, 53, 61 & 62).* |
| Hourly Speeds | Calculated by PPSUITE Post Processor | Hourly speed distribution file used by MOVES to estimate emission factors | Higher volumes produce lower speeds in 2030 BAU |
| I/M Data | Provided by MDE | Based on current I/M program | Different I/M Program Characteristics |
| Fuel Characteristics | Provided by MDE for MOVES2014a model | Fuel characteristics vary by year | Different Fuel Characteristics |
| Temperatures | Provided by MDE | Average Monthly Temperature sets | *Same Data Source* |
| Vehicle Population | Light duty vehicles: used vehicle population data provided by MDE for 2014 baseline and applied growth rates to forecast population to 2030 BAU<br>Heavy duty trucks: Calculated by PPSUITE Post Processor; MOVES2014a Default Miles/Vehicle Population Data | Number of vehicles by MOVES source type which impact forecasted start and evaporative emissions | 2030 BAU based on projected demographic and VMT growth |

## Traffic Volume and VMT Forecasts

The traffic volumes and VMT within the MDOT SHA traffic database were forecast to estimate future year emissions. Several alternatives are available to determine forecast growth rates, ranging from historical VMT trends to the use of MPO-based travel models that include forecast demographics for distinct areas in each county. For the 2030 BAU scenario, the forecasts were determined based on historic trends of 1990-2014 highway performance monitoring system (HPMS) VMT growth. The average statewide annualized growth rate through 2030 for this scenario is 1.7 percent. Table A.2 summarizes the growth rates by county.

## Table A.2 VMT Annual Growth Rates (Per Maryland CAP) for 2030 BAU

| County | 2030 BAU (Based on 1990-2014 HPMS) |
|---|---|
| Allegany | 1.2% |
| Anne Arundel | 1.7% |
| Baltimore | 1.3% |
| Calvert | 2.6% |
| Caroline | 1.3% |
| Carroll | 1.8% |
| Cecil | 2.2% |
| Charles | 2.1% |
| Dorchester | 1.4% |
| Frederick | 2.5% |
| Garrett | 1.9% |
| Harford | 1.6% |
| Howard | 2.9% |
| Kent | 0.1% |
| Montgomery | 1.4% |
| Prince George's | 1.6% |
| Queen Anne's | 2.3% |
| Saint Mary's | 1.8% |
| Somerset | 1.11% |
| Talbot | 1.8% |
| Washington | 2.2% |
| Wicomico | 2.1% |
| Worcester | 1.1% |
| Baltimore City | 0.7% |
| ***Statewide*** | **1.7%** |

Table A.3 summarizes total 2014 baseline and 2030 forecast VMT by vehicle type.

## Table A.3 2014 Baseline and 2030 BAU VMT by Vehicle Type

| Annual VMT (millions) | 2014 Baseline | 2030 BAU |
|---|---|---|
| **Light-Duty** | 52,253 | 66,517 |
| **Medium/Heavy-Duty Truck & Bus** | 4,147 | 5,304 |
| **TOTAL VMT (in millions)** | **56,400** | **71,821** |

The analysis process (e.g. using PPSUITE post processor) re-calculates roadway speeds based on the forecast volumes. As a result, future year emissions are sensitive to the impact of increasing traffic growth on regional congestion.

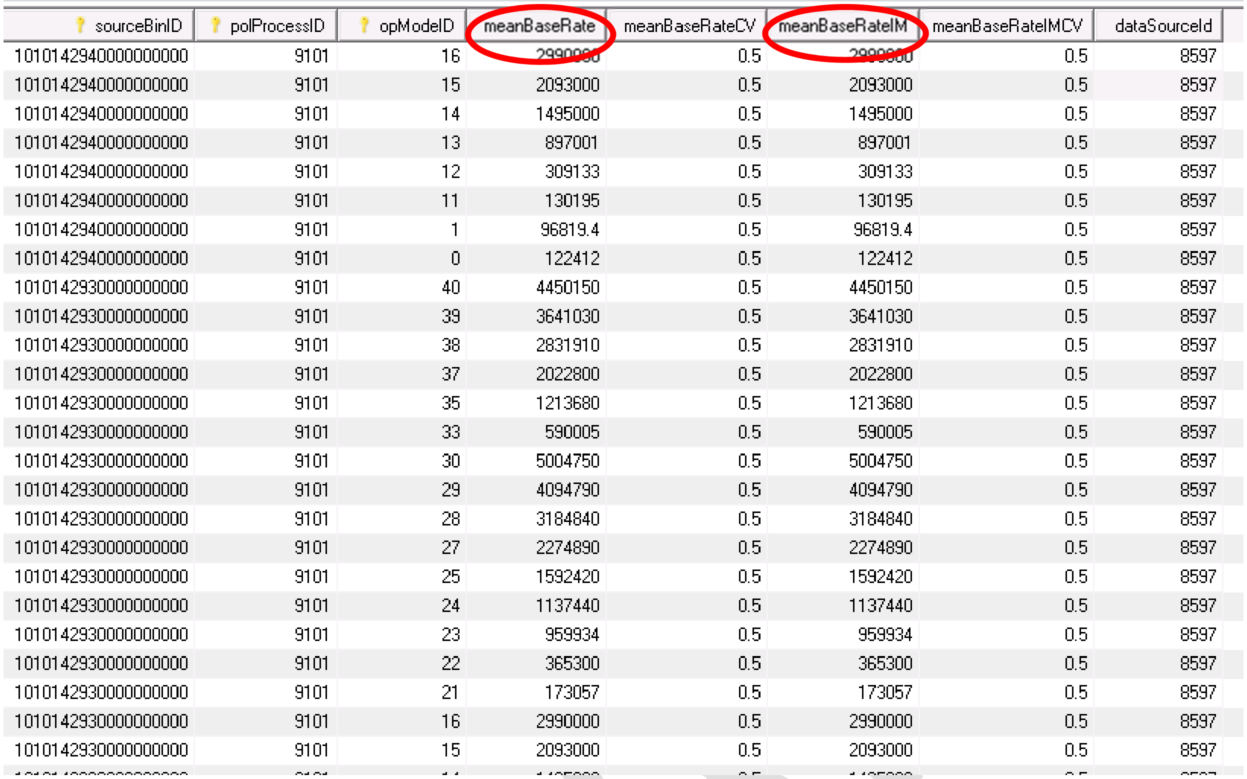
# Vehicle Technology Adjustments

The MOVES2014a emission model includes the effects of the following post-2014 vehicle programs on future vehicle emission factors:

- **National Program (Model Years 2012-2016)** – The light-duty vehicle fuel economy for model years between 2012 and 2016 are based on the May 7, 2010 Rule “Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule” (EPA-HQ-OAR-2009-0472-11424). Fuel economy improvements begin in 2012 until an average 250 gram/mile $CO_2$ standard is met in year 2016. This equates to an average fuel economy near 35 mpg.
- **National Program Phase 2 (Model Years 2017-2025)** – The light-duty vehicle fuel economy for model years between 2017 and 2025 are based on the October 15, 2012 Rule “2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards” (EPA-HQ-OAR-2010-0799 and No. NHTSA-2010-0131). The new fuel economy improvements apply to model years 2017 to 2025. The standards are projected to result in an average 163 gram/mile of $CO_2$ in model year 2025. This equates to an average fuel economy of 54.5 mpg.
- **Maryland Clean Car Program** – The Maryland Clean Car Program implements California’s low emissions vehicle (LEV) standards to vehicles purchased in Maryland starting with model year 2011. By creating a consistent national fuel economy standard, the 2012-2016 National Program and the Phase 2 2017-2025 National Program, which closely resemble the California program, replaces Maryland’s Clean Car Program for those model years. As a result, the GHG reduction credits for the Maryland Clean Car Program, apply only to 2011 model year vehicles and post-2011 electric vehicles that meet the California’s zero emission program (ZEV) requirement.
- **National 2014-2018 Medium and Heavy Vehicle Standards** – The medium- and heavy- duty vehicle fuel economy for model years between 2014-2018 are based on the September 15, 2011 Rule “Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles”. The rulemaking has adopted standards for three main regulatory categories: combination tractors, heavy-duty pickups and vans, and vocational vehicles. For combination tractors, the final standard will achieve 9 to 23 percent of reduction in carbon dioxide (CO2) emissions and fuel consumption by the 2017 model year compared to the 2010 baseline. For heavy-duty pickup trucks and vans, separate standards have been established for gasoline and diesel trucks, which will achieve up to a 10 percent reduction for gasoline vehicles and a 15 percent reduction for diesel vehicles by the 2018 model year (12 and 17 percent respectively if accounting for air conditioning leakage). Lastly, for vocational vehicles, the final standards would achieve CO2 emission reductions from six to nine percent by the 2018 model year.

The above technology programs that apply to model years 2015 and beyond vehicles were not included in the 2030 BAU, as they are included as credits applied to BAU emissions. To remove the potential emission credits of these programs, the MOVES2014a default database was revised. Fuel economy assumptions within MOVES2014a are provided as vehicle energy consumption rates within the “EmissionRates” table as illustrated in Figure A.4.

