Maryland Department of the Environment

Appendix F

Documentation of Maryland PATHWAYS Scenario Modeling

2030 GGRA 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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Contents

1 Executive Summary

1.1 Report Background

Energy + Environmental Economics (E3) has been supporting the Maryland Department of the Environment (MDE) in developing energy and emissions scenarios to chart a path towards decarbonization in the State. These scenarios then feed into a macroeconomic assessment of Maryland's greenhouse gas (GHG) reduction policies conducted by the Regional Economic Studies Institute (RESI) at Towson University. This analysis was divided into three 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) included an evaluation of deeper GHG reduction scenarios with additional measures. A draft Greenhouse Gas Emissions Reduction Act (GGRA) plan was released in October, 2019 by MDE to achieve Maryland's goal of reducing greenhouse gas (GHG) emissions by 40% by 2030.
- The third phase (2020-2021) includes an update of the reference case developed in the first phase and an evaluation of two additional GHG reduction scenarios with more aggressive measures.

This report provides documentation for the assumptions, methods, and results of the third phase 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 the other GHG reduction scenarios which considered additional and increased actions to achieve Maryland's established GHG emissions targets.

Based on Maryland's 2017 inventory, the most recently available consistent set of data, 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 2017 Gross GHG Emissions by Sector and Subsector (80.1 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, which is used as a counterfactual to model changes from incremental actions, especially energy efficiency. The State's Reference Scenario builds on this counterfactual by translating existing Maryland policies into their impacts on new equipment and infrastructure across all sectors of the economy (e.g. buildings, transportation, electricity generation). 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) under the Clean Energy Jobs Act, EmPOWER efficiency, and zero emission vehicle (ZEV) memorandum of understanding (MOU). A complete list of policies in the Baseline

[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

and Reference Scenarios is provided in Section 2.3. This analysis does not consider energy or economic impacts of COVID-19.

In Figure 1-2 we compare the Reference Scenario emissions trajectory to Maryland's climate goals. The existing GGRA goals are set to reach greenhouse gas (GHG) emissions levels 25% below 2006 levels by 2020, 40% 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.

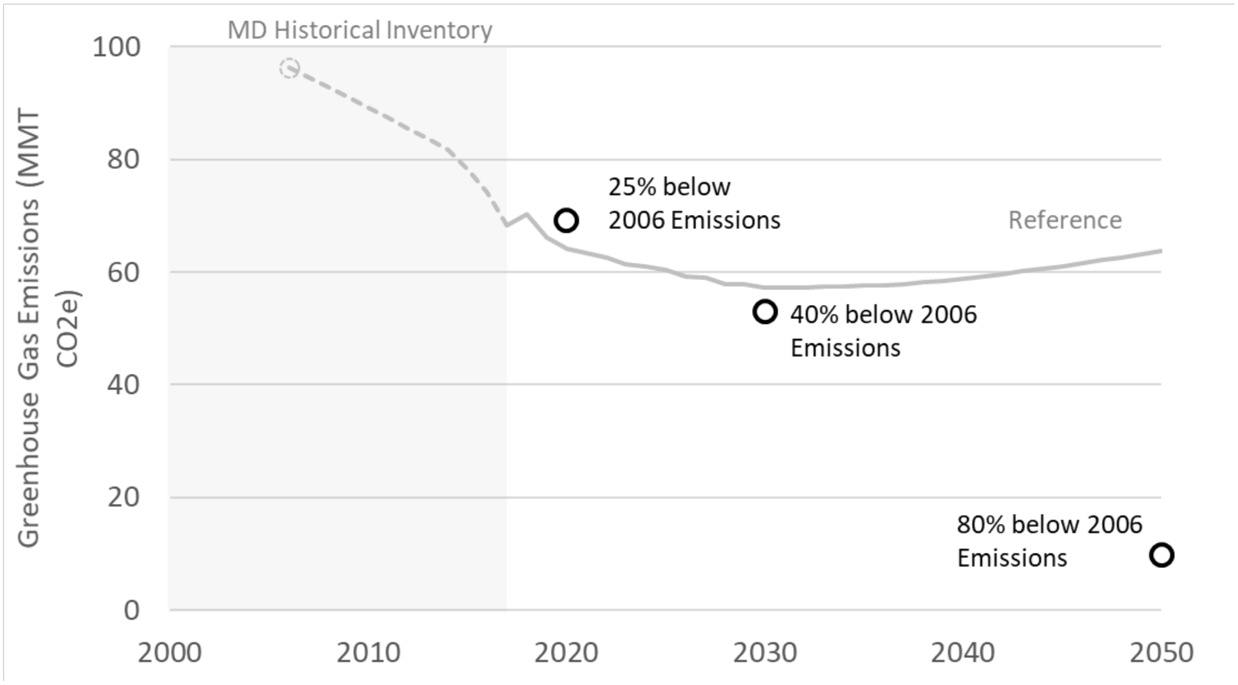

Figure 1-2. Maryland Net GHG Emissions Results for Reference Scenario, 2018-2050 compared to the adopted GHG targets[3]. The increase in emissions in 2018 is resulted from the expansion of Cove Point LNG Terminal.

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 (108.1 MMT CO2e) and emissions sinks from sequestration on natural and working lands 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	69.3	53.0	9.8
Reference Scenario	64.2	57.2	63.7
Difference	*-5.1*	*4.2*	*53.9*

[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.

1.3 Policy Scenario Results

Figure 1-3 shows the results for all policy scenarios explored as a part of this phase of the analysis. The results from the prior phases of analysis were published along with the 2019 GGRA Draft Plan.[4] Each policy scenario was designed with a specific philosophy in mind. The MWG Scenario assumes more aggressive energy efficiency measures and electrification of buildings and light-duty vehicles. The 2030 GGRA Plan features more medium and heavy-duty vehicle electrifications and higher in-state clean energy resource requirement for electricity generation. The different policies and measures in the two scenarios, however, result in very similar emissions trajectories.

1. **MWG Scenario**: Policies and measures selected by the Maryland Commission on Climate Change's Mitigation Working Group (MWG) for consideration by the State
2. **2030 GGRA Plan**: MDE's plan to achieve additional GHG reductions beyond the existing GGRA 2030 target.

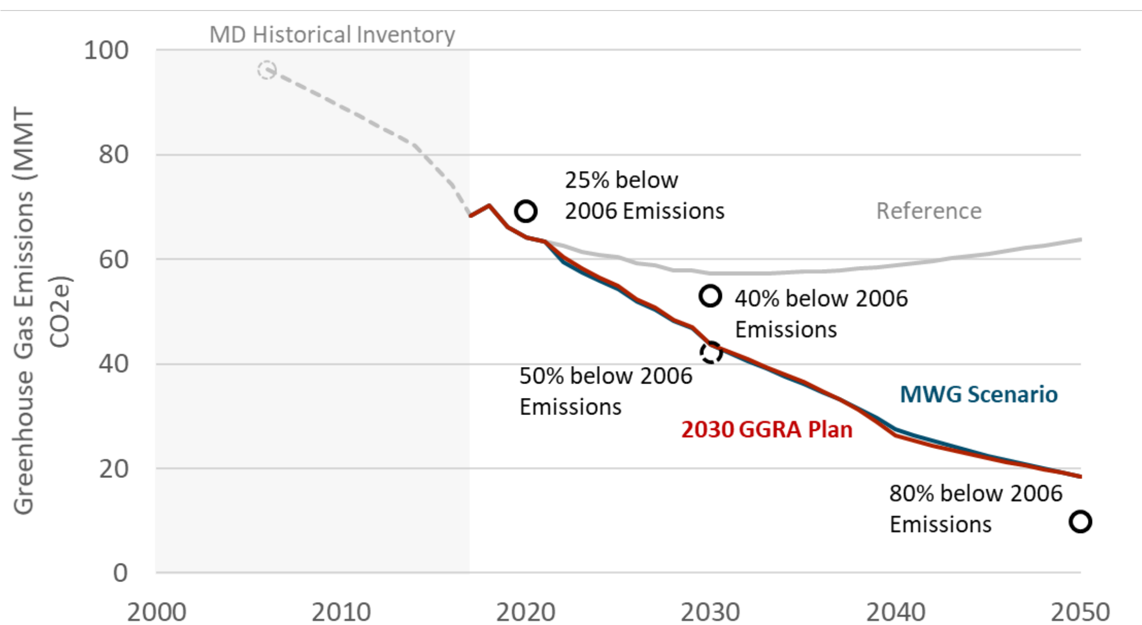

Figure 1-3. Maryland Net GHG Emissions Results for Policy Scenarios, 2018-2050 compared to the adopted GHG targets. The Greenhouse Gas Emissions Reduction Act requires 40% GHG reduction by 2030. The 50% GHG reduction goal is being compared to in this analysis as the state is considering more ambitious near-term target.

The two policy scenarios result in similar GHG trajectories through 2050. Both policy scenarios meet the 2020 goal and the existing 2030 goal required by the GGRA, but they fall short of achieving 50% GHG reduction below 2006 emissions by 2030, which the state is considering as an ambitious near-term target. The two scenarios also highlight the need for additional policy mechanisms to achieve the emission reductions necessary to meet the 2050 economy-wide GHG goal.

[4]https://mde.maryland.gov/programs/Air/ClimateChange/Documents/2019GGRAPlan/Appendices/Appendix%20F%20-%20Documentation%20of%20Maryland%20PATHWAYS%20Scenario%20Modeling.pdf

Table 1-2. Policy Scenario Net GHG Emission Results

[MMT CO2e]	2020	2030	2040	2050
MWG Scenario	64.2	43.6	27.5	18.5
2030 GGRA Plan	64.2	43.6	26.4	18.4
GHG Goals	69.3	53.0	31.4	9.8

Supplemental analysis will be conducted as sensitivity on the 2030 GGRA Plan. The sensitivity analyses will have varied assumptions about federal government programs, rate of consumer adoption, and nuclear energy generation to reflect more or less difficult environments for achieving the 2030 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 key interactions 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 and emissions 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)[5]. 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.

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.

[5] LEAP is developed by the Stockholm Environment Institute. More information on the LEAP software can be found at www.energycommunity.org

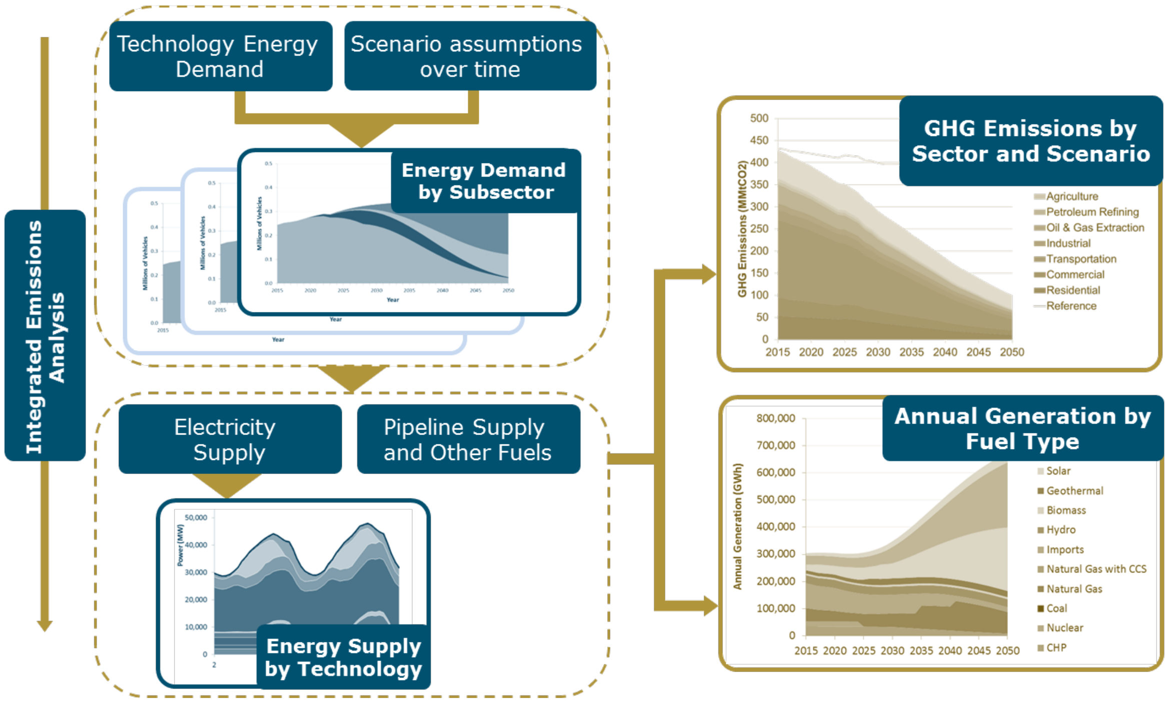

Figure 2-1. PATHWAYS Energy Modeling Framework

2.3 Scenarios

E3 modeled four 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) required by the Clean Energy Jobs Act, EmPOWER efficiency in buildings, and zero emission vehicle (ZEV) memorandum of understanding (MOU)
- **Two 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)**
Clean Electricity Standard	None	50% RPS by 2030 (Clean Energy Jobs Act)
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	Continued growth in deployment until net metering cap (1500 MW by 2026)
Energy Efficiency (Res., Com. & Industrial)	None	EmPOWER goals for 2015-2023, Calibrated to EmPOWER filing targets
Building Code	None	Continued building code improvement that leads to improved building shells in all new construction by 2030
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; continued growth in ZEV LDVs driven by the ZEV Mandate
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 2017 GHG Inventory levels	Small amount of forest management and healthy soils conservation practices

Each policy scenario was designed with a specific philosophy in mind. Detailed assumptions for each Scenario are detailed in Table 2-2. The MWG Scenario assumes more aggressive energy efficiency measures and building and light-duty vehicle electrifications. The 2030 GGRA Plan features more medium and heavy-duty vehicle electrifications and higher in-state clean energy resource requirement for electricity generation.

