Technical Appendix:
Maryland’s Climate Pathway

An analysis of actions the state can take to achieve Maryland's nation-leading greenhouse gas emissions reduction goals

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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 6.0

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 6.0.

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 6.0 is based on the open-source release of GCAM-USA 6.0.[1] GCAM-USA-CGS 6.0 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 6.0 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 6.0, 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 6.0. 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 6.0.

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 2-7. 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 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
- 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 Maryland's Climate Pathway 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, our Maryland's Climate Pathway 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 Maryland's Climate Pathway scenario is shown in Supplementary Table 1 alongside results from our Current Policies scenario. The modeling assumptions underlying this scenario are listed in Supplementary Tables 2-7.

2.3.1. Additional modeled Maryland-specific policies

Electricity Sector

- Clean electricity standard of 100% by 2035
- Regional Greenhouse Gas Initiative target of zero by 2040

Transportation Sector

- Advanced Clean Fleets
- 100% electric bus sales by 2025
- Additional vehicle miles traveled reduction policies

Buildings Sector

- Zero-emission appliance standards
- Zero-emission construction standards
- Extended energy efficiency standards

Industry and Other Sectors

- "Buy Clean" standards to increase efficiency and electrification
- 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

Supplementary Table 1. Results by Sector

Sector/GHG	Emissions 2006 ($MMTCO_2e$)	Emissions 2020 ($MMTCO_2e$)	Emissions 2031 ($MMTCO_2e$)		Change from 2006 to 2031 ($MMTCO_2e$)		Change relative to 2006 (%)	
			Current Policies	Maryland's Climate Pathway	Current Policies	Maryland's Climate Pathway	Current Policies	Maryland's Climate Pathway
Electricity	42.6	18.4	7.2	4.9	-35.4	-37.7	-83%	-89%
Transport	35.6	29.8	21.9	18.3	-13.7	-17.3	-38%	-49%
Commercial	4.5	5.2	4.2	3.3	-0.3	-1.3	-8%	-28%
Residential	6.2	5.7	4.4	3.7	-1.8	-2.5	-30%	-40%
Industrial	6.4	2.7	3.3	1.4	-3.2	-5.0	-49%	-79%
IPPU	9.3	7.2	5.7	4.9	-3.6	-4.3	-39%	-46%
Fossil Fuel Industry	3.9	4.6	3.1	2.9	-0.8	-1.0	-20%	-26%
Waste Management	9.9	8.4	6.2	6.0	-3.7	-3.9	-37%	-40%
Agriculture	3.3	3.1	3.1	2.9	-0.2	-0.3	-6%	-9%
Forestry and Land Use	-7.8	-8.3	-8.3	-8.3	-0.5	-0.5	-7%	-7%
Gross GHG Total	**121.7**	**85.1**	**58.9**	**48.3**	**-62.7**	**-73.4**	**51.5%**	**60.3%**

Supplementary Table 2. Representation of Policies for the Electricity Sector in GCAM-USA-CGS 6.0

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Maryland's Climate Pathway Scenario
Maryland	Renewable 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 Electricity Standard (CES) 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.
	Cap and invest	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 2040. This was implemented by setting an emissions constraint in the power sector for RGGI states, with a linear interpolation between 2020 and 2040.
	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 almost 1 $MMTCO_2$ 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 3. Representation of Policies for the Transportation Sector in GCAM-USA-CGS 6.0

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Maryland's Climate Pathway 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.
	Bus ZEV incentives and sales targets	Not explicitly modeled in this scenario.	A combination of investments and fleet procurement targets lead to 100% electrification of all new bus sales in 2025. This was modeled by raising the sales shares to reach 100% electric by 2025.

	Vehicle miles traveled (VMT) reductions	Current state and local planning lead to annual average VMT growth of 2% from 2020 through 2030. This is in line with Maryland Department of Transportation's analysis for Maryland's Greenhouse Gas Reduction Act.[9] 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.	Federal investment, state and local planning lead to annual average VMT reductions of 0.67% between 2025 and 2030, resulting in annual average VMT growth of 1% between 2020 and 2030 (consistent with current ambition in leading states).[10] 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.
Federal – IRA	Section 13401 - 30D: Clean vehicle credit	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 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 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.