Figure A.4 MOVES Default “EmissionRate” Table



| sourceBinID | polProcessID | opModelID | meanBaseRate | meanBaseRateCV | meanBaseRateIM | meanBaseRateIMCV | dataSourceId |
|---|---|---|---|---|---|---|---|
| 1010142940000000000 | 9101 | 16 | 2990000 | 0.5 | 2990000 | 0.5 | 8597 |
| 1010142940000000000 | 9101 | 15 | 2093000 | 0.5 | 2093000 | 0.5 | 8597 |
| 1010142940000000000 | 9101 | 14 | 1495000 | 0.5 | 1495000 | 0.5 | 8597 |
| 1010142940000000000 | 9101 | 13 | 897001 | 0.5 | 897001 | 0.5 | 8597 |
| 1010142940000000000 | 9101 | 12 | 309133 | 0.5 | 309133 | 0.5 | 8597 |
| 1010142940000000000 | 9101 | 11 | 130195 | 0.5 | 130195 | 0.5 | 8597 |
| 1010142940000000000 | 9101 | 1 | 96819.4 | 0.5 | 96819.4 | 0.5 | 8597 |
| 1010142940000000000 | 9101 | 0 | 122412 | 0.5 | 122412 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 40 | 4450150 | 0.5 | 4450150 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 39 | 3641030 | 0.5 | 3641030 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 38 | 2831910 | 0.5 | 2831910 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 37 | 2022800 | 0.5 | 2022800 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 35 | 1213680 | 0.5 | 1213680 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 33 | 590005 | 0.5 | 590005 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 30 | 5004750 | 0.5 | 5004750 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 29 | 4094790 | 0.5 | 4094790 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 28 | 3184840 | 0.5 | 3184840 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 27 | 2274890 | 0.5 | 2274890 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 25 | 1592420 | 0.5 | 1592420 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 24 | 1137440 | 0.5 | 1137440 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 23 | 959934 | 0.5 | 959934 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 22 | 365300 | 0.5 | 365300 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 21 | 173057 | 0.5 | 173057 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 16 | 2990000 | 0.5 | 2990000 | 0.5 | 8597 |
| 1010142930000000000 | 9101 | 15 | 2093000 | 0.5 | 2093000 | 0.5 | 8597 |

To remove the benefits of the post-2014 programs, the database was revised so that all energy rates beyond 2014 were the same as model year 2014 for each vehicle type, model year and fuel type. The table was updated per the following steps:

1. Open the “EmissionRate” table in the latest MOVES2014a default database (named: movesdb20161117). The fields to be modified include: *meanBaseRate* & *meanBaseRateIM* (values in both fields are the same)
2. Select records in the table that are related to energy consumption. This includes records with the polProcessID = 9101, 9102, 9190 and 9191.
3. Use the sourceBinID field to determine how each record correlates to vehicle type, model year and fuel type.
4. Modify meanBaseRate & meanBaseRateIM fields to be same for all model years beyond 2014 for the applicable vehicle type, model year and fuel type.

## Emission Results

The 2014, and 2030 BAU scenarios emission results for the Maryland statewide GHG inventories are provided in Table A.4 for 2014 Baseline, and A.5 for the 2030 BAU scenario. Within each table, emissions are also provided by fuel type and vehicle type.

## Table A.4 2014 Annual On-Road GHG Emissions (mmt)

| | VMT (Millions) | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2e$ |
|---|---|---|---|---|---|
| **TOTAL** | **56,399** | **28.58** | **0.00108** | **0.00078** | **28.84** |
| *By Fuel Type* | | | | | |
| Gasoline | 51,824 | 22.185 | 0.000759 | 0.000767 | 22.433 |
| Diesel | 4,491 | 6.355 | 0.000287 | 0.000010 | 6.365 |
| CNG | 7.2 | 0.009 | 0.000036 | 0.000001 | 0.010 |
| E-85 | 77 | 0.033 | 0.000002 | 0.000001 | 0.033 |
| By MOVES Vehicle Type | | | | | |
| Motorcycle | 340 | 0.125 | 0.000010 | 0.000001 | 0.126 |
| Passenger Car | 25,765 | 9.336 | 0.000242 | 0.000277 | 9.425 |
| Passenger Truck | 20,927 | 10.229 | 0.000399 | 0.000364 | 10.348 |
| Light Commercial Truck | 5,221 | 2.561 | 0.000117 | 0.000100 | 2.593 |
| Intercity Bus | 71 | 0.125 | 0.000002 | 0.000000 | 0.125 |
| Transit Bus | 51 | 0.067 | 0.000038 | 0.000001 | 0.068 |
| School Bus | 127 | 0.122 | 0.000006 | 0.000000 | 0.122 |
| Refuse Truck | 43 | 0.078 | 0.000002 | 0.000000 | 0.078 |
| Single Unit Short-haul Truck | 1,437 | 1.478 | 0.000072 | 0.000028 | 1.488 |
| Single Unit Long-haul Truck | 79 | 0.076 | 0.000004 | 0.000001 | 0.076 |
| Motor Home | 20 | 0.021 | 0.000002 | 0.000001 | 0.022 |
| Combination Short-haul Truck | 526 | 0.945 | 0.000018 | 0.000001 | 0.946 |
| Combination Long-haul Truck | 1,793 | 3.418 | 0.000173 | 0.000004 | 3.424 |

## Table A.5 2030 BAU Annual On-Road GHG Emissions (mmt)

| | VMT (Millions) | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2e$ |
|---|---|---|---|---|---|
| **TOTAL** | **71,821** | **31.57** | **0.00099** | **0.00041** | **31.71** |
| *By Fuel Type* | | | | | |
| Gasoline | 63,611 | 23.337 | 0.000332 | 0.000386 | 23.460 |
| Diesel | 5,947 | 7.370 | 0.000608 | 0.000013 | 7.389 |
| CNG | 10.1 | 0.011 | 0.000025 | 0.000001 | 0.012 |
| E-85 | 2,253 | 0.848 | 0.000026 | 0.000014 | 0.853 |
| *By MOVES Vehicle Type* | | | | | |
| Motorcycle | 432 | 0.160 | 0.000013 | 0.000002 | 0.161 |
| Passenger Car | 32,707 | 10.601 | 0.000163 | 0.000165 | 10.654 |
| Passenger Truck | 26,713 | 10.762 | 0.000200 | 0.000179 | 10.820 |
| Light Commercial Truck | 6,665 | 2.701 | 0.000070 | 0.000048 | 2.717 |
| Intercity Bus | 90 | 0.151 | 0.000005 | 0.000000 | 0.151 |
| Transit Bus | 64 | 0.079 | 0.000028 | 0.000001 | 0.080 |
| School Bus | 164 | 0.145 | 0.000012 | 0.000000 | 0.145 |
| Refuse Truck | 47 | 0.078 | 0.000003 | 0.000000 | 0.078 |
| Single Unit Short-haul Truck | 1,850 | 1.734 | 0.000113 | 0.000012 | 1.740 |
| Single Unit Long-haul Truck | 101 | 0.089 | 0.000006 | 0.000000 | 0.089 |
| Motor Home | 22 | 0.022 | 0.000001 | 0.000000 | 0.022 |
| Combination Short-haul Truck | 673 | 1.101 | 0.000036 | 0.000002 | 1.103 |
| Combination Long-haul Truck | 2,293 | 3.945 | 0.000342 | 0.000005 | 3.954 |

# Appendix B. 2030 Strategy Definitions and Assumptions

## Policy Scenario 1 (On-the-Books)

As its name implies, this scenario evaluates the emission reductions from funded projects and programs. This includes projects and programs in the Consolidated Transportation Program (CTP), land development assumptions consistent with local plans and Maryland Department of Planning goals, and GHG reducing projects included in fiscally constrained MPO metropolitan transportation plans.

### 2030 Plans & Programs yield lower annual vehicle miles traveled (VMT) growth (1.4 percent per year compared to 1.7 percent per year for business as usual)

**Strategy Description:** Modeled VMT and emissions outcomes (through MOVES2014a) from implementation of most recently adopted MPO fiscally constrained long-range transportation plans and cooperative land use forecasts.

**Key Assumptions**: The VMT projections of implementing the plans and programs that include MPO planned projects (highway and transit) and future regional demographic projections developed by the jurisdictions in cooperation with Maryland Department of Planning (MDP), show an expected decrease of 3.159 billion VMT in 2030 relative to the business as usual VMT growth rate. Annual VMT growth rates as forecast by the Baltimore Metropolitan Council (BMC) and Metro Washington Council of Governments (MWCOG) within their modeling areas have been used for modeling purposes. Outside of these MPO counties, SHA developed highway performance monitoring system (HPMS) VMT growth rates from 1990 to 2014 are used.

**Estimation Methodology:** The 2030 Plans and Programs use information from the CTP, each MPO TIP and MTP, and land use, population, and employment projections from the Maryland Department of Planning (MDP) to estimate the emission trend-line through 2030. The average statewide annualized VMT growth rate through 2030 for the plans and programs scenario is 1.4 percent as compared to a 1.7 percent BAU, based on which emission reductions have been estimated using MOVES by attributing it to VMT based on travel activity inputs by source types (vehicle types).

### On-Road Technology (CHART, Traveler Information)

**Strategy Description:** This strategy covers on-road technology as it relates to the statewide implementation of CHART system with its five components including Traffic and Roadway Monitoring; Incident Management; 511 - Traveler's Information; System Integration and Communication; and Traffic Management.

**Key Assumptions**: Based on the existing coverage and effectiveness of CHART in the areas of incident response and other streamlined operations, the total annual emission reductions are estimated based on existing rates of coverage and coverage expansion, and effectiveness from SHA's annual CHART reports.

**Estimation Methodology:** Based on CHART's existing coverage area, VMT affected is estimated by facility types (roadway types – rural/urban and restricted/unrestricted access). Emission reductions are based on VMT for all vehicles on those roadway facilities impacted by the existing and expanded CHART coverage.

## Freight and Freight Rail Programs (Class I railroad improvements and MTA rail projects)

**Strategy Description:** Implementation of the Norfolk Southern Crescent Corridor and CSX National Gateway provides new capacity and eliminates bottlenecks for access to the Port of Baltimore and rail access westward toward PA and OH and south toward VA and NC. These privately funded programs are in addition to ongoing MTA investments in Maryland freight rail corridor improvements.

**Key Assumptions**: Potential projects to enable double-stack rail access to the Port of Baltimore have evolved over the last decade. Prior 2020 analysis assumed the planned components of the National Gateway project would be complete by 2020. Using that same analysis, but assuming it now is complete by 2030 (given the current status) is more realistic.

**Estimation Methodology:** Truck VMT impacted due to these improvements is estimated based on information collected from project studies (for example: 850,000 long-haul trucks annually impacted by the Crescent Corridor project) and similar information from the National Gateway project (share of MD truck VMT only included in the estimation).