1. **MWG Scenario**: Policies and measures selected by the Mitigation Working Group (MWG) for consideration by the State

2. **2030 GGRA Plan**: MDE's plan to potentially achieve beyond the 2030 GHG target

Table 2-2. Key Assumptions in Policy Scenarios

	MWG Scenario	**2030 GGRA Plan**
Clean Electricity Standard	75% Clean energy by 2030, 100% by 2040	75% Clean and Energy Standard (CARES) by 2030, 100% by 2040; carveout for in-state clean energy resources reaching 10% by 2030 and 30% by 2040
RGGI	Accelerated RGGI cap that achieves 100% reductions by 2040	
Nuclear power	Assume Calvert Cliffs is relicensed in 2034/2036 at end of license	
Existing coal power	Chalk Point retired by 2022; all remaining in-state coal-fired power plants are ramped down and retired by 2030 as market forces cause coal retirements and Maryland complies with the increasingly stringent RGGI cap	
Rooftop PV	Increased net metering cap to 3 GW by 2030	
Energy Efficiency (Res., Com. & Industrial)	Additional EmPOWER achievements in efficiency as proxy for 3% annual savings goal (100% high efficiency electric sales by 2030, reduction in transmission and distribution losses from 5.4% to 4.6%)	Continued effort for efficiency in buildings (50% high efficiency electric sales by 2030, 25% for natural gas appliance sales); Renewed EmPOWER program pursing broader efficiency improvement (improved building shells for all new construction and 25% of retrofit buildings by 2030)
Electrification of buildings (e.g. NG furnace to heat pumps)	Aggressive building electrification (heat pump sales increase to 95% by 2050)	High levels of building electrification (heat pumps sales increase to 50% by 2030 and 80% by 2040) reflecting reformed EmPOWER program pursuing broader GHG and energy efficiency goals.
Fuel Economy Standards	Federal CAFE standards for LDVs through 2026	Extension of Federal CAFE standards for LDVs through 2030
Zero Emission Vehicles in Light Duty	Aggressive sales after 2025 (800,000 by 2030, 5 Million by 2050)	Increased sales after 2025, and aggressive sales after 2030 (790,000 by 2030, 4.5 Million by 2050) consistent with analysis performed for the Transportation and Climate Initiative (TCI).
Heavy Duty Vehicles	Aggressive sales of electric and diesel hybrid HDVs (40% sales by 2030 and 95% by 2050); truck stop electrification and zero-emission truck corridors	Aggressive sales of ZEV HDVs to meet the ZEV Truck Mandate (35% sales by 2030 and 100% by 2050); truck stop electrification and zero-emission truck corridors
Vehicle Miles Traveled	0.6% growth rate for LDV VMTs: Additional smart growth and transit measures	
Other transportation sectors (e.g. buses,	Electrification of 50% of transit buses by 2030, 100% by 2050; Electrification of 50% of construction vehicles by 2040, 100% by 2050	Electrification of 75% of transit buses by 2030

construction vehicles)		
Industrial energy use	30% reduction below Reference Scenario by 2050	
Biofuels	Existing ethanol and biodiesel blends	
Other (fossil fuel industry, industrial processes, agriculture, waste management, forestry)	More aggressive measures in enteric fermentation & manure management, forest management and healthy soils	Additional acreage in forest management and healthy soils conservation practices; reduced methane emissions from natural gas transmission and distribution.

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 2-3. 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)[6]
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	1.2%	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 2018-2050)	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 2017 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.

Table 2-4. Building 2017 Energy Consumption by Subsector in Maryland

Sector	Subsector	Energy Use in 2017 [Tbtu]	Percent of 2017 Energy Use [%]
Residential	Air conditioning	7	2%
	Clothes drying	-	0%
	Clothes washing	5	1%
	Cooking	1	0%

[6] Available online: https://planning.maryland.gov/MSDC/Documents/popproj/HouseholdProj.pdf

	Dishwashing	9	2%
	Freezing	1	0%
	Lighting	1	0%
	Refrigeration	4	1%
	Space heating	9	2%
	Water heating	80	21%
	Residential Other*	42	11%
Commercial	Air conditioning	31	8%
	Cooking	2	1%
	General service lighting	9	2%
	High intensity discharge lighting	6	1%
	Linear fluorescent lighting	5	1%
	Refrigeration	2	1%
	Space heating	5	1%
	Ventilation	61	16%
	Water Heating	15	4%
	Commercial Other*	21	6%
	All Sectors	*383*	*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. programmable 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 2-5. Reference Scenario Assumptions for Building Energy Efficiency

Category of Efficiency	**Reference Scenario Assumption**
Building retrofits for high efficiency building shells	Improved building shells in all new construction by 2030 to represent continued building code improvement

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 is 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, consistent with utility filings for the 2018-2020 program cycle.

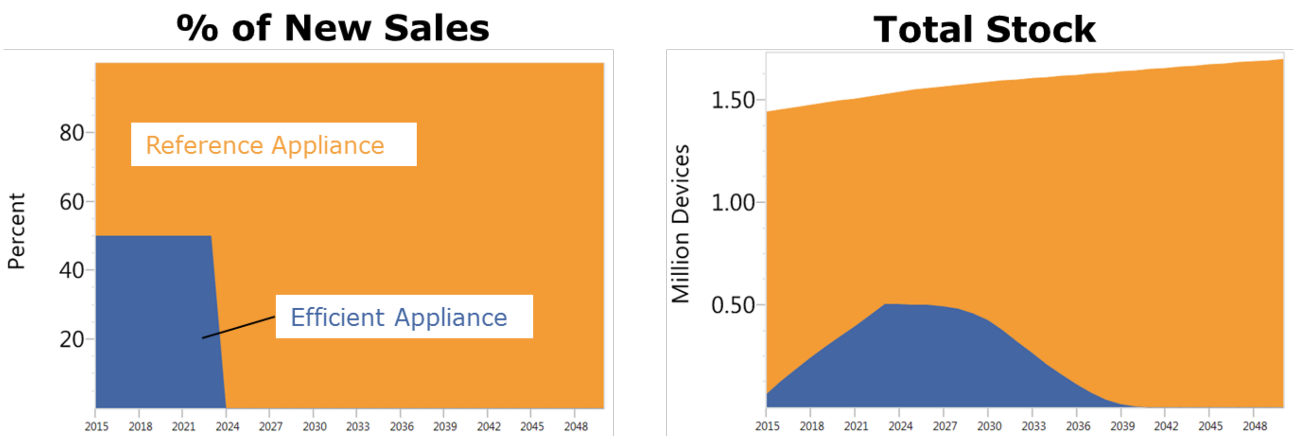

Figure 2-3. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, Reference Scenario

2.4.2.3 MWG Scenario

The MWG Scenario 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 2-6. MWG Scenario Assumptions for Building Energy Efficiency

Category of Efficiency	**MWG Scenario Assumption**
Building retrofits for high efficiency building shells	Improved building shells in all new construction by 2030 to represent continued building code improvement
New technology sales	Start from 50% new sales in 2015 through 2023 and ramp up to **100% by 2030** to reflect increased EE targets from utilities 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	5% 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 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

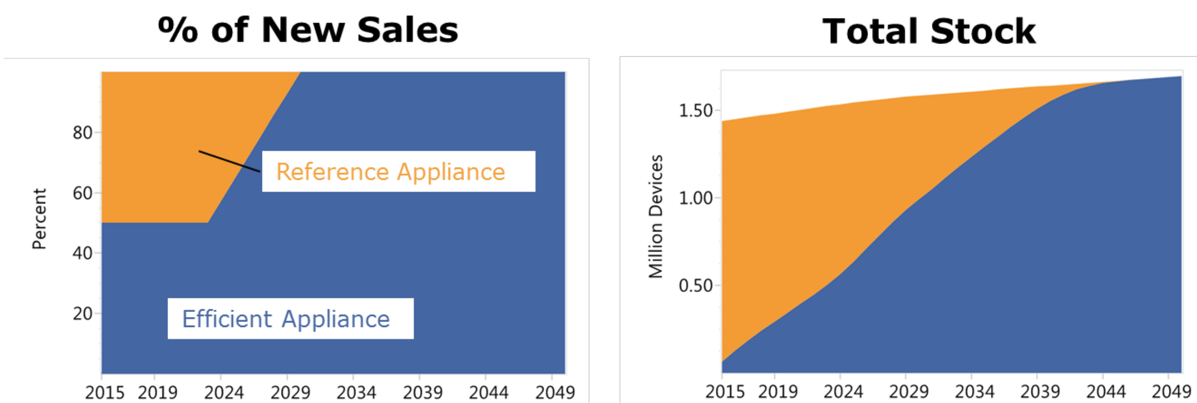

Figure 2-5. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, MWG Scenario

2.4.2.4 2030 GGRA Plan

The 2030 GGRA Plan adopts energy efficiency and building electrification measures that are similar to level of efforts in the MWG Scenario with some differences.

Table 2-7. 2030 GGRA Plan Assumptions for Building Energy Efficiency

Category of Efficiency	2030 GGRA Plan
Building retrofits for high efficiency building shells	Improved building shells for all new construction and 25% of retrofit buildings by 2030 to reflect efforts beyond building improvement
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	50% of new sales of electric heat pump by 2030 and 80% by 2040, 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

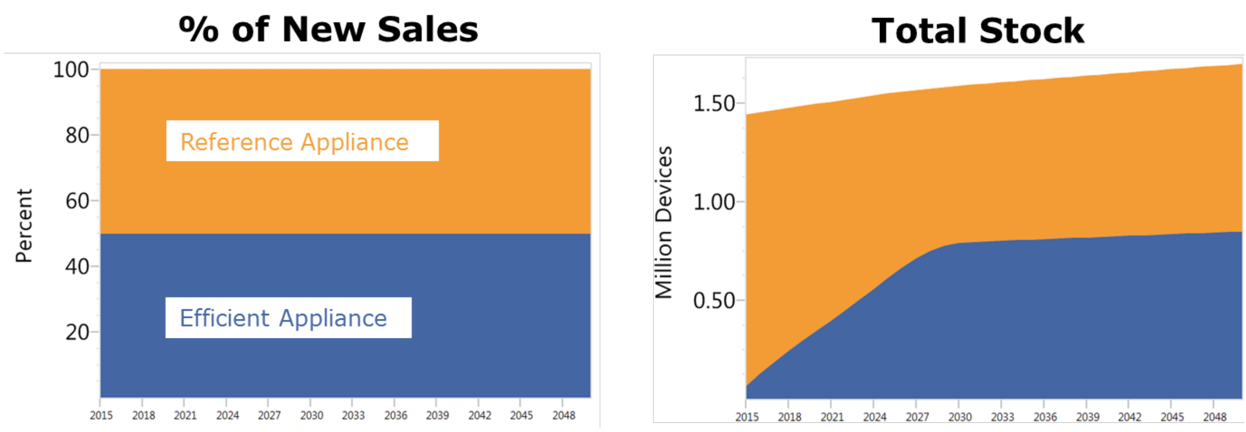

Figure 2-6. Assumed New Sales for Electric Building Appliances and Resulting Appliance Stocks, 2030 GGRA Plan

2.4.2.5 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 the MWG Scenario we assume heat pump space heater adoption increases to about 50% in 2030 and 95% by 2050, 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). The 2030 GGRA Plan follows adoption trends from the National Renewable Energy Laboratory's Electrification Futures Study,[7] resulting in slightly lower adoption of heat pump space heaters after

[7] https://www.nrel.gov/docs/fy18osti/71500.pdf

2040. The annual sales percentage and resulting stocks of residential heat pump space heaters are shown in Figure 2-7 and Figure 2-8.

