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Maryland's Climate Pollution Reduction Plan: *Modeling Appendix*

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MARYLAND'S CLIMATE POLLUTION REDUCTION PLAN: MODELING APPENDIX

POLICIES TO REDUCE STATEWIDE GREENHOUSE GAS EMISSIONS 60% BY 2031 AND PUT MARYLAND ON A PATH TO ACHIEVE NET-ZERO EMISSIONS BY 2045

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1. GLOSSARY OF EMISSIONS CATEGORIES AND SECTOR TERMINOLOGY

Electricity Emissions
Biomass: Emissions from bio-based fuels for electricity power generation, excluding bio-based waste incineration which is accounted for in the *Waste Management* sector.
Coal: Emissions from coal combustion for electricity power generation.
Gas: Emissions from natural gas combustion for electricity power generation.
Oil: Emissions from fuel oil combustion for electricity power generation.
Imported: Emissions associated with imported electricity into Maryland, calculated using an average emissions intensity for states in the PJM interconnection. Maryland is a net importer of electricity, meaning that the State consumes more electricity than is produced in the State. For this analysis, it was assumed that all power generated in Maryland was consumed in Maryland, and that remaining electricity demand was met by imported power from the PJM interconnection.

Transportation Emissions
Aviation: Emissions from aviation fuel combustion arising from fuel sold in Maryland.
Lubricants, Natural Gas, and LPG: Emissions from fuel combustion for non-road mobile transportation sector fuels including Lubricants (from fuel oil combustion), Natural Gas, and Liquefied Petroleum Gas (LPG) for the production of solvents and synthetic rubber.
Marine: Emissions from combustion of fuels supplied to commercial marine vessels and recreational marine equipment.
Nonroad Diesel: Emissions from fuel combustion for nonroad diesel mobile transportation sources that do not normally operate on public roadways including construction equipment, mining equipment, etc.
Nonroad Gas: Emissions from fuel combustion for nonroad gasoline mobile transportation sources that do not normally operate on public roadways including lawn and garden equipment, commercial equipment, recreational vehicles, etc.
Road: Emissions from fuel combustion for vehicles that traditionally operate on public roadways including cars, light-duty trucks, motorcycles, vans, buses, and freight trucks.

Buildings Emissions
Biomass: Emissions from bio-based fuels from energy consumption in the buildings sector. In Maryland, this is primarily wood combustion.
Coal: Emissions from coal combustion in the buildings sector. As of the 2020 inventory, coal use in commercial and residential buildings has been eliminated in Maryland.
Commercial: Emissions from an energy-consuming sector that consists of service-providing facilities and associated equipment.
Gas: Emissions from natural gas combustion in the buildings sector.
Oil: Emissions from fuel oil combustion in the buildings sector.
Residential: Emissions from an energy-consuming sector that consists of living quarters for private households including multi-family and rental housing.

Industry Emissions
Biomass: Emissions from bio-based fuels combustion for industry are calculated by multiplying fuel consumption by a carbon content coefficient. In Maryland, this is primarily wood.
Coal: Emissions from coal combustion in industry.
Gas: Emissions from natural gas combustion in industry.

Oil: Emissions from fuel oil combustion in industry.

Industrial Processes and Product Use Emissions

Cement: Process-related greenhouse gas (GHG) emissions from cement production due to clinker production and finish grinding. These emissions are not due to fuel combustion (which is included in the "Industry" sector), but from chemical processes.

Electricity Transmission and Distribution: Emissions of sulfur hexafluoride (SF_6) used in electrical transmission and distribution equipment. Emissions from electric power transmission and distribution are calculated by multiplying the quantity of SF_6 consumed by an emission factor which includes estimates of leakage.

Iron and Steel: Emissions from iron and steel production from process-based sources, excluding fuel combustion-based emissions. Iron and steel production in Maryland ended in 2012 with the closure of the last steel plant in the state.

ODS Substitutes: Emissions of Hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs) used as substitutes for ozone depleting substances (ODS). The majority of emissions come from cooling and refrigeration equipment, solvents in various industrial processes, and as blowing agents for making insulating foams.

Other: Combined emissions from limestone and dolomite, soda ash, and ammonia and urea production for non-fertilizer usage.

Ammonia and Urea Production (Non-fertilizer Usage): Emissions from the release of carbon dioxide from ammonia and urea production. The majority of emissions associated with ammonia and urea production and consumption comes from fertilizer usage but this section accounts for emissions from non-fertilizer usage.

Limestone and Dolomite: Emissions from limestone and dolomite use for industrial purposes other than cement production. The primary source of emissions from limestone consumption is the calcination of limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) to create lime (CaO). Limestone is heated during these processes, generating carbon dioxide as a byproduct.

Soda Ash: Emissions from soda ash manufacturing and consumption. Commercial soda ash (sodium carbonate) is used in many familiar consumer products, such as glass, soap and detergents, paper, textiles, and food. Most soda ash is consumed in glass and chemical production. Other uses include water treatment, flue gas desulfurization, soap and detergent production, and pulp and paper production. Carbon dioxide is also released when soda ash is consumed.

Fossil Fuel Industry Emissions

Coal: Emissions from the coal mining industry within Maryland, including from underground mines, surface mines, abandoned coal mines, and post-mining activities such as transportation and coal handling. Emissions are primarily due to methane emitted from ventilation systems and degasification systems.

Gas: Emissions from the natural gas industry include emissions from production, transmission, and distribution. Maryland emissions are primarily due to consumption and leakage for services in transmission and distribution, as well as venting and flaring.

Waste Management Emissions

Incineration: Emissions produced during municipal solid waste combustion in incinerators or waste to energy plants or open burning of waste.

Landfills: Emissions from waste decomposition at municipal and industrial solid waste landfills, accounting for both fugitive and flared methane, and captured methane that is combusted for energy production (this includes both open and closed landfills).

Wastewater: Methane and nitrous oxide emissions from municipal wastewater treatment and wastewater created during industrial processes.

Agriculture Emissions
Agricultural Burning: Emissions from agricultural burning are calculated by multiplying the amount of crop produced by a series of factors to calculate the amount of crop residue produced and burned, the resultant dry matter, and the carbon/nitrogen content of this dry matter.
Agricultural Soils: Emissions from fertilizer application, animal wastes, and plant residues used in the management of agricultural soils.
Enteric Fermentation: Emissions (primarily methane) from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock that emit methane as a byproduct. Emissions from Enteric Fermentation are calculated by multiplying each animal population by an animal- and region-specific emission factor.
Manure Management: Emissions (primarily methane) produced by the anaerobic decomposition of the organic matter in manure. Emissions estimates from manure management are based on manure that is stored and treated at livestock operations.
Urea Fertilizer Usage and Liming: Emissions from urea fertilizer, limestone and dolomite application (liming) to agriculture soils. Applying these substances to agricultural soils generates carbon dioxide emissions.

Forestry and Land Use Emissions
Agricultural Soil Carbon: Emissions from agricultural soil carbon depend on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of carbon into agricultural soils.
Forest Fires: Methane and nitrous oxide emissions from biomass burned in forest fires. Carbon dioxide emissions from forest fires are inherently captured under total forest carbon flux calculations, so they are not included here.
Settlement Soils: Emissions from fertilization of settlement and forest soils. Settlement soils include all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.
Tree and Forest Carbon: The forest carbon flux is the sum of the fluxes for above- and below-ground biomass, dead wood, litter, soil organic carbon, and wood products in use and in landfills. As carbon is also sequestered through trees in urban areas, tree carbon emissions also include changes in urban tree carbon stocks by calculating tree growth minus biomass losses resulting from pruning and mortality. As trees die or drop branches and leaves on the forest floor, decay processes will increase soil carbon.
Wetlands and Submerged Aquatic Vegetation (SAV): Emissions from coastal wetlands, flooded lands, and submerged aquatic vegetation are the balance of carbon sinks and methane releases.
Wood Products and Landfilled Carbon: Emissions from carbon stored in harvested wood products, such as lumber, furniture and other durable wood products, as well as wood products disposed of in landfills that do not decay completely.

Electricity Generation Technologies
Biomass: Electricity production from biomass inclusive of both conventional steam turbines and integrated gasification combined cycle (IGCC) systems.
Biomass with CCS: Electricity production from biomass inclusive of both conventional steam turbines and integrated gasification combined cycle (IGCC) systems. Resulting carbon dioxide emissions are captured with a capture rate that gradually improves over time (to 88% in 2045).

Coal: Electricity production from both conventional pulverized coal power plants utilizing steam turbines and integrated gasification combined cycle systems.
Coal with CCS: Electricity production from both conventional pulverized coal power plants utilizing steam turbines and integrated gasification combined cycle systems. Resulting carbon dioxide emissions are captured with a capture rate that gradually improves over time (to 88% in 2045).
Gas: Electricity production from natural gas through both conventional steam turbines and combined cycle turbines.
Gas with CCS: Electricity production from natural gas through both conventional steam turbines and combined cycle turbines. Resulting carbon dioxide emissions are captured with a capture rate that gradually improves over time (to 88% in 2045).
Hydro: Electricity generation from hydropower.
Nuclear: Electricity generation from second generation light water reactors. In Maryland this is solely the two reactors at Calvert Cliffs.
Oil: Electricity production from refined liquids through both conventional steam turbines and combined cycle turbines. Refined liquids are primarily oil, but may also include liquified natural gas or coal, and bio-based liquid fuels.
Solar: All solar-powered electricity generation technologies, including grid-based and rooftop solar photovoltaics, and concentrated solar thermal power. Some generation may also include dedicated energy storage.
Wind - onshore: Electricity generation from commercial-scale wind turbines on land. Some generation may also include dedicated energy storage.
Wind - offshore: Electricity generation from commercial-scale wind turbines off-shore.
Imported: Electricity consumed in Maryland in excess of what is generated within Maryland, assumed to be generated within the states included in the PJM interconnection.

Transportation Sector
Aviation: Passenger transportation in the aviation sector, including conventional fossil-fuel powered flight as well as battery electric and hydrogen powered aircraft in future years.
Bus and Rail: Bus has 5 separate technologies (all those under car as well as natural gas powered buses). Rail in this case refers to traditional passenger rail and high-speed rail, including both fossil-fuel powered rail and electric trains.
Car: Passenger transportation in cars, not inclusive of SUVs. Vehicle types include standard vehicles with an internal combustion engine that runs on liquid fuels, hybrid vehicles, hydrogen-powered fuel cell electric vehicles, and battery electric vehicles.
Electric vehicle: Inclusive of both battery electric vehicles and hydrogen powered fuel cell electric vehicles.
Freight Rail: Freight transportation on trains with different engine types including internal combustion, hybrid, fuel cell electric, and battery electric.
Freight transportation: All transportation associated with moving freight and shipping material, as opposed to moving people (passenger transportation).
Heavy Truck: Freight transportation in Class 7-8 vehicles. Vehicle types include standard vehicles with an internal combustion engine that runs on liquid fuels, hybrid vehicles, hydrogen-powered fuel cell electric vehicles, and battery electric vehicles.
Light Truck: Freight transportation in Class 1-3 vehicles. Vehicle types include standard vehicles with an internal combustion engine that runs on liquid fuels, hybrid vehicles, hydrogen-powered fuel cell electric vehicles, and battery electric vehicles.

Medium Truck: Freight transportation in Class 4-6 vehicles. Vehicle types include standard vehicles with an internal combustion engine that runs on liquid fuels, hybrid vehicles, hydrogen-powered fuel cell electric vehicles, and battery electric vehicles.
Motorcycle: All 2 and 3-wheeled vehicles fall under this category, with two technologies (battery electric and standard internal combustion engines) included. This is strictly passenger transportation.
Passenger transportation: Broad categorization that includes all transportation of people rather than freight. It includes aviation, bus and rail, car, SUV and truck, motorcycle, and walking and biking.
Shipping: Marine shipping of freight cargo.
SUV and Truck: Passenger transportation in large cars (SUVs) and trucks. Vehicle types include standard vehicles with an internal combustion engine that runs on liquid fuels, hybrid vehicles, hydrogen-powered fuel cell electric vehicles, and battery electric vehicles. Vehicles with engine displacement of approximately 3.5L fall under this category.
Vehicle miles traveled: The distance cumulatively traveled by vehicles of a given classification. It does not account for the number of people in each vehicle.
Walk and Bike: Passenger transportation via walking or cycling.
Zero Emission Vehicle: Vehicles with zero emissions during normal transport operations, including battery electric vehicles and fuel cell electric vehicles.

