THE CENTER FOR
CLIMATE STRATEGIES

Comprehensive Analysis of Maryland's Short- and Long-term Climate Stabilization and Clean Energy Goals and Investment Requirements

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Technical Report

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Overview

This report by the Center for Climate Strategies (CCS) provides a comprehensive, detailed, and state of the art model of current and future greenhouse gas (GHG) emissions in Maryland, and of energy sector and non-energy activities that drive future emissions. It provides assessments of the potential for new and enhanced technologies and practices to be implemented at scale in all sectors in Maryland to reach short- and long-term state climate mitigation and clean energy goals from 2024 to 2050, including the 2031 Climate Solutions Now Act, 2035 Clean Energy Goal, 2035 and 2040 Renewable Portfolio Standard, and 2045 and 2050 Net Zero goal.

Results of the assessment indicate a strong potential for attainment of state climate mitigation and clean energy goals and targets, as well as beneficial economic and energy outcomes, while offering major savings in avoided energy and infrastructure costs equal to approximately two thirds of all new investment. Throughout the process, the assessment identifies specific challenges to attainment of emissions reduction goals related to timing of actions, the capacity of implementing organizations, and the dependence of goal attainment on favorable policy, budget, and investment conditions in Maryland.

The assessment results and tools can be used to address policy, budget, and finance needs for GHG emissions reduction in Maryland and to address the need for further development and implementation of state climate change mitigation and clean energy actions. The outputs can also be linked to other tools used to address critical policy design and implementation issues such as targeting of actions and benefits to low income and disadvantaged communities, mobilization of new investment through matching of sources, use of private and public funds in the design of blended finance mechanisms and partnerships, and detailed monitoring and evaluation of future Maryland actions — all starting from a comprehensive statewide perspective of current and future GHG emissions and their sources.

The report includes a detailed business as usual (BAU) forecast of current energy and economic trends in Maryland, state and federal policies, and energy and non-energy sector technologies and practices across all sectors through 2050 (described as Current Policies). In addition, it provides multi metric assessment of the potential impacts of a wide range of new specific actions in all sectors (described as Additional Actions) toward reaching goals and targets. The analysis includes GHG emissions reductions, social costs and benefits, and financial investment requirements for individual and aggregate actions, along with estimates of future emissions and energy use for the full range of fuels and technologies. The assessment also provides transparent assumptions, data sources, and methods.

The assessment is based on application by CCS of the Low Emissions Analysis Platform (LEAP), the most widely applied energy systems modeling platform in the world with over 46,000 users in 190 countries — complemented by the CCS GHG Strategy Tool, a transparent spreadsheet system developed through widely applied state, provincial, and city level analysis of sector level actions in all economic sectors by CCS inside and outside the US. Inputs to the assessment of BAU and new actions involved technical conferrals by CCS with a wide range of Maryland stakeholders and state and national research institutions.

Abbreviations

$	United States dollar
$B	Billions of United States dollar
$M	Millions of United States dollar
AC	Alternating Current
ACC II	Advanced Clean Cars II
AEO	Annual Energy Outlook (USDOE EIA)
AIM	American Innovation and Manufacturing Act
BES	Battery energy storage
BEV	Battery electric vehicle
Btu	British thermal unit
CAPEX	Capital expenditures (initial investment costs)
CARB	California Air Resources Board
CCS	Center for Climate Strategies
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CRF	Capital recovery factor
CSNA	Climate Solutions Now Act
DC	Direct current
EIA	USDOE Energy Information Administration
EPA	US Environmental Protection Agency
FiT	Feed-in Tariffs
FPV	Floatovoltaics
GDP	Gross domestic product
GGRA	Greenhouse Gas Reduction Act
GHG	Greenhouse gas
GHI	Global horizontal irradiance
GIS	Geographic information system
GJ	Gigajoule (billion Joules, a measure of energy)
GW	Gigawatt
GWh	Gigawatt-hour
GWP	Global Warming Potential
Ha	Hectare

HDV	Heavy-duty vehicles
HDT	Heavy-duty trucks
HH	Households
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
IPPU	Industrial processes and product use
kg	kilogram
km	kilometer
kW	Kilowatt
kWh	Kilowatt-hour
kWh/m^2	Kilowatt-hour per square meter
kWp	Kilowatt-peak
lb	Pound
LBNL	Lawrence-Berkeley National Laboratory
LCOE	Levelized cost of energy (or levelized cost of electricity)
LDA	Light-duty autos
LDT	Light-duty trucks, includes sports utility vehicles (SUVs)
LDV	Light-duty vehicles (typically, LDA plus LDT)
LEAP	Low Emissions Analysis Platform
LED	Light-emitting diode (Lighting technologies)
LFG	Landfill gas
LI	Low Income (households)
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas (a mixture of propane and butane)
LULC	Land use/land cover
m^2	Square meter
MARC	Maryland Area Rail Commuter
MCC	Maryland Climate Change Commission
MCEC	Maryland Clean Energy Center
MD	Maryland
MDE	Maryland Department of Environment
MD DHCD	Maryland Department of Housing and Community Development
MDOT	Maryland Department of Transportation
mi	Miles

$MMtCO_2e$	Million metric tons of CO_2e
MPG	Miles per gallon
MPGe	Miles per gallon equivalent (used for electric vehicles)
MSW	Municipal solid waste
MV	Medium voltage
MW	Megawatt
MWh	Megawatt-hour
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NREL ATB	NREL Annual Technology Baseline
O&M	Operations and maintenance
OPEX	Operating expenses
Pass-mi	Passenger-miles
PHEV	Plug-in hybrid electric vehicles
PJM	Pennsylvania/Jersey/Maryland regional transmission organization
POWER	Promoting Offshore Wind Energy Resources Act
PPA	Power purchase agreement
PV	Photovoltaic
PVOUT	Photovoltaic electricity output
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standard
SCC	Social cost of carbon (environmental externality adder)
SEI	Stockholm Environment Institute
SEI US	Stockholm Environment Institute United States Centre
STP	Standard temperature and pressure
T&D	Transmission and distribution
TJ	Terajoule
Tg	Teragram (10^{12} grams, or million metric tons)
TWh	Terawatt-hour (or billion kWh)
US DOE	United States Department of Energy
US EPA	United States Environmental Protection Agency
VMT	Vehicle-miles traveled
W	Watt
WACC	Weighted Average Cost of Capital
WtE	Waste-to-energy

1. Report Summary

1.1 Background and goals

Maryland has a series of current and proposed statewide climate change mitigation and clean energy goals related to greenhouse gas (GHG) emissions reductions, renewable energy expansion, and additional clean energy goals. State leadership also is sensitive to national and international climate change goals and Maryland's role in their achievement, including current steps by the US government to implement the 2015 Paris Agreement, such as the deployment of federal funding and incentives for climate mitigation and clean energy, and future steps related to the recent fossil fuel transition agreement by the 28th Conference of the Parties (COP).[1] Maryland has been actively involved in state climate leadership actions since 2008 and the advent of its first climate action plan commitment through the 2009 Greenhouse Gas Reduction Act[2] and the 2008 EmPOWER Maryland Energy Efficiency Act.[3]

Today, Maryland's short-term economy-wide climate goals focus on the target year of 2031, with mid-term goals for clean energy and renewable energy in 2035 and 2040, and a long-term goal of reaching net zero emissions by 2045. Under the State of Maryland's Climate Solutions Now Act of 2022 (CSNA), "…a target has been established at 60% (over the 2006 level) by 2031 and net-zero emissions by 2045." In December 2023 the Maryland Department of Environment (MDE) released a state climate plan and conceptual roadmap for CSNA attainment, with a further plan for reaching net zero expected in March 2024.[4] Additional current and proposed state laws, policies, and commitments related to climate change mitigation include the Maryland 2035 Clean Energy Goal and Maryland 2040 Renewable Portfolio Standard (RPS), also under consideration for 2035. The state has identified many but not all the specific sector level policies, programs, technologies, practices, and implementation mechanisms required for attainment of these goals and related social, economic, policy, and investment objectives. All are under some level of further development, assessment, and implementation inside and outside the government.

The purpose of this study is to provide a current, comprehensive, multi-objective and multi-metric assessment of specific sector-level technology and practice-based policy and program measures that can achieve short- intermediate- and long-term climate and clean energy goals. The study involved the identification and evaluation of business as usual (BAU) reference case forecasts of energy and resources sectors and subsector activities and emissions that includes current public policies and trends affecting them (Current Policies Scenario), as well as identification and assessment of new actions that build upon current conditions and actions to reach public policy goals (Additional Actions Scenario). Key impact metrics include GHG emissions reductions, energy use and energy resource impacts (including energy and resource savings), direct economic and financial costs and

MARYLAND CLIMATE AND CLEAN ENERGY GOALS:

- GHG emissions 60% below 2006 level by 2031
- Net-zero emissions by 2045
- 100% Clean Energy by 2035 (proposed)
- 100% Renewable Energy by 2040 (proposed) and 2035 (under consideration)

[1] COP28 Agreement Signals "Beginning of the End" of the Fossil Fuel Era | UNFCCC
[2] MDOT Greenhouse Gas Reduction Act (GGRA) Plan - MDOT (maryland.gov).
[3] EmPOWER Maryland
[4] State of Maryland (undated, but probably late 2023), "Climate Change Program (maryland.gov)".

savings, potential effects on low-income households and disadvantaged communities, social costs of carbon emissions reduction (SCC), and in some cases, impacts on emissions of non-GHG air pollutants.

These metrics, which are related to the costs and performance of GHG emissions mitigation actions, are a crucial first step in identifying, prioritizing, and enabling actions to be further developed and implemented through specific governance and financing mechanisms. Results of the study support a range of policy, program, and investment activities needed to fully implement Maryland climate change mitigation and clean energy goals. The development of the study involved technical collaboration and conferral with a wide range of public and private experts and stakeholders across economic sectors and technology areas in the public and private sectors and civil society.

1.2 Key Findings

- GHG emission reductions in the BAU Current Policies Scenario will be well short of reaching the goals of reducing emissions from 2006 levels by 60% by 2031 and reaching net zero GHG emissions by 2045, as well as the 2035 and 2040 clean electricity targets.
- The Additional Actions Scenario reduces 2031 emissions by more than 10 MMtCO_2e relative to Current Policies, reaching a reduction of 55% from 2006 emissions. This leaves a gap of less than 6 MMtCO_2e to meet Maryland's 2031 goal of 60% reduction relative to 2006 GHG emission. This scenario meets the 2031 goal by 2033.
- The Additional Actions case falls short of achieving net zero emissions by the end by 2045, but it comes close, with Maryland's gross GHG emissions falling from 87 MMtCO_2e in 2023 to 15 MMtCO_2e by 2050. After subtracting carbon sinks of approximately 8 MMtCO_2e provided by forests, soils, and landfills, net emissions reach about 7 MMtCO_2e by 2050.
- Under the Additional Actions Scenario, Maryland's renewable generation reaches 68% of total electricity output by 2040, with 17% of the rest being nuclear generation, and the remaining 15% derived from imports from PJM (the PA/NJ/Maryland transmission system). Assuming the RGGI (Regional Greenhouse Gas Initiative) states accomplish their clean generation goals, by 2040, Maryland's electricity would be entirely sourced from clean energy.
- By 2035, only about 3% of Maryland's in-state generation comes from fossil fuel, and the fraction of the state's overall electricity supplies that come from clean energy (nuclear, renewables, and a modest amount of biofuel) therefore depends mostly on the degree to which imports from PJM are carbon-free. Our assumption is that the effective CO_2e per MWh to generate the power imported to Maryland will fall by about two-thirds in the Additional Actions case, leaving the state at above 90% clean energy for electricity generation in 2035.
- The full implementation of these GHG emissions reduction actions, relative to the Current Policies case, results in average annual net costs of $38 million in 2024-2031, rising to $2.4 billion in 2045-2050. The overall net social costs of moving from the Current Policies case to the Additional Actions case are more than offset if a social cost of carbon in $190 per t$CO_2$e[5] is applied, resulting in an annual net benefit of over $4 billion by 2045.

[5] Values of $185 and $190 per ton, the latter in 2020 dollars, have been proposed by the US EPA. See Resources for the Future (2022), "Social Cost of Carbon More Than Triple the Current Federal Estimate, New Study Finds", dated Sept. 1, 2022 and Supplementary Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review", dated September, 2022. The latter document actually proposes a range of SCC values, rising by the

- Up front investments over this same period are estimated at $11 billion for the 2024-2031 period, with additional increments of investment of $22 billion to 2035 (4 years), $29 billion to 2040 (5 years), and $36 billion to 2045 (5 years), and $41 to 2050 (5 years). These investments will enable Maryland consumers to avoid considerable annual expenses for fossil fuels and have ancillary benefits such as reduction of local air pollution and job creation.
- Long-term investments in climate stabilization actions by Maryland are generational in nature, with benefit streams continuing for periods of 20 years or more. For instance, benefits from much of the upfront investments in the 2024-31 period extend past 2050.
- About two thirds of cumulative annualized costs over the 2024-2050 forecast period are expected to be offset by the avoidance of expenditures on fossil fuels that would occur under a BAU scenario, creating major end use savings for energy consumers and significant payback capability for long-term financing of CAPEX requirements.
- Overall investment requirements for implementation of climate stabilization and clean energy goals in Maryland are very consistent in scale with UNFCCC estimates of global investment needed to meet goals of the Paris Agreement and mid-century temperature stabilization goals.[6]
- The Low Emissions Analysis Platform (LEAP) modeling platform and database for Maryland created in this study provide a highly detailed, comprehensive identification and multi-metric assessment of end uses of funds for technologies, practices, and infrastructure in all economic sectors that enables targeted matching of sources and uses of funds, and the design of blended finance mechanisms at scale to enable full implementation of Additional Actions.

1.3 Results

1.3.1 GHG Emissions

Figures 1-1 and 1-2 show the historical (2015-2021) and projected (2022-2050) GHG emissions under the BAU Current Policies and Additional Actions Scenarios by sector. The CSNA targets are shown by the dotted line.

As shown in Figure 1-1, the 60%-reduction-by-2031 target, at just over 48 MMtCO_2e of gross emissions,[7] will not be met under current policies. Reaching that goal will require about 16 additional MMtCO_2e of annual emissions reduction actions by 2031. The graph does not show the annual net sinks (emissions reductions) from the forestry and land use (FOLU), waste management (landfill carbon storage), and Agricultural (agricultural soil carbon storage) sectors in Maryland, which are estimated at just under 8 MMtCO_2e of carbon dioxide equivalent absorbed annually. The gross emissions goal shown for Maryland in 2045 therefore is set at about 8 MMtCO_2e and, as shown in the graph, will require significant additional reductions beyond current policies across multiple subsectors for Maryland to achieve.

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year of emissions and when lower discount rates ("Near-term Ramsey Discount Rate") are used to value the economic impacts of climate damages.

[6] For more information on global climate mitigation investment requirements, see McKinsey & Company, The net-zero transition: What it would cost, and what it would bring, January 2022.

[7] Note that this goal has been adjusted, relative to a goal strictly based on MDE gross emissions from the (updated) 2006 inventory, to account for the difference in the way the modeling reported here counts CO2 emissions from waste-to-energy (WTE) plants (as 70% biogenic emissions) and landfills (100% biogenic) and the convention used in MDE reporting (all carbon emissions from waste counted as if they were fossil-based emissions). This adjustment reduces the 2031 emissions target by about 0.6 MMtCO_2e, from 48.7 to 48.1 MMtCO_2e gross emissions.

Similarly, the Additional Actions case falls short of achieving net zero emissions by the end by 2045, but it comes close, with Maryland's gross GHG emissions falling from 87 MMtCO$_2$e in 2023 to 15 MMtCO$_2$e by 2050. After subtracting carbon sinks of approximately 8 MMtCO$_2$e provided by forests, soils, and landfills, net emissions reach about 7 MMtCO$_2$e by 2050.

Figure 1-2 also shows that emissions from energy supply are near zero by 2040. Under this scenario, Maryland's renewable generation reaches 68 percent of total electricity output by 2040, with 17 percent of the rest being nuclear generation, and the remainder imports from PJM, which, assuming the RGGI states accomplish their clean generation goals, would also presumably be also generated exclusively (or almost exclusively) using renewables and nuclear power. As such, by 2040, Maryland's electricity use would be entirely from clean energy sources.

Figure 1-1: Maryland GHG Emissions by Sector under the BAU Current Policies Scenario

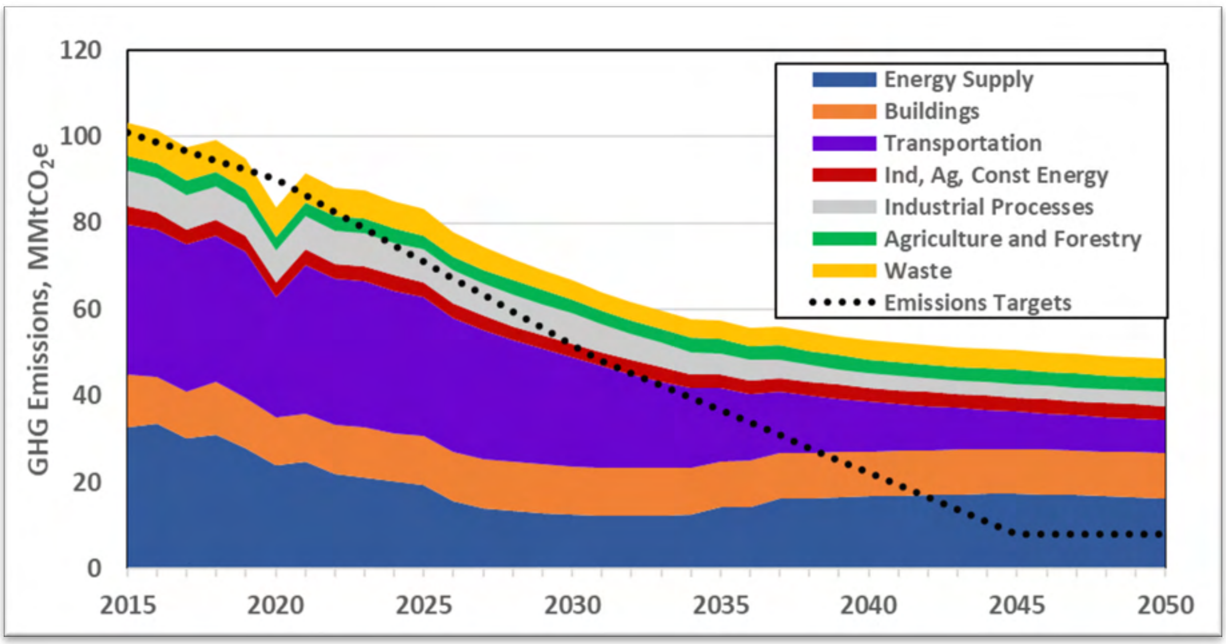
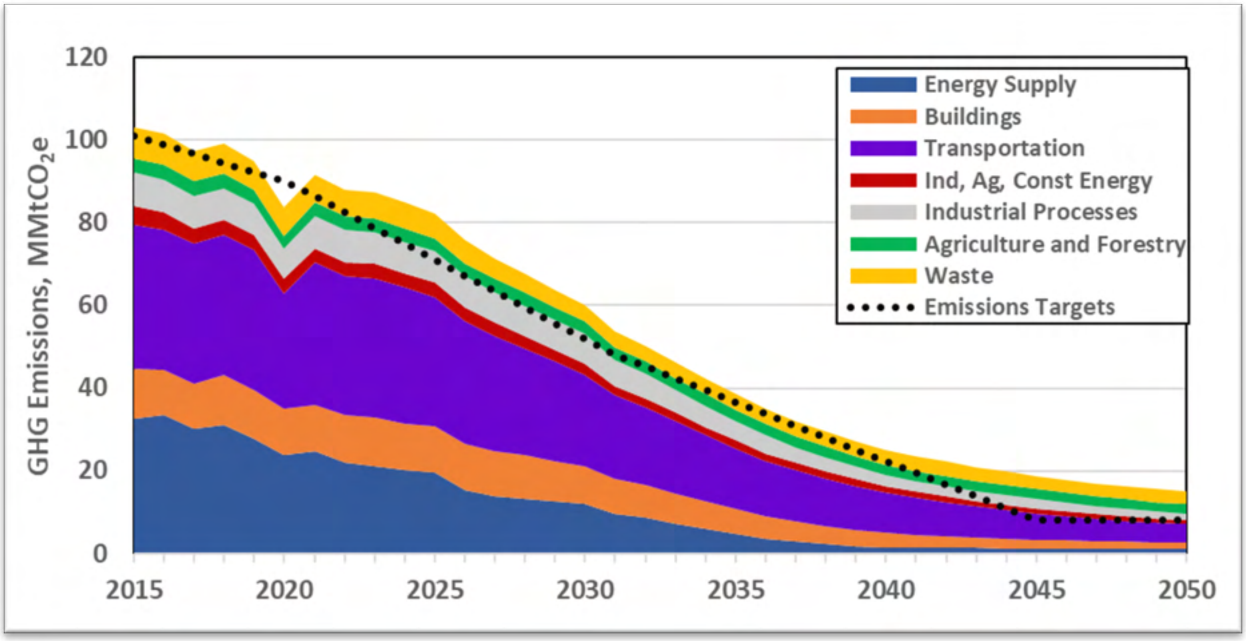


Figure 1-2: GHG Emissions by Sector in the Additional Actions Case



1.3.2 Costs and Benefits

The figures and tables below show detailed cost results for net annual social costs and investments alongside the emission reductions for each type of technology or activity. Net social costs include a combination of economic costs and benefits involving those affected by policy and its implementation when viewed from the perspective of government and society. Investment requirements include the net financial costs of investments for technology, infrastructure, and other fixed expenses (also known as capital expenditures or CAPEX) as well a variable and ongoing expenses for operations and inputs to production, including acquisition of fuels (also known as operating expenditures or OPEX) viewed from the perspective of implementers and investors. Note that of necessity this study has evaluated the costs shown in the figures and tables below based on current published estimates for technology costs. As policies such as those associated with the Additional Actions case are deployed in Maryland and elsewhere around the country and around the world, it is likely that the incremental costs of emissions-reducing actions relative to business-as-usual will drop, and the benefits—in terms of avoided fossil fuel (and fossil fuel supply-chain) costs—may rise. Costs may fall as those organizations manufacturing, installing, financing, and operating low-carbon technologies and systems become accustomed to deploying and using low-carbon approaches, and find perhaps unexpected efficiencies in low-carbon approaches.

The net social costs of the Additional Actions Scenario are shown In Table 1-1. Net social costs here are defined as the incremental annualized costs (including annualized investment plus annual operation and maintenance costs) of additional actions relative to costs of the activities in particular sectors that are included in the Current Policies case. Social costs are computed for each year and separately for each type of device, vehicle, and for which the Additional Action scenario differs from the Current Policies case, meaning that both costs (for example, higher sales of electric trucks) and benefits (for example, reduction of purchases of diesel trucks) of the additional actions are counted. Social costs also include savings in fuel costs, such as for Current Policies purchases of gasoline, diesel, natural gas, and imported electricity avoided by the measures (shown as a reduction in cost of "Fuels and Electricity" in the Additional Actions Case.

Net social costs add to $38 million in 2031, rising to $2.4 billion annually by 2050. About **two thirds of cumulative annualized costs over the 2024-2050 forecast period are ultimately offset by the avoidance of expenditures on fossil fuels that would occur under a BAU scenario**, creating major end use savings for energy consumers and significant payback capability for long-term financing of CAPEX requirements. If the social cost of carbon (set at $190 per ton), the net total costs of the additional actions are strongly negative, indicating an annual net **benefit** of almost $2 billion in 2031 to almost $4 billion by 2045.

Table 1-2 and Figure 1-3 show estimated net investment costs for the Additional Actions case relative to the Current Policies case for the forecast period split into five time periods corresponding to upcoming state goals and targets. Investment costs are generally higher than social costs in the periods shown because the full cost of purchase or installation is shown in the year of implementation rather than financed over the life of the equipment or project. In addition, total investment costs do not net out benefits such as fuel cost savings.

The total net investment costs required for the additional actions sum to about $11 billion for the 2024-2031 period, with additional increments of investment of $22 billion to 2035 (four years), $29 billion to 2040 (five years), and $36 billion to 2045 (five years), and $41 billion to 2050 (five years), with a total of $139 billion over the entire 2024-2050 period. Once again, even though these figures include neither benefits related to avoided fuel costs nor benefits related to avoided GHG emissions, these total investment costs represent a small fraction of Maryland's economic output, even by 2050. To provide some perspective on what seems to be a very large number, $139 billion **represents just under one percent of total projected Maryland GDP** over the 2024-2050 period. The additional costs of mitigating climate change are thus quite small when compared with the size of Maryland's economy and BAU spending within sectors.

In most cases the entities—private or public—that make investments in GHG emissions reduction would typically be financing the costs through multiple sources of investments. For example, investments in new rooftop or utility-scale solar power are likely to be financed by banks or other sources of commercial capital, and thus the actual outlays in any given year by the entities owning new or upgraded facilities will be functions of the interest rate secured through financing, the amount of down-payment required/provided by consumers or investors, and other factors. For public institutions, the actual annual outlay will be a function again of financing available, for example, using state or municipal bonds or debt and equity from private or public entities, as well as contributions to the GHG emissions-reduction investments secured through federal programs.

Figure 1-3. **Estimated Investment Costs by Time Period Relative to Current Policies**

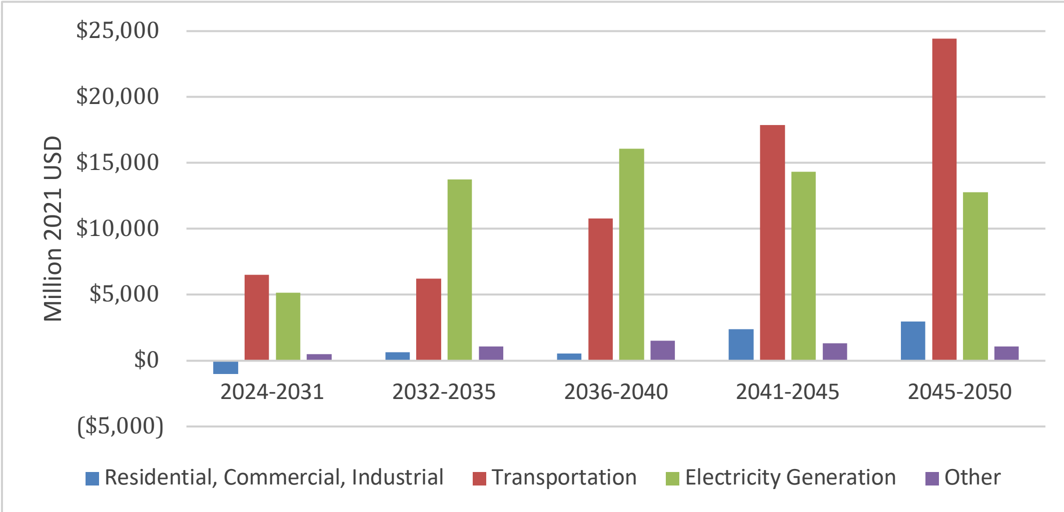


Figure 1-4. **Estimated Annual Emission Reductions Relative to Current Policies**

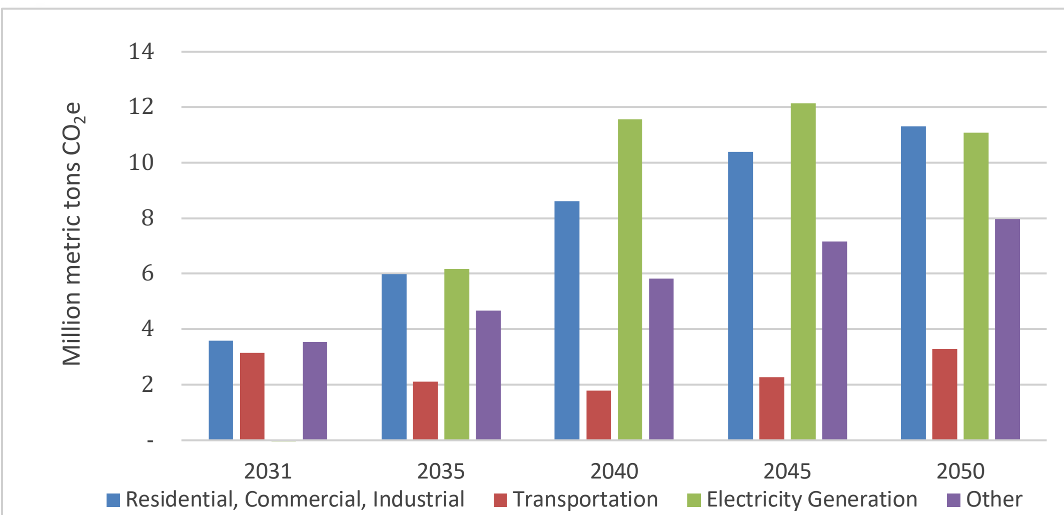


Table 1-1: Summary of Annual Social Costs Results of Additional Actions Case Relative to Current Policies Case

CATEGORY	Estimated Annualized Costs (Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]					Annual Emission (Million tCO_2e) Reduction				
	2024-2031	2032-2035	2036-2040	2041-2045	2045-2050	2031	2035	2040	2045	2050
Energy Demand (Equipment/Infrastructure) [ii]	**$166**	**$430**	**$576**	**$901**	**$1,180**	**-6.7**	**-8.1**	**-10.4**	**-12.7**	**-14.6**
Residential Space Heating / Air Conditioning [iii]	($16)	($19)	($36)	($14)	($9)	-1.0	-1.7	-2.6	-3.2	-3.4
Residential Water Heating	$0	($5)	($13)	($7)	($2)	-0.7	-1.1	-1.3	-1.3	-1.4
Residential Cooking and Clothes Drying	($0)	($1)	($2)	($1)	($1)	0.0	0.0	-0.1	-0.2	-0.2
Commercial Space Heating / Air Conditioning [iii]	$36	$68	$72	$102	$111	-0.7	-1.3	-2.0	-2.5	-2.7
Commercial Water Heating	$1	$1.7	$1.3	$0.9	$0.4	-0.1	-0.2	-0.3	-0.3	-0.3
Commercial Cooking	$10	$52	$70	$70	$74	-0.1	-0.3	-0.7	-0.8	-0.9
Transportation--Additional Heavy Truck Electrification	$3	$7	$4	$4	$4	-0.2	-0.3	-0.5	-0.8	-1.1
Transportation--EV Charging Infrastructure (Bus, Heavy Truck)	$0	$1	$7	$18	$30					
Transportation--VMT reduction: Expansion of Transit	$110	$212	$258	$381	$472	-2.9	-1.8	-1.2	-1.4	-2.1
Transportation--VMT reduction: E-bikes	$22	$108	$207	$338	$489					
Industry--Cement Kiln Electrification and Electrical Efficiency	$0	$1	$2	$2	$2	-0.6	-0.6	-0.6	-0.6	-0.6
Industry--Other Electrification and Efficiency	$1	$3	$5	$7	$9	-0.3	-0.6	-0.9	-1.2	-1.5
Agriculture, Construction, Mining	$0	$0	$0	$0	$0	-0.1	-0.2	-0.2	-0.3	-0.4
Energy Supply (Equipment/Infrastructure) [ii]	**$200**	**$1,180**	**$2,924**	**$4,369**	**$5,537**	**-2.7**	**-9.4**	**-15.2**	**-16.1**	**-15.1**
Transmission and Distribution	$22	$49	$63	$63	$63	-0.5	-0.9	-1.2	-1.4	-1.5
LNG Exports	$0	($3)	($3)	($3)	($3)	-1.9	-1.9	-1.9	-1.9	-1.9
Rooftop Solar	$32	$127	$232	$424	$696	0.0	-6.2	-11.6	-12.2	-11.1
Electricity Generation--Offshore Wind	$2	$472	$1,652	$2,636	$3,388					
Electricity Generation--Solar	$66	$234	$376	$522	$593					
Electricity Generation--Storage	$96	$386	$549	$697	$826					
Electricity Generation--Avoided Fossil	($17)	($126)	($226)	($302)	($375)					
Electricity Generation--Calvert Cliffs Life Extension	$0	$47	$269	$305	$314					
Electricity Generation, Retirement of Waste-to-Energy Plants	($3)	($21)	($21)	($21)	($21)					
Electricity, Other	$3	$14	$22	$31	$36					
Biogas Production	$0	$3	$8	$12	$16	*Emission Reductions shown under Non-Energy*				
Other Energy Supply	($1)	($3)	$2	$2	$2	-0.2	-0.4	-0.5	-0.5	-0.5

CATEGORY	Estimated Annualized Costs (Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]					Annual Emission (Million tCO_2e) Reduction				
	2024-2031	2032-2035	2036-2040	2041-2045	2045-2050	2031	2035	2040	2045	2050
Non-Energy Sources	**($4)**	**($17)**	**($22)**	**($15)**	**($5)**	**-0.8**	**-1.5**	**-2.2**	**-3.3**	**-3.9**
Enteric Fermentation Mitigation	($7)	($26)	($42)	($51)	($54)	-0.1	-0.2	-0.3	-0.4	-0.4
Agricultural Soils	$3	$6	$7	$9	$10	0.0	-0.1	-0.1	-0.1	-0.1
Manure Digesters	*Costs shown under Energy Supply - Biogas Production*					0.0	-0.1	-0.1	-0.2	-0.3
WWTP Biogas						-0.2	-0.5	-0.8	-1.4	-1.4
Composting and Increased Landfill Gas Control	$0	$1	$2	$4	$4	-0.4	-0.2	0.0	0.0	-0.1
Cement Clinker Substitution and CCS	$0	$2	$11	$23	$36	-0.2	-0.5	-0.8	-1.1	-1.6
Fuels and Electricity Cost/Savings	**($328)**	**($290)**	**($1,789)**	**($3,096)**	**($4,277)**	Emission Reductions show up under Energy Demand and Energy Supply				
Primary, Natural Gas	($55)	($273)	($394)	($443)	($463)					
Primary, Nuclear	$0	$13	$92	$103	$103					
Secondary, Biogas	$1	$3	$1	($1)	($2)					
Secondary, Diesel	$16	($14)	($100)	($262)	($456)					
Secondary, Gasoline	($8)	($20)	($31)	($44)	($58)					
Secondary, Ethanol and Gasohol E10	($472)	($581)	($406)	($302)	($271)					
Secondary, Jet Kerosene	($95)	($168)	($216)	($284)	($386)					
Secondary, Sustainable Aviation Fuel	$37	$78	$123	$158	$217					
Secondary, Electricity	$0	($1)	($62)	($363)	($1,008)					
Secondary, Imported Electricity	$250	$692	($762)	($1,608)	($1,895)					
Secondary, Other	($3)	($18)	($34)	($49)	($57)					
OVERALL ESTIMATED TOTAL	**$38**	**$1,320**	**$1,711**	**$2,175**	**$2,440**	**-10.2**	**-18.9**	**-27.8**	**-32.0**	**-33.6**
Implied Net Cost per tCO2e Reduced	**$4**	**$70**	**$62**	**$68**	**$73**					
Social Cost of Carbon at $195 per tCO_2e	**($1,947)**	**($3,599)**	**($5,281)**	**($6,074)**	**($6,392)**					
Net Cost Including Social Cost of Carbon	**($1,909)**	**($2,279)**	**($3,569)**	**($3,900)**	**($3,951)**					

[i] Annual average costs for the period indicated; includes annualized investment and annual operation and maintenance costs. Costs shown are incremental to the Current Policies Scenario.

[ii] Includes the incremental costs or savings of new equipment or infrastructure relative to the Current Policies Scenario. Any costs or savings related to changes in fuel or electricity consumption are shown under the Fuels and Electricity heading.

[iii] Costs for space heating/air conditioning equipment include both the incremental costs of installing heat pumps instead of fossil fuel equipment as well as the savings associated with not needing to purchase separate air conditioning equipment. Note that for individual buildings there may be up-front costs, since space heating equipment may need to be replaced before air conditioning equipment has reached the end of its life.

Table 1-2: Estimated Net Investment Costs for Additional Actions Case Relative to Current Policies Case

CATEGORY	Estimated Investment Costs (Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]					Annual Emission (Million tCO_2e) Reduction				
	2024-2031	2032-2035	2036-2040	2041-2045	2045-2050	2031	2035	2040	2045	2050
Energy Demand (Equipment/Infrastructure) [ii]	**$5,484**	**$6,871**	**$11,345**	**$20,236**	**$27,362**	**-6.7**	**-8.1**	**-10.4**	**-12.7**	**-14.6**
Residential Space Heating / Air Conditioning [iii]	($1,169)	($669)	($1,654)	($609)	($371)	-1.0	-1.7	-2.6	-3.2	-3.4
Residential Water Heating	$224	($17)	($336)	($84)	($123)	-0.7	-1.1	-1.3	-1.3	-1.4
Residential Cooking and Clothes Drying	($12)	($25)	($95)	($62)	($51)	0.0	0.0	-0.1	-0.2	-0.2
Commercial Space Heating / Air Conditioning [iii]	($907)	($732)	($804)	($377)	($288)	-0.7	-1.3	-2.0	-2.5	-2.7
Commercial Water Heating	$74	$91	$94	$76	$50	-0.1	-0.2	-0.3	-0.3	-0.3
Commercial Cooking	$689	$1,861	$3,119	$3,097	$3,295	-0.1	-0.3	-0.7	-0.8	-0.9
Transportation--Additional Heavy Truck Electrification	$163	$324	$489	$660	$745	-0.2	-0.3	-0.5	-0.8	-1.1
Transportation--EV Charging Infrastructure (Bus, Heavy Truck)	$0	$35	$328	$807	$1,344					
Transportation--VMT reduction: Expansion of Transit	$4,991	$2,559	$1,956	$3,326	$3,451	-2.9	-1.8	-1.2	-1.4	-2.1
Transportation--VMT reduction: E-bikes	$1,346	$3,321	$8,007	$13,063	$18,869					
Industry--Cement Kiln Electrification and Electrical Efficiency	$18	$13	$24	$33	$42	-0.6	-0.6	-0.6	-0.6	-0.6
Industry--Other Electrification and Efficiency	$66	$110	$216	$305	$398	-0.3	-0.6	-0.9	-1.2	-1.5
Agriculture, Construction, Mining	$0	$0	$0	$0	$0	-0.1	-0.2	-0.2	-0.3	-0.4
Energy Supply (Equipment/Infrastructure) [ii]	**$5,651**	**$14,742**	**$17,456**	**$15,459**	**$13,803**	**-2.7**	**-9.4**	**-15.2**	**-16.1**	**-15.1**
Transmission and Distribution	$322	$877	$1,179	$1,011	$898	-0.5	-0.9	-1.2	-1.4	-1.5
LNG Exports	$38	$0	$0	$0	$0	-1.9	-1.9	-1.9	-1.9	-1.9
Rooftop Solar	$938	$1,191	$1,594	$3,169	$3,898	0.0	-6.2	-11.6	-12.2	-11.1
Electricity Generation--Offshore Wind	$211	$8,630	$11,738	$8,690	$6,737					
Electricity Generation--Solar	$1,516	$1,427	$1,580	$1,448	$1,318					
Electricity Generation--Storage	$2,495	$2,631	$1,928	$1,746	$1,566					
Electricity Generation--Avoided Fossil	($86)	($158)	($792)	($794)	($733)					

CATEGORY	Estimated Investment Costs (Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]					Annual Emission (Million tCO_2e) Reduction				
	2024-2031	2032-2035	2036-2040	2041-2045	2045-2050	2031	2035	2040	2045	2050
Electricity, Other	$74	$22	$51	$55	($0.6)					
Biogas Production	$21	$22	$71	$42	$42	*Emission Reductions shown under Non-Energy*				
Other Energy Supply	$124	$99	$107	$92	$78	-0.2	-0.4	-0.5	-0.5	-0.5
Non-Energy Sources	**$13**	**$82**	**$144**	**$186**	**$74**	**-0.8**	**-1.5**	**-2.2**	**-3.3**	**-3.9**
Enteric Fermentation Mitigation	$0	$0	$0	$0	$0	-0.1	-0.2	-0.3	-0.4	-0.4
Agricultural Soils	$0	$0	$0	$0	$0	0.0	-0.1	-0.1	-0.1	-0.1
Manure Digesters	*Costs shown under Energy Supply - Biogas Production*					0.0	-0.1	-0.1	-0.2	-0.3
WWTP Biogas						-0.2	-0.5	-0.8	-1.4	-1.4
Composting and Increased Landfill Gas Control	$13	$8	$29	$0	$0	-0.4	-0.2	0.0	0.0	-0.1
Cement Clinker Substitution and CCS	$0	$73	$115	$186	$74	-0.2	-0.5	-0.8	-1.1	-1.6
OVERALL ESTIMATED TOTAL	**$11,148**	**$21,694**	**$28,944**	**$35,881**	**$41,239**	**-10.2**	**-18.9**	**-27.8**	**-32.0**	**-33.6**

[i] Cumulative investments costs for the period indicated. Costs shown are incremental to the Current Policies Scenario.

[ii] Includes the incremental costs or savings of new equipment or infrastructure relative to the Current Policies Scenario. Any costs or savings related to changes in fuel or electricity consumption are shown under the Fuels and Electricity heading.

[iii] Costs for space heating/air conditioning equipment include both the incremental costs of installing heat pumps instead of fossil fuel equipment as well as the savings associated with not needing to purchase separate air conditioning equipment. Note that for individual buildings there may be up-front costs, since space heating equipment may need to be replaced before air conditioning equipment has reached the end of its life.