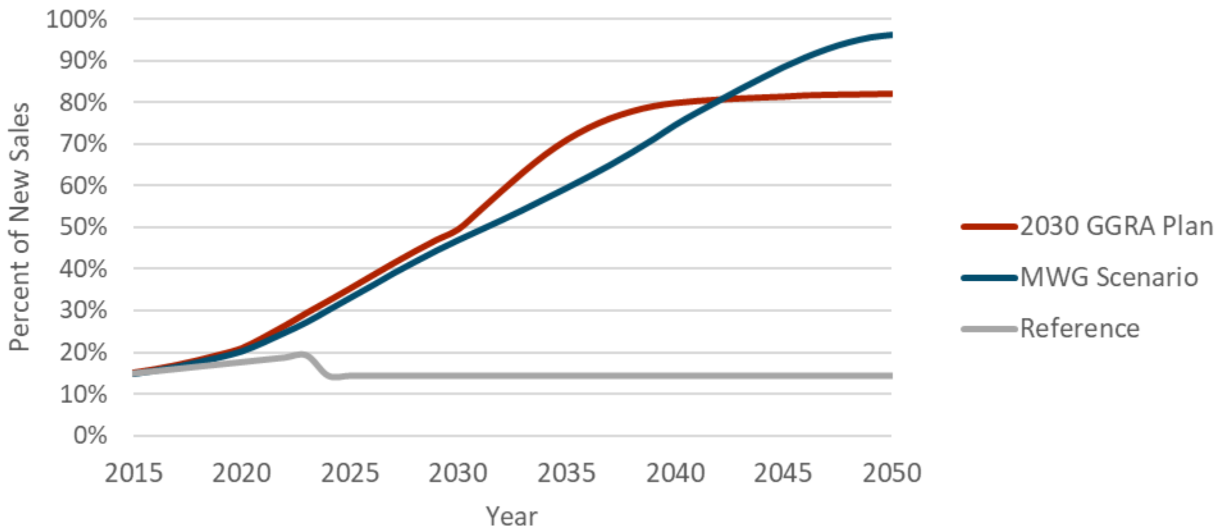

Figure 2-7. Percent of annual new sales of residential electric heat pump space heaters in all scenarios.

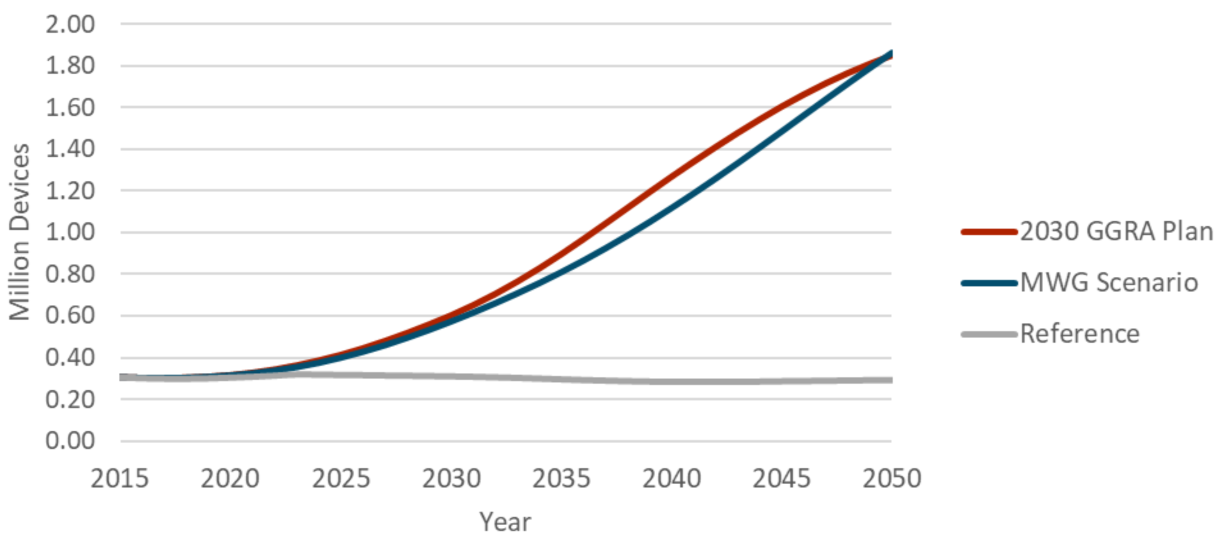

Figure 2-8. Total number of residential electric heat pump space heaters in all scenarios.

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 2-8. Industry 2017 Energy Consumption by Fuel in Maryland

Sector	Fuel	Energy Use in 2017 [Tbtu]	% of 2017 Energy Use [%]
Industry (All Subsectors)	Coal	12.3	22%
	Diesel	5.3	10%
	Renewable Diesel	-	0%
	Electricity	12.8	23%
	Natural Gas	16.5	30%
	Biogas	-	0%
	LPG	1.5	3%
	Lubricants	1.0	2%
	Gasoline	2.9	5%
	Misc. Petroleum Products	0.3	1%
	Special Napthas	2.8	5%
	Residual Fuel Oil	0.1	0%
	All Sectors	*55.4*	*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 2-9. 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.

Energy consumption and the associated emissions from Cove Point LNG facility are added in 2018 and those from Luke Paper Mill are removed in 2019 following its closure.

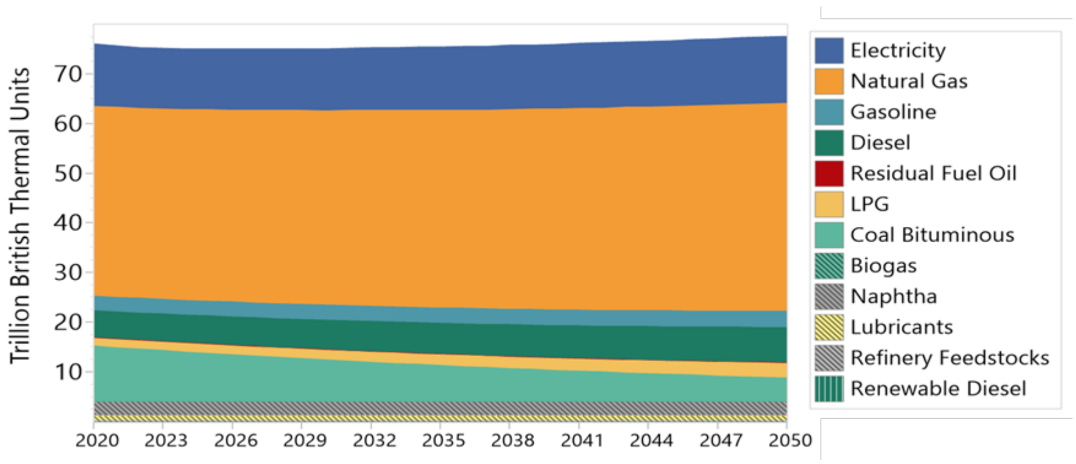

Figure 2-9. Total Industrial Energy Consumption in the Reference Scenario

2.4.3.3 MWG Scenario

In the MWG Scenario, 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.

2.4.3.4 2030 GGRA Plan

The 2030 GGRA Plan has the same industrial efficiency assumptions as the MWG Scenario.

2.4.3.5 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 2-10. Scenario compound annual growth rates by fuel for Maryland's Industry Sector (2017-2050)

Fuel	MWG Scenario	2030 GGRA Plan
Coal	-3.8%	-3.8%
Diesel	-3.9%	-3.9%
Electricity	-0.6%	-0.6%

Natural Gas	-1.0%	-1.0%
LPG	1.2%	1.2%
Gasoline	-0.7%	-0.7%
Misc. Petroleum Products	-1.0%	-1.0%
Special Napthas	-1.0%	-1.0%
Residual Fuel Oil	0.0%	0.0%

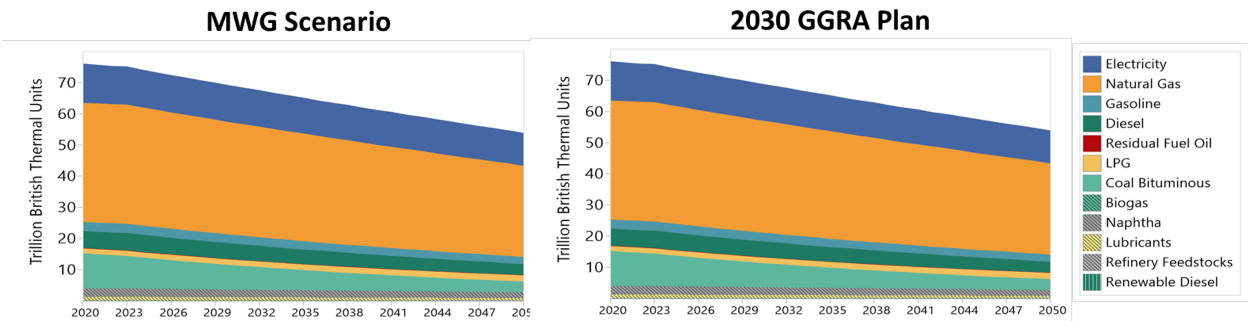

Figure 2-10. Total Industrial Energy Consumption in both policy scenarios

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 2-11. Transportation 2017 Subsector Energy Consumption in Maryland

Sector	Subsector	Energy Use in 2017 [Tbtu]	% of 2017 Energy Use [%]
Light duty vehicles	Light Duty Autos	119	28%
	Light Duty Trucks	166	39%
Medium and Heavy Duty Vehicles	Medium and Heavy Duty Trucks	95	22%
Transportation Other	Aviation*	10	2%
	Rail*	4	1%
	Bunker Fuels*	1	0%
	Farm*	2	0%
	Construction*	23	5%
	Marine*	2	0%
	Motorcycle*	2	0%
	Other*	0	0%

	Bus*	4	1%
	All Sectors	*428*	*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.

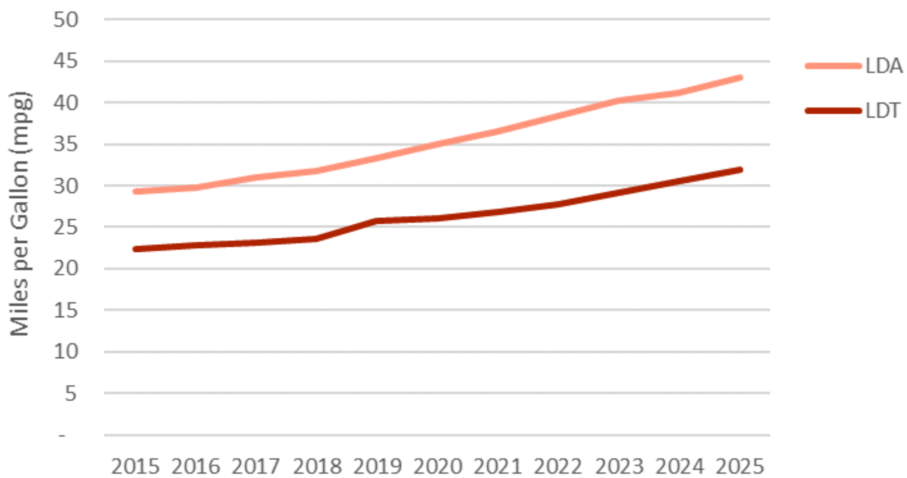

Figure 2-11. Marginal Fuel Economy for Gasoline LDVs in Maryland

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 42% ZEV light duty auto (LDA) sales by 2030, and 8% ZEV light duty truck (LDT) sales by 2030. In our stock rollover methodology, this means that of all the LDAs that are purchased in 2030 (either due to retirement or new growth), 12% will be battery electric vehicles (EVs) and 2% will be plug-in hybrid electric vehicles (PHEVs). This assumption is shown for LDAs and LDTs in Figure 2-12. No changes were assumed in the heavy-duty fleet.

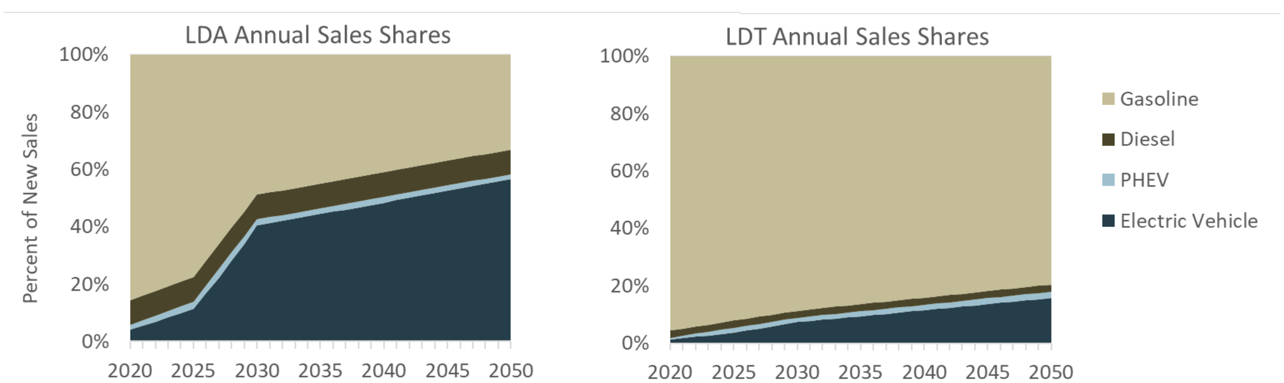

Figure 2-12. New Sales Rates for LDAs and LDTs in Reference Scenario

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 MWG Scenario

The MWG scenario 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 medium and heavy duty vehicles, construction vehicles, and buses.