General Terms
Biomass Liquids: Any liquid fuel derived from bio-based sources, including ethanol, Fischer-Tropsh derived biofuels, bio-diesel, etc.
Fossil Liquids: Primarily refers to oil, but may also include small amounts of liquified natural gas or coal.
Global Warming Potential (GWP): The ratio of how much energy 1 ton of a greenhouse gas will absorb relative to 1 ton of CO_2 over a given time period. Larger GWP's indicate a stronger warming impact from the non-CO_2 greenhouse gas.
Compact Development: Housing development measured according to the following formula

$$Share\ multi\ family\ housing\ + (Share\ single\ family\ housing * \%\ in\ PFA * \%\ on\ small\ parcels)$$

2. GCAM-USA-CGS

The estimates of economy-wide emissions reductions in this analysis are based on a version of the Global Change Analysis model (GCAM) with a detailed representation of the U.S. energy system at the state level (GCAM-USA). We refer to the version of GCAM-USA used in this study as GCAM-USA-CGS.

The global version of GCAM is an open-source Integrated Assessment Model (IAM) that represents the energy and economic systems for 32 geopolitical regions, including the United States.[1] GCAM represents land use and agriculture in 384 land regions nested within 235 water basins. GCAM tracks emissions of a range of greenhouse gases (GHGs) and air pollutants from energy, agriculture, land use, and other systems.

GCAM-USA is a version of GCAM that disaggregates the U.S. energy and economy components into 50 states and the District of Columbia while maintaining the same level of detail in the rest of the world and for water and land sectors. The energy system formulation in GCAM-USA consists of detailed representations of depletable primary sources such as coal, gas, oil, and uranium, in addition to renewable resources such as bioenergy, hydropower, wind, and geothermal.

GCAM-USA also includes representations of the processes that transform these resources into final energy carriers, such as oil refining and electric power. These energy carriers, in turn, are used to deliver services to end users in the buildings, transportation, and industrial sectors. The electric power sector includes representations of a range of power generation technologies, including those fueled by fossil fuels, renewables, bioenergy, and nuclear power.

GCAM-USA is a market equilibrium model. The equilibrium in each period is solved by finding a set of market prices such that supplies and demands are equal to one another in all markets as the actors in the model adjust the quantities of the commodities they buy and sell. GCAM operates in 5-year time-increments, with each new period starting from the conditions that emerged in the last. GCAM-USA tracks flows of energy carriers, ensuring that energy supply and demands are met globally and regionally. Most end-use technologies, such as cars, building technologies, and electricity generation units, are tracked in vintages, with equipment that is retired in each period replaced with new equipment plus additional capacity needed to supply any increase in demand.

GCAM-USA-CGS is based on the open-source release of GCAM-USA 6.0.[1] GCAM-USA-CGS has been modified for the purposes of this study, for example, to reflect the latest renewable energy costs and vehicle technology costs. It is also calibrated to the latest non-CO_2 marginal abatement cost curves from the U.S. Environmental Protection Agency.[2]

2.1. OVERVIEW OF MODELING APPROACH FOR USA AS A WHOLE

Given the scope of this project, we focused on modeling detailed and specific policies for Maryland, though the starting point for our model set-up also includes high-level policies for other states. This overall USA set-up is summarized in this section. To develop our modeled scenarios, we used bottom-up aggregation tools and data analysis to evaluate and quantify the impacts of policies and climate actions in isolation and within specific sectors. We then used this information in GCAM-USA-CGS to estimate the economy-wide implications of these associated policies. The overall modeling approach used was consistent with previous analysis, including Accelerating America's Pledge (2019), An All-In Climate Strategy Can Cut U.S. Emissions by 50% by 2030 (2021), Blueprint 2030 (2021), and An All-In Pathway to 2030: The Beyond 50 Scenario (2022).[3-6]

The modeled scenarios were produced by changing parameters in GCAM-USA-CGS, either directly or based on information from bottom-up aggregation analysis. For several policy drivers included in the analysis, bottom-up aggregation was either not feasible or not required given the relatively small scale of potential impacts. Impacts of policies on activity drivers were directly implemented into GCAM-USA-CGS. In Maryland, for example, Maryland's EV sales targets were modeled by designating a certain percentage of new vehicles as EVs for each model year, though this impact could be effected through a number of bottom-up policy measures including state- and city-level incentives and rebates for consumers, and from recent policies enabled by new spending unlocked from the Inflation Reduction Act (IRA) of 2022.

By contrast, nuclear capacity retention is an example of a policy lever that was explicitly modeled using a more bottom-up approach. Nuclear power plants at risk of retirement before 2030 were identified on a state-by-state basis. In Maryland, we also assumed that Calvert Cliffs Units 1 and 2 would be relicensed again for continued operation through 2050. This assessment was then translated to state-level capacity and generation values by year, which were integrated into GCAM-USA-CGS.

All policies explicitly included in the analysis were modeled at the state and/or national levels. City, business, and institution-based policies were aggregated at the state level or assumed to be embedded within or supportive of the national and state policies and, therefore, not explicitly modeled to remove risk of double-counting. As an example of state-level aggregation, the impacts of renewable targets from states, cities, and electric power utilities were aggregated together at the state level, with city and utility targets being counted as additional in situations where a higher percentage of renewable generation was targeted by the smaller-scale entity. More details on specific policies can be found in Supplementary Tables 2-7.

2.2. THE CURRENT POLICIES SCENARIO

In our Current Policies scenario, we modeled existing policies in Maryland and other states, as well as federal actions, including many of the climate-related provisions from the Bipartisan Infrastructure Legislation (BIL) and the recently enacted IRA. Existing policies in Maryland are defined as all on-the-books policies, including those which are not yet implemented but will be implemented based on legislative mandates. A full list of the IRA provisions and Maryland policies and assumptions that we modeled is shown below. Additionally, detailed modeling assumptions for all policies are shown in Supplementary Tables 1-8. Details on overall emissions reductions in the U.S. as a result of current policies, including the IRA, can be found in our Beyond 50 report.[4]

2.2.1. MODELED IRA POLICIES

Electricity Sector

- Section 13101 – Production tax credit (PTC) extension
- Section 13102 – Investment tax credit (ITC) extension
- Section 13015 – PTC for existing nuclear
- Section 13302 – Residential clean energy credit
- Section 13701 – New clean electricity PTC
- Section 13702 – New clean electricity ITC

- Section 50144 – Energy community reinvestment financing
- Section 13104 – 45Q: extension of credits for captured CO_2

Transportation Sector

- Sections 13201/13202 – Extension of incentives for biofuels
- Section 13203 – Sustainable aviation biofuels
- Section 13401 – Clean vehicle credit
- Section 13403 – Commercial clean vehicle credit
- Section 13404 – Alternative refueling property credit
- Section 13704 – Clean fuel PTC

Buildings Sector

- Section 13301 – Energy efficient home improvement credit
- Section 13303 – Energy efficient commercial building deduction
- Section 13304 – Energy efficient home credit
- Section 50121 – Home energy efficiency credit
- Section 50122 – High efficiency home rebate program

Industry and Other Sectors

- Section 13204 – 45V: production credits for clean hydrogen
- Section 60113 – Methane emissions reduction program

2.2.2. MODELED MARYLAND-SPECIFIC POLICIES/ASSUMPTIONS

Electricity Sector

- Renewable Portfolio Standard
- Regional Greenhouse Gas Initiative
- Planned coal retirements
- Relicensing of nuclear power plants

Transportation Sector

- Advanced Clean Cars II
- Advanced Clean Trucks
- 100% electric bus sales for school and transit buses
- Vehicle miles traveled reduction policies

Buildings Sector

- EmPOWER energy efficiency standards
- Building Energy Performance Standards

Industry and Other Sectors

- Natural gas methane regulations
- HFC regulations
- Landfill methane regulations

2.3. THE CURRENT + PLANNED POLICIES SCENARIO

Maryland's existing policies, combined with existing federal policies and actions from other states, collectively provide a major boost to climate action in the state. Yet these policies will not be enough on their own for Maryland to meet its 2031 and 2045 climate targets. Our analysis finds that these targets can be met through new and enhanced policies in Maryland. Thus, Current + Planned Policies scenario models a comprehensive climate strategy with additional actions in Maryland that allow it to achieve a 60% reduction in GHG emissions from 2006 levels in 2031, and net zero by 2045. A sector-by-sector breakdown of the results for the Current + Planned Policies scenario is shown in Supplementary Table 10 alongside results from the Current Policies scenario. The modeling assumptions underlying these scenarios are listed in Supplementary Tables 1-8.

2.3.1. ADDITIONAL MODELED MARYLAND-SPECIFIC POLICIES

Electricity Sector
- Clean Power Standard of 100% by 2035
- Regional Greenhouse Gas Initiative target of zero by 2035

Transportation Sector
- Advanced Clean Fleets
- Additional vehicle miles traveled reduction policies

Buildings Sector
- Zero-emission heating equipment standards
- Zero-emission construction standards
- Extended energy efficiency standards
- Clean Heat Standard

Industry and Other Sectors
- Fuel switching for cement and other industry
- Methane reductions with marginal abatement cost curves for gas, waste and agriculture

Economy-Wide
- Economy-wide cap and invest policy to achieve remaining emission reductions (with exemption for certain sectors)

Supplementary Table 1. Representation of Policies for the Electricity Sector in GCAM-USA-CGS

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Current + Planned Policies Scenario
Maryland	Renewable/clean energy targets	The current Renewable Portfolio Standard (RPS) target of 50% by 2030 is modeled, with the target held constant after 2030. Other state and local-level incentives and policies for deploying renewables are assumed to be supportive of this goal. This was implemented by setting a minimum % of total electricity load to be met by renewable generation.	A Clean Power Standard (CPS) of 100% by 2035 is modeled. This was implemented by setting a minimum % of total electricity load to be met by zero/low-emissions sources of generation, including renewable energy, nuclear, biomass, and natural gas CCS. This standard was also assumed to apply to emissions from imported electricity through mechanisms such as time-matched renewable energy certificates (RECs).
	Regional Greenhouse Gas Initiative	The current Regional Greenhouse Gas Initiative (RGGI) target of 30% emissions reductions below 2020 levels by 2030 is modeled. This was implemented by setting an emissions constraint in the power sector for RGGI states, with a linear interpolation between 2020 and 2030, with the target held constant after 2030.	The RGGI target is strengthened to reach zero emissions by 2035. This was implemented by setting an emissions constraint in the power sector for RGGI states, with a linear interpolation between 2020 and 2035.
	Coal power retirement	We assume the achievement of all planned and announced retirements of coal-fired power plants in Maryland. This was implemented by setting a constraint on coal power generation to reach zero by 2025.	
	Nuclear power retainment	We assume the existing Calvert Cliffs units 1&2 are relicensed again after 2034 and 2036. This was implemented by maintaining nuclear generation at today's levels through 2050.	
Federal – IRA	Section 13101: Production tax credit (PTC)	Modeled as a $26/MWh subsidy for solar, wind, geothermal and biomass technologies through 2024. We assume that all projects pay prevailing wages. A 7.5% reduction in the credit value is assumed due to the transferability provision.	
	Section 13102: Investment tax credit (ITC) extension	Modeled as a 30% subsidy for offshore wind and storage technologies through 2024, with the simplifying assumption that all projects pay prevailing wages. A 7.5% reduction in the credit value is assumed due to the transferability provision.	
	Sections 13701 and 13702: New clean electricity PTC and ITC	Modeled in the same way as sections 13101 and 13102 through 2030, with phasedown after 2030.	
	Section 13302: Residential clean energy credit	Modeled by updating the rooftop ITC, which results in an additional 0.7GW/yr increase in electricity generation from rooftop PV, with phasedown after 2030.	
	Section 13015: PTC for existing nuclear	Modeled as a $15/MWh subsidy for nuclear technologies through 2030, with the simplifying assumption that all projects pay prevailing wages. We assume that these incentives, in combination with non-federal incentives and zero-emission credits, prevent the	

		economic retirement of nuclear plants. As such, we model Georgia Vogtle units 3&4 coming online by 2025, and maintain nuclear capacity at today's levels.	
	Section 50144: Energy community reinvestment financing	Modeled as $250 billion in loans and guarantees used to accelerate the retirement of coal-fired power generation and fund the construction of renewable electricity-generating capacity. Our central estimate is that this will accelerate the retirement of 38 GW of additional coal-fired capacity beyond already-scheduled retirements by 2030.	Coal is phased out by 2030 due to a combination of market forces, state coal-exit policies, and regulatory compliance costs. This was modeled by setting a national constraint on coal power to reach zero by 2030, and by prohibiting the buildout of new coal plants in all states.
	Section 13104 - 45Q: Extension of credits for captured CO_2	Extension of existing credits for captured CO_2 at $85/ton is implemented through 2030. We assume this subsidy will result in sequestration levels consistent with analyses by Rhodium Group and Edmonds et al.[7,8] We modeled this exogenously by specifying sequestration for coal CCS and gas CCS, resulting in 130 $MMTCO_2$ annual sequestration nationally by 2030, which is held constant through 2050. In Maryland, gas CCS is introduced in 2035 at 0.6 $MMTCO_2$ annual sequestration, which is held constant through 2050.	
Other States	Renewable energy targets	Current state-level RPS targets are modeled. City- and utility-level goals were assumed to be supportive of these state-level targets and additional only in cases where a higher percentage is targeted. These were implemented by setting a minimum % of total electricity load to be met by renewable generation.	