1.4 Actions Included in the Analysis

1.4.1 BAU Baseline with Current Policies

Current and recent policies included in the Current Policies case (BAU baseline) are listed below and described in more detail in the full technical report. Based on review and assessment, including federal guidelines, they include the following actions:[8]

Energy Supply

- Solar Carve out (Utility capacity expansion limited by PJM interconnection approval process)
- Community Solar system deployment
- RGGI RPS (Regional Greenhouse Gas Initiative renewable portfolio standard) goals, but only to extent modeled in Annual Energy Outlook 2023 (AEO or AEO2023)[9]
- Planned retirements of coal-fired power plants
- Calvert Cliffs nuclear units assumed retired in 2034/36
- Promoting Offshore Wind Energy Resources (POWER) Act offshore wind expansion
- Implementation of energy storage

Buildings, Facilities, and Industry

- Continue implementation of EmPOWER, the electric utility-sponsored program for supporting energy efficiency improvements in the residential, commercial, and industrial sectors
- State and Montgomery County Building Energy Performance Standards
- All-electric Building Codes in Montgomery and Howard Counties
- AIM (American Innovation and Manufacturing) Act and MD HFC Regulations (non-energy industrial emissions reduction)

Transportation

- Implementation of Advance Clean Cars II (ACC II) rules
- CAFE (corporate average fuel economy) Standards, as included in AEO2023 modeling
- Advanced Clean Trucks (ACT) Rule
- WMATA (Washington Metro Transit Authority) vehicle electrification
- MTA (Maryland transit authority) vehicle electrification
- Construction of the Purple Line electrified light rail system
- Other ongoing trends and policies (some national and international), including motorcycle electrification, growth of e-bike usage, air transport electrification and use of sustainable aviation fuel, other transport electrification, ongoing electrification of lawn and garden equipment, and use of alternative fuels for marine shipping

Non-energy Sectors

- State 2035 Waste Generation and Diversion Goals
- MD Landfill Methane Rule
- Maryland 5 Million Tree Program

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[8] The Current Policies Scenario was based on state and federal projections as well as current state policies, as presently funded and as projected to be implemented. The Current Policies scenario was assembled by working with climate stakeholders in Maryland and including input from Maryland GHG emissions modeling efforts by other groups. More details of this process are provided in the full technical report for this study.

[9] US Department of Energy, Energy Information Administration, Annual Energy Outlook 2023

1.4.2 Additional Actions beyond BAU

The GHG emissions reduction actions included in the Additional Actions case -- although not fully exhaustive of all actions in all sectors Maryland could take to reduce emissions -- include reduction measures across virtually all applicable technologies and best practices and initiate substantial transformation of several economic sectors in Maryland towards environmental sustainability. A summary list of the elements of the Additional Actions case is provided below. Specific sector level actions evaluated through LEAP and GHG Strategy Tool modeling for short- and long-term goal attainment are included within the following sectors:

Buildings Sector

- **Low Income (LI) Electrification**: Replaces fossil fuel space heating and water heating devices with heat pump devices in low-income households, with 60% of such households electrified by 2031 (starting from a baseline of 31%), and 100% by 2040.
- **All Electric Building Code Expansion**: Follows the assumptions of all electric building code policies developed for Montgomery and Howard County but extends those assumptions to the entire state. Assumes all new buildings and major renovations are all-electric.
- **Building Energy Performance Standards**: Extends assumptions in the Current Policies Scenario by assuming that 20% reduction in heating and cooling energy use is achieved by 2030 and reduces the minimum size of buildings (multifamily residential and commercial/institutional) covered by the policy in increments through 2031, ultimately covering buildings of floor area 10,000 square feet and greater.
- **EmPOWER Restructuring**: Starting in 2025, fossil fuel equipment stocks are reduced by 1.9% each year, replaced through sales of electric equipment meeting the same end-uses. This program is assumed to replace the existing electric utility-run, energy-efficiency focused EmPOWER program.
- **Zero NOx Appliance Standards**: Assumes sale shares of all fossil fuel residential and commercial space heaters, water heaters, stove, and clothes dryers go to zero, with shares of electric equipment (using a range of technologies) rising to 100%, by 2031.

Transportation Sector

- **Vehicle Miles Traveled (VMT) Reduction**: Assumes that vehicle miles traveled in light duty vehicles are reduced by 20% relative to the Current Polices case as of 2031, starting in 2025, and continues to decrease to 75% of Current Polices levels by 2050. A small portion of the passengers displaced from light duty vehicles are shifted to passenger rail and e-bikes, with about half accommodated by greater use of an expanded bus fleet. The rest of the displaced trips are assumed to be accounted for by more trips on foot or non-motorized bikes and scooters, increased vehicle occupancy (carpooling), and other changes that do not add to transportation energy use.
- **Additional HDV, Bus, and Heavy Equipment Electrification**: Assumes that truck electrification, rather than plateauing in 2035 as in the Current Policies case, reaches 80% of vehicles sold in 2036, and continues through 2050, reaching 100% (sum of battery electric, diesel plug-in hybrid vehicles, and gasoline plug-in hybrid vehicles) by that year.

- **Rail Electrification**: Assumes that 50% of MARC trains are electrified by 2031,[10] increasing to 100% by 2050, and that 25% of rail freight is electrified by 2031, increasing to 75% by 2050.
- **Freight Mode Shift and Rail Freight Electrification**: Assumes that 10% of 2021 Maryland road freight is shifted to rail by 2031, and 25% by 2050, starting in 2026. In addition, we assume, as above, that 75% of rail freight in Maryland is electrified by 2050, starting in 2025.
- **Other Transportation Electrification**: Assumes that electrification increases in Marine Watercraft and Recreational Equipment to 15% by 2030 and 70% by 2050, and in Lawn and Garden Equipment to 50% by 2030 and 90% by 2050.
- **Air Transport Improvements and Sustainable Aviation Fuel:** Assumes that the aircraft and operations improvements in the Federal Aviation Administration's, *United States 2021 Aviation Climate Action Plan* are achieved,[11] increasing efficiency relative to the Current Policies case, and that 50% of jet fuel used is "sustainable aviation fuel" by 2050, as in one of the scenarios in the FAA report. Once again, these improvements may be encouraged by Maryland, but will not occur without coordinated national, and in fact, international action.

Industrial Sector

- **Cement Sector Electrification**: Substitution of electricity for natural gas and coal use to provide heat in cement kilns. All the kilns operated by Maryland's two cement producers are assumed converted by 2031.
- **Cement Clinker Substitution**: Assumes expanded use of "clinker" (the main component of cement) substitutes in cement blending, with 35% of clinker substituted for by 2050.
- **Industrial Energy Efficiency and Electrification**: Assumes energy efficiency improvements in electricity end-uses of 10% by 2050, relative to the Current Policies, case, in non-cement industries and for electricity use in the cement industry and assumes that 80% of motor fuel and natural gas use in non-cement industries is replaced with electricity by 2050.

Energy Supply

- **Utility Solar Expansion**: Assumes that restrictions on approval of PJM (and local) solar capacity expansion are lifted such that the amount of capacity listed in the current PJM queue as "Active" (a little less than 4000 MW, including existing capacity) is deployed by 2031, and that capacity continues to increase, more or less linearly based on annual deployment in 2025-2031 (500 MW added/year), through 2050, to over 13,000 MW by 2050.
- **Expanded Offshore Wind**: Assumes that offshore wind power development proceeds as per existing state goals, that is, rises to 8500 MW by 2040, but then continues to rise to 11,000 MW by 2045 and 13,000 MW by 2050.
- **Calvert Cliffs Life Extension**: Assume that both units at the Calvert Cliffs Nuclear Plant will have their lifetimes extended through at least 2050. This will represent the second extension for the Calvert Cliffs units, which were built in the 1970s.

[10] Up from an estimated 28% in 2023, based on activity on the electrified Penn Line, although that is a very rough approximation that should be revised through consultation with transport officials. MARC is the "Maryland Area Rail Commuter."

[11] Federal Aviation Administration (FAA, 2021), *United States 2021 Aviation Climate Action Plan*.

- **RGGI Net Zero Generation by 2040:** Assumes that a zero CO_2e emissions goal from generation is reached by 2040 by the RGGI states, and thus by the states exporting power to Maryland, and as a result the emission factor for CO_2e per MWh of imported electricity falls to zero by 2040, with a phase-in period starting after 2025.
- **Rooftop Solar Expansion**: Assumes that a combination of incentives, falling costs for rooftop and community solar, willingness to raise net metering caps, support for siting of rooftop and community solar, and increased effort at developing the rooftop solar industry in Maryland results after 2025 in annual growth in rooftop solar roughly a third higher than projected in the AEO2023 reference case over 2021-2050. This results in total solar rooftop capacity (including community solar, some of which may not be strictly roof-mounted) of nearly 6000 MW by 2040, and over 10,000 MW by 2050.
- **Expanded Electricity Storage**: Assumes that policies are implemented such that current state target for storage deployment (3000 MW by 2033) is reached, and that decreasing electricity storage costs, state and federal incentives for deployment, and active assistance with siting results in a total of 7000 MW deployed by 2050.[12]
- **Natural Gas Generation Retired**: Assume that natural gas-fired capacities in the state (combined cycle, steam turbine, and combustion turbine) are trended from their existing levels in the RPL case to zero as of 2036, starting in 2028. Oil-fired plants, which operate at very low-capacity factors even in the Current Policies case, are assumed to be retired on the same schedule as well.
- **Retirement of Waste to Energy (WTE) Generation**: Assumes that the state's two major WTE (Waste-to-Energy) plants, Wheelabrator Baltimore and Montgomery County, are retired at the end of 2030, with the heat demand now provided to the "Baltimore Steam Loop" by the Baltimore plant to be provided by a new electric heat pump-driven district energy plant.[13]
- **Liquefied Natural Gas (LNG) Liquefaction Electrification**: Assumes that starting in 2031 the Cove Point LNG plant uses electricity for its natural gas liquefaction "train" rather than burning natural gas in combustion turbines that drive compressors.[14]

Non-Energy Emissions Sources

- **Methane Capture from Landfills**: Assumes that landfills in Maryland increase the rate at which methane is captured to 80% (from 75% under the current rule) by 2031, with the captured gas used for electricity generation.
- **Expanded Composting**: Assumes that the state capacity for composting will increase to 750,000 tons per year by 2045.
- **Biogas Production and Use**: Assumes that anaerobic waste treatment of livestock wastes and sewage, producing biogas (a mixture of methane and CO_2) that is captured for use, are expanded such that 70% of dairy and poultry wastes by 2045 and all of sewage treated with anaerobic digestion (16.3% according to the MDE inventory) are covered by these systems. The biogas produced is used to generate electricity for the central power grid.

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[12] Note that this scenario also includes the assumptions of the offshore wind and utility solar expansion cases, as renewables charging capacity is otherwise insufficient to charge this much storage.

[13] Wastes no longer used in the WTE plants is treated with a combination of landfilling and composting, with about 80% of landfill emissions captured and used as fuel gas. Note that this option also provides important non-GHG pollutant emissions reductions, including for low-income communities.

[14] Electrification is implemented all at once, just before 2031, as Cove Point has just one liquefaction train, but there may be ways of phasing in electrification. Investment costs for electrification will be significant, but natural gas savings (or revenues for additional LNG exports) will be substantial, and there will also be offsetting O&M savings.

- **Enteric Methane Mitigation**: Assumes that 100% of dairy and feedlot beef cattle will be given feed additives to reduce enteric methane production by 2045.
- **Biofertilizer:** Assumes that biofertilizer, defined as products containing live microorganisms applied to soil, seeds, or plants, improved nutrient availability and uptake reducing the need for chemical fertilizers, will be used on 80% of cropland currently using synthetic fertilizer by 2045.
- **Soil Management Program:** Assumes that conservation crop rotation and cover crop usage will be expanded to an additional 250,000 acres each by 2050.

1.5 Methods and General Approach

1.5.1 Modeling Tools

Evaluation of the Current Policies and Additional Actions cases (scenarios) has been carried out using LEAP, which is an accounting-based energy and economic systems modeling tool, augmented with the use of the Excel-based CCS GHG Strategy Tool for non-energy sectors.[15] The scenario descriptions and results provided, in aggregate and by sector, describe the estimated GHG emissions reductions, energy demand impacts, and energy supply changes from implementing a set of additional actions beyond recent policies in Maryland, which we refer to as "Additional Actions." These results focus on non-cost impacts of the scenarios (energy use or production by fuel and sector, and resulting GHG emissions), but also provide a set of estimates summarizing cost impacts, including social costs and investment costs, of GHG-reduction actions beyond current policies that will likely be required to move Maryland closer to its climate mitigation goals.

1.5.2 General Approach

The general approach, modeling methods, and data sources for this study are described in detail in the Appendix to this report. The general approach used for this analysis is as follows:

- As the basis for the BAU **Current Policies** case, CCS has adapted national and regional projections from US Department of Energy (USDOE) Energy Information Administration (EIA) most recent (2023) Annual Energy Outlook (AEO) to simultaneously include the projected trends in technology, energy-using activities, and other parameters in AEO2023 on a Maryland-specific basis, and to also reflect the US federal policies affecting the energy sector that are implicit to the Reference case modeling in AEO2023.
- Some current policies were determined to be currently under implementation, but at a level that is unlikely to achieve the full targeted emission reductions by the stated target date. These policies were in many cases included in the model but assuming a partial emissions reductions level or later dates of full implementation. These cases are described in the sector-level tables provided in section 4.
- CCS and the experts and stakeholders consulted, including Maryland stakeholders, adapted the approach used by USDOE EIA to determine how to model Maryland current policies by considering first whether a given policy was sufficiently fully enacted as of the time of modeling (including in April/May of 2023) to be considered certain or highly likely to come into effect. We then considered whether the policy had sufficient funding, if needed, and the regulatory authority to be fully implemented. We also considered whether those agencies responsible for implementing certain policies were likely to have sufficient staffing and organization to implement the policy to the degree and on the timescale implied by the policy.

[15] For more detail and an overview on the GHG Strategy Tool, see the CCS 'Tools' page.

- Finally, for the Current Policies case, we considered whether there were major barriers to the implementation of policies that, in the estimation of the experts consulted, including in the Maryland stakeholder working groups, would prevent those policies from being fully developed during the expected period. Examples of such barriers could include institutional or legal hurdles to implementation, or likely market or technical impediments to full implementation.
- With the Current Policies case completed as a point of departure, a list of **Additional Actions** was compiled and elaborated. These Additional Actions were models in a set of about 25 different LEAP scenarios that were then compiled to form the overall Additional Actions case. Each scenario includes changes from Current Policies case conditions with respect to the timing and/or extent of deployment and/or other attributes of technologies—ranging from appliance electrification to electric heavy-duty trucks and distributed solar generation—tracks the cost of implementing the scenario and allows calculation of the emissions impacts of the scenario. The collective emissions impacts and costs of scenarios assembled into the Additional Actions case are also calculated and are often different from the simple sum of individual scenario impacts due to interactions between scenarios.[16]
- For several non-energy sources of GHG emissions in Maryland, CCS used its Excel-based **CCS GHG Strategy Tool** to catalog current emissions and sinks and project changes in those emissions. Those results were imported into LEAP, which has the facility to track and report emissions from non-energy as well as energy sectors, although in some cases the GHG Strategy Tool enables more detailed evaluation of current and future emissions than is readily possible in LEAP alone. The combination of the two tools in this way allows comprehensive reporting of GHG emissions and sinks in Maryland from the LEAP model for the Reference/Current Policies case and for the individual LEAP scenarios that together form the Additional Actions case.

1.5.3 Key Data and Information Sources

CCS's development of the LEAP dataset in use in Maryland began with an older LEAP dataset prepared by the firm E3 for the Maryland Department of Environment for the modeling of the Maryland Greenhouse Gas Reduction Act (GGRA). CCS has updated this dataset to include information on energy demand and supply activities through the year 2021, as available. CCS has also expanded and elaborated the structure of the model to include detail on additional sectors and end-uses, as well as to model the impact of current Maryland, and in some cases regional, policies.

In addition to the LEAP dataset inherited by CCS as described above, CCS has used the following major sources of information on energy use, economic activities, demography, and GHG emissions in Maryland, in some cases with adjustments to national and regional data for use in the Maryland model:

- AEO2023 inputs and Reference case results, in some cases, available by region. In some cases, where applicable, results of other AEO2023 scenarios were also consulted.[17]
- MDE GHG inventories for 2014, 2017, and 2020.[18]

[16] For a detailed explanation of how individual and collective actions are calculated using the LEAP model, see the LEAP MACC Report page.
[17] For example, USDOE EIA (2023), "Annual Energy Outlook 2023, Table 54. Electric Power Projections by Electricity Market Module Region, Case: Reference case, Region: PJM / East", was used as a starting point for future trends in the Maryland electricity sector.
[18] See, Maryland Department of Environment, Greenhouse Gas Inventory.

- USDOE EIA historical energy use statistics, by fuel types and sector at the state level.[19]
- Other USDOE and EPA statistics, as well as statistics from other federal agencies such as the US Department of Transportation (USDOT) and the Federal Highway Administration.[20]
- National and regional results of the USDOE surveys of energy use in the residential (RECS), commercial (CBECS) and manufacturing sectors (MECS).[21]
- State of Maryland Statistics, including population, state output, and many others.[22]
- County-level statistics for Maryland.
- Websites of counties and local agencies, including transportation agencies and systems such as the Maryland Department of Transportation (MDOT), the Maryland Transit Administration (MTA) and the Maryland Area Rail Commuter (MARC) train system.[23]
- Inputs and results of Maryland applications of the USEPA's US State Energy Data System (SEDS).
- Inputs and outputs of other modeling tools applied to energy-using sectors in Maryland, such as for transportation subsectors.
- Statewide and county websites describing current climate and energy policies, as well as other existing and planned activities and infrastructure, such as plans for transportation systems.
- Existing analyses of climate and energy policies on the national and state levels.
- Cost projections for renewable and other energy technologies from the National Renewable Energy Laboratory (NREL) and others.[24]
- Information from news articles and the academic literature, including, for example, information on plans for industrial plants.

The above presents only a subset of the information sources consulted to prepare the Maryland LEAP model. More details are provided in the Appendix to this report.

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[19] For example, the USDOE EIA (2023) publishes statistics on natural gas use by state as "Natural Gas Consumption by End Use", with annual Maryland data through 2022.
[20] For example, USDOT Federal Highway Administration Policy and Governmental Affairs, Office of Highway Policy Information (2023), Highway Statistics 2021 [and earlier versions of same], dated February 2023.
[21] The periodic national and regional surveys of energy use are provided as USDOE EIA (various years), "Residential Energy Consumption Survey (RECS)", "Commercial Buildings Energy Consumption Survey (CBECS)", and "Manufacturing Energy Consumption Survey (MECS)". In general, CCS used results from the smallest available region that included Maryland to inform LEAP modeling. Data from these surveys adapted for use in LEAP included shares of fuel use by end use, energy intensities, and other information.
[22] For example, Maryland State Archives (2023), "MARYLAND AT A GLANCE, ECONOMY, MANUFACTURING", dated September 25, 2023.
[23] For example, MDOT/MTA (2021), *Rebuilding Better: Committed to an Equitable Transit Future*, September, 2021.
[24] NREL (2023), "Electricity Annual Technology Baseline (ATB) Data Download".

2. Introduction

2.1 Setting of Study

Although Maryland is one of the smallest US states by land area, ranking 42nd overall,[25] and is home to just under 6.2 million people,[26] ranking 19th among states,[27] Maryland's gross domestic product in 2022 was just over 480 billion dollars, ranking it 17th.[28] Maryland once had a number of large manufacturing centers, including hosting what was the world's biggest steel plant along the Baltimore waterfront.[29] Over the last few decades Maryland has transitioned to a largely service-oriented economy, with manufacturing accounting for just over six percent of GDP in 2022, while, for example, the combination of finance/insurance and real estate plus government services accounted for over 40 percent of GDP.

From an energy supply/demand perspective, Maryland uses about five times more energy than it produces, with imports of fossil fuels from elsewhere in the nation and from abroad augmenting modest in-state coal and natural gas production and electricity generation from renewable sources. Most of Maryland's fossil fuel production is in the Appalachians portion of the state, in Maryland's western region. Maryland uses about 60 percent more electricity than it generates, with imports from the PJM (Pennsylvania/Jersey/Maryland) grid[30] supplementing in-state production of electricity mostly from nuclear power (the 1700 MW Calvert Cliffs generating station, on Chesapeake Bay), and from a growing fleet of natural gas-fired plants. Coal-fired generation provided about 14 percent of Maryland's in-state power by 2021, having fallen from over 60 percent in 2002 as much of Maryland's coal-fired capacity has been retired. About 12 percent of Maryland's in-state electricity generation came from renewable resources in 2021, with over 40 percent of that coming from the nearly century-old Conowingo hydroelectric plant.[31] Although Maryland contains many rapidly growing areas, particularly those on the outskirts of the Washington DC metro area, it also includes areas where buildings and other infrastructure are older and less efficient, including in low-income urban and rural areas.[32]

Under the State of Maryland's Climate Solutions Now Act of 2022 (CSNA), "…a target has been established at 60% (over the 2006 level) by 2031 and net-zero emissions by 2045". The Maryland Department of Environment (MDE) delivered the Maryland Climate Pollution Reduction Plan in

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25 Wikipedia (2023), "List of U.S. states and territories by area".
26 The estimated population of Maryland as of July 2022 was 6,164,660 according to the United States Census Bureau (2022), "QuickFacts, Maryland".
27 World Atlas (2023), "US States By Population".
28 Wikipedia (2023), "List of U.S. states and territories by GDP", and based on data from the US Bureau of Economic Analysis (2023) "GDP by State".
29 See, for example, J.M. Giordano (2019), "Shuttered: Images from the Fall of Bethlehem Steel", note on an exhibition at the Baltimore Museum of Industry, and Stephen Winick (2017), "Industrial Boom and Bust: the living heritage of the Sparrows Point Steel Mill (Baltimore, MD)", Library of Congress Blogs, dated May 4, 2017. A new chapter in the life of the Bethlehem Steel site appears to be about to begin, however, as a portion of the site is set to become the location for Sparrows Point Steel, at which US Wind will manufacture components for wind power systems. See, for example, Laurelle Stelle (2023), "Decrepit steel mill that once was the world's largest getting a surprising second life: 'A welcome and positive rebirth'", *TCD*, dated December 10, 2023.
30 PJM is a regional transmission operator serving 13 eastern and midwestern states and the District of Columbia. See "PJM: Who We Are".
31 See USDOE Energy Information Administration (EIA, 2023), "Maryland State Profile and Energy Estimates" last updated November 17, 2022.
32 Examples of low-income rural areas include those served by the Maryland Rural Development Commission (MRDC), mostly in western Maryland and in counties on the eastern shore of the Chesapeake. See, for example, MRDC (undated), "About MRDC".

December 2023[33], with Maryland's Priority Climate Action Plan expected in March 2024.[34] GHG emissions reductions of 60 percent are to be measured relative to the 2006 gross GHG emissions as listed in the MDE GHG Inventory for that year (updated). As the 2006 MDE inventory estimated "20-year GWP" GHG emissions in Maryland at 121.68 million metric tons carbon dioxide equivalent ($MMtCO_2e$), the implied gross emissions target for Maryland based on the CSNA in 2031 is 48.67 $MMtCO_2e$. Further reduction to "net zero" GHG emissions by 2045 implies gross emissions (net of projected forest growth and other carbon sinks) must be reduced to about 8 $MMtCO_2e$ in that year (and thereafter).

2.2 Goals of Study

Several statewide policies have been promulgated in Maryland to move toward reductions in the state's GHG emissions. Many of these policies adapt or adopt policies from other states, and/or build upon US Federal policies. What has been unclear, to date, is the degree to which policies recently enacted, together with trends in various sectors of the economy responsible for emissions of GHG emissions, will allow Maryland to approach or meet emissions reduction goals for 2031, 2045/2050, and years in between. Determining how current policies, as presently funded and implemented, will contribute to Maryland's CSNA goals is crucial to the next step in climate mitigation policy development and implementation in the state and in determining what additional policies need to be implemented to reach the CSNA goals. Establishing the extent to which current policies will contribute to achieving Maryland's climate change mitigation goals has been a key goal of and milestone in the study undertaken by the Center for Climate Strategies (CCS) and the model for this scenario is described in this Report as the "Current Policies" scenario.

The next step, and a key goal of this study, was identification of a set of "Additional Actions" for climate mitigation implementation in the next two-plus decades, and estimation of the impacts of those actions and their costs relative to Current Policies. CCS did this by working with a group of stakeholders and incorporating examples and ideas from other emissions reduction studies and groups working toward climate change mitigation, including new and enhanced versions of existing actions. The team developed a set of scenarios for emissions reduction, spanning the Maryland energy demand and supply sectors, including non-energy GHG emissions sources, and evaluated them individually and in aggregate.

For both the Current Policies and Additional Actions cases, evaluation has been carried out using an accounting-based modeling tool called the Low Emissions Analysis Platform (LEAP),[35] augmented with the use of the Excel-based CCS GHG Strategy Tool for non-energy sectors.[36] The scenario descriptions and results provided in this Report, in aggregate and by sector, describe the estimated GHG emissions reductions, energy demand impacts, and energy supply changes from implementing a set of additional actions beyond recent policies in Maryland, and are referred to as Additional Actions. Most of these actions are based on policies suggested by organizations participating in climate change policy fora in Maryland,[37] with some added by the CCS modeling team based on additional technical input and

[33] Maryland Department of the Environment (2023) "Maryland Climate Pollution Reduction Plan".
[34] State of Maryland (undated, but probably late 2023), "Climate Change Program".
[35] LEAP is developed and maintained by the Stockholm Environment Institute-US Center. See the Overview and Software Download pages for more information.
[36] See, for example, CCS (2021), "New CCS Desktop GHG Strategy Tool Kickstarts Decarbonization Pathways," dated October 18, 2021.
[37] A number of the Additional Actions included in this analysis have had their genesis or been refined in discussions with Maryland stakeholders and others participating in Technical Working Group and other discussions organized by the Maryland stakeholders, as well as with experts from Maryland and beyond. Variants of the Additional Actions have been included in other modeling efforts undertaken by or on behalf of Maryland agencies, as well implemented in, planned, or suggested for implementation in other jurisdictions.

expertise as consistent with and/or beneficial to reaching Maryland's emissions reduction goals. Comparing the results of the Additional Actions case to the Current Policies case, including results for energy use by sector, production of fuels and other forms of energy (such as electricity and heat) to meet energy demand, GHG emissions, and costs provides estimates of the degree to which additional climate change mitigation actions help to meet state emissions targets, and what the cost-effectiveness of those actions are likely to be.

The overall goals of this study have therefore been to:

- **Update and elaborate a model of emissions of GHG emissions in** Maryland from energy and non-energy sources that comprehensively tracks the use of fuels and other energy forms from each of Maryland's economic sectors and key energy infrastructure, as well as related activities in Maryland that contribute to GHG emissions. The LEAP (Low Emissions Analysis Platform) modeling tool was used along with CCS' GHG Strategy tool to project energy use and non-energy activities, and to estimate current and future GHG emissions.
- Estimate the extent to which **policies recently enacted**, together with existing trends in the various sectors of the economy, **will allow Maryland to approach or meet its emissions reduction goals** for 2031 and 2045 (as well as intervening years and through 2050), as a crucial step to evaluating what additional policies will need to be implemented to reach the CSNA goals, as well as other state climate goals such as renewable portfolio standards and clean energy targets. This analytical step involved the definition and development of a **Current Policies** Scenario of energy and non-energy GHG emissions and associated activities for the state of Maryland, with projections through the year 2050.
- Consult existing lists of potential GHG emissions mitigation measures, actions, and policies (many of which overlap) for Maryland, and working with stakeholders, **to develop estimates of how additional actions and policies that could be implemented** by the State and Federal governments, as well as by the private sector, could affect Maryland's future economy wide GHG emissions. This work resulted in the **Additional Actions** Scenario of energy and non-energy GHG emissions and associated activities for the state of Maryland, with projections also through the year 2050.
- **Estimate the direct economic costs of the Additional Actions** case and its elements (individual actions or groups of actions) **relative to the Current Policies** case to estimate the annualized total social costs and investment costs required to implement the suite of Additional Actions.

CCS hopes that the work described in this Report will be built upon, in collaboration with Maryland officials and other stakeholders, to augment, refine the evaluation of, and plan implementation of additional actions to help Maryland address and ultimately achieve its climate change mitigation goals.

2.3 Additional GHG emissions modeling efforts in Maryland

Previous studies, including a recent study by the University of Maryland's Center for Global Sustainability commissioned by MDE,[38] have addressed the potential of current policies and additional actions to make progress on Maryland's climate change mitigation goals. These studies have used

[38] Kathleen M. Kennedy, Alicia Zhao, Steven J. Smith, Kowan O'Keefe, Bradley Phelps, Shannon Kennedy, Ryna Cui, Camryn Dahl, Sarah Dodds, Shawn Edelstein, Shelby Francis, Eshna Ghosh, George Hurtt, Daraius Irani, Lei Ma, Yang Ou, Ruisha Praisa, Amber Taylor, Aishwary Trivedi, Nicholas Wetzler, Jared Williams, Nathan Hultman (2023), *Maryland's Climate Pathway: An Analysis of Actions the State Can Take to Achieve Maryland's Nation-Leading Greenhouse Gas Emissions Reduction Goals*, University of Maryland's Center for Global Sustainability, dated June, 2023.

modeling approaches, including largely econometric approaches, that are different than the largely accounting-based modeling of climate action benefits and costs described in this report. These different modeling approaches also provide valuable and complementary perspectives on climate change policy in the state, and CCS has benefited greatly in the development of the work described here from exchanging views on climate policy modeling with the University of Maryland team and others.

3. Summary Comparison of Current Policies and Additional Actions Scenarios

The differences between the Current Policies and Additional Actions Scenarios—the latter a composite case composed of the 25-plus individual action scenarios—represent the benefits and costs of implementing a set of additional GHG emissions reduction actions over and above the impacts and costs of current BAU policies and underlying trends. The Current Policies and Additional Actions cases result in different levels and types of energy use, electricity generation and other energy supply activities, GHG emissions, and social costs and benefits, and requirements for investment. This section focuses on key differences between the two cases. The Current Policies and Additional Actions Scenarios are described in detail in Sections 4 and 5.

3.1 GHG Emissions

The combination of the Additional Actions beyond the Current Policies case reduces 2031 emissions by more than 10 million metric tons of carbon dioxide equivalent (MMtCO_2e), as shown in Figure 3-1 and Figure 3-2 below. This leaves a gap of less than 6 MMtCO_2e to meet Maryland's 2031 goal of 60 percent reduction relative to 2006 GHG emission levels as estimated by MDE. With continued progress, this scenario does, however, **meet the 2031 goal by 2033**.

The model results show impacts through 2050, often by extending impacts of proposed policies through 2050. Overall, relative to the Current Policies case, the additional actions reduce Maryland's GHG emissions by nearly 34 MMtCO_2e/year by 2050, and by a cumulative 530 MMtCO_2e from 2024 through 2050.

The Additional Actions Scenario's deep emissions reductions occur throughout the Maryland economy. Figure 3-3 shows emissions reductions from energy demand sectors totaling over 14 MMtCO_2e by 2050, with significant emissions reductions in residential and commercial, transportation, and industrial emissions. An additional 15 MMtCO_2e of GHG emissions reductions (Figure 3-4) come from energy supply actions by 2050. Emissions reductions from electricity generation are the most substantial, but also significant are emissions reductions from LNG exports and from natural gas T&D, due to reduced natural gas consumption. About 4.0 MMtCO_2e of GHG emissions reductions come from reductions in non-energy emissions, as shown in Figure 3-5.

In Figure 3-2 below and later figures, *Demand* includes primary energy demand (electricity and fuels) in buildings, transportation, industry, agriculture, construction. *Energy Supply* (referred to as "transformation" in LEAP, because energy supply processes transform a resource or fuel into one or more fuels, such as in oil refining or electricity generation and/or move a fuel from place to place) includes electricity generation, transmission and distribution of electricity and natural gas, and fossil fuel supply. *Non-energy* refers to all emissions not directly related to energy supply or demand, including industrial processes and product use, agriculture, and waste management.

Figure 3-1: GHG Emissions in the Additional Actions Case

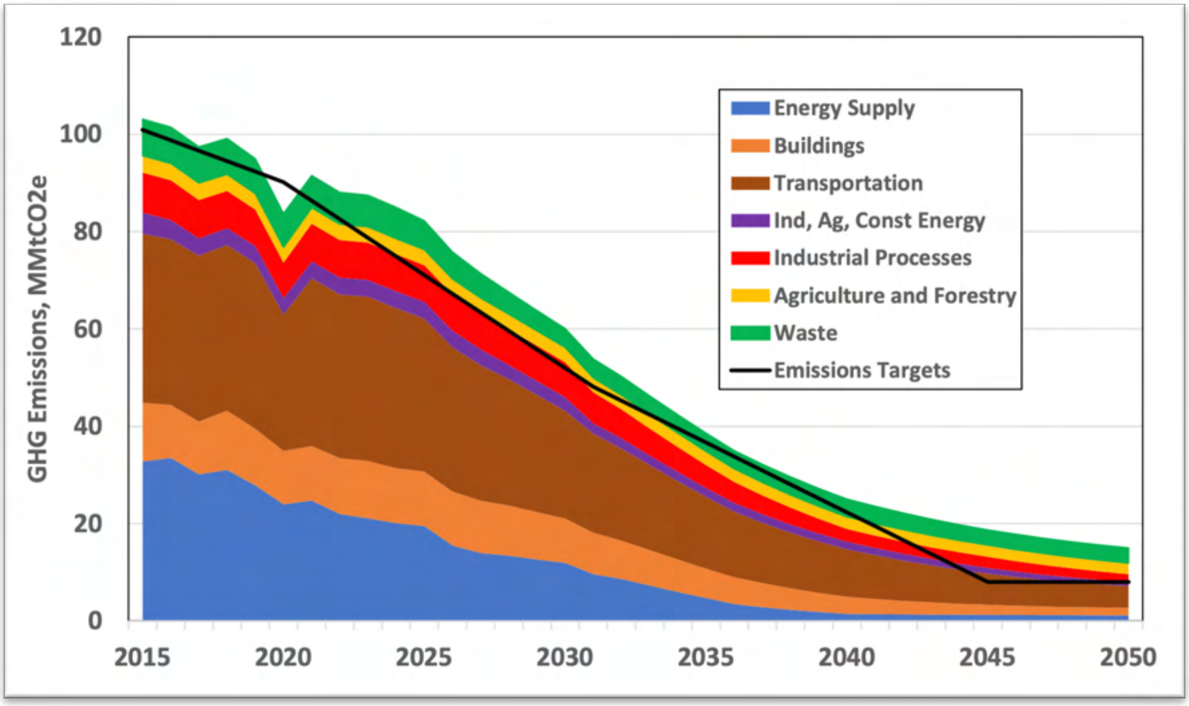


Figure 3-2: Emissions Reductions from Additional Actions Relative to the Current Policies Case

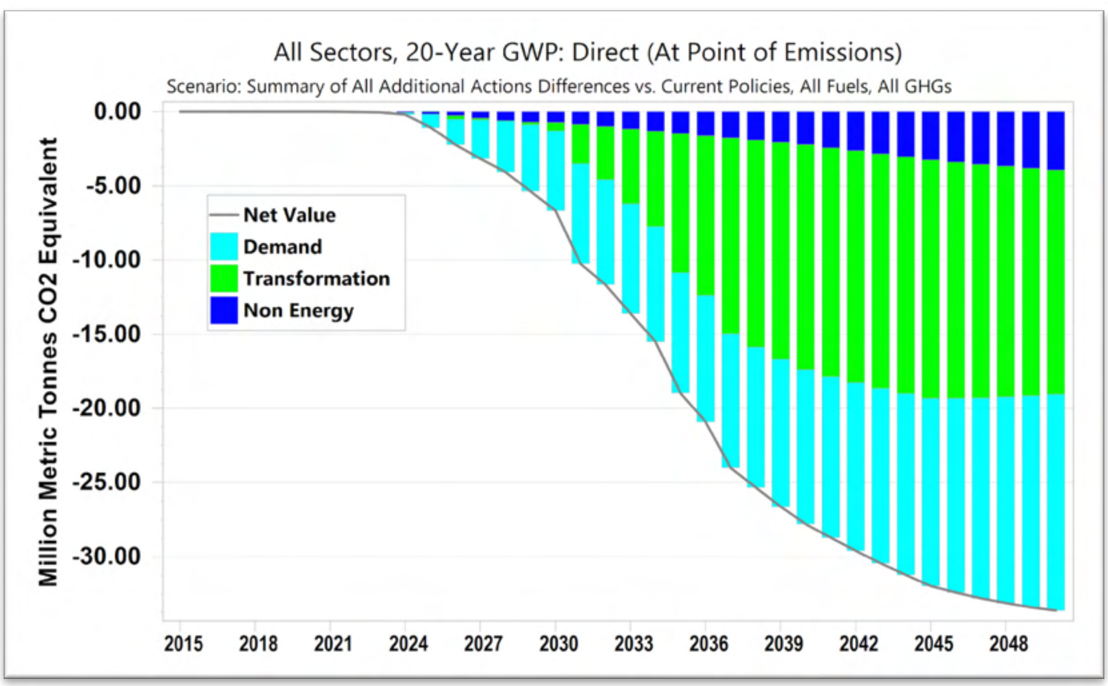


Figure 3-3: Energy Demand Emissions Reductions from Additional Actions Relative to the Current Policies Case

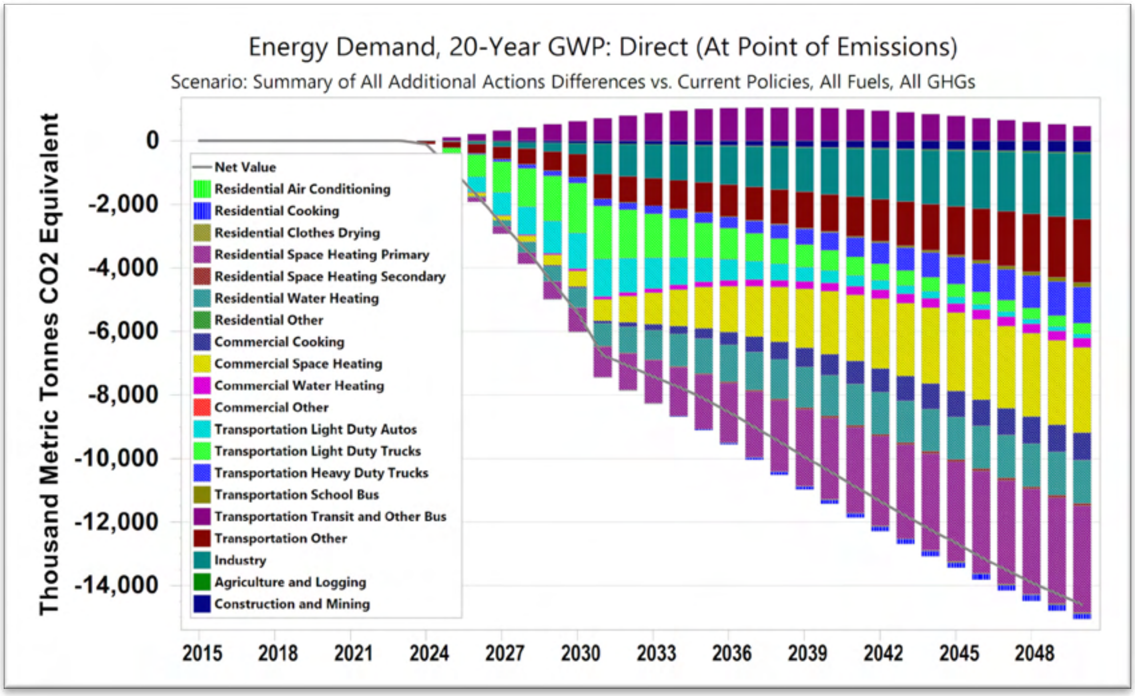


Figure 3-4: Energy Supply Emissions Reductions from Additional Actions Relative to the Current Policies Case

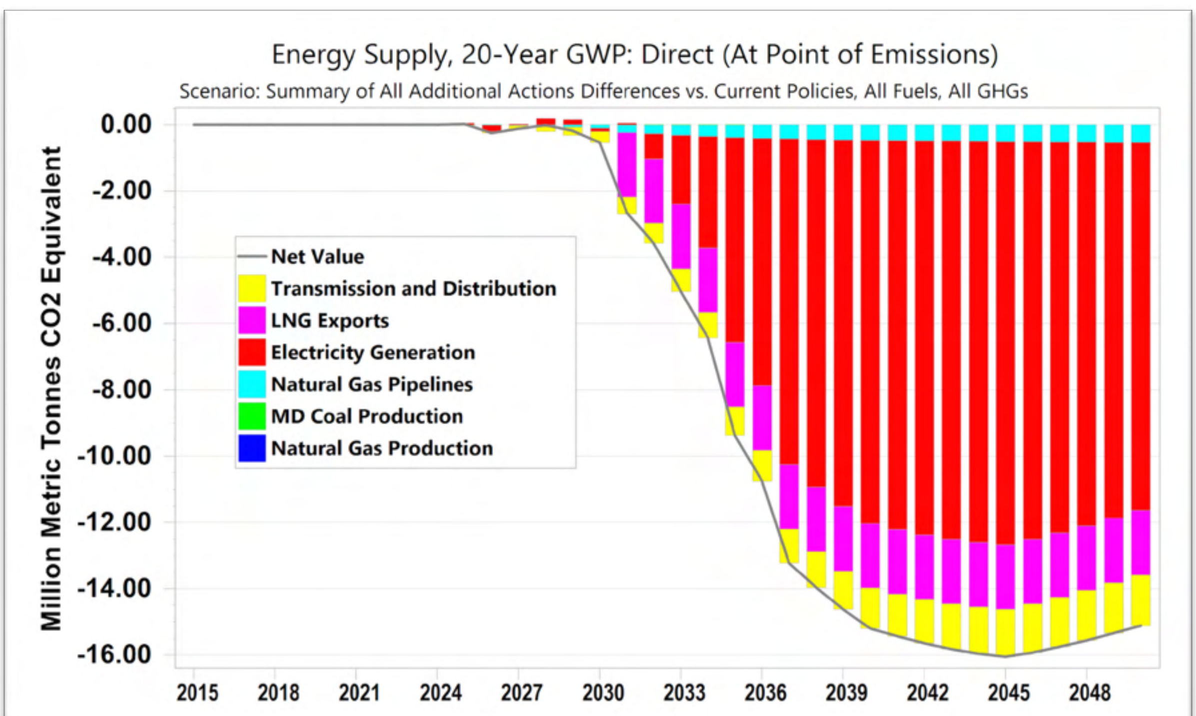
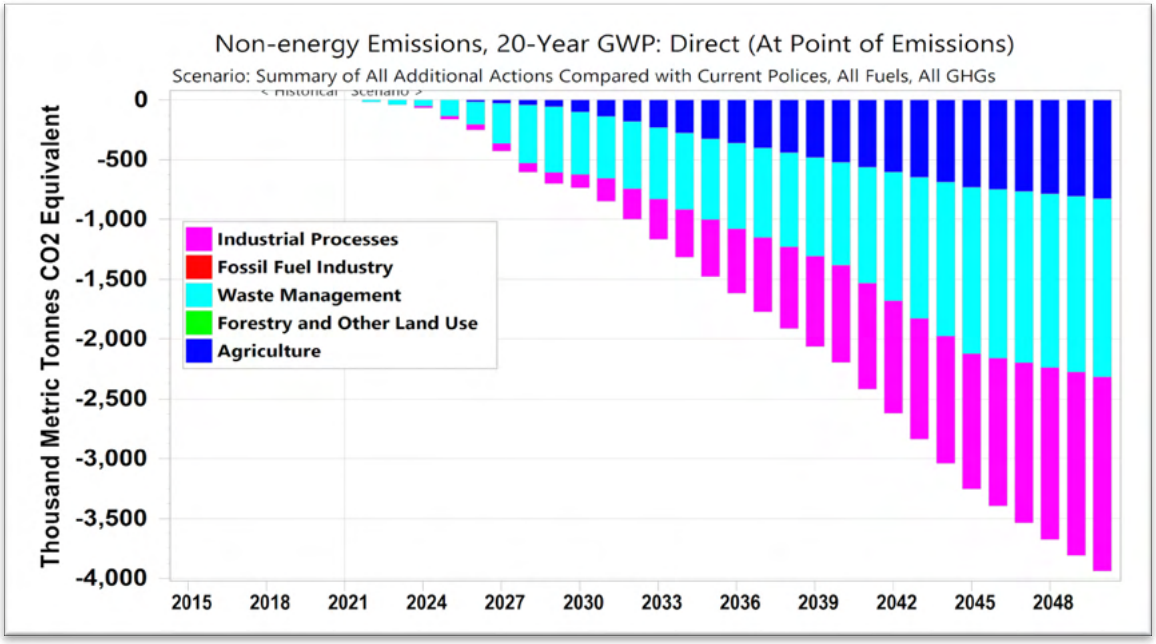


Figure 3-5: Non-energy Supply Emissions Reductions from Additional Actions Relative to the Current Policies Case



3.2 Social costs and benefits

The net social costs of the Additional Actions Scenario, relative to the Current Policies case, are shown through 2050 in Figure 3-6. Social costs here are defined for most actions as the sum of the incremental annualized net costs and savings (including annualized investment plus annual operation and maintenance costs as well as avoided costs) of additional actions relative to costs of the activities in particular sectors that are included in the Current Policies case. For example, when the Additional Actions case calls for additional deployment of community solar in 2040, relative to the Current Policies case, the social cost difference shown will include an annualized cost (similar to a mortgage payment) for the additional megawatts of community solar deployed through 2040 that includes the capital (investment, or CAPEX costs) of the additional community solar deployed, financed at a specified interest rate—typically five percent per year on a real basis—plus the additional operations and maintenance costs for those additional community solar systems.