Table 2-12. MWG Scenario Assumptions for Transportation

Category of Transportation Measures	**MWG Scenario Assumption**
Vehicle Miles Traveled (VMT) reductions	Annual LDV VMT is reduced to 23% below Reference 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 8% 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 Medium and 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 100% of construction vehicles by 2050, electrification of 70% of transit buses by 2030, 100% by 2035. AEO 2017 reference scenario growth rates by fuel for all other subsectors

2.4.4.4 2030 GGRA Plan

The 2030 GGRA Plan has slightly lower level of ZEV LDV adoption compared to the MWG Scenario. The 2030 GGRA Plan achieves 35% of ZEV medium and heavy vehicle sales by 2030 and 100% by 2050 following Maryland's participation in the zero-emission medium and heavy vehicle Memorandum of Understanding (MOU). Annual VMT reductions were also estimated by the Maryland Department of Transportation.

Table 2-13. 2030 GGRA Plan Assumptions for Transportation

Category of Transportation Measures	2030 GGRA Plan Assumption
Vehicle Miles Traveled (VMT) reductions	Annual LDV VMT is reduced to 12% below Reference by 2030 and continued to 2050 based on Maryland Department of Transportation (MDOT) emerging and innovative strategies for highway management, smart transit, etc.
Zero-emission Light Duty Vehicle (LDV) sales	65% new sales of ZEVs (electric vehicle and plug-in hybrid) in LDAs and 25% in LDTs by 2030 and 100% by 2050 assuming aggressive ZEV adoption
Zero-emission Medium and Heavy Duty Vehicle (HDV) sales	35% new sales of electric vehicle by 2030 and 100% by 2050 to reflect requirement by the medium and heavy ZEV Memorandum of Understanding (MOU)
Transportation Other	Electrification of 75% of transit buses by 2050 (equal to 42% of total buses), AEO 2017 reference scenario growth rates by fuel for all other subsectors

2.4.4.5 Transportation Assumptions Summary

All scenarios include similar assumptions about ZEV sales through 2025, but then sales assumptions diverge, with the MWG Scenario assuming more aggressive adoption after 2030. Assumptions for total new sales of ZEVs and resulting total stocks is shown in Figure 2-13.

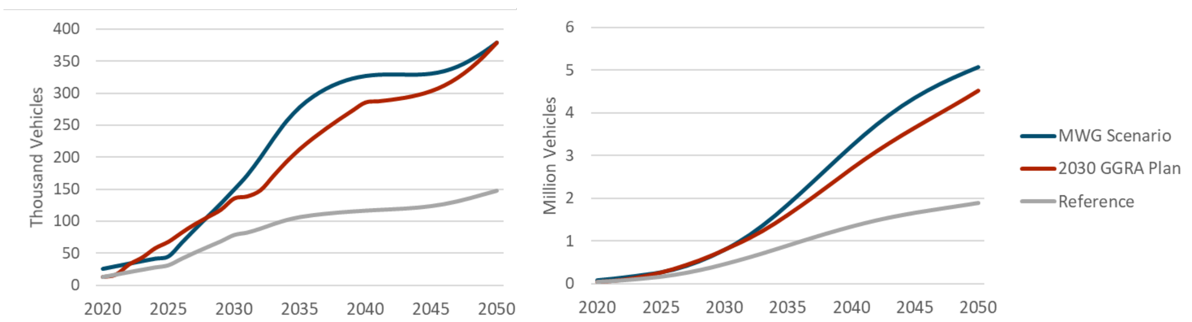

Figure 2-13. Annual new sales (left) and stock (right) of Light-Duty ZEVs (electric vehicle and plug-in hybrid) for all scenarios, 2020-2050.

Total ZEV LDV stocks are reported in Table 2-20.

Table 2-14. Total Stock of Zero Emission Light Duty Vehicles, Reference Scenario and both policy scenarios

Reference							
	2020	2025	2030	2035	2040	2045	2050
EVs	25,183	118,605	383,640	803,416	1,240,258	1,563,832	1,792,608
PHEVs	12,356	40,814	72,419	93,006	101,703	103,214	107,200
Total ZEVs	**37,539**	**159,420**	**456,059**	**896,422**	**1,341,961**	**1,667,046**	**1,899,808**
MWG Scenario							
	2020	2025	2030	2035	2040	2045	2050
EVs	65,615	204,043	597,233	1,418,844	2,535,743	3,542,466	4,292,745
PHEVs	22,510	68,300	199,110	436,223	682,480	807,897	775,072
Total ZEVs	**88,124**	**272,343**	**796,343**	**1,855,067**	**3,218,223**	**4,350,364**	**5,067,818**
2030 GGRA Plan							
	2020	2025	2030	2035	2040	2045	2050
EVs	25,183	221,771	730,996	1,525,787	2,575,067	3,505,539	4,336,477
PHEVs	12,356	35,275	59,709	84,465	117,064	152,894	190,800
Total ZEVs	**37,539**	**257,046**	**790,706**	**1,610,253**	**2,692,131**	**3,658,434**	**4,527,277**

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 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.

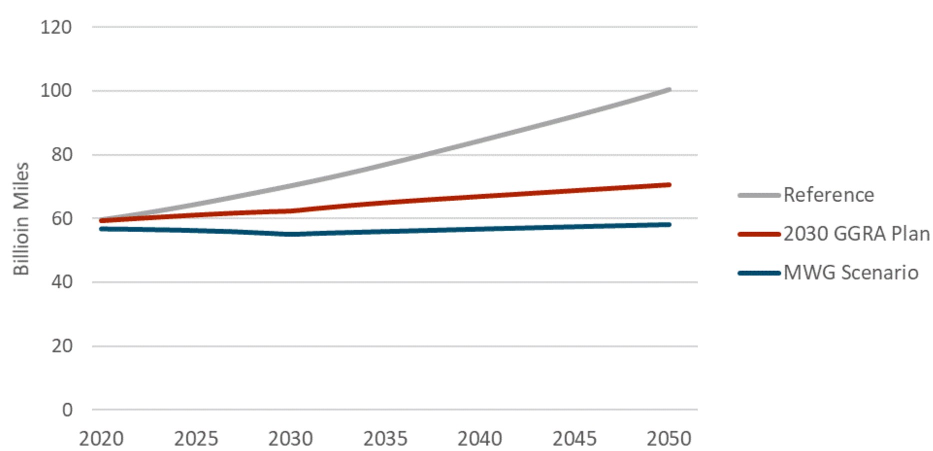

Figure 2-14. Total Vehicle Miles Traveled (VMT) for all scenarios, 2020-2050.

Table 2-15 Total Vehicle Miles Traveled for all scenarios. Units: Billion Miles

	2020	2025	2030	2035	2040	2045	2050
Reference	59.8	64.6	70.4	77.0	84.5	92.2	100.5
MWG Scenario	56.8	56.2	55.0	55.9	56.7	57.5	58.2
2030 GGRA Plan	59.3	61.1	62.4	65.0	67.0	68.9	70.7

2.4.5 Electricity Sector representation

The Maryland Pathways model represents the operations of the electricity sector independently, 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. The model is integrated with electricity demands from buildings, industry, and transportation, so modeled generators are dispatched to meet electric loads from each modeled scenario.

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 2-16. 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 2-17. 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), while the Skipjack project is expected to provide 120 MW (455,482 MWh / year).

The Maryland Pathways model includes 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 hourly dispatch capability 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, the availability of natural gas units in the winter months is reduced and coal units are placed 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"[8]. 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[9] and the 2016 *Renewable Energy Portfolio Standard Report* from the Public Service Commission of Maryland[10]. 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 in 2020, 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.

The updated Reference Scenario in the third phase of the study achieves the 50% RPS goal by 2030, consistent with the program laid out in the Clean Energy Jobs Act of 2019 (CEJA)[11]. This 50% RPS goal includes resource-specific carveouts for Tier 1 Solar and Offshore Wind: (1) in-state solar generation reaching 14.5% by 2028, and (2) offshore wind build reaching 400 MW by 2026, 800 MW by 2028 and 1200 MW by 2030 in addition to the planned U.S. Wind project and the Skipjack project. Wind RECs are purchased from PJM.

The updated Reference also assumes that the RGGI cap continues to tighten to reach 30% reduction from 2020 to 2030, which we modeled as a reduction in the imports emission factor, weighted by RGGI states in PJM

The Maryland Department of the Environment provided guidance regarding the resources to be ramped down to make room for the increase in renewable energy generated within the state. New renewable

[8] 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/

[9] 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

[10] The report can be found at https://www.psc.state.md.us/wp-content/uploads/CY16-RPS-Annual-Report-1.pdf

[11] The text of the bill can be found here http://mgaleg.maryland.gov/2019rs/bills_noln/sb/esb0516.pdf

resources constructed within the state (Tier 1 Solar PV, including Rooftop PV, and Offshore Wind) result in a decrease in in-state coal 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 2-15, below, shows the breakdown of generation by resource type coming out of the LEAP model.

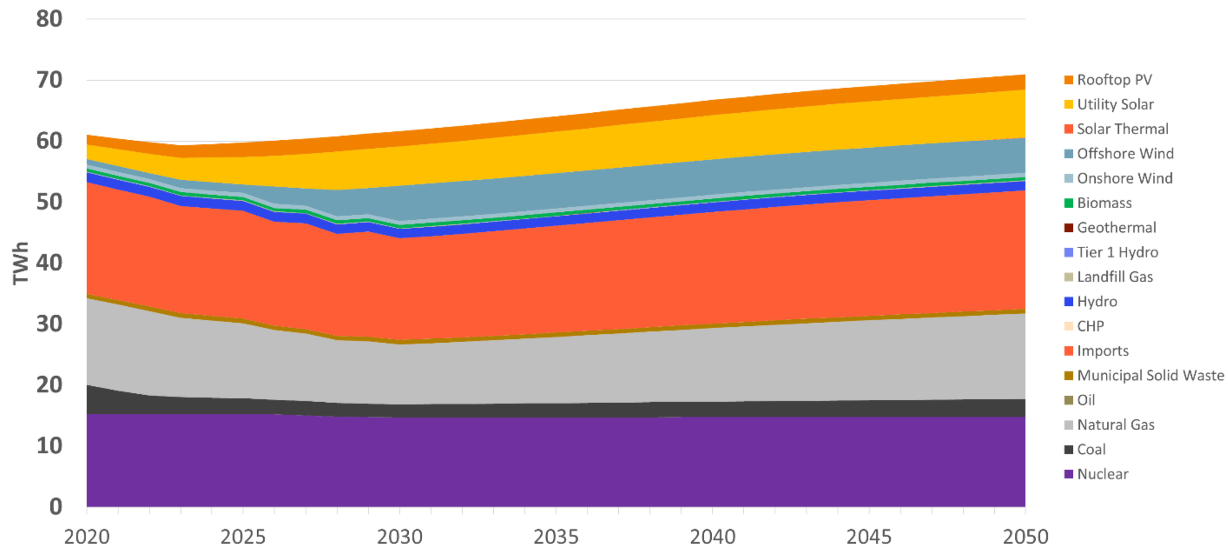

Figure 2-15. Annual Generation by Resource Type – Reference Case

2.4.5.3 MWG Scenario

The MWG Scenario extended the 50% RPS by 2030 (modeled in Reference) to a 100% Standard by 2040, while also tightening the RGGI emissions cap between 2030 and 2050. [12]

We leveraged modeling completed by Resources for the Future (RFF) and their E4ST model and then calibrated to additional requests from the Mitigation Working Group in LEAP[13]. The increased standard 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 2018 in Reference, it counts toward the goal in the MWG Scenario. The 100% requirement results in roughly a 75% RPS by 2040, with the remainder of electricity demand being met by nuclear power (Calvert Cliffs)

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[12] 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.

[13] Neither E4ST or LEAP is a detailed electricity operations model, so neither model can tell us how reliable this system is in a given year, or exactly what renewable integration technologies may be required (e.g. battery storage, long-duration storage, renewable overbuild). For this scenario, we assume that imported power from PJM balances the system to maintain reliability.

and imports from PJM. Net metering cap is assumed to increase to 3 GW by 2030, modeled as rooftop solar.

The MWG Scenario also assumes that the RGGI cap continues to tighten to get to 100% reduction by 2040, which we modeled as a reduction in the imports emission factor, weighted by RGGI states in PJM (incl. PA and NJ). This results in the shutdown of all coal generation within the state by 2030 and all in-state natural gas generation by 2040, replaced primarily by imports from out-of-state (not covered by the RGGI caps). Remaining emissions from PJM do carry an emissions factor, so though in-state generation is 100% zero-carbon, the total electric sector continues to have emissions associated with non-RGGI imports.

The resulting generation mix for the MWG Scenario is shown in Figure 2-17.