Supplementary Table 2. Representation of Policies for the Transportation Sector in GCAM-USA-CGS

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Current + Planned Policies Scenario
Maryland	LDV ZEV sales mandates and targets	The Advanced Clean Cars II sales targets are modeled, reaching 15% EV sales by 2025, 54% by 2030, and 100% by 2035. The 2030 sales percentage was estimated by taking ACC II sales target and accounting for program flexibilities (historical credits, early compliance credits, EJ credits), and the 2025 sales percentage was estimated by interpolating between current reality and the 2030 sales percentage based on California's EV sales growth curve. Other state and local-level incentives and policies for purchasing EVs are assumed to be supportive of this goal. This was implemented by fixing the percentage of new EV sales for each model period.	
	Freight truck ZEV sales mandates and targets	The Advanced Clean Trucks sales targets are modeled, reaching 7-11% EV sales by 2025, 30-50% by 2030, and 40-75% by 2035, depending on truck type. Other state and local-level incentives and policies for purchasing EVs are assumed to be supportive of this goal. This was implemented by fixing the percentage of new EV sales for each model period.	An Advanced Clean Fleets policy of 100% EV sales by 2045 is modeled. This policy is assumed to be supportive of Advanced Clean Trucks in model years 2030 and 2035.

<table>
<tr><td></td><td>Bus ZEV incentives and sales targets</td><td colspan="2">Transit and school buses achieve 100% electric sales by 2025, based on the Maryland Zero Emission Bus Transition Act Legislative Report and the CSNA.[9,10] All other buses follow Advanced Clean Trucks sales targets.</td></tr>
<tr><td></td><td>Vehicle miles traveled (VMT) reductions</td><td>As a result of the recovery after COVID, VMT grows at an average annual rate of 2.7% between 2020 and 2025. After 2025, VMT grows at an average annual rate of 1.3% between 2025 and 2030. In the period 2020-2030, VMT grows by 2% per year on average. This is in line with Maryland Department of Transportation's analysis for Maryland's Greenhouse Gas Reduction Act, and draft analysis provided for this report.[11]

VMT reductions are modeled as reductions in passenger-miles traveled and ton-miles traveled. These units represent the transportation of a single person/ton over a single mile and are not equivalent to VMT. However, the percentage changes between model years can be interpreted in terms of percentage change in VMT. Passenger-miles and ton-miles can be converted into VMT by using assumptions on the average number of people/tons transported and the average miles traveled by each vehicle type.</td><td>As a result of the recovery after COVID, VMT grows at an average annual rate of 2.7% between 2020 and 2025. After 2025, the annual average VMT reduction rate of 0.67% from the Pathway analysis was maintained through 2030 for the present scenario on the basis of the state's prior GHG plan (2030 GGRA Plan) having transportation strategies that achieve a comparable rate of VMT reduction for the same period when fuel reduction strategies are credited. Quantification of Maryland's updated transportation strategies was not available at the time of the present modeling. In the period 2020-2030, VMT grows by 1% per year on average.

The VMT trajectory beyond 2030 was also maintained from the Pathway analysis (0.9% annual average VMT reduction rate between 2030 and 2045) on the basis of MDOT's Maryland Transportation Plan objective of reducing VMT per capita by 20%, and reflects a sustained level of funding.[12]

VMT reductions are modeled as reductions in passenger-miles traveled and ton-miles traveled. These units represent the transportation of a single person/ton over a single mile and are not equivalent to VMT. However, the percentage changes between model years can be interpreted in terms of percentage change in VMT. Passenger-miles and ton-miles can be converted into VMT by using assumptions on the average number of people/tons transported and the average miles traveled by each vehicle type.</td></tr>
<tr><td>Federal – IRA</td><td>Section 13401 - 30D: Clean vehicle credit</td><td colspan="2">This tax credit has a maximum value of $7,500 with an EV being eligible for half of the credit if its battery meets domestic assembly requirements and other half of the credit is contingent upon a specific share of the minerals used in the battery being sourced for North American or other free trade countries. We assume that the US auto manufacturing sector will reorient itself so that all new EVs produced by 2030 will meet these requirements, and that by 2025, half of EVs sold will meet these requirements. If the car meets the battery assembly and mineral sourcing requirements, a consumer can receive the full value of the tax credit provided that their income does not exceed the income eligibility threshold and that the sales price of the car does not exceed MSRP eligibility thresholds. We find that 89% of Americans meet the income requirement and further assume that they would only purchase EVs that meet the MSRP threshold. Altogether, this yields</td></tr>
</table>

		an EV tax credit with an effective value of $6,673, implemented as a capital cost reduction. We assume that for the 2031-2035 model period that the tax credit takes on a value 40% of the 2030 value because it is scheduled to expire in 2032.
	Section 13404: Alternative refueling property credit	This credit is assumed to be a $1,000 property credit available for LDV charging infrastructure for individuals in rural and low-income census tracts. Based on census data, 17.4% of Americans live in counties that are either rural or low-income, so the $1,000 property credit is modeled as a weighted average national subsidy of $174 for capital infrastructure cost for EVs. We assume that for the 2031-2035 model period that the tax credit takes on a value 40% of the 2030 value because it is scheduled to expire in 2032.
	Section 13403 - 45W: Commercial clean vehicle credit	This tax credit is modeled as a $40,000 capital cost reduction for electric heavy duty freight trucks, and a $7,500 capital cost reduction for electric medium duty and light duty freight trucks. We assume that for the 2031-2035 model period that the tax credit takes on a value 40% of the 2030 value because it is scheduled to expire in 2032.
	Sections 13201, 13202, and 13203: Extension of incentives for biofuels	Implemented as subsidies in 2025 for biodiesel, cellulosic ethanol, FT biofuels, cellulosic ethanol with CCS, and FT biofuels with CCS. We assume that jet fuel is the first market for FT biofuel, and FT biofuels therefore receive the aviation fuel credit.
Federal – BIL	Section 11401 and 11403: Grants from charging and fueling infrastructure, Carbon reduction program, and National Electric Vehicle Formula Program	We assume BIL allocates $10.7 billion investment to LDV EV charging infrastructure**.** This is implemented as an $802 reduction in per vehicle charging infrastructure cost, based on modeled vehicle fleet size in GCAM-USA-CGS 6.0, for model periods 2025 and 2030.
	Section 11115 and 11403: Congestion mitigation and air quality improvement program, and Carbon reduction program	We assume BIL allocates $4.24 billion investment to medium- and heavy-duty truck EV charging infrastructure. This is implemented as a $9,211 reduction in per vehicle charging infrastructure cost, based on fleet size in GCAM-USA-CGS 6.0, for model periods 2025 and 2030.
	Sections 71101 and 30018: Clean school bus program and Grants for buses and bus facilities	BIL's $5 billion investment in school bus electrification is implemented as a $25,000 reduction in per vehicle purchase cost for model periods 2025 and 2030. A $2.6 billion investment in transit bus electrification is implemented as a $29,167 reduction in per vehicle purchase cost for model periods 2025 and 2030.
Federal – Regulations	CAFE standards for LDVs	Internal combustion engine GHG performance standards are modeled to reflect efficiency improvement rates from recently updated Corporate Average Fuel Economy standards so that nationally, fuel efficiency reaches 166 gCO_2/mi for new passenger cars and 219 gCO_2/mi for new SUVs by 2030. Note: these are based on the NHTSA minimum standard and are not inclusive of ZEVs.

Other	Electrification of nonroad gas and diesel	No emissions reductions from Nonroad Gasoline and Nonroad Diesel sources were assumed under Current Policies. Both remain constant at 2020 levels through 2050.	Nonroad gasoline emissions were assumed to reduce to 50% of 2020 levels by 2050, declining linearly from 2025. This assumption was based on regulations and trends expected to impact the market for relevant technologies in Maryland. These include local regulations (e.g., Montgomery County[13] and Washington D.C[14] regulations on leaf blowers) and regulations in other states (e.g., California's regulation on small off-road engines[15]). Rapid electrification of nonroad gasoline usage is also supported by industry projections for the lawncare sector, which accounts for the majority of emissions. Nonroad diesel emissions are assumed to electrify more slowly, declining linearly from 2025 to achieve 25% reduction in emissions relative to 2020 by 2050. Nonroad diesel is primarily used in heavy equipment such as construction or mining and is therefore expected to be more difficult to electrify than nonroad gasoline. The small reduction in emissions included here is assumed to be driven by spillover effects from heavy trucking, which would require similar technologies to decarbonize.

Supplementary Table 3. Representation of Policies for the Buildings Sector in GCAM-USA-CGS

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Current + Planned Policies Scenario
Maryland	Energy efficiency standards	Current state-level energy efficiency resource standards for building electricity under EmPOWER were modeled at 2.25% in 2025 and 2.5% in 2030 by reducing residential and commercial building electric service demands. This assumption was applied to all residential and building floorspace.	Energy efficiency resource standards under EmPOWER are extended at 2.5% in electricity annual savings through 2050 by reducing residential and commercial building electric service demands. This assumption was applied to all residential and building floorspace.
	Electrification	Maryland's Building Energy Performance Standards are modeled, with associated reductions in electricity consumption due to the proposed energy use intensity targets in line with Lawrence Berkeley National Lab's (LBNL's) analysis.[16] This was implemented by increasing the share of electricity so that half of commercial floorspace (i.e. the estimated floorspace covered by BEPS) would reach net-zero by 2040.	A zero-emissions heating equipment standard is modeled by having appliance sales for space heating and hot water heating reach 100% electric by 2030. A zero-emissions construction standard is layered on top of this policy by having all appliance sales for new construction reach 100% electric by 2030, with the assumption that half of the appliance sales are for new buildings. A Clean Heat Standard is used to achieve the remaining emissions reductions needed in the buildings sector, based on the economy-wide reductions guided by modeling of the cap and invest program.
Federal – IRA	Section 13303: Energy efficient commercial building deduction	This provision is estimated to reduce commercial HVAC costs by 3%. We modeled this provision as a 3% subsidy for commercial high-efficiency heating and cooling technologies in 2025 and 2030.	
	Sections 13301 - 25C and 13304 and 50121: Energy efficient home improvement credit, Energy efficient home credit, and Home energy efficiency credit	These provisions include subsidies for replacing existing end-use equipment with more efficient alternatives such as heat pumps, offsetting a share of labor and installation costs for technologies that generate renewable energy, and building new homes that save 50% more heating and cooling energy relative to 2006. These provisions are modeled by improving shell efficiency in residential buildings based on the AEO 2022 "Alternative Policies – Extended Credit" case.[17]	
	Section 51022: High efficiency home rebate program	Modeled as a subsidy to high-efficiency technologies in residential buildings in 2025 and 2030. We assume that two-thirds of consumers are eligible for this credit, so we implemented this as a weighted average across all consumers with the effective value of the credit modeled to be 66% of each of the following: $1,750 to electric heat pump water heaters, $4,000 to electric heat pumps for space heating, $420 to electric ovens, $420 to electric heat pump clothes dryers, $1,600 for high-efficiency air conditioning. Adequate funding is assumed for this program.	