## Public Transportation (projects not included in current modeling assumptions for MPO MTPs, but determined to be fully funded for implementation by 2030)

**Strategy Description:** This strategy includes projects designed to increase public transit capacity, improve operations and frequency, and implementation of new BRT corridors. Projects include dedicated bus lanes/transit service priority, bus rapid transit (US 29) in Montgomery and Howard Counties, other Montgomery County BRT corridors include MD 355 and Randolph Road, the Baltimore North Avenue Rising project, and the Southern Maryland Commuter Bus initiative.

**Key Assumptions**: Ridership estimates from recent and ongoing studies for each project corridors are converted into annual transit trips, which are then multiplied by an average commute trip length (16 miles based on MWCOG model estimates) to obtain annual VMT and emission reductions. Emissions from transit vehicles are included within the baseline MOVES modeling.

**Estimation Methodology:** Projects and initiatives with data on projected ridership and other indicators for estimation of reduced travel activity, use of transit as a lower alternative emissions intensive mode of travel have been included in the analysis.

## Public Transportation (fleet replacement / technology based on current procurement)

**Strategy Description:** This strategy includes MTA planned fleet replacement to Clean Diesel and WMATA planned fleet replacement based on current replacement strategy.

**Key Assumptions**: Based on MTA's planned bus replacement schedule and other fleet replacement information, total number of active bus fleet that need to be replaced was estimated from FY 2018-2030. It is assumed that 3,000 gallons of fuel is reduced per year by new clean diesel buses.

**Estimation Methodology:** Reduction of 100 - 160 tons of greenhouse gas per year compared to a 40' diesel bus and 75 - 110 tons compared to an existing 40' diesel-hybrid bus.

## TDM (Commuter Choice MD, Commuter Connections ongoing/expanding programs)

**Strategy Description:** The following programs are included for consideration towards reduction in VMT: Commuter Connections Transportation Emission Reduction Measures** (MWCOG), Guaranteed Ride Home, Employer Outreach, Integrated Rideshare, Commuter Operations and Ridesharing Center, Telework Assistance, Mass Marketing, MTA Transportation Emission Reduction Measures, MTA College Pass, MTA Commuter Choice Maryland Pass, and Transit Store in Baltimore.

**Key Assumptions**: A trend-line extrapolation of annual VMT reductions from the full suite of TDM programs is used as a proxy for funding levels and strategy effectiveness, resulting in a VMT reduction 0.82 percent proportional to 2030 VMT, which is applied to the VMT for the year 2030.

**Estimation Methodology:** MWCOG's TERMS documentation has information on potential daily reduction in vehicle trips and daily VMT reductions by TDM program, which have been used to estimate the total potential VMT reduction for 2030. This data was applied to MD's share of the regional VMT. TDM program data from BMC region was added to the Metro Washington total to estimate the total TDM program emission reduction potential.

### Pricing Initiatives (MDTA conversion to All Electronic Tolling)

**Strategy Description:** Ongoing Conversion to All-Electronic Tolling.

**Key Assumptions**: It is assumed that 92.6 percent of LDVs and 7.4 percent of HDVs are impacted in the year 2030 based on Attainment Report data on all electronic tolling. Assume 1 minute of idling per transaction for 50 percent of transactions and 1.5 minutes for other 50 percent obtained from MDOT (MDTA estimate)

**Estimation Methodology:** Reduced emissions from avoided idling is estimated for the share of fleet to estimate avoided emissions.

### Bicycle and Pedestrian Strategies (continuation of State and local programs)

**Strategy Description:** Continued system expansion through SHA, MTA, and MVA programs in the CTP such as Bikeshare, Bikeways, retrofit programs, and Federal grants as summarized in the 2018-2023 CTP in addition to locally funded projects within the MWCOG and BMC 2017-2022 TIPs.

**Key Assumptions**: Assumes VMT reductions due to availability of bicycle and pedestrian facility lane miles (assuming connectivity is maintained and incrementally added to the existing network).

**Estimation Methodology:** Baseline VMT reductions for bike trips less than 5 miles in length and walk trips less than a mile in length were estimated using their existing mode shares. Ratios of baseline VMT reduction to linear mile of facility was estimated thereafter. Future linear miles of pedestrian and bicycle facility based on targets indicated in the 2018 MDOT Attainment Report (2018 AR) were estimated and factored to the increased extent based on the ratio of baseline reductions to arrive at the 2030 VMT reductions to estimate the emission reductions in the form of avoided auto-trips.

### Land-Use and Location Efficiency (consistent with MDP assumptions)

**Strategy Description:** MDP projection of 75 percent compact development for 10 percent of development / redevelopment through 2030. Compact development is assumed to reduce VMT by 30 percent relative to standard density / mix development. This strategy partially captures MDOT/MDP commitment to TOD across 20 designated locations in Maryland.

**Key Assumptions**: The approach is based on the methodology provided in *CO2 Reductions Attributable to Smart Growth in California* by Reid Ewing, Ph.D., National Center for Smart Growth, University of Maryland, and Arthur C. Nelson, Ph.D., FAICP, Director of Metropolitan Research, University of Utah.

**Estimation Methodology:** 75 percent compact development for 10 percent of development / redevelopment is multiplied by the assumed 30 percent VMT reduction from the study noted above, and an assumed ratio of 90% CO2 reduced for every unit of VMT reduction results in a total 2 percent CO2 reduction for this strategy. **MDP 2030: % CO2 reduction = 0.75 x 0.1 x 0.3 x 0.9 = 2%**

### Drayage Track Replacements

**Strategy Description:** This strategy estimates the benefit of replacing 600 total dray trucks resulting from MDE, MDOT and Federal grants through 2030, which is based on the current replacement rate.

**Key Assumptions**: This strategy assumes current funding program implementation levels to continue through 2030.

**Estimation Methodology:** Emission reductions are based on increased fuel efficiency (and thereby the total fuel use reductions) of dray trucks which replace the current trucks in operation.

### BWI Airport Parking Shuttle Bus Replacements

**Strategy Description:** This strategy involves replacement of BWI airport parking shuttles - 50 diesel buses with clean diesel buses and 20 CNG buses.

**Key Assumptions**: Acquisition information based on what is publicly available from MDOT and news sources including the types of vehicles replacing the existing vehicles.

**Estimation Methodology:** Emission reductions are based on increased fuel efficiency of clean diesel and CNG as fuel for improved emissions in operation.

## Policy Scenario 2 (Emerging and Innovative)

This scenario acknowledges that attaining the 2030 goal will require additional investments to expand or accelerate deployment of previously planned strategies, deployment of new best-practice strategies, and capitalizing on the opportunities created by new transportation technologies. All of the strategies in this scenario require additional funding and, in some cases, private sector commitment. The 25 strategies in this scenario (17 emerging and 8 innovative) represent a combination of approaches to reduce GHG emissions with varying levels of confidence and MDOT responsibility.

### Emerging

### Freeway Management/Integrated Corridor Management

**Strategy Description:** This strategy assumes implementation of an Integrated Corridor Management strategy on all urban limited access corridors.

**Key Assumptions**: This strategy assumes integrated corridor management, intelligent transportation systems, or advanced traffic management systems for the three corridors listed.

**Estimation Methodology:** Deployment of these strategies are already widespread throughout Maryland. Through 2030, this strategy assumes that some level of corridor management (including ramp metering), intelligent transportation systems, or advanced traffic management systems are in place on all urban restricted access facilities. The FHWA, “Travel and Emissions Impacts of Highway Operations Strategies,” Final Report, by Cambridge Systematics, and the work of MWCOG's multisector working group (as documented in the January 2016 report) are used to support this analysis.

## Arterial System Operations and Management

**Strategy Description:** This strategy estimates the benefits of implementing Arterial System Operations and Management including expanded signal coordination and control on all urban principal and minor arterials by 2030.

**Key Assumptions**: Only urban arterials are being assumed to be covered as part of this strategy through 2030.

**Estimation Methodology:** Emission reductions are attributed to VMT impacted during the peak period resulting in improved speeds for travel happening on select facilities (urban arterials) for all traffic.

## Limited Access System Operations and Management

**Strategy Description:** This strategy evaluates the emission reductions benefits of implementation of a Limited Access System Operations and Management including deployment of technologies like ramp metering.

**Key Assumptions**: For ramp metering, a two-minute wait time on average was considered during peak hours at ramp entrance. Ramp fraction was estimated at 8 percent from MOVES defaults.

**Estimation Methodology:** Improvement of speeds on urban restricted access facilities causes emission reductions. This is offset by a fraction by the waiting vehicles on the ramps, which results in additional idling emissions. Net emission reductions are estimated for this strategy.

## Managed Lanes (Traffic Relief Plan Implementation)

**Strategy Description:** This strategy estimates the emissions benefit of Chapter 30 projects (Traffic Relief Plan) to add express toll lanes to the routes of three of Maryland's most congested highways — the Interstate 495 Capital Beltway, the I-270 spur connecting Frederick to D.C., and the Baltimore-Washington Parkway between the two cities.

**Key Assumptions**: The congestion affects 260,000 motorists daily on I-270, 240,000 motorists daily on I-495 and 120,000 motorists each day on the Baltimore-Washington Parkway.

**Estimation Methodology:** Based on the project list and benefits as estimated by SHA, estimated daily fuel reductions were translated into 2030 emission reductions.

## Intermodal Freight Centers Access Improvement

**Strategy Description:** As noted in the Strategic Goods Movement Plan, reliability improvements and congestion mitigation that positively impact supply chain costs associated with driver and truck delay and fuel consumption is a desired outcome. The strategy to achieve this includes SHA and MDTA continuing to advance appropriate measures to reduce or mitigate the effects of congestion on industry supply chains.

**Key Assumptions**: The strategy has been applied to intermodal sections in Maryland and the mileage is assumed to be similar to the national share of 1.4 percent (as data on intermodal facilities mileage in MD was not able to be estimated based on available data).