Supplementary Table 4. Representation of Policies for the Buildings Sector in GCAM-USA-CGS 6.0

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Maryland's Climate Pathway Scenario
Maryland	Energy efficiency standards	Current state-level energy efficiency resource standards under EmPOWER were modeled at 2.25% in 2025 and 2.5% in 2030 by reducing state-level building service demands.	Energy efficiency resource standards under EmPOWER are extended at 2.5% in annual savings through 2050 by reducing state-level building service demands.
	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.[11] This was implemented by increasing the share of electricity so that half of commercial buildings would reach net-zero by 2040	A zero-emissions appliance standard is modeled by having appliance sales for space heating and hot water heating go to 100% electric by 2030. A zero-emissions construction standard is layered on top of this policy by having all appliance sales for new construction go to 100% electric by 2030, with the assumption that half of the appliance sales are for new buildings.
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: Nonbusiness energy property credit, Energy efficient home credit, and Home energy efficiency credit	Modeled by improving shell efficiency in residential buildings based on the AEO 2022 "Alternative Policies – Extended Credit" case.[12]	
	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.	

Supplementary Table 5. Representation of Policies for the Industrial Sector in GCAM-USA-CGS 6.0

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Maryland's Climate Pathway 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 38% 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 18% by 2030.
	Electrification	Not explicitly modeled in this scenario.	State procurement and buy clean standards drive electrification of non-cement industrial energy use to be consistent with NREL's High/Rapid 2050 electrification scenario, with the electricity share increasing by 9 percentage points by 2030.[13] Corporate targets were assumed to be supportive of state-level electrification levels.
	Efficiency improvements	Not explicitly modeled in this scenario.	State procurement and buy clean standards drive improved industrial energy savings to 2% compared to Current Policies by 2030, based on LBNL analysis of ISO 50001 standards[14] and "high achievable" potential from EPRI state-level analysis.[15] City and corporate targets were assumed to be supportive of state savings levels.
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 CCS is introduced in 2035, resulting in 0.05 $MMTCO_{2,}$ 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 6. Representation of Policies for Other Sectors in GCAM-USA-CGS 6.0

Type of Policy	Modeled Policy	Current Policies Scenario (Includes BIL & IRA)	Maryland's Climate Pathway 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.[16] 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).[17–19] 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. No additional policy action is modeled in this sector to reduce methane emissions.
	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.[20] 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 10% over the 2026-2050 period, equivalent to annual reductions of 0.4%.
	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 (consistent with analysis and modeling results developed by CARB)[1]	

[1] 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 and extrapolated to additional states. The tool's Kigali phasedown scenario was used as a proxy for the impact of the AIM Act.

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)	Maryland's Climate Pathway Scenario
Maryland	Economy-wide GHG targets	Not explicitly modeled in this scenario.	For Maryland, the economy-wide target (referred to as "cap and invest" in the main text) is set so that the 2031 net emissions goal is reached, as well as the net zero target in 2045.
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.	

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 8). 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*[12] and Rhodium Group[21].

Supplementary Table 8. Core Assumptions for Maryland

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)[22], Global Energy Monitor's Global Coal Plant Tracker (July 2022)[23], and the EPA NEEDS database (October 2022)[24]. 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 2.3% 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	Electricity technology costs are updated with NREL Annual Technology Baseline 2022 assumptions. Solar and wind base technology costs decrease by 63% and 44% from 2015 levels by 2030, respectively. Offshore wind technology costs decrease by 57% from 2015 levels by 2030. These cost assumptions impact the deployment of renewables in the electricity sector.

3. COBRA

The health impacts of Maryland's Climate Pathway were modeled using the EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).[25] A screening model used regularly in the research community,[26–28] COBRA is a free, easy-to-use EPA model employed as a preliminary analysis of health impacts from environmental/energy policy changes.[25] 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.[29] Overall, the results represent a very conservative estimate of the total health impacts from the Pathway 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 Pathway 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.

3.1 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.[29]

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)[30], 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.[31] 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.[29,32]

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.

3.2 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.[29] 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.[29] 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).[29] Many studies were aggregated to determine the appropriate VSL, and it is a sum of numerous small risk reductions for many people.[29] 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.[29] 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.[29] See the COBRA manual for further information.[29]