Supplementary Table 4. Representation of Policies for the Industrial Sector in GCAM-USA-CGS

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Current + Planned Policies Scenario
Maryland	Fuel switching away from coal	Not explicitly modeled in this scenario.	The Union Bridge cement facility's plan for fuel switching to gas is modeled by increasing the share of gas to 62% by 2030. Plans to switch from coal to a refuse-derived fuel (RDF) mix at the Hagerstown cement facility were also represented by an increasing biomass portion of the cement fuel mix, reaching 17% by 2030.
Federal – IRA	Section 13104 - 45Q: Extension of credits for captured CO_2	Extension of existing credits for captured CO_2 at $85/ton is implemented through 2030. We assume this subsidy will result in sequestration levels consistent with Rhodium Group analysis.[7] We modeled this exogenously by specifying sequestration across various industrial sectors, resulting in 93 $MMTCO_2$ annual sequestration nationally in 2030, and held constant through 2050. In Maryland, paper pulp and cement CCS are introduced in 2035, resulting in 0.36 $MMTCO_2$, annual sequestration through 2050.	
	Sections 13204: Production credit for clean hydrogen	Modeled as different subsidies to hydrogen technologies depending on their carbon intensities. We assume that fossil hydrogen without CCS doesn't qualify and fossil hydrogen with CCS claims 45Q instead, and that 50% of projects pay prevailing wages.	

Supplementary Table 5. Representation of Policies for Other Sectors Outside of GCAM-USA-CGS

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Current + Planned Policies Scenario
Maryland	Natural gas methane regulations	The percent change in natural gas consumption from 2020 in each period was used to calculate the baseline projection for methane emissions in the fossil fuel sector. Then, the EPA MAC curve reductions for this sector were converted to percent reductions from baseline emissions.[18] Under the Maryland natural gas methane regulations, it was assumed that all technically feasible reductions in the EPA MAC curves from replacing high-bleed pneumatic devices in the natural gas industry are achieved, plus all reductions relating to leak detection & repair, reciprocating compressors, and blowdown events that are achievable at less than zero dollars per tCO_2e. In addition, both Transco Station and Cove Point LNG are potential candidates to be subject to the IRA methane fee that will reach $1,500/$tCH_4$ (equivalent to $60/$tCO_2e$).[19-21] Accordingly, additional reductions that could be achieved at this level on the EPA MAC curves are accounted for.	All additional reductions for the fossil fuel industry in this scenario are driven by the cumulative impact of other policies in other sectors that drive a significant reduction in natural gas consumption. This reduction in consumption is assumed to drive a further reduction in methane emissions from Maryland's fossil fuel industry, in line with IPCC inventory conventions.[22] No additional policy action is modeled in this sector to reduce methane emissions, but the EPA MAC curve reductions for this sector that were converted to percent reductions from baseline emissions are adjusted proportionately to the reduction in the baseline projection for methane emissions from the fossil fuel industry.
	Inclusion of Cove Point in RGGI	Under current policies, Cove Point is exempted from regulation under RGGI.	The Cove Point LNG facility was assumed to be included under RGGI, and therefore subject to requirements to reduce CO_2 emissions from the burning of fossil fuels as part of facility operation.
	Landfill methane regulations	The baseline emissions trajectory for landfill methane emissions was assumed to remain constant from the 2020 emissions level due to waste diversion efforts offsetting increase in municipal solid waste generation from a growing population. Analysis for Maryland's draft landfill methane regulations include a minimum and maximum potential emissions reduction.[23] It was assumed that landfill methane emissions will fall 46% by 2030 from 2020 levels, equivalent to the average of the two estimates from the draft regulation's analysis.	Additional reductions were modeled by assuming that waste diversion efforts would improve by 20% over the 2026-2050 period, equivalent to annual reductions of 0.8%.
	HFC regulations	HFC phasedown is implemented consistent with the AIM Act and Maryland HFC regulations, reducing emissions up to 49% from baseline trajectory by 2030. Emissions impacts from national and state-level HFC regulations were derived from a short-lived climate pollutant tool developed by California Air and Resources Board. The tool's Kigali phasedown scenario was used as a proxy for the impact of the AIM Act, and for end uses covered by Maryland's regulation the SNAP + Kigali scenario was used for the combined impact of the AIM Act and Maryland's regulation.	

Supplementary Table 6. Representation of Forestry and Land Use Sector Outside of GCAM-USA-CGS

The emissions and sequestration projections for the Forestry and Land Use sector were provided by MDE, through their collaboration with other state agency and university partners. For the Current + Planned Policies scenario, the Forestry and Land Use sector differs from the other emissions sectors in that it reflects a technical potential of carbon sequestration that could be achieved, with an ambitious level of additional action, rather than a policy commitment.

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Current + Planned Policies Scenario
Maryland	Tree and Forest Carbon	The projection of forest carbon utilizes an analysis conducted by the UMD Department of Geographical Sciences in consultation with MDE and the Maryland Department of Natural Resources. The Current Policies scenario considers growth and aging of existing trees, historical rates of disturbance, and existing policies such as the Forest Conservation Act and Tree Solutions Now Act.	The technical potential used in the Current + Planned Policies scenario is based on new plantings through 2045 at specified levels of potential afforestation/reforestation. The analysis evaluated a range of planting scenarios and 400,000 acres of new planting area was chosen as the illustrative technical potential for this report.
	Agricultural Soil Carbon	The historical and projected flux of agricultural soil carbon is based on a project utilizing the U.S. Department of Agriculture (USDA) COMET-Farm tool. The project was funded through a United States Climate Alliance Technical Assistance Grant and led by MDE and the Maryland Department of Agriculture. The new accounting method developed through this project utilizes state-specific data and will be incorporated in Maryland's GHG inventory. The Current Policies scenario is based on maintaining the current level of implementation of agricultural conservation practices, namely no-till residue/tillage management, cover crops, and nutrient management.	The technical potential used in the Current + Planned Policies scenario reflects expanding adoption of current practices to 80% of cropland by 2035, and full compliance for nutrient management.
	Wetlands and SAV	Projections of carbon sequestration and methane emission in wetlands and submerged aquatic vegetation (SAV) utilize acreage projections provided by the Maryland Department of Natural Resources. For SAV, the Current Policies scenario holds 2020 acreage constant. For coastal wetlands, results were provided by the Maryland Department of Natural Resources from prior modeling conducted in partnership with The Nature Conservancy, George Mason University, and Warren Pinnacle Consulting.[22] The analysis used the Sea Level Affecting Marshes Model (SLAMM) to evaluate expected change in wetland area due to projected sea level rise. For this report a scenario of 1.4 feet of sea level rise by 2050 was used for both Current Policies and the technical potential under Current + Planned Policies.	The technical potential reflects the SAV goals for Maryland's portion of the Chesapeake Bay. In this analysis the 2025 goal of 79,355 acres was used for 2031 and the long-term goal of 114,065 acres was used for 2045.

	Wood Products and Landfilled Carbon	Wood Products and Landfilled Carbon has two categories: "Landfilled Yard Trimmings and Food Scraps" and "Wood Products and Landfills (i.e., harvested wood products)". Harvested wood products were held constant at 2020 levels. Yard trim and food scraps were reduced linearly from 2020 levels to 0 in 2050, representing increased efforts to divert this category away from landfills.
	Settlement Soils and Forest Fires	Settlement Soils and Forest Fires were held constant at 2020 levels.

Supplementary Table 7. Representation of Policies for Economy-Wide GHG Targets in GCAM-USA-CGS 6.0

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Current + Planned Policies Scenario
Maryland	Economy-wide GHG targets	Not explicitly modeled in this scenario.	For Maryland, the economy-wide target (implemented through the "cap and invest" program) is set so that the 2031 gross emissions goal is reached, as well as the net zero target in 2045. The cap covers most economy-wide sectors, including road transportation, commercial and residential buildings, industry, and cement process emissions. There are exemptions for electricity, agriculture, forestry and land use, fossil fuel industry, non-cement IPPU, waste management, aviation, rail, shipping, and non-road diesel sectors.
Other States		The achievement of economy-wide GHG targets for the leading cohort of states was modeled by applying a constraint on CO_2 emissions.	

Supplementary Table 8. Mitigation strategies implemented from EPA Marginal Abatement Cost Curves.
The range of mitigation costs for each technology is in units of 2015 USD per ton of CO_2 equivalent using the IPCC AR4 100-year GWP to be consistent with the data annex to the EPA's state-level non-CO_2 mitigation report.[18] For livestock, the maximum mitigation costs included in this analysis are \$20/tCO_2e, with funding assumed to come at least in part from the State. For wastewater, the maximum mitigation costs included are \$1,701/tCO_2e. For oil and natural gas systems, the maximum mitigation cost is \$60/tCO_2e except for phasing out pneumatic devices in this sector which have high mitigation costs because the potential emissions reductions associated with phasing out pneumatic devices are very small.

Sector	Strategy	Description (copied from EPA (2019) "Global Non-CO2 GHG Emission Projections & Marginal Abatement Costs Analysis: Methodology Documentation" with additional context where necessary)	Cost range (2015\$/tCO_2e using IPCC AR4 100-year GWP to be consistent with the EPA analyses)	Range of annual reductions (% below 2020 MD inventory CH_4 emissions in each technology's respective sector)
Livestock	**Enteric Fermentation: Antibiotics**	Antibiotics (e.g., monensin) may be fed to cattle to promote increased weight gain and reduce feed intake per metric ton of meat produced. Federal and state law allow for antibiotic usage for disease treatment, thus using it for the purpose of reducing GHG emissions may require changes to existing laws surrounding its usage.	**-\$210 – -\$141**	**0% – 0.589%**
	Enteric Fermentation: Antimethanogen	Antimethanogen is a vaccine that can be administered to animals to suppress CH4 production in the rumen. The vaccine is currently in infancy of development with limited information on emission reduction efficiency, long-term mitigation effects, and animal health impacts.	**-\$1,189 – -\$66**	**0% – 2.769%**
	Enteric Fermentation: Bovine Somatrophin (bST)	bST may be administered to dairy cattle to increase milk production. However, increased milk production may require additional feed and there are barriers to public acceptance of hormone use.	**-\$310 – -\$244**	**0% – 1.354%**
	Enteric Fermentation: Intensive grazing	Intensive grazing means improving nutrition through more intensive pasture management and cattle rotations to allow for regrowth while decreasing reliance on prepared rations.	**-\$8 – \$12**	**0% – 0.545%**
	Enteric Fermentation: Propionate precursors	Propionate precursors (malate, fumarate) may be administered to animals daily. Hydrogen produced in the rumen through fermentation can react to produce either CH4 or propionate. By adding propionate precursors to animal feed, more hydrogen is used to produce propionate and less CH4 is produced.	**-\$49 – \$3**	**0% – 4.100%**

