Appendix F

Documentation of Maryland PATHWAYS Scenario Modeling

2019 GGRA Draft Plan

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Documentation of Maryland PATHWAYS Scenario Modeling

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Prepared for the Maryland Department of Environment

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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%

[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.

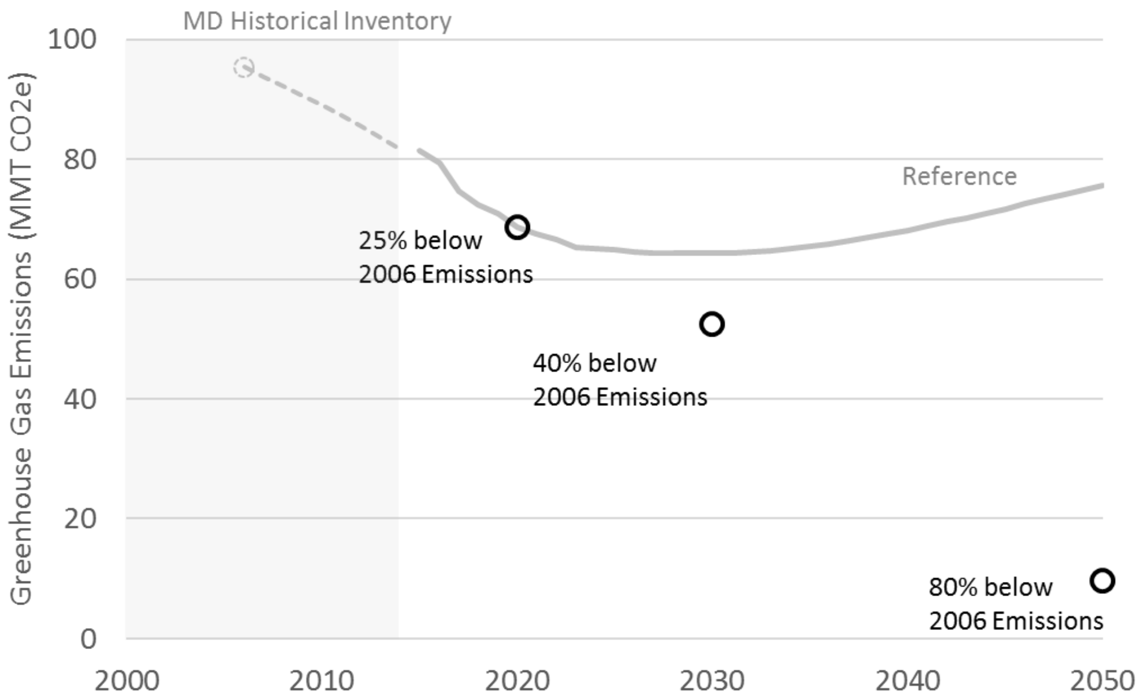

Figure 1-2. Maryland Net GHG Emissions Results for Reference Scenario, 2015-2050 compared to the adopted GHG targets[3]

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

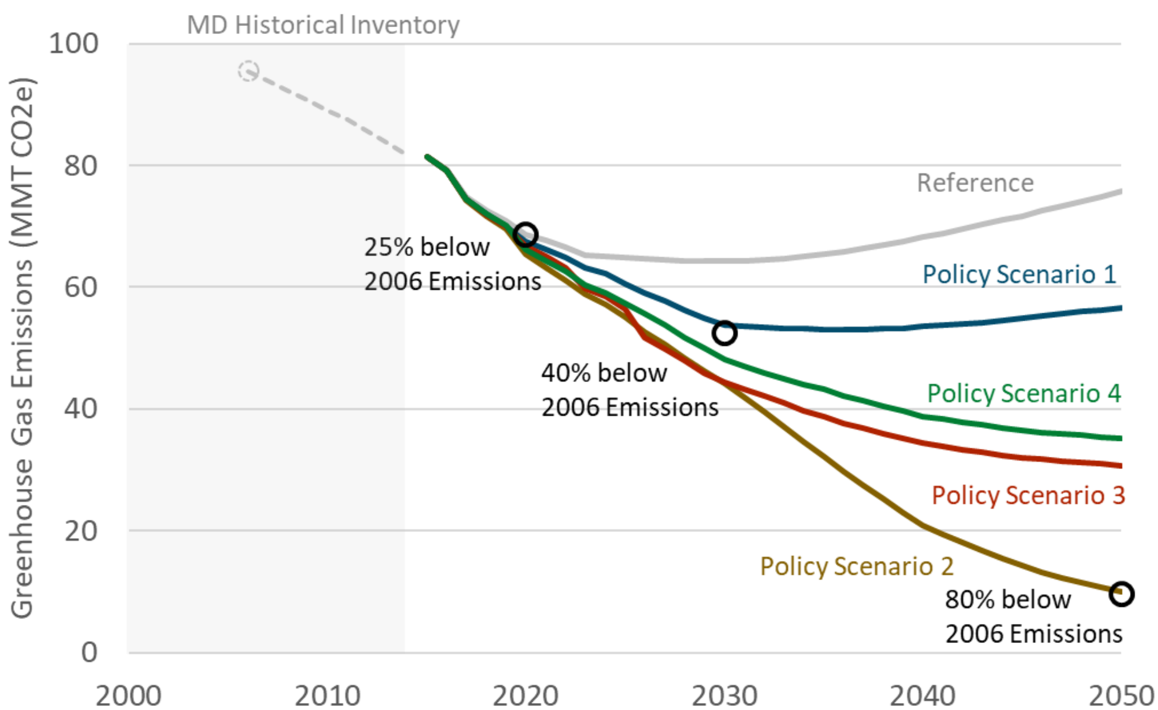

Figure 1-3. Maryland Net GHG Emissions Results for Policy Scenarios, 2015-2050 compared to the adopted GHG targets

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.

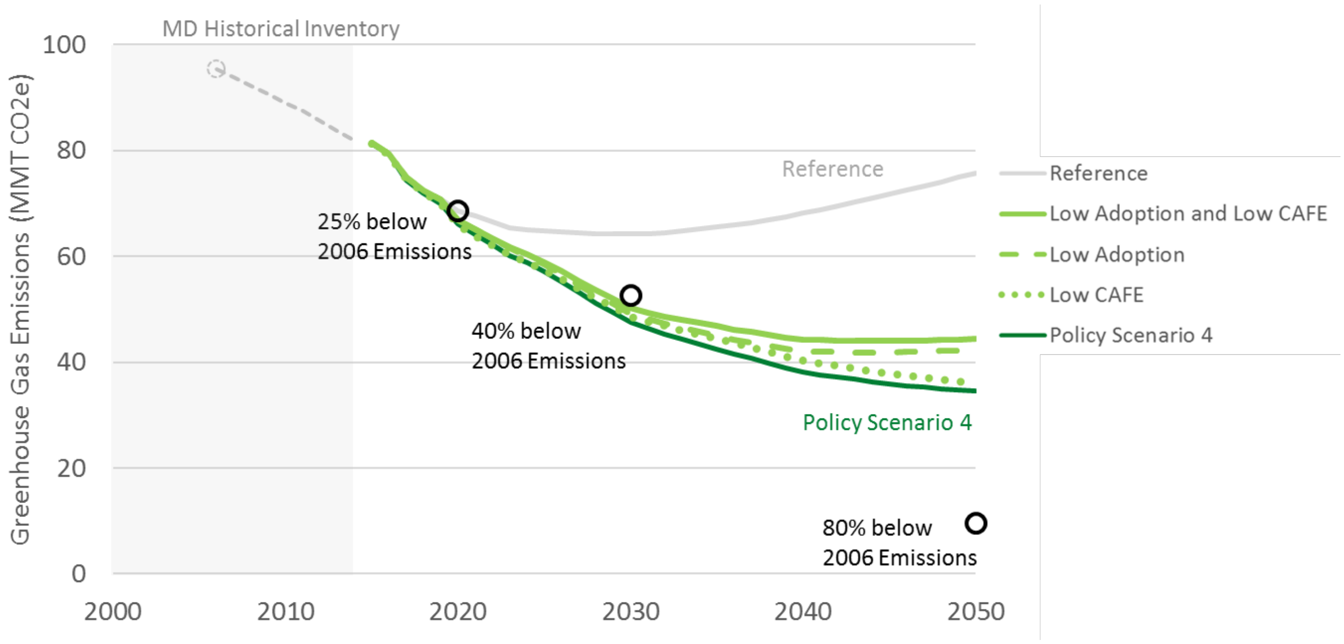

Figure 1-4. Maryland Net GHG Emissions for Sensitivities on Policy Scenario 4, 2015-2050

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.

[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.

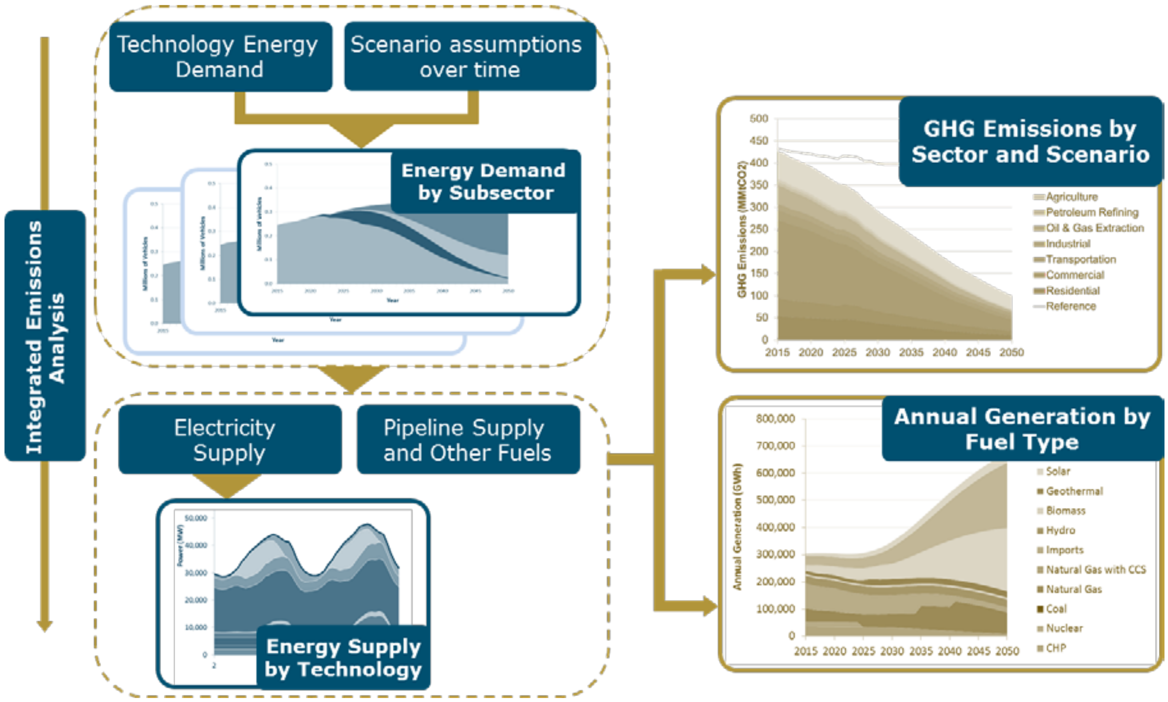

Figure 2-1. PATHWAYS Energy Modeling Framework

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 50% RPS by 2030	25% RPS by 2020 100% Clean and Energy Standard (CARES) by 2040	25% RPS by 2020 50% RPS by 2030	25% RPS by 2020 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.

[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.

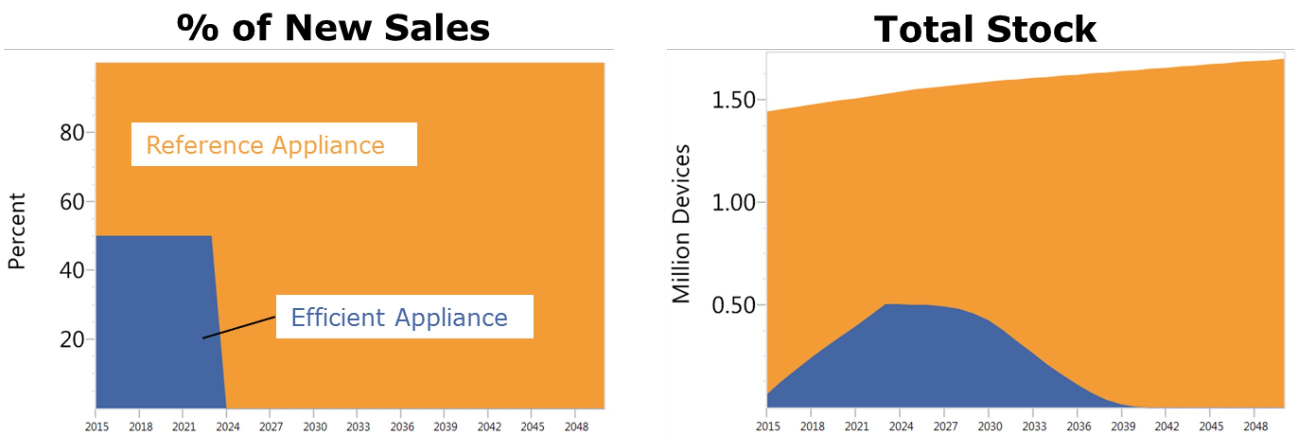

Figure 2-3. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Reference Scenario

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 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 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