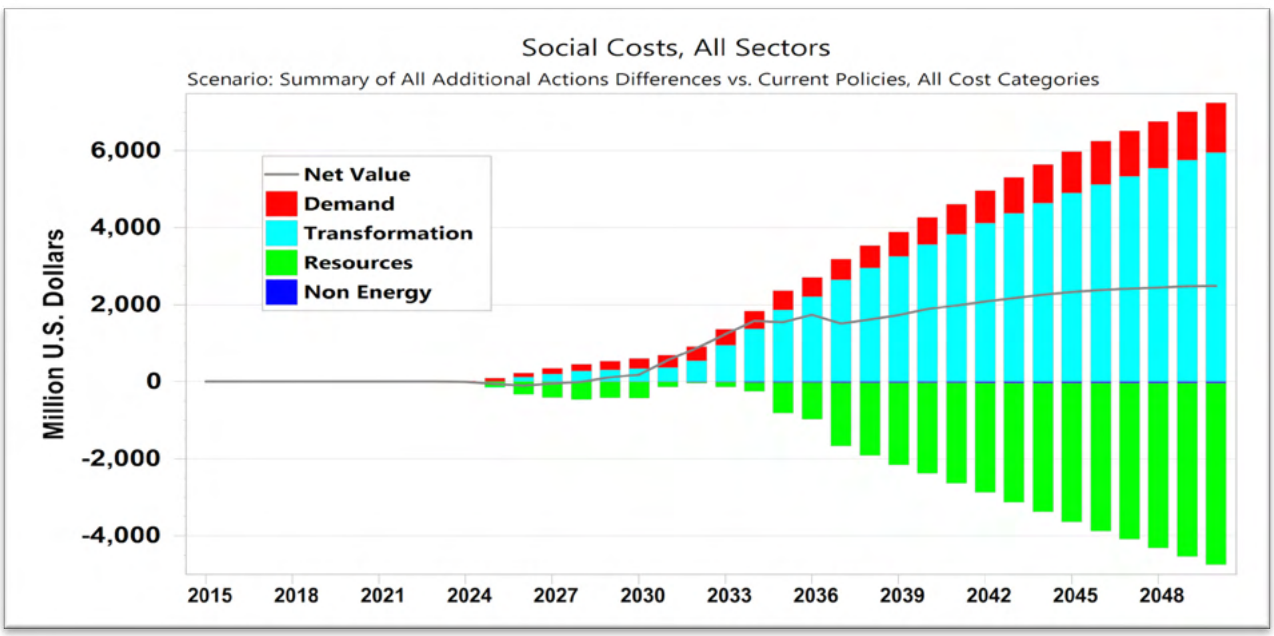
Social costs are computed for each year over the life of the project and its investment horizon and are calculated separately for each type of device (for example residential heat pumps), vehicle (for example, electric autos), and process (for example, offshore wind power plants) for which the Additional Action scenario differs from the Current Policies case. The project and investment periods for Additional Actions ranges from 10 to 20 years and averages 12-15 years for most. Both costs (for example, higher sales of electric trucks) and benefits (for example, reduction of purchases of diesel trucks) of the additional actions are counted. Social costs also include savings in fuel costs, such as for Current Policies purchases of gasoline, diesel, natural gas, and imported electricity avoided by the measures (shown as a reduction in cost of “Resources” in the Additional Actions Case).

Overall, the results shown in Figure 3-6 indicate that the GHG savings provided by the Additional Actions case are produced at an average undiscounted net cost that exceeds the direct benefits of the actions, about \$70 (2021 dollars) per tCO_2e avoided. However, this calculation **does not include any benefits of**

GHG emissions reductions or other environmental benefits. If a higher environmental adder is included—for example, a value of $190 per ton CO_2e has been floated by the USEPA as representative of damages potentially caused by climate change—this results in the net benefits of the measures included in the Additional Actions Scenario vastly outweighing the costs of those actions.[39] The negative "resource" costs shown in Figure 3-6 represent the value of purchases of fuels and resources—mostly gasoline, diesel, and natural gas—that are avoided in the Additional Actions case relative to the Current Policies case, a level of about two thirds of all investment required for Additional Actions. Note that these net savings to the state's consumers—over $4 billion per year by 2050—are valued at wholesale fuel costs and would be roughly twice as much if valued at the retail costs that consumers pay at the pump or through their natural gas bills.

Table 3-1 shows a summary of net annual social costs by major element of the Additional Actions case, split into five time periods within the forecast period to correspond with upcoming state goals and targets. Net annual social costs add to $38 million in the 2024-2031 period, rising to $2.4 billion annually by 2050. If CO_2e emissions are costed at $190 per ton, the net total costs of the additional actions are strongly negative, indicating a net benefit through 2031 of over $4.2 billion relative to the Current Policies case. If the social cost of carbon is set at $190 per ton, the net total costs of the additional actions are strongly negative, indicating an annual net benefit of almost $2 billion in 2031, and almost $4 billion by 2045.

Figure 3-6: Social Cost of Additional Actions Relative to the Current Policies Case, All Sectors



[39] Values of $185 and $190 per ton, the latter in 2020 dollars, have been proposed by the US EPA. See Resources for the Future (2022), "Social Cost of Carbon More Than Triple the Current Federal Estimate, New Study Finds," dated Sept. 1, 2022 and Supplementary Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review," dated September, 2022. The latter document proposes a range of SCC values, rising by the year of emissions and when lower discount rates ("Near-term Ramsey Discount Rate") are used to value the economic impacts of climate damages.

Table 3-1: Summary of Annual Social Costs Results of Additional Actions Case Relative to Current Policies Case

CATEGORY	Estimated Annualized Costs (Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]					Annual Emission (Million tCO_2e) Reduction				
	2024-2031	2032-2035	2036-2040	2041-2045	2045-2050	2031	2035	2040	2045	2050
Energy Demand (Equipment/Infrastructure) [ii]	**$166**	**$430**	**$576**	**$901**	**$1,180**	**-6.7**	**-8.1**	**-10.4**	**-12.7**	**-14.6**
Residential Space Heating / Air Conditioning [iii]	($16)	($19)	($36)	($14)	($9)	-1.0	-1.7	-2.6	-3.2	-3.4
Residential Water Heating	$0	($5)	($13)	($7)	($2)	-0.7	-1.1	-1.3	-1.3	-1.4
Residential Cooking and Clothes Drying	($0)	($1)	($2)	($1)	($1)	0.0	0.0	-0.1	-0.2	-0.2
Commercial Space Heating / Air Conditioning [iii]	$36	$68	$72	$102	$111	-0.7	-1.3	-2.0	-2.5	-2.7
Commercial Water Heating	$1	$1.7	$1.3	$0.9	$0.4	-0.1	-0.2	-0.3	-0.3	-0.3
Commercial Cooking	$10	$52	$70	$70	$74	-0.1	-0.3	-0.7	-0.8	-0.9
Transportation--Additional Heavy Truck Electrification	$3	$7	$4	$4	$4	-0.2	-0.3	-0.5	-0.8	-1.1
Transportation--EV Charging Infrastructure (Bus, Heavy Truck)	$0	$1	$7	$18	$30					
Transportation--VMT reduction: Expansion of Transit	$110	$212	$258	$381	$472	-2.9	-1.8	-1.2	-1.4	-2.1
Transportation--VMT reduction: E-bikes	$22	$108	$207	$338	$489					
Industry--Cement Kiln Electrification and Electrical Efficiency	$0	$1	$2	$2	$2	-0.6	-0.6	-0.6	-0.6	-0.6
Industry--Other Electrification and Efficiency	$1	$3	$5	$7	$9	-0.3	-0.6	-0.9	-1.2	-1.5
Agriculture, Construction, Mining	$0	$0	$0	$0	$0	-0.1	-0.2	-0.2	-0.3	-0.4
Energy Supply (Equipment/Infrastructure) [ii]	**$200**	**$1,180**	**$2,924**	**$4,369**	**$5,537**	**-2.7**	**-9.4**	**-15.2**	**-16.1**	**-15.1**
Transmission and Distribution	$22	$49	$63	$63	$63	-0.5	-0.9	-1.2	-1.4	-1.5
LNG Exports	$0	($3)	($3)	($3)	($3)	-1.9	-1.9	-1.9	-1.9	-1.9
Rooftop Solar	$32	$127	$232	$424	$696	0.0	-6.2	-11.6	-12.2	-11.1
Electricity Generation--Offshore Wind	$2	$472	$1,652	$2,636	$3,388					
Electricity Generation--Solar	$66	$234	$376	$522	$593					
Electricity Generation--Storage	$96	$386	$549	$697	$826					
Electricity Generation--Avoided Fossil	($17)	($126)	($226)	($302)	($375)					
Electricity Generation--Calvert Cliffs Life Extension	$0	$47	$269	$305	$314					
Electricity Generation, Retirement of Waste-to-Energy Plants	($3)	($21)	($21)	($21)	($21)					
Electricity, Other	$3	$14	$22	$31	$36					
Biogas Production	$0	$3	$8	$12	$16	*Emission Reductions shown under Non-Energy*				
Other Energy Supply	($1)	($3)	$2	$2	$2	-0.2	-0.4	-0.5	-0.5	-0.5

CATEGORY	Estimated Annualized Costs (Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]					Annual Emission (Million tCO_2e) Reduction				
	2024-2031	2032-2035	2036-2040	2041-2045	2045-2050	2031	2035	2040	2045	2050
Non-Energy Sources	**($4)**	**($17)**	**($22)**	**($15)**	**($5)**	**-0.8**	**-1.5**	**-2.2**	**-3.3**	**-3.9**
Enteric Fermentation Mitigation	($7)	($26)	($42)	($51)	($54)	-0.1	-0.2	-0.3	-0.4	-0.4
Agricultural Soils	$3	$6	$7	$9	$10	0.0	-0.1	-0.1	-0.1	-0.1
Manure Digesters	*Costs shown under Energy Supply - Biogas Production*					0.0	-0.1	-0.1	-0.2	-0.3
WWTP Biogas						-0.2	-0.5	-0.8	-1.4	-1.4
Composting and Increased Landfill Gas Control	$0	$1	$2	$4	$4	-0.4	-0.2	0.0	0.0	-0.1
Cement Clinker Substitution and CCS	$0	$2	$11	$23	$36	-0.2	-0.5	-0.8	-1.1	-1.6
Fuels and Electricity Cost/Savings	**($328)**	**($290)**	**($1,789)**	**($3,096)**	**($4,277)**	Emission Reductions show up under Energy Demand and Energy Supply				
Primary, Natural Gas	($55)	($273)	($394)	($443)	($463)					
Primary, Nuclear	$0	$13	$92	$103	$103					
Secondary, Biogas	$1	$3	$1	($1)	($2)					
Secondary, Diesel	$16	($14)	($100)	($262)	($456)					
Secondary, Gasoline	($8)	($20)	($31)	($44)	($58)					
Secondary, Ethanol and Gasohol E10	($472)	($581)	($406)	($302)	($271)					
Secondary, Jet Kerosene	($95)	($168)	($216)	($284)	($386)					
Secondary, Sustainable Aviation Fuel	$37	$78	$123	$158	$217					
Secondary, Electricity	$0	($1)	($62)	($363)	($1,008)					
Secondary, Imported Electricity	$250	$692	($762)	($1,608)	($1,895)					
Secondary, Other	($3)	($18)	($34)	($49)	($57)					
OVERALL ESTIMATED TOTAL	**$38**	**$1,320**	**$1,711**	**$2,175**	**$2,440**	**-10.2**	**-18.9**	**-27.8**	**-32.0**	**-33.6**
Implied Net Cost per tCO2e Reduced	**$4**	**$70**	**$62**	**$68**	**$73**					
Social Cost of Carbon at $195 per tCO_2e	**($1,947)**	**($3,599)**	**($5,281)**	**($6,074)**	**($6,392)**					
Net Cost Including Social Cost of Carbon	**($1,909)**	**($2,279)**	**($3,569)**	**($3,900)**	**($3,951)**					

[i] Annual average costs for the period indicated; includes annualized investment and annual operation and maintenance costs. Costs shown are incremental to the Current Policies Scenario.

[ii] Includes the incremental costs or savings of new equipment or infrastructure relative to the Current Policies Scenario. Any costs or savings related to changes in fuel or electricity consumption are shown under the Fuels and Electricity heading.

[iii] Costs for space heating/air conditioning equipment include both the incremental costs of installing heat pumps instead of fossil fuel equipment as well as the savings associated with not needing to purchase separate air conditioning equipment. Note that for individual buildings there may be up-front costs, since space heating equipment may need to be replaced before air conditioning equipment has reached the end of its life.

3.3 Required Investment (CAPEX O&M) Relative to Current Policies

Table 3-2 shows estimated net investment costs for the Additional Actions case relative to the Current Policies case for the forecast period split into five time periods. Investment costs are generally higher than social costs in the periods shown because the full cost of purchase or installation is shown in the year of implementation rather than financed over the life of the equipment or project. This is analogous to reporting the full up front purchase price of a home rather than its monthly or annual mortgage payment stretching over 15-30 years. In addition, total investment costs include outlay expenses only and do not include fuel cost savings or new revenues that may be stimulated by such spending. The estimation of investment requirement is important to understanding the total funds that need to be transacted up front and on an ongoing basis as part of policy and program implementation. The savings generated by such investment can act to facilitate financing by providing a payback mechanism.

The total net investment costs required for the additional actions sum to about $11 billion for the 2024-2031 period, $22 billion over 2032-2035 (four years), $29 billion from 2036-2040 (five years), $36 billion from 2041-2045 (five years), and $41 billion from 2046-2050 (five years), for a total of $139 billion over the entire 2024-2050 period. Once again, even though these figures include neither benefits related to avoided fuel costs, nor benefits related to avoided GHG emissions, these total investment costs represent a small fraction of Maryland's economic output, even by 2050. **$139 billion represents just under one percent of total projected Maryland GDP** over the 2024-2050 period. The additional costs of mitigating climate change are thus quite small when compared with the size of Maryland's economy and BAU spending within sectors.

In most cases, the entities, private or public, that make investments in GHG emissions reduction would be financing the costs through multiple sources of investments. For example, investments in new rooftop or utility-scale solar power are likely to be financed by banks or other sources of commercial capital. Thus, the actual outlays in any given year by the entities owning new or upgraded facilities will be functions of the interest rate secured through financing, the amount of down-payment required/provided by consumers or investors, and other factors. For public institutions, the actual annual outlay will be a function, again, of financing available, such as using state or municipal bonds or debt and equity from private or public entities, as well as contributions to the GHG emissions-reduction investments secured through federal programs. Again, the savings generated by investments can be used to facilitate financing and payback methods that make such investments potentially attractive. Savings based financing is a common practice that can be applied to climate mitigation actions.

Table 3-2: Estimated Net Investment Costs for Additional Actions Case Relative to Current Policies Case

CATEGORY	Estimated Investment Costs (Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]					Annual Emission (Million tCO_2e) Reduction				
	2024-2031	2032-2035	2036-2040	2041-2045	2045-2050	2031	2035	2040	2045	2050
Energy Demand (Equipment/Infrastructure) [ii]	**$5,484**	**$6,871**	**$11,345**	**$20,236**	**$27,362**	**-6.7**	**-8.1**	**-10.4**	**-12.7**	**-14.6**
Residential Space Heating / Air Conditioning [iii]	($1,169)	($669)	($1,654)	($609)	($371)	-1.0	-1.7	-2.6	-3.2	-3.4
Residential Water Heating	$224	($17)	($336)	($84)	($123)	-0.7	-1.1	-1.3	-1.3	-1.4
Residential Cooking and Clothes Drying	($12)	($25)	($95)	($62)	($51)	0.0	0.0	-0.1	-0.2	-0.2
Commercial Space Heating / Air Conditioning [iii]	($907)	($732)	($804)	($377)	($288)	-0.7	-1.3	-2.0	-2.5	-2.7
Commercial Water Heating	$74	$91	$94	$76	$50	-0.1	-0.2	-0.3	-0.3	-0.3
Commercial Cooking	$689	$1,861	$3,119	$3,097	$3,295	-0.1	-0.3	-0.7	-0.8	-0.9
Transportation--Additional Heavy Truck Electrification	$163	$324	$489	$660	$745	-0.2	-0.3	-0.5	-0.8	-1.1
Transportation--EV Charging Infrastructure (Bus, Heavy Truck)	$0	$35	$328	$807	$1,344					
Transportation--VMT reduction: Expansion of Transit	$4,991	$2,559	$1,956	$3,326	$3,451	-2.9	-1.8	-1.2	-1.4	-2.1
Transportation--VMT reduction: E-bikes	$1,346	$3,321	$8,007	$13,063	$18,869					
Industry--Cement Kiln Electrification and Electrical Efficiency	$18	$13	$24	$33	$42	-0.6	-0.6	-0.6	-0.6	-0.6
Industry--Other Electrification and Efficiency	$66	$110	$216	$305	$398	-0.3	-0.6	-0.9	-1.2	-1.5
Agriculture, Construction, Mining	$0	$0	$0	$0	$0	-0.1	-0.2	-0.2	-0.3	-0.4
Energy Supply (Equipment/Infrastructure) [ii]	**$5,651**	**$14,742**	**$17,456**	**$15,459**	**$13,803**	**-2.7**	**-9.4**	**-15.2**	**-16.1**	**-15.1**
Transmission and Distribution	$322	$877	$1,179	$1,011	$898	-0.5	-0.9	-1.2	-1.4	-1.5
LNG Exports	$38	$0	$0	$0	$0	-1.9	-1.9	-1.9	-1.9	-1.9
Rooftop Solar	$938	$1,191	$1,594	$3,169	$3,898	0.0	-6.2	-11.6	-12.2	-11.1
Electricity Generation--Offshore Wind	$211	$8,630	$11,738	$8,690	$6,737					
Electricity Generation--Solar	$1,516	$1,427	$1,580	$1,448	$1,318					

<table>
<tr><th rowspan="2">CATEGORY</th><th colspan="5">Estimated Investment Costs
(Social Costs, Million 2021 USD, Undiscounted) Incremental to Current Policies [i]</th><th colspan="5">Annual Emission (Million tCO_2e) Reduction</th></tr>
<tr><th>2024-2031</th><th>2032-2035</th><th>2036-2040</th><th>2041-2045</th><th>2045-2050</th><th>2031</th><th>2035</th><th>2040</th><th>2045</th><th>2050</th></tr>
<tr><td>Electricity Generation--Storage</td><td>$2,495</td><td>$2,631</td><td>$1,928</td><td>$1,746</td><td>$1,566</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Electricity Generation--Avoided Fossil</td><td>($86)</td><td>($158)</td><td>($792)</td><td>($794)</td><td>($733)</td></tr>
<tr><td>Electricity, Other</td><td>$74</td><td>$22</td><td>$51</td><td>$55</td><td>($0.6)</td></tr>
<tr><td>Biogas Production</td><td>$21</td><td>$22</td><td>$71</td><td>$42</td><td>$42</td><td colspan="5">Emission Reductions shown under Non-Energy</td></tr>
<tr><td>Other Energy Supply</td><td>$124</td><td>$99</td><td>$107</td><td>$92</td><td>$78</td><td>-0.2</td><td>-0.4</td><td>-0.5</td><td>-0.5</td><td>-0.5</td></tr>
<tr><td>Non-Energy Sources</td><td>$13</td><td>$82</td><td>$144</td><td>$186</td><td>$74</td><td>-0.8</td><td>-1.5</td><td>-2.2</td><td>-3.3</td><td>-3.9</td></tr>
<tr><td>Enteric Fermentation Mitigation</td><td>$0</td><td>$0</td><td>$0</td><td>$0</td><td>$0</td><td>-0.1</td><td>-0.2</td><td>-0.3</td><td>-0.4</td><td>-0.4</td></tr>
<tr><td>Agricultural Soils</td><td>$0</td><td>$0</td><td>$0</td><td>$0</td><td>$0</td><td>0.0</td><td>-0.1</td><td>-0.1</td><td>-0.1</td><td>-0.1</td></tr>
<tr><td>Manure Digesters</td><td colspan="5" rowspan="2">Costs shown under Energy Supply - Biogas Production</td><td>0.0</td><td>-0.1</td><td>-0.1</td><td>-0.2</td><td>-0.3</td></tr>
<tr><td>WWTP Biogas</td><td>-0.2</td><td>-0.5</td><td>-0.8</td><td>-1.4</td><td>-1.4</td></tr>
<tr><td>Composting and Increased Landfill Gas Control</td><td>$13</td><td>$8</td><td>$29</td><td>$0</td><td>$0</td><td>-0.4</td><td>-0.2</td><td>0.0</td><td>0.0</td><td>-0.1</td></tr>
<tr><td>Cement Clinker Substitution and CCS</td><td>$0</td><td>$73</td><td>$115</td><td>$186</td><td>$74</td><td>-0.2</td><td>-0.5</td><td>-0.8</td><td>-1.1</td><td>-1.6</td></tr>
<tr><td>OVERALL ESTIMATED TOTAL</td><td>$11,148</td><td>$21,694</td><td>$28,944</td><td>$35,881</td><td>$41,239</td><td>-10.2</td><td>-18.9</td><td>-27.8</td><td>-32.0</td><td>-33.6</td></tr>
</table>

[i] Cumulative investments costs for the period indicated. Costs shown are incremental to the Current Policies Scenario.

[ii] Includes the incremental costs or savings of new equipment or infrastructure relative to the Current Policies Scenario. Any costs or savings related to changes in fuel or electricity consumption are shown under the Fuels and Electricity heading.

[iii] Costs for space heating/air conditioning equipment include both the incremental costs of installing heat pumps instead of fossil fuel equipment as well as the savings associated with not needing to purchase separate air conditioning equipment. Note that for individual buildings there may be up-front costs, since space heating equipment may need to be replaced before air conditioning equipment has reached the end of its life

3.4 Energy demand

Figure 3-7 shows the substantial reduction in fossil fuel use—including of gasoline, diesel, and natural gas—from implementation of the measures in the Additional Actions case. The increase in electricity use beyond the Current Policies case is also shown. **By 2050**, relative to the Current Policies case, **the Additional Actions case reduces annual gasoline use in the state by 140 million gallons** (Figure 3-8), **annual diesel consumption by 250 million gallons** (Figure 3-9), **and annual natural gas use by over 150 trillion Btus** (160 million GJ, as shown in Figure 3-10)**.** In 2031, when gasoline fueled LDVs are still a majority of the fleet, **VMT reductions produce even higher annual savings, 340 million gallons per year**. Reductions in diesel use are offset in part by additional diesel use from the expanded use of bus transport, an increase that peaks in the late 2030s. Annual electricity use, on the other hand, is 19 terawatt hours (TWh, or billion kilowatt-hours) higher in 2050 in the Additional Actions case (Figure 3-11). This is an increase caused by aggressive electrification of formerly fossil-fuel using appliances, equipment, vehicles, and other devices across the Maryland economy, offset in part by reductions in electric LDV use through VMT reduction actions. Aviation fuel use shows a reduction in jet kerosene use caused by a combination of aircraft efficiency improvement measures, some electrification, and a partial switch to use of sustainable aviation fuel (Figure 3-12). Note that the Current Policies case already includes substantial reductions in transport fossil fuel use, particularly gasoline/gasohol, through implementation of the Advanced Clean Cars program, which is why the additional gasoline savings from the Additional Actions case are not higher.

Figure 3-7: Comparison of Energy Demand by Fuel in the Additional Actions Case Relative to the Current Policies Case

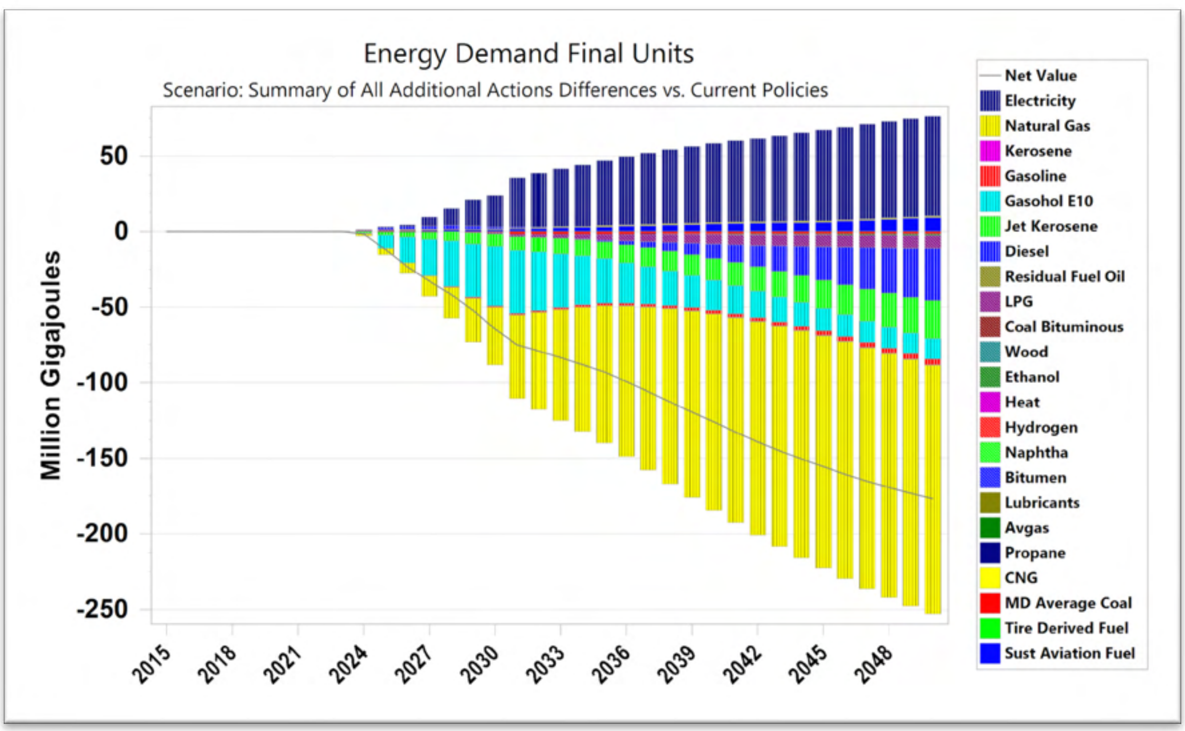


Figure 3-8: Comparison of Gasoline/Gasohol Demand by Sector and End Use in the Additional Actions Case Relative to the Current Policies Case

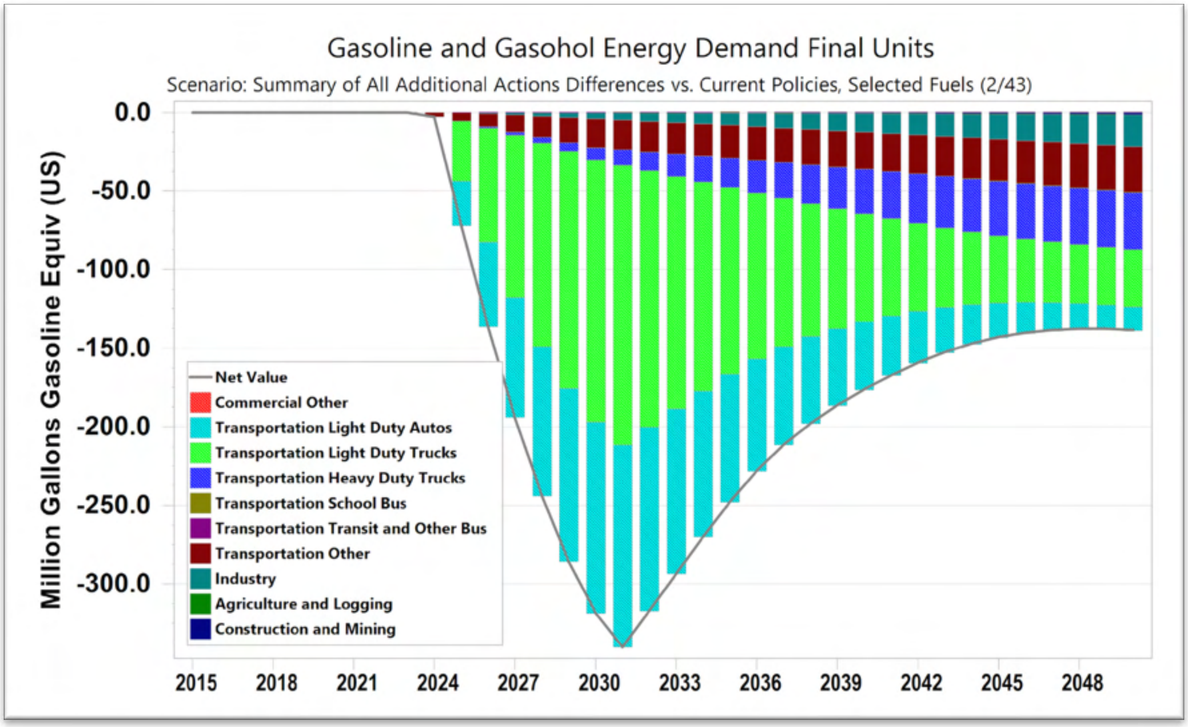


Figure 3-9: Comparison of Diesel Demand by Sector and End Use in the Additional Actions Case Relative to the Current Policies Case

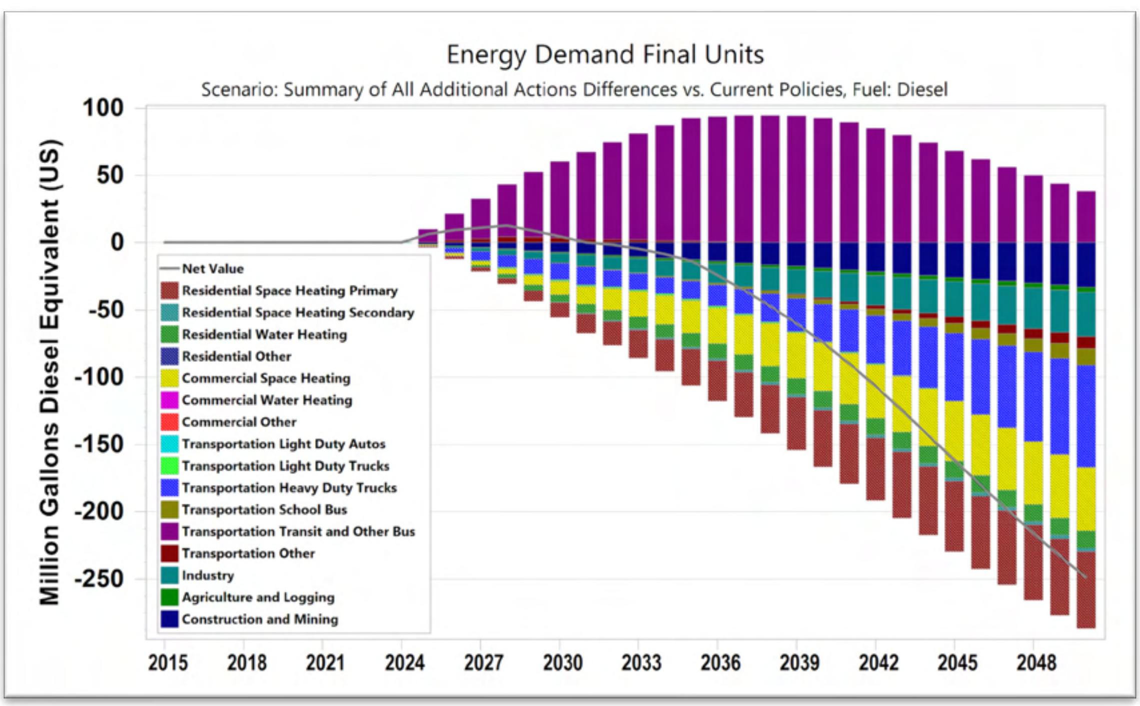


Figure 3-10: Comparison of Natural Gas Demand by Sector and End Use in the Additional Actions Case Relative to the Current Policies Case

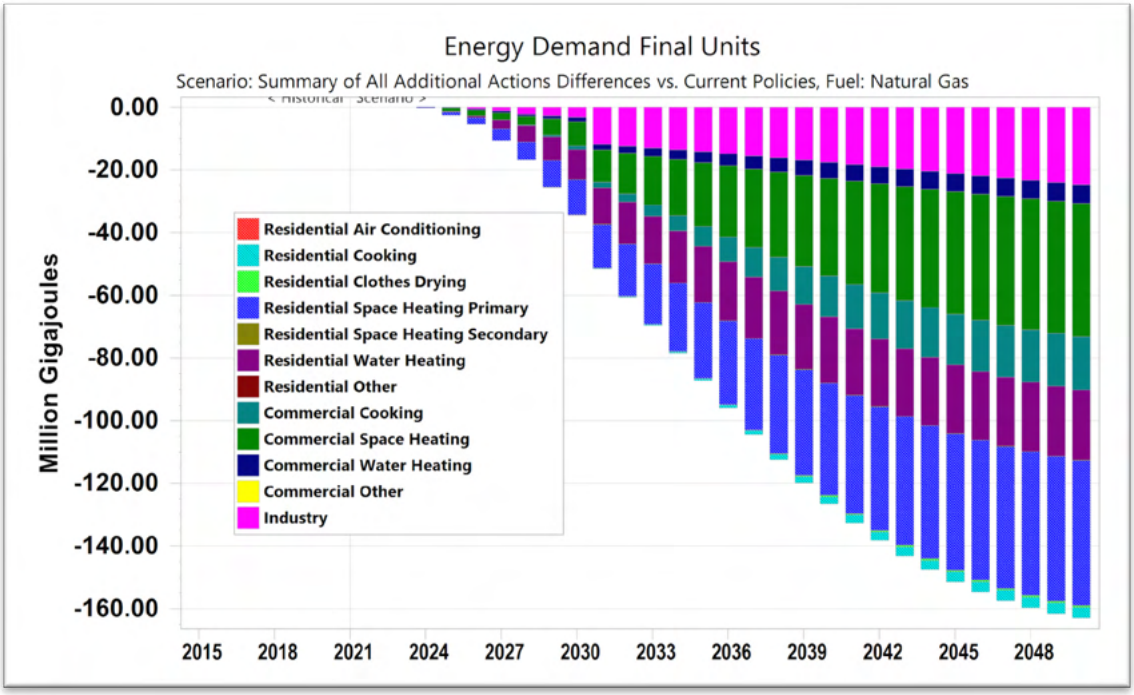


Figure 3-11: Comparison of Electricity Demand by Sector and End Use in the Additional Actions Case Relative to the Current Policies Case

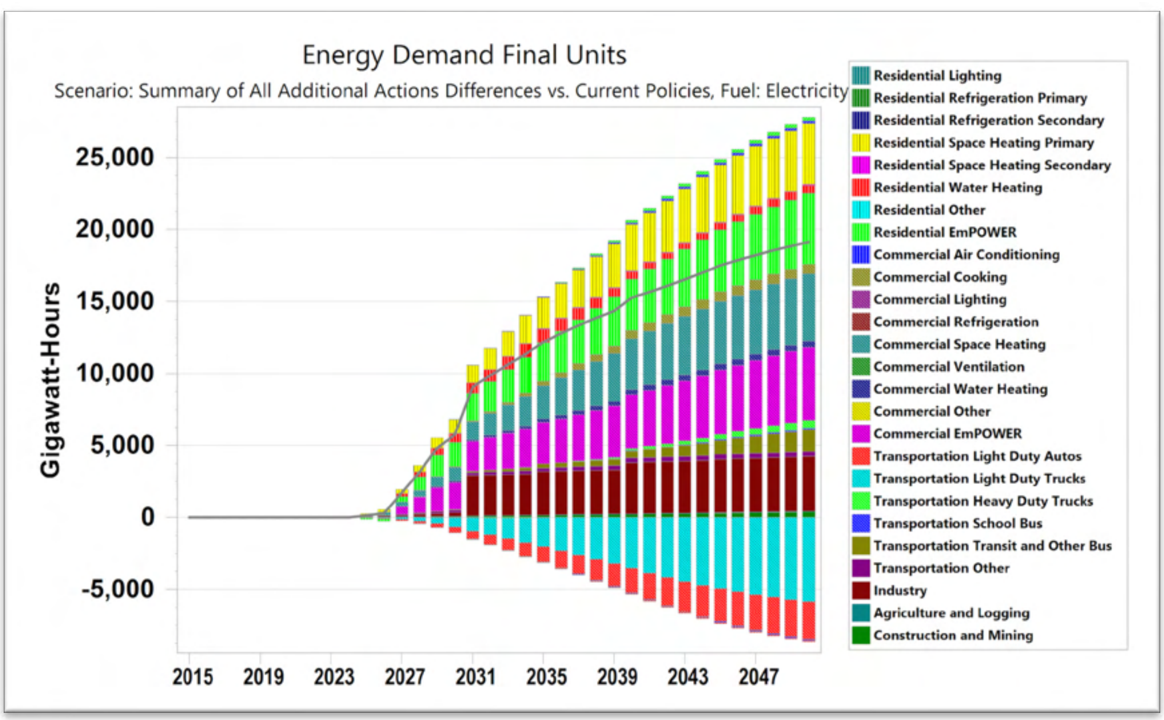
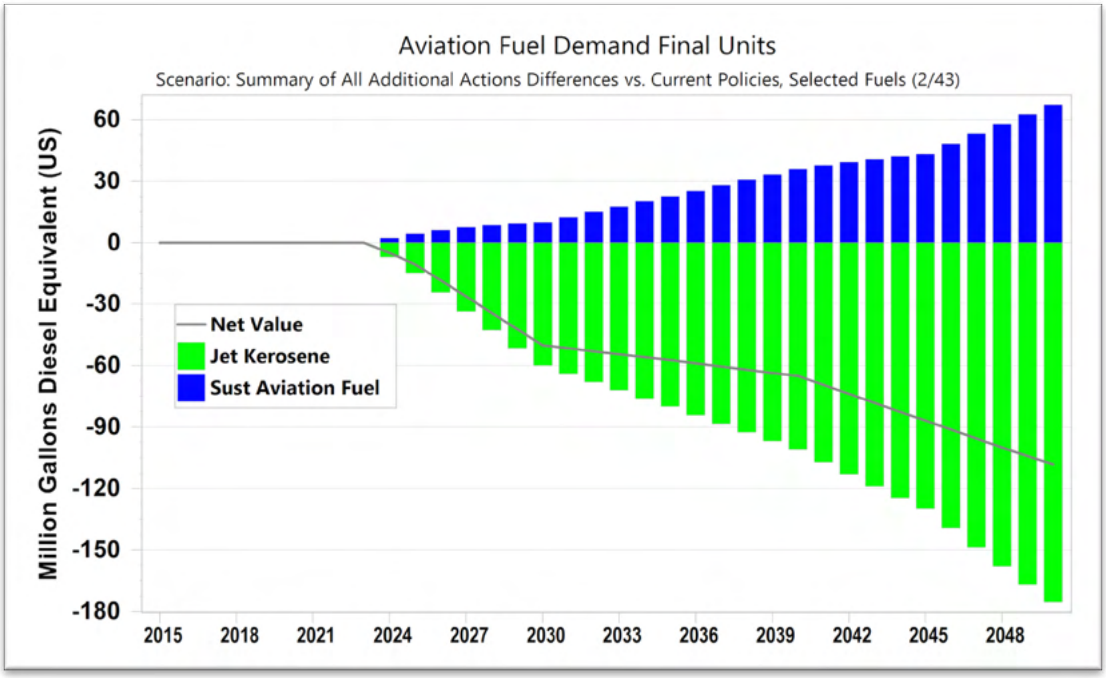


Figure 3-12: Comparison of Jet Aviation Fuel Demand in the Additional Actions Case Relative to the Current Policies Case



3.5 Energy supply

A substantial shift in Maryland to more electricity production, especially clean electricity, will be well underway by 2031 in both cases with natural gas electricity production and electricity imports decreasing and renewable generation increasing over time. Figure 3-13 shows the net differences in generation sources between the Additional Actions and Current Policies cases on an annual basis and reveals the difference in pace and generation type. **In the Additional Actions case, Maryland's renewable generation (plus existing nuclear generation) meets 96 percent of the state's electricity needs by 2050**, with the rest imported from the remainder of the PJM transmission grid, which should also be renewable if the RGGI states meet their renewable generation targets. By 2040, Maryland's renewable generation—including rooftop PV generation—reaches 68 percent of total electricity output, with an additional 17 percent from nuclear generation, and the remaining 15% imported from PJM, which would also presumably be generated exclusively (or almost exclusively) using renewables and nuclear power. As such, **by 2040, Maryland's electricity use would be entirely from clean energy sources** under the Additional Actions case. As of 2035, in the Additional Actions case, 52 percent of Maryland's electricity comes from renewable sources (distributed and central-station), 19 percent from nuclear, 1.9 percent from fossil-fueled generation (almost all gas), and the remaining 27.1% from imports. If imported power is roughly two-thirds carbon-free by 2035, Maryland's total generation in that year would be around 90 percent "clean energy." For comparison, by 2040 in the Current Policies case electricity supply would be 31 percent renewables (central station and distributed) and 43 percent imports.