Livestock, manure management	**Large-scale complete mix digester with engine**	Complete-mix digesters are more common in warmer climates, where manure is flushed out of barns or pens with water, lowering the solids' concentration to a level generally between 3% and 10%. Often the manure accumulates in a mixing tank before entering the digester. These digesters make use of gravity and pumps to move the manure through the system. These digesters are typically heated to maintain a constant temperature and gas flow	**-$33 – $8**	**0% – 3.525%**
	Large scale complete mix digester without engine		**$14 – $18**	**0% – 3.418%**
	Large-scale covered lagoon with engine	Covered earthen lagoons are the simplest of the systems used in developed countries and generally the least expensive, although there is quite a bit of variation in the systems that have been built. This system is used with low manure solids' concentration (less than 3%) and can be used for swine or dairy cattle. CH4 is captured by covering the lagoon where manure is stored with a floating cover and piping the gas out to a flare or used on-farm. Because these digesters are not generally heated, the available gas flow varies significantly over the course of the year.	**-$57 – $14**	**0% – 3.525%**
	Large scale covered lagoon without engine		**$10 – $20**	**0% – 3.522%**
	Large-scale fixed-film digester with engine	Fixed-film digesters may be appropriate when concentrations of solids are very low, such as in swine manure management situations where manure is very diluted with water. Fixed-film digesters consist of a tank packed with inert media on which bacteria grow as a biofilm.	**-$21 – -$13**	**0% – 0.107%**
	Large-scale plug-flow digester with engine	Plug-flow digesters consist of long and relatively narrow heated tanks, often built below ground level, with gas-tight covers. Plug-flow digesters are only used for dairy manure because they require higher manure solids' content, around 11% to 13%.	**$15 – $17**	**0% – 3.418%**
	Large-scale plug-flow digester without engine		**$19 – $20**	**0% – 3.415%**
Wastewater	**Latrine to aerobic wastewater treatment plant**	Reduction in CH4 emissions by adding a collection system and centralized treatment facility where the current practice is decentralized wastewater treatment using latrines.	**$781 – $846**	**0% – 1.491%**
	Septic tank to aerobic wastewater	Reduction in CH4 emissions by adding a collection system and centralized treatment facility where the current practice	**$452 – $1,701**	**0% – 39.144%**

	treatment plant	is decentralized wastewater treatment using septic tanks.		
	Wastewater treatment plant with anaerobic sludge digester with co-gen	Reduction in CH4 emissions for the existing condition of a centralized collection system without a treatment facility. Contaminants in wastewater are removed via a variety of physical, chemical, and biological methods. An anaerobic wastewater treatment plant typically comprises many unit operations divided into stages of treatment: pretreatment, primary treatment, secondary treatment, and tertiary treatment.	**$216 – $335**	**0% – 10.578%**
Oil and natural gas systems	**Changes in operational practices**	Direct inspection & maintenance type activities at transmission and distribution facilities	**$22 – $28**	**0.019% – 0.157%**
		Directed inspection & maintenance at compressor stations	**-$10 – -$8**	**0.896% – 7.473%**
		Directed inspection and maintenance of compressors - transport	**$1 – $34**	**0.408% – 3.404%**
		Direct inspection & maintenance - (production gas well/pipeline leaks/chemical injection pumps)	**-$7 – $15**	**0.055% – 0.459%**
		Directed inspection & maintenance at gate stations and surface facilities	**-$7 – -$2**	**0.919% – 7.666%**
		Reciprocating compressor rod packing (Static-Pac)	**-$1 – -$1**	**0.714% – 5.958%**
		Fuel gas retrofit for BD valve - Take reciprocal compressors offline	**-$7 – -$6**	**1.117% – 9.320%**
	Equipment modifications and upgrades	Convert gas pneumatic controls to instrument air	**$37,502 – $5,219,543**	**0.001% – 0.009%**
		Replacing high-bleed pneumatic devices in the natural gas industry	**$33 – $38,415**	**0.000% – 0.003%**
		Early replacement of reciprocating compressor rod packing rings	**$2 – $5**	**0.152% – 1.268%**

		Early replacement of reciprocating compressor rod packing rings and rods	**$7 – $32**	**0.187% – 1.563%**
		Replacing wet seals with dry seals in centrifugal compressors	**-$12 – -$11**	**0.413% – 3.446%**
	Installation of new equipment	Installing surge vessels for capturing blowdown vents	**$5 – $33**	**0.083% – 0.691%**

2.4. CORE ASSUMPTIONS

The results of this study depend on many assumptions about how Maryland might evolve in the future. This study uses a set of core assumptions for drivers including economic growth, population growth, coal power retirement, nuclear power retainment, and energy demands reflecting economic impacts associated with COVID-19 in 2020 and subsequent recovery (Supplementary Table 9). Our core assumptions draw from a set of data sources that are referenced in the main report and other parts of this technical appendix, for example EIA's *Annual Energy Outlook*[17] and Rhodium Group[24].

Supplementary Table 9. Core Assumptions for Maryland. More detailed information on these categories can be found in the Data Annex.

Drivers	Scenario assumptions
Economic Growth	Overall GDP decreases by 3.5% year-on-year in 2020. It increases by 0.66% per year on average through 2030, then grows by 1.2% per year on average through 2045. GDP is one of the primary drivers of overall demand growth in all sectors of the economy, which has a direct impact on emissions.
Population Growth	Population grows by 0.65% per year on average through 2030, and then grows by 0.47% per year on average through 2045. Population is one of the primary drivers of overall demand growth in all sectors of the economy, which has a direct impact on emissions.
Retirement of coal-fired power plants	All existing coal-fired power plants are assumed to retire by 2025. Announced retirement dates were collected from 3 sources: EIA-860 (2021)[25], Global Energy Monitor's Global Coal Plant Tracker (July 2022)[26], and the EPA NEEDS database (October 2022)[27]. For plants in which retirement dates differ between these sources, the earliest retirement date was used. The retirement of coal power plants impacts fossil fuel emissions in the electricity sector and the need for new electric generation capacity.
Retainment of nuclear power plants	The existing Calvert Cliffs units 1 & 2 are assumed to be relicensed through 2050. This impacts the availability of low/zero-emission technologies in the electricity sector.
Transportation Energy Demand	Transport sector energy demand decreases by 12.6% from 2015 levels in 2020, with recovery through 2025. This directly impacts emissions in the transportation sector.
Industry Energy Demand	Industry sector energy demand decreases by 4.1% from 2015 levels in 2020, with recovery through 2025. This directly impacts emissions in the industry sector.
Buildings Energy Demand	Buildings sector energy demand decreases by 4.7% from 2015 levels in 2020, with recovery through 2025. This directly impacts emissions in the buildings sector.
Building Floorspace	Residential floorspace growth is assumed to grow at the rate of households growth as projected by the Maryland Department of Planning. Commercial floorspace trends with GDP growth in the model. This directly impacts on emissions in the buildings sector.
Technology Costs	Technology costs are updated with NREL Annual Technology Baseline 2022 assumptions.[28]

2.5. SUPPLEMENTARY MODELING RESULTS

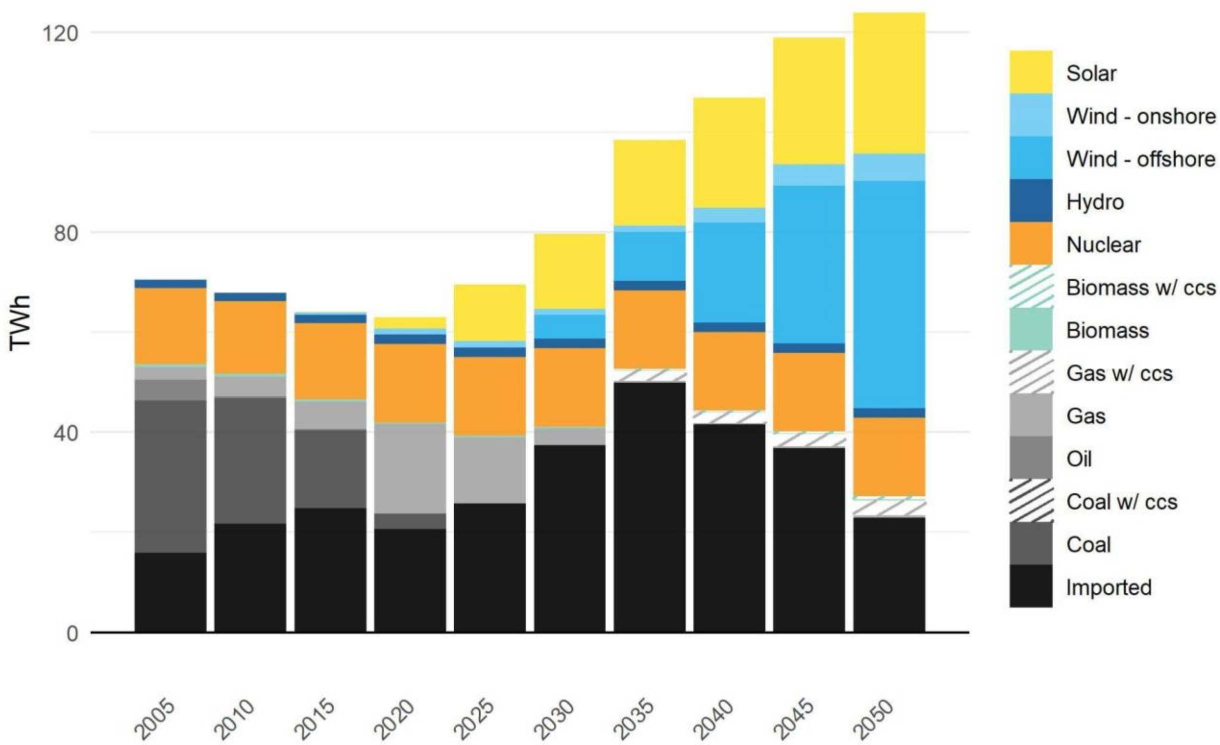
Supplementary Table 10. Results by Sector. Note that positive percent changes in the Forestry and Land Use sector indicate increased carbon sequestration.

Sector/GHG	Emissions 2006 ($MMTCO_2e$)	Emissions 2020 ($MMTCO_2e$)	Emissions 2031 ($MMTCO_2e$)		Change from 2006 to 2031 ($MMTCO_2e$)		Change from 2006 to 2031 (%)	
			Current Policies	Current + Planned Policies	Current Policies	Current + Planned Policies	Current Policies	Current + Planned Policies
Electricity	42.5	18.3	7.4	4.9	-35.1	-37.6	-83%	-89%
Transport	35.6	29.8	22.1	19.1	-13.5	-16.4	-38%	-46%
Commercial	4.5	5.2	4.2	3.2	-0.3	-1.3	-8%	-29%
Residential	6.2	5.7	4.4	3.7	-1.8	-2.5	-29%	-41%
Industrial	6.4	2.7	3.3	1.1	-3.2	-5.3	-49%	-83%
IPPU	9.4	7.3	6.2	5.4	-3.3	-4.0	-35%	-43%
Fossil Fuel Industry	3.9	4.6	3.6	2.6	-0.3	-1.3	-7%	-34%
Waste Management	10.0	8.4	6.2	5.7	-3.7	-4.3	-37%	-43%
Agriculture	3.2	3.1	3.1	2.9	-0.2	-0.4	-5%	-12%
Forestry and Land Use	-8.6	-9.1	-9.0	-9.3	-0.4	-0.7	+5%	+9%
Gross GHG Total	**121.7**	**85.1**	**60.4**	**48.5**	**-61.3**	**-73.2**	**50.3%**	**60.2%**

2.5.1 ELECTRICITY

In both scenarios, coal power is assumed to phase out by 2025, per datasets from EIA-860,[25] Global Energy Monitor's Global Coal Plant Tracker,[26] the U.S. Environmental Protection Agency (EPA) NEEDS database,[27] and the announcement of the Warrior Run facility's retirement by AES.[29] In-state generation meets the RPS target of 50% by 2030 and complies with the current RGGI target, with federal tax incentives lowering the costs of renewables. In Current + Planned Policies, natural gas is rapidly displaced by renewable sources by 2031 under more stringent requirements from RGGI and the CPS, and the early retirement of natural gas plants as a result of the cap and invest program. All remaining natural gas plants are equipped with carbon capture and sequestration (CCS) technology by 2035, which would be supported by the recently proposed EPA rule on power plant emissions.[30] The majority of remaining emissions come from natural gas generation and electricity imported from surrounding states. Due to the rapid electrification in end-use sectors, the demand for electricity grows by 25% from today's levels by 2031, a level of growth comparable to electricity demand increases seen in Maryland in the 1990s.[31]

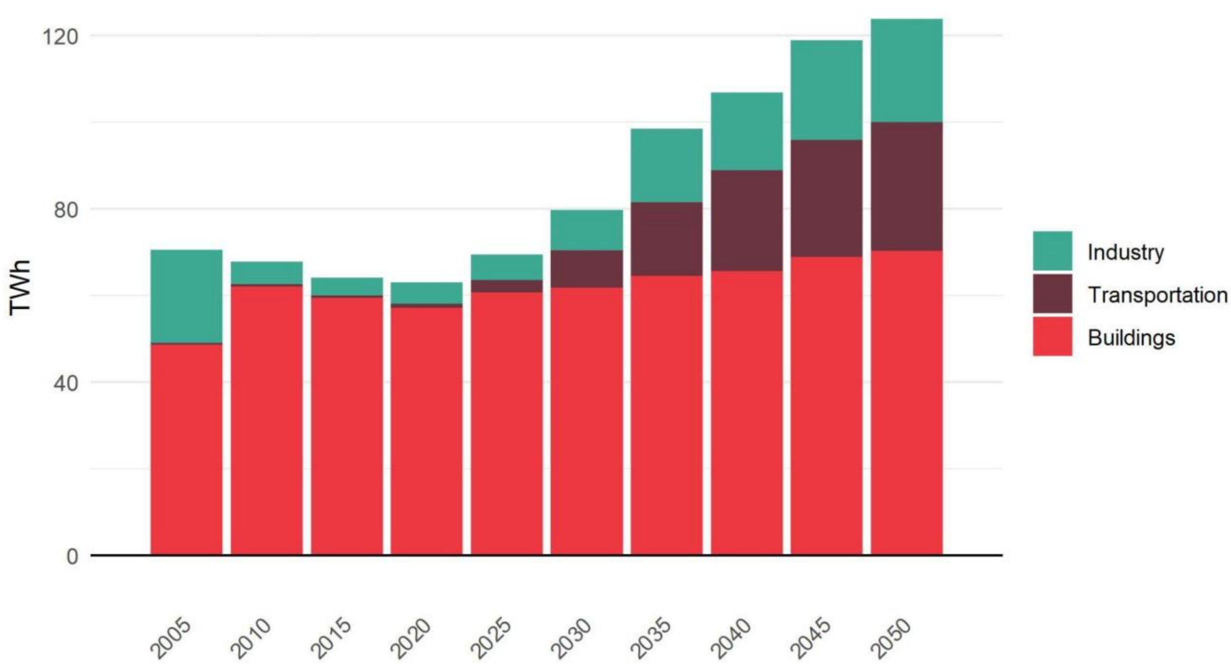
Figure S1. Electricity generation by technology in Maryland, with imported electricity from surrounding states shown separately.