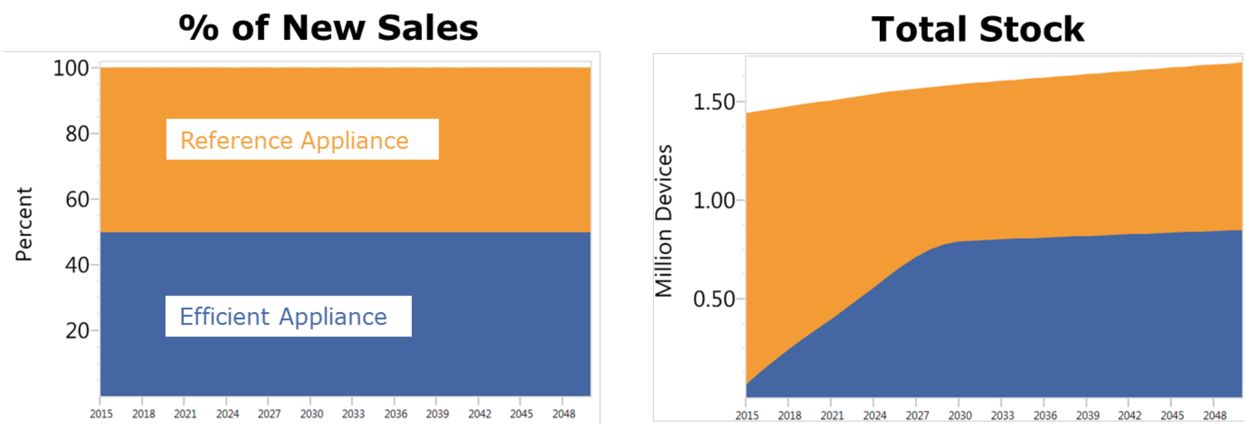

Figure 2-4. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Policy Scenario 1

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

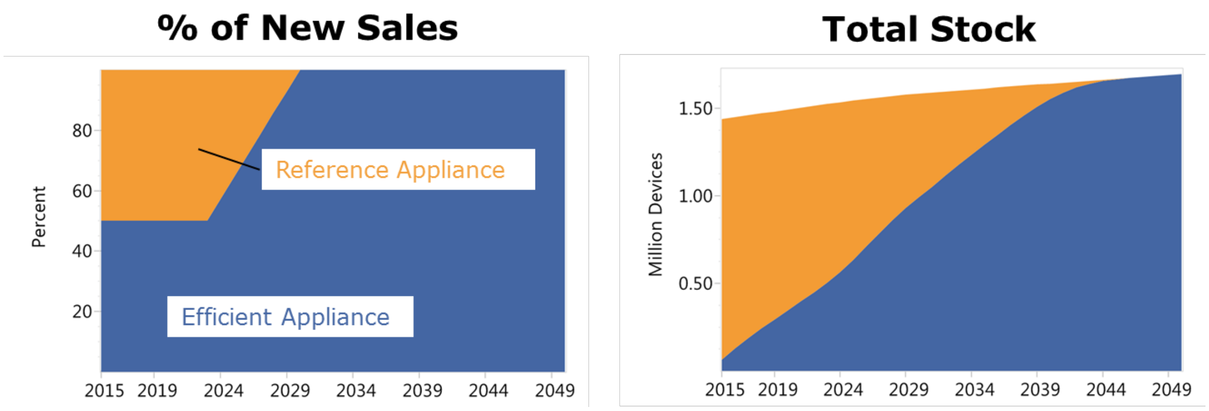

Figure 2-5. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Policy Scenario 2

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 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 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

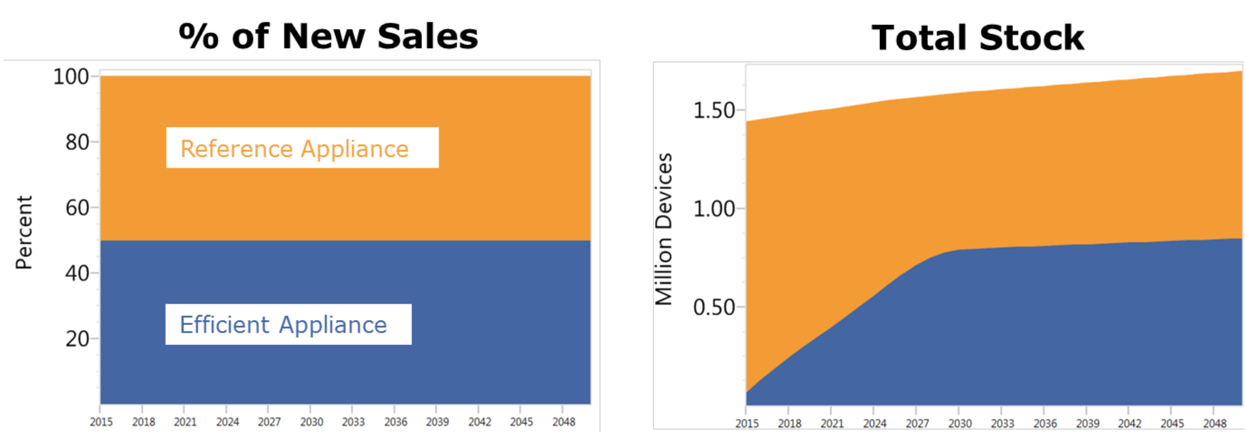

Figure 2-6. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Policy Scenario 3 (identical assumption to Policy Scenario 1)

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 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 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.

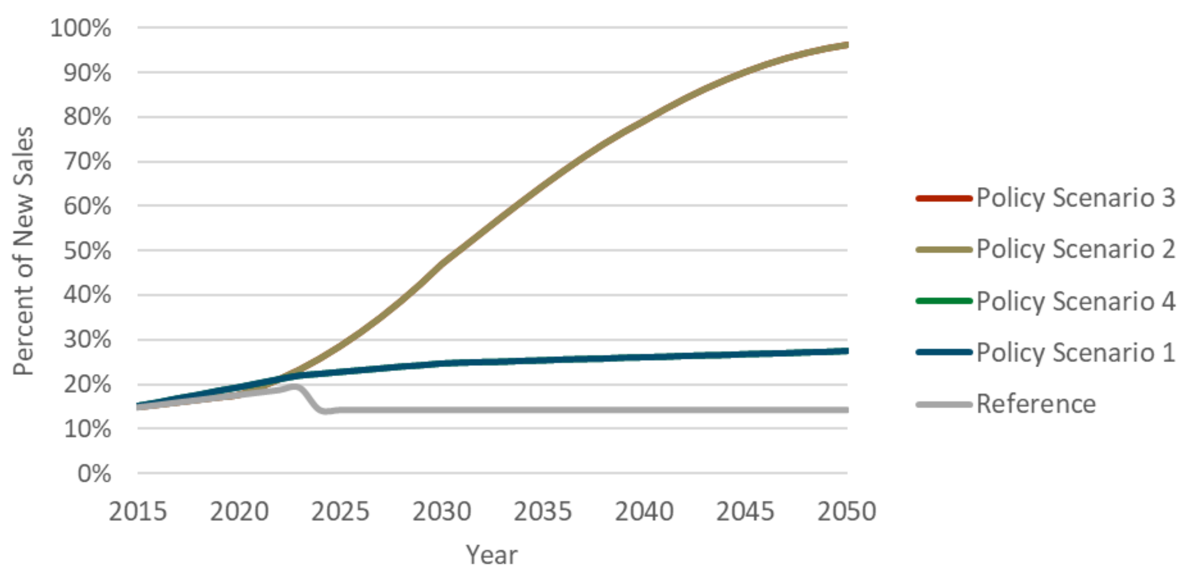

Figure 2-7. Percent of annual new sales of residential electric heat pump space heaters in all four policy scenarios. Policy Scenario 3 has the same sales as Policy Scenario 2. Policy Scenario 4 has the same sales as Policy Scenario 1.

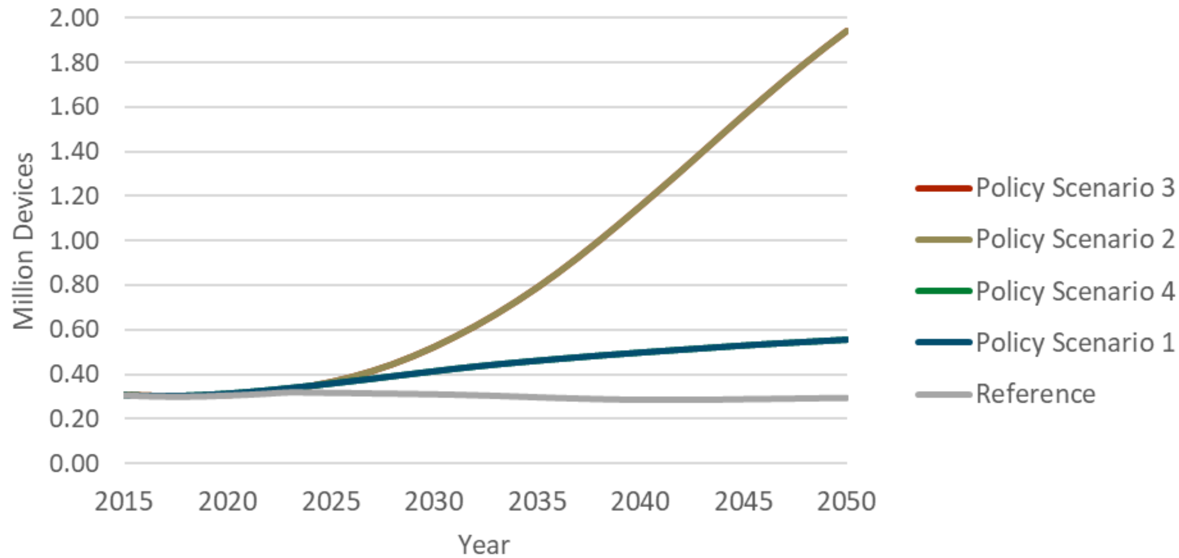

Figure 2-8. Total number of residential electric heat pump space heaters in all four policy scenarios. Policy Scenario 3 has the same stock of electric heat pumps as Policy Scenario 2. Policy Scenario 4 has the same stock as Policy Scenario 1.

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.

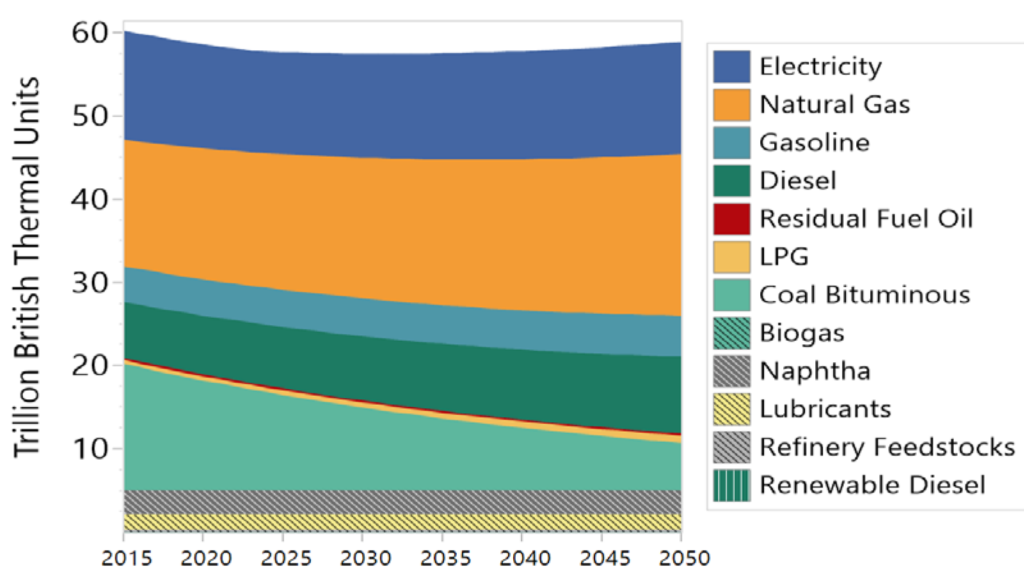

Figure 2-9. Total Industrial Energy Consumption in the Reference Scenario

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%

[6] Assumed based on EPRI (2017), "State Level Electric Energy Efficiency Potential Estimates"

Residual Fuel Oil	0.0%	0.0%	0.0%	0.0%

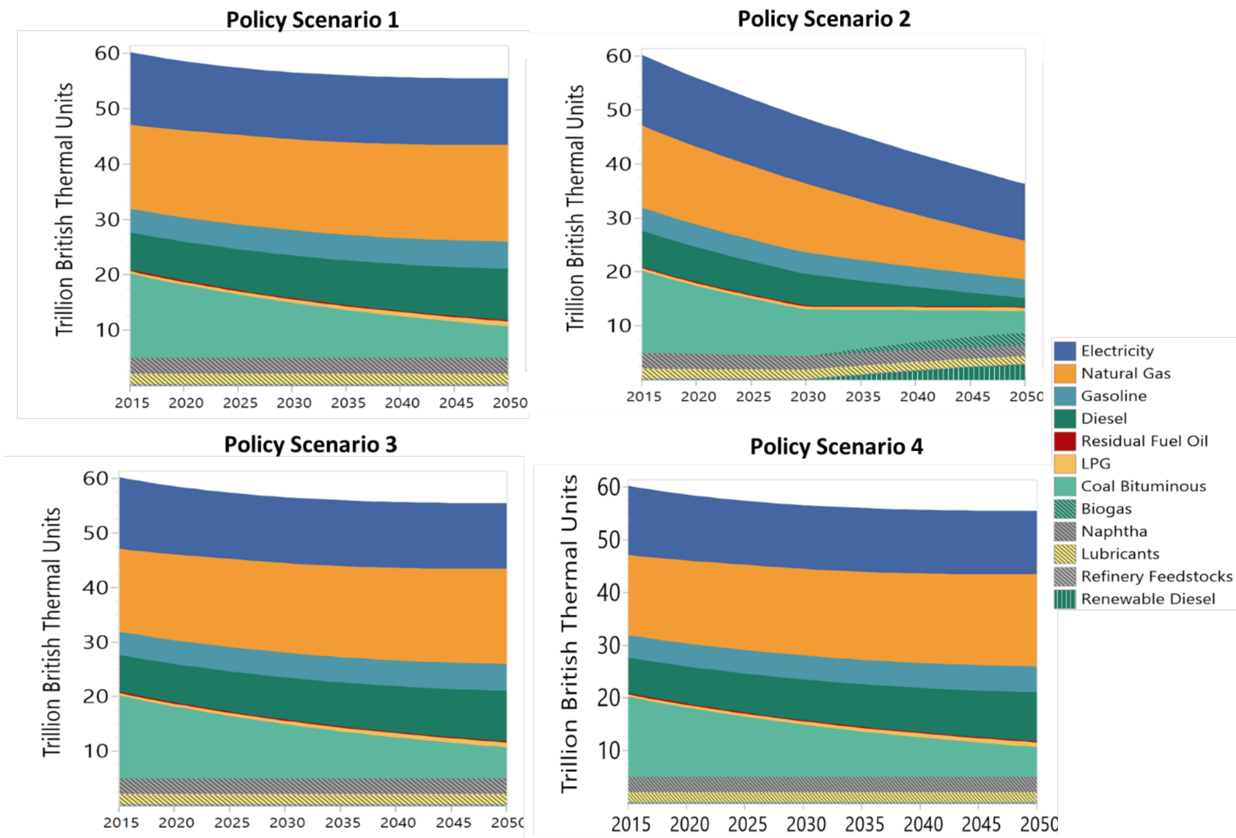

Figure 2-10. Total Industrial Energy Consumption in All Policy Scenarios

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.