The extensive demand-side electrification carried out in the Additional Actions case, not surprisingly, increased the requirements for electricity relative to the Current Policies case. Figure 3-14 shows the evolution of total electricity output in each of the two cases — both from the different types of distributed solar photovoltaic (PV) systems and from all types of utility-scale generation (including imports). Overall, distributed PV generation by 2050 in the Additional Actions case is over three times that in the Current Policies case. Utility-scale solar PV generation in the Additional Actions case is more than twice that in the Current Policies Scenario by 2050.

The other major supply-side change in the Additional Actions case is the electrification of LNG production, which requires significant electricity inputs, but provides a large decrease in gas consumption for LNG liquefaction, and thus, a major decrease in GHG emissions.

Figure 3-13: Utility-scale (Central Station) Electricity Output by Sources, Difference between Additional Actions and Current Policies Cases

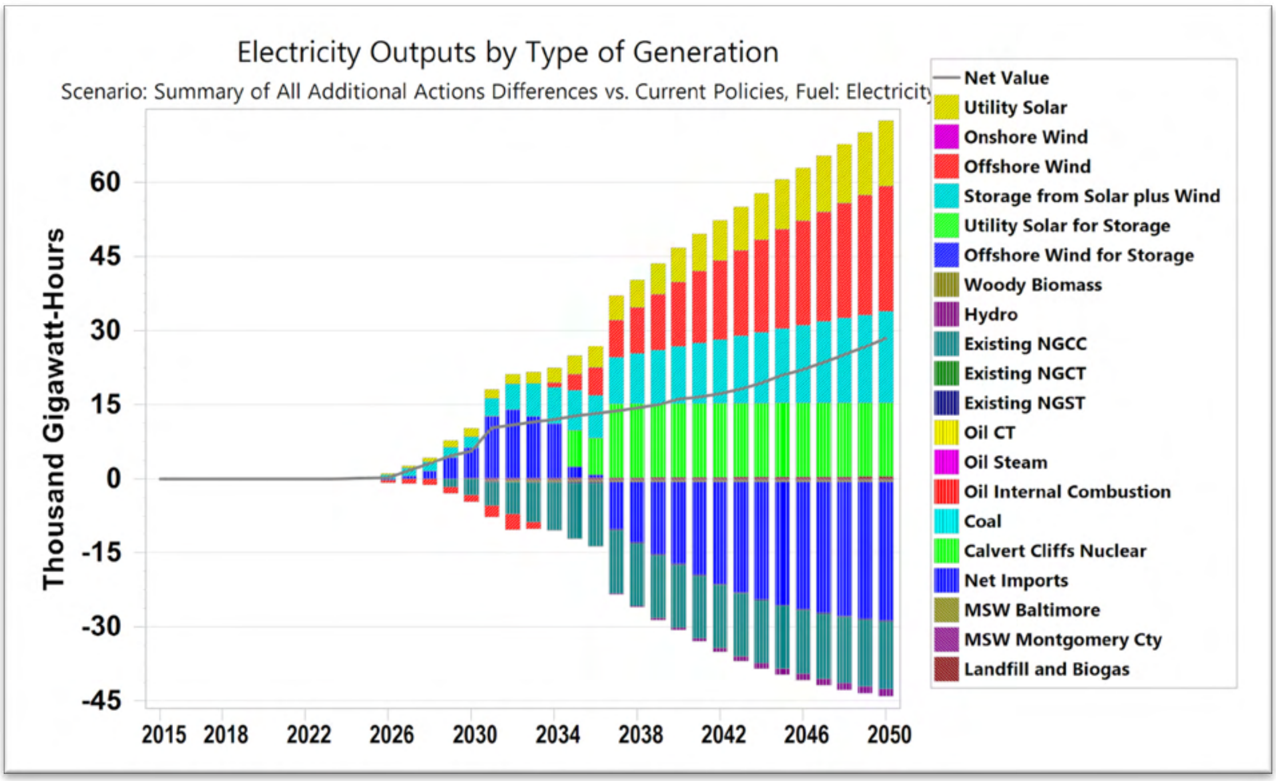
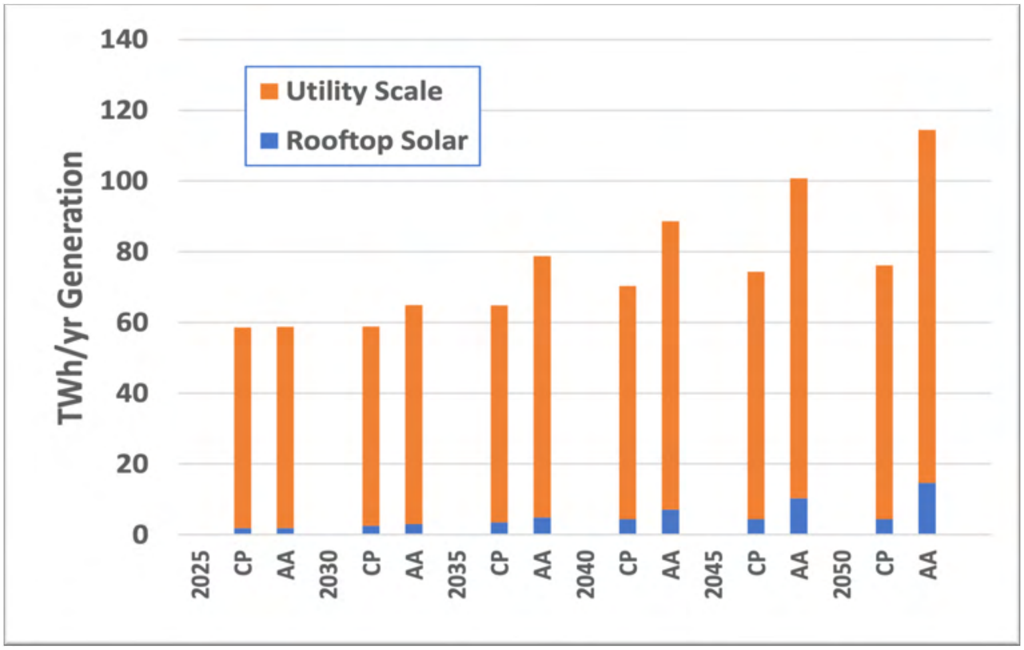


Figure 3-14: Comparison of Electricity Output in the Additional Actions and Current Policies Cases, Rooftop Solar Plus Utility-scale



4. Current Policies Scenario

4.1 Overall Theme and Key Results of Current Policies Scenario

The Current Policies Scenario in the Maryland LEAP model was designed to serve as a baseline for evaluation of additional GHG emissions reduction actions. As such, the Current Policies case includes the estimated impacts on Maryland's future GHG emissions of both current trends and those Federal and state policies that have been judged—by CCS working with Maryland experts and stakeholders—to be sufficiently well-funded, provided with adequate regulatory authority, and to have implementation sufficiently well-staffed and organized to meet the policy targets. In some instances, policy targets were adjusted downward if these criteria were not met. The Current Policies case serves as the yardstick against which the Additional Actions case and its component actions/scenarios, as described in Section 5.

The remainder of this subsection provides an overview of the policies included in the Current Policies case, followed by a summary of the energy demand and supply and GHG emissions results associated with the case. The following subsections provide additional detail for modeling element inputs (energy demand, energy supply, and non-energy) that drive the Current Policies case, as well as the results in terms of energy supply and demand and GHG emissions.

The underlying basis of the Current Policies Scenario in many cases are the projections included in the USDOE EIA's AEO 2023 modeling effort. CCS used AEO2023 Reference case national projections, as well as regional results when available (Mid-Atlantic/South Atlantic and PJM), as the starting point for the Current Policies case. Onto this base projection, CCS layered expected savings from state and federal policies.

The current and recent policies included in the Current Policies case are:

Energy Supply

- Solar Carve out (Utility capacity expansion limited by PJM interconnection approval process)
- Community Solar system deployment
- RGGI RPS (Regional Greenhouse Gas Initiative renewable portfolio standard) goals, but only to the extent modeled in Annual Energy Outlook 2023 (AEO2023)[40]
- Planned retirements of coal-fired power plants
- Calvert Cliffs nuclear units assumed retired in 2034/36
- Promoting Offshore Wind Energy Resources (POWER) Act offshore wind expansion
- Implementation of energy storage

Buildings, Facilities, and Industry

- Continued implementation of EmPOWER, the electric utility-sponsored program for supporting energy efficiency improvements in the residential, commercial and (to a lesser extent) industrial sectors
- State and Montgomery County Building Energy Performance Standards
- All-electric Building Codes in Montgomery and Howard Counties
- AIM (American Innovation and Manufacturing) Act and MD HFC Regulations (non-energy industrial emissions reduction)

Transportation

- Implementation of Advance Clean Cars II (ACC II) rules
- CAFE (Corporate Average Fuel Economy) Standards, as included in AEO2023 modeling
- Advanced Clean Trucks (ACT) Rule
- WMATA (Washington Metro Transit Authority) vehicle electrification
- MTA (Maryland Transit Authority) vehicle electrification
- Construction of the Purple Line electrified light rail system
- Other ongoing trends and policies (some national and international), including motorcycle electrification, growth of e-bike usage, air transport electrification and use of sustainable aviation fuel, other transport electrification, ongoing electrification of lawn and garden equipment, and use of alternative fuels for marine shipping

Non-energy Sectors

- State 2035 Waste Generation and Diversion Goals
- MD Landfill Methane Rule
- Maryland 5 Million Tree Program

Based on CCS's analysis, current and recent policies as currently implemented will not allow Maryland to reach either its 2031 emissions reduction goal or its 2045 net zero GHG emissions goal. Recent and current policies and technology trends will reduce Maryland's emissions substantially from 2006 levels by 2031, with an overall reduction on the order of 47 percent of gross 2006 emissions. This trend leaves the state short of its goal of 60 percent reductions by about 16 MMtCO2e in 2031, measured based on 20-year global warming potentials (GWPs).[41] Under current policies Maryland will not reach its 2031 goal

[40] US Energy Information Administration Annual Energy Outlook 2023

[41] Note that "GWP" refers to global warming potentials—measures of the degree to which a unit (one kilogram, for example) of a particular GHG affects climate relative to the climate effect of a kilogram of carbon dioxide. A "20-year GWP", for example,

until after 2050. The "net zero by 2045" goal will not be achieved without additional policies and/or through the benefits of additional technological trends currently unforeseen.

Figure 4-1: Maryland GHG Emissions by Sector under the Current Policies Scenario

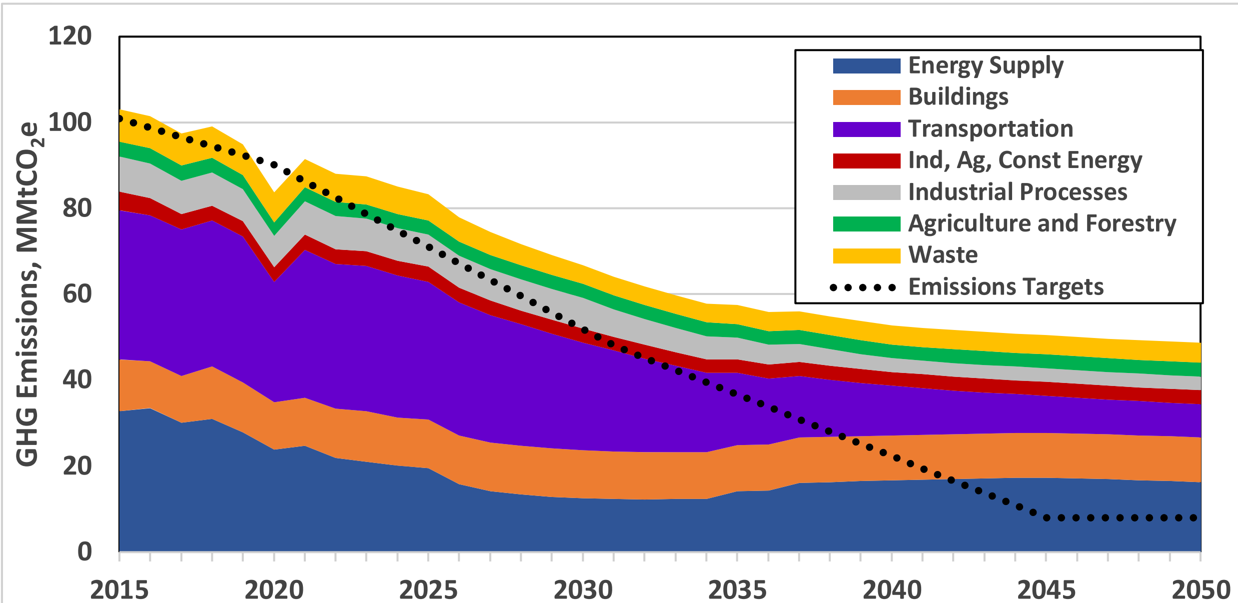


Figure 4-1, shows CSNA targets for gross GHG emissions by year (black line) and the projection for GHG emissions for the MD LEAP model reference case including Current Policies (the "Current Policies" case). As shown, the 60-percent-reduction-by-2031 target, at just over 48 $MMtCO_2e$ of gross emissions,[42] will not be met under current policies. Reaching that goal will require about 16 additional $MMtCO_2e$ of annual emissions reduction actions by 2031. The graph does not show the annual net sinks (emissions reductions) from the forestry and land use (FOLU), waste management (landfill carbon storage), and agriculture (agricultural soil carbon storage) sectors in Maryland, which are estimated at just under 8 $MMtCO_2e$ of carbon dioxide equivalent absorbed annually. Therefore, the gross emissions goal shown for Maryland in 2045 is set at about 8 $MMtCO_2e$ and, as shown in Figure 4-1 below, will require significant additional reductions beyond current policies across multiple subsectors.

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for methane, considers the impacts on climate of an individual GHG over a 20-year time horizon. GWPs are used to place the emissions of all the different GHGs—CO_2, methane, nitrous oxide, and many others—on the same "CO_2 equivalent" basis, so that the impacts of the different GHGs on climate can be summed. 20-year GWPs are used in this modeling and throughout this Report instead of the more commonly used 100-year GWPs. This convention is consistent with the approach used in the Climate Solutions Now Act of 2022 and the Maryland Department of Environment's GHG Inventories. The principal effect of use of 20-year GWPs on the modeling described here, relative to use of 100-year GWPs, is that it tends to amplify the impact on total CO_2e of methane emissions relative to CO_2 emissions, as the IPCC (Intergovernmental Panel on Climate Change) 20-year GWP used for methane is 85, whereas the 100-year GWP for methane is 30. LEAP has the capability to produce composite GHG emissions results using 20-year, 100-year, or 500-year GWPs.

[42] Note that this goal has been adjusted, relative to a goal strictly based on MDE gross emissions from the (updated) 2006 inventory, to account for the difference in the way the modeling reported on here counts carbon dioxide emissions from waste-to-energy plants (as 30 percent biogenic emissions) and landfills (100% biogenic) and the convention used in MDE reporting (all carbon emissions from waste to energy plants and landfills counted as if they were fossil-based emissions). This adjustment reduces the 2031 emissions target by about 0.6 $MMTCO_2e$, from 48.7 to 48.1 $MMTCO_2e$ gross emissions.

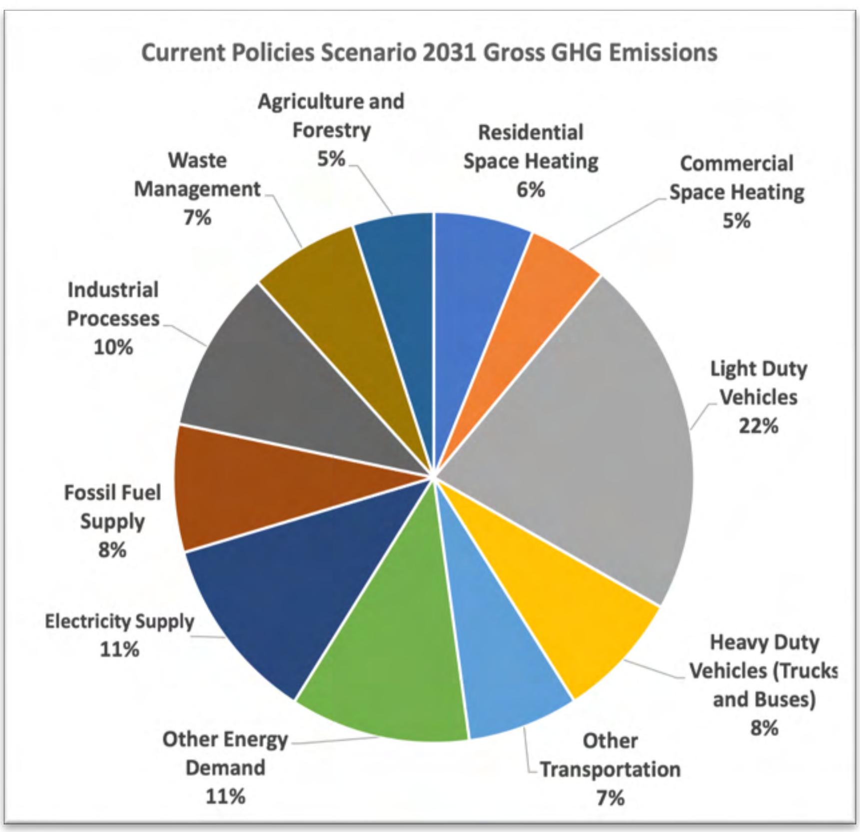
Table 4-1: Maryland Current Policies Scenario Gross GHG Emissions and Targets, 2021-2050

LEAP Data Branch*	2021	2026	2031	2038	2045	2050
Demand (energy use)	49.1	45.8	37.8	27.1	22.3	21.4
Energy Supply (“Transformation”)	24.7	15.8	12.3	16.3	17.4	16.3
Non-Energy	17.7	16.4	14.0	11.6	10.9	11.0
Total	91.6	78.0	64.1	54.9	50.6	48.7
Reduction from 2006	24%	35%	47%	54%	58%	59%
Remaining above targets (MMtCO$_2$e)			16.0		40.7	

*Note: *Demand* includes primary energy demand (electricity and fuels) in buildings, transportation, industry, agriculture, construction. *Energy Supply* (referred to as “transformation” in LEAP, because energy supply processes transform a resource or fuel into one or more fuels, such as in oil refining or electricity generation and/or move a fuel from place to place) includes electricity generation, transmission and distribution of electricity and natural gas, and fossil fuel supply. *Non-energy* refers to all emissions not directly related to energy supply or demand, including industrial processes and product use, agriculture, and waste management.

The pie chart below (Figure 4-2) shows the shares of remaining gross GHG emissions in 2031 in the Current Policies Scenario. Emission sources that will need additional reductions are distributed across all sectors; many additional actions will therefore need to be implemented to reach the 2031 and 2045 goals.

Figure 4-2: Maryland Current Policies Case GHG Emissions by Sector, 2031



In choosing how or whether to include specific current policies in the Reference/Current Policies Scenario, we used criteria consistent with those used by the USDOE EIA in the development of EIA's Annual Energy Outlook (AEO). The criteria used for the AEO Reference case are as follows:

> "The version of the National Energy Modeling System (NEMS) used for the U.S. Energy Information Administration's (EIA) Annual Energy Outlook 2022 (AEO2022) generally represents current legislation, environmental regulations, and international protocols, including recent government actions that had implementing regulations as of the end of November 2021. The potential effects of proposed federal and state legislation, regulations, or standards are not reflected in NEMS. In addition, NEMS does not reflect sections of legislation that have been enacted but have not been funded or lack implementation regulations. A list of the federal and selected state legislation and regulations included in AEO2022, including how we incorporated them, is provided in each module's documentation. This document provides an overview of all the relevant regulations and includes summary tables that represent both new and existing legislation and regulations represented in NEMS."[43]

In keeping with the EIA criteria described above to choose how or whether to include particular current policies in the Reference/Current Policies Scenario, CCS used criteria consistent with those used in the development of EIA's AEO by asking:

- Is a given policy sufficiently fully enacted as of the time of modeling of the Current Policies case (April/May of 2023) to be certain or highly likely to come into effect?
- Does the policy have sufficient funding, if needed, and/or regulatory authority to be fully implemented?
- Are those agencies responsible for implementing certain policies likely to have sufficient staffing and organization to implement the policy to the degree and on the timescale implied by the policy?
- Are there major barriers to the implementation of policies that, in the estimation of the experts consulted, would prevent those policies from being fully developed during the expected period?

If the answers to any of the first three questions above appeared to be "no", the answer to the last question was "yes," or there were significant uncertainties in answering the questions, CCS either did not include an estimate of the emissions reduction from the policy in the Current Policies case, or reduced the estimated reduction to a level that seemed consistent with expected policy implementation, funding, institutional capabilities, and barriers to implementation.

To incorporate local knowledge about current policies affecting (or potentially affecting) GHG emissions in Maryland, CCS worked with Technical Working Groups (TWGs) organized by Maryland stakeholders in each of the sectors described below to identify current policies, assess whether the policies would contribute substantially to GHG emissions reduction, and prepare and review a set of quantitative assumptions associated with each policy to enable modeling. TWG members reached out to experts beyond the Maryland stakeholders for advice on quantitative assumptions and the justifications for same, and that advice was in most cases incorporated in the Current Policies case modeling of the energy demand and supply sectors described here.

[43] See USDOE EIA (2022), *Summary of Legislation and Regulations Included in the Annual Energy Outlook 2022*, dated March 2022 It appears that as of this writing, a similar document has not yet been released for AEO2023, but we assume that this general approach is still in use in NEMS modeling.

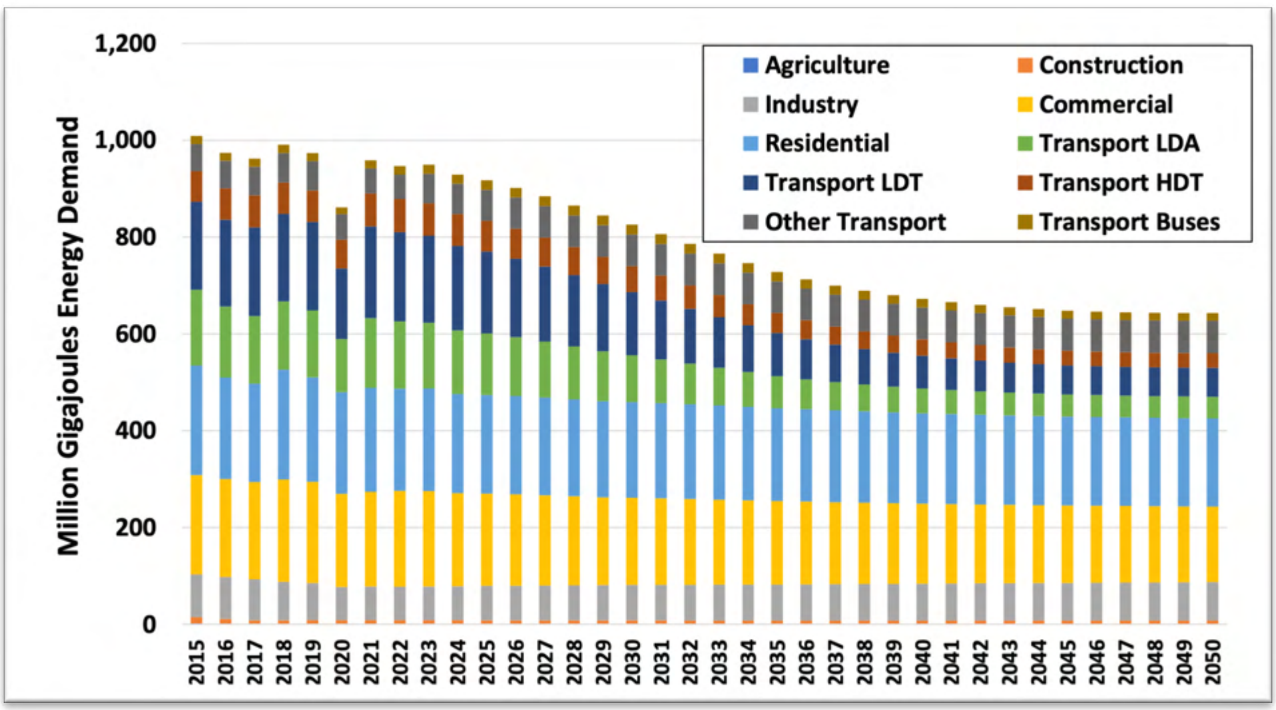
The remainder of this section of the Report provides general descriptions of how each of the current policy elements listed above are modeled in LEAP. Many additional policies for emissions reduction, including extensions to existing policies, are described in section 5 of this Report.

4.2 Demand Sector Actions in Current Policies Scenario

4.2.1 Overall Energy Demand Results

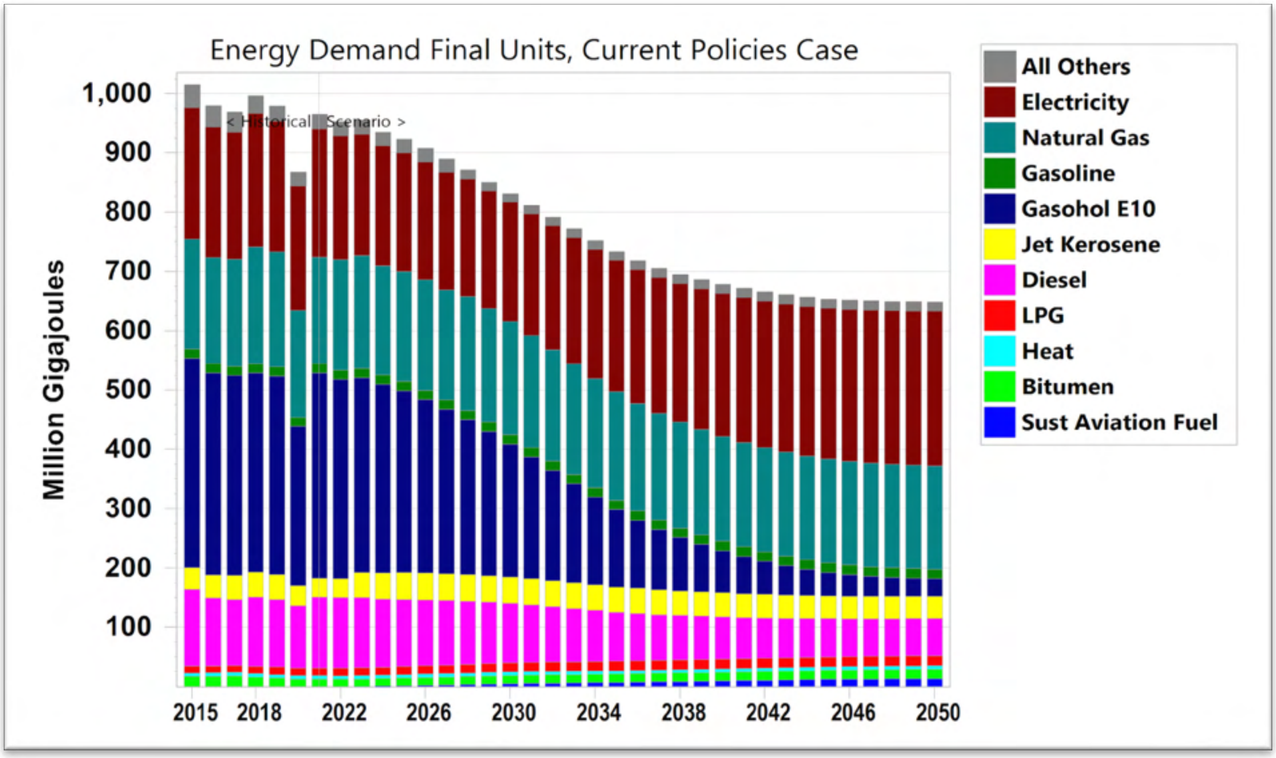
The residential, commercial, and transportation sectors dominate energy use in the Current Policies case throughout the modeling period, as shown in Figure 4-3 below. Overall energy use in the state declines by about a third by 2050, mostly as a result of fuel switching in the transportation sector and general efficiency improvements across sectors.

Figure 4-3: Overall Energy Use in Maryland by Sector, Current Policies Case



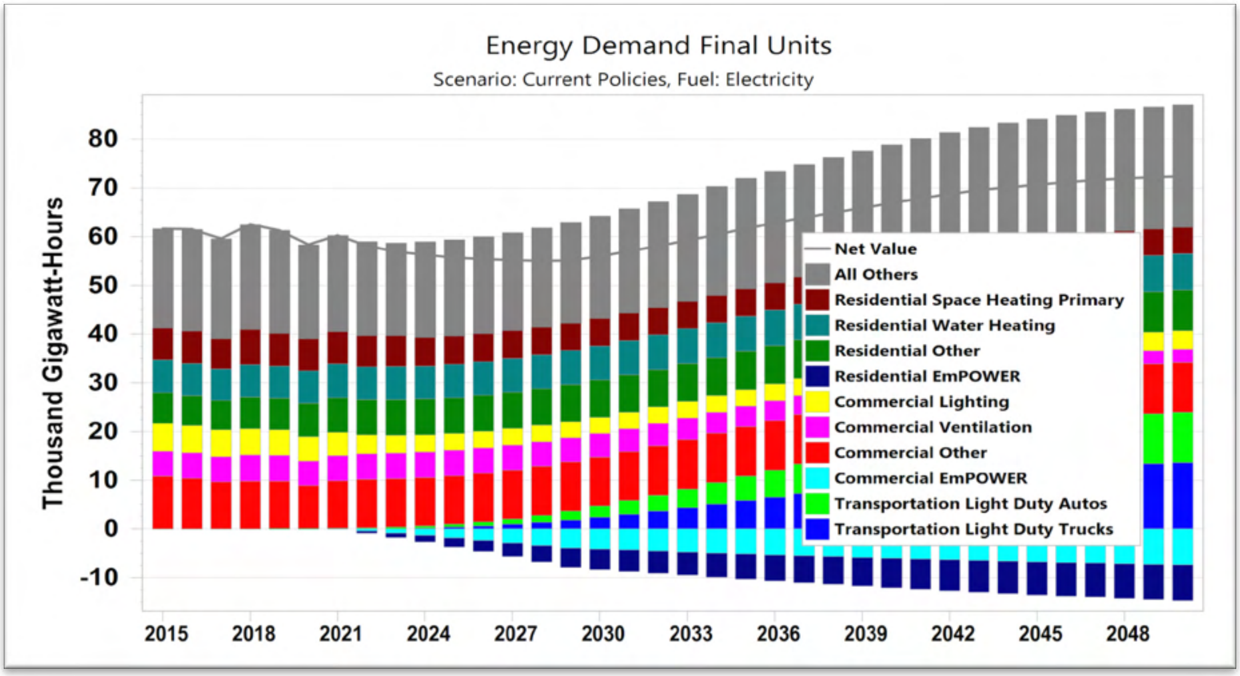
Electricity use expands in the Current Policies case, while diesel use and, in particular, gasoline falls substantially as heavy and, especially, light duty vehicles are electrified (Figure 4-4).

Figure 4-4: Overall Energy Use in Maryland by Fuel, Current Policies Case



Electricity use in the Current Policies case declines somewhat in the late 2020s, mostly as a result of the continued effectiveness of the EmPOWER energy efficiency programs, but rises thereafter to a total of 70 TWh (70 thousand GWh) by the late 2040s as E-vehicles are phased in. The substantial savings from the EmPOWER program are shown as negative values in Figure 4-5 and reduce the net demand (gray line) below the gross demand for electricity.

Figure 4-5: Overall Electricity Use in Maryland, Current Policies Case



4.2.2 Buildings

Table 4-2 describes the current policy actions for Buildings, Facilities, and Industry considered for the Current Policies Scenario. The highlighted rows are those included in the Current Policies Scenario. Additional descriptions of key policies, and of the way that they were modeled in the Maryland LEAP dataset, follow the table.

Table 4-2: Current Buildings, Facilities, and Industry Policy Actions

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
MD Energy Efficiency Appliance Standards	Not modeled, most covered appliances are either water savings or are for electrical end uses grouped in the "other" category in the model and are assumed to be a very small share of energy consumption. In addition, data on the expected reduction in energy consumption resulting from the standards were not identified.	NA

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
EmPOWER	Included, this program has been in place for several years and goals have been met in recent years. Note that there will likely be a change in goal structure.	Modeled as a negative electricity demand in the Residential and Commercial Sectors (50% in each), not allocated to specific end uses. 2% reduction in electricity sales (relative to 2016) in 2022-2024, 2.25% reduction in 2025-2026, 2.5% in 2027-2029, trended down to 0.5% in 2050.
Low Income EmPOWER goal	Not modeled as a separate program, included as part of the above, since it is a carve out of the total EmPOWER reductions. May be split out later if needed for New Policies Scenario modeling.	See above
IRA incentives	Included to the extent included in Annual Energy Outlook 2023	AEO data were used to estimate forecasted stock shares and efficiencies of building equipment. More savings may be possible, but program details are still in development.
State and Montgomery County Building Energy Performance Standards	Included, but with partial implementation by 2030.	Low penalties result in some level of non-compliance. Goal of 20% reduction in direct GHG emissions by 2030 is assumed to be fully achieved in 2035, with lower level (12%) reductions in 2030.
Montgomery and Howard County, All Electric Building Code	Included, modeled approximately at present, impacts are small in 2031 and likely will have some overlap with BEPS and IRA impacts	NA
DHCD BeSMART Home Energy Loan Program	Not included or modeled as direct emissions reduction measure, as they are assumed to be enabling actions for other modeled impacts	NA
DHCD Multifamily housing financing programs		
MEA SEIF- Low-to-Moderate Income Energy Efficiency Grant Program		
DHCD Weatherization Assistance Program		
DHCD MEAP crisis repair and weatherization		
Homeowner Assistance Fund WholeHome Grant Program		

EmPOWER Maryland: Enacted in 2008, EmPOWER Maryland originally established a statewide goal of a 15% reduction in per capita electricity consumption and peak demand by the end of 2015. In 2022, via Climate Solutions Now Act, the goals were updated to a 2.25% reduction per year in 2025 and 2026, and a 2.5%/yr. reduction in 2027 against 2016 levels. The program is administered by the Public Service Commission, carried out by utilities and contractors, as well as the Maryland Department of Housing and Community Development (DHCD). See Public Utilities §7–211(b).

EmPOWER reductions were estimated as a negative demand not allocated to specific end uses. Reductions were split 50/50 between the Residential and Commercial sectors. Reductions in electricity demand were estimated based on the target reduction values times the net-to-gross ratio of 0.71 that estimates the impacts of the program not including free riders. The targets were assumed as follows: 2% reduction in electricity sales (relative to 2016) in 2022-2024, 2.25% reduction in 2025-2026, 2.5% in 2027-2029, then trended down to 0.5% in 2050. Reductions in electricity demand were estimated based on the target reduction values times the net-to-gross ratio of 0.71, which is used to estimate the impacts of the program excluding "free riders".[44,45]

Building Energy Performance Standards: State and Montgomery County Building Energy Performance Standards impacts were estimated by estimating the fraction of Residential and Commercial buildings covered by the standards, based on data provided by MDE and data from the state CAMA building database. While the legislation for this policy was passed in 2022, it has not yet been implemented and the level of compliance is uncertain. The standard mandates 20% reductions in GHG emissions for covered buildings by 2030; however, a lower level of reduction (around 12%) was assumed to be achieved in 2030, with the full 20% achieved by 2035. To meet the required reductions, 40% is assumed to come from building re-tuning, 12% is assumed to come from building envelope improvements, and 48% is assumed to come from electrification of space heating and water heating equipment.

Montgomery and Howard County All-Electric Codes: Impacts for all-electric building codes for Montgomery County and Howard County were estimated using the fraction of statewide Residential and Commercial building area in these two counties. This fraction was applied to the fraction of new building area, based on growth in households and commercial floorspace, plus an estimate of 1% of building area being renovated in each year. The resulting fraction of covered buildings was then added to the sales fractions of electric heat pump space heaters and electric resistance water heaters starting in 2027.

Figure 4-6 and Figure 4-7 show, respectively, the Residential and Commercial energy demand, including fuels and electricity. EmPOWER savings are quite significant, even with the assumption that fractional savings will decline over time. Figure 4-8 and Figure 4-9 show the demand for electricity only, with modest increases in most end-uses but with savings from EmPOWER more than offsetting the increases in emissions.

[44] The EmPOWER Maryland Energy Efficiency Act REPORT OF 2022.

[45] The term "free riders," when applied to energy efficiency programs, refers to program participants (for example, households and businesses) who would have adopted energy efficiency improvements even in the absence of an incentive program, but who also took advantage of the incentives offered as a part of the energy efficiency program.