**Estimation Methodology:** Potential reduction is based on the share of truck VMT operating in congested conditions (less than 50 percent of free-flow speed) and the potential extent of a strategy aimed at reducing the share of truck VMT operating in congested conditions. Benefits would be localized to individual intersections/interchanges and ramps, as well as local streets/intermodal connectors providing access to the Port of Baltimore and other intermodal facilities.

## Commercial Vehicle Idle Reduction, Low-Carbon Fleet

**Strategy Description:** Commercial Vehicle Idle Reduction assumes enforcement of anti-idling law Maryland's Idling Law (Transportation Article §22-402) and have expanded regulations on use of auxiliary power units (APUs) in MD truck areas.

**Key Assumptions**: Daily total HDV idling is limited by the number of parking spaces, occupancy, and non-TSE installed spaces. This strategy definition considers extended idling only and not short-term idling (e.g., at a delivery/pick-up point). It is assumed that APUs will be used to power the trucks during the time spent idling. Idling emission rates for HDV and APUs are derived and given that this is also a strategy with implications for PM emission reductions, PM emissions are also presented in the results.

**Estimation Methodology:** It is estimated that trucks would have spent time idling in absence of this law. A high case and a low case for emission reductions is estimated considering all or just 50 percent of extended idling is handled by APUs. High case adopted and presented in the results estimates 2,173 total HDVs avoiding extended idling as a result of this strategy.

## Eco-Driving

**Strategy Description:** This strategy is assumed to be undertaken as a general marketing program with basic outreach and information brochure about the savings included.

**Key Assumptions**: Assumptions based on the extent of government led programs. Private sector programs not included. For example, fleet operators of trucks, logistical operation enterprises conduct eco-driving for their fleet separately and typically have a higher degree of focus and return on results from the programs. It is assumed that 2 percent of the statewide population are reached using these general marketing programs. Out of these people, only 50 percent (1 percent of total population) have on-board display tools that have on-board display tools that provide feedback from eco-driving. The benefits of eco-driving are two-pronged - one by training and the other due to attention being paid to the on-board display tools. Heavy duty trucks included for this analysis are only assumed to be a part of the general marketing campaign and no specific training provided elsewhere.

**Estimation Methodology:** Adoption rates and skill/habit retention are kept intentionally low as this campaign is just a marketing and education campaign. They are typically higher for rigorous training and educational campaigns.

## Lead by example - Alternative Fuel Usage in State Fleet

**Strategy Description:** This strategy is already being tracked as part of MDOT's Excellerator program and includes deployment of alternative fuel vehicles and fuels including ultra-low Sulphur diesel, biodiesel, and E-85 as the proposed as alternatives.

**Key Assumptions**: It is assumed that the program continues to be implemented at current levels resulting in reduced diesel and gasoline fuel use as it is replaced by blended fuels.

**Estimation Methodology:** Reductions are based on changes in carbon intensity due to diverse fuel choices and blends.

## Truck Stop Electrification

**Strategy Description:** This strategy assumes equipping all public truck bays to be equipped with electrification for powering trucks during overnight stays or time otherwise spent as extended idling.

**Key Assumptions**: Strategy assumes a range of deployment of electrification of truck stops throughout the state. Three scenarios of deployment (all public spaces, 50 percent of public spaces, and 10 percent of public spaces are considered). Average rates of truck stop utilization is set at 50 percent. It is assumed that the electricity source for powering the truck is similar to using an APU (without having to compute the power supplied for the duration and its source and its energy footprint).

**Estimation Methodology:** Three scenarios for deployment in 2030 – 100 percent, 50 percent and 10 percent of public spaces available across the state are considered and presented as high/medium/and low cases. The high case of deployment (all public places) is chosen for estimation purposes.

## Transit capacity/service expansion (fiscally unconstrained)

**Strategy Description:** Projects in fiscally constrained LRTPs **post-2030** or in needs or aspirations-based plan (unconstrained). These potential enhancements/expansions to Maryland's transit system are extensive, including extension of the Baltimore Metro Green Line and multiple bus rapid transit corridors in Montgomery, Prince Georges, Howard, and Anne Arundel Counties. Most of these projects are identified in the BMC and MWGOG LRTPs for implementation post-2030 or identified as a need for a corridor study. This includes every other potential BRT corridor, TOD build outs, MGIP/Cornerstone Plan build out, and references to a Green Line extension in Baltimore and new/updated MARC stations at West Baltimore and Bayview.

**Key Assumptions**: Assumes that some of these projects will have the necessary funding and will be operationalized by 2030 to realize potential GHG reduction benefits.

**Estimation Methodology:** Emission reductions estimated based on individual project information including potential ridership estimates as reduced VMT. MTA fleet replacement and benefits of TOD build-out from 20 incentive zones is estimated using MDP’s TOD planning tool. Estimated reductions of TOD are based on zonal classifications based on number of households impacted and trips reduced (by location coefficient types).

## Expanded TDM strategies (dynamic), telecommute, non-work strategies

**Strategy Description:** The implementation and coverage of TDM strategies considered in the Policy Scenario 1 is doubled and the impact of those programs resulting in an increased share of VMT reductions by 2030. This approach reflects a renewed and expanded commitment to TDM, including more extensive financial incentives or disincentives to driving alone and dynamic ridesharing options.

**Key Assumptions**: Assuming increased coverage of TDM strategies based on additional funding influx resulting in the same proportion of increase in VMT reductions.

**Estimation Methodology:** Reduced VMT due to expansion of the TDM programs is doubled under this scenario and emission reductions are estimated for the share of passenger car VMT impacted.

## Expanded bike/pedestrian system development

**Strategy Description:** Expanded bicycle and pedestrian facility infrastructure by an increased pace which corresponds to 150 percent of the existing bicycle and pedestrian infrastructure provision target.

**Key Assumptions**: Future linear miles of pedestrian and bicycle facilities were estimated based on targets provided in the 2018 MDOT Attainment Report (2018 AR). In each case, two numbers were estimated. The first number corresponds to the target indicated in the 2018 AR and is referred to below as "existing rate" strategy below. The second number corresponds to 150 percent of the 2018 AR target and is referred to below as the "increased rate" strategy below.

**Estimation Methodology:** The above growth rates were applied to the existing linear miles of sidewalk and bicycle facility on state-owned roads in urban areas, as determined from data provided by SHA, to calculate future linear miles of sidewalk and bicycle facility in urban areas for each strategy.

## Freight Rail Capacity Constraints/Access (Howard St. Tunnel)

**Strategy Description:** Potential projects to enable double-stack rail access to the Port of Baltimore have evolved over the last decade. The new direction is to expand the Howard Street tunnel as described in the recent FASTLANE Grant application submitted jointly by MDOT and CSX. Regardless of how this project is funded, this strategy assumes implementation by 2030, and estimates the impacts on truck movements to and from the Port.

**Key Assumptions**: Building out the Howard Street Tunnel and enabling double-stacking directly to the Port of Baltimore by 2030.

**Estimation Methodology:** Reduced emissions based on VMT reduction due to double-stacking. VMT reduced is for combination long-haul trucks affected by this improvement only.

## Regional Clean Fuel Standard

**Strategy Description:** Similar to approach in the 2015 Transportation and Climate Initiative (TCI) analysis, a clean fuels standard to achieve a 15 percent reduction in carbon intensity by 2030 was evaluated.

**Key Assumptions**: Emission reductions estimated for the year 2025 in the TCI analysis were used for the year 2030, to correspond to a 12-year base-year and scenario year gap (TCI analysis used 2013 as the base year).

**Estimation Methodology:** Emission reductions due to reduction from baseline in the TCI study have been applied to the 2030 VMT (discounted for EVs).

## MARC Growth and Investment Plan (MGIP) / Cornerstone Plan Completion

**Strategy Description:** This strategy involves advancing the MGIP 2030-2050 vision for projects to be accelerated to be operational by 2030.

**Key Assumptions**: Assumes no fiscal constraints and includes projects that are assumed to be accelerated for implementation by 2030.

**Estimation Methodology:** Projected ridership potential attributable to the total plan implementation is estimated to occur by 2030 as a result of accelerated improvement of the plan.

## EV Scenario + Additional 100K Ramp Up (total of 704,840 EV s)

**Strategy Description:** An additional 100,000 EVs are assumed to be rolled-out from 2025 along the same splits of BEV and PHEV shares to make up a total of 704,840 total EVs on the road in the year 2030.

**Key Assumptions**: Keeping the share of BEV/PHEVs same as in the MDOT/MDE scenario. 55 percent of PHEV VMT is assumed to be electric.

**Estimation Methodology:** All the emissions except for the PHEV's fuel driving share of 45 percent are assumed to be avoided.

### 50 percent EV Transit Bus Fleet

**Strategy Description:** This is a what-if scenario to estimate the emission reduction benefits of having a 50 percent transit bus fleet in the year 2030.

**Key Assumptions**: Procurement policies change as early as 2020 with a commitment to 100 percent of bus replacements as a battery electric or plug-in hybrid electric through 2030.

**Estimation Methodology:** Half of the emissions attributable to transit buses in Maryland in 2030 are estimated to be avoided.

### Connected and Automated Vehicle Technologies

**Strategy Description:** This strategy estimates the emission reduction benefits of market penetration of ACVs and provision of adequate infrastructure to enable V2V and V2I technologies.

**Key Assumptions**: Core assumptions regarding market penetration of AVs, change in VMT, and fuel savings have been adopted from a 2015 ENO Transportation Center study on AV deployment which lays out three scenarios of AV deployment, of which the low-end penetration of 10 percent by 2030 is considered in this analysis.

**Estimation Methodology:** The following changes are estimated due to deployment of AVs from an emissions perspective:

- Emissions associated with VMT increase resulting from mobility benefits (AVs added to the fleet – this increases emissions and thereby a negative impact, estimated at **20 percent increase**);
- Fuel savings due to AVs (savings of AVs only, estimated at **13 percent reduction**);
- Congestion reduction benefits on freeways and arterials (assumed LOS E to C on restricted access roadways and unrestricted access roadways). These are due to vehicles following automated vehicles, etc. Level of service criteria for restricted and unrestricted roadway types obtained from HCM and emission rates are applied at the different operating speeds (bins) and assigned to VMT by that roadway type (estimated at 15 percent reduction for limited access facilities and 5 percent reduction for arterials).