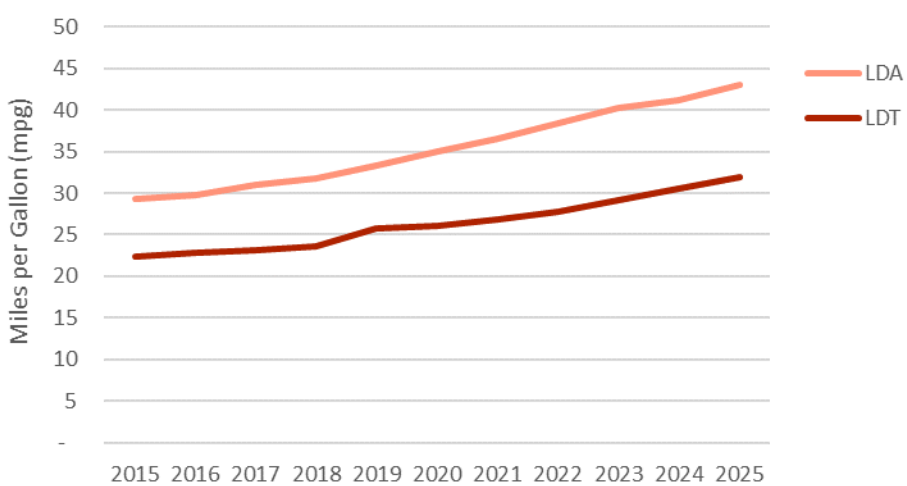

Figure 2-11. Marginal Fuel Economy for Gasoline LDVs in Maryland

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.

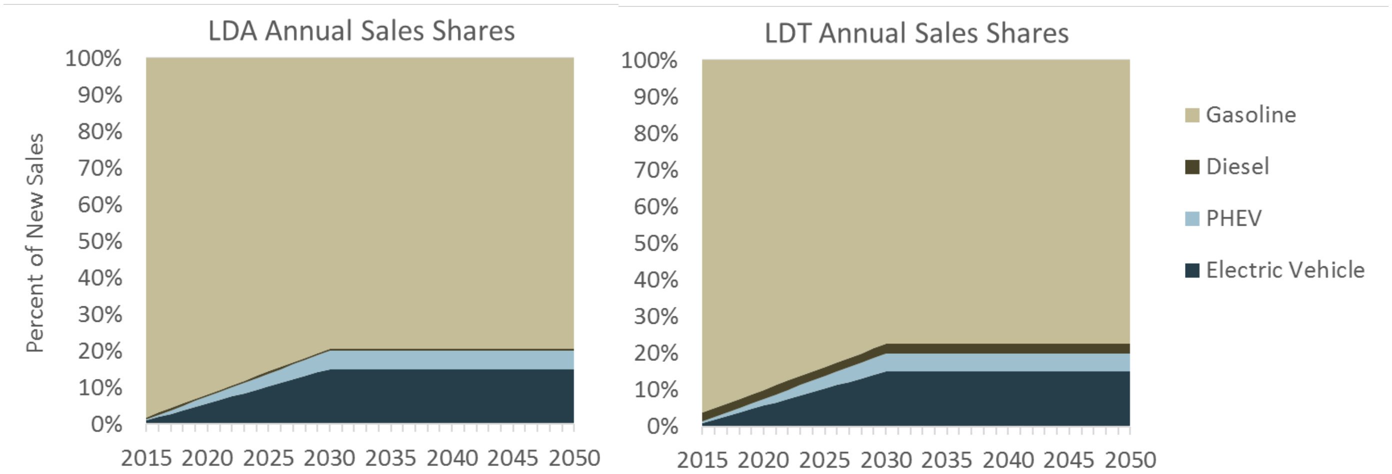

Figure 2-12. New Sales Rates for LDAs and LDTs in Reference Scenario

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. 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. 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.

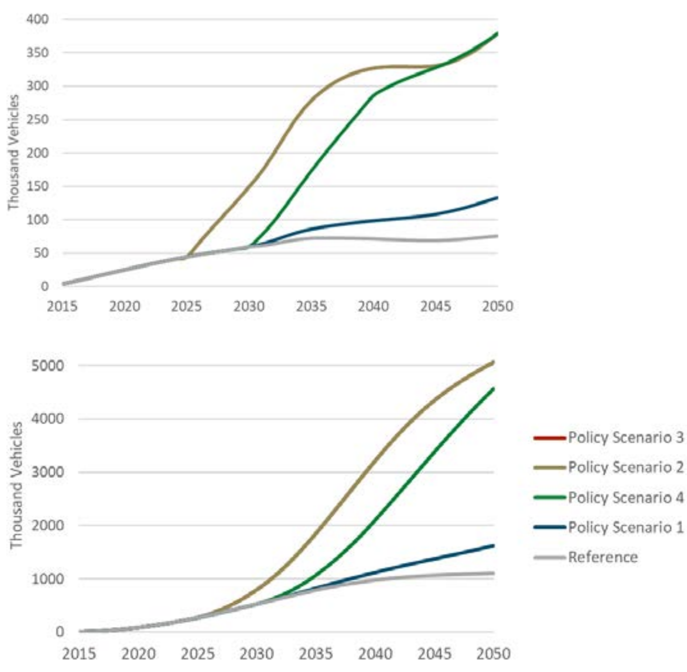

Figure 2-13. Annual new sales (left) and stock (right) of Light-Duty ZEVs (electric vehicle and plug-in hybrid) for all scenarios, 2015-2050. Policy Scenario 3 has the same ZEV sales and stocks as Policy Scenario 2

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.

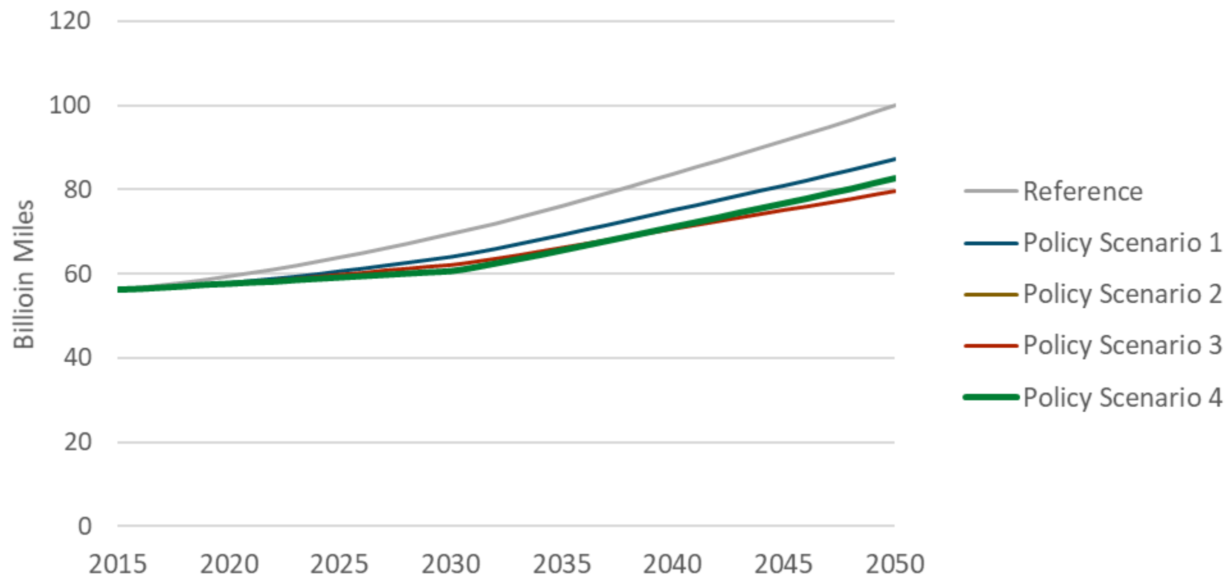

Figure 2-14. Total Vehicle Miles Traveled (VMT) for all scenarios, 2015-2050, Policy Scenario 2 and Policy Scenario 4 have the same VMT.

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.

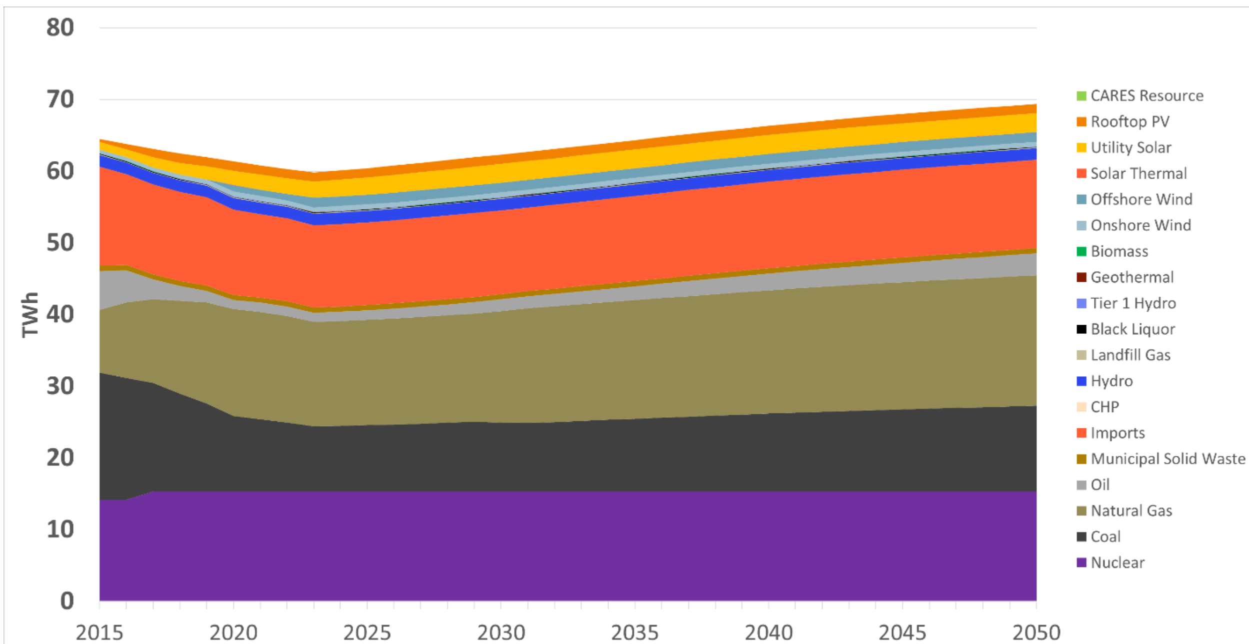

Figure 2-15. Annual Generation by Resource Type – Reference Case

[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.

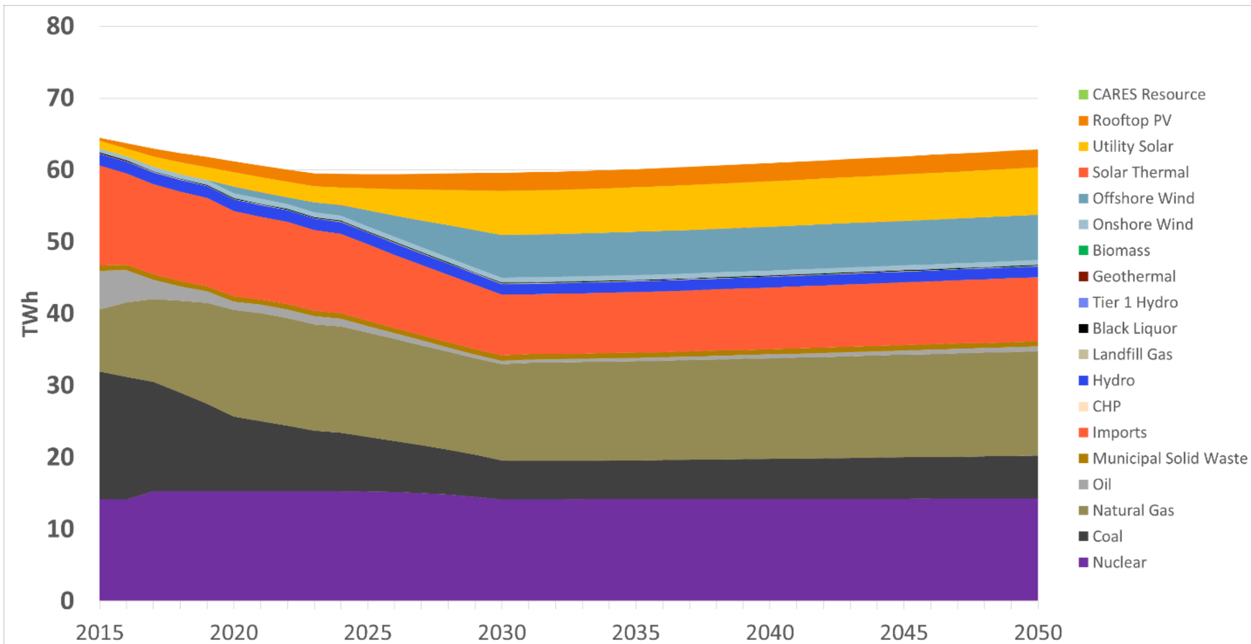

Figure 2-16. Annual Generation by Resource Type – Policy Scenario 1

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).