Supplementary Table 9. Total Health Benefits by County in Maryland in 2031

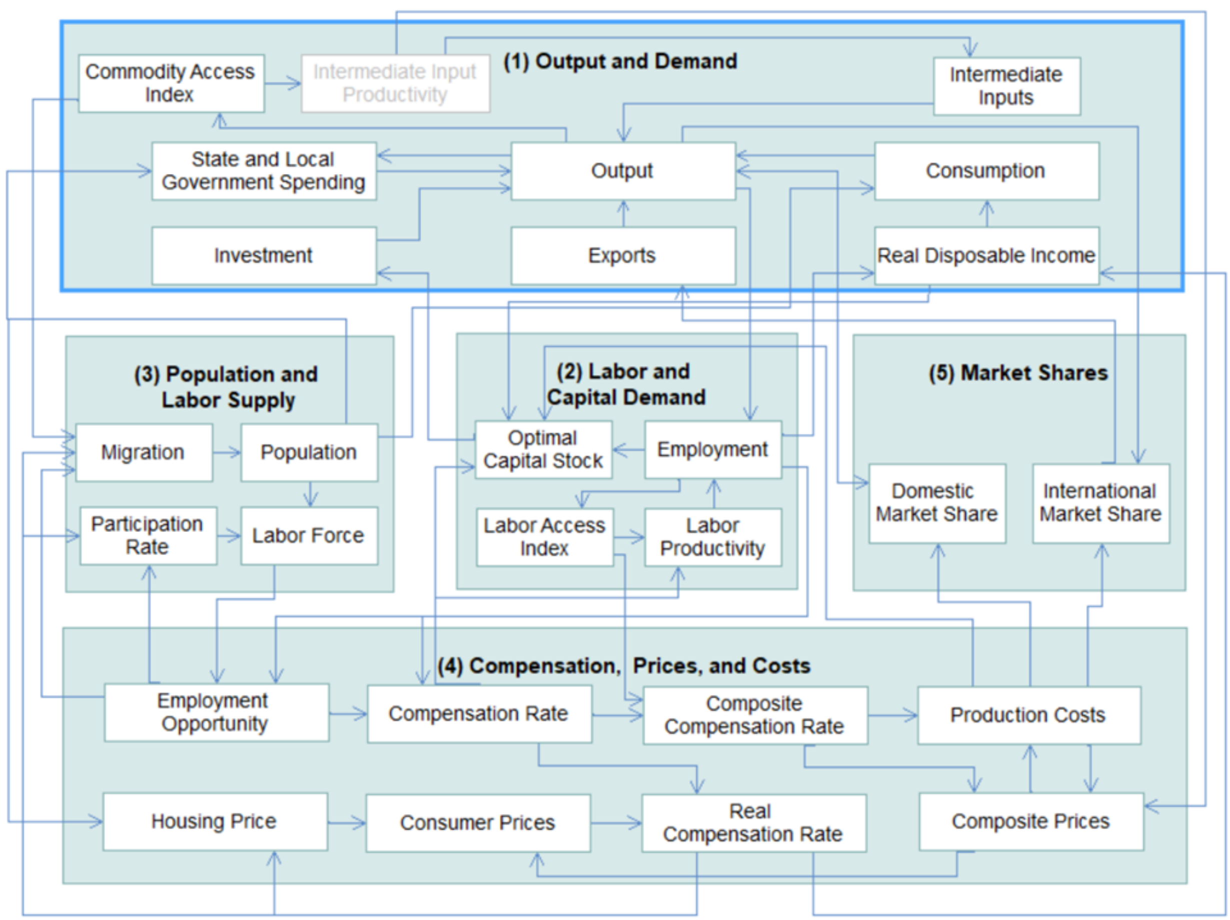
County	Current Policies PM2.5 (μg/m^3)	Maryland's Climate Pathway PM2.5 (μg/m^3)	Delta PM2.5 (μg/m^3)	Total Health Benefits ($) - low estimate	Total Health Benefits ($) - high estimate
Allegany	6.751	6.717	0.035	2,346,000	5,285,000
Anne Arundel	7.080	6.981	0.099	39,186,000	88,354,000
Baltimore	7.523	7.455	0.068	44,203,000	99,598,000
Calvert	6.726	6.659	0.067	5,509,000	12,451,000
Caroline	6.587	6.546	0.042	1,129,000	2,549,000
Carroll	7.573	7.531	0.042	7,149,000	16,100,000
Cecil	7.394	7.345	0.049	4,230,000	9,559,000
Charles	6.745	6.693	0.052	5,696,000	12,849,000
Dorchester	6.517	6.468	0.050	1,428,000	3,205,000
Frederick	7.323	7.280	0.043	8,126,000	18,320,000
Garrett	6.272	6.255	0.016	433,000	976,000
Harford	7.604	7.545	0.059	13,591,000	30,627,000
Howard	7.441	7.380	0.061	10,201,000	23,001,000
Kent	7.071	7.016	0.055	1,271,000	2,857,000
Montgomery	7.223	7.162	0.062	34,930,000	78,319,000
Prince Georges	7.281	7.204	0.077	41,587,000	93,330,000
Queen Annes	6.893	6.833	0.061	2,847,000	6,411,000
St Marys	6.535	6.475	0.061	4,812,000	10,826,000
Somerset	6.264	6.220	0.044	1,054,000	2,367,000
Talbot	6.719	6.660	0.060	2,545,000	5,727,000
Washington	7.303	7.265	0.037	4,646,000	10,485,000
Wicomico	6.324	6.281	0.043	3,614,000	8,140,000
Worcester	6.159	6.120	0.038	2,198,000	4,953,000
Baltimore City	7.438	7.314	0.124	53,679,000	120,840,000