### Variable Speeds / Speed Management on Freeways

**Strategy Description:** This strategy estimates the potential emission reduction benefits of speed limit enforcement on urban restricted roadways.

**Key Assumptions**: This strategy assumes applying speed management strategies during non-peak periods. Different emission factors for average speeds used for LDVs and HDVs to reflect marginal differences between the two classes of vehicles. Note enforcement may come about more through automated vehicle technology rather than traditional means.

**Estimation Methodology:** Difference between emission rates of VMT without enforcement (higher speed) and under speed enforcement (55 mph) applied to the VMT for that vehicle type.

## Zero-Emission Trucks/Truck Corridors

**Strategy Description:** This strategy considers establishment of infrastructure and vehicle replacements for implementation of zero emission corridors connecting to the Port of Baltimore in comparison with the I-710 Calstart Corridor study.

**Key Assumptions**: This strategy assumes participation of 700 dray trucks in Maryland that operate in the Port of Baltimore area only.

**Estimation Methodology:** Emission reductions estimated from savings during both running and idling times and applied to annual dray truck VMT and total dray trucks in Maryland.

## Ride-hailing / Mobility as a Service (MaaS)

**Strategy Description:** Ride-hailing services not only encourage cost-saving and emission reducing measures like carpooling (the price savings of serves like Uber pool and Lyft Line), but also as a first/last mile connection between users and other modes, reducing the needs for SOV ownership. Mobility as a Service deployment at scale will be the replacement of private auto trips with the use of ride-hailing services either shared or SOV**.**

**Key Assumptions**: Impacts on reduced vehicle ownership, reduced travel activity to be estimated based on national literature pointing to a range of anywhere between 10 to 20 percent adoption of car sharing by 2030.

**Estimation Methodology:** Reduction in passenger trips due to decreased car ownership, impact due to reduced travel activity, and impact due to trip consolidation and increased occupancy of vehicles

## Pay-As-You-Drive (PAYD) Insurance

**Strategy Description:** PAYD is a usage-based insurance program where charges are based on usage and driver behavior, which is offered by several auto insurance companies in the US. This strategy involves adoption of PAYD insurance, which has been observed in multiple studies to reduce VMT.

**Key Assumptions**: 5 percent of Maryland drivers are enrolled in PAYD by 2030. The assumed VMT reduction associated with PAYD insurance premiums is 8 percent based on national studies.

**Estimation Methodology:** Reduction in travel activity due to reduced mileage as a result of PAYD. Reduction assumed at 8 percent (low case) as documented in a range of PAYD studies and literature review.

## Freight Villages/Urban Freight Consolidation Centers

**Strategy Description:** Consolidated freight distribution centers to utilize cleaner last-mile delivery trucks for urban areas.

**Key Assumptions**: It is being assumed that only short haul truck VMT is being impacted. The regional extent to which this strategy is applied is confined to the "urban freight corridor mileage distribution" as cited in the MD Strategic Goods Movement Plan 2018 (75 miles).

**Estimation Methodology:** Improved emission factor applied for short haul trucks VMT (1.759 billion VMT in 2030) attributable to the urban freight corridor mileage distribution.

### High-Speed Passenger Rail / SCMAGLEV / Loop

**Strategy Description:** This strategy assumes a build out of the NEC Vision, or construction of the SCMAGLEV and/or Loop, to facilitate intercity passenger rail travel through 2030.

**Key Assumptions**: Ridership potential based on Maryland's share of NEC's ridership. Potential next generation passenger rail trips in 2030 estimated on the same share of total corridor ridership. Further analysis pending ridership estimates from ongoing SCMAGLEV and Loop research.

**Estimation Methodology:** Amtrak's America 2050 report provides projected ridership numbers for Next Gen HSR for NE Corridor for the year 2030.

## Policy Scenario 3 (Pricing and Revenue)

This scenario takes a look at possibilities for addressing the primary challenge associated with implementing Policy Scenario 2 – funding. A market pricing approach could include current revenue sources, or augment or replace some of these sources with a VMT or carbon pricing approach. Among these options, MDOT estimated the outcomes of a carbon pricing strategy based on potential as a more sustainable and equitable revenue source. **This analysis was conducted for the scenario planning purposes of this report and is in no way indicative of MDOT's policy position.**

### Regional Carbon Price comparable to TCI Approach (RGGI for Transportation Sector)

**Strategy Description:** For the purpose of supporting MWG's scenario planning process, MDOT developed an estimation of a potential Carbon Pricing mechanism based on its more sustainable revenue source, ability to encourage further transformation to a low-carbon or zero carbon fleet, and lower equity concerns.

**Key Assumptions**: Used consistent assumptions with the 2015 TCI analysis, including ranges of cost per ton and VMT change to travel cost elasticities.

**Estimation Methodology:** MDOT analyzed four different Carbon Pricing tests based on the following assumptions:

- **Test 1** – $30 per ton $CO_2e$ (consistent with TCI analysis) applied to all on-road mobile source emissions starting in 2025
- **Test 2** – $30 per ton $CO_2e$ (consistent with TCI analysis) applied to all on-road mobile source emissions starting in 2021
- **Test 3** – Carbon price increasing annually from $20 per ton in 2020 to the social cost of carbon, $62.25 by 2030, applied to all on-road mobile source emissions starting in 2025
- **Test 4** – Carbon price increasing annually from $20 per ton in 2020 to the social cost of carbon, $62.25 by 2030, applied to all on-road mobile source emissions starting in 2021

# Appendix B. 2030 Strategy Definitions and Assumptions

## Policy Scenario 1 (On-the-Books)

As its name implies, this scenario evaluates the emission reductions from funded projects and programs. This includes projects and programs in the Consolidated Transportation Program (CTP), land development assumptions consistent with local plans and Maryland Department of Planning goals, and GHG reducing projects included in fiscally constrained MPO metropolitan transportation plans.

### 2030 Plans & Programs yield lower annual vehicle miles traveled (VMT) growth (1.4 percent per year compared to 1.7 percent per year for business as usual)

**Strategy Description:** Modeled VMT and emissions outcomes (through MOVES2014a) from implementation of most recently adopted MPO fiscally constrained long-range transportation plans and cooperative land use forecasts.

**Key Assumptions**: The VMT projections of implementing the plans and programs that include MPO planned projects (highway and transit) and future regional demographic projections developed by the jurisdictions in cooperation with Maryland Department of Planning (MDP), show an expected decrease of 3.159 billion VMT in 2030 relative to the business as usual VMT growth rate. Annual VMT growth rates as forecast by the Baltimore Metropolitan Council (BMC) and Metro Washington Council of Governments (MWCOG) within their modeling areas have been used for modeling purposes. Outside of these MPO counties, SHA developed highway performance monitoring system (HPMS) VMT growth rates from 1990 to 2014 are used.

**Estimation Methodology:** The 2030 Plans and Programs use information from the CTP, each MPO TIP and MTP, and land use, population, and employment projections from the Maryland Department of Planning (MDP) to estimate the emission trend-line through 2030. The average statewide annualized VMT growth rate through 2030 for the plans and programs scenario is 1.4 percent as compared to a 1.7 percent BAU, based on which emission reductions have been estimated using MOVES by attributing it to VMT based on travel activity inputs by source types (vehicle types).

### On-Road Technology (CHART, Traveler Information)

**Strategy Description:** This strategy covers on-road technology as it relates to the statewide implementation of CHART system with its five components including Traffic and Roadway Monitoring; Incident Management; 511 - Traveler's Information; System Integration and Communication; and Traffic Management.

**Key Assumptions**: Based on the existing coverage and effectiveness of CHART in the areas of incident response and other streamlined operations, the total annual emission reductions are estimated based on existing rates of coverage and coverage expansion, and effectiveness from SHA’s annual CHART reports.

**Estimation Methodology:** Based on CHART’s existing coverage area, VMT affected is estimated by facility types (roadway types – rural/urban and restricted/unrestricted access). Emission reductions are based on VMT for all vehicles on those roadway facilities impacted by the existing and expanded CHART coverage.

## Freight and Freight Rail Programs (Class I railroad improvements and MTA rail projects)

**Strategy Description:** Implementation of the Norfolk Southern Crescent Corridor and CSX National Gateway provides new capacity and eliminates bottlenecks for access to the Port of Baltimore and rail access westward toward PA and OH and south toward VA and NC. These privately funded programs are in addition to ongoing MTA investments in Maryland freight rail corridor improvements.

**Key Assumptions**: Potential projects to enable double-stack rail access to the Port of Baltimore have evolved over the last decade. Prior 2020 analysis assumed the planned components of the National Gateway project would be complete by 2020. Using that same analysis, but assuming it now is complete by 2030 (given the current status) is more realistic.

**Estimation Methodology:** Truck VMT impacted due to these improvements is estimated based on information collected from project studies (for example: 850,000 long-haul trucks annually impacted by the Crescent Corridor project) and similar information from the National Gateway project (share of MD truck VMT only included in the estimation).

## Public Transportation (projects not included in current modeling assumptions for MPO MTPs, but determined to be fully funded for implementation by 2030)

**Strategy Description:** This strategy includes projects designed to increase public transit capacity, improve operations and frequency, and implementation of new BRT corridors. Projects include dedicated bus lanes/transit service priority, bus rapid transit (US 29) in Montgomery and Howard Counties, other Montgomery County BRT corridors include MD 355 and Randolph Road, the Baltimore North Avenue Rising project, and the Southern Maryland Commuter Bus initiative.

**Key Assumptions**: Ridership estimates from recent and ongoing studies for each project corridors are converted into annual transit trips, which are then multiplied by an average commute trip length (16 miles based on MWCOG model estimates) to obtain annual VMT and emission reductions. Emissions from transit vehicles are included within the baseline MOVES modeling.