[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.

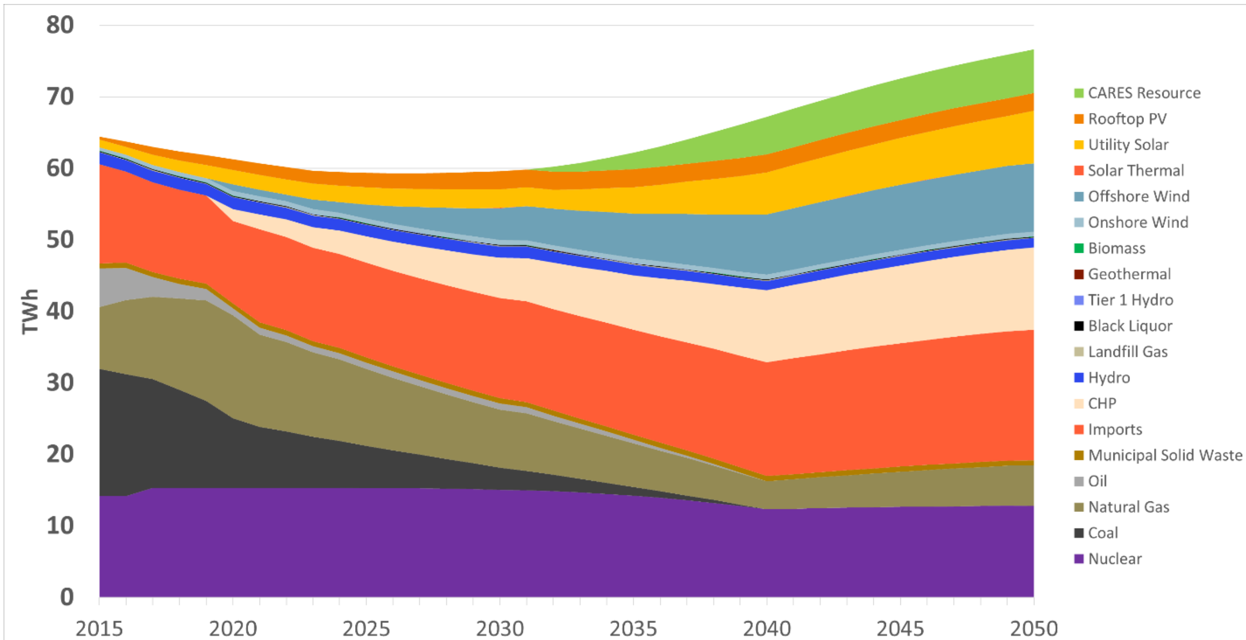

Figure 2-17. Annual Generation by Resource Type – Policy Scenario 2

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.

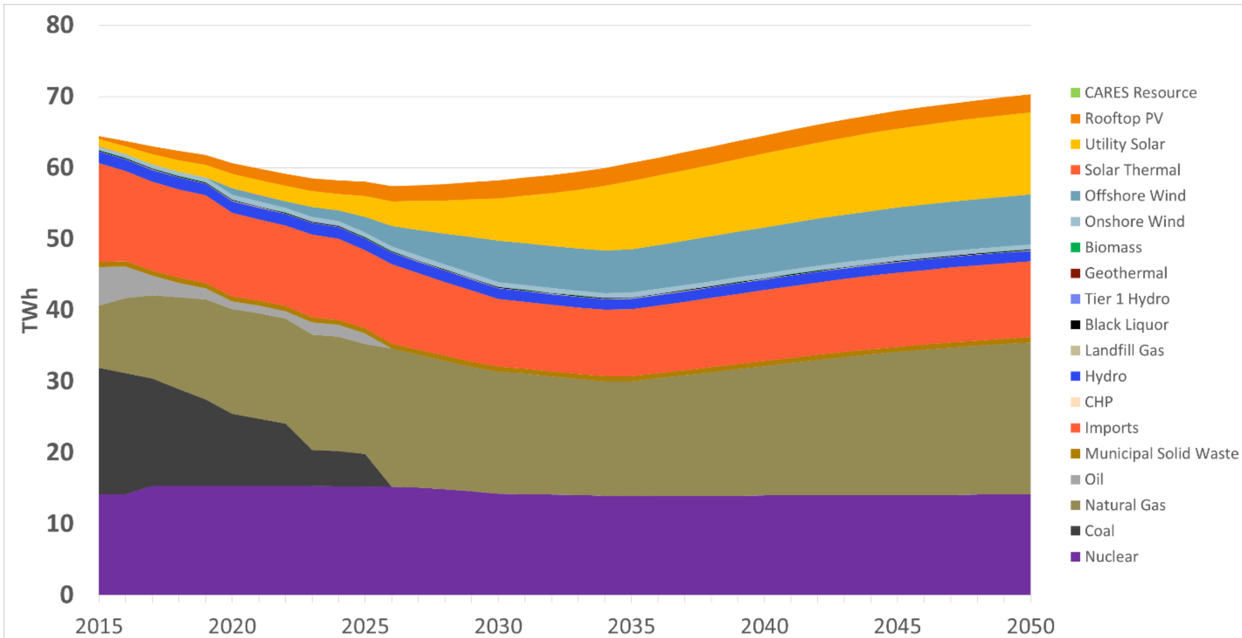

Figure 2-18. Annual Generation by Resource Type – Policy Scenario 3

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.

[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.

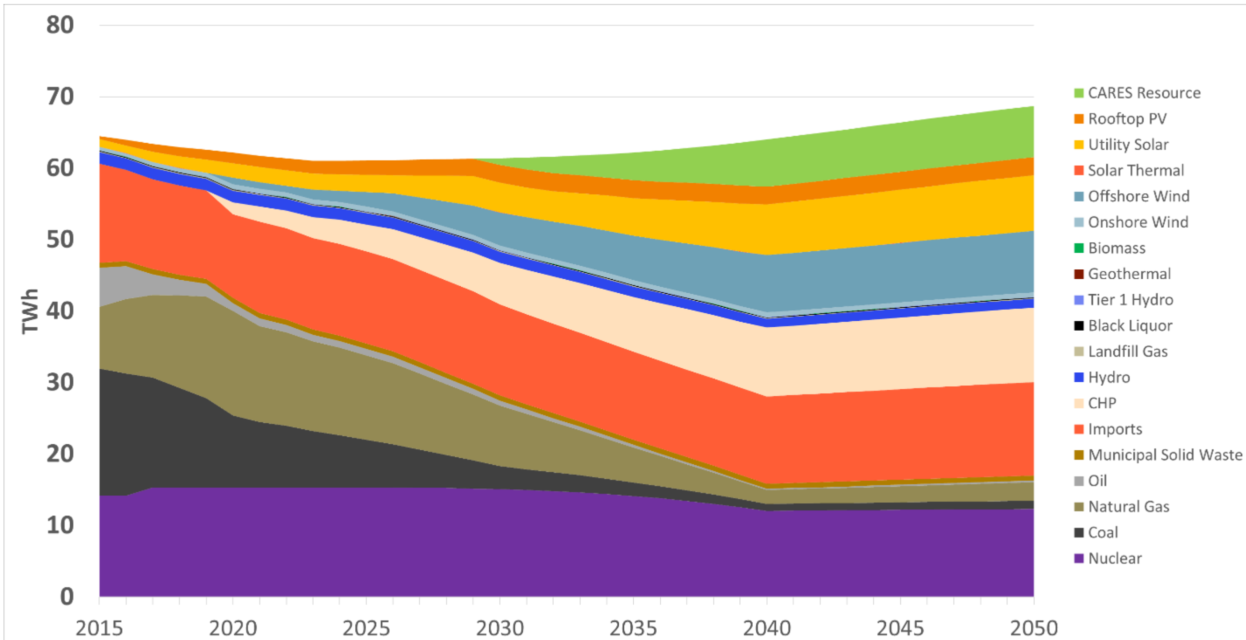

Figure 2-19. Annual Generation by Resource Type – Policy Scenario 4

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.

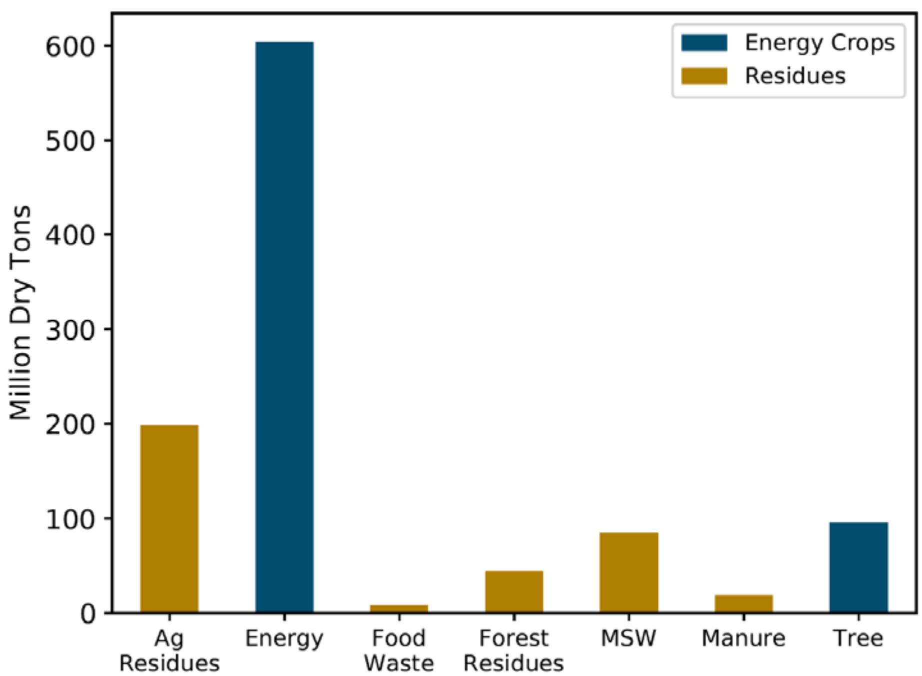

Figure 2-20. National Biomass Feedstock Supply by 2040 by Resource Category

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

[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.

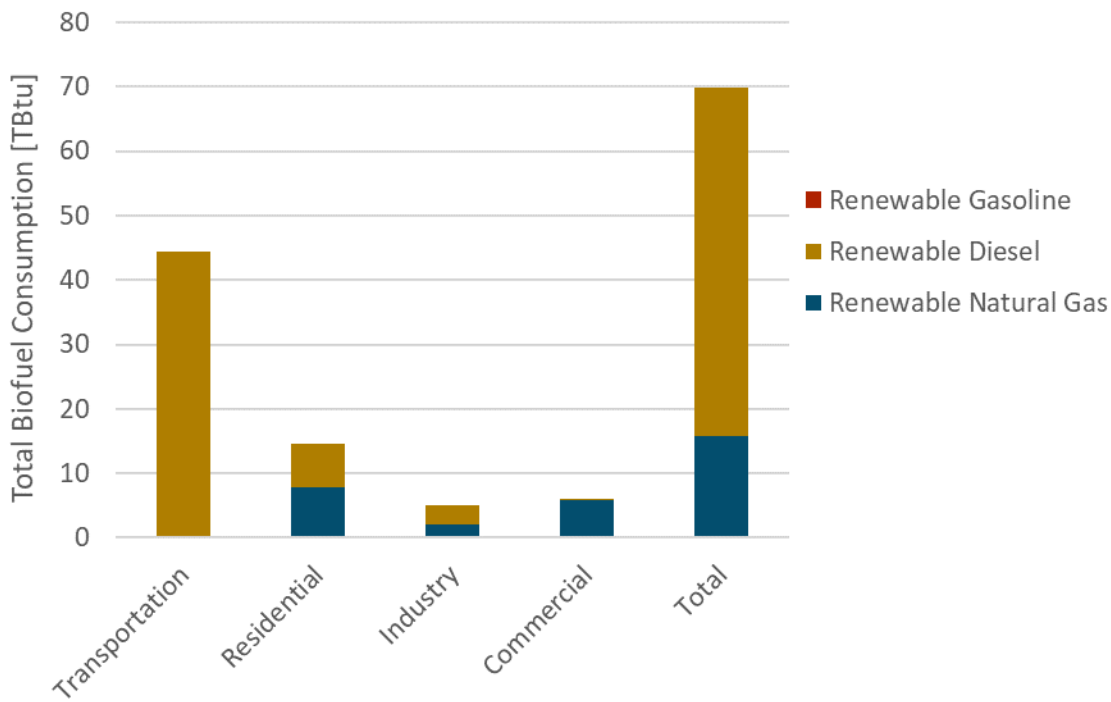

Figure 2-21. Total Advanced Biofuel Production by Sector and Biofuel in 2050, Policy Scenario 2

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.