Under Current + Planned Policies, solar generation increases by fivefold and wind generation increases by four-fold by 2031, with solar accounting for 35% of in-state generation and wind accounting for 14%. Offshore wind represents nearly 80% of total wind generation in 2031, reaching an estimated capacity of 2.8 GW in 2035, which falls short of the 8.5 GW target that Maryland has set for 2031.[32] Nuclear generation is held constant at 2020 levels due to the relicensing of Calvert Cliffs through 2050.

With the phaseout of coal by 2025, the only major remaining in-state source of emissions is natural gas. By 2031, natural gas generation in Current + Planned Policies falls by over 82% from today's levels, accounting for less than an 8% share of in-state generation, compared to a 13% share under the Current Policies scenario.

Figure S2. Electricity consumption in Maryland by sector.



Imported electricity from surrounding PJM states makes up over 45% of the electricity generation in Maryland in 2031 and contributes to almost 85% of the remaining emissions in the power sector. In this pathway, although Maryland achieves its renewable and clean energy targets for in-state generation, the rapid expansion of solar and wind from current levels in this scenario is not sufficient to meet the growth in electricity demand from end-use sectors and to make up for reductions in natural gas generation. This means that Maryland must also increase imports from other states. The amount of imported electricity will depend on the relative cost of in-state vs out of state generation and the rate at which new generation can be built in-state to supply increased demands from electrification. Further increases of in-state deployment of clean energy sources in the near-term beyond what is included in this scenario would decrease the need for imports.

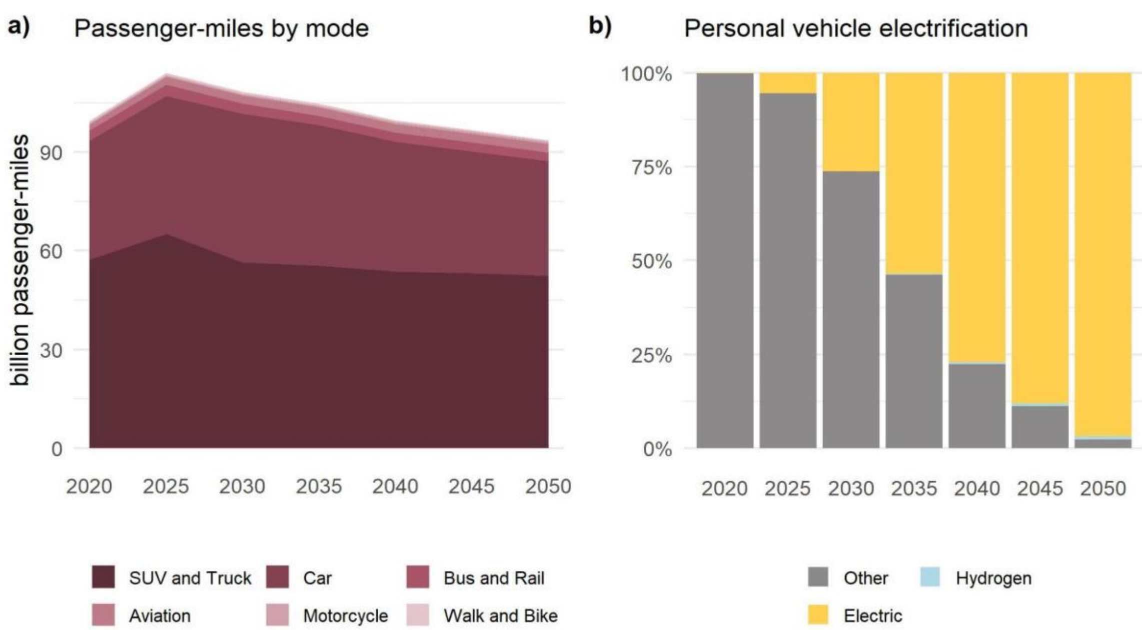
To meet the net-zero goal, renewables deployment continues to ramp up, reaching almost 75% of in-state generation by 2045. Additional wind generation is predominately offshore at almost 90% of total wind generation, reaching nearly 9 GW in capacity.[32] As electrification of end-use sectors continues to increase, electricity consumption also grows nearly 50% from 2031 levels by 2045, primarily driven by increased consumption in the transportation sector. Natural gas with CCS is introduced in the 2030s and contributes to 3% of in-state generation by 2045. Residual emissions from natural gas after the implementation of CCS are due to imperfect capture rates, which are generally expected to be at most 95%. Biomass with CCS is also introduced in the 2030s, though it plays a minor role, making up less than 1% of the generation mix in 2045. To help meet electricity demand, imported electricity from surrounding states continues at a level slightly lower than the modeled value for 2030.

2.5.2. TRANSPORTATION

In both scenarios, Maryland achieves the ACC II and ACT targets starting in 2027, with federal EV tax incentives and investments lowering the costs of EVs. At the same time, CAFE standards increase the efficiency of new on-road internal combustion engine (ICE) vehicles as well as the deployment of EVs. The Advanced Clean Fleets policy is also implemented, complementing ACT to drive freight truck sales to 100% EVs by 2045. Smart growth and transportation demand management policies reduce personal vehicle travel through ridesharing and mode-switching to public transit, biking and walking.[11] These changes are presented here in passenger-miles traveled, which encompasses any movement of a person over a single mile via any transportation mode. Similarly, changes in freight tonnage movement are presented in ton-miles traveled, which encompasses transportation of one metric ton of freight over a single mile via any transportation mode. Although passenger-miles and ton-miles are not equivalent to VMT, the percentage changes between model years can be interpreted in terms of percentage changes in VMT. With additional policies in Current + Planned Policies scenario, passenger-miles in personal vehicles are further reduced through additional smart growth transportation policies, and ton-miles are reduced for freight trucks due to the cap and invest program resulting in reduced diesel consumption through service demand reductions and mode shifts.

Passenger car, SUV, and pick-up truck ZEV sales reach 66% by 2030 and 100% by 2035 in Current + Planned Policies, achieving Maryland's ACC II target. In the near term, battery EVs dominate, and hydrogen-powered fuel-cell EVs play a minor role. While passenger-miles grow with economic development in 2025, smart growth policies and the cap and invest program reduce passenger-miles in 2030. As a result of these drivers, passenger-miles increase by 0.8% annually from 2020 to 2030 on average, compared to 2% annually in that same period under Current Policies.

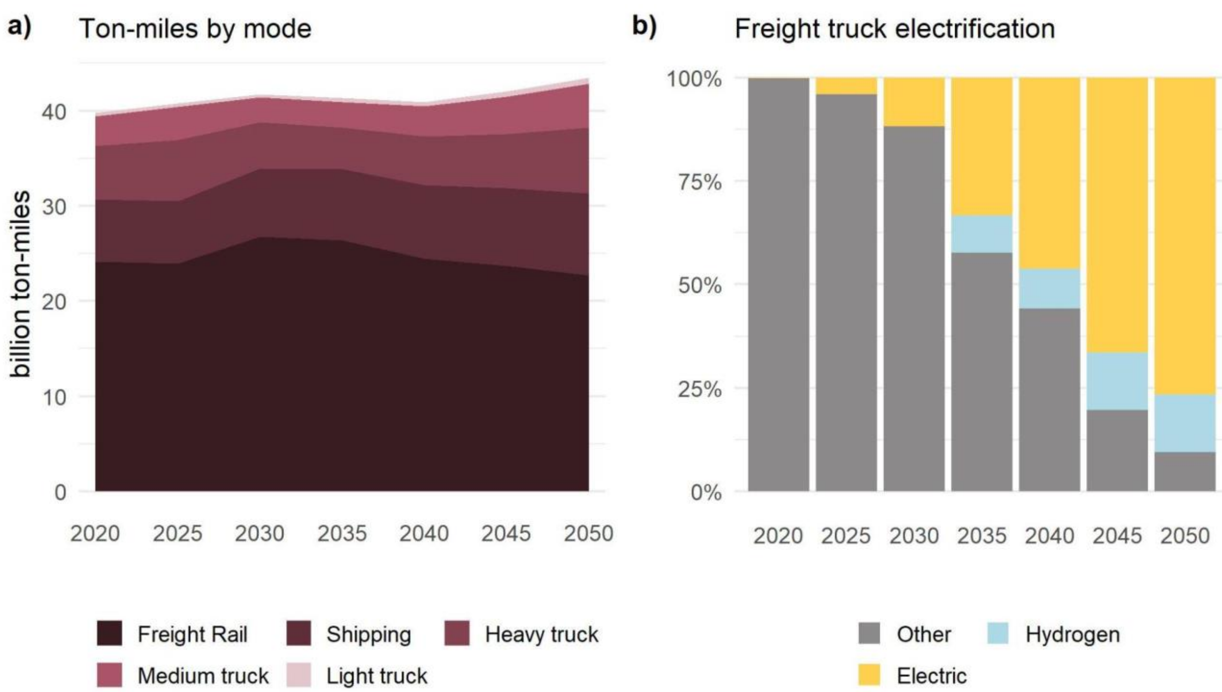
Figure S3. (a) Passenger transport in Maryland by mode. (b) Percent electrification of personal vehicles, inclusive of Cars and SUVs and Trucks as seen in (a).



Freight truck ZEV sales reach 30-50% by 2030, and 40-75% by 2035, depending on truck type, achieving Maryland's ACT target. In the near term, battery EVs dominate, and hydrogen-powered fuel-cell EVs play a minor role. While ton-miles supplied by freight truck service grow with economic development in 2025, the cap and invest program reduces freight truck service in 2030 in order to rapidly reduce diesel use and decarbonize the sector. As a result of these drivers, average ton-miles traveled in freight trucks increase by 2.5% annually from 2020 to 2025 but decline by 5% from 2025 to 2030. This results in a decrease of 1.3% annually from 2020 to 2030 on average, compared to an increase of 1.5% annually in that same period under Current Policies.

To meet the net-zero goal, ZEVs reach 100% sales for all on-road vehicles by 2045. Fuel cell EVs, powered by hydrogen, play a larger role in freight trucking in the 2040s. Transport service also continues to decrease for passenger vehicles through continued expansion of smart-growth policies and the cap and invest program. In the 2040s, there is also potential for aviation, rail, and shipping to reduce emissions through the use of low-carbon fuels.

Figure S4. (a) Freight transport in Maryland by mode. (b) Percent electrification of freight trucks.