**Estimation Methodology:** Projects and initiatives with data on projected ridership and other indicators for estimation of reduced travel activity, use of transit as a lower alternative emissions intensive mode of travel have been included in the analysis.

## Public Transportation (fleet replacement / technology based on current procurement)

**Strategy Description:** This strategy includes MTA planned fleet replacement to Clean Diesel and WMATA planned fleet replacement based on current replacement strategy.

**Key Assumptions**: Based on MTA’s planned bus replacement schedule and other fleet replacement information, total number of active bus fleet that need to be replaced was estimated from FY 2018-2030. It is assumed that 3,000 gallons of fuel is reduced per year by new clean diesel buses.

**Estimation Methodology:** Reduction of 100 - 160 tons of greenhouse gas per year compared to a 40’ diesel bus and 75 - 110 tons compared to an existing 40’ diesel-hybrid bus.

## TDM (Commuter Choice MD, Commuter Connections ongoing/expanding programs)

**Strategy Description:** The following programs are included for consideration towards reduction in VMT: Commuter Connections Transportation Emission Reduction Measures** (MWCOG), Guaranteed Ride Home, Employer Outreach, Integrated Rideshare, Commuter Operations and Ridesharing Center, Telework Assistance, Mass Marketing, MTA Transportation Emission Reduction Measures, MTA College Pass, MTA Commuter Choice Maryland Pass, and Transit Store in Baltimore.

**Key Assumptions**: A trend-line extrapolation of annual VMT reductions from the full suite of TDM programs is used as a proxy for funding levels and strategy effectiveness, resulting in a VMT reduction 0.82 percent proportional to 2030 VMT, which is applied to the VMT for the year 2030.

**Estimation Methodology:** MWCOG's TERMS documentation has information on potential daily reduction in vehicle trips and daily VMT reductions by TDM program, which have been used to estimate the total potential VMT reduction for 2030. This data was applied to MD's share of the regional VMT. TDM program data from BMC region was added to the Metro Washington total to estimate the total TDM program emission reduction potential.

## Pricing Initiatives (MDTA conversion to All Electronic Tolling)

**Strategy Description:** Ongoing Conversion to All-Electronic Tolling.

**Key Assumptions**: It is assumed that 92.6 percent of LDVs and 7.4 percent of HDVs are impacted in the year 2030 based on Attainment Report data on all electronic tolling. Assume 1 minute of idling per transaction for 50 percent of transactions and 1.5 minutes for other 50 percent obtained from MDOT (MDTA estimate)

**Estimation Methodology:** Reduced emissions from avoided idling is estimated for the share of fleet to estimate avoided emissions.

## Bicycle and Pedestrian Strategies (continuation of State and local programs)

**Strategy Description:** Continued system expansion through SHA, MTA, and MVA programs in the CTP such as Bikeshare, Bikeways, retrofit programs, and Federal grants as summarized in the 2018-2023 CTP in addition to locally funded projects within the MWCOG and BMC 2017-2022 TIPs.

**Key Assumptions**: Assumes VMT reductions due to availability of bicycle and pedestrian facility lane miles (assuming connectivity is maintained and incrementally added to the existing network).

**Estimation Methodology:** Baseline VMT reductions for bike trips less than 5 miles in length and walk trips less than a mile in length were estimated using their existing mode shares. Ratios of baseline VMT reduction to linear mile of facility was estimated thereafter. Future linear miles of pedestrian and bicycle facility based on targets indicated in the 2018 MDOT Attainment Report (2018 AR) were estimated and factored to the increased extent based on the ratio of baseline reductions to arrive at the 2030 VMT reductions to estimate the emission reductions in the form of avoided auto-trips.

## Land-Use and Location Efficiency (consistent with MDP assumptions)

**Strategy Description:** MDP projection of 75 percent compact development for 10 percent of development / redevelopment through 2030. Compact development is assumed to reduce VMT by 30 percent relative to standard density / mix development. This strategy partially captures MDOT/MDP commitment to TOD across 20 designated locations in Maryland.

**Key Assumptions**: The approach is based on the methodology provided in *CO2 Reductions Attributable to Smart Growth in California* by Reid Ewing, Ph.D., National Center for Smart Growth, University of Maryland, and Arthur C. Nelson, Ph.D., FAICP, Director of Metropolitan Research, University of Utah.

**Estimation Methodology:** 75 percent compact development for 10 percent of development / redevelopment is multiplied by the assumed 30 percent VMT reduction from the study noted above, and an assumed ratio of 90% CO2 reduced for every unit of VMT reduction results in a total 2 percent CO2 reduction for this strategy. **MDP 2030: % CO2 reduction = 0.75 x 0.1 x 0.3 x 0.9 = 2%**

### Drayage Track Replacements

**Strategy Description:** This strategy estimates the benefit of replacing 600 total dray trucks resulting from MDE, MDOT and Federal grants through 2030, which is based on the current replacement rate.

**Key Assumptions**: This strategy assumes current funding program implementation levels to continue through 2030.

**Estimation Methodology:** Emission reductions are based on increased fuel efficiency (and thereby the total fuel use reductions) of dray trucks which replace the current trucks in operation.

### BWI Airport Parking Shuttle Bus Replacements

**Strategy Description:** This strategy involves replacement of BWI airport parking shuttles - 50 diesel buses with clean diesel buses and 20 CNG buses.

**Key Assumptions**: Acquisition information based on what is publicly available from MDOT and news sources including the types of vehicles replacing the existing vehicles.

**Estimation Methodology:** Emission reductions are based on increased fuel efficiency of clean diesel and CNG as fuel for improved emissions in operation.

# Policy Scenario 2 (Emerging and Innovative)

This scenario acknowledges that attaining the 2030 goal will require additional investments to expand or accelerate deployment of previously planned strategies, deployment of new best-practice strategies, and capitalizing on the opportunities created by new transportation technologies. All of the strategies in this scenario require additional funding and in some cases private sector commitment. The 25 strategies in this scenario (17 emerging and 8 innovative) represent a combination of approaches to reduce GHG emissions with varying levels of confidence and MDOT responsibility.

## Emerging

### Freeway Management/Integrated Corridor Management

**Strategy Description:** This strategy assumes implementation of an Integrated Corridor Management strategy on all urban limited access corridors.

**Key Assumptions**: This strategy assumes integrated corridor management, intelligent transportation systems, or advanced traffic management systems for the three corridors listed.

**Estimation Methodology:** Deployment of these strategies are already widespread throughout Maryland. Through 2030, this strategy assumes that some level of corridor management (including ramp metering), intelligent transportation systems, or advanced traffic management systems are in place on all urban restricted access facilities. The FHWA, “Travel and Emissions Impacts of Highway Operations Strategies,” Final Report, by Cambridge Systematics, and the work of MWCOG's multisector working group (as documented in the January, 2016 report) are used to support this analysis.

## Arterial System Operations and Management

**Strategy Description:** This strategy estimates the benefits of implementing Arterial System Operations and Management including expanded signal coordination and control on all urban principal and minor arterials by 2030.

**Key Assumptions**: Only urban arterials are being assumed to be covered as part of this strategy through 2030.

**Estimation Methodology:** Emission reductions are attributed to VMT impacted during the peak period resulting in improved speeds for travel happening on select facilities (urban arterials) for all traffic.

## Limited Access System Operations and Management

**Strategy Description:** This strategy evaluates the emission reductions benefits of implementation of a Limited Access System Operations and Management including deployment of technologies like ramp metering.

**Key Assumptions**: For ramp metering, a two-minute wait time on average was considered during peak hours at ramp entrance. Ramp fraction was estimated at 8 percent from MOVES defaults.

**Estimation Methodology:** Improvement of speeds on urban restricted access facilities causes emission reductions. This is offset by a fraction by the waiting vehicles on the ramps, which results in additional idling emissions. Net emission reductions are estimated for this strategy.

## Managed Lanes (Traffic Relief Plan Implementation)

**Strategy Description:** This strategy estimates the emissions benefit of Chapter 30 projects (Traffic Relief Plan) to add express toll lanes to the routes of three of Maryland's most congested highways — the Interstate 495 Capital Beltway, the I-270 spur connecting Frederick to D.C., and the Baltimore-Washington Parkway between the two cities.

**Key Assumptions**: The congestion affects 260,000 motorists daily on I-270, 240,000 motorists daily on I-495 and 120,000 motorists each day on the Baltimore-Washington Parkway.

**Estimation Methodology:** Based on the project list and benefits as estimated by SHA, estimated daily fuel reductions were translated into 2030 emission reductions.

## Intermodal Freight Centers Access Improvement

**Strategy Description:** As noted in the Strategic Goods Movement Plan, reliability improvements and congestion mitigation that positively impact supply chain costs associated with driver and truck delay and fuel consumption is a desired outcome. The strategy to achieve this includes SHA and MDTA continuing to advance appropriate measures to reduce or mitigate the effects of congestion on industry supply chains.

**Key Assumptions**: The strategy has been applied to intermodal sections in Maryland and the mileage is assumed to be similar to the national share of 1.4 percent (as data on intermodal facilities mileage in MD was not able to be estimated based on available data).

**Estimation Methodology:** Potential reduction is based on the share of truck VMT operating in congested conditions (less than 50 percent of free-flow speed) and the potential extent of a strategy aimed at reducing the share of truck VMT operating in congested conditions. Benefits would be localized to individual intersections/interchanges and ramps, as well as local streets/intermodal connectors providing access to the Port of Baltimore and other intermodal facilities.

## Commercial Vehicle Idle Reduction, Low-Carbon Fleet

**Strategy Description:** Commercial Vehicle Idle Reduction assumes enforcement of anti-idling law Maryland's Idling Law (Transportation Article §22-402) and have expanded regulations on use of auxiliary power unites (APUs) in MD truck areas.