Figure 4-6: Residential Sector Energy Demand in Maryland, Current Policies Case

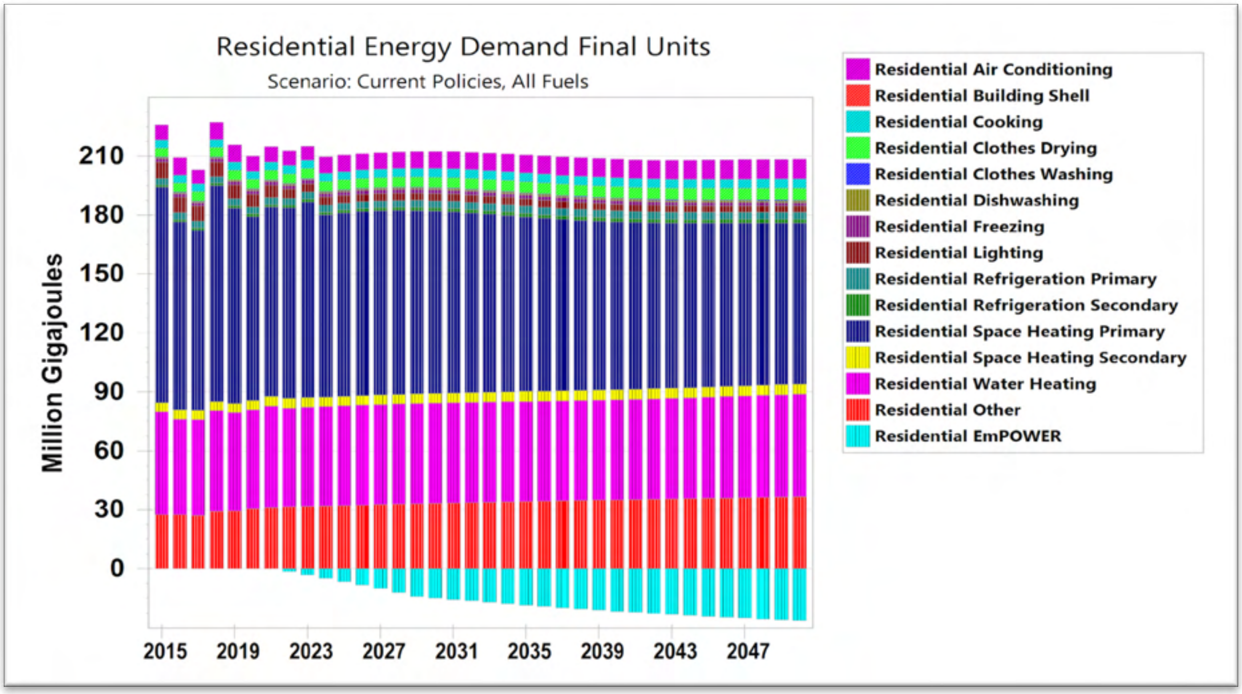


Figure 4-7: Overall Commercial Sector Energy Demand in Maryland, Current Policies Case

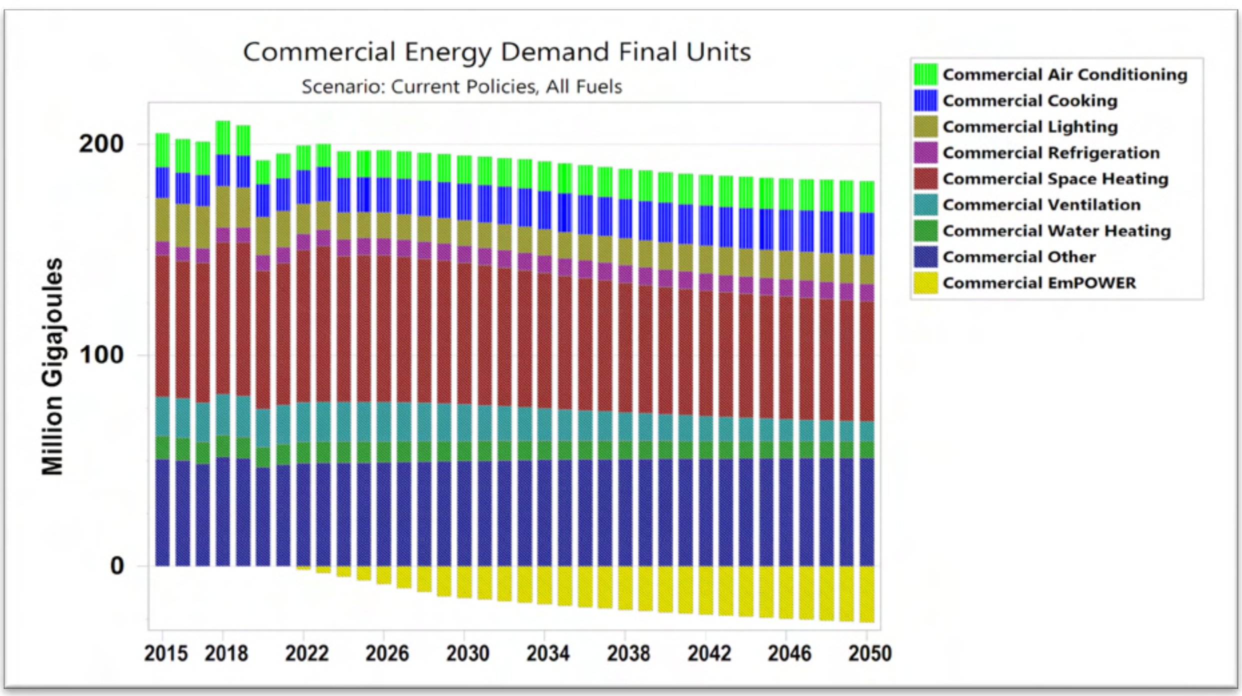


Figure 4-8: Residential Sector Electricity Demand in Maryland, Current Policies Case

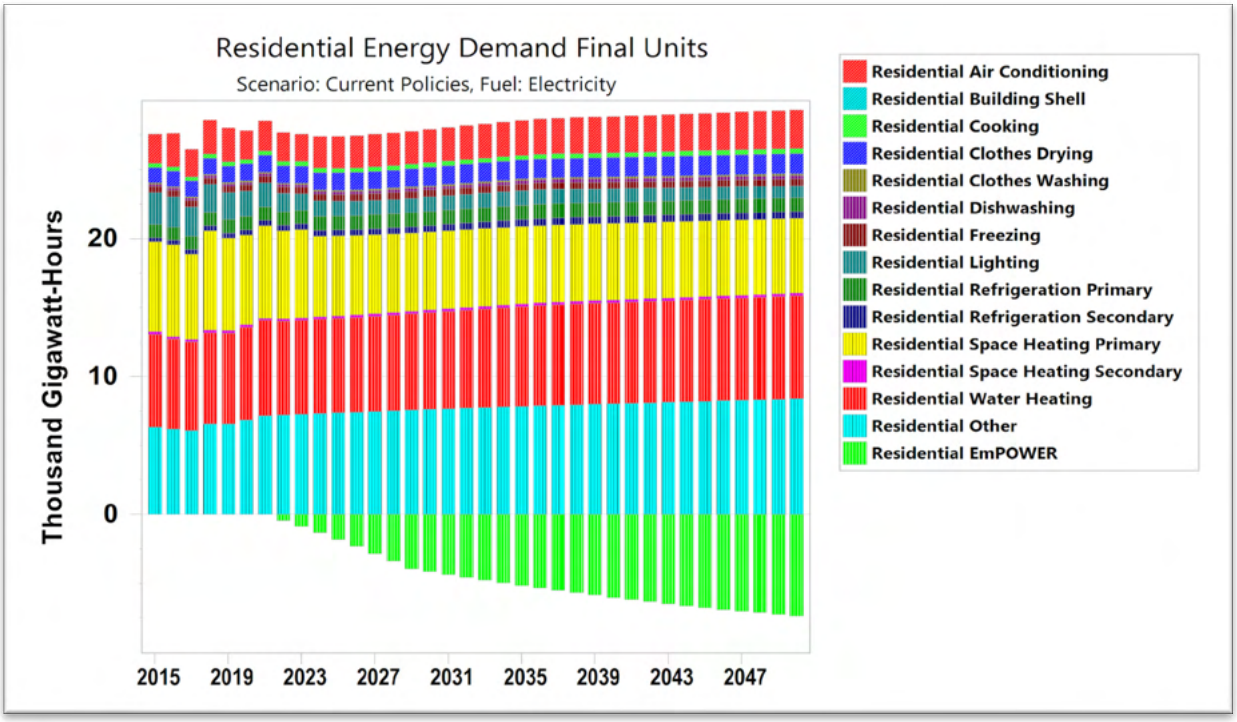


Figure 4-9: Residential Sector Electricity Demand in Maryland, Current Policies Case

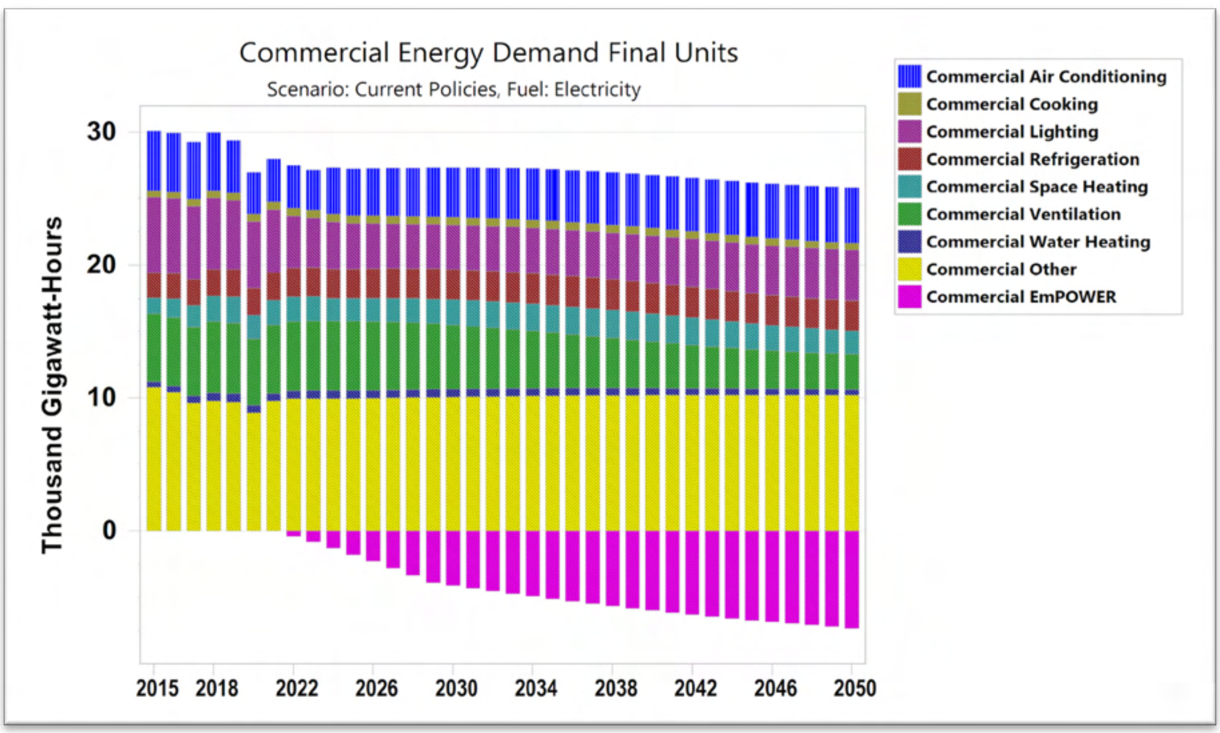
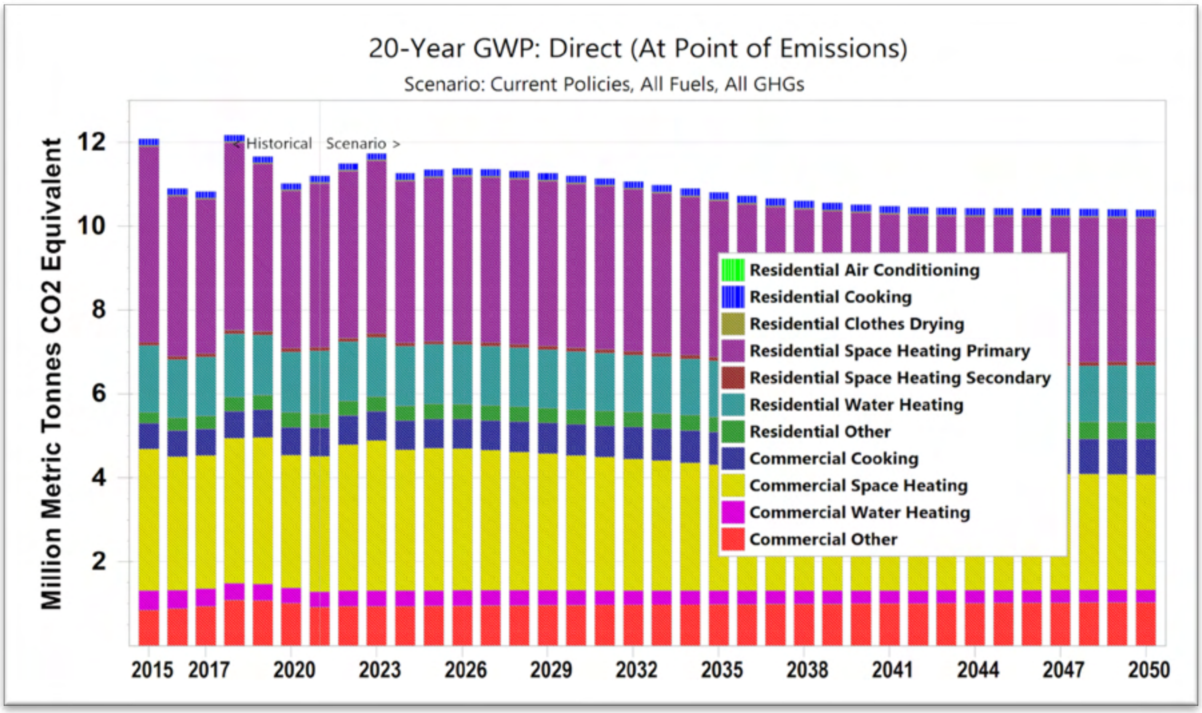


Figure 4-10, below, shows the direct emissions in the Residential and Commercial Sectors in the Current Policies Scenario. Space and Water Heating dominate direct Residential and Commercial GHG emissions, accounting for 66% and 15% of the Buildings sector emissions in 2023, respectively. Under this scenario, overall emissions in the Buildings sectors are expected to decrease by less than one percent by 2031 and by 7.2 percent by 2045, relative to 2021 emissions.

Figure 4-10: Buildings Sector Direct GHG Emissions, Current Policies Case



4.2.3 Transportation

Table 4-3 describes the current policy actions for Transport considered for the Current Policies Scenario. The highlighted rows are those included in the Current Policies Scenario. Details of how selected actions were modeled follow, along with energy use and GHG emissions results for the transportation sector.

Table 4-3: Current Transportation Sector Policies

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
Advanced Clean Cars (ACC) II	Included, adopted March 2023	Assumptions: ZEVs, of which 20% are PHEVs, constitute 43% of sales in calendar 2027, rising to 76% in 2031 and 100% in 2035. In anticipation of these regs, sales of ZEVs in MD start to deviate from AEO2023 values in calendar 2025. AEO2023 MPGe trends for EVs, and PHEVs operate on electricity for an average of 55% of VMT.

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
IRA incentives	Not included since any impact is assumed to be included in impacts of ACC II regulations.	NA
CAFE standards	Included in the baseline through AEO 2023 estimates used for Reference Case.	NA
VMT reduction policies	Not included since policies currently on the books seem likely to have modest effect, if any. Note that we do model the impact of the Purple Line (see below), on VMT, which is modest.	NA
Congestion Mitigation	Not included due to lack of data and assumed modest impact.	NA
Advanced Clean Trucks (ACT) Rule	Included in the baseline, state adopted rule in 2023	Assumed to take effect with 2027 model year. Modeled based on California ACT rule, with modifications for rule timing and the composition of Maryland's truck fleet
IIJA	Included only in terms of bus electrification as described below.	NA
WMATA electrification	Included in the baseline	1500-1600 WMATA buses, of which half are assumed to be housed in MD
MTA electrification	Included as announced by individual jurisdictions.	Modeled based on the introduction of electric (and in one case, hydrogen) school and transit buses as announced by various jurisdictions and agencies.
Electrification of state fleet		
General Bus Electrification		
Local land-use policies - Transit Orientated Development	Not modeled as Current Policies	NA
Multistate MD and HD MOU		
Pilot program for utilities to provide rebates for EV school buses		
Transit Safety & Investment Act	Not included or modeled as direct emissions reduction measure, assumed to be an enabling action for bus electrification and other transit actions.	NA
Purple Line (DC-area Metro extension with	Included in the baseline; long planned and assumed to be	The Purple Line is assumed to start in 2027 and ramp up to stated levels of ridership by 2030,

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
Light Rail line traversing an area in Maryland roughly along the I-495 Beltway).	implemented mostly as currently scheduled.	with ridership displacing VMT increasing 1 percent annually thereafter. The estimated impacts of the Purple Line on statewide VMT are very modest (<0.1%). Value scaled for light rail kWh per vehicle mile to produce an estimate of the electricity used in the Purple line, but that estimate could be improved direct information from Purple Line planners can be obtained.
Motorcycle Electrification	Included as described at right.	Assumed rough estimate of 20% of the motorcycles on the road by 2050 will be electric (1% by 2028), with penetration of the market starting in 2023. This may prove to be an underestimate, given expected growth in the North American electric motorcycle market in this decade.[46]
E-bikes	Included as described at right.	Reference case estimate for E-bike penetration and usage, basically increasing E-bike use about 20-fold from 2021-2050. Light duty vehicle (LDV) VMT is reduced (modestly) by the estimated distance not traveled in LDVs due to E-bike usage, estimated to be on the order of a few percent of total LDV VMT by 2050.
Electrified Air Transport	Included as described at right.	Assumed a slow transition towards electricity, hydrogen, and "sustainable aviation fuel" (apparently, largely soybean oil based) in the Reference plus Current Policies case, with those three fuels displacing 43% of jet kerosene by 2050.
Electrified Rail Transport	Not included in the Current Policies case. Given the institutional resistance to rail freight electrification in the US, it seems likely to be initiated at a national level in the US, and there would be little MD could do to stimulate it happening except in concert with many other states.	NA
Alternative Fuels for Marine Shipping	Included in the baseline.	Provisionally added Hydrogen (5% by 2050) and LNG (20% by 2050) for the reference case based on trends in ship orders from various sources, although these levels of penetration would be well short of IMO's net zero goals.

[46] See, for example, Prescient and Strategic Intelligence (2023), "North America Electric Scooter and Motorcycle Market Report", dated January 2023.

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
Electrification of "Other Transportation"	Included as described at right.	For each of these branches we have assumed significant electrification in the Current Policies case. Lawn and Garden equipment is being electrified the fastest, based on market figures (and our observations), so we assume the stock of equipment will be 25% electric in 2030, and 60% in 2050. For marine watercraft and recreational equipment, we assume that the stock will be 5% electric in 2030 and 25% electric in 2050. In all three cases these may be more likely underestimates than overestimates.[47]

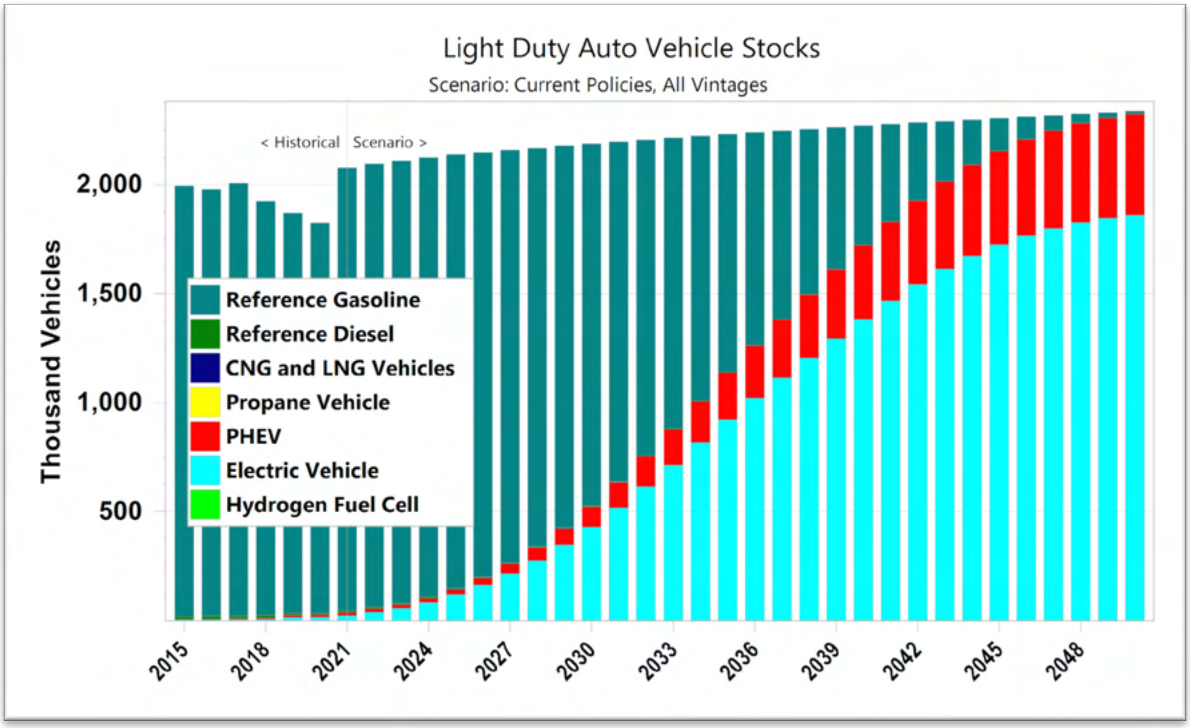
Guiding assumptions and intermediate results for the transportation sector for the Current Policies case are listed below. Additional details can be found in the Technical Appendix to this report (Section 3.2).

- Annual vehicle miles traveled per light-duty vehicle (LDV) rises slowly throughout the modeling period, offset only modestly (about two percent by 2050) by e-bike and Purple Line use.
- Light duty vehicle stocks turn over almost completely to electric and plug-in hybrid electric vehicles (PHEV) by 2050 (see Figure 4-11 and Figure 4-12 below).
- Heavy duty truck stocks are approximately 50% battery electric and PHEV vehicles by 2050 (Figure 4-13).
- The overall distance traveled by heavy trucks increases only slightly by 2050 (Figure 4-14), meaning that the annual distance traveled per truck decreases over the modeling period.
- The shares of vehicle stocks of school buses and transit and other buses that are electric vehicles rise to just under half of the total bus stocks by 2050 (see Figure 4-15 and Figure 4-16).
- There are about 2 million e-bikes in use in Maryland by 2050, together used to travel about 2 billion miles per year.
- The share of passenger enplanements on electric aircraft (probably mostly short-haul journeys) rises to 10 percent of the total in 2040, and 20 percent by 2050.

[47] Sales of electric lawn and garden equipment have been increasing rapidly. One source indicates that as of 2020 sales of electric lawn and garden equipment were already 17% of the market (Cleantechnica (2022). "The Emergence of Everyday Electric Outdoor Machines".). We assume that in the Current Policies case the stock of lawn and garden equipment is 25% electric by 2030, factoring in a rough lifetime of about 8-10 years (although Consumer Reports says six years--https://www.weekand.com/home-garden/article/long-should-lawnmower-last-18027848.php) for gasoline-powered equipment, and assuming that sales of electric equipment will be in the 30+ percent range (or more) by 2030. We assume that the reference case stock of lawn and garden equipment will be 60% electric by 2050. One comparison of fuel use in a commercial gardening application has a gas mower using 700 gallons of gasoline per year while an equivalent electric mower uses 900 kWh. This implies energy use of 84,188 kBtu gasoline versus 3,071 kBtu electricity, or 27.42 times less than gasoline (Univ of Illinois. (2022). "Electric Lawn Mowers".). Another comparison is 0.65 gallons per half acre with a gasoline push lawnmower versus 0.91 kWh for a battery-powered electric mower for the same area of lawn (https://www.wisebread.com/we-do-the-math-will-an-electric-mower-trim-lawn-care-costs), yielding a ratio of 25.29. Pending additional investigations, we use an energy intensity for electric lawn and garden equipment that is 15 times less than gasoline as a conservative assumption.

- We assume that the use of sustainable aviation fuel (SAF) in MD effectively starts in 2024, with SAF substituting for 0.1 percent of jet fuel used in that year (on the order of 300,000 gallons).[48] From there, we assume that SAF use will ramp up to 10 percent by 2030, consistent with the sustainability goals of major airlines, and 20 percent by 2045, although the latter goal may need to be revised. SAF is assumed to have a carbon intensity 74.7% lower than typical jet fuel, at least to start.[49]

Figure 4-11: Evolution of Light Duty Auto Stocks in the Current Policies Case



[48] See, for example, the SAF project at BWI, as described, for example, in Aviation Pros (2023), "Fraport USA Launches Major Sustainability Project at Baltimore/Washington International Thurgood Marshall Airport," dated March 14, 2023.
[49] Based on the default assumption in the 4AIR Sustainable Aviation Fuel (SAF) Calculator. Over time, SAF may be made of biogenic feedstocks that are less carbon-intensive to produce and/or using green hydrogen made with carbon-free electricity.

Figure 4-12: Evolution of Light Duty Truck Stocks in the Current Policies Case

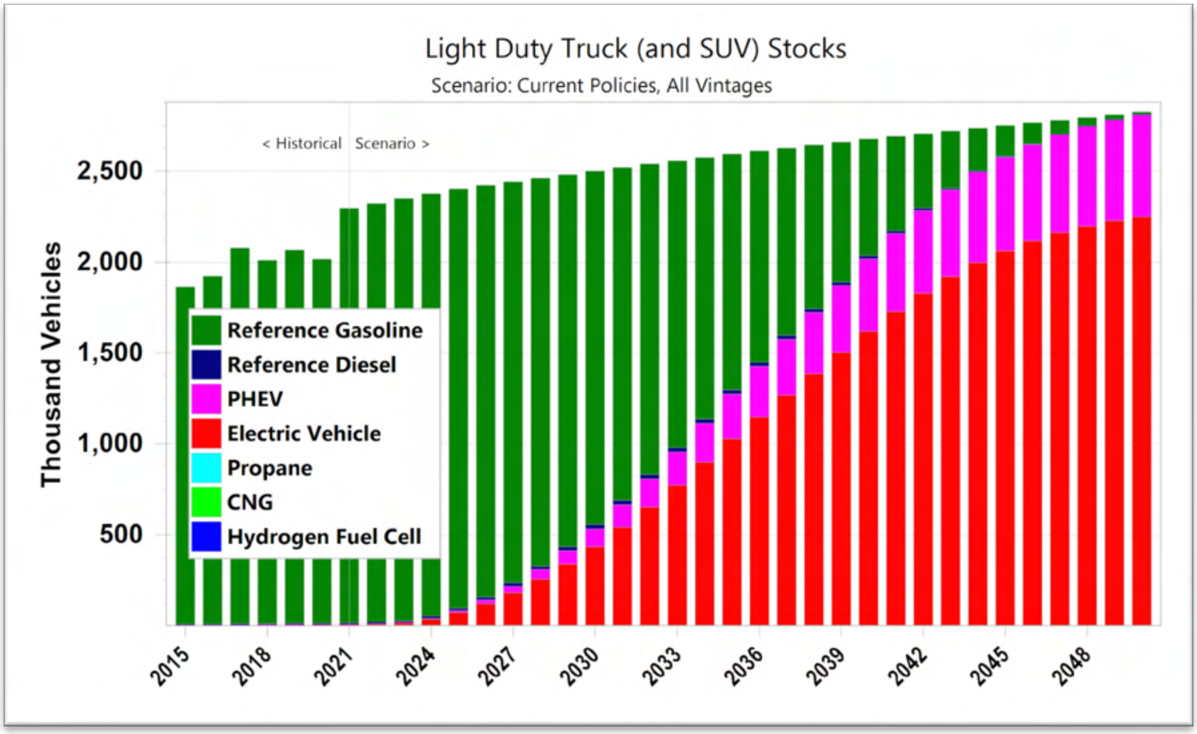


Figure 4-13: Evolution of Heavy-Duty Truck Stocks in the Current Policies Case

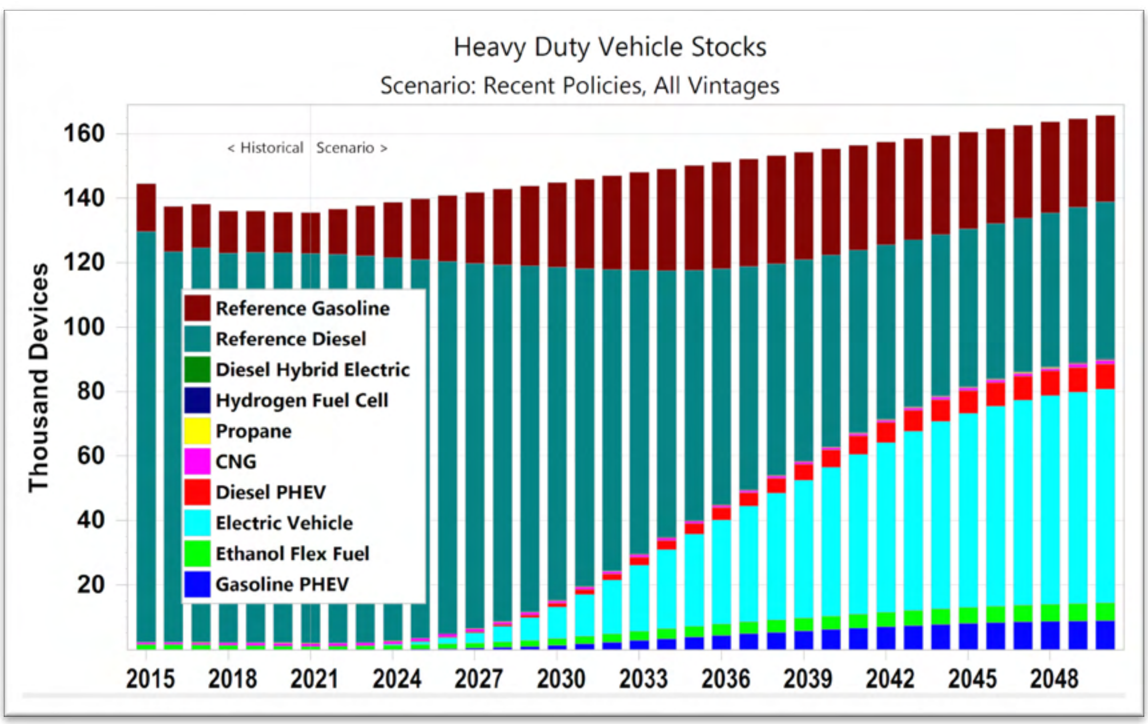


Figure 4-14: Heavy-Duty Truck Distance Traveled in the Current Policies Case

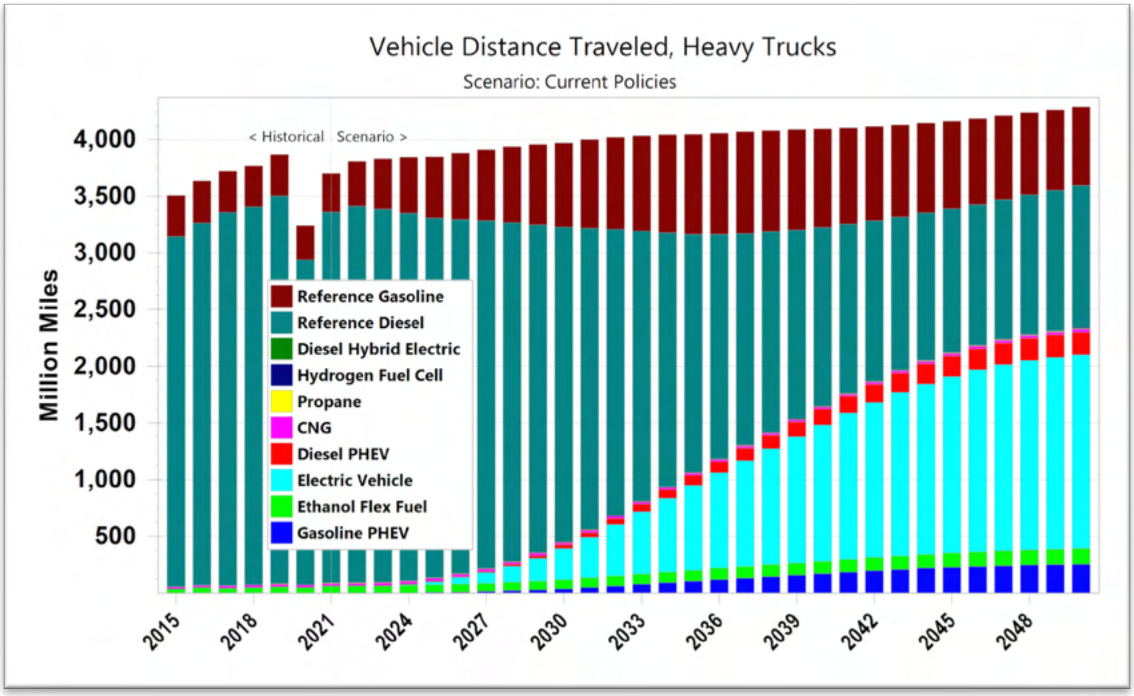


Figure 4-15: School Bus Stocks by Fuel Type in the Current Policies Case

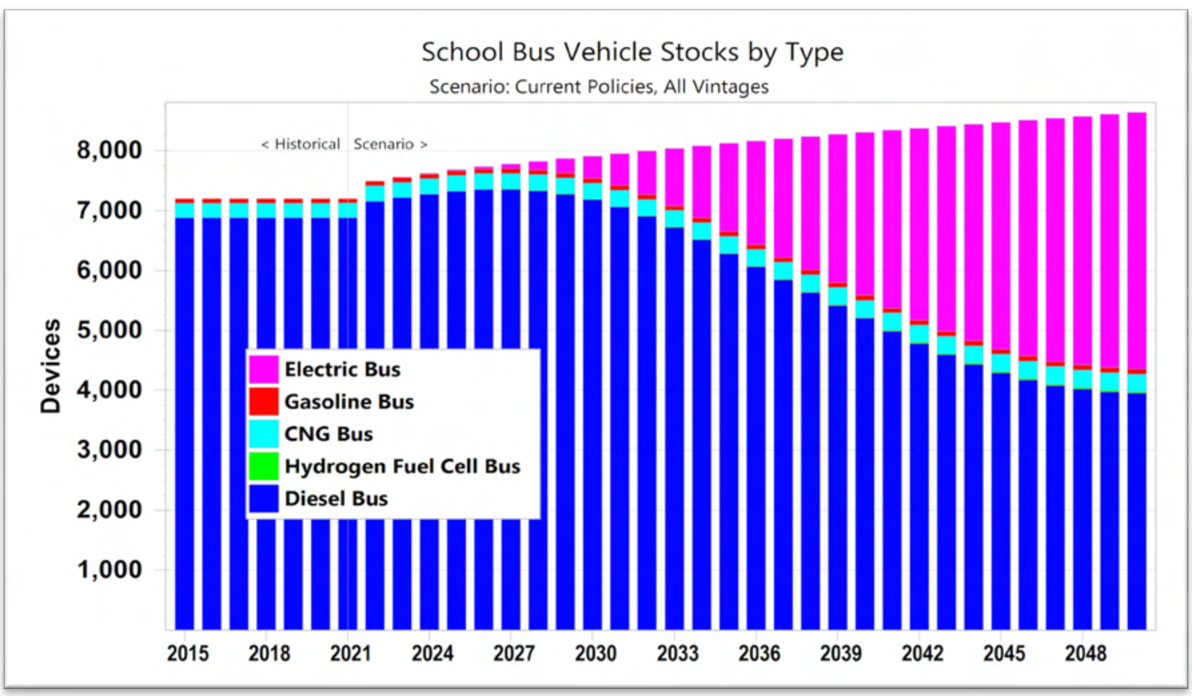
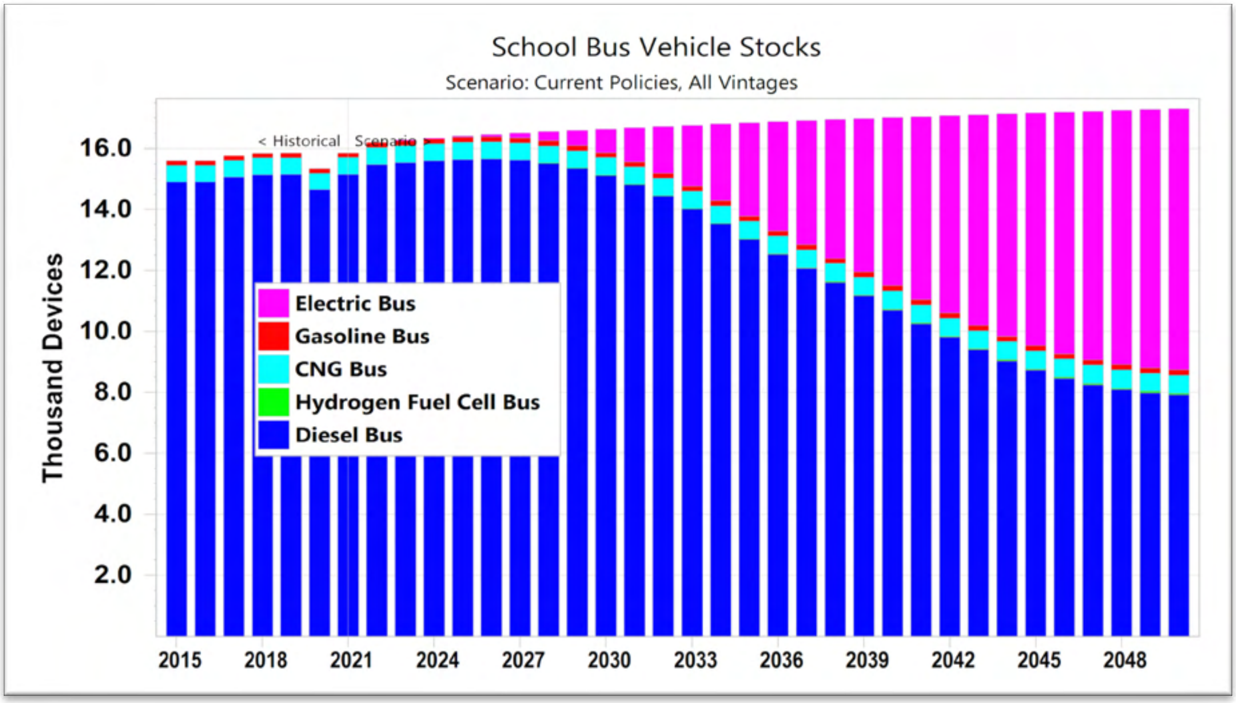


Figure 4-16: Transit and Other Bus Stocks by Fuel Type in the Current Policies Case



We assume that neither **rail freight nor MARC** are electrified by 2050.

We very roughly estimate Purple Line energy use and ridership based on the limited information we were able to immediately locate about the project.[50] See Figure 4-17 for a map of the Purple Line project.[51] Our estimates start with the information in the statement "The Purple Line is estimated to take 17,000 cars off of the road daily, saving 1 million gallons of gas within 20 years."[52] The calculations and assumptions involved in this estimate are as follows:

- The 17,000 cars removed from the road because their drivers (and passengers) are traveling on the Purple Line average 28.65 miles per gallon (AEO Stock average for 2030). Assuming each rider rides an average of 20% of the 16.2-mile length of the line in each direction, and previously traveled in a car with an average of 1.4 occupants, daily avoided gasoline use would be 2,747 gallons per day, which implies, at 365 days per year, and about 1 million gallons of gasoline avoided per year.
- The Purple Line will operate approximately 6695 hours per year. With an approximate average time spacing between trains of 10 minutes (a rough average of on and off peak), and a speed of 16 miles per hour, the trains would cover an average of 642,720 miles per year.[53]

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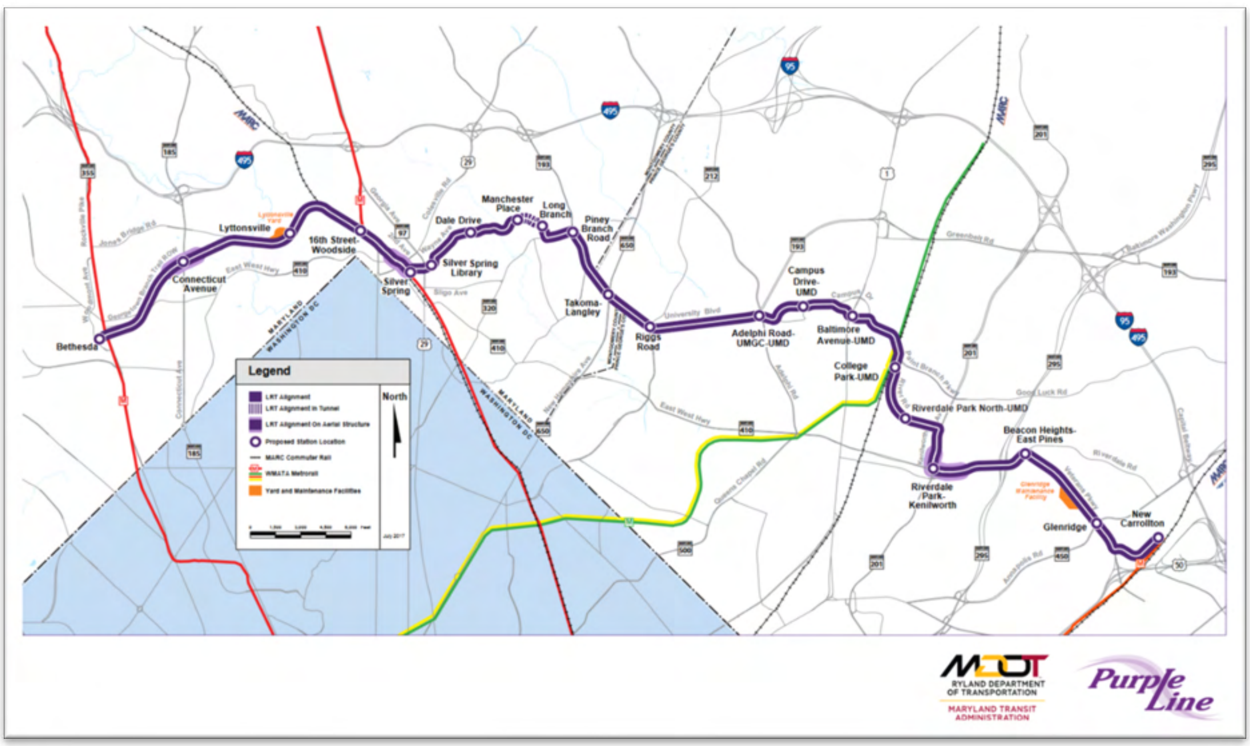
[50] CCS is hopeful that for future iterations of the model we will be able to engage officials with knowledge of the expected parameters of Purple Line, which would be very helpful in improving these estimates.
[51] Figure from Purple Line project site.
[52] From Purple Line overview.
[53] Average speed of trains (including stops) from DC Policy Center (2019). "Our region needs better suburb-to-suburb transit, but a Metro loop isn't the best option".

- Another source lists daily projected ridership of 64,800,[54] which would be slightly more than the 47,600 riders removed from cars estimated above. However, not all Purple Line riders will be switching from cars. VMT avoided by the Purple Line based on the above ridership would be about 40 million annually by 2030, which would be about 0.062% of LDV VMT at that time.
- Given a capacity of 431 people per train (80 seated), if all trains were full for all hours of operation, the total person-miles (in this case, seat-miles) traveled per day would be 758,938. Given the assumptions above, passenger miles traveled would be 209,952 per day, which implies an average capacity factor of 28% (based on standing and seated capacity) and seems plausible.
- Purple Line service is set to begin in the fall of 2026[54]. We model Purple Line service as effectively beginning in January of 2027, with ridership (indicated as VMT avoided) in the first year about 50%, increasing to 100% by 2030, and further increasing at a rate of about one percent annually thereafter, or slightly faster than population growth in MD. We assume no change in Purple Line annual distance traveled over time.