4. REMI PI+

Regional Economic Models, Inc. (REMI) is a dynamic hybrid general equilibrium and input-output model used by various federal and state government agencies in economic policy analysis. Specifically, Maryland's Climate Pathway was modeled using REMI PI+ Version 2.2. By using the REMI PI+, the model is calibrated specifically to the economic and demographic structure of Maryland for this analysis.

The underlying structure of the REMI PI+ model is composed of linkages between five different components: output and demand; labor and capital demand; population and labor supply; compensation, prices, and costs; and market shares. These components—which can be thought of as policy injection points--are then linked by a large system of simultaneous equations. Thus, when a dollar is injected into the model, the economic impacts are spread through the entire system.[33] This can be seen below in Figure 1.

Supplementary Figure 1: REMI Model Linkages, *Source: REMI PI+*



To generate these policy variable inputs, capital costs and energy consumption costs provided by CGS were translated into appropriate inputs for REMI. This model enumerates the combined economic impacts of each dollar spent by the following: employees relating to the economic events, other supporting vendors (business services, retail, etc.), each dollar spent by these vendors on other firms, and each dollar spent by the households of the event's employees, other vendors' employees, and other businesses' employees.

For example, a policy scenario that leads to an increase in the purchase of heat pumps will trigger two effects. On one hand, both retail establishments as well as manufacturers that sell heat pumps will experience higher demand and therefore higher sales. On the other hand, consumers of heat pumps will need to spend money and reallocate their budgets accordingly. Both of these effects are captured in REMI, allowing for a more complete accounting of both the benefits and costs of policies. Economic benefits are modeled in REMI as a change in consumer or business demand while economic costs are modeled as the corresponding change in capital or fuel costs.

As a dynamic model, REMI features the ability to capture price effects, wage changes, and behavioral effects through time. Another benefit of the model compared to traditional static models is that the regional constraint is built in, which accounts for limited resources over time. A situation like this is built into the model using current industry data and employment information from Bureau of Economic Analysis (BEA) data. The REMI model also captures the effects occurring between industries and minimizes the potential for double-counting in employment, output, and wages. The ability to capture effects throughout a span of time provides a detailed representation of an economic event over time and its effects on the study area.

To assess specific impacts, REMI first constructs a baseline model of the local economy, which then allows policy variables to be layered on top to see how aspects of the new policy affect the economic outcomes. The difference between the policy scenario and baseline forecast represents the economic impact of the policy.

One shortcoming of the REMI model used in this analysis is that all firms producing electric power are aggregated into a single utilities sector, regardless of if the power is generated by a renewable source, such as wind, or by fossil fuels, such as coal. This aggregation structure can lead to unintuitive indirect impacts. With the baseline model, an increase in sales of wind energy would be treated the same as an increase in sales of coal power. Because REMI uses one set of economic multipliers to estimate how utility firms spend their revenues on support products and services, an increase in revenue for a wind plant would lead to an increase in purchases of coal or petroleum products within the model.

Therefore, the Project Team separated electric power generation into three categories:

- Wind electric power generation
- Solar electric power generation
- General electric power generation

General electric power generation uses the same multipliers as the baseline electric power generation sector within REMI. To create the other two custom industries, the Project Team customized REMI using industry multipliers from IMPLAN, another input-output economic modeling software.

To populate the REMI output multipliers, RESI cross walked IMPLAN industry classifications to REMI. Because IMPLAN uses a more granular set of industry codes than REMI, some IMPLAN industries were combined. The results were then input into REMI as custom industries.