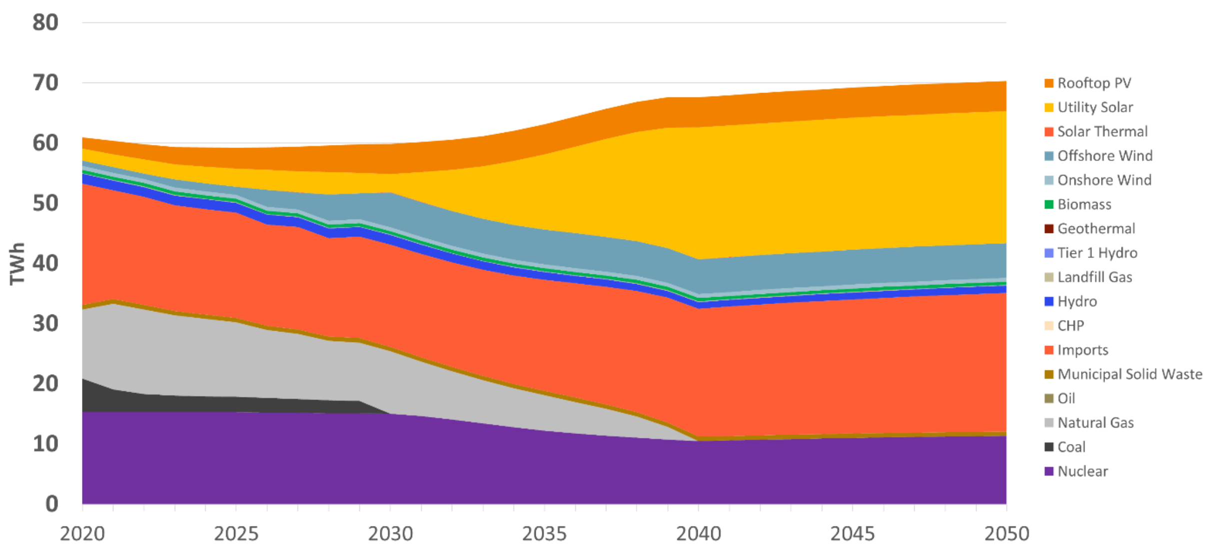

Figure 2-17. Annual Generation by Resource Type – MWG Scenario

2.4.5.4 2030 GGRA Plan

In the 2030 GGRA Plan has similar requirements for the electricity sector as the MWG Scenario: Maryland meets the existing 2020 RPS of 25%, and then adopts a 50% Clean and Renewable Energy Standard (CARES) target for 2030 and 100% CARES target for 2040.

The difference in the 2030 GGRA Plan from the MWG scenario is the modeling of carveout for in-state clean energy resources to reach 10% of total generation by 2030 and 30% by 2040. We leveraged modeling completed by Resources for the Future (RFF) and their E4ST model, and ramped up in-state solar and added Combined Heat and Power (CHP), both eligible as in-state clean energy resources, to meet the in-state clean energy carveout.

As in the MWG Scenario, this scenario assumes RGGI cap continues to tighten to get to 100% reduction by 2040.

The resulting generation mix for the 2030 GGRA Plan is shown Figure 2-19.

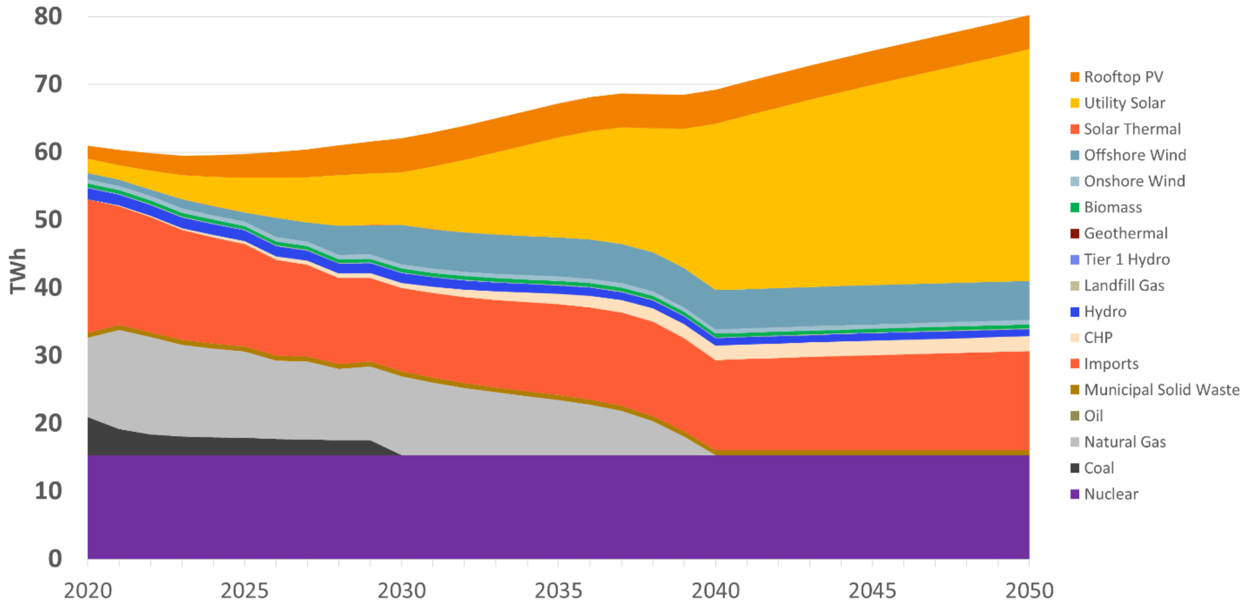

Figure 2-19. Annual Generation by Resource Type – 2030 GGRA Plan

2.4.6 Non-Combustion

2.4.6.1 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 emission sinks from sequestration on natural and working lands, which 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 2017 GHG Inventory.

Table 2-18. Non-Combustion Emissions and Emissions sinks in Maryland, 2017

Sector	Subsector	2017 [MMT CO2e]
Agriculture	Agricultural Burning	0.01
	Agricultural Soils	0.78
	Enteric Fermentation	0.51
	Manure Management	0.31
	Urea Fertilizer Usage	0.01
Sequestration on Natural and Working Lands	Agricultural Soils	-0.05
	Forest Fires	0.02
	Forested Landscape	-10.45
	Urban Forestry and Land Use	-1.33

Fossil Fuel Industry	Coal Mining	0.12
	Natural Gas Industry	0.61
Industrial Processes	Ammonia and Urea Production	0.00
	Cement Manufacture	1.51
	Electric T and D Systems	0.04
	Limestone and Dolomite Use	0.15
	ODS Substitutes	3.57
	Soda Ash	0.04
Waste Management	Landfills	0.57
	Residential Open Burning	0.03
	Waste Combustion	1.19
	Wastewater Management	0.71
Total Non-Combustion Emissions		10.15
Total Non-Combustion Emissions Sinks		-11.79
Total Net Non-Combustion Emissions		-1.64

2.4.6.2 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.

2.4.6.3 MWG Scenario

The MWG assumes aggressive GHG reductions in agriculture, forests, and soils, as well as the SNAP reductions in ODS substitutes, as indicated in Table 2-28.

Table 2-19. MWG Scenario Assumptions for Non-Combustion Emissions

Category of Non-Combustion	MWG Scenario Assumption
Agriculture	Reductions in Enteric Fermentation: 16% below 2014 levels by 2030 Reductions in Manure Management: 65% below 2014 levels by 2030
Sequestration on Natural and Working Lands	Increased level of forestry sequestration by 10% from 2017 levels by 2030
Fossil Fuel Industry	None
Industrial Processes	Reductions in ODS substitutes: 23% below 2014 levels by 2030 (SNAP)
Waste Management	None

2.4.6.4 2030 GGRA Plan

The 2030 GGRA Plan includes the enhanced sinks measure as well as the SNAP reductions in ODS substitutes, but does not include the agriculture measures that do not currently have a policy mechanism in Maryland.

Table 2-20. 2030 GGRA Plan Assumptions for Non Combustion Emissions

Category of Non Combustion	**2030 GGRA Plan Assumption**
Agriculture	None
Sequestration on Natural and Working Lands	Additional acreage in forest management and healthy soils conservation practices
Fossil Fuel Industry	Reduced methane emissions from natural gas transmission and distribution.
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.

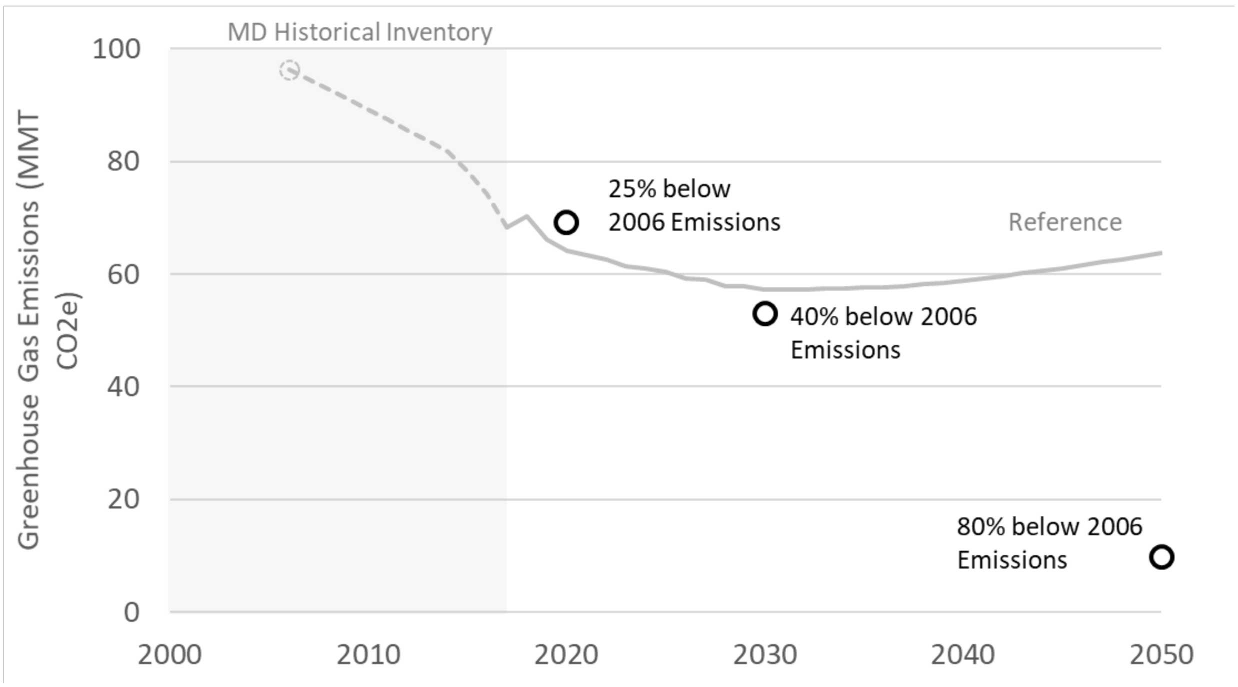

Figure 3-1. Maryland Net GHG Emissions Results for Reference Scenario, 2018-2050

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 through 2030, due to the RPS requirements.

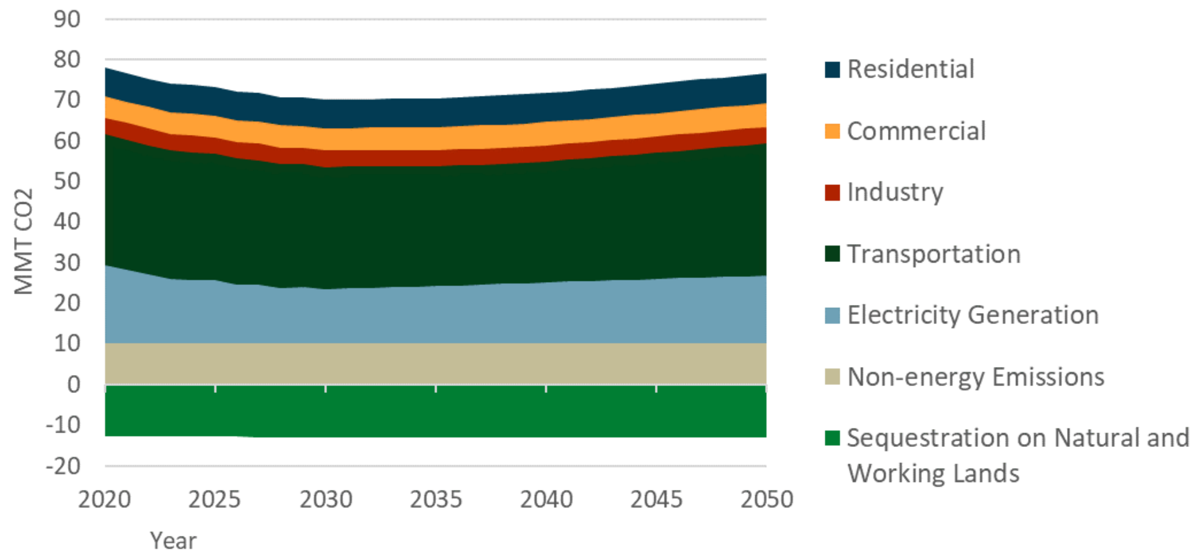

Figure 3-2. Maryland Gross GHG Emissions by Sector in the Reference Scenario, 2020-2050[14]

Both policy scenarios meet the 2020 goal and the existing 2030 goal required by the GGRA, but they fall short of achieving 50% GHG reduction below 2006 emissions by 2030, which the state is considering as an ambitious near-term target. The two scenarios also highlight the need for additional policy mechanisms to achieve the emission reductions necessary to meet the 2050 economy-wide GHG goal.