**Key Assumptions**: Daily total HDV idling is limited by the number of parking spaces, occupancy, and non-TSE installed spaces. This strategy definition considers extended idling only and not short term idling (e.g., at a delivery/pick-up point). It is assumed that APUs will be used to power the trucks during the time spent idling. Idling emission rates for HDV and APUs are derived and given that this is also a strategy with implications for PM emission reductions, PM emissions are also presented in the results.

**Estimation Methodology:** It is estimated that trucks would have spent time idling in absence of this law. A high case and a low case for emission reductions is estimated considering all or just 50 percent of extended idling is handled by APUs.  High case adopted and presented in the results estimates 2,173 total HDVs avoiding extended idling as a result of this strategy.

## Eco-Driving

**Strategy Description:** This strategy is assumed to be undertaken as a general marketing program with basic outreach and information brochure about the savings included.

**Key Assumptions**: Assumptions based on the extent of government led programs. Private sector programs not included. For example, fleet operators of trucks, logistical operation enterprises conduct eco-driving for their fleet separately and typically have a higher degree of focus and return on results from the programs. It is assumed that 2 percent of the statewide population are reached using these general marketing programs. Out of these people, only 50 percent (1 percent of total population) have on-board display tools that have on-board display tools that provide feedback from eco-driving. The benefits of eco-driving is two-pronged - one by training and the other due to attention being paid to the on-board display tools. Heavy duty trucks included for this analysis are only assumed to be a part of the general marketing campaign and no specific training provided elsewhere.

**Estimation Methodology:** Adoption rates and skill/habit retention are kept intentionally low as this campaign is just a marketing and education campaign. They are typically higher for rigorous training and educational campaigns.

## Lead by example - Alternative Fuel Usage in State Fleet

**Strategy Description:** This strategy is already being tracked as part of MDOT's Excellerator program and includes deployment of alternative fuel vehicles and fuels including ultra low Sulphur diesel, bio-diesel, and E-85 as the proposed as alternatives.

**Key Assumptions**: It is assumed that the program continues to be implemented at current levels resulting in reduced diesel and gasoline fuel use as it is replaced by blended fuels.

**Estimation Methodology:** Reductions are based on changes in carbon intensity due to diverse fuel choices and blends.

## Truck Stop Electrification

**Strategy Description:** This strategy assumes equipping all public truck bays to be equipped with electrification for powering trucks during overnight stays or time otherwise spent as extended idling.

**Key Assumptions**: Strategy assumes a range of deployment of electrification of truck stops throughout the state. Three scenarios of deployment (all public spaces, 50 percent of public spaces, and 10 percent of public spaces are considered). Average rates of truck stop utilization is set at 50 percent. It is assumed that the electricity source for powering the truck is similar to using an APU (without having to compute the power supplied for the duration and its source and its energy footprint).

**Estimation Methodology:** Three scenarios for deployment in 2030 – 100 percent, 50 percent and 10 percent of public spaces available across the state are considered and presented as high/medium/and low cases. The high case of deployment (all public places) is chosen for estimation purposes.

## Transit capacity/service expansion (fiscally unconstrained)

**Strategy Description:** Projects in fiscally constrained LRTPs **post-2030** or in needs or aspirations based plan (unconstrained). These potential enhancements/expansions to Maryland's transit system are extensive, including extension of the Baltimore Metro Green Line and multiple bus rapid transit corridors in Montgomery, Prince Georges, Howard, and Anne Arundel Counties. Most of these projects are identified in the BMC and MWGOG LRTPs for implementation post-2030 or identified as a need for a corridor study. This includes every other potential BRT corridor, TOD build outs, MGIP/Cornerstone Plan build out, and references to a Green Line extension in Baltimore and new/updated MARC stations at West Baltimore and Bayview.

**Key Assumptions**: Assumes that some of these projects will have the necessary funding and will be operationalized by 2030 to realize potential GHG reduction benefits.

**Estimation Methodology:** Emission reductions estimated based on individual project information including potential ridership estimates as reduced VMT. MTA fleet replacement and benefits of TOD build-out from 20 incentive zones is estimated using MDP’s TOD planning tool. Estimated reductions of TOD are based on zonal classifications based on number of households impacted and trips reduced (by location coefficient types).

## Expanded TDM strategies (dynamic), telecommute, non-work strategies

**Strategy Description:** The implementation and coverage of TDM strategies considered in the Policy Scenario 1 is doubled and the impact of those programs resulting in an increased share of VMT reductions by 2030. This approach reflects a renewed and expanded commitment to TDM, including more extensive financial incentives or disincentives to driving alone and dynamic ridesharing options.

**Key Assumptions**: Assuming increased coverage of TDM strategies based on additional funding influx resulting in the same proportion of increase in VMT reductions.

**Estimation Methodology:** Reduced VMT due to expansion of the TDM programs is doubled under this scenario and emission reductions are estimated for the share of passenger car VMT impacted.

## Expanded bike/pedestrian system development

**Strategy Description:** Expanded bicycle and pedestrian facility infrastructure by an increased pace which corresponds to 150 percent of the existing bicycle and pedestrian infrastructure provision target.

**Key Assumptions**: Future linear miles of pedestrian and bicycle facilities were estimated based on targets provided in the 2018 MDOT Attainment Report (2018 AR). In each case, two numbers were estimated. The first number corresponds to the target indicated in the 2018 AR and is referred to below as "existing rate" strategy below. The second number corresponds to 150 percent of the 2018 AR target and is referred to below as the "increased rate" strategy below.

**Estimation Methodology:** The above growth rates were applied to the existing linear miles of sidewalk and bicycle facility on state-owned roads in urban areas, as determined from data provided by SHA, to calculate future linear miles of sidewalk and bicycle facility in urban areas for each strategy.

### Freight Rail Capacity Constraints/Access (Howard St. Tunnel)

**Strategy Description:** Potential projects to enable double-stack rail access to the Port of Baltimore have evolved over the last decade. The new direction is to expand the Howard Street tunnel as described in the recent FASTLANE Grant application submitted jointly by MDOT and CSX. Regardless of how this project is funded, this strategy assumes implementation by 2030, and estimates the impacts on truck movements to and from the Port.

**Key Assumptions**: Building out the Howard Street Tunnel and enabling double-stacking directly to the Port of Baltimore by 2030.

**Estimation Methodology:** Reduced emissions based on VMT reduction due to double-stacking. VMT reduced is for combination long-haul trucks affected by this improvement only.

### Regional Clean Fuel Standard

**Strategy Description:** Similar to approach in the 2015 Transportation and Climate Initiative (TCI) analysis, a clean fuels standard to achieve a 15 percent reduction in carbon intensity by 2030 was evaluated.

**Key Assumptions**: Emission reductions estimated for the year 2025 in the TCI analysis were used for the year 2030, to correspond to a 12 year base-year and scenario year gap (TCI analysis used 2013 as the base year).

**Estimation Methodology:** Emission reductions due to reduction from baseline in the TCI study have been applied to the 2030 VMT (discounted for EVs).

### MARC Growth and Investment Plan (MGIP) / Cornerstone Plan Completion

**Strategy Description:** This strategy involves advancing the MGIP 2030-2050 vision for projects to be accelerated to be operational by 2030.

**Key Assumptions**: Assumes no fiscal constraints and includes projects that are assumed to be accelerated for implementation by 2030.

**Estimation Methodology:** Projected ridership potential attributable to the total plan implementation is estimated to occur by 2030 as a result of accelerated improvement of the plan.

### EV Scenario + Additional 100K Ramp Up (total of 704,840 EV s)

**Strategy Description:** An additional 100,000 EVs are assumed to be rolled-out from 2025 along the same splits of BEV and PHEV shares to make up a total of 704,840 total EVs on the road in the year 2030.

**Key Assumptions**: Keeping the share of BEV/PHEVs same as in the MDOT/MDE scenario. 55 percent of PHEV VMT is assumed to be electric.

**Estimation Methodology:** All the emissions except for the PHEV's fuel driving share of 45 percent are assumed to be avoided.

### 50 percent EV Transit Bus Fleet

**Strategy Description:** This is a what-if scenario to estimate the emission reduction benefits of having a 50 percent transit bus fleet in the year 2030.

**Key Assumptions**: Procurement policies change as early as 2020 with a commitment to 100 percent of bus replacements as a battery electric or plug-in hybrid electric through 2030.

**Estimation Methodology:** Half of the emissions attributable to transit buses in Maryland in 2030 are estimated to be avoided.

## Innovative

### Connected and Automated Vehicle (CAV) Technologies

**Strategy Description:** This strategy estimates the emission reduction benefits of market penetration of ACVs and provision of adequate infrastructure to enable V2V and V2I technologies.

**Key Assumptions**: Core assumptions regarding market penetration of AVs, change in VMT, and fuel savings have been adopted from a 2015 ENO Transportation Center study on AV deployment which lays out three scenarios of AV deployment, of which the low-end penetration of 10 percent by 2030 is considered in this analysis.

**Estimation Methodology:** The following changes are estimated due to deployment of AVs from an emissions perspective:

- Emissions associated with VMT increase resulting from mobility benefits (AVs added to the fleet – this increases emissions and thereby a negative impact, estimated at **20 percent increase**);
- Fuel savings due to AVs (savings of AVs only, estimated at **13 percent reduction**);
- Congestion reduction benefits on freeways and arterials (assumed LOS E to C on restricted access roadways and unrestricted access roadways). These are due to vehicles following automated vehicles, etc. Level of service criteria for restricted and unrestricted roadway types obtained from HCM and emission rates are applied at the different operating speeds (bins) and assigned to VMT by that roadway type (estimated at 15 percent reduction for limited access facilities and 5 percent reduction for arterials).

### Variable Speeds / Speed Management on Freeways

**Strategy Description:** This strategy estimates the potential emission reduction benefits of speed limit enforcement on urban restricted roadways.

**Key Assumptions**: This strategy assumes applying speed management strategies during non-peak periods. Different emission factors for average speeds used for LDVs and HDVs to reflect marginal differences between the two classes of vehicles. Note enforcement may come about more through automated vehicle technology rather than traditional means.