Figure 4-17: Map of the Under-construction Purple Line Light Rail System



We estimate energy use per vehicle-mile on the Purple Line based on the following:

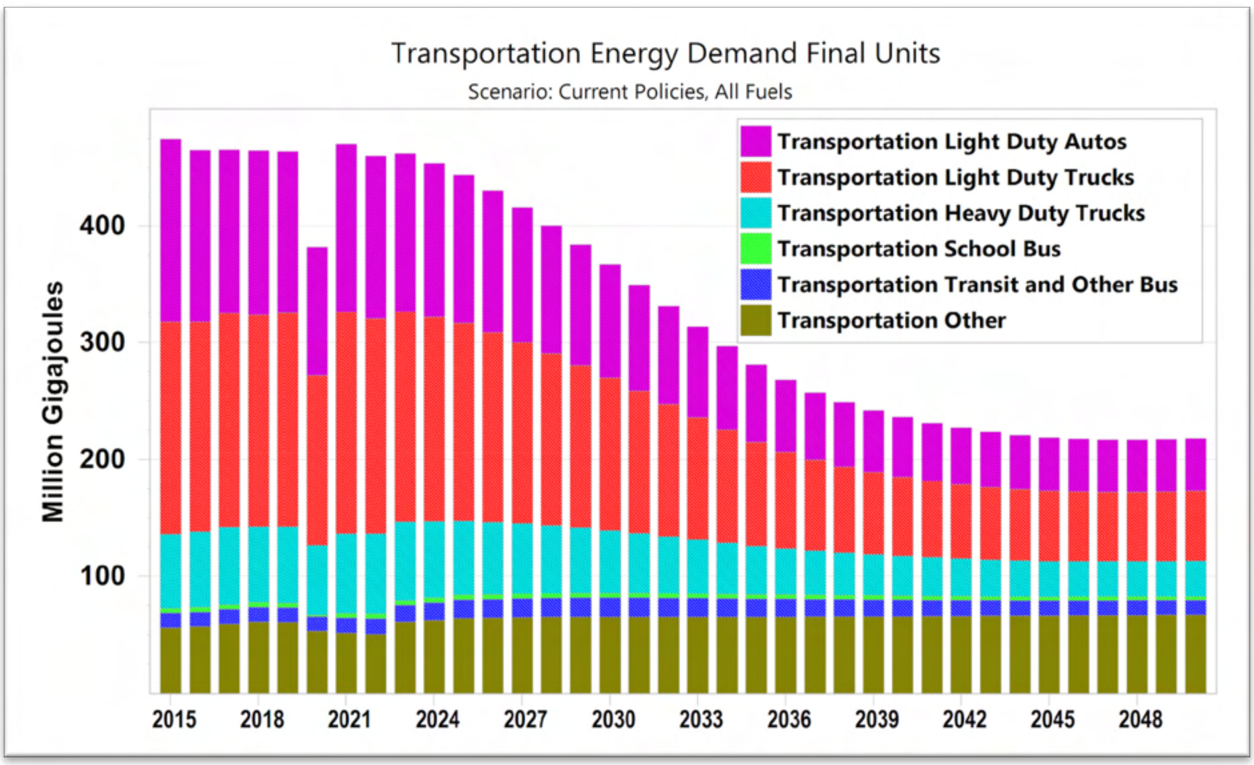
> "A Siemens study of Combino light rail vehicles in service in Basel, Switzerland over 56 days showed net consumption of 1.53 kWh/vehicle-km, or 5.51 MJ/vehicle-km. Average passenger load was estimated to be 65 people, resulting in average energy efficiency of 0.085

[54] Ridership in 2030 from MDOT (2009) "Governor O'Malley Announces Purple Locally Preferred Alternative".

MJ/passenger-km. The Combino in this configuration can carry as many as 180 with standees. 41.6% of the total energy consumed was recovered through regenerative braking".[55] Assuming that kWh/vehicle-km scales with capacity, we estimate the energy use of Purple Line light rail as about 5.9 kWh/vehicle-mile. This would suggest an electricity use per year for the purple line of about 3.8 GWh per year.

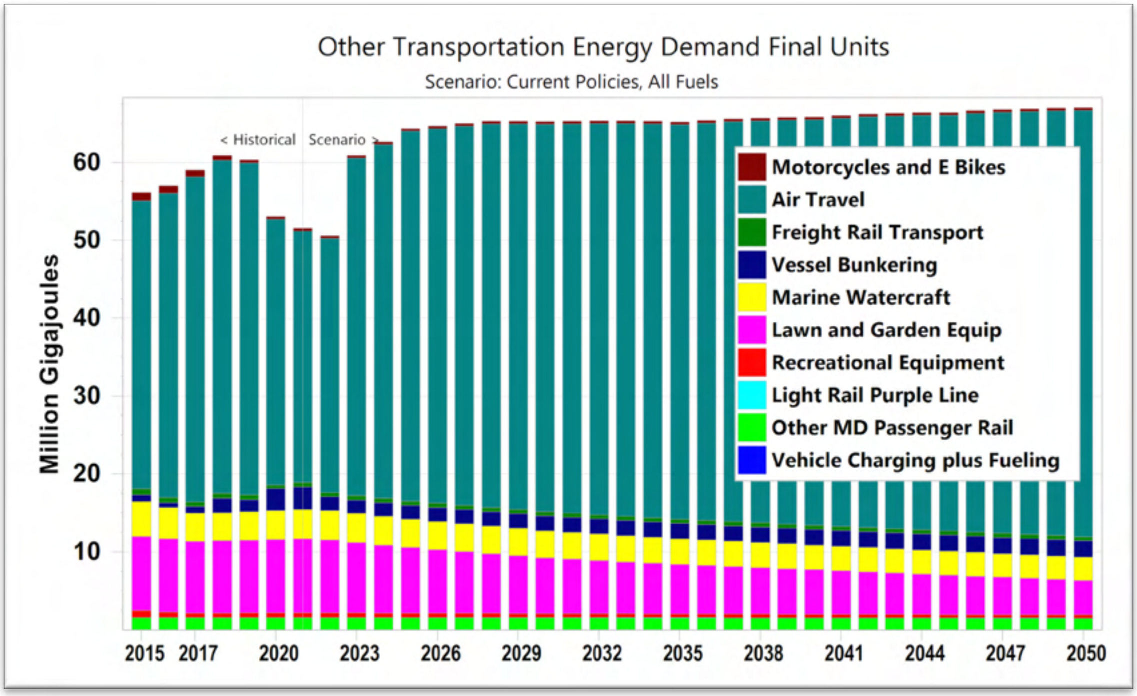
The Current Policies Scenario results for all fuels demand in the transportation sector are shown in Figure 4-18. Demand for fuel in light duty vehicles declines substantially, as more efficient EVs replace gasoline vehicles, but not as much in the other vehicle classes. Overall demand in other transportation increases somewhat over time on a net basis, with air travel constituting a large share of increases (Figure 4-19).

Figure 4-18: Current Policies Scenario Energy Demand by Subsector



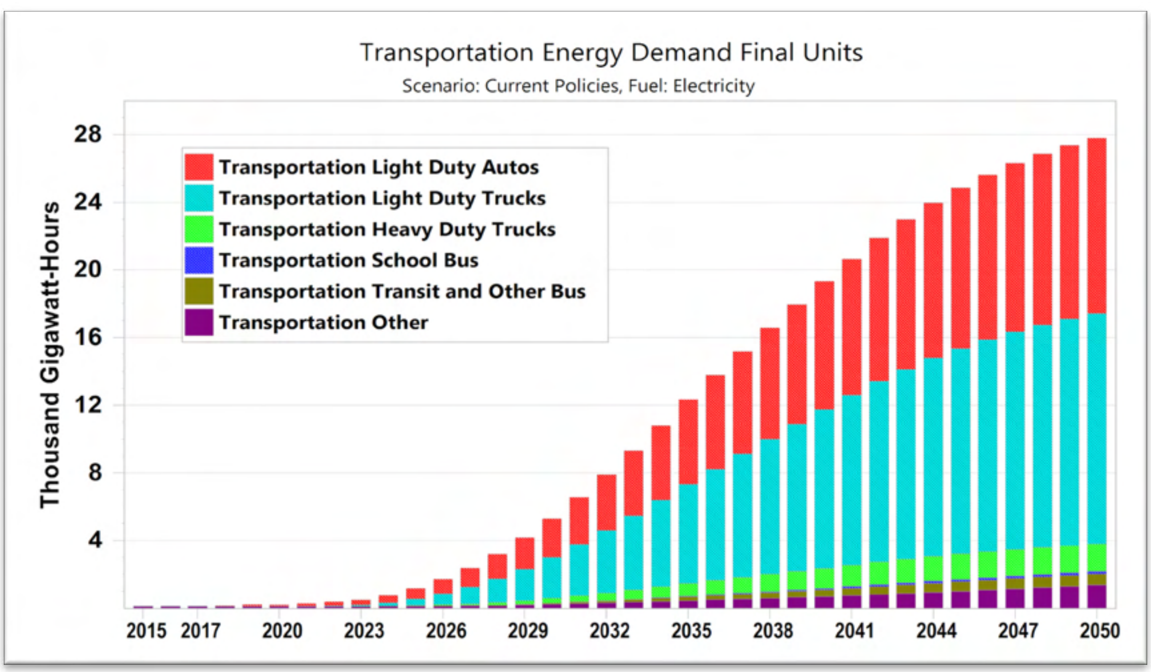
[55] From Chem Europe. "Fuel efficiency in transportation".

Figure 4-19: Current Policies Scenario Energy Demand in Other Transportation



Electricity demand in the transportation sector (Figure 4-20) increases from less than a thousand GWh in 2023 to nearly 28 TWh by 2050, driven mostly be electrification of LDV stocks.

Figure 4-20: Current Policies Scenario Transportation Electricity Demand by Subsector



Consistent with the reduction in LDV fuel consumption due to electrification, the overall GHG emissions from the transportation sector decrease markedly by 2050, from over 30 $MMtCO_2e$ in the early 2020s to well under 10 $MMtCO_2e$ by 2050, as shown in Figure 4-21. Emissions in the Other Transportation categories, taken as a whole, decline much less, due to the persistence of emissions from air travel (Figure 4-22).

Figure 4-21: Current Policies Scenario GHG Emissions in the Transport Sector

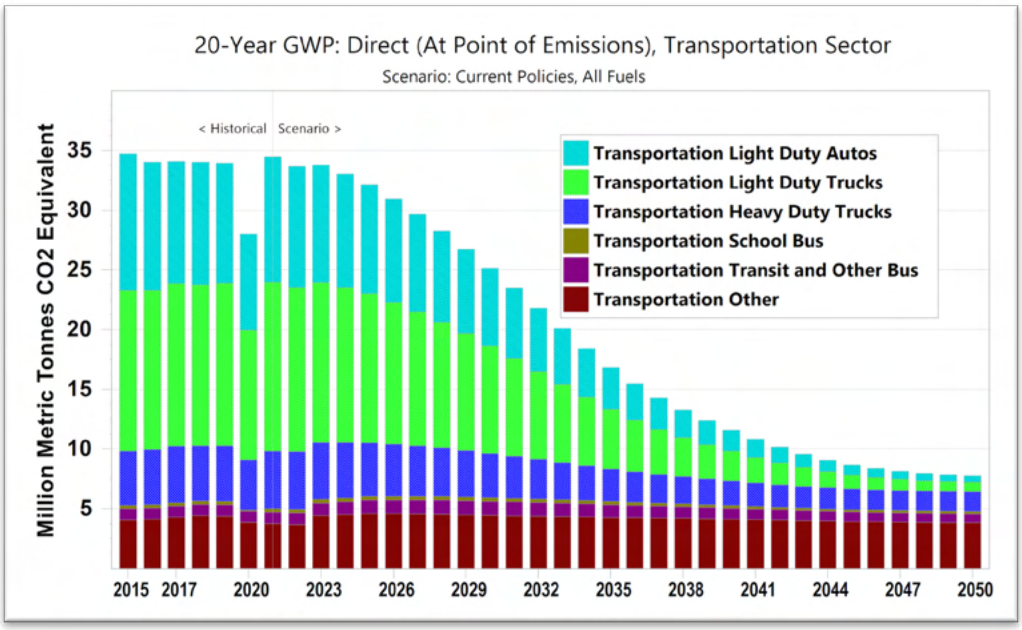
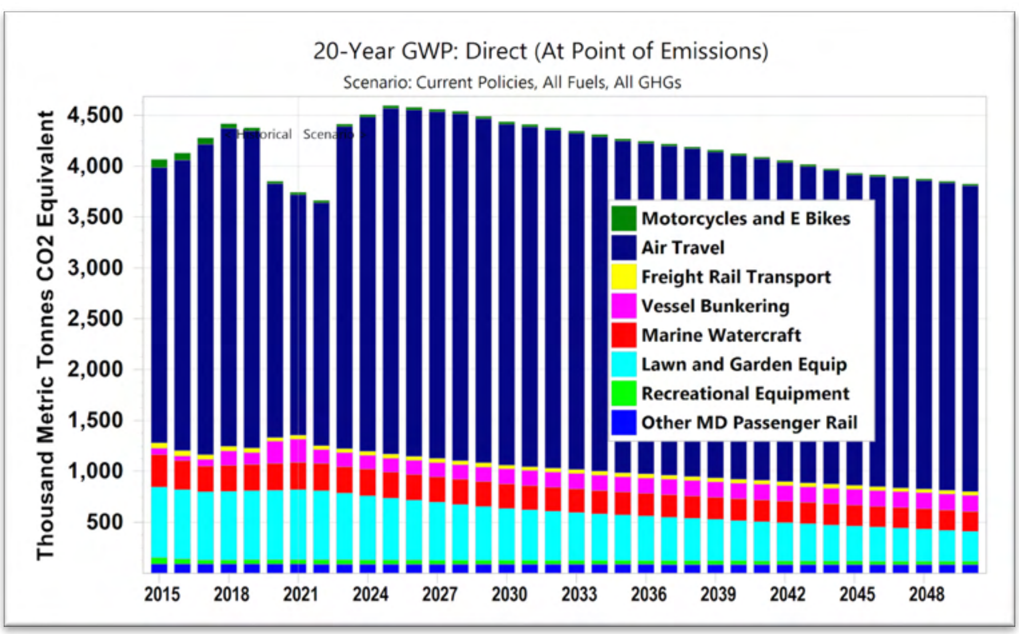


Figure 4-22: Current Policies Scenario GHG Emissions in the Other Transport Subsector



Millions of vehicle charging stations will need to be added over time as LDVs, in particular, are electrified. Most of these additions will be home charging stations (level 1 LDV and most of level 2 LDV in Table 4-4). As gasoline vehicle use declines, the number of LDV fuel pumps are estimated to decline as well. Note that the estimates provided in Table 4-4 should be thought of as representative orders of magnitude for each category, because in practice the number of EV charging stations in Maryland will depend on factors such as the mix of housing types, driver/owner preference, the locations of service facilities and other places where EV chargers might be sited, and other considerations.

Table 4-4: Estimated Requirements for Charging Stations in Maryland Under the Current Policies Case

	2023	2025	2030	2035	2040	2045	2050
LDV Fuel Pumps	18,996	19,058	17,282	13,416	9,244	5,933	4,643
Level 1 Chargers LDV	15,153	39,158	184,679	422,019	654,534	828,151	898,553
Level 2 Chargers LDV	53,252	137,613	649,013	1,483,094	2,300,221	2,910,358	3,157,774
Level 3 Chargers LDV	866	2,238	10,553	24,115	37,402	47,323	51,346
Level 2 Chargers HDV	1	144	1,488	4,297	7,139	9,573	10,756
Level 3 Chargers HDV	1	144	1,488	4,297	7,139	9,573	10,756

4.2.4 Industry

No overarching specific GHG emissions reduction policies for the industrial sector are included in the Current Policies case beyond those included implicitly through reflection of existing trends and policies in the AEO2023 Reference scenarios, which was used as the basis for the Current Policies case. The most significant change in industrial sector emissions, shown in Figure 4-23, is the result of a planned change to use natural gas instead of coal in one of the two in-state Maryland cement producers. Figure 4-24 shows the trend of overall industrial demand in the Current Policies case. Energy demand rises slowly as the Maryland economy and cement production grow, offset in part by modest ongoing energy efficiency improvements in both modeled industrial subsectors.

Figure 4-23: Industrial Sector GHG Emissions, Current Policies Case

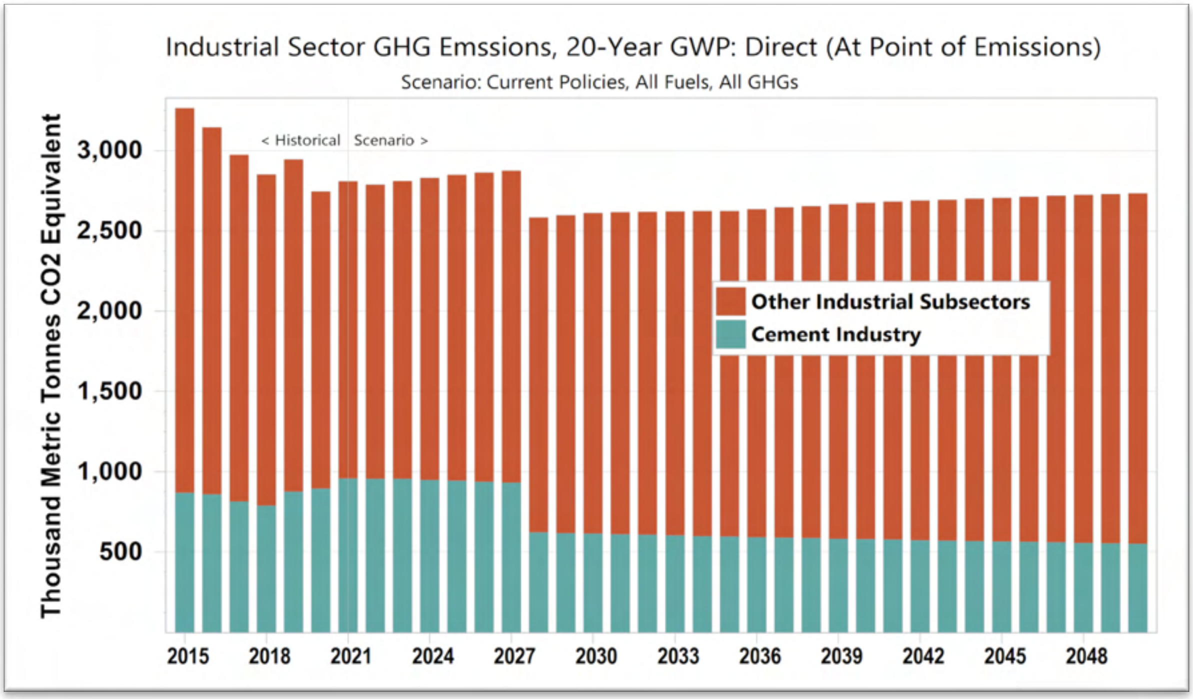
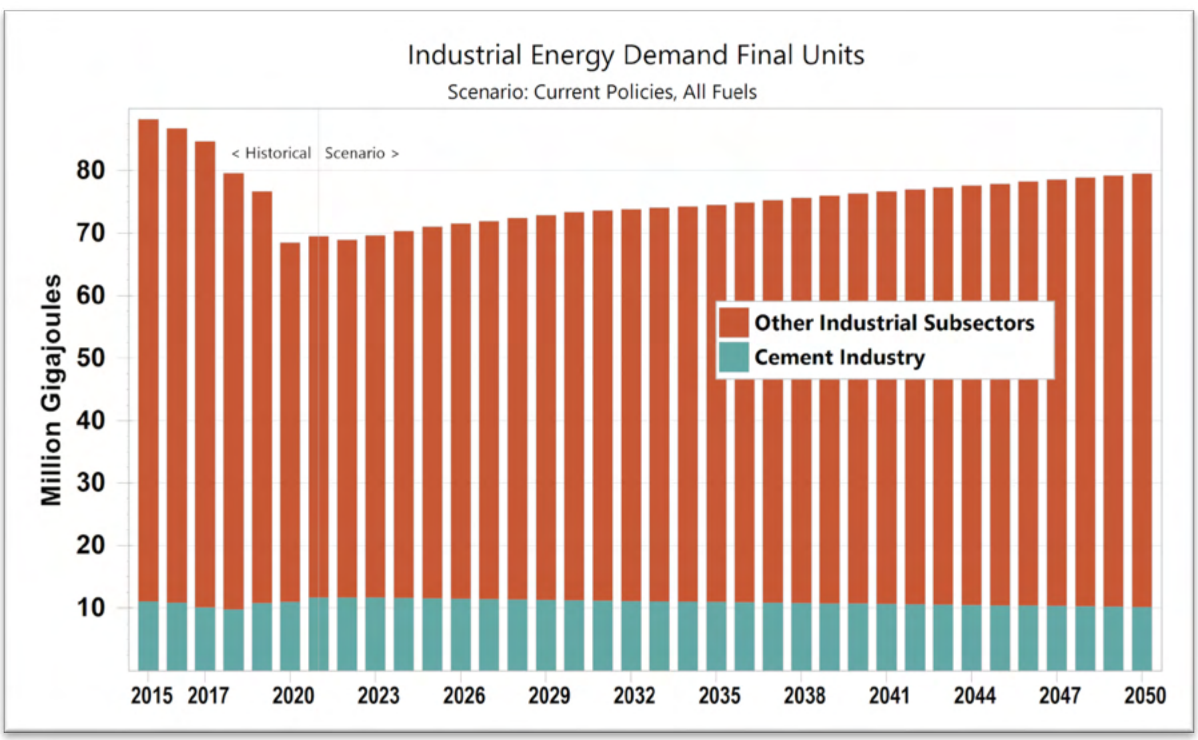


Figure 4-24: Industrial Sector Energy Demand, Current Policies Case



4.2.5 Other Sectors

The only significant changes to recent trends in other sectors for the Current Policies Scenario are partial electrification of equipment in Agriculture (and Logging, which accounts for a small fraction of energy use in the branch), and Construction and Mining sectors, as shown in Table 4-5.

Note that other (non-energy) emissions from the Agriculture sector are covered through modeling in the GHG Strategy Tool, whose results are transferred to corresponding non-energy branches in LEAP for reporting and are discussed below.

Table 4-5: Current Agriculture/Logging and Construction/Mining Energy Use Policy Actions

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
Electrification of Agricultural/Logging and Construction/Mining Machinery	Included in the baseline with assumption of partial electrification by 2050	Assumed 20% electrification of agricultural and construction equipment by 2050.

Energy use in the Agriculture and Logging, and Construction and Mining sectors are shown in Figure 4-25 and Figure 4-26, respectively. In both cases, diesel fuel use dominates, and a combination of slow ongoing improvements in energy intensity (use of energy per acre farmed and per unit of construction sector economic output) plus replacement of some diesel fuel use with the use of more efficient electricity-driven equipment reduces overall energy demand. These changes are reflected in the overall reduction in GHG emissions in both sectors, with emissions declining slowly after the mid-2020s (Figure 4-27 and Figure 4-28.

Figure 4-25: Agricultural and Logging Energy Demand, Current Policies Case

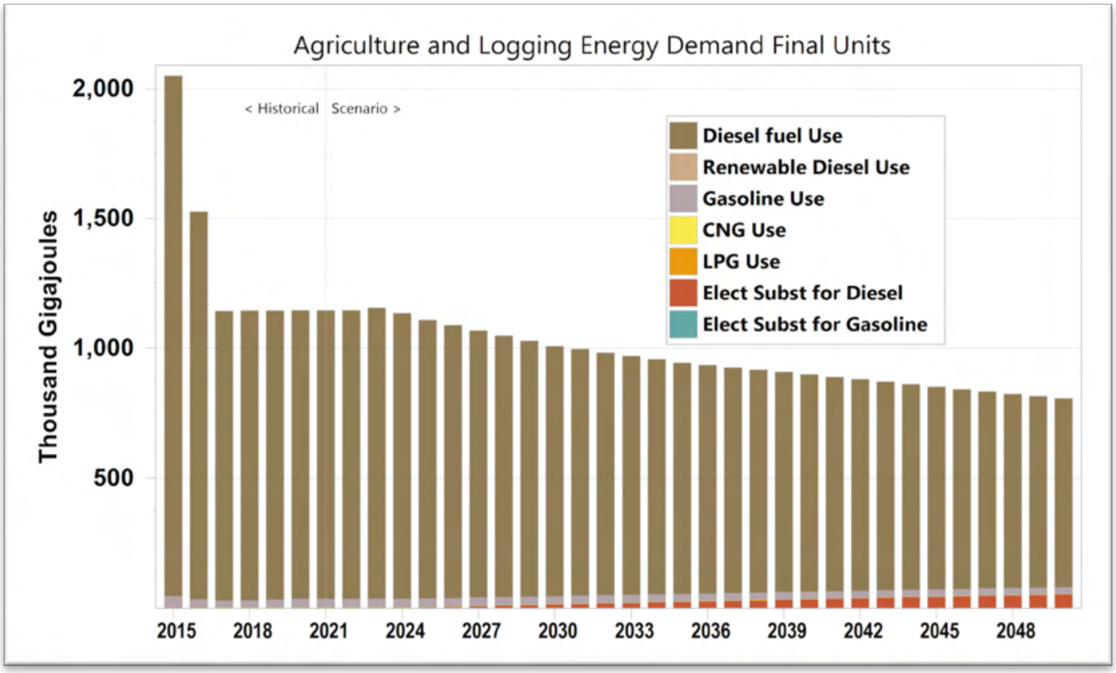


Figure 4-26: Construction and Mining Energy Demand, Current Policies Case

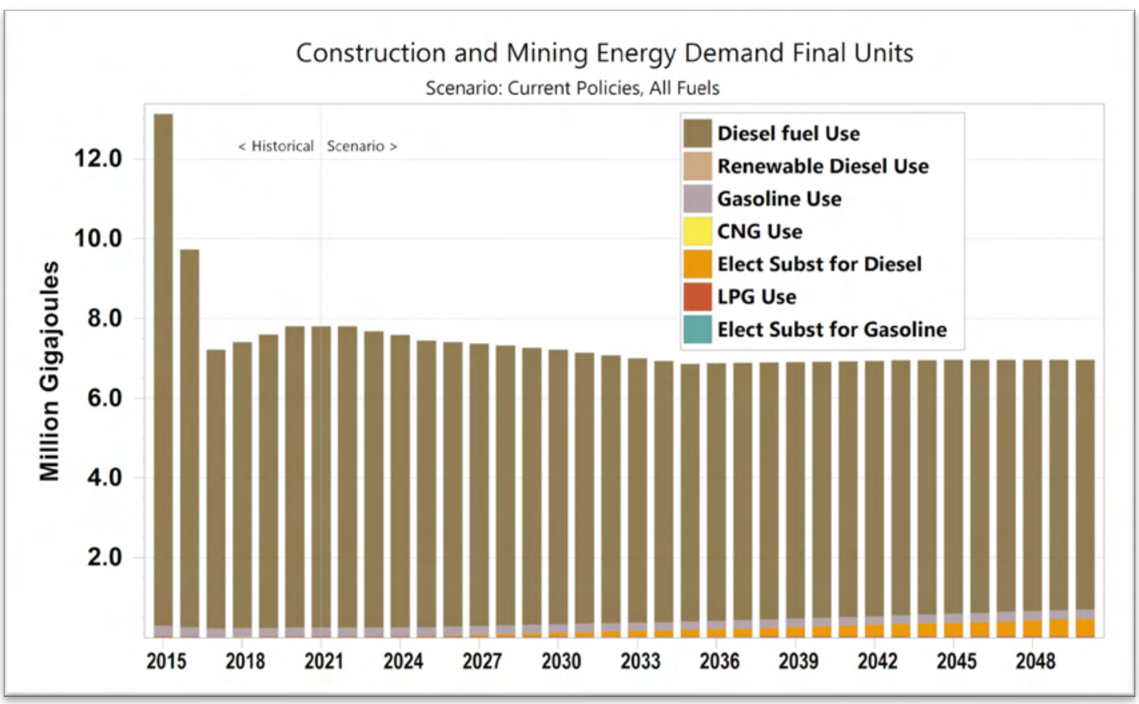


Figure 4-27: Agricultural and Logging GHG Emissions, Current Policies Case

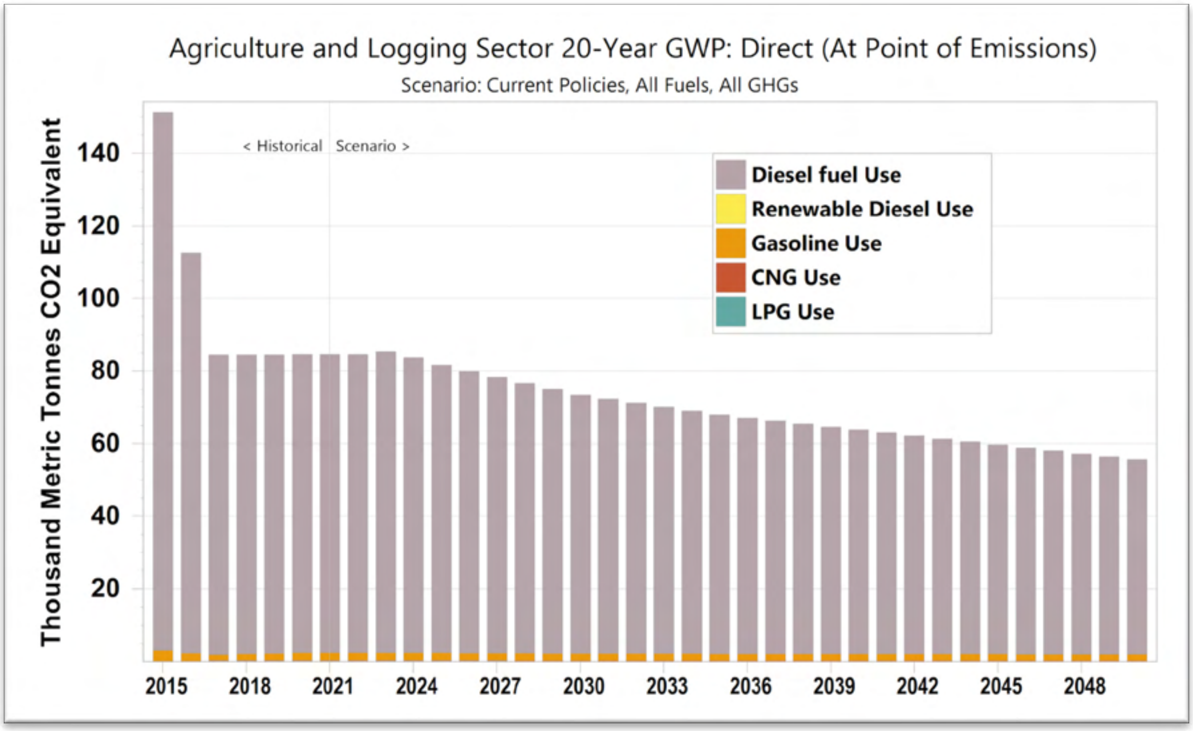
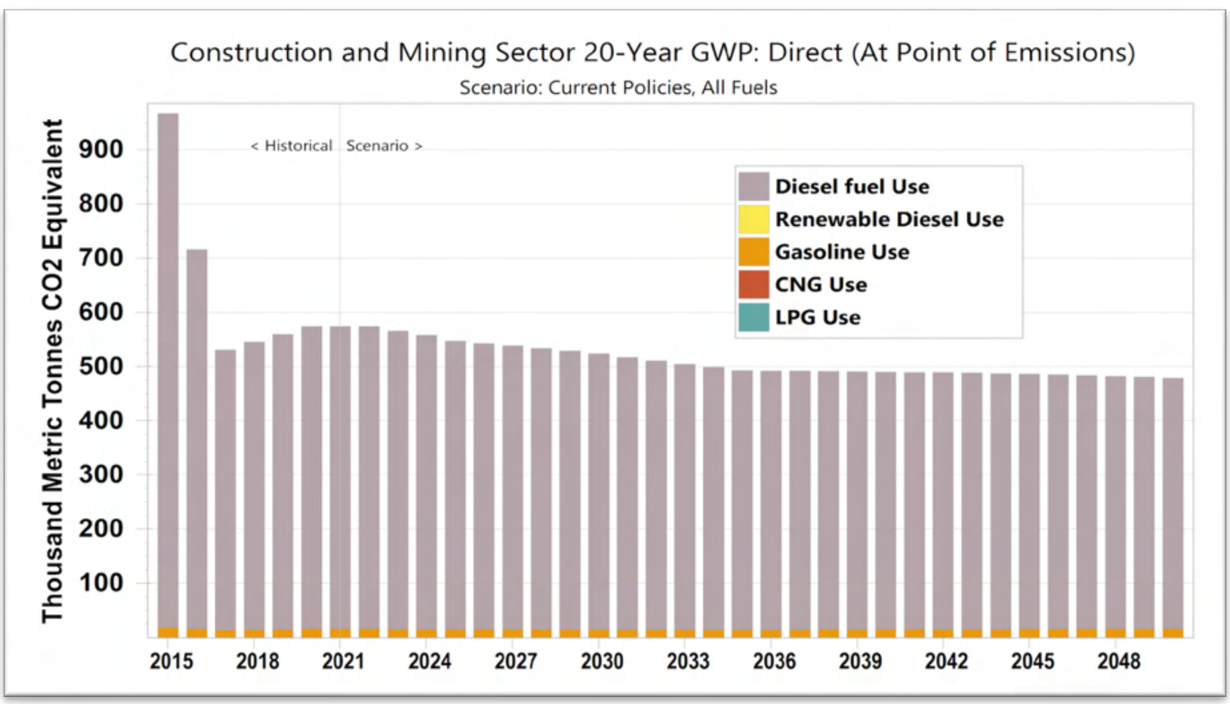


Figure 4-28: Construction and Mining Sector GHG Emissions, Current Policies Case



4.3 Energy Supply

Table 4-6 describes the current policy actions for Energy Supply considered for the Current Policies Scenario. The highlighted rows are those included in the Current Policies Scenario. These policies focus primarily on electricity generation, including expanding use of central station solar, wind, and storage power plants, as well as distributed solar power.

Table 4-6: Current Energy Supply Policy Actions

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
Renewable Portfolio Standard (RPS)	Not modeled as a direct emission reduction program. This goal is met through the actions listed below.	NA
RPS Offshore Wind Requirement	Not modeled as a direct emission reduction program. This goal is met through the actions listed below.	NA
Solar Carve Out: Siting/Land Use Policies	Included in the Current Policies case, local jurisdiction-specific siting/land use policies are being actively implemented, state tax incentives passed in 2022.	Utility solar in service as of 2031 estimated at almost 2600 MW, including 400 MW reported in service as of 2021. Additions thereafter assumed to be at 100 MW per year.
Solar Carve Out: Interconnection Reform		
Solar Carve Out: State and Local Incentives		
Community Solar	Included in the baseline, pilot program expanded in 2022, state tax incentives passed in 2022	Assumed 750 MW of community solar by 2030, and 1250 MW in 2045. Community solar is entered as a "process" in LEAP under Rooftop Solar, but capacity is de-rated by a factor to account for distribution losses not avoided, currently estimated at 2 percent, pending finding data on the split between T&D losses in MD or a comparable jurisdiction.
Montgomery County Community Choice Energy	Not included or modeled as direct emissions reduction programs, assumed to be enabling actions for other modeled impacts	NA
Other County Clean Energy Commitments		
SMECO Clean Energy Commitment		
Regional Greenhouse Gas Initiative (RGGI)[56]	Included in the baseline to the degree reflected in AEO2023, but does not	GHG emission factor of electricity imports to MD estimated to be

[56] Note on RGGI goals for emissions reduction: Assuming as a rough approximation, for the purposes of this analysis, that generation in the RGGI states covered by PJM is approximately equal to that in PJM East plus PJM Dominion (PJM East leaves out part of Pennsylvania, and PJM Dominion leaves out part of Virginia but covers part of North Carolina, which is not part of the RGGI agreement), and that generation in PJM East and PJM Dominion goes to zero carbon by 2040, the approximate PJM Overall factor for CO_2 emission corresponding to electricity imports to MD would be somewhat (perhaps 5 percent) lower in approximately 2031 than in the early 2020, but about 50 percent lower in 2040 and 45 percent lower in 2050. We can use that

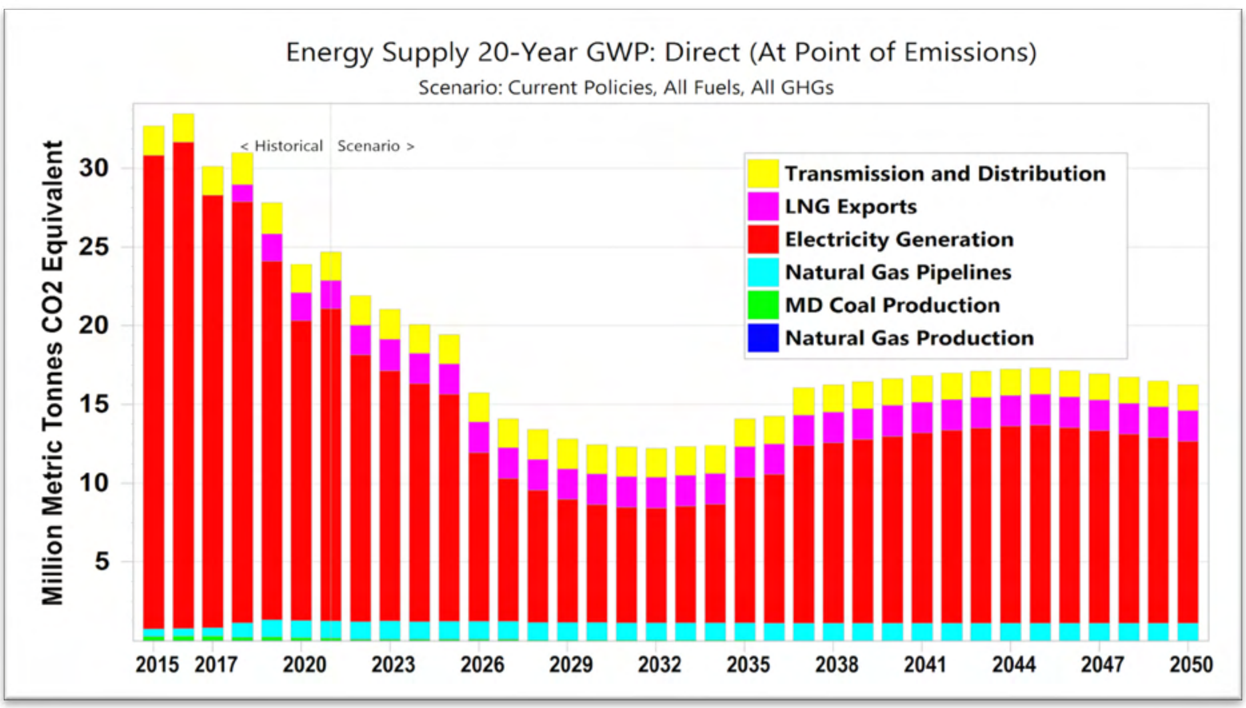
Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
	include, for example, net zero-emission by all RGGI states (that would export power to MD through PJM) by 2040, in part because RGGI is a voluntary organization, and the behavior of its carbon market is uncertain to yield results.	approximately 5% lower in 2031, 50% lower in 2040, and 45% lower in 2050, based on proportion of PJM covered by RGGI.
Planned coal retirements	Included in the baseline as described at right	All coal plants except Warrior Run are assumed to cease coal combustion by 2025. Warrior Run is assumed to run through 2030 because it has a PURPA contract.
IRA incentives	Not included in the baseline beyond what is included Annual Energy Outlook 2023. Assumed to not markedly accelerate renewables deployment in MD beyond other Current Policies.	Not included in part because of the current uncertainty as to how IRA funds will be targeted and spent, and in part because other barriers—such as interconnection barriers or T&D bottlenecks—that seem likely, if not overcome, to limit the extent of IRA investments.
Calvert Cliffs nuclear units re-licensing in mid-2030s	Not included in the baseline Current Policies Scenario given the age of the units. However, this can be included in other scenarios.	NA
Carbon Capture & Storage (CCS) on gas plants	Not included in the Current Policies Scenario. No active proposals in Maryland. Enabled through CSNA that allows CCS only "if the technology has been scientifically proven".	NA
EPA Power Plant carbon emissions regulations	Not included because the regulations have not been finalized	As the regulations cover new plants with intermediate or higher capacity factors (effectively, NGCC plants) with the most stringent requirements, for (effectively) CCS, they would have limited impact in MD. We could reconsider this in the future based on the regulations adopted.
Net Metering	Not included or modeled as direct emissions reduction measure since SEIA projections of this action result in rooftop solar capacity lower than	NA

approach to model RGGI impacts if we believe that the RGGI states will achieve zero carbon emissions by 2040 without the application of additional policies. For now, we model the emissions implications of MD imports from PJM as equal to average emissions per MWh for generation in PJM East from AEO2023, which is somewhat different (somewhat higher, although hardly at all in 2030) than implied emissions from imports if we model imports having carbon emissions equal to the average of all of PJM from AEO2023. We have built in the option to easily switch between these two sets of imports emission factors (PJM East versus PJM Overall) in LEAP and can relatively easily add an estimate of RGGI impacts as above if Maryland stakeholders feel that the RGGI goal will be achieved under current policies.

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
	AEO 2023. Assumed to be an enabling action for solar implementation.	
POWER ACT	Included in the Current Policies case, US Wind and Skipjack projects under development and expected to begin generation in 2025 and 2027, respectively.	Assumed offshore wind capacity at 1266 MW by 2027 (966 MW Skipjack plus 300 MW US Wind), 2000 MW in 2028, 3000 MW in 2032, 6000 MW in 2036, and 8500 MW in 2040.
Energy Storage	Included in the Current Policies case, HB910 directs PSC to create energy storage program which results in 750 MW by 2027, 1500 MW by 2030, 3000 MW by 2033.	Assumed that storage capacities are installed on schedule, powered on a capacity basis 50% by solar and 50% by wind, giving storage an overall capacity factor on the order of 25% (6 hours per day), and dispatchable at that level.

As shown in Figure 3-29, overall emissions from energy supply systems in Maryland fall substantially through about 2030, then rise somewhat due to higher demand for electricity. This is a result of demand-side electrification, plus retirement of the Calvert Cliffs nuclear units, the output of which must be replaced by a combination of gas-fired power and (mostly) additional imports from the rest of PJM.