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

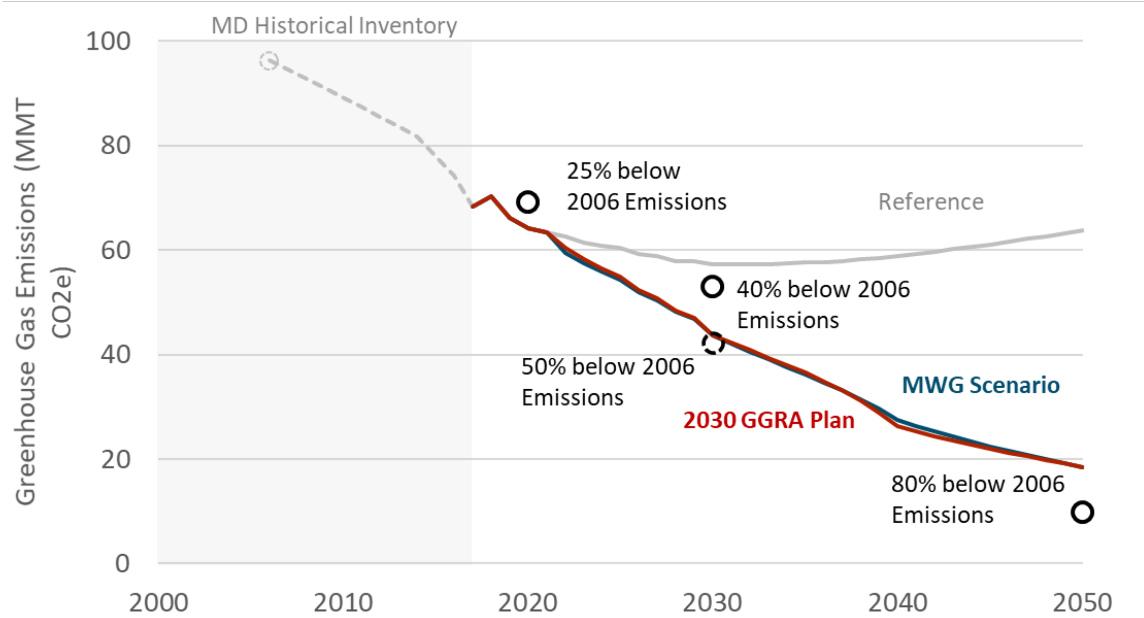

Figure 3-3. Total Net GHG Emissions by Scenario Relative to Policy Targets

Figure 3-4 shows total emissions by sector in each Policy Scenario. The most notable reductions in both the MWG and the 2030 GGRA Plans are in transportation due to increasing ZEV adoptions and electricity generation due to the increasingly stringent CARES requirements.

Table 3-1. Total Net GHG Emissions by Policy Scenario

[MMT CO2e]	2020	2030	2040	2050
MWG Scenario	64.2	43.6	27.5	18.5
2030 GGRA Plan	64.2	43.6	26.4	18.4
GHG Goals	69.3	53.0	31.4	9.8

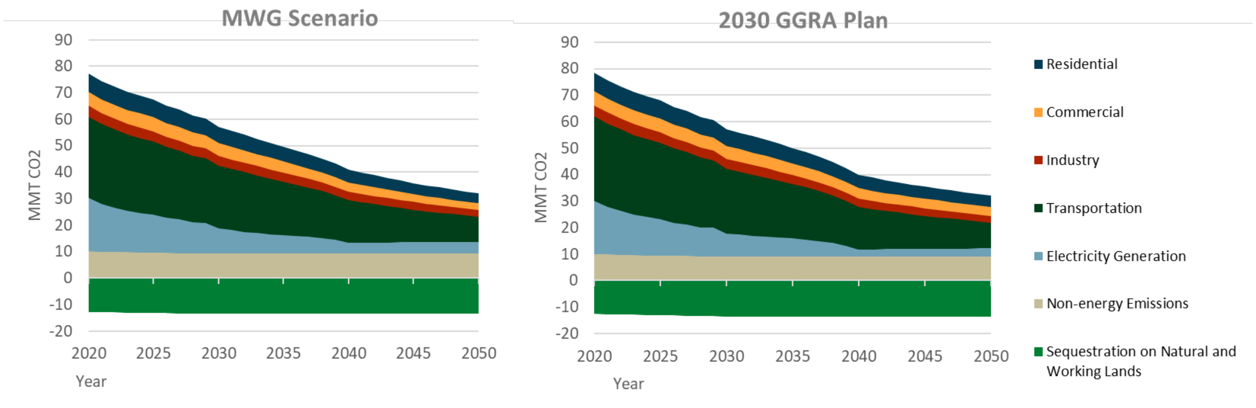

Figure 3-4. Maryland Gross GHG Emissions by Sector in both policy scenarios, 2020-2050[15]

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.

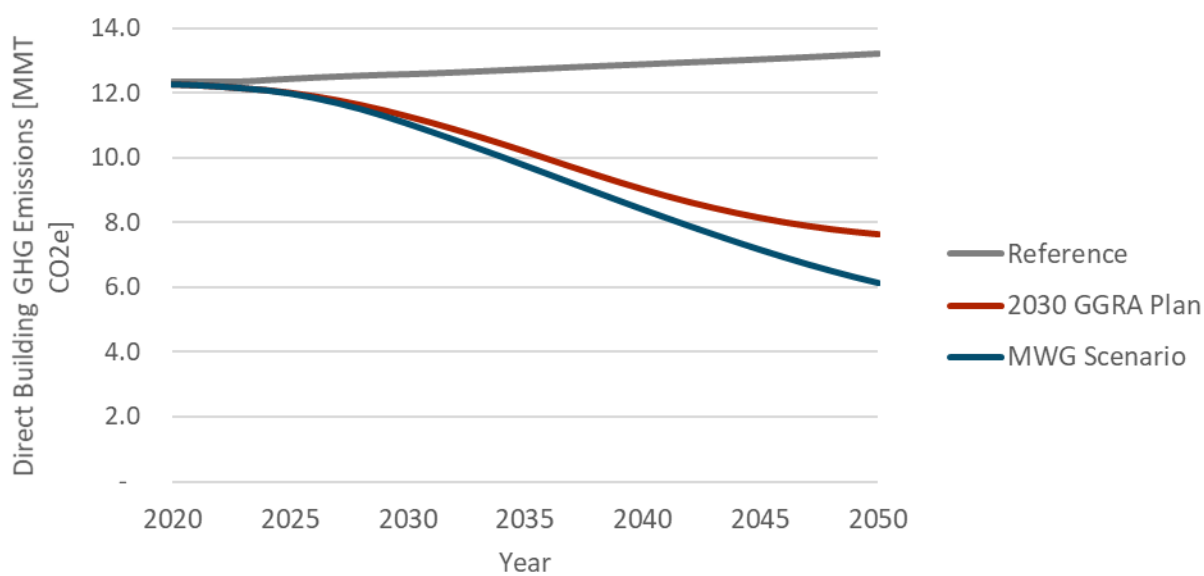

Figure 3-5. Total Direct Emissions by Scenario in Buildings.

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

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.

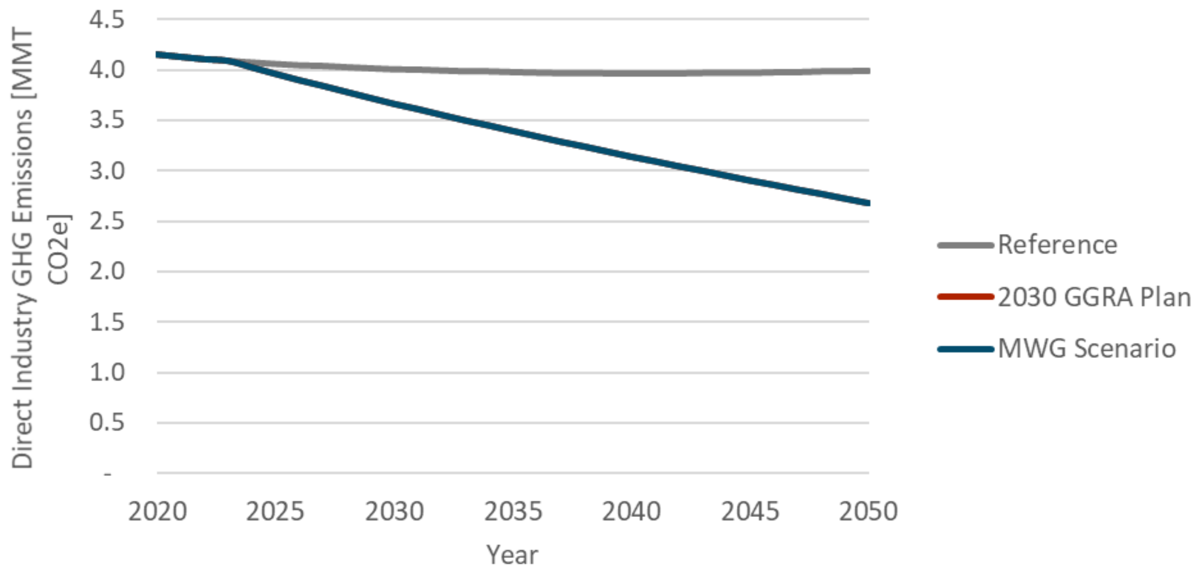

Figure 3-6. Total Direct Emissions by Scenario in Industry. MWG Scenario and the 2030 GGRA Plan have the same industrial emissions trajectory.

3.2.3 Transportation

Reductions in emissions in the transportation sector are achieved through efficiency and electrification. 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.

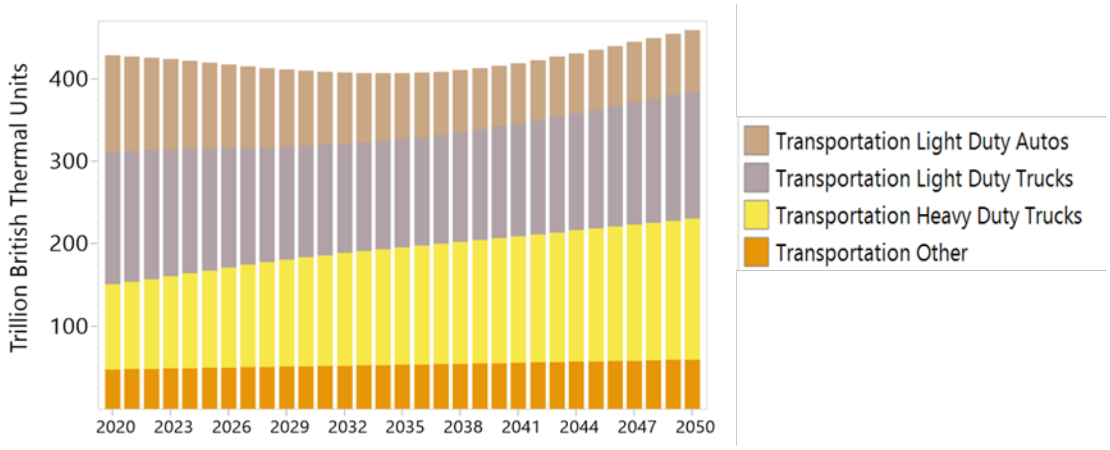

Figure 3-7. Total Energy Consumed in Transportation by Subsector, Reference Scenario

Additional electric vehicle sales and VMT reductions reduce energy consumption further in the policy scenarios, as shown in Figure 3-8.

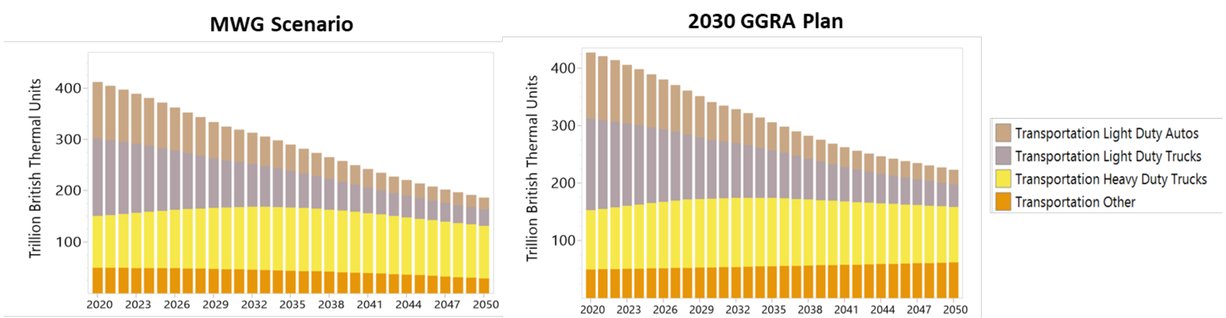

Figure 3-8. Total Energy Consumed in Transportation by Subsector, both policy scenarios

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

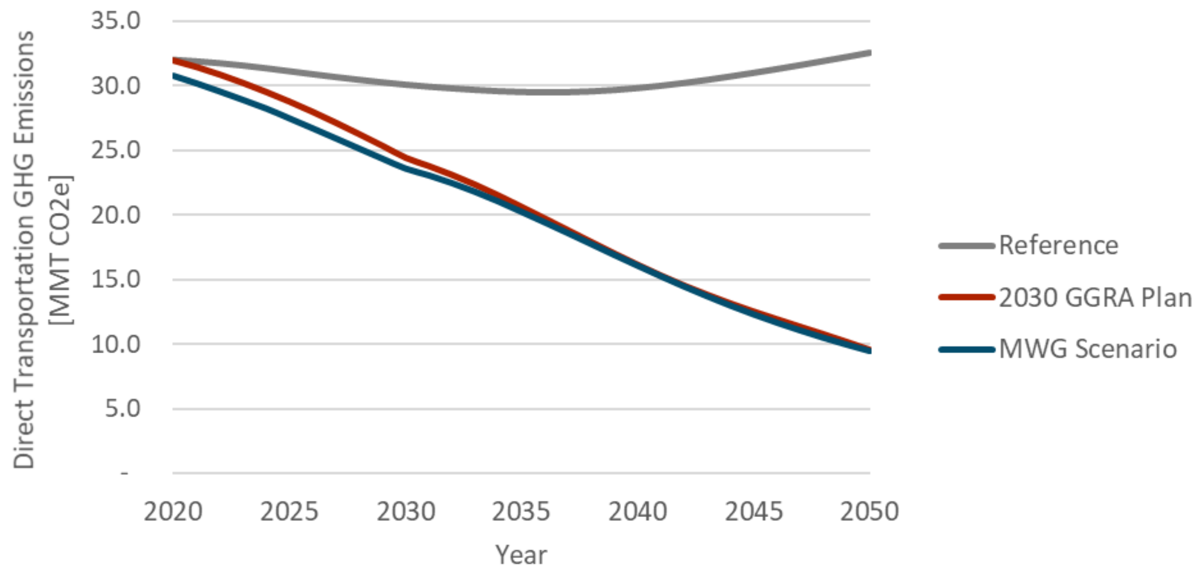

Figure 3-9. Total Direct GHG Emissions in Transportation by Scenario

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.