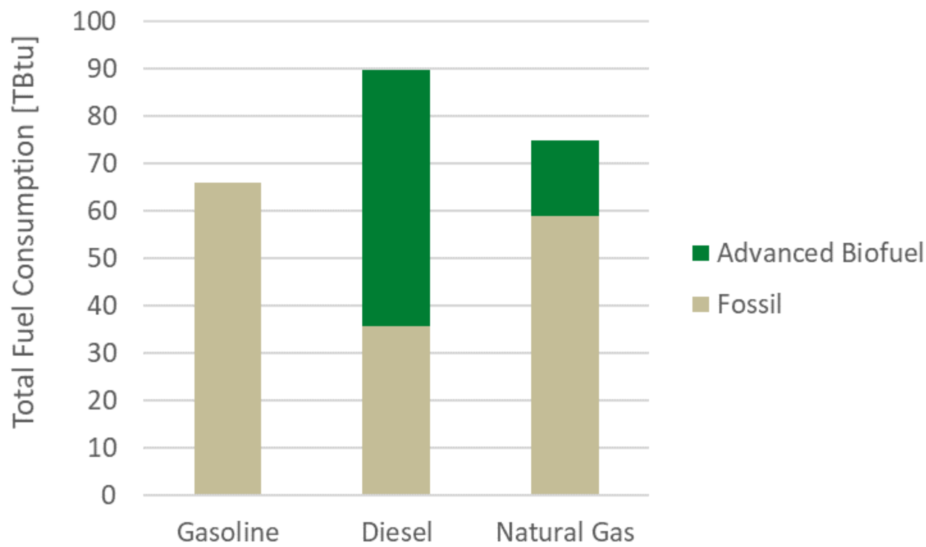

Figure 2-22. Total Fuel Consumption for Gasoline, Diesel, and Natural Gas by Primary Fuel Composition in 2050, Policy Scenario 2

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 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.

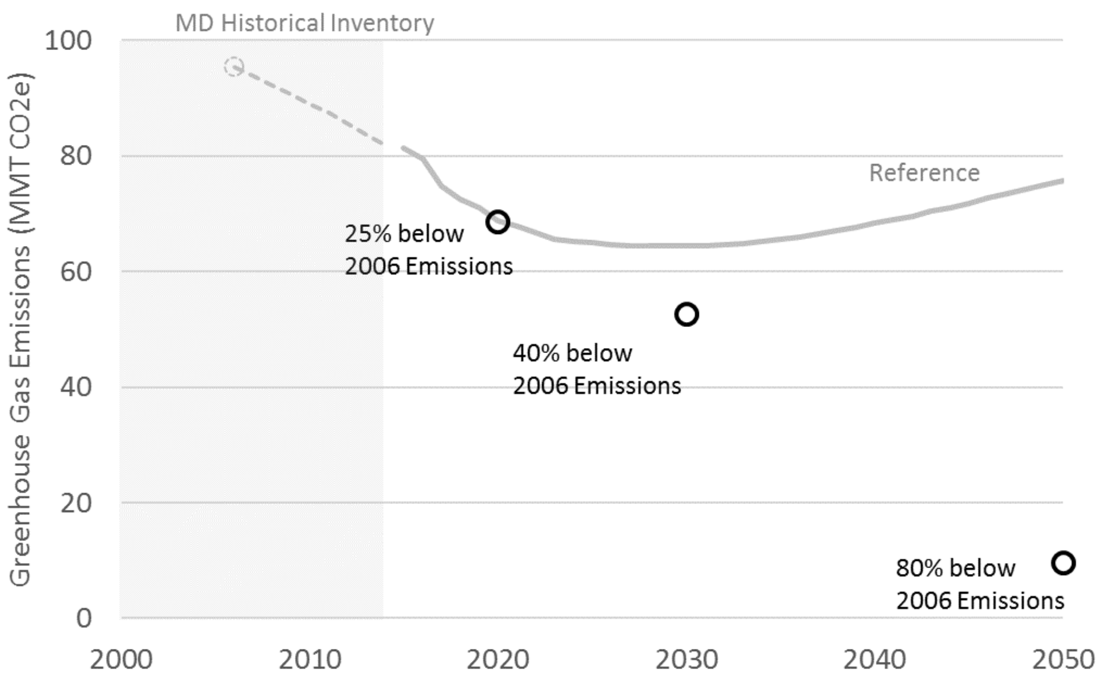

Figure 3-1. Maryland Net GHG Emissions Results for Reference Scenario, 2015-2050

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.

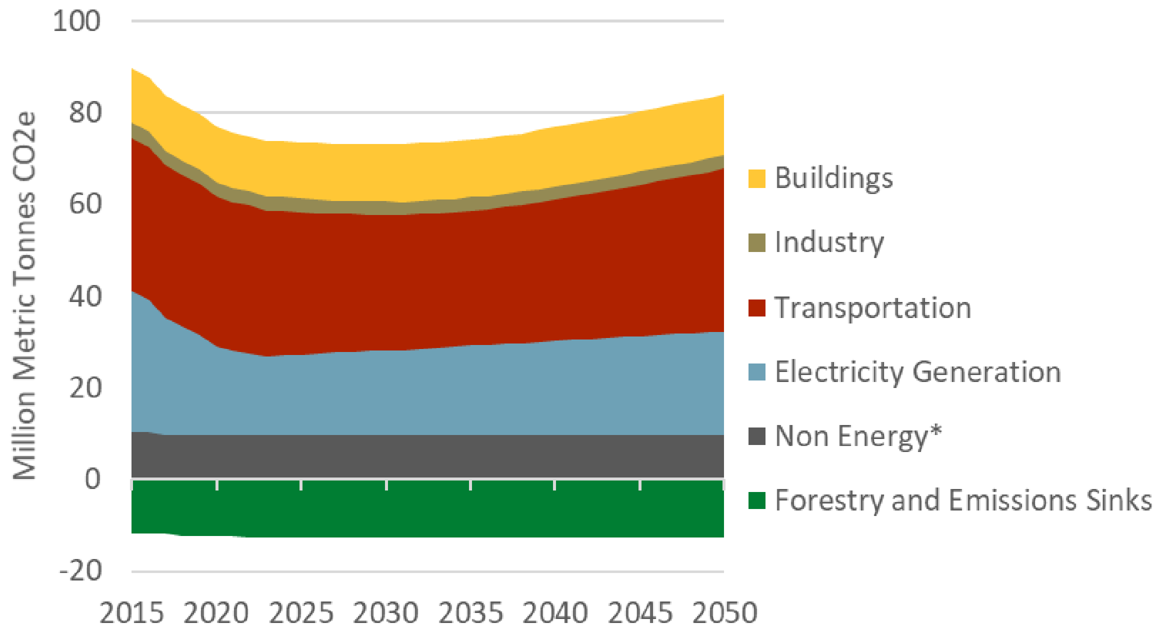

Figure 3-2. Maryland Gross GHG Emissions by Sector in the Reference Scenario, 2015-2050[17]

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.

[17] *Non Energy includes Agriculture, Waste Management, Industrial Processes and Fossil Fuel Industry emissions

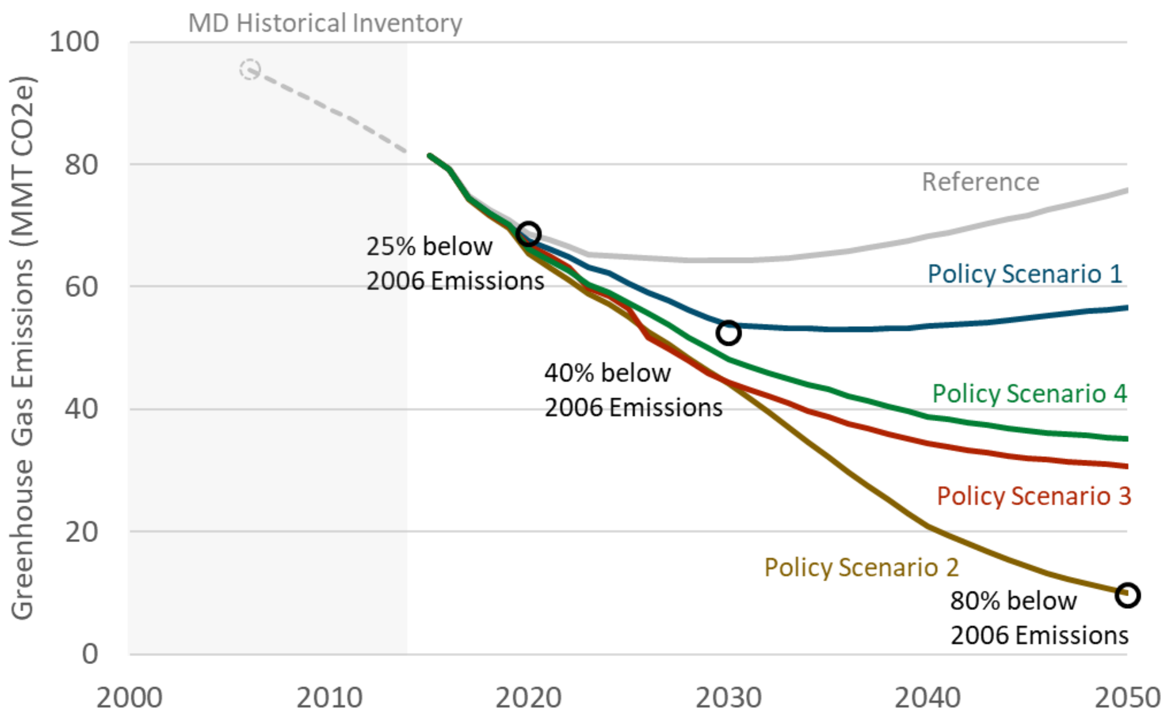

Figure 3-3. Total Net GHG Emissions by Scenario Relative to Policy Targets

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

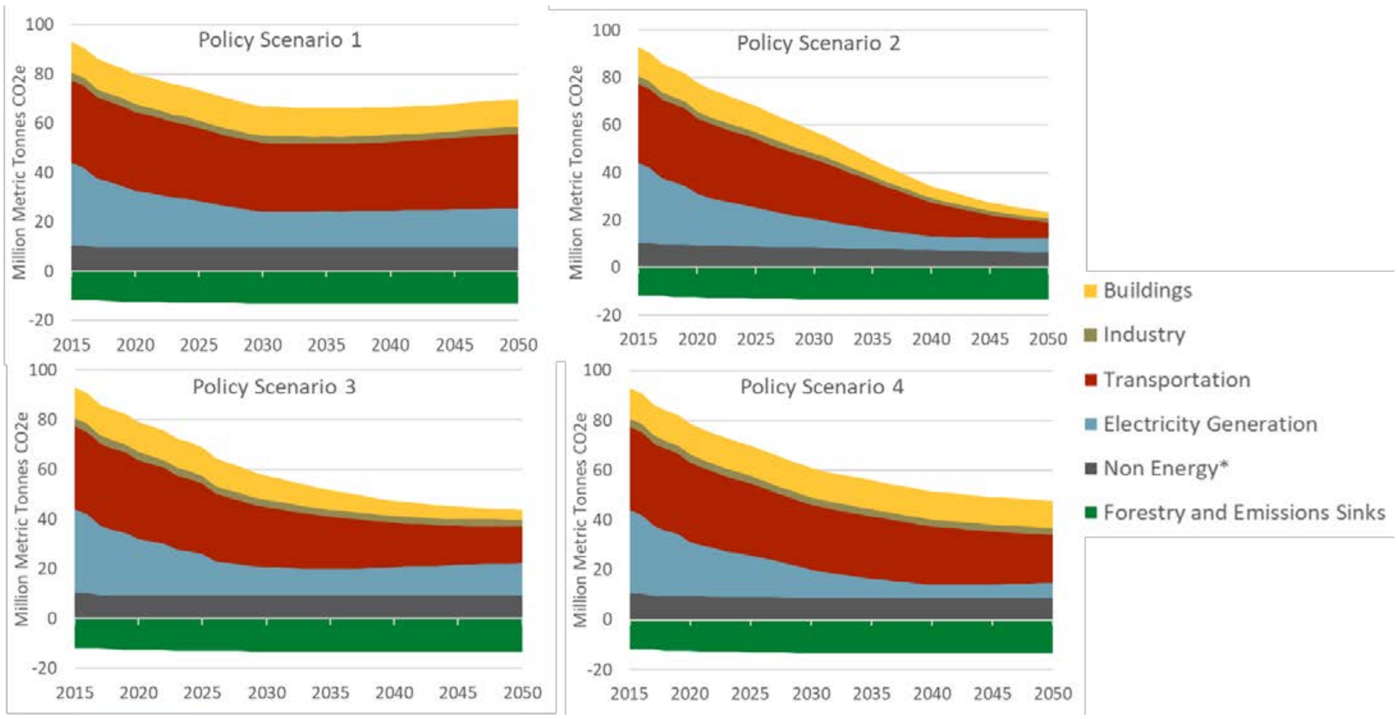

Figure 3-4. Maryland Gross GHG Emissions by Sector in the four policy scenarios, 2015-2050[18]

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.

[18] *Non Energy includes Agriculture, Waste Management, Industrial Processes and Fossil Fuel Industry emissions

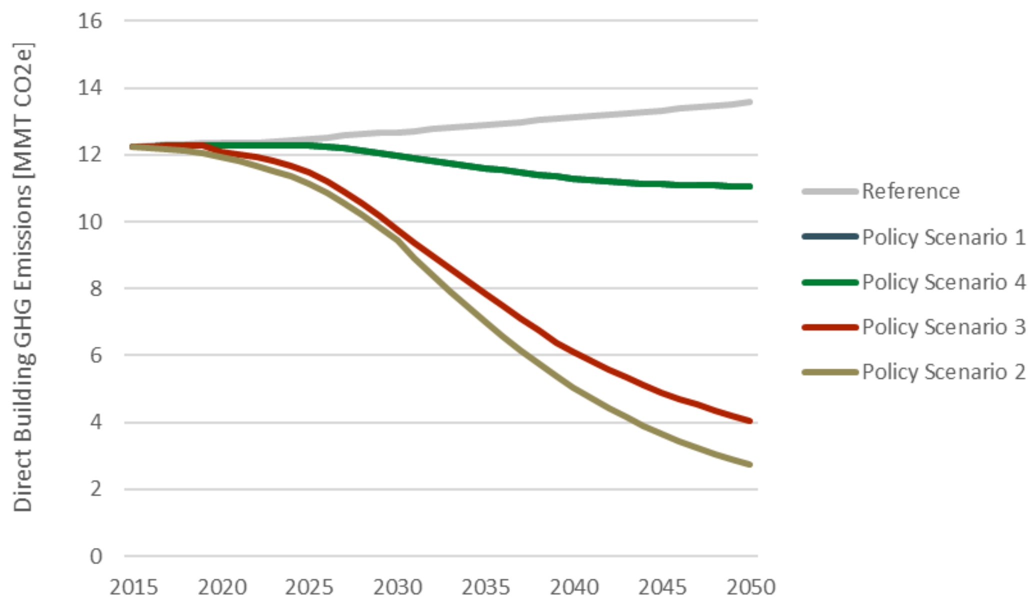

Figure 3-5. Total Direct Emissions by Scenario in Buildings. Policy Scenario 4 has the same direct emissions in Buildings as Policy Scenario 1.