The solar and wind power generation industries look substantially different than the general electric power generation industry, as illustrated in Supplementary Table 10. These industries have a higher value-added component at 0.82 and 0.90, for solar and wind respectively, compared to the base utilities industry, which has a value-added component of 0.79. Because much of the value-added component is due to earnings, on average, it can be expected that jobs in the base utilities industry will be lower paying than those in the solar and wind industries. In terms of intermediate demand, the base utilities industry relies heavily on fossil fuel intensive industries such as oil and gas extraction, petroleum and coal products manufacturing, and mining (except oil and gas). Solar and wind, on the other hand, rely more heavily on services (both professional and support services), construction, and real estate.

Supplementary Table 10: Top Five Intermediate Demand Industries for Utilities and the Solar and Wind Custom Industries, *Source: REMI PI+, RESI*

	Intermediate Demand Industry	Multiplier
Base Utilities	Oil and gas extraction	0.046
	Petroleum and coal products manufacturing	0.033
	Professional, scientific, and technical services	0.019
	Mining (except oil and gas)	0.013
	Scenic and sightseeing transportation; Support activities for transportation	0.012
Solar Power Generation	Professional, scientific, and technical services	0.035
	Scenic and sightseeing transportation; Support activities for transportation	0.019
	Construction	0.016
	Administrative and support services	0.015
	Real estate	0.010
Wind Power Generation	Professional, scientific, and technical services	0.019
	Scenic and sightseeing transportation; Support activities for transportation	0.010
	Construction	0.009
	Administrative and support services	0.008
	Real estate	0.006

Estimating Health Impacts with COBRA

All outputs from COBRA were translated into inputs appropriate for use in REMI. Health impact figures output by COBRA are represented in the COBRA model through an increase in the survival rate, the cost of hospitalization, an increase in the amenity value, a change in productivity, and increased consumer income.[2]

In the REMI model, changes to adult mortality and infant mortality are represented through a change in the survival rate, which represents the percentage of a given population expected to

[2] The amenity value measures non-economic improvements to quality of life in a region, which has an effect on migration patterns.

die in a single year. To determine the change in the survival rate, RESI compared the decreased mortality from the COBRA model to the population size of each Maryland region. An adjustment to the COBRA output was also required to accurately adjust the survival rate for each year.

While most health impacts in COBRA are limited to occurrences within a single year, impacts on premature mortality are determined using a 20-year lag structure. For any change in premature deaths resulting from a single year of emissions, 30 percent of those deaths are assumed to occur in the first year, 50 percent occurs evenly from years two to five after the emissions year, and the final 20 percent occurs over years six to twenty.[29] Mortality changes for each year in the COBRA model were adjusted so that the REMI input reflected the change in mortality that occurs within a given year, rather than the change in mortality caused by a single year of emissions.

Six of the health impacts measured by COBRA involve admittance or visitation to a hospital. To determine the cost of hospitalization for these issues, RESI relied on health data from HCUPnet, an online system which uses data from the Healthcare Cost and Utilization Project (HCUP). Using HCUPnet, RESI obtained average hospital charges in Maryland for each of the relevant conditions.[34] For each reduced incidence of hospital admittance in the COBRA model, RESI decreased medical revenue in the REMI model by an amount equal to the average hospital charge for that condition, reallocating the revenue to consumers, government, and private insurance in proportion to their contribution to the medical bill based on payer data also provided by HCUPnet.[3]

In many cases, a health incident involving hospital admission will result in an absence from work and decreased productivity. COBRA additionally measures missed work days and restricted activity days not directly resulting from one of the other measured health impacts.[4] RESI utilized HCUPnet data to determine the average length of stay for each of the hospital admissions. The productivity gained from a reduction in missed work days was input into REMI as an equivalent increase in employment. RESI calculated the increase in employment by measuring the total reduction in missed work days against the number of active working days in a calendar year.[5]

The change to the amenity value is based on four additional health impacts in the COBRA model: acute bronchitis, upper respiratory symptoms, lower respiratory symptoms, and asthma exacerbation.[6] Since these impacts do not involve hospital admission or missed work days, they are reflected in the REMI model using a change in the amenity value for each region. The values entered into the model were taken directly from COBRA's valuation of each of the four health impacts.

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[3] Revenue was reallocated in the REMI model to insurance carriers, federal, state, and local government, and consumer spending.

[4] For RESI's model, a single restricted activity day is treated as 0.5 missed work days.

[5] Active working days exclude weekends and non-working holidays.

[6] The amenity value in REMI is a "willingness-to-pay" measure representing quality in life. For example, if a state A has cleaner air and water than state B, state A will have a higher amenity value. This higher amenity value means state A will have higher immigration rates with economic indicators changing through that avenue.

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