Figure 4-29: Overall GHG Emissions from Energy Supply, Current Policies Case

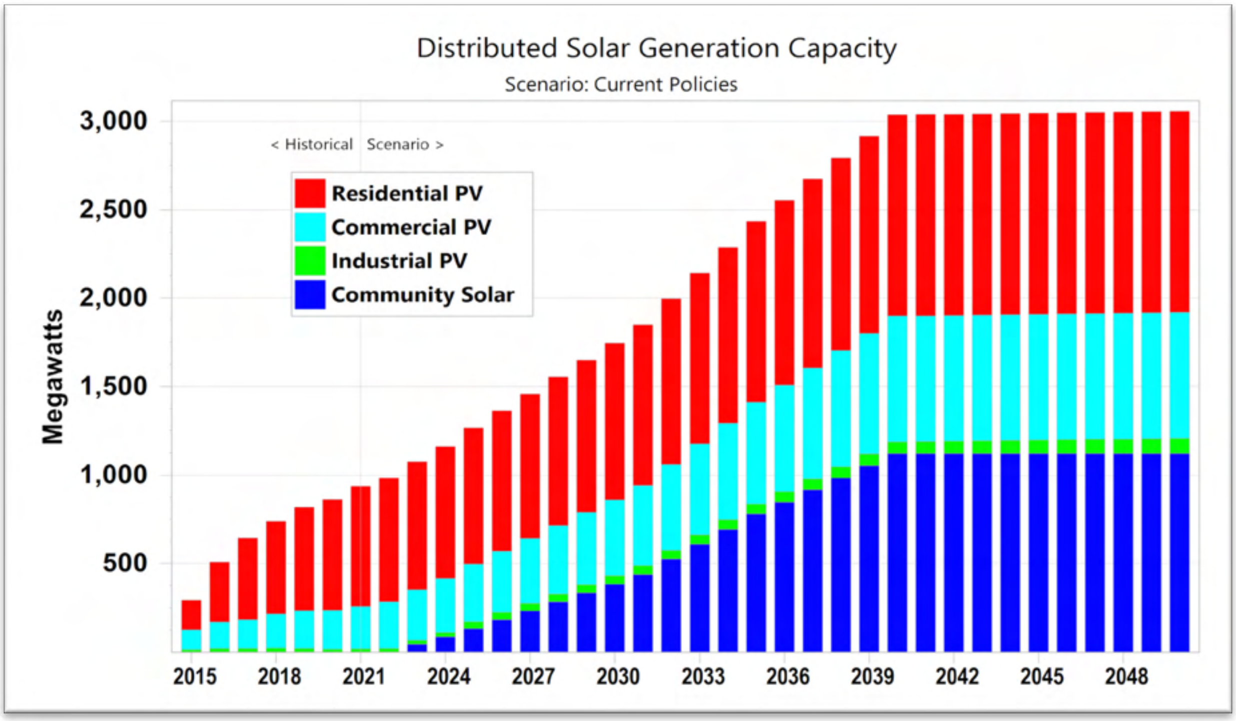


The following subsections provide additional details of Current Policies modeling inputs and key results for each of the individual energy supply systems.

4.3.1 Distributed Solar Generation

Distributed solar generation in the Current Policies case grows from about 1000 MW in 2022 to over 3000 MW in 2040, at which point capacity essentially plateaus due to current limits in Net Metering laws (Figure 4-30).

Figure 4-30: Distributed Solar Generation Capacity by Type, Current Policies Case



4.3.2 Central station generation

Key assumptions for policies affecting central station generation (utility-owned or, more typically, owned by independent power producers (IPP)), in the policies included in the Current Policies case include:

- Solar Carve out: Utility capacity expansion of solar PV deployment is limited by the PJM interconnection approval process). For the Current Policies case, we assume based on input from Maryland solar industry stakeholders and other experts, that over 1,400 MW will be online by the start of 2027, with about 2,700 MW online by 2032. However, growth after 2032, projected at 6,000 MW by 2036 and 8500 MW by 2040, is assumed to happen much more slowly without further revisions to current policies and reach only about 4,500 MW by 2050.
- RGGI RPS goals are met, but only to the extent modeled in AEO2023, which leaves RGGI electrical output well short of "net zero" even by 2035, although net emissions per MWh falls from 0.36 tCO_2e/MWh in 2022 to around 0.2 tCO_2e/MWh for 2035 through 2050.
- The retirement of coal-fired power proceeds as planned, with generation phased out after 2025, and ceasing after 2030.

- The Calvert Cliffs nuclear units are assumed retired in 2034 and 2036 at the end of their first life extension operating licenses.
- POWER ACT offshore wind expansion takes place, resulting in about 3,000 MW deployed by 2032, but with no growth in capacity thereafter. Onshore wind capacity in Maryland grows very slowly, consistent with trends in AEO2023, rising by about 100 MW by 2050 from its 2021 levels of 190 MW.
- About 760 MW of energy storage (battery-electric systems providing peaking power for the grid) is installed by 2030, but with no growth thereafter.

The combination of these changes in the electricity generation system, combined with underlying trends and changes in electricity demand, results in a reduction in GHG emissions from the electricity generation sector from around 20 MMtCO$_2$e in 2021 to 7.3 MMtCO$_2$e by 2031 (see Figure 4-31). Emissions rise again due to the combination of rising electricity demand and the retirement of the Calvert Cliffs nuclear generating units, with the additional net electricity needs supplied mostly from imports from the remainder of PJM. Figure 4-32 and Figure 4-33, respectively, show the trends in generation capacity and output by type of central station generator in the Current Policies case, underscoring trends away from coal-fired generation, and toward growth in solar and wind power, but then in the 2030s the solar and wind capacity and output growth stalling significantly.

Figure 4-31: GHG Emissions from Central Station Electricity Generation, Current Policies Case

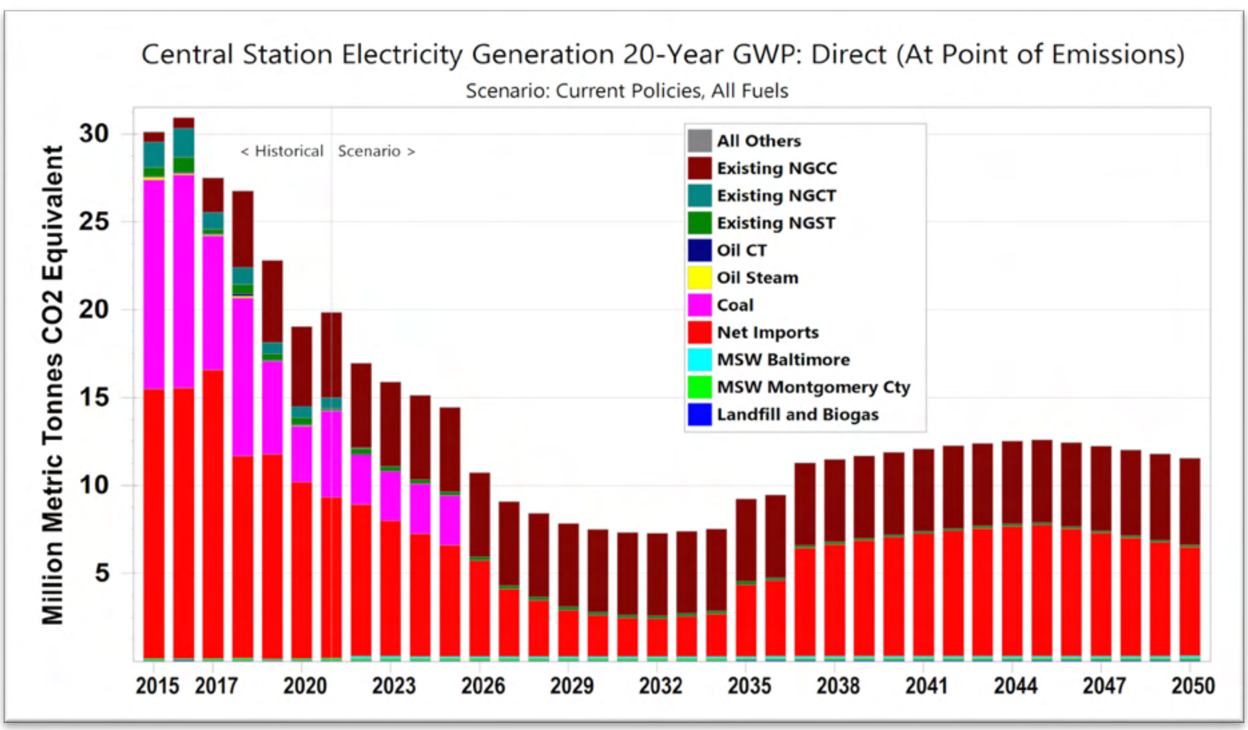


Figure 4-32: Generation Capacity in Central Station Electricity Generation, Current Policies Case

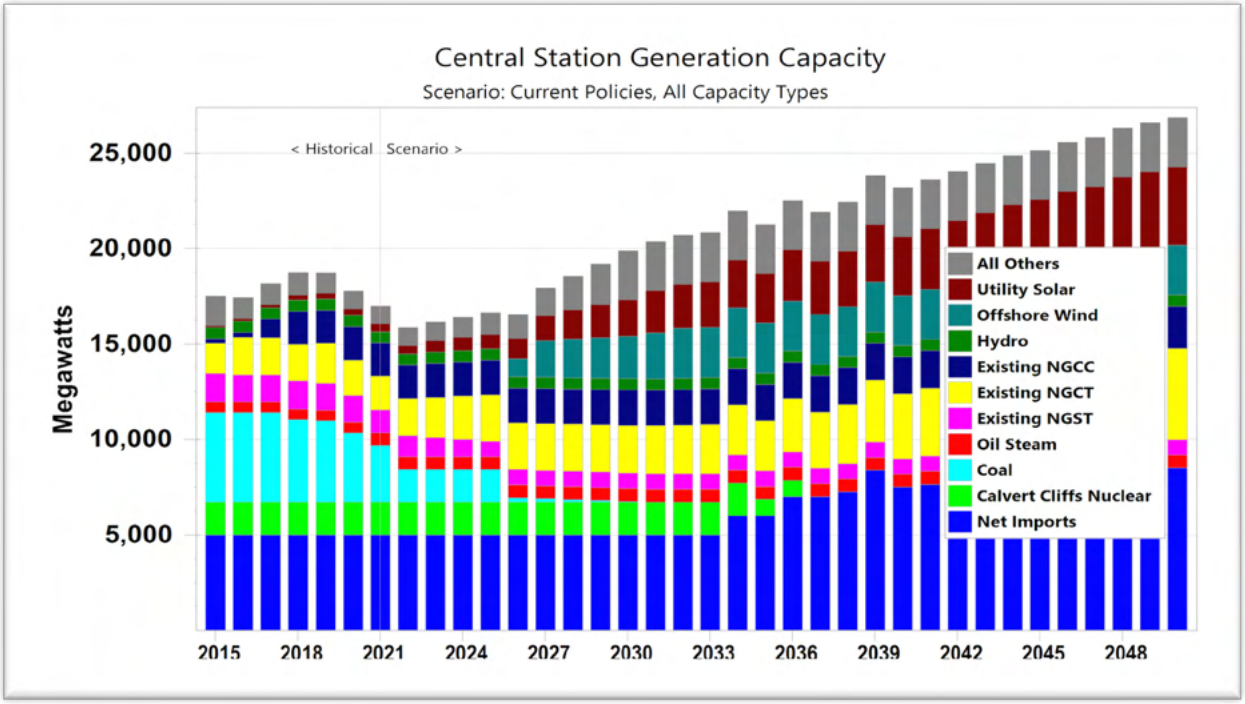
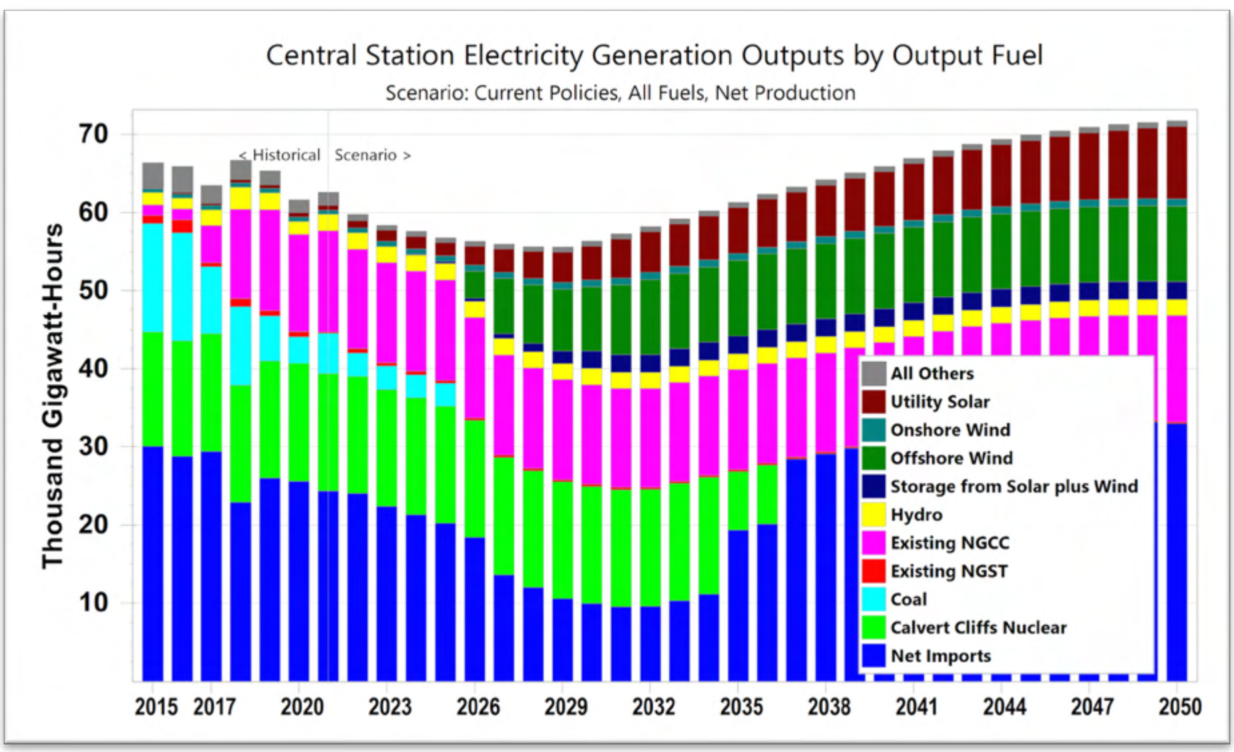


Figure 4-33: Generation Output in Central Station Electricity Generation, Current Policies Case



4.3.3 Other Energy Supply

Emissions and activity from other energy supply, although in some cases quite significant, are less in aggregate than emissions from electricity generation in the Current Policies case through 2050, as shown in Figure 4-34 and Table 4-7. Of the non-energy sectors, the major sources of emissions are:

- **Natural gas transmission and distribution**, which falls slowly after 2027 from about 1.9 $MMtCO_2e$ in 2023 to about 1.6 $MMtCO_2e$ in 2050, as electrification and renewable generation sources displace some natural gas consumption (Figure 4-35).
- **Natural gas consumption for LNG liquefaction** at the Cove Point LNG facility, which total 1.95 $MTCO_2e$ from 2025-on (Figure 4-36), given no significant change in the technology used for liquefaction, and assuming that the output of the plant remains at near full capacity (300 million GJ of LNG per year, or about 5.35 million metric tons of LNG annually).
- **Natural gas pipeline compressor stations**, which fall slightly from the late 2020s through 2045, but remain at about 1.1 $MMtCO_2e$ for most of the modeling period (Figure 4-37).

Figure 4-34: GHG Emissions from All Energy Supply Sources, Current Policies Case

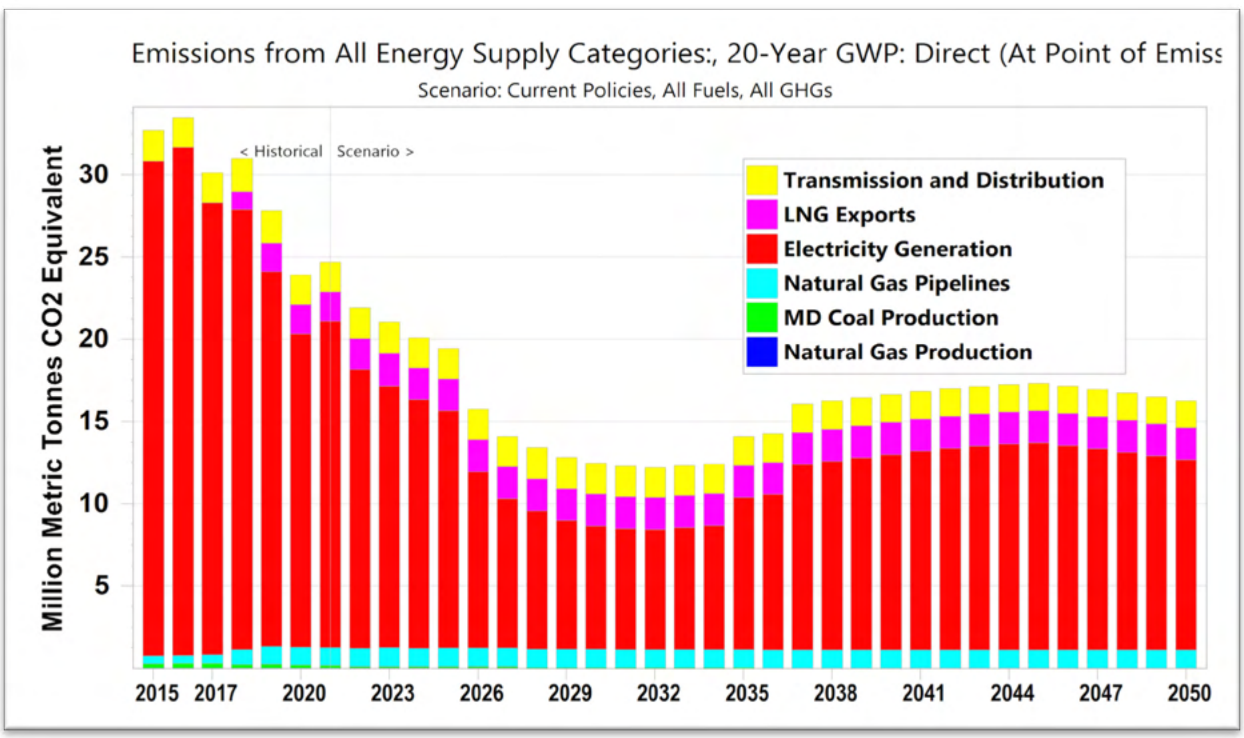


Table 4-7: Summary of GHG Emissions from All Energy Supply Sources, Current Policies Case

Energy Supply Category	2023	2025	2030	2035	2040	2045	2050
Transmission and Distribution	1.91	1.85	1.88	1.78	1.70	1.66	1.64
LNG Exports	2.01	1.95	1.95	1.95	1.95	1.95	1.95
Electricity Generation	15.88	14.42	7.49	9.23	11.89	12.59	11.55
Natural Gas Pipelines	1.16	1.13	1.14	1.12	1.11	1.11	1.12
MD Coal Production	0.10	0.10	0.02	0.02	-	-	-
Natural Gas Production	0.0003	0.0003	0.0003	-	-	-	-
Total	**21.06**	**19.45**	**12.47**	**14.09**	**16.65**	**17.31**	**16.25**

Figure 4-35: GHG Emissions from Natural Gas Transmission and Distribution, Current Policies Case

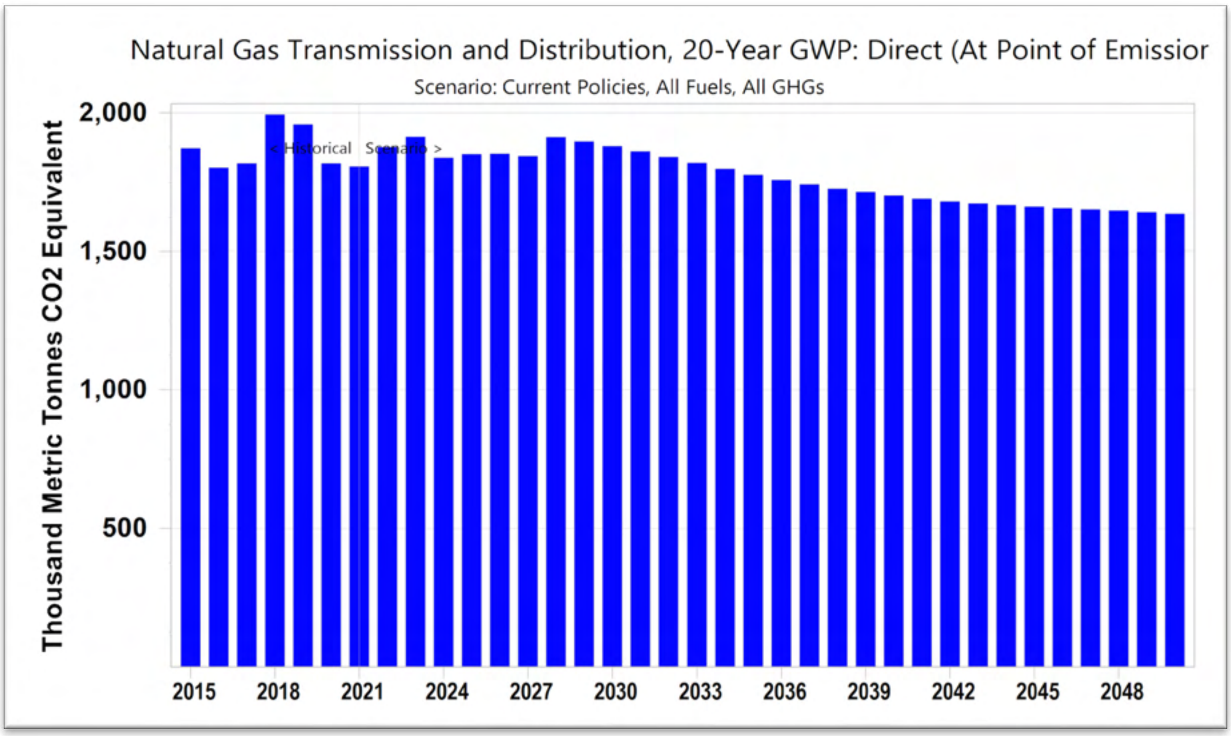


Figure 4-36: GHG Emissions from LNG Export Terminal Operations, Current Policies Case

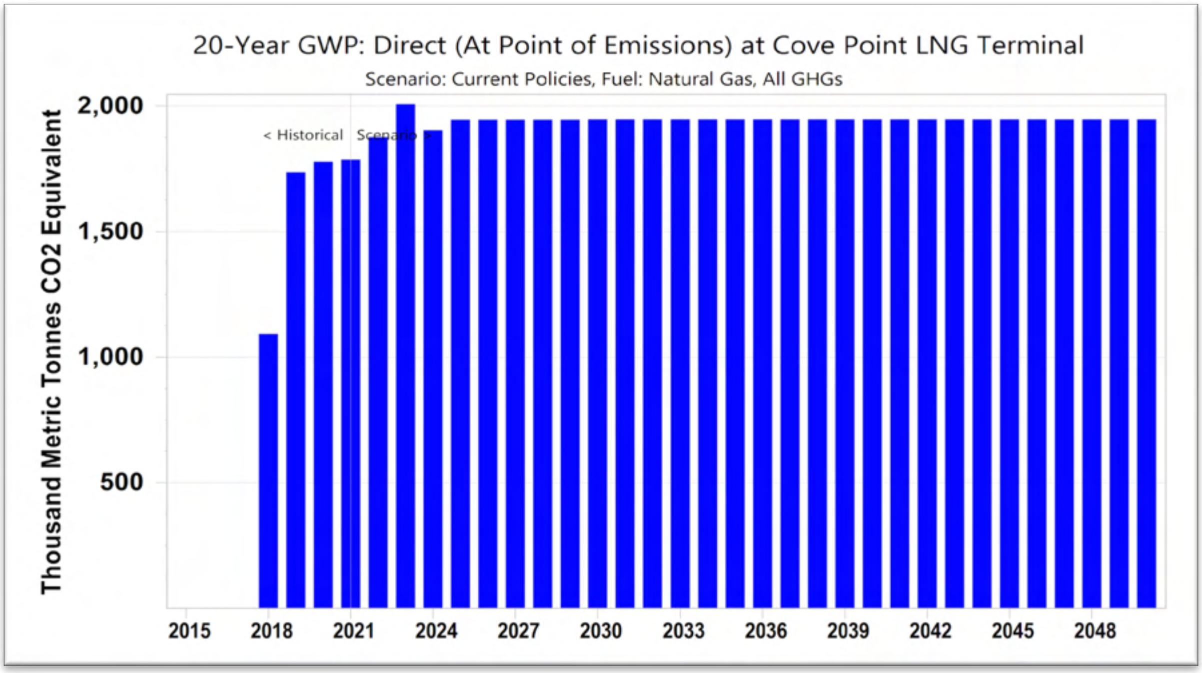
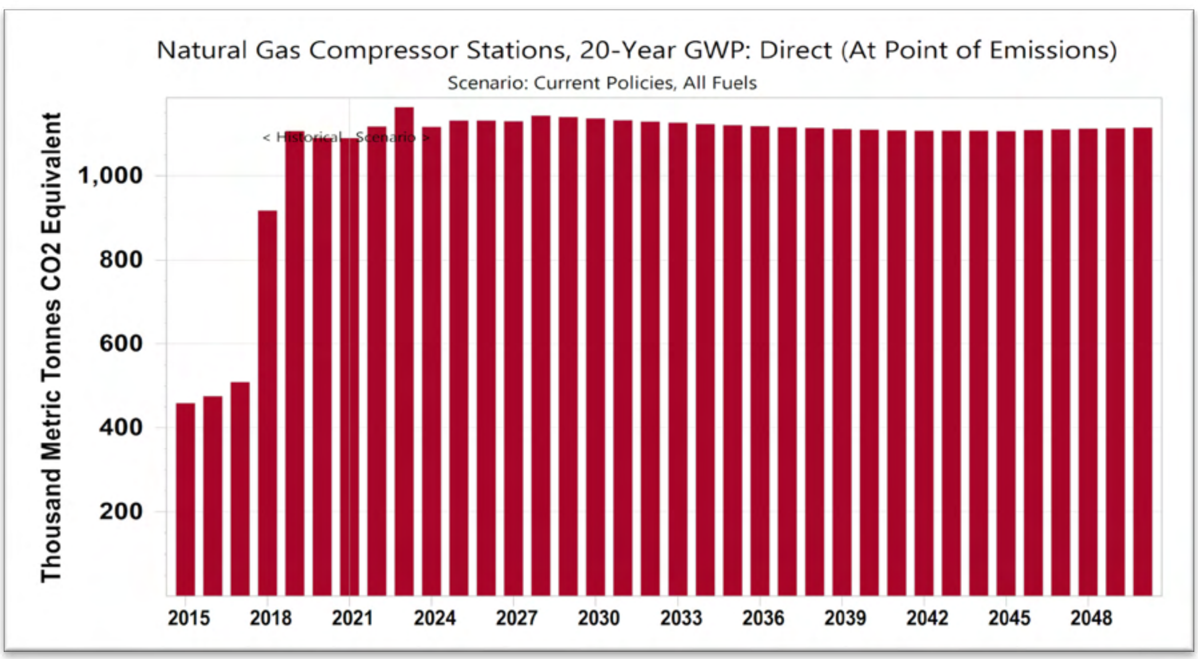


Figure 4-37: GHG Emissions from Natural Gas Compressor Stations, Current Policies Case



Other sources of emissions from energy supply in Maryland include coal production and natural gas production, the output of which are small relative to the major coal and gas producing states and have been declining in recent years as mines and wells are closed. Both coal and natural gas production in

Maryland are assumed to cease by the mid-2030s, as shown by the emissions trends in Figure 4-38 and Figure 4-39.

Figure 4-38: GHG Emissions from Coal Mining In Maryland, Current Policies Case

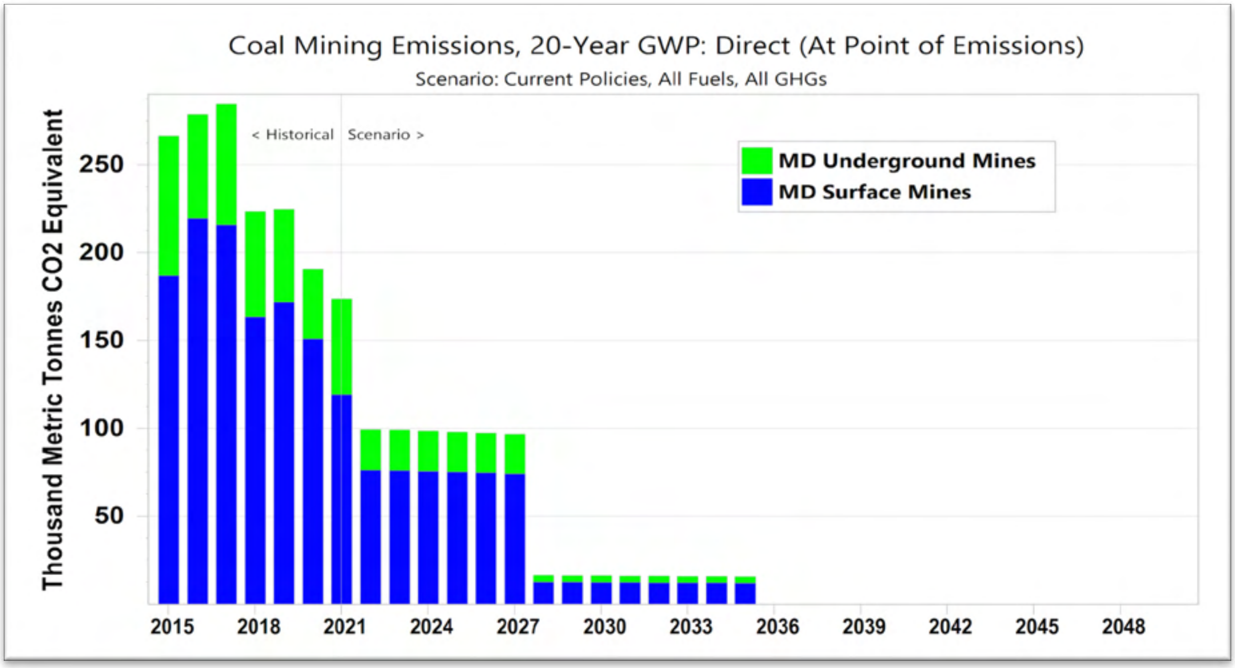
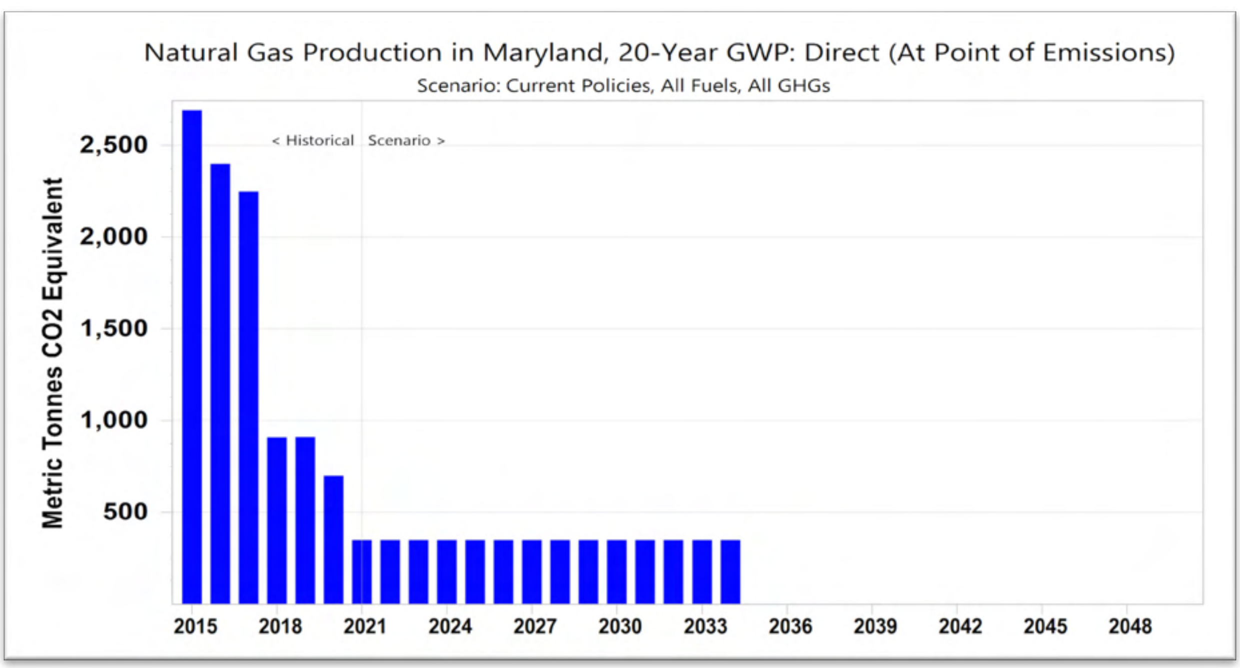


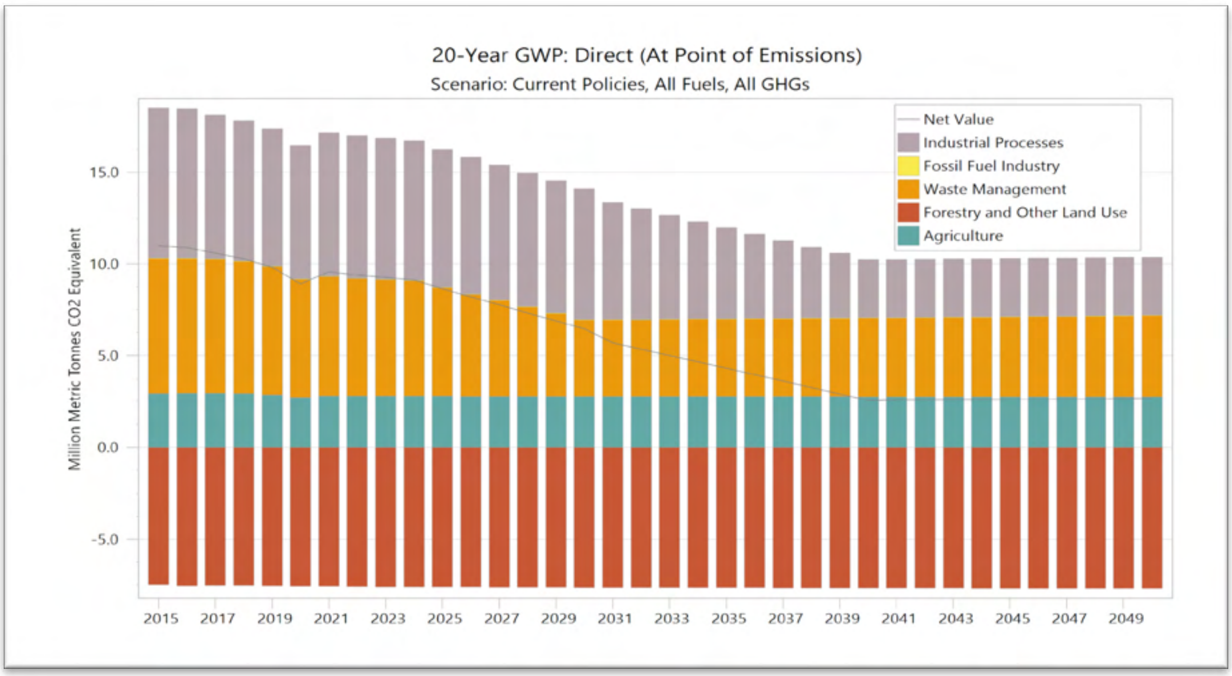
Figure 4-39: GHG Emissions from Natural Gas Production In Maryland, Current Policies Case



4.4 Non-energy

Non-energy GHG emissions in Maryland are mainly associated with industrial processes, waste management, and agriculture, partially offset by the net absorption of carbon dioxide by Maryland's forests ("forest sinks"), as shown in Figure 4-40. Non-energy emissions, although significantly less than energy-sector emissions as of 2023, remain significant through the modeling period.

Figure 4-40: Summary of Net GHG Emissions from Non-Energy Sources, Current Policies Case



4.4.1 Industrial Product Use

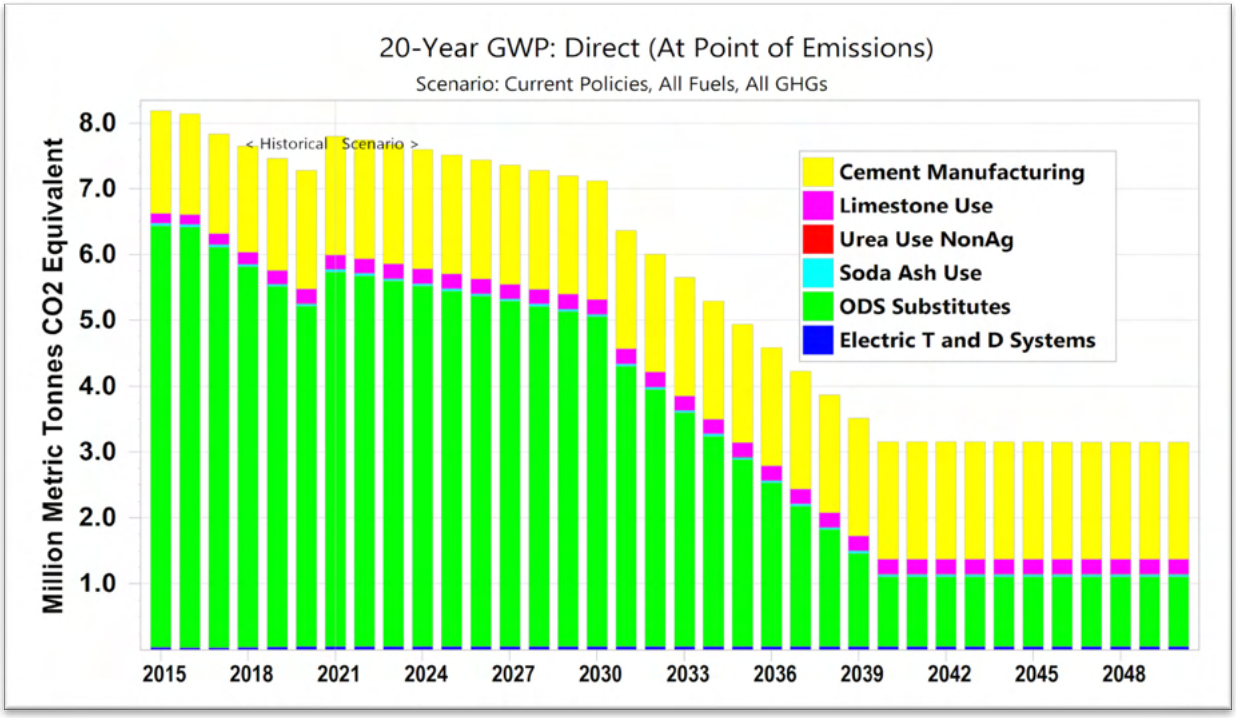
The American Innovation and Manufacturing (AIM) Act[57] and Maryland HFC Regulations regulate production and consumption of hydrofluorocarbons (HFCs), which are potent GHGs. The impact of these regulations was modeled as a reduction in HFC emissions of 25% by 2030 and 85% by 2035, as indicated in Table 4-8. The resulting change in industrial emissions by type is shown in Figure 4-41. Overall non-energy industrial emissions decrease by more than half as a result of the HFC regulations policy.

Table 4-8: Current Industrial Processes and Product Use Policy Actions

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
AIM Act and Maryland HFC Regulations	Included, reductions are mandated by both federal and state regulations	25% reduction in HFC emissions by 2030, 85% by 2035.

[57] USEPA, Protect Our Climate by Reducing Use of HFCs.

Figure 4-41: Non-energy Industrial GHG Emissions, Current Policies Case



4.4.2 Waste Management

As part of the non-energy sectors, Waste sector emissions and sinks are also largely covered through modeling in the GHG Strategy Tool, although some modeling of power plants burning municipal solid waste and landfill gas are covered in Energy Supply. For other waste emissions categories, the results of analyses are transferred to corresponding non-energy branches in LEAP for reporting. Non-energy categories of emissions and sinks covered here are emissions from landfills, composting, and wastewater.

Table 4-9 describes current policy actions for the Waste sector considered for the Current Policies Scenario. Additional details on the modeling of the waste sector policies included are provided below, and the emissions trend for the sector is shown in Figure 4-42. In the Current Policies case, emissions of methane from landfills decrease to 2030, then begin to increase slightly in part due to increased landfilled waste volumes resulting from closure of the state's two large waste-to-energy plants. Emissions from wastewater treatment increase slightly over time as population increases.