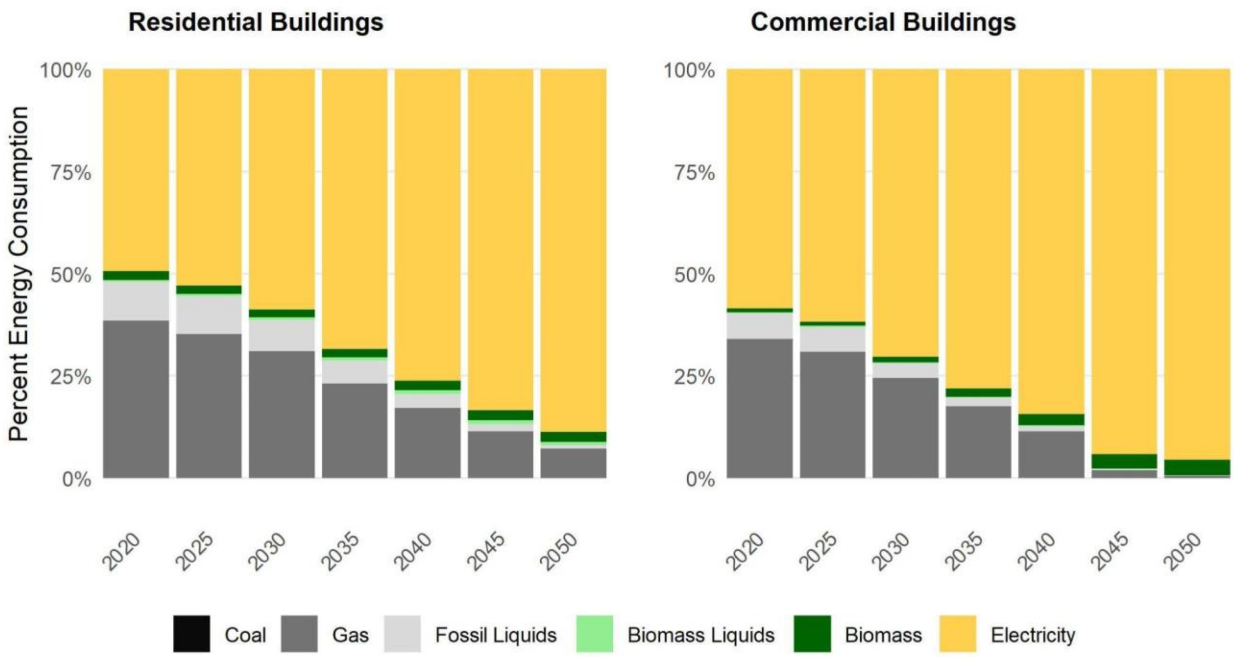
2.5.3 BUILDINGS

In both scenarios, Maryland implements EmPOWER's energy efficiency standards and BEPS at the state level, aided by federal incentives and rebates for electrification and efficiency. For BEPS, both electrification and EUI improvements are modeled. Additional policies in Current + Planned Policies scenario accelerate the phaseout of natural gas and petroleum so that over 94% of new appliance sales are zero emission by 2031.

As zero-emission heating equipment standards and zero-emission constructions standards kick in, the share of electricity increases to nearly 60% of total residential energy consumption in 2031, while natural gas consumption falls to 30%. Biomass and biofuels stay about the same and play a minor role in the near term. At the same time, total residential building energy use falls by 15% from today's levels due to efficiency measures from EmPOWER and from electrification.

Commercial buildings also electrify rapidly due the standards mentioned above, as well as requirements under BEPS (which apply to half of the commercial building space, and a small fraction of residential buildings in Maryland). The share of electricity increases to 70% of total commercial energy consumption in 2031, while natural gas consumption falls to 24%. At the same time, commercial building energy use decreases by 6% from today's levels due to efficiency measures from EmPOWER and the BEPS EUI requirement.

Figure S5. Percent electrification of residential and commercial building services.

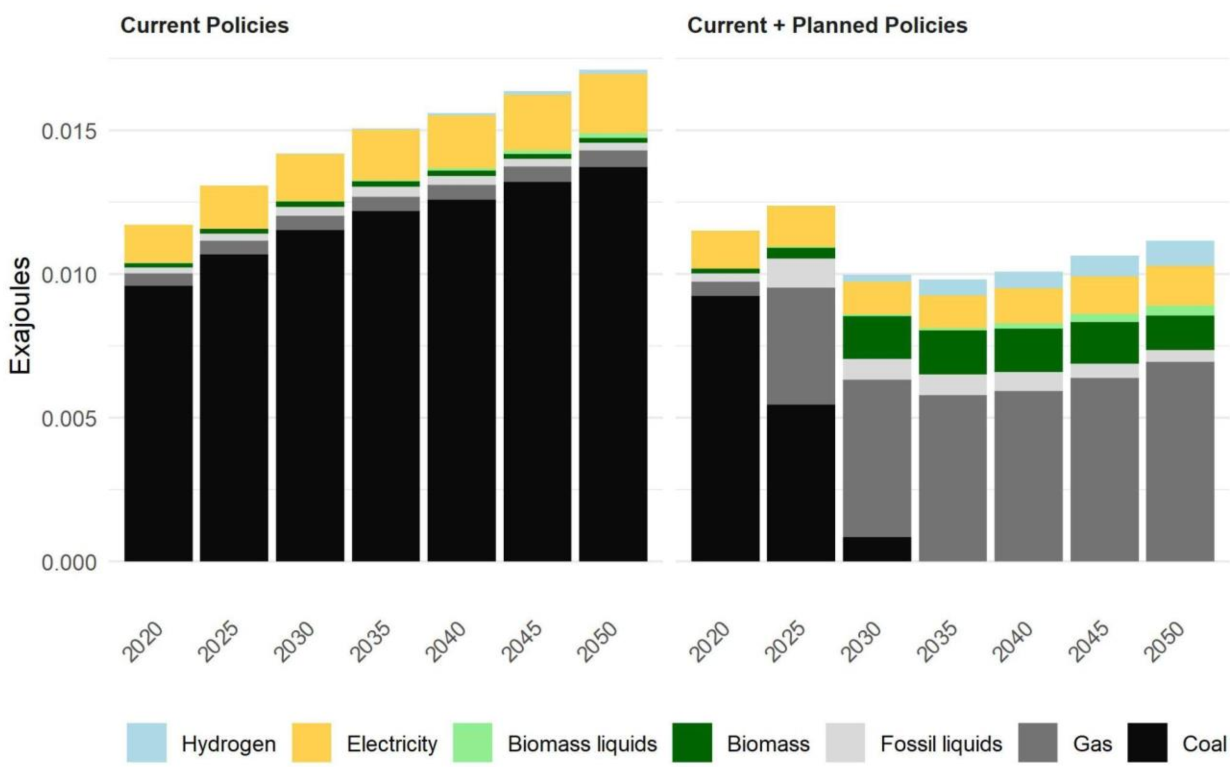


In order to meet the net-zero goal, both sectors rapidly electrify so that by 2045, electricity accounts for 83% and 94% of the energy consumption in residential and commercial buildings, respectively. In addition to space heating and hot water heating, other new appliance sales are at nearly 100% electric by 2045. Building energy demand decreases by an additional 20% from 2031 levels due to energy efficiency measures, and the relative increase in efficiency from using electric appliances.

2.5.4 INDUSTRY

There are two cement plants in Maryland, one in Union Bridge and one in Hagerstown. Historical emissions from these plants have grown over time, and, without any action to prevent them, emissions are expected to continue rising with increasing demand as seen in the Current Policies scenario. However, both plants expect to switch the bulk of their production in 2023 to a type of cement known as Portland Limestone Cement (PLC), which has a lower clinker factor and correspondingly lower emissions.[33] This efficiency measure could help to stabilize overall fuel use while still allowing for some industry growth. Additionally, both plants are planning to reduce the carbon intensity of their fuel mix. The Union Bridge facility is planning to switch their primary fuel source from coal to natural gas in 2027, and the Hagerstown facility is planning to transition nearly half of its fuel use to a refuse-derived fuel mix within the next 5 years.[33] These corporate actions, combined with the effects of the economy-wide cap and invest program, are represented in Current + Planned Policies. They result in a reduction of overall energy use by the cement industry and a transition away from coal to natural gas and bio-based fuels.

Figure S6. Fuel use in Maryland cement industry.



Non-cement industries within the State similarly see a trend of lower growth in energy demand under Current + Planned Policies compared to Current Policies, which would need to be achieved through efficiency measures or lower rates of demand growth. Further emissions reductions are achieved through greater electrification, increased use of biofuels, and phasing out the small amount of coal use that remains in the sector.

To reach net-zero, fossil fuels continue to be replaced by electrification and bio-based fuels. Continued use of natural gas with CCS will play a role in certain industries, potentially including cement. Overall energy use within the sector increases substantially in 2040 and 2045, due to the introduction of carbon dioxide removal (CDR) technologies to offset remaining emissions across the Maryland economy. CDR energy consumption peaks in 2045 at 25% of total industrial energy use. This is a large deployment of CDR technologies in terms of overall magnitude and illustrates the substantial challenge to Maryland to reach net-zero GHG emissions in 2045. A range of CDR technologies and a combination of approaches could be used to help meet the net zero goal,[34] but it is unclear if these technologies will be available for large-scale deployment in the timeframe shown here. However, some approach will be needed to offset residual CO_2 and non-CO_2 emissions. Lowering the number of residual emissions would also lower the amount of offset needed.

Figure S7. Fuel use in non-cement industries in Maryland.

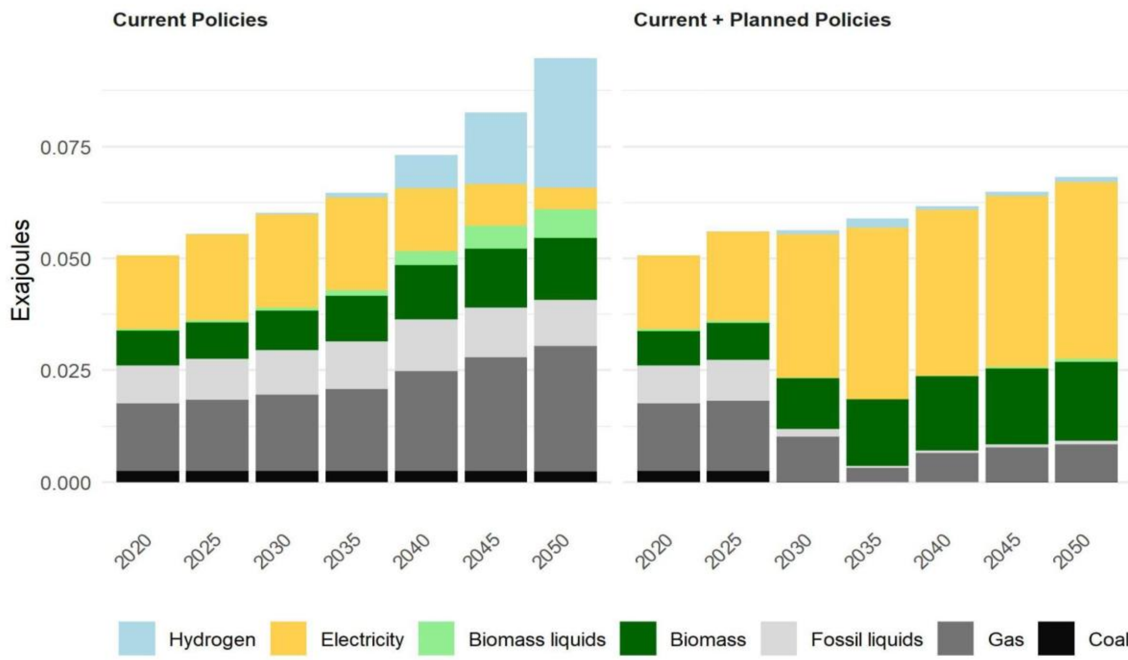
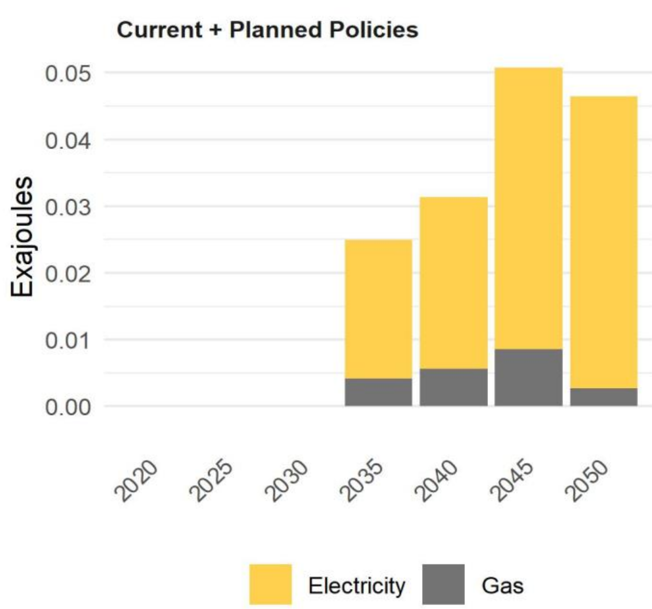


Figure S8. Fuel use for CO_2 removal in Maryland.