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.

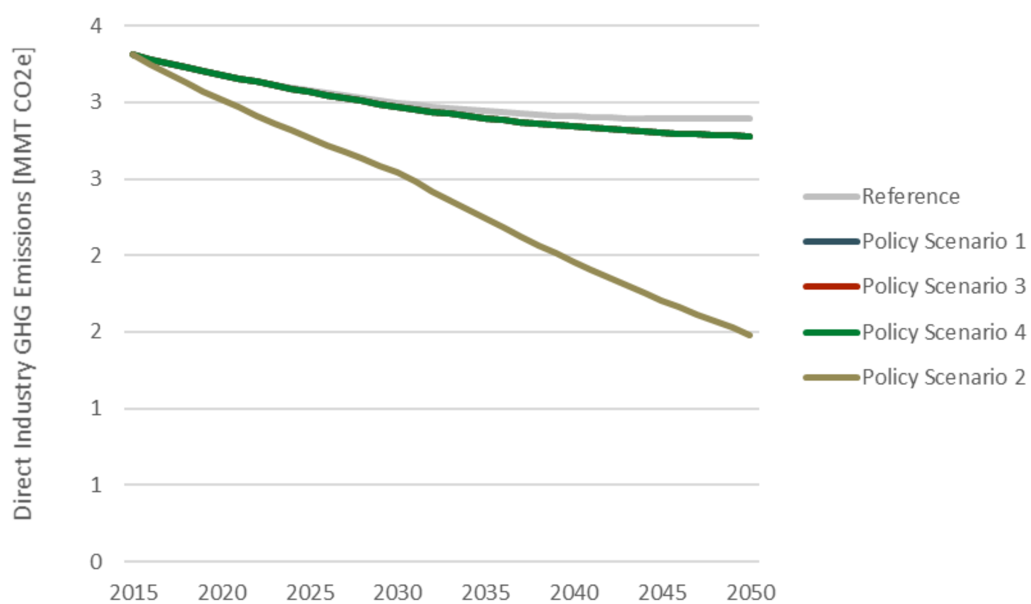

Figure 3-6. Total Direct Emissions by Scenario in Industry. Policy Scenarios 1 and 3 have the same emissions. Policy Scenario 3 and Policy Scenario 4 have same direct emissions in Industry as Policy Scenario 1.

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.

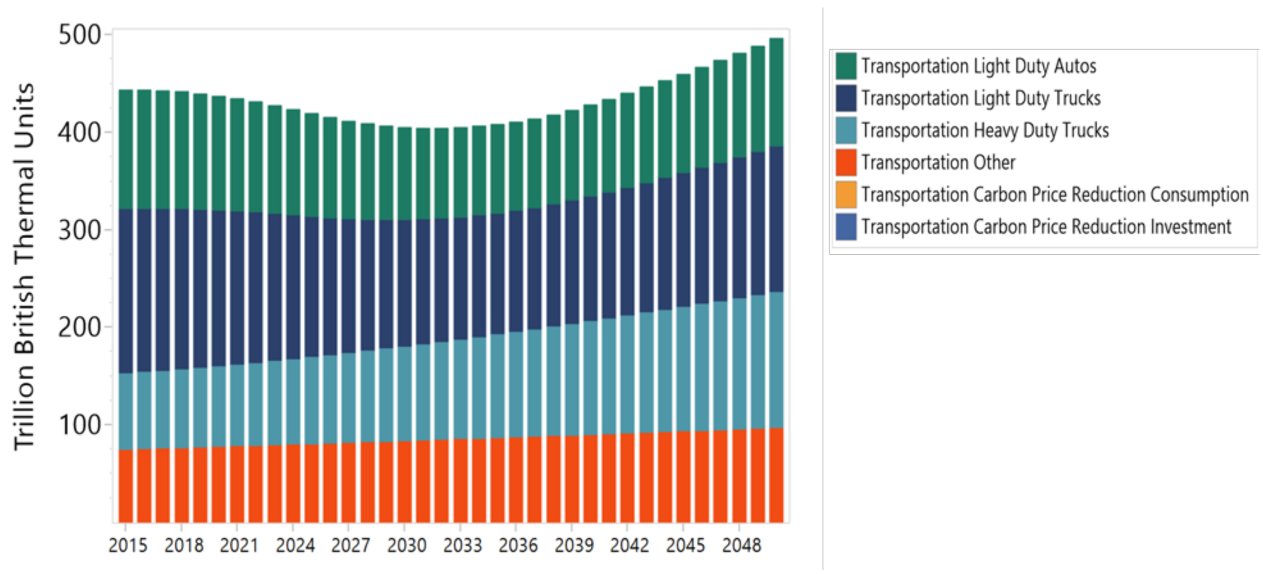

Figure 3-7. Total Energy Consumed in Transportation by Subsector, Reference Scenario

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.

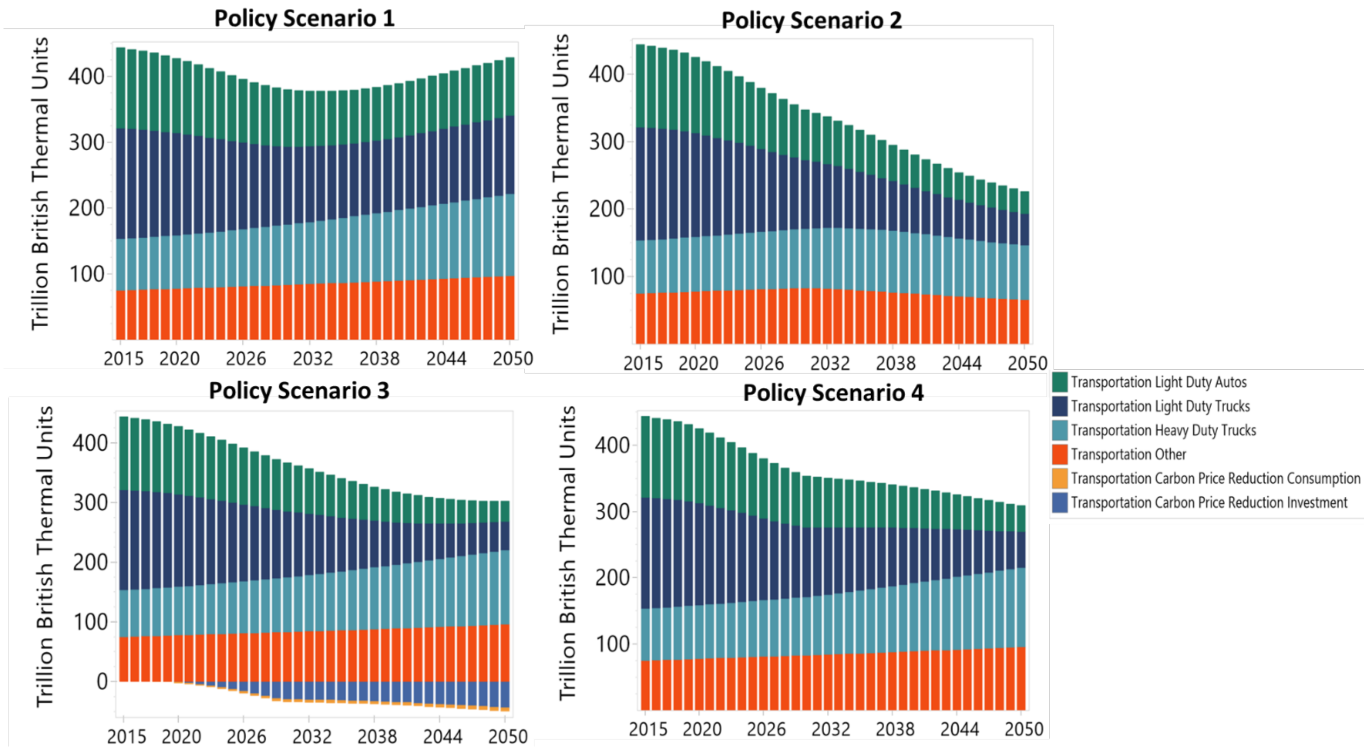

Figure 3-8. Total Energy Consumed in Transportation by Subsector, all four policy scenarios

The resulting emissions for Transportation sectors are shown in Figure 3-9.

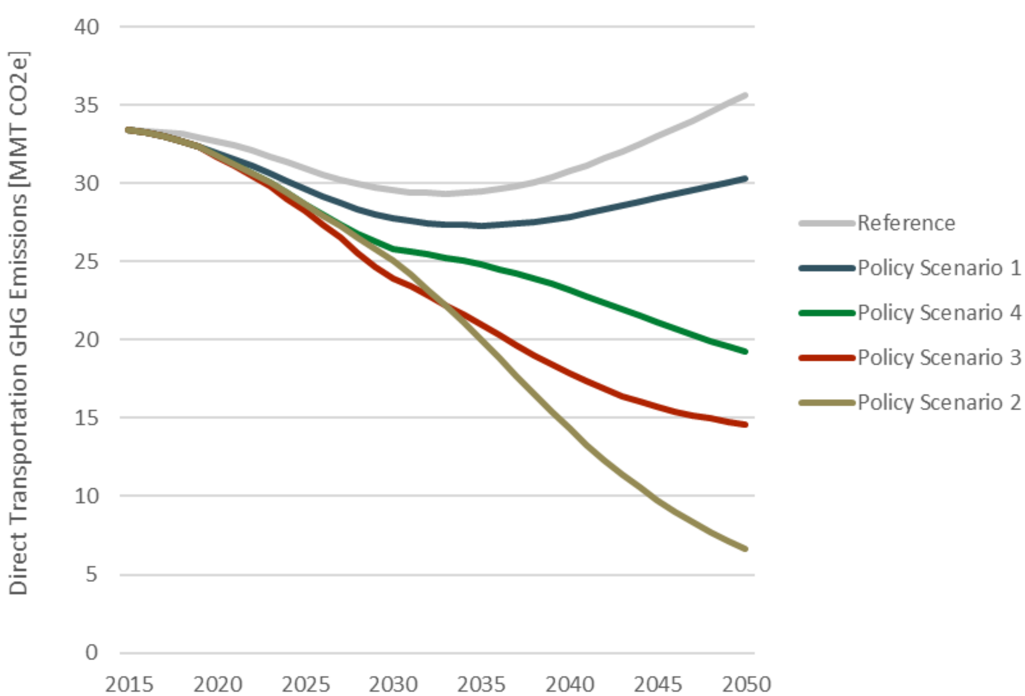

Figure 3-9. Total Direct GHG Emissions in Transportation by Scenario

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.

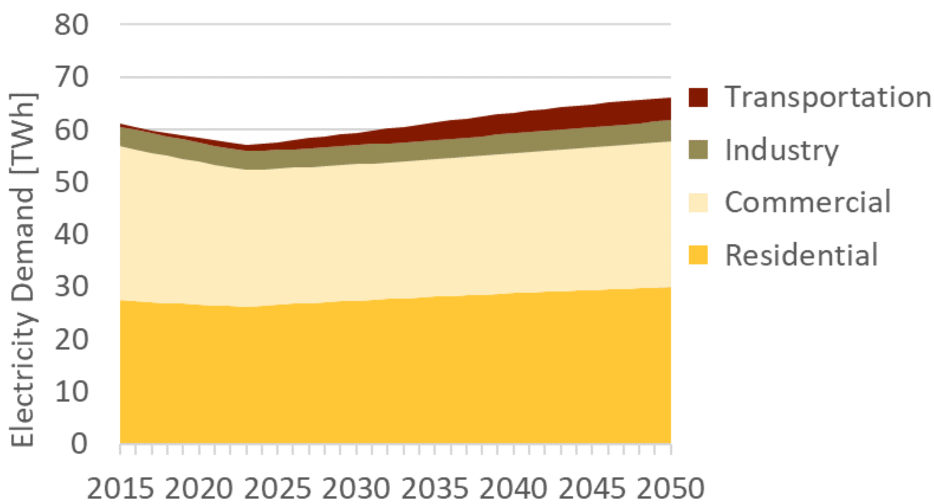

Figure 3-10. Total Electric Load by Sector, Reference Scenario

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.