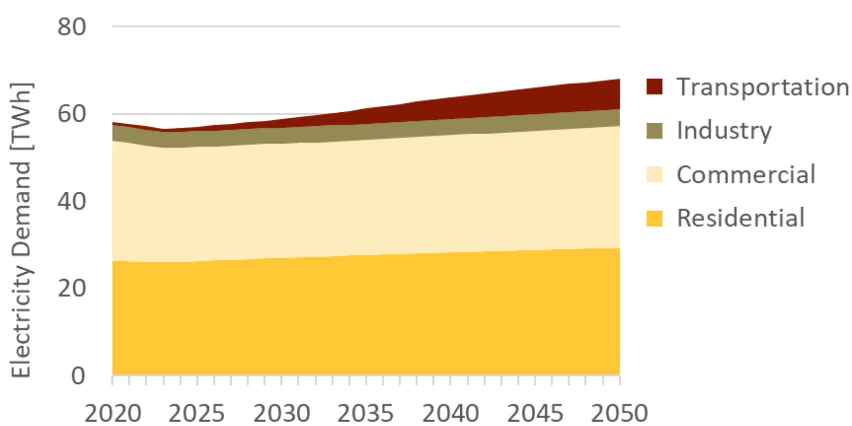

Figure 3-10. Total Electric Load by Sector, Reference Scenario

In each of the Policy Scenarios both electric efficiency and electrification impacts total electricity demand in buildings. Transportation electrification is the most prominent new load, highlighted in Figure 3-11.

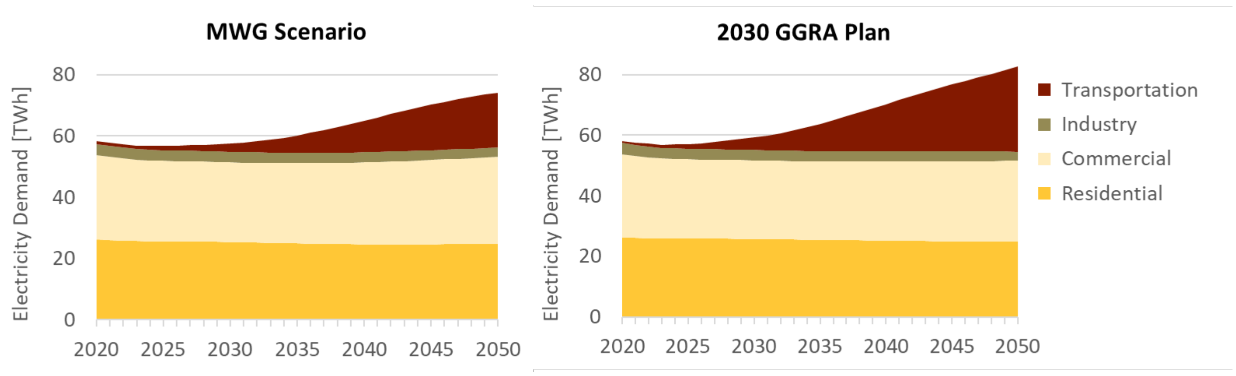

Figure 3-11. Total Electric Load by Sector and Policy Scenario

3.2.4 Electricity Generation

In the Reference Scenario, emissions from the electricity sector declines rapidly until 2030 driven by the RPS requirements, shown in Figure 3-12. After 2030, load growth and slowing renewable deployment cause emissions to slowly climb.

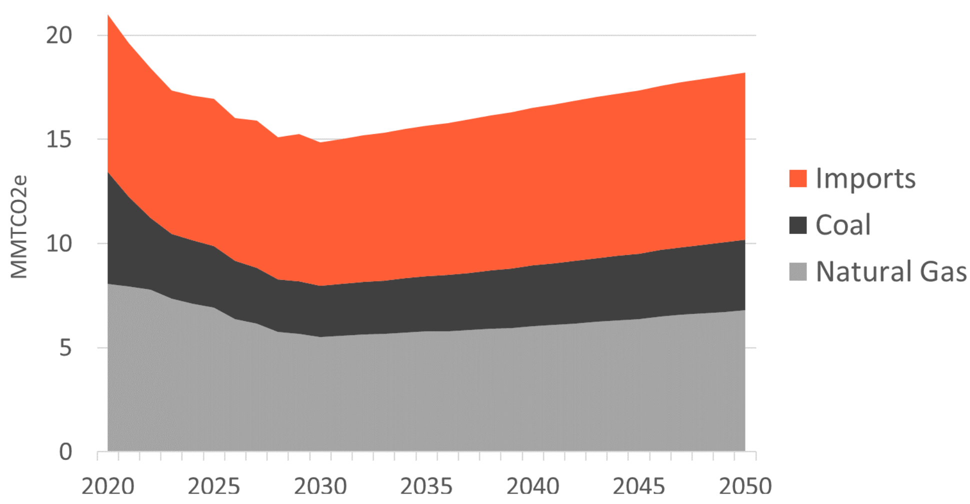

Figure 3-12. Annual Electricity Emissions by Resource Type, Reference Scenario

Emissions from the electricity sector decline sharply in both the MWG Scenario and the 2030 GGRA Plan, due to the increasing clean energy standards, which displace coal and natural gas generation. The declining emissions intensity of imports from PJM due to tightening RGGI caps regionwide also contributes to the decline in emissions. After 2030, increasing electrification loads and slowing renewable deployment cause emissions to slowly climb.

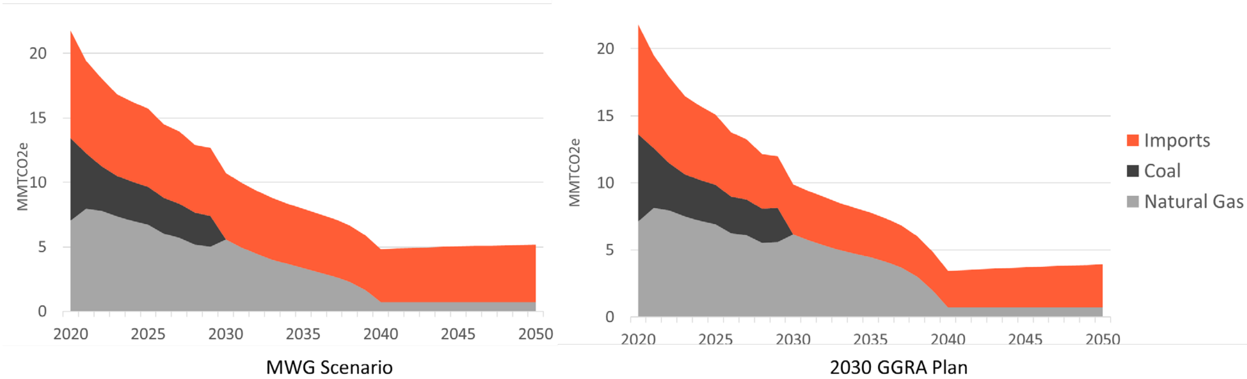

Figure 3-13. Annual Electricity Emissions by Resource Type and Policy Scenario

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.

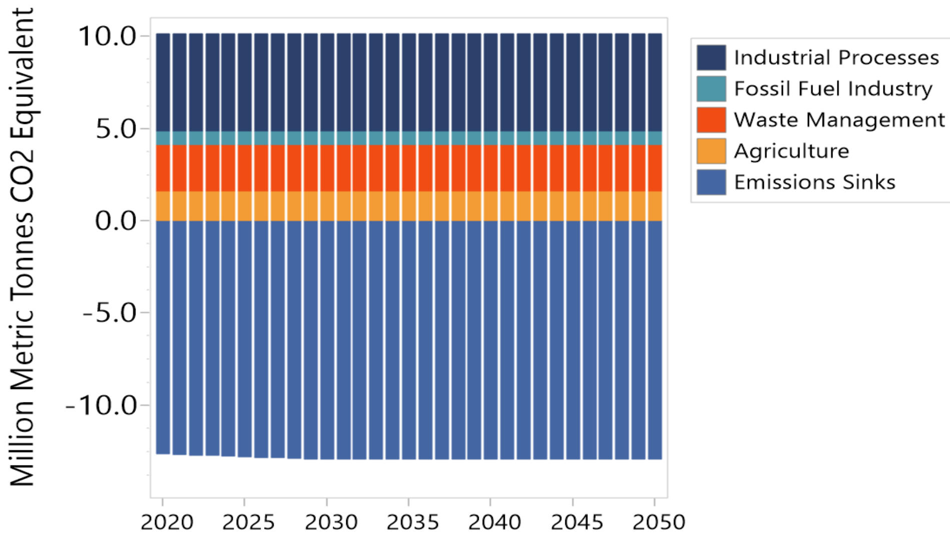

Figure 3-14. Non-Combustion Emissions in the Reference Scenario

The MWG Scenario achieves more GHG reductions than the 2030 GGRA Plan in forestry, soils, and agriculture.

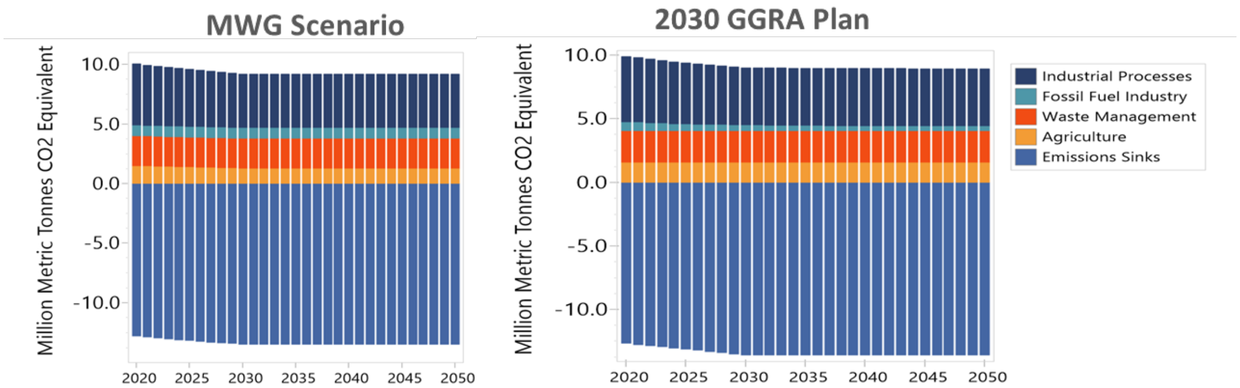

Figure 3-15. Non-Combustion Emissions in both policy scenarios

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 MWG Scenario

Table 4-1 shows the original measures and actions quantified from MDOT for the MWG Scenario. 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 PATHWAYS model.

Table 4-1. 2030 annual reductions of VMT and transportation fuel in the MWG Scenario (provided by MDOT)

"On-The-Books"				
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	26,431,915	HDV only	-	-

MTA rail projects including new locomotive technologies)				
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
"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	-	Urban Restricted - On-road fleet	9,353,658	678,303

(increased levels of enforcement)				
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 4-2 Description of MDOT strategies in the MWG Scenario

"On-The-Books"	
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 for 10% of development / redevelopment 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.

"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.