3. EMISSIONS REDUCTIONS ATTRIBUTABLE TO SPECIFIC POLICIES

Policy Attribution was calculated in each table below by comparing scenarios with and without a specific policy modeled. A baseline was established by excluding the Cap and Invest program from the "Current + Planned Policies" scenario, and subsequent policies were compared against this "No Cap and Invest" scenario. In structuring the scenarios in this way, we are creating similar circumstances in which the only difference is the single policy for which the attributable emissions reductions are being calculated. For example, to determine the attributable emissions reductions from the Advanced Clean Fleets policy, we run the baseline "No Cap and Invest" scenario and then run a "No Cap and Invest excluding Advanced Clean Fleets" scenario. The difference in emissions between scenarios is due to the influence of the excluded policy, and thus the resulting difference indicates the emission reductions associated with that specific policy (in this example, the Advanced Clean Fleets policy).

Given the emissions reduction attribution of each policy is determined independently, it is not expected that the emissions avoided from each would sum to the 2031 and 2045 goal. This is due to the fact that GCAM is a dynamic model, and the policies considered here can have interactions which in turn has implications for emissions reduction potential. Additionally, the baseline scenario here does not include the Cap and Invest program.

Table 11. Reductions in GHG emissions attributable to specific policies.

Scenario	Policy	Sector	Table for reference	2031 Reduction (MMTCO2e)	2045 Reduction (MMTCO2e)
Current + Planned Policies	Renewable Portfolio Standard (RPS)	Electricity	1	0.647	-1.561
Current + Planned Policies	Clean Power Standard (CPS)	Electricity	1	0.895	2.507
Current + Planned Policies	Regional Greenhouse Gas Initiative (RGGI)	Electricity	1	0.271	0.729
Current + Planned Policies	Vehicle Miles Traveled (VMT) reduction policies	Transportation	2	0.684	1.089
Current + Planned Policies	Advanced Clean Cars II	Transportation	2	0.902	5.814
Current + Planned Policies	Advanced Clean Trucks	Transportation	2	0.496	0.821
Current + Planned Policies	Advanced Clean Fleets	Transportation	2	-0.001	1.782
Current + Planned Policies	Building Energy Performance Standards (BEPS)	Buildings	3	0.083	0.621
Current + Planned Policies	EmPOWER	Buildings	3	0.841	0.816
Current + Planned Policies	Zero-emission Construction Standards, Zero-Emission Heating Equipment Standards	Buildings	3	0.765	3.433
Current + Planned Policies	Clean Heat Standard	Buildings	3	0.769	0.757

Current + Planned Policies	Fuel switching for cement and other industry	Industry	4	0.299	0.464
Current Policies	MD HFC Regulations	IPPU	5	0.611	1.631
Current + Planned Policies	Reduction in natural gas usage	Fossil Fuel Industry	5	0.862	2.060
Current + Planned Policies	Inclusion of Cove Point in RGGI	Fossil Fuel Industry	5	0.183	0.913
Current Policies	MD Landfill regulation	Waste Management	5	2.280	2.280
Current + Planned Policies	Cap and Invest	Economy-wide	7	3.476	15.558

Table 12. Additional reductions assumed from industry trends and sub-state policies.

Scenario	Policy	Sector	Table for reference	2031 Reduction (MMTCO2e)	2045 Reduction (MMTCO2e)
Current + Planned Policies	Nonroad Diesel	Transportation	2	0.062	0.206
Current + Planned Policies	Nonroad Gas	Transportation	2	0.124	0.519

Table 13. Additional reductions attributable to public investment, inclusive of federal funds distributed by the State for these purposes.

Scenario	Policy	Sector	Table for reference	2031 Reduction (MMTCO2e)	2045 Reduction (MMTCO2e)
Current + Planned Policies	Enteric Fermentation	Agriculture	8	0.123	0.123
Current + Planned Policies	Manure Management	Agriculture	8	0.081	0.100
Current + Planned Policies	Additional waste diversion	Waste Management	5	0.129	0.426
Current + Planned Policies	Wastewater	Waste Management	8	0.431	0.470

4. COBRA

The health impacts of Current + Planned Policies were modeled using the EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).[35] A screening model used regularly in the research community,[36-38] COBRA is a free, easy-to-use EPA model employed as a preliminary analysis of health impacts from environmental/energy policy changes.[35] The model provides an estimate of health benefits from pollution reduction, both in terms of symptom incidence reduction and monetized valued. COBRA models the impact of policies on twelve health outcomes due to five different co-pollutants. These co-pollutants include fine particulate matter 2.5 micrometers in diameter and smaller ($PM_{2.5}$) and precursor chemicals for $PM_{2.5}$ (ammonia (NH_3), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs)), which COBRA converts in its calculations.

Two of the health impacts have a low and high estimate due to two sets of assumptions used by COBRA to estimate the sensitivity of that particular health impact.[39] Overall, the results represent a very conservative estimate of the total health impacts from the Current + Planned Policies scenario compared to the Current Policy scenario. The results shown here represent the benefits delivered in 2031 alone, but positive benefits will likely be realized beginning in the late 2020s and be beneficial for the state through mid-century. Additionally, though their effect is likely very small, the agriculture, waste management, and forestry and land use sectors are not included in the COBRA modeling. This is because these sectors were not modeled within GCAM, and the COBRA inputs were taken from the GCAM results. Lastly, the COBRA results are driven by population and the difference in pollutants between the Current Policies and Current + Planned Policies scenario. The Current Policies scenario itself will likely bring health benefits to the state as it emphasizes replacing dirtier energy sources and vehicles with cleaner ones, but these benefits are not captured in this analysis.

4.1 METHODOLOGY

Evaluation of the health impacts of the Pathway scenario focus on benefits delivered specifically in 2031 to provide a snapshot of benefits upon reaching the 2031 GHG emissions reduction target established in the CSNA. The pollutants analyzed in COBRA are modeled explicitly in GCAM, and therefore the difference in pollutants between the two scenarios could be calculated from GCAM results. This was done by linearly interpolating the rate of change in pollutant emissions from 2023 to 2031 in the GCAM results for the Current Policies and Pathway scenarios. This rate of change was applied to COBRA's emission profile for 2023 to generate an input file for 2031. The process of input file development was largely developed by Dr. Dan Loughlin at the EPA, who provided valuable guidance on this part of the methodology. Pollutant sources in GCAM were also matched to the corresponding pollutant categories in COBRA. This is important given that COBRA uses a series of source-receptor matrices to calculate the county level impacts of air quality changes based on specific emissions sources known to exist in those locations, and matching the sources between the two models allows for accurate geographic allocation of pollutant emissions changes across the state.[39]

A custom 2031 population file was also developed using a similar methodology. COBRA's built-in 2023 population file was used as the base, and then growth rates developed for the Shared Socio-economic Pathway 2 (SSP2) by the EPA's Integrated Climate and Land-Use Scenarios (ICLUS)[40], were applied to generate a 2031 population input file. No changes were made to the health impact valuation, air quality functions, or other default settings. The only custom inputs were the baseline and policy scenario emissions file derived from GCAM results, and the population file derived from ICLUS projections.

Finally, COBRA requires the user to choose a discount rate to apply to the monetized value of the projected health benefits. This discount rate aids in determining the current value of a future benefit, with higher discount rates putting a lower value on future benefits.[41] COBRA provides two options for the discount rate - 3% and 7%. A discount rate of 3% was chosen for this analysis based on EPA guidance and best practices in the scientific literature, which finds that expert philosophers and economists recommend a 2% discount rate for valuation of climate mitigation benefits.[39-42]

Health benefits were also modeled in COBRA for each 5-year time-step in the GCAM model from 2025-2050 as an input for the broader economic benefits analysis performed in the REMI PI+ model. This enabled an estimate of cumulative benefits between 2025 and 2031, calculated using a linear interpolation of total health benefits output for years between 2025 and 2030. While interpolation of benefits for years not modeled explicitly in GCAM introduces some additional uncertainty, benefits are still expected to be a conservative estimate for the reasons described above.

The benefits reported here represent a very conservative estimate of health benefits from fully realizing the Current + Planned Policies scenario due to several methodological considerations. Some sectors, such as waste management, agriculture, and forestry and land use, were not modeled explicitly in GCAM. Because the pollutant changes used as COBRA inputs were derived from GCAM outputs, those sectors are not included in COBRA analysis. Further changes in pollutants resulting from off-model programs would likely result in positive health impacts as well, but they are not shown modeled here. Additionally, the benefits of enacting Current Policies are likely substantial, but these are not represented here because COBRA only captures impacts relative to a baseline, not the benefits of the baseline itself.

4.2 MONETIZED VALUE

By default, COBRA generates results in 2017$ for monetized values. Depending on the analysis year chosen, different income levels are employed (2016, 2023, 2028). The 2028 income level was used in this analysis to be consistent with the default settings described above. COBRA assumes willingness to pay for risk reductions in mortality, and other health impacts, will increase as real income increases in line with best available research.[39] Therefore, using the 2028 (as opposed to 2016, 2023) analysis year for valuation functions indicates higher value (in 2017$) of avoided mortality and other impacts. Further explanation for valuation of each health impact can be found in the manual.[39] As a final step, monetized values were converted to $2023 using the conversion factors from the REMI PI+ model to ensure consistency in reported results. For the version of REMI used in this analysis, the factor for converting $2017 to $2023 was 1.12868.

Given that a majority of economic benefits come from avoided mortality, it is important that avoided mortality is properly defined and understood. The EPA estimates the monetary value of avoided mortality based on the value of a statistical life (VSL).[39] Many studies were aggregated to determine the appropriate VSL, and it is a sum of numerous small risk reductions for many people.[39] Additionally, the estimates of avoided mortality occur over a 20 year period, and COBRA employs a lag structure in which 30% of premature deaths happen in the first year, 50% happening in years 2-5, and 20% in years 6-20.[39] The COBRA documentation notes the value of a statistical life and its corresponding monetary value is not the same as the value of an individual life.[39] See the COBRA manual for further information.[39]

Supplementary Table 14. Total Health Benefits by County in Maryland in 2031

County	Current Policies PM2.5 (µg/m^3)	Current + Planned Policies PM2.5 (µg/m^3)	Delta PM2.5 (µg/m^3)	Total Health Benefits ($) - low estimate	Total Health Benefits ($) - high estimate
Allegany	6.751	6.725	0.026	1,551,000	3,495,000
Anne Arundel	7.080	7.049	0.031	10,931,000	24,652,000
Baltimore	7.523	7.485	0.037	21,381,000	48,182,000
Calvert	6.725	6.708	0.017	1,231,000	2,783,000
Caroline	6.587	6.575	0.012	294,000	664,000
Carroll	7.573	7.549	0.024	3,583,000	8,069,000
Cecil	7.393	7.375	0.019	1,433,000	3,238,000
Charles	6.745	6.724	0.021	1,983,000	4,475,000
Dorchester	6.517	6.506	0.012	295,000	663,000
Frederick	7.322	7.298	0.024	4,036,000	9,100,000
Garrett	6.271	6.263	0.009	206,000	465,000
Harford	7.603	7.577	0.026	5,387,000	12,142,000
Howard	7.441	7.400	0.041	6,036,000	13,612,000
Kent	7.071	7.053	0.018	369,000	830,000
Montgomery	7.223	7.185	0.038	19,117,000	42,867,000
Prince Georges	7.280	7.233	0.047	22,444,000	50,375,000
Queen Annes	6.893	6.879	0.014	568,000	1,280,000
St Marys	6.535	6.521	0.014	1,015,000	2,284,000
Somerset	6.264	6.253	0.011	236,000	530,000
Talbot	6.719	6.704	0.015	583,000	1,312,000
Washington	7.302	7.283	0.019	2,077,000	4,688,000
Wicomico	6.324	6.310	0.014	1,035,000	2,331,000
Worcester	6.158	6.145	0.013	661,000	1,490,000
Baltimore City	7.438	7.386	0.051	19,737,000	44,443,000

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