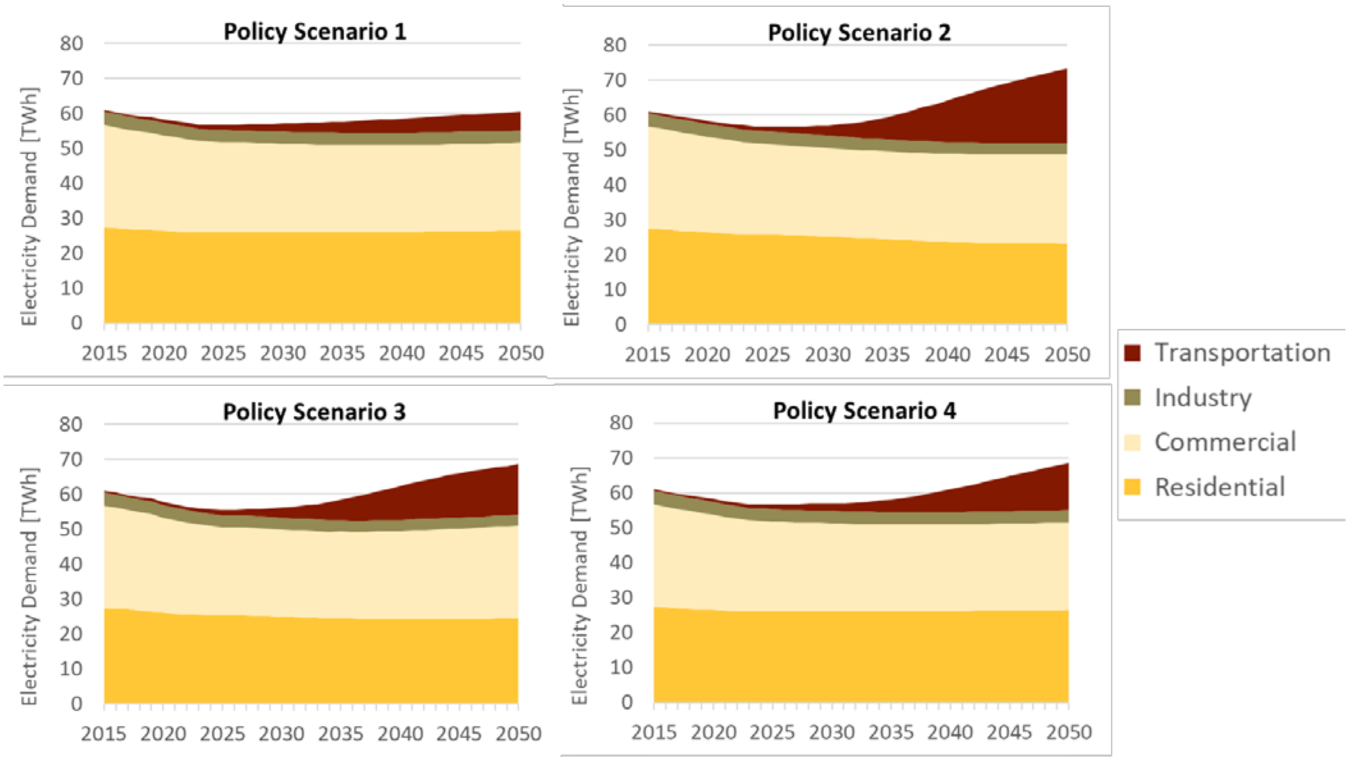

Figure 3-11. Total Electric Load by Sector and Policy Scenario

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.

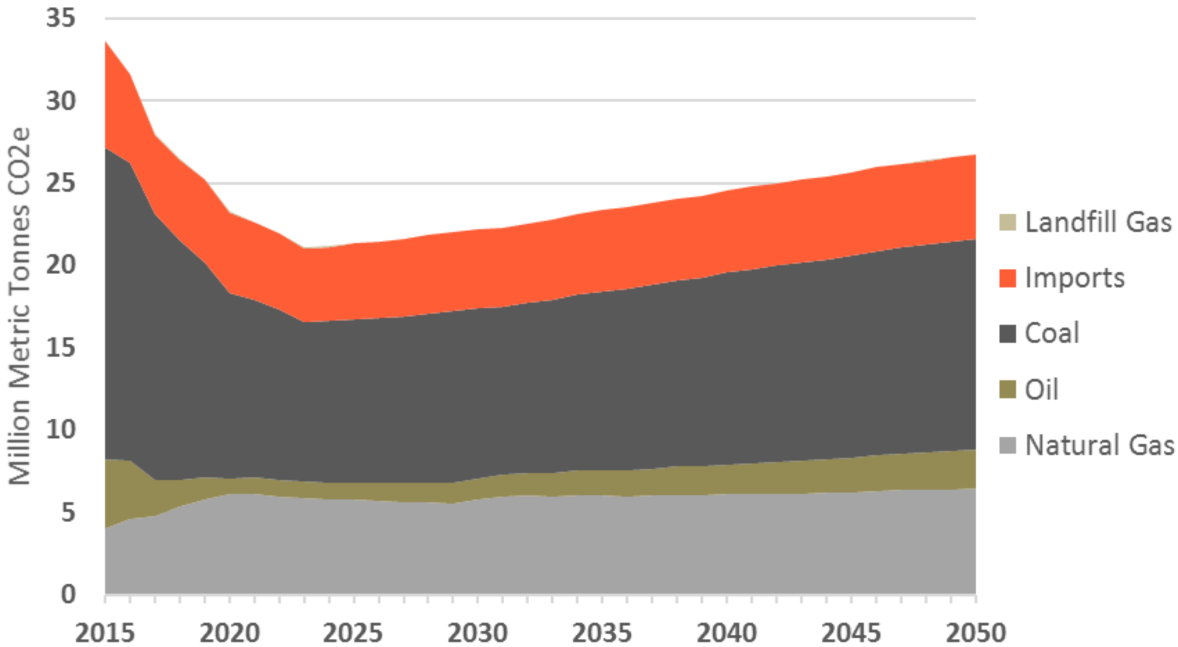

Figure 3-12. Annual Electricity Emissions by Resource Type, Reference Scenario

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.

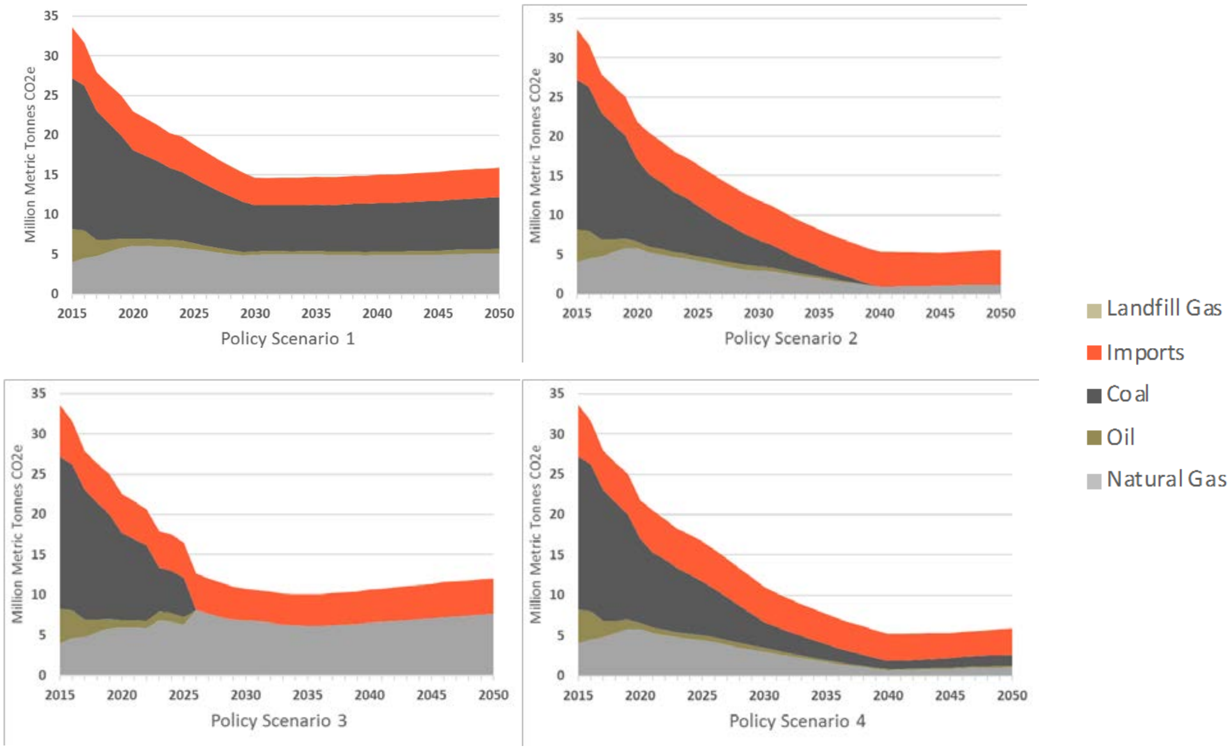

Figure 3-13. Annual Electricity Emissions by Resource Type and Policy Scenario

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.

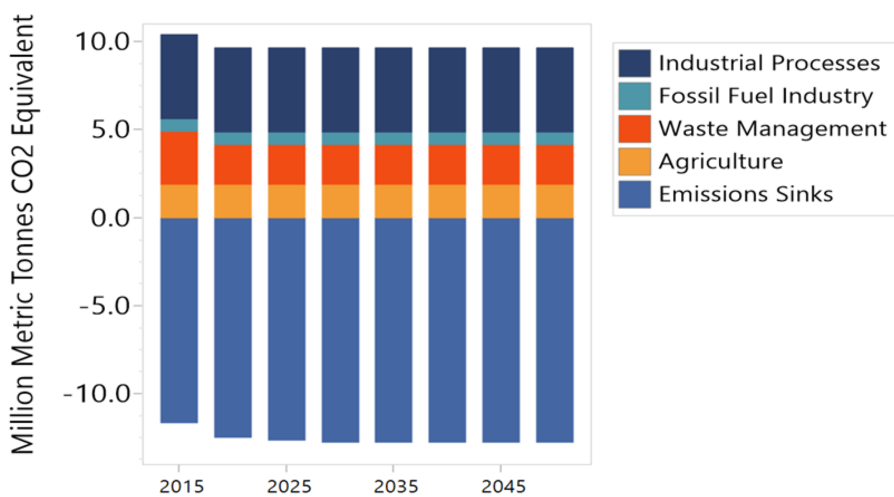

Figure 3-14. Non-Combustion Emissions in the Reference Scenario

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.

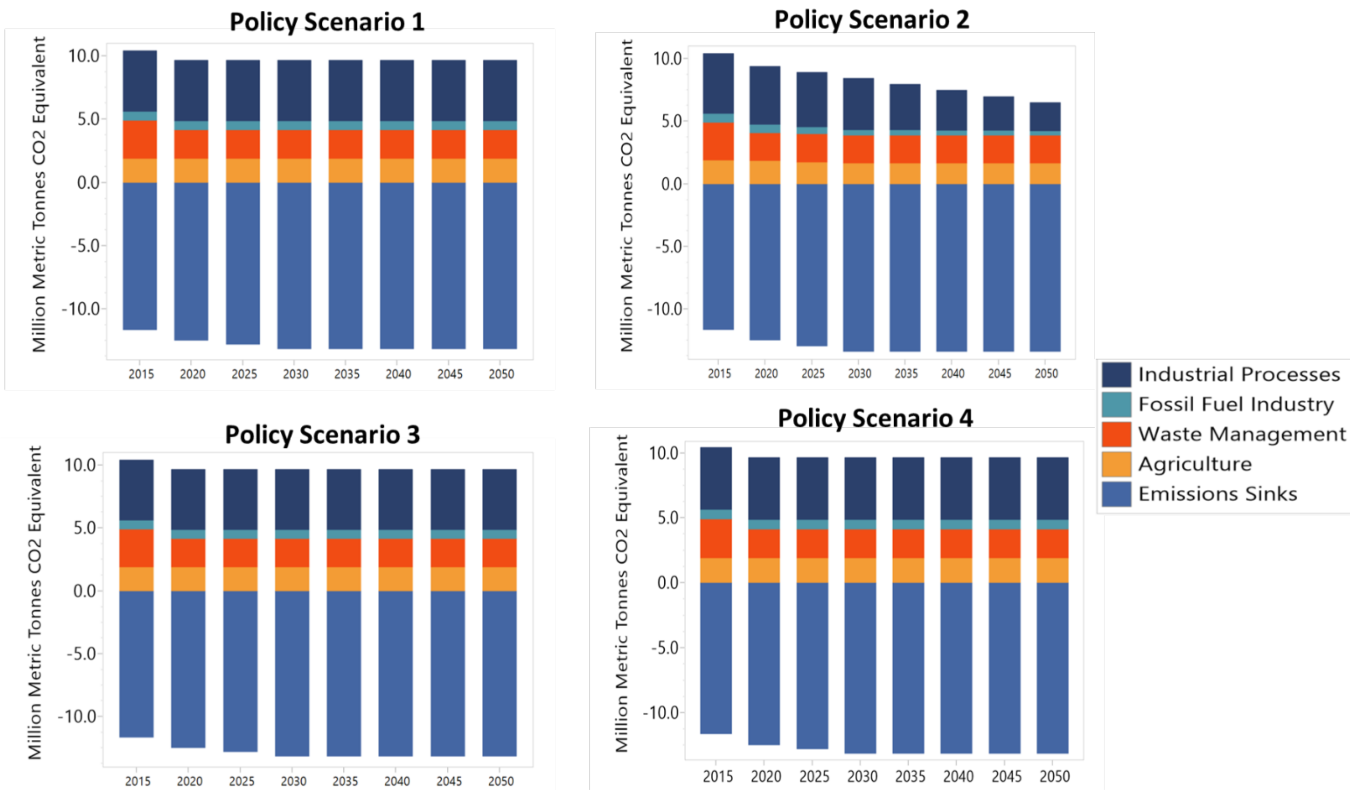

Figure 3-15. Non-Combustion Emissions in all four policy scenarios

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.