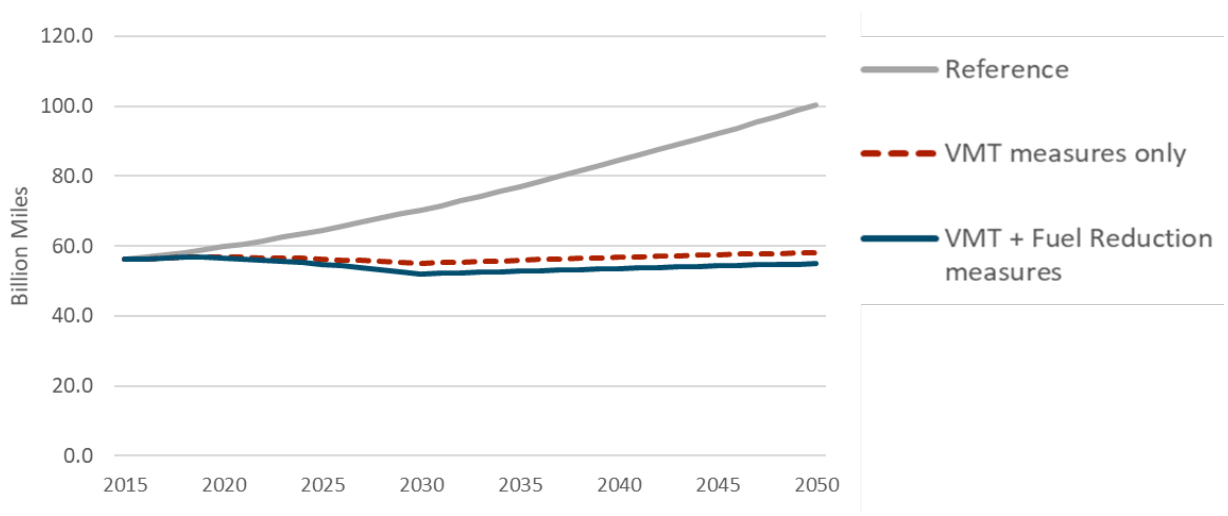

Figure 4-2. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, MWG Scenario

4.1.2 2030 GGRA Plan

Table 4-3 shows the original measures and actions quantified from MDOT for the 2030 GGRA Plan.

Table 4-3 2030 annual reductions of VMT and transportation fuel in the 2030 GGRA Plan (provided by MDOT)

"On-The-Books"				
Strategy	**VMT Reduction**	**VMT type**	**Fuel reduction (g gasoline)**	**Fuel reduction (g diesel)**
2018/2019 MPO Plans & Programs yield lower annual VMT growth (0.6%/yr)	4,875,000,000	On-road fleet		
On-Road Technology (Transportation System Management and Operations - CHART and other traffic management technologies)			14,523,134	1,248,264
Freight and Freight Rail Programs (National Gateway, Howard Street Tunnel, and MTA rail projects)	26,431,915	HDV only		
Public Transportation (new capacity, improved operations/ frequency, BRT)	41,280,947	LDV only		
Public Transportation (50% EV transit bus fleet)				
Intercity Transportation Initiatives (Amtrak NE	22,266,900	LDV only		

Corridor, Intercity bus)				
Transportation Demand Management	531,827,159	LDV only		
Pricing Initiatives (Electronic Tolling)			2,250,994	171,660
Bicycle and Pedestrian Strategies (Provision of non-motorized infrastructure including sidewalks and bike lanes)	88,267,500	LDV only		
Drayage Track Replacements				520,629
BWI Airport parking shuttle bus replacements				-
State Vehicle Fleet (Fleet Innovation Plan)			645,522	
"Emerging & Innovative Strategies"				
Strategy	**VMT Reduction**	**VMT type**	**Fuel reduction (g gasoline)**	**Fuel reduction (g diesel)**
TSMO/Integrated Corridor Management - Limited Access System		Urban Restricted Access VMT - On-road fleet	6,877,787	591,146
TSMO/Integrated Corridor		Urban Unrestricted	9,157,450	787,083

Management - Arterial System		Access VMT - On-road fleet		
Variable Speeds/Speed Management		Urban Restricted Access VMT - On-road fleet	1,024,702	88,073
Speed Management on Freeways (increased levels of enforcement)		Urban Restricted - On-road fleet	3,519,817	302,528
Autonomous/Connected Vehicle Technologies		On-road fleet	60,229,566	5,176,735
Intermodal Freight Centers Access Improvements		HDV only		127,063
Commercial Vehicle Technologies (Idle Reduction, Low-Carbon Fleet, Dynamic Routing)		HDV only		193,070
Zero-Emission Truck Corridors		HDV only		207,152
Freight Villages/Urban Freight Consolidation Centers		HDV only		190,876

Transit capacity/service expansion (fiscally unconstrained, including MTA, WMATA, LOTS, and other intercity providers)	70,072,669	LDV only		
MARC Growth and Investment Plan / Cornerstone Plan Completion	137,784,697	LDV only		
TOD Build-out (20 incentive zones)	119,886,091	LDV only		
50% to 75% EV Transit Bus Fleet		HDV only		615,214
Expanded TDM strategies - Dynamic ridesharing/mobility and non-work demand management	995,937,400	LDV only		
Expanded telework	2,075,495,906	LDV only		
Expanded bike/pedestrian system development	146,178,750	LDV only		

High-Speed Passenger Rail/SCMAGLEV	41,101,449	LDV only		
EV Market Share Ramp-up to Meet ZEV Mandate goals		LDV only	22,069,168	
Regional Clean Fuel Standard		On-road fleet	79,431,276	6,827,123
Eco-Driving		LDV and HDV	3,693,253	317,435
Pay-as-you-drive Insurance	447,805,289	LDV only	10,922,796	

Table 4-4 Description of MDOT strategies in the 2030 GGRA Plan

"On-The-Books"	
Strategy	**Description**
2018/2019 MPO Plans & Programs yield lower annual VMT growth (0.6%/yr)	Modeled VMT and emissions outcomes from implementation of most recent MPO fiscally constrained long-range transportation plans and cooperative land use forecasts.
On-Road Technology (Transportation System Management and Operations - CHART and other traffic management technologies)	Continuation of MDOT SHA's CHART program, Smart Traffic Signals within the Traffic Relief Plan, and ongoing implementation of SHAs TSMO Strategic Plan (2018) and TSMO Master Plan will expand the scope and coverage of advanced traffic management and information systems across Maryland roadways. These technologies help manage incidents and reduce congestion through traffic monitoring, incident management, travel information, communications, and traffic management.
Freight and Freight Rail Programs (National Gateway, Howard Street Tunnel, and MTA rail projects)	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, including rail double-stack service through the expanded Howard Street Tunnel.
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 not included in MPO modeling in the plans and

	programs. This includes North Avenue Rising, MD 355/MD586/US29 BRT in Montgomery County, and MARC reliability/park-and-ride/station improvements.
Public Transportation (50% EV transit bus fleet)	Applies to replacing MTA and WMATA bus fleets in Maryland (appx. 1,500 buses) to a 50% EV fleet by 2030 (consistent with MDOTs Fleet Innovation Plan).
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 and benefits created through 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 of all MDTA facilities 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 bicycle facility lane miles and improved bicycle level of comfort consistent with existing and planned infrastructure improvements, repaving, and new facilities highlighted in the 2020 - 2025 CTP and current SHA plans.
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.
State Vehicle Fleet (Fleet Innovation Plan)	Conversion of MDOT fleet (non-revenue vehicles) to EVs (initial focus on passenger vehicles only)
"Emerging & Innovative Strategies"	
Strategy	**Description**
TSMO/Integated Corridor Management - Limited Access System	This strategy assumes integrated corridor management , intelligent transportation systems, or advanced traffic

	management systems for urban restricted access roadways in the state
TSMO/Integrated Corridor Management - Arterial System	This strategy assumes corridor management , intelligent transportation systems, or advanced traffic management systems are in place on all urban arterials.
Variable Speeds/Speed Management	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.
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.
Autonomous/Connected Vehicle Technologies	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.
Intermodal Freight Centers Access Improvements	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 Technologies (Idle Reduction, Low-Carbon Fleet, Dynamic Routing)	Considers extended idling only and not short term idling (e.g. 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.
Zero-Emission 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
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)

Transit capacity/service expansion (fiscally unconstrained, including MTA, WMATA, LOTS, and other intercity providers)	Potential transit network improvements and expansions noted in BMC and MWCOG long-range plans, in addition to other projects with recent/ongoing planning. This includes the Southern Maryland Rapid Transit Study, Corridor Cities Transitway, additional BRT corridors in Montgomery County, and priority "Early Opportunity" corridors noted in the Central Maryland Regional Transit Plan.
MARC Growth and Investment Plan / Cornerstone Plan Completion	Improvements to MARC service include completion of the fourth track on the Penn Line to facilitate service expansion (which requires new Susquehanna and Bush River crossings and replacement of the B&P Tunnel); reduced peak headways, new midday service, and weekend service on the Camden Line (including expansion to three main tracks between Baltimore and Washington); increased service, longer trains, and expanded parking on the Brunswick Line; and, implementation of VRE-MARC Run-Through Service.
TOD Build-out (20 incentive zones)	Estimated TOD build-out across 20 locations totals 1an additional 36,000 households, each with an average VMT reduction of 33% to 56% based on average VMT savings by transit zone density.
50% to 75% EV Transit Bus Fleet	Applies to MTA and WMATA bus fleets in Maryland (appx. 1,500 buses)
Expanded TDM strategies - Dynamic ridesharing/mobility and non-work demand management	The TDM programs included in PS1 are broadly expanded consistent with a market-wide implementation of dynamic TDM programs including on-demand ride sharing/shared mobility/microtransit services plus greater market penetration of on-demand deliveries/services through autonomous/drone technologies.
Expanded telework	In light of COVID19 the share of people who are teleworking has seen a multi-fold increase compared to the levels a year ago. It has been a near unanimous opinion in the research literature reviewed for this strategy analysis that the increase in telework trends is going to be a long term phenomenon. There are different views about the share of people now teleworking under the COVID19 constraints who will remain to telework long after the impacts of the pandemic.

Expanded bike/pedestrian system development	Assumes VMT reductions due to availability of bicycle facility lane miles and improved bicycle level of comfort consistent with a 2x increase in existing and planned infrastructure improvements, repaving, and new facilities highlighted in the 2020 - 2025 CTP and current SHA plans.
High-Speed Passenger Rail/SCMAGLEV	Assumes build-out of the NEC Vision Plan (low range) by 2030 and NEC NextGen Plan and MAGLEV (high range)
EV Market Share Ramp-up to Meet ZEV Mandate goals	Additional 80,000 EVs by 2030, compared to the TCI projection included in the reference case, are required to reach the 540k ZEV mandate targets.
Regional Clean Fuel Standard	Consistent with TCI approach assuming a 15% clean fuel standard (applied to fuel consumption from remaining ICE fleet above and beyond RFS). Ultimately this strategy should be deployed as a regional approach for gasoline and diesel fuel.
Eco-Driving	Statewide commitment to a marketing and education program and voluntary adoptions by Maryland drivers, including private passenger vehicles and commercial vehicles (light, medium, and heavy-duty trucks).
Pay-as-you-drive Insurance	Range of 5 to 10% of licensed Maryland drivers use a pay-as-you-drive auto insurance premium by 2030.

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.

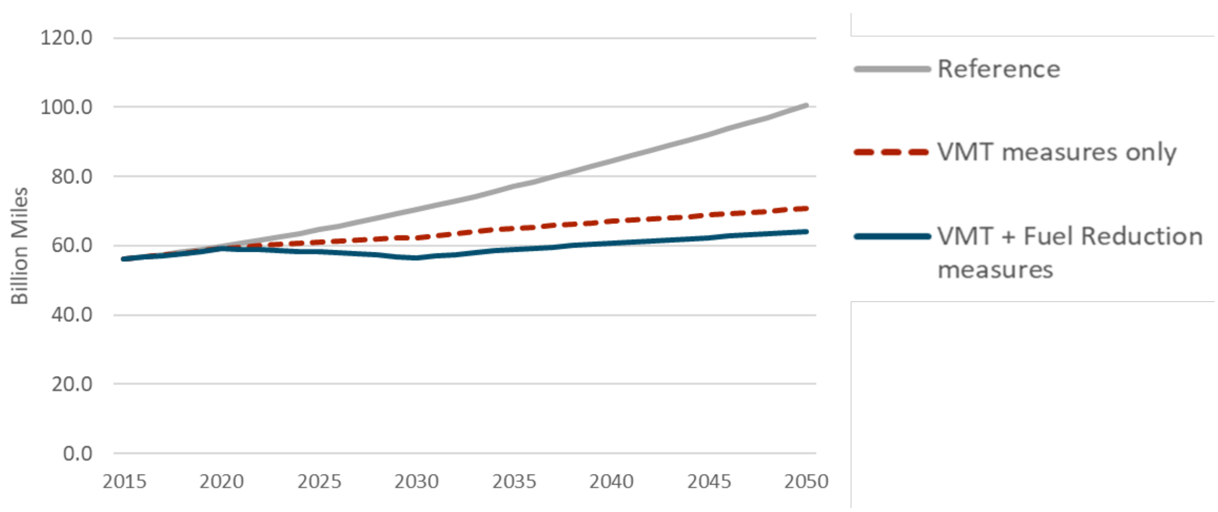

Figure 4-4. Effective VMT from direct VMT reductions and reduced fuel consumption modeled as VMT, 2030 GGRA Plan