**Estimation Methodology:** Difference between emission rates of VMT without enforcement (higher speed) and under speed enforcement (55 mph) applied to the VMT for that vehicle type.

## Zero-Emission Trucks/Truck Corridors

**Strategy Description:** This strategy considers establishment of infrastructure and vehicle replacements for implementation of zero emission corridors connecting to the Port of Baltimore in comparison with the I-710 Calstart Corridor study.

**Key Assumptions**: This strategy assumes participation of 700 dray trucks in Maryland that operate in the Port of Baltimore area only.

**Estimation Methodology:** Emission reductions estimated from savings during both running and idling times and applied to annual dray truck VMT and total dray trucks in Maryland.

## Ride-hailing / Mobility as a Service (MaaS)

**Strategy Description:** Ride-hailing services not only encourage cost-saving and emission reducing measures like carpooling (the price savings of serves like Uber pool and Lyft Line), but also as a first/last mile connection between users and other modes, reducing the needs for SOV ownership. Mobility as a Service deployment at scale will be the replacement of private auto trips with the use of ride-hailing services either shared or SOV**.**

**Key Assumptions**: Impacts on reduced vehicle ownership, reduced travel activity to be estimated based on national literature pointing to a range of anywhere between 10 to 20 percent adoption of car sharing by 2030.

**Estimation Methodology:** Reduction in passenger trips due to decreased car ownership, impact due to reduced travel activity, and impact due to trip consolidation and increased occupancy of vehicles

## Intercity Bus Service Expansion

**Strategy Description:** This strategy evaluates the emission reduction benefits of expansion of planned long distance bus service in Maryland. MDOT MTA administers the MDOT MTA Intercity Bus (ICB) Program. MDOT MTA ICB Program sponsors intercity bus services in the following corridors: I-86, US-50, US-40.

**Key Assumptions**: Expanded service assumes additional service to other corridors or capacity addition (headway improvement) on existing routes as needed.

**Estimation Methodology:** Estimate the benefits of long distance auto VMT now traveled in long-distance buses. Emission reductions are a result of lower carbon intensive travel.

## Pay-As-You-Drive (PAYD) Insurance

**Strategy Description:** PAYD is a usage-based insurance program where charges are based on usage and driver behavior, which is offered by several auto insurance companies in the US. This strategy involves adoption of PAYD insurance, which has been observed in multiple studies to reduce VMT.

**Key Assumptions**: 5 percent of Maryland drivers are enrolled in PAYD by 2030. The assumed VMT reduction associated with PAYD insurance premiums is 8 percent based on national studies.

**Estimation Methodology:** Reduction in travel activity due to reduced mileage as a result of PAYD. Reduction assumed at 8 percent (low case) as documented in a range of PAYD studies and literature review.

### Freight Villages/Urban Freight Consolidation Centers

**Strategy Description:** Consolidated freight distribution centers to utilize cleaner last-mile delivery trucks for urban areas.

**Key Assumptions**: It is being assumed that only short haul truck VMT is being impacted. The regional extent to which this strategy is applied is confined to the "urban freight corridor mileage distribution" as cited in the MD Strategic Goods Movement Plan 2018 (75 miles).

**Estimation Methodology:** Improved emission factor applied for short haul trucks VMT (1.759 billion VMT in 2030) attributable to the urban freight corridor mileage distribution.

### High-Speed Passenger Rail/SCMAGLEV

**Strategy Description:** This strategy assumes a build out of the NEC Vision, or construction of the SCMAGLEV and/or Hyperloop, to facilitate intercity passenger rail travel through 2030.

**Key Assumptions**: Ridership potential based on Maryland's share of NEC's ridership. Potential next generation passenger rail trips in 2030 estimated on the same share of total corridor ridership. Further analysis pending ridership estimates from ongoing SCMAGLEV and Hyperloop research.

**Estimation Methodology:** Amtrak's America 2050 report provides projected ridership numbers for Next Gen HSR for NE Corridor for the year 2030.

## Policy Scenario 3 (Pricing and Revenue)

This scenario takes a look at possibilities for addressing the primary challenge associated with implementing Policy Scenario 2 – funding. A market pricing approach could include current revenue sources, or augment or replace some of these sources with a VMT or carbon pricing approach. Among these options, MDOT estimated the outcomes of a carbon pricing strategy based on potential as a more sustainable and equitable revenue source. **This analysis was conducted for the scenario planning purposes of this report and is in no way indicative of MDOT's policy position.**

### Regional Carbon Price comparable to TCI Approach (RGGI for Transportation Sector)

**Strategy Description:** For the purpose of supporting MWG's scenario planning process, MDOT developed an estimation of a potential Carbon Pricing mechanism based on its more sustainable revenue source, ability to encourage further transformation to a low-carbon or zero carbon fleet, and lower equity concerns.

**Key Assumptions**: Used consistent assumptions with the 2015 TCI analysis, including ranges of cost per ton and VMT change to travel cost elasticities.

**Estimation Methodology:** MDOT analyzed four different Carbon Pricing tests based on the following assumptions:

- **Test 1** – $30 per ton $CO_2e$ (consistent with TCI analysis) applied to all on-road mobile source emissions starting in 2025
- **Test 2** – $30 per ton $CO_2e$ (consistent with TCI analysis) applied to all on-road mobile source emissions starting in 2021

- **Test 3** – Carbon price increasing annually from $20 per ton in 2020 to the social cost of carbon, $62.25 by 2030, applied to all on-road mobile source emissions starting in 2025
- **Test 4** – Carbon price increasing annually from $20 per ton in 2020 to the social cost of carbon, $62.25 by 2030, applied to all on-road mobile source emissions starting in 2021

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# Appendix K

## MDA Recommended Practices

# 2019 GGRA Draft Plan

# Greenhouse Gas Reductions From Agriculture: Menu of Recommended Practices

GHG estimates from comet-planner.nrel.colostate.edu/COMET-Planner_Report_Final.pdf

| | | GHG Reduction | | |
|---|---|---|---|---|
| **NRCS Conservation Practices** | | **Mt CO2e/ac/yr** | | |
| **Cropland Management** | **Description of practice** | **$CO_2$** | **$N_2O$** | **Sum** |
| Conventional Tillage to No Till (CPS 329) | | 0.42 | -0.11 | 0.31 |
| Conventional Tillage to Reduced Tillage (CPS 345) | Reduced tillage = strip till | 0.13 | 0.07 | 0.20 |
| N Fertilizer Management (CPS 590) | Improve N fertilizer management to reduce by 15% through 4R or nitrification inhibitors | 0.00 | 0.11 | 0.11 |
| Replace N Fertilizer w/ Soil Amendments (CPS 590) | Soil amendments include compost, manure | 1.75 | 0.00 | 1.75 |
| Conservation Crop Rotation (CPS 328) | Decrease fallow or add perennial crop to rotation | 0.21 | 0.01 | 0.22 |
| Cover Crops (CPS 340) | Add seasonal cover crop to cropland | 0.32 | 0.05 | 0.37 |
| Insert forage planting into rotation (CPS 512) | Add annual or perennial forage to rotation | 0.21 | 0.01 | 0.22 |
| Mulching (CPS 585) | Add high carbon mulch to cropland | 0.32 | NA | 0.32 |
| **Land use changes- add herbaceous plants** | | | | |
| Conservation Cover (CPS 327) | Convert to permanent unfertilized grass, legume, pollinator or other mix, ungrazed | 0.98 | 0.28 | 1.26 |
| Forage and biomass planting (CPS 512) | Convert to grass, forage or biomass plant | 0.21 | 0.01 | 0.22 |
| Riparian herbaceous cover (CPS 390) | Convert area near water to permanent unfertilized grass | 0.98 | 0.28 | 1.26 |
| Contour buffer strips (CPS 332), | Covert strips to permanent unfertilized grass, legume, pollinator or other mix | 0.98 | 0.28 | 1.26 |
| Field border (CPS 386) | Convert strips to permanent unfertilized grass/legume to reduce runoff | 0.98 | 0.28 | 1.26 |
| Filter Strip (CPS 393) | Convert strips to permanent unfertilized grass/legume | 0.98 | 0.28 | 1.26 |
| Grassed Waterway (CPS 412) | Convert strips to permanent unfertilized grass/legume to filter water | 0.98 | 0.28 | 1.26 |
| Vegetative barrier (CPS 601/342) | Plant stiff vegetative cover on hillsides or by streams to reduce erosion; can be used in critical areas | 0.98 | 0.28 | 1.26 |
| **Land use changes- add woody plants** | | | | |
| Convert unproductive cropland or grassland to farm woodlot (CPS 612) | Plant trees and shrubs in marginal cropland to restore diversity, improve water quality | 1.98 | 0.28 | 2.26 |
| Tree & shrub establishment (CPS 612) | Plant trees and shrubs | 1.98 | 0.28 | 2.26 |
| Riparian Forest Buffer Establishment (CPS 391) | Replace strip of cropland near water with woody plants | 2.19 | 0.28 | 2.47 |
| Alley Cropping (CPS 311) | Replace 20% of annual cropland with woody plants | 1.71 | 0.03 | 1.74 |
| Multistory Cropping (CPS 379) | Replace 20% of cropland with trees & shrubs of different heights, could be permaculture | 1.71 | 0.03 | 1.74 |
| Hedgerows (CPS 422) | Replace strip of cropland with one row woody plants, could combine with Conservation Cover for pollinators | 1.42 | 0.28 | 1.70 |
| **Grazing** | | | | |
| Silvopasture (CPS 381) | Add trees and shrubs tograzed pastures (> 20 plants/acre | 1.34 | 0.00 | 1.34 |
| Prescribed grazing/rotational grazing (CPS 528) | Short-term intense grazing in small paddocks | 0.26 | 0.00 | 0.26 |

*Note: Some implementation guidelines not listed in the NRCS Conservation Practice Standards (CPS) may be required to ensure adequate carbon sequestration and alignment with the GHG reduction estimates from COMET-Planner.*