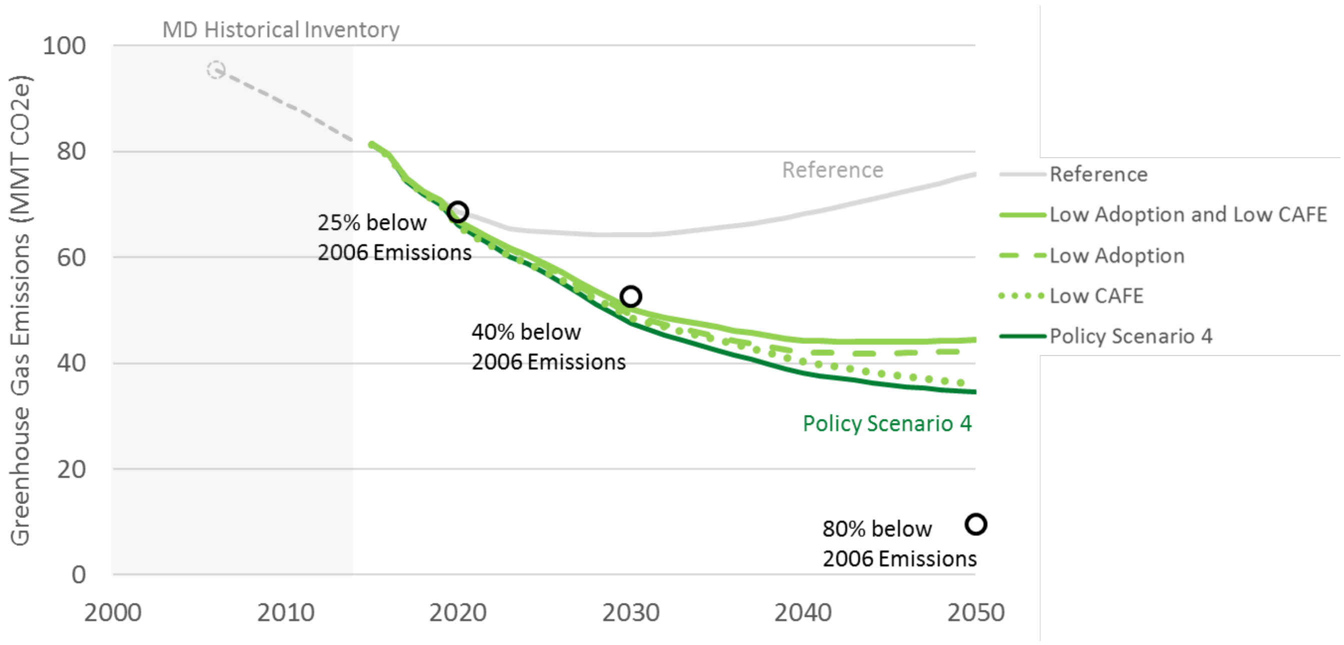

Figure 3-16. Maryland Net GHG Emissions for Sensitivities on Policy Scenario 4, 2015-2050

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.

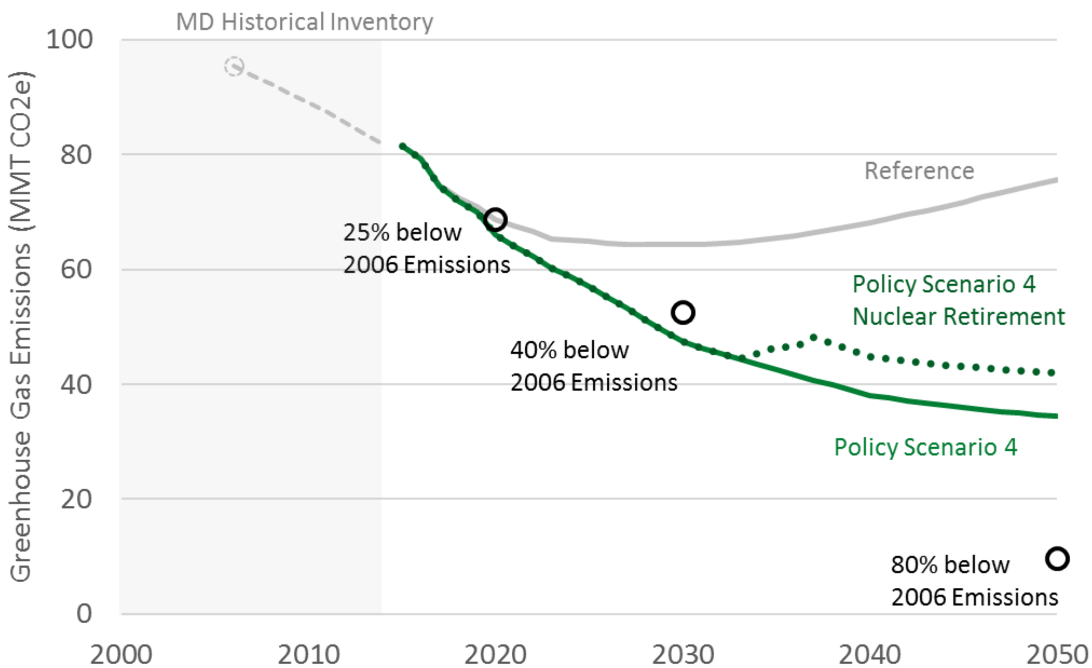

Figure 3-17. Maryland Net GHG Emissions for Policy Scenario 4 with and without Nuclear Retirement

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.

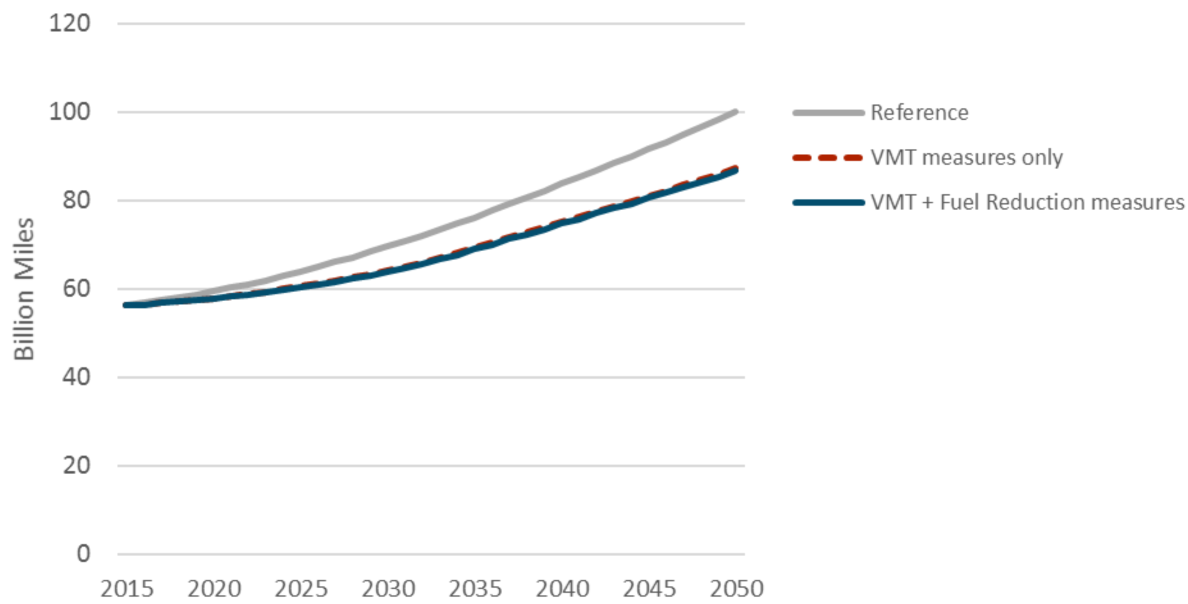

Figure 4-1. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 1

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: 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.

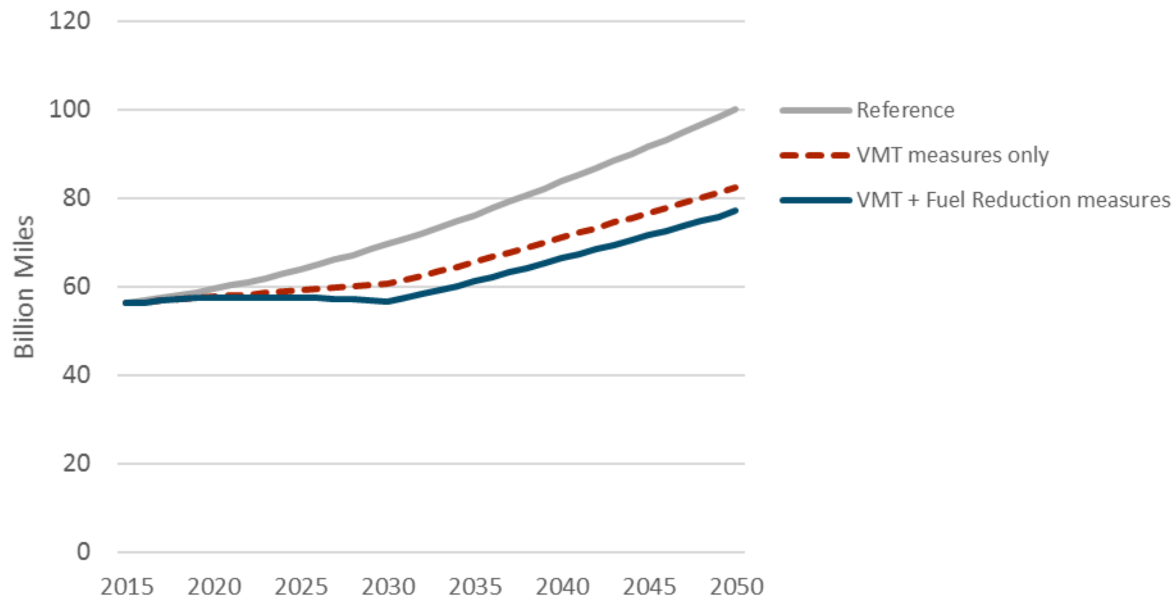

Figure 4-2. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 2

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.

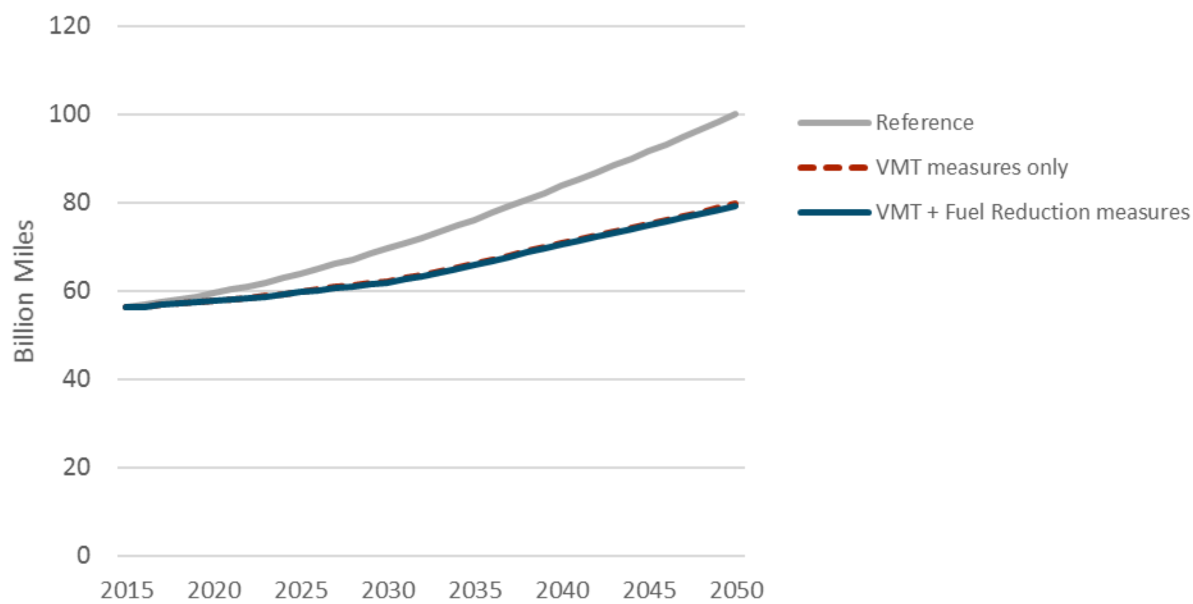

Figure 4-3. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 3

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.

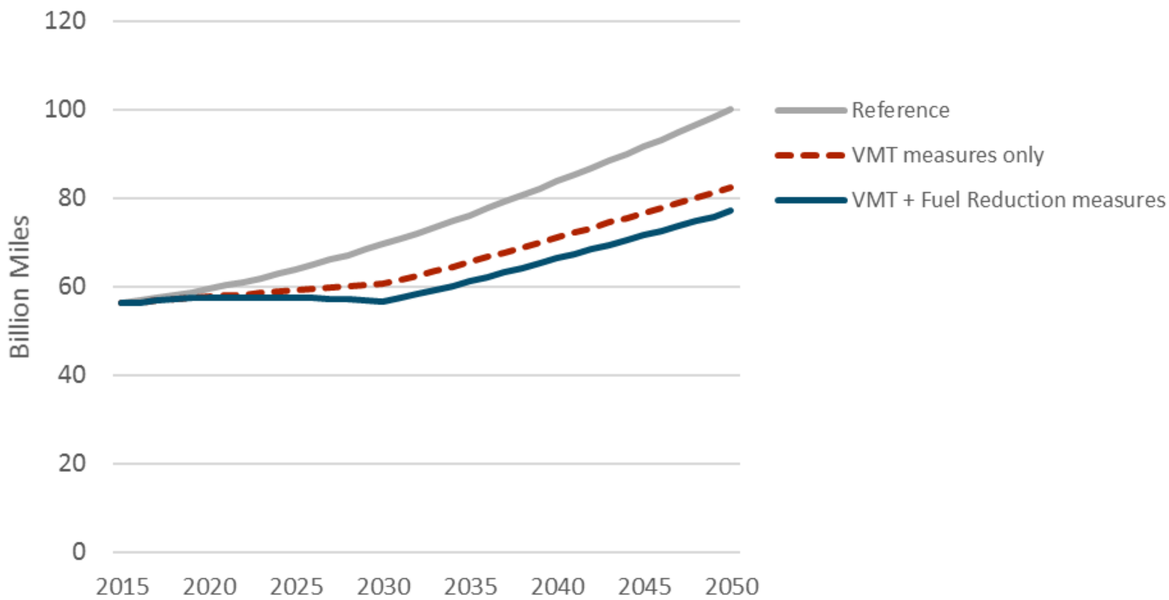

Figure 4-4. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, Policy Scenario 4