Table 4-9: Current Waste Policy Actions

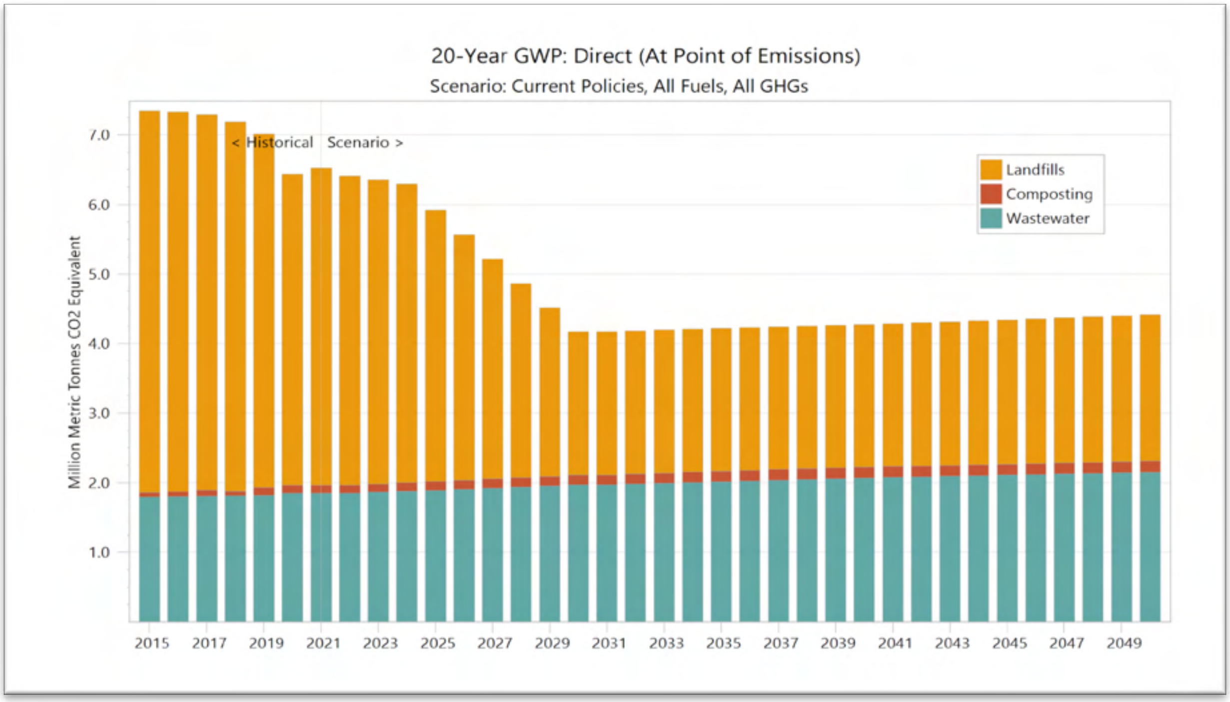
Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
State 2035 waste generation and waste diversion goals	Included in the baseline, state has made progress toward these goals in recent years supported by local programs below	20% reduction in MSW generation and 237% increase in food waste composting between 2020 and 2035. Based on historical data and goals in MD Solid Waste Management and Diversion Reports.
Anne Arundel County Food Scraps and Food-Soiled Paper Program	Not modeled as a separate impact	NA
Baltimore City's Food Matters program	Not modeled as a separate impact	NA
Howard County Feed the Green Bin Program	Not modeled as a separate impact	NA
Prince George County Curbside Composting Program	Not modeled as a separate impact	NA
State landfill methane regulations	Included in the baseline, proposed regulation finalized in 2022 and submitted to EPA for approval as part of state plan for MSW landfills	Modeled by applying average of minimum and maximum methane (51%)

State 2035 waste generation and waste diversion goals: The Waste Reduction and Resource Recovery Plan for Maryland set a series of voluntary statewide metrics, including reducing waste generation per capita to 5.5 lb./person/day (from 6.08 lb. in 2020) and increasing food waste diversion from 18 percent in 2020 to 60 percent by 2035. Diversion rates of other organics, such as yard waste, are already at or very near the goals set for 2035. These goals were used to estimate future disposal of organic waste in landfills.

State landfill methane regulations: In 2023, Maryland adopted new regulations for control of methane at municipal solid waste landfills. The impact of these new regulations on landfill emissions was modeled as a 51 percent reduction in emissions by 2031, based on the maximum reduction estimated in the Technical Support Document for the regulation.[58] This reduction was estimated to be a total average control rate of 75% of all methane generated by MD landfills. Additional methane reduction was assumed to come from flaring, with the level of methane capture for electricity generation kept at the current rate.

[58] Technical Support Document for COMAR 26.11.42 – Control of Methane Emissions from Municipal Solid Waste Landfills, 2022.

Figure 4-42: Waste Sector GHG Emissions, Current Policies Case



4.4.3 Agriculture and Forestry

As part of the non-energy sectors, Agriculture and Forestry sector emissions and sinks are also covered through modeling in the GHG Strategy Tool, the results of which are transferred to corresponding non-energy branches in LEAP for reporting. Non-energy categories of emissions and sinks covered include emissions from livestock and agricultural soils, forest carbon flux, mineral soils, and wildfires and prescribed burns.

Table 4-10 describes the current policy actions for Agriculture and Forestry considered for the Current Policies Scenario and is limited to a tree planting initiative. Figure 4-43 shows that agricultural non-energy GHG emissions change relatively little over time in the Current Policies case.

Table 4-10: Current Agriculture and Forestry Policy Actions

Policy Action	Level of Inclusion and Rationale	Description of Modeling Assumptions
Conservation Reserve Enhancement Program (CREP)	Not modeled, since this program has been active for many years, any impact is assumed to be included in baseline land cover change data	NA
Tax Benefits for Conservation Easement Donations	Not modeled, assumed to be included in baseline land cover change data	NA
Maryland Urban and Community Forestry Committee (MUCFC) Grants program	Not modeled, under current level of implementation, program impact assumed to be very small on a statewide basis.	NA
Forest Conservation and Management Program	Not modeled, since this program has been active for many years, any impact is assumed to be included in baseline land cover change data.	NA
Maryland Forest Legacy Program	Not modeled, under current level of implementation, program impact assumed to be small.	NA
Income Tax Modification Program	Not modeled, under current level of implementation, program impact assumed to be small.	NA
Woodland Incentive Program - WIP	Not modeled, under current level of implementation, program impact assumed to be small.	NA
5 Million Trees Initiative	Included, program currently under implementation.	Modeled as 500,000 trees planted each year from 2021 to 2050. Planting density assumed to be 350 trees/acre, with growth rates at 1.14 tC/acre for 0-10 year stands and 1.74 tC/acre, 11-10 year stands, and 2.07 tC/acre for 21-30 year stands.

5 Million Trees Initiative: The Maryland Department of the Environment (MDE) is the coordinating agency for the state's plan to plant and maintain 5 million native trees in Maryland by 2031.[59] The annual sequestration from these trees was modeled assuming a planting density assumed to be 350 trees/acre,[60] with growth rates at 1.14 tC/acre for 0-10 year stands and 1.74 tC/acre, 11-10 year stands, and 2.07 tC/acre for 21-30 year stands estimated from Maryland forest inventory data.[61]

[59] Maryland Department of the Environment. Five Million Trees in Maryland.
[60] Chesapeake Riparian Forest Buffer Network, Frederick County's Office of Sustainability and Environmental Resources (2019). "Creek ReLeaf – Reforestation in Frederick County, Maryland".
[61] USFS (2023). "EVALIDator 2.1.0".

Figure 4-43: Non-energy Agricultural Sector GHG Emissions, Current Policies Case

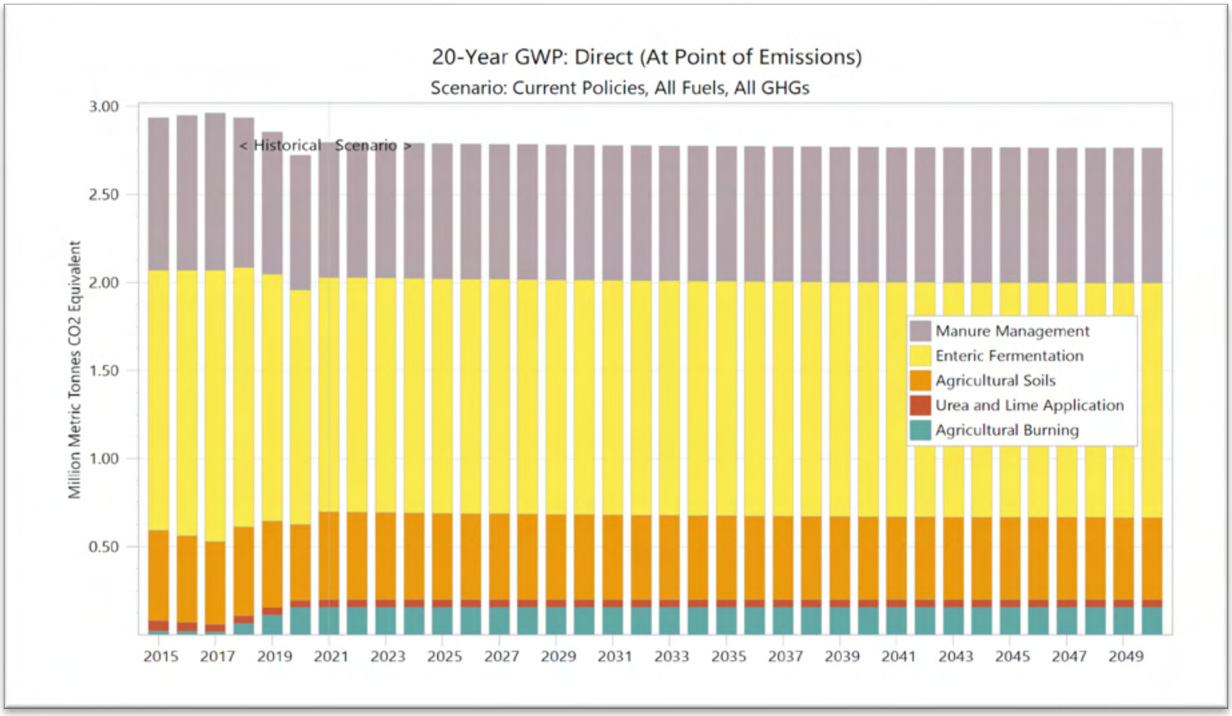
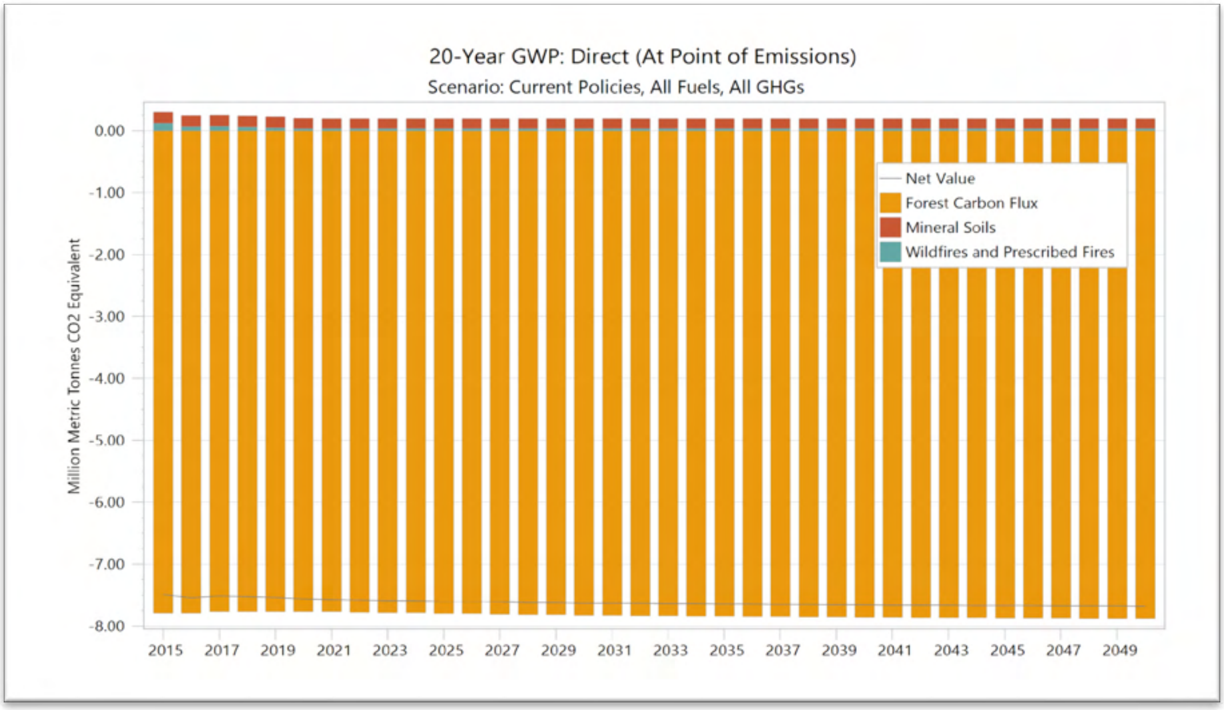


Figure 4-44 shows the trend in GHG emissions and sinks from the forestry and other land use sectors. Here emissions from mineral soils and wildfires, totaling just under 200,000 tCO_2e per year after 2021, are much more than offset by about 7.8 million tCO_2e per year of forest carbon flux, most of which is increases in above-ground biomass in Maryland's forests. This carbon "sink" offsets some of Maryland's net GHG emissions and means that Maryland's gross emissions need to fall to about the level of forest sinks to reach "net zero."

Figure 4-44: Non-energy Forestry and Other Land Use Sector GHG Emissions, Current Policies Case



The final category of emissions included in the non-energy listing is emissions of methane from abandoned coal mines.[62] This source is listed in the MDE GHG emissions inventories as being minor, about 25,000 $MTCO_2e$ annually. We have no further information on it, but emissions from abandoned mines may be worth investigating further as more mines are closed, and as these emissions are likely not well characterized.

5. Additional Actions Scenarios: Inputs and Results

5.1 Overall Theme and Results of Additional Actions Scenario

The Additional Actions case is a composite of more than 25 different LEAP "scenarios," each of which includes changes designed to reduce GHG emissions in Maryland that go beyond those included in the Current Policies case. In some instances, those changes include emissions reduction measures not included significantly or effectively in Current Policies. In other cases, additional actions continue or build upon current policies by extending current policies, specifying more aggressive measure implementation targets, leading to increased short-term or longer-term emissions reductions. In most cases, the additional actions involve implementation of technologies that are already available or nearing commercialization, and therefore have established performance and cost information.

[62] Abandoned coal mines are included in the non-energy sector because they do not correspond to ongoing energy sector activities.

The individual elements of the Additional Actions case are actions that in most cases have already been suggested and discussed by Maryland stakeholders. In other cases, additional actions have been developed by CCS, but are consistent with actions suggested by stakeholders, have appeared on potential lists of actions developed during Maryland climate action planning fora, or reflect actions implemented or recommended in other jurisdictions. In general, the individual actions that make up the Additional Actions case reflect actions that are implemented on aggressive but reasonable implementation schedules, assuming efficient planning and development of programs that consider and overcome existing barriers to program success. These barriers include funding shortfalls, administrative bottlenecks, regulations that may prevent or delay actions, logistical challenges, lack of human and organizational capacity, and other obstacles to implementing actions to achieve emissions mitigation goals.

The full set of Additional Actions beyond the Current Policies case reduces 2031 emissions by more than 10 MMtCO_2e, as shown in Figure 5-1 and Figure 5-2, below. This would still leave a gap, albeit of less than 6 MMtCO_2e, to meeting Maryland's 2031 goal of 60 percent reduction relative to 2006 GHG emission levels as estimated by MDE. This scenario does, however, **meet the 2031 goal by 2033**.

The model results show impacts through 2050, often by extending impacts of proposed policies through 2050. Overall, relative to the Current Policies case, the additional actions reduce Maryland's GHG emissions by nearly 34 MMtCO_2e/year by 2050, and by a cumulative 530 MMtCO_2e from 2024 through 2050. The process of defining many of the Additional Actions focused substantially on GHG emissions reduction recommendations designed to work toward the 2031 target. However, many actions with impacts largely beyond 2031 have also been included in the current Additional Actions case.

Figure 5-1: GHG Emissions in the Additional Actions Case

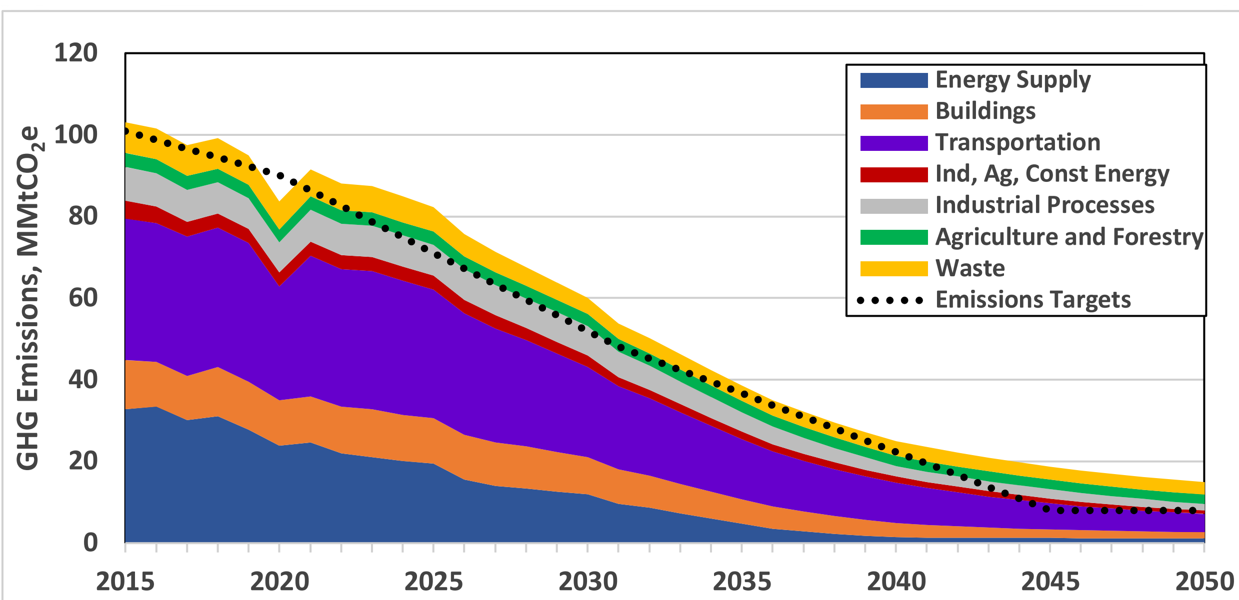
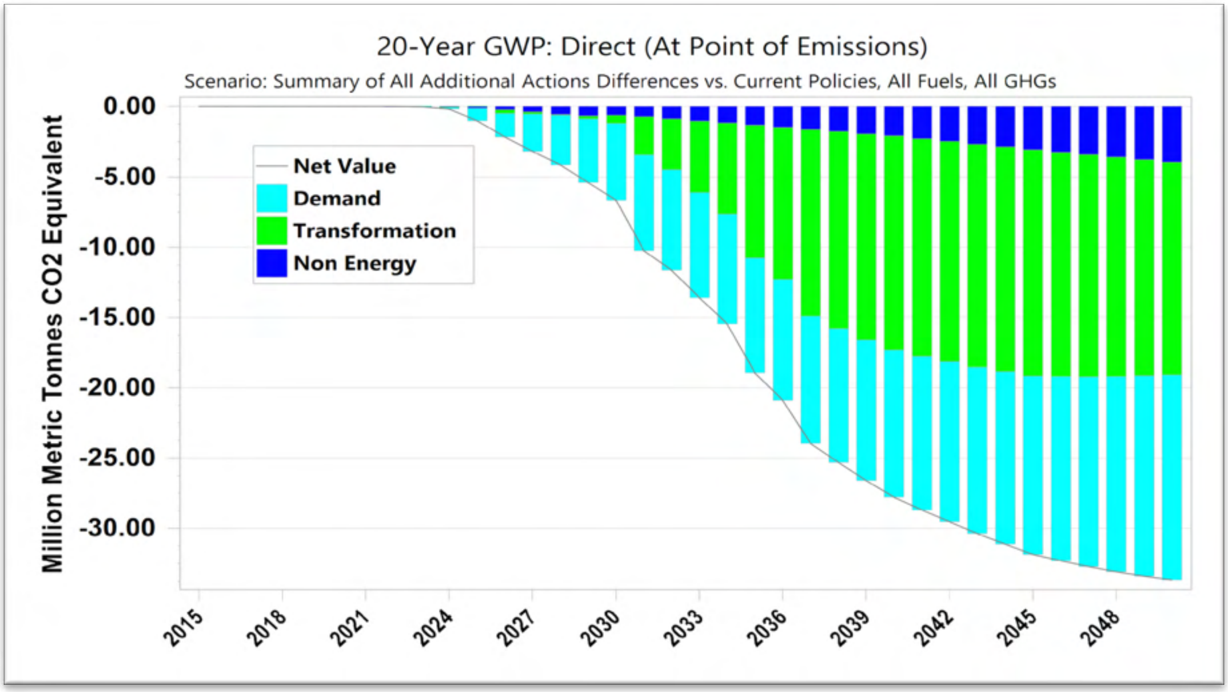


Figure 5-2: Emissions Reductions from Additional Actions Relative to the Current Policies Case



5.1.1 Elements of the Additional Actions case

The GHG emissions reduction actions included in the Additional Actions case include reduction measures across virtually all sectors and begin the process of substantial transformation of many economic sectors in Maryland towards environmental sustainability. A summary list of the elements of the Additional Actions case is provided below, and individual scenarios are explained more detail in the remainder of this section.

Buildings Sectors

- **Low Income Electrification**: Replaces fossil fuel space heating and water heating devices with heat pump devices in low-income households, with 60% of such households electrified by 2031 (starting from a baseline of 31%), and 100% by 2040.
- **All Electric Building Code Expansion**: Follows the metrics of all electric building code policies developed for Montgomery and Howard County but extends those metrics to the entire state. Assumes all new buildings and major renovations are all-electric.
- **Building Energy Performance Standards**: Extends policies in the Current Policies Scenario by assuming that a 20% reduction in heating and cooling energy use is achieved by 2030 and that the minimum size of buildings (multifamily residential and commercial/institutional) covered by the policy is reduced in increments through 2031, ultimately covering buildings of floor area 10,000 square feet and greater.
- **EmPOWER Restructuring**: Starting in 2025, fossil fuel equipment stocks are reduced by 1.9% each year, replaced through sales of electric equipment meeting the same end-uses. This program is assumed to replace the existing electric utility-run, energy-efficiency focused EmPOWER program.

- **Zero NOx Appliance Standards**: Assumes sale of all fossil fuel residential and commercial space heaters, water heaters, stove, and clothes dryers go to zero, with shares of electric equipment (using a range of technologies) rising to 100 percent, by 2031.

Transportation Sector

- **VMT Reduction**: Assumes that vehicle miles traveled in light duty vehicles are reduced by 20% relative to the Current Polices case by 2031, with reductions starting in 2025 and continuing to decrease to 75% of Current Polices levels by 2050. A small portion of the passengers displaced from light duty vehicles are shifted to passenger rail and e-bikes, with about half accommodated by greater use of an expanded bus fleet. The rest of the displaced trips are assumed to be accounted for by more trips on foot or non-motorized bikes and scooters, increased vehicle occupancy (carpooling), and other changes that do not add to transportation energy use.
- **Additional HDV, Bus, and Heavy Equipment Electrification**: Assumes that truck electrification, rather than plateauing in 2035 as in the Current Policies case, reaches 80 percent of vehicles sold in 2036, and continues increasing through 2050, reaching 100 percent (sum of battery electric, diesel plug-in hybrid vehicles, and gasoline plug-in hybrid vehicles) by that year.
- **Rail Electrification**: Assumes that 50% of MARC trains are electrified by 2031,[63] increasing to 100% by 2050, and that 25% of rail freight is electrified by 2031, increasing to 75% by 2050.
- **Freight Mode Shift and Rail Freight Electrification**: Assumes that 10% of 2021 Maryland road freight is shifted to rail by 2031, and 25% by 2050, starting in 2026. In addition, we assume, as above, that 75% of rail freight in Maryland is electrified by 2050, starting in 2025.
- **Other Transportation Electrification**: Assumes that electrification increases in Marine Watercraft and Recreational Equipment to 15% by 2030 and 70% by 2050, and in Lawn and Garden Equipment to 50% by 2030 and 90% by 2050.
- **Air Transport Improvements and Sustainable Aviation Fuel:** Assumes that the aircraft and operations improvements in the Federal Aviation Administration's, *United States 2021 Aviation Climate Action Plan* are achieved, [64] increasing efficiency relative to the Current Policies case, and that 50 percent of jet fuel used is "sustainable aviation fuel" by 2050, as in one of the scenarios in the FAA report. Once again, these improvements may be encouraged by Maryland, but will not occur without coordinated national, and in fact, international action.

Industrial Sector

- **Cement Sector Electrification**: Substitution of electricity for natural gas and coal use to provide heat in cement kilns. All the kilns operated by Maryland's two cement producers are assumed converted by 2031.
- **Cement Clinker Substitution**: Assumes expanded use of "clinker" (the main component of cement) substitutes in cement blending, with 35 percent of clinker substituted for by 2050.
- **Industrial Energy Efficiency and Electrification**: Assumes energy efficiency improvements of 10 percent by 2050, relative to the Current Policies case, in electricity end-uses for non-cement industries and for electricity use in the cement industry. Assumes that 80 percent of motor fuel and natural gas use in non-cement industries is replaced with electricity by 2050.

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[63] Up from an estimated 28 percent in 2023, based on activity on the electrified Penn Line, although that is a very rough approximation that should be revised through consultation with transport officials. MARC is the "Maryland Area Rail Commuter".

[64] Federal Aviation Administration (FAA, 2021), *United States 2021 Aviation Climate Action Plan*.

Energy Supply

- **Utility Solar Expansion**: Assumes that restrictions on approval of PJM (and local) solar capacity expansion are lifted such that the amount of capacity listed in the current PJM queue as "Active" is deployed by 2031 (a little less than 4000 MW, including existing capacity). Assumes that capacity continues to increase, more or less linearly based on annual deployment in 2025-2031 (500 MW added/year), through 2050, to over 13,000 MW by 2050.
- **Expanded Offshore Wind**: Assumes that offshore wind power development proceeds as per existing state goals, rising to 8500 MW by 2040, 11,000 MW by 2045 and 13,000 MW by 2050.
- **Calvert Cliffs Life Extension**: Assumes that both units at the Calvert Cliffs Nuclear Plant will have their lifetimes extended through at least 2050. This will represent the second extension for the Calvert Cliffs units, which were built in the 1970s.
- **RGGI Net Zero Generation by 2040:** Assumes that a zero CO_2e emissions goal from generation is reached by 2040 in the RGGI states, and thus by the states exporting power to Maryland. As a result, the emission factor for CO_2e per MWh of imported electricity falls to zero by 2040, with a phase-in period starting after 2025.
- **Rooftop Solar Expansion**: Assumes a combination of incentives, falling costs for rooftop and community solar, willingness to raise net metering caps, support for siting of rooftop and community solar, and increased effort at developing the rooftop solar industry in Maryland. This results, after 2025, in annual growth in rooftop solar roughly a third higher than projected in the AEO2023 reference case over 2021-2050. The total solar rooftop capacity (including community solar, some of which may not be strictly roof-mounted) increases to nearly 6000 MW by 2040, and over 10,000 MW by 2050.
- **Expanded Electricity Storage**: Assumes that policies are implemented such that the current state target for storage deployment (3000 MW by 2033) is reached, and that decreasing electricity storage costs, state and federal incentives for deployment, and active assistance with siting results in a total of 7000 MW deployed by 2050.[65]
- **Natural Gas Generation Retired**: Assumes that natural gas-fired capacities in the state (combined cycle, steam turbine, and combustion turbine) are trended from their existing levels in the RPL case to zero as of 2036, starting in 2028. Oil-fired plants, which operate at very low-capacity factors even in the Current Policies case, are assumed to be retired on the same schedule as well.
- **Retirement of Waste to Energy (WTE) Generation**: Assumes that the state's two major WTE (Waste-to-Energy) plants, Wheelabrator Baltimore and Montgomery County, are retired at the end of 2030, with the heat demand now provided to the "Baltimore Steam Loop" by the Baltimore plant to be provided by a new electric heat pump-driven district energy plant.[66]
- **LNG Liquefaction Electrification**: Assumes that starting in 2031 the Cove Point LNG plant uses electricity for its natural gas liquefaction "train" rather than burning natural gas in combustion turbines that drive compressors.[67]

[65] Note that this scenario also includes the assumptions of the offshore wind and utility solar expansion cases, as renewables charging capacity is otherwise insufficient to charge this much storage.
[66] Wastes no longer used in the WTE plants is treated with a combination of landfilling and composting, with about 80 percent of landfill emissions captured and used as fuel gas. Note that this option also provides important non-GHG pollutant emissions reductions, including for low-income communities.
[67] Electrification is implemented all at once, just before 2031, as Cove Point has just one liquefaction train, but there may be ways of phasing in electrification. Investment costs for electrification will be significant, but natural gas savings (or revenues for additional LNG exports) will be substantial, and there will also be offsetting O&M savings.

Non-Energy Emissions Sources

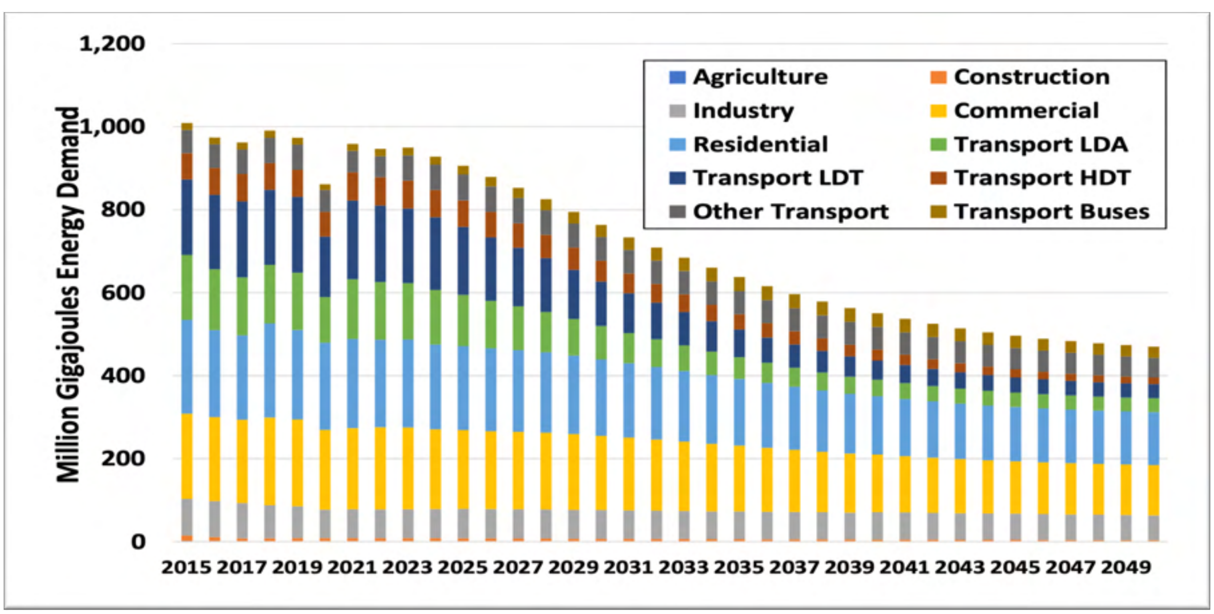
- **Methane Capture from Landfills**: Assumes that landfills in Maryland increase the rate at which methane is captured to 80% (from 75% under the current rule) by 2031, with the captured gas used for electricity generation.
- **Expanded Composting**: Assumes that the state capacity for composting will increase to 750,000 tons per year by 2045.
- **Biogas Production and Use**: Assumes that anaerobic waste treatment of livestock wastes and sewage, producing biogas (a mixture of methane and CO_2) that is captured for use, are expanded such that 70% percent of dairy and poultry wastes by 2045 and all percent of sewage treated with anaerobic digestion (16.3% according to the MDE inventory) are covered by these systems. The biogas produced is used to generate electricity for the central power grid.
- **Enteric Methane Mitigation**: Assumes that 100% of dairy and feedlot beef cattle will be given feed additives to reduce enteric methane production by 2045.
- **Biofertilizer:** Assumes that biofertilizer, defined as products containing live microorganisms applied to soil, seeds, or plants, improved nutrient availability and uptake reducing the need for chemical fertilizers, will be used on 80% of cropland currently using synthetic fertilizer by 2045.
- **Soil Management Program:** Assumes that conservation crop rotation and cover crop usage will be expanded to an additional 250,000 acres each by 2050.

5.2 Demand sector actions in Additional Actions Scenario

5.2.1 Overall energy demand results

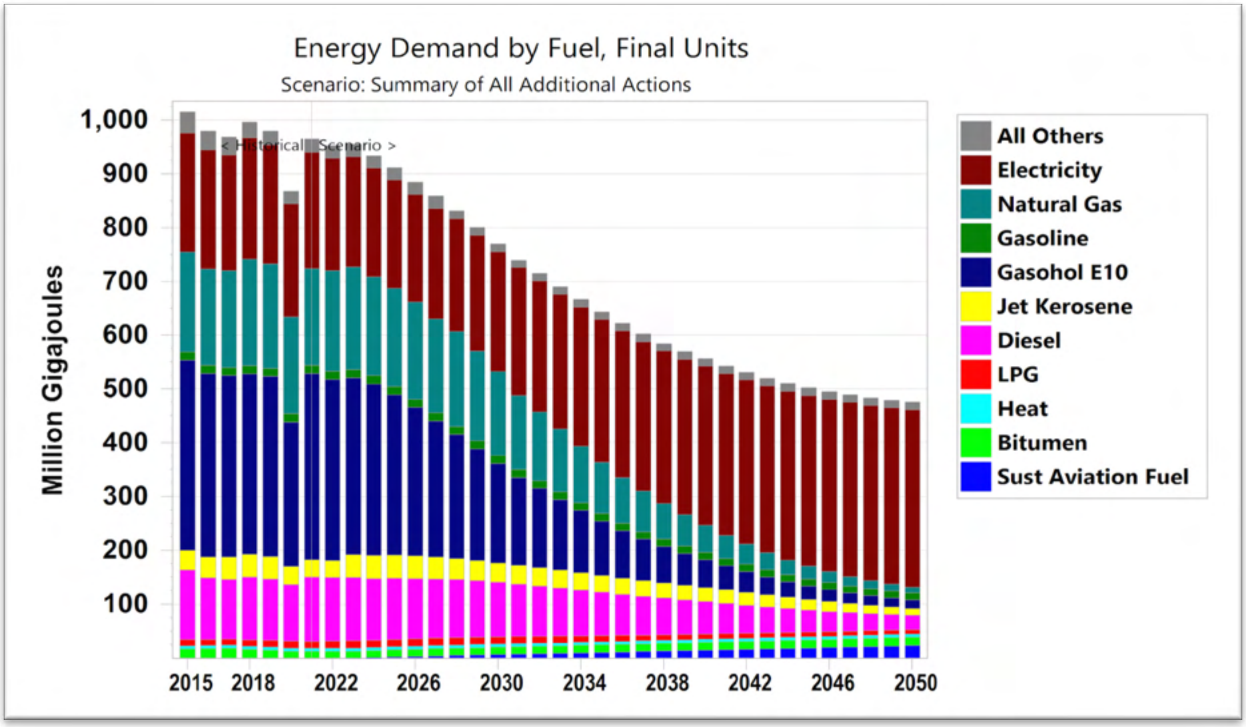
As shown in Figure 5-3, the residential, commercial, and transportation sectors dominate energy use in the Additional Actions case, as they do under current policies, throughout the modeling period. Overall energy use in the state declines by about half by 2050, mostly as a result of substantial fuel switching to electricity (mostly) in the buildings and transportation sectors, as well as through efficiency improvements across sectors.

Figure 5-3: Overall Energy Use in Maryland by Sector, Additional Actions Case



Electricity use expands greatly in the Additional Actions case, while the use of diesel fuels, gasohol/gasoline,[68] and natural gas fall substantially due to electrification across sectors (Figure 5-4).

Figure 5-4: Overall Energy Use in Maryland by Fuel, Additional Actions Case



Looking at electricity use in the Additional Actions case, after a slight decline in the late 2020s due to continuing efficiency improvements, electricity demand rises rapidly to over 90 TWh by 2050, as shown in Figure 5-5. The step increase in electricity demand in the industrial sector in 2031 is due to the electrification of cement production in that year.

Overall direct GHG emissions from energy demand in Maryland decrease from nearly 49 MMtCO_2e in 2023 to less than nine and seven MMtCO_2e in 2045 and 2050, respectively, with the bulk of the decrease coming from electrification across sectors.

[68] Most "gasoline" sold in Maryland is actually "Gasohol E10", which is 10 percent ethanol.

Figure 5-5: Overall Electricity Use in Maryland, Additional Actions Case

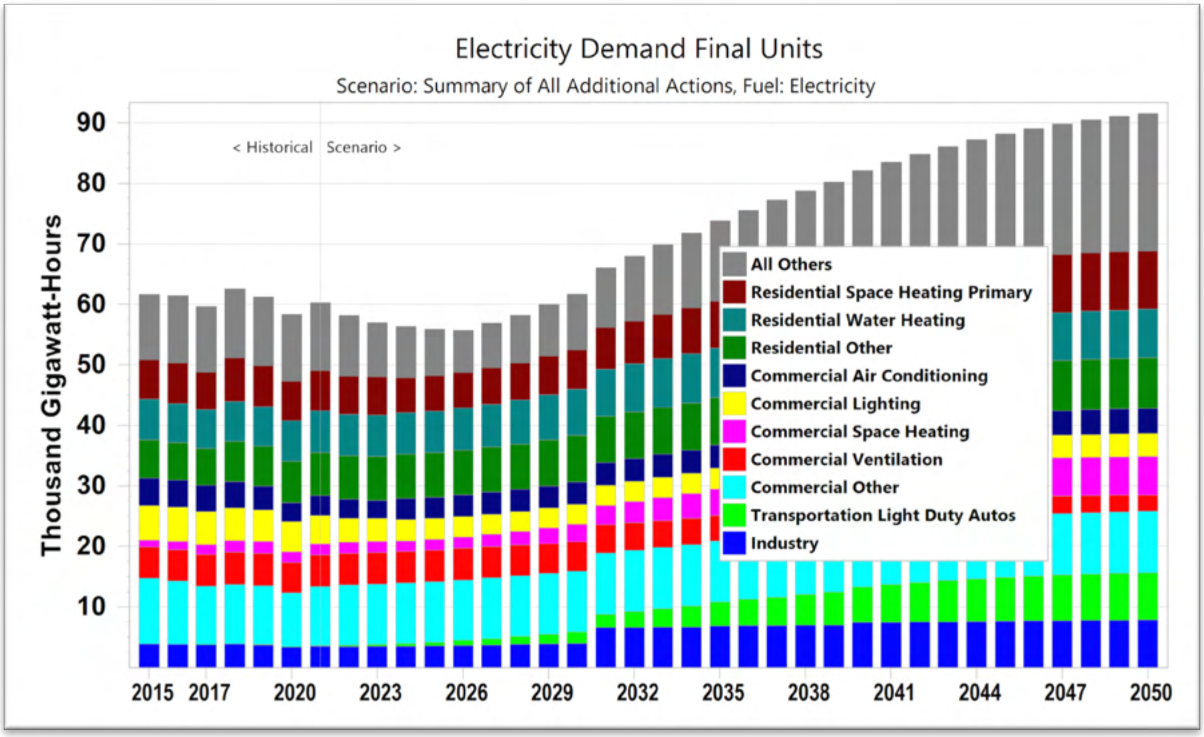
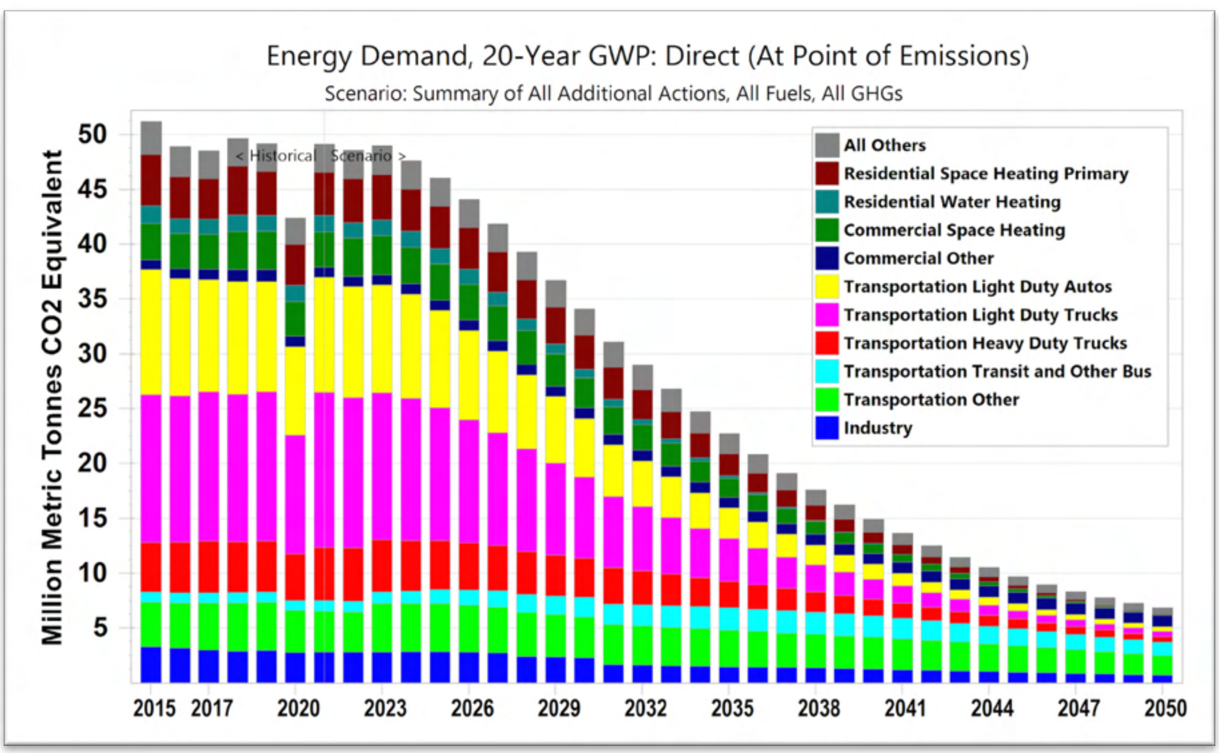


Figure 5-6: Overall GHG Emissions from Energy Demand in Maryland, Additional Actions Case



5.2.2 Buildings

The following Buildings actions were modeled as part of the Additional Actions Scenario. Note that there are significant overlaps between these actions which were addressed during modeling.

Low Income Electrification (LIE scenario): Replaces fossil fuel space heating and water heating devices with heat pump devices in low-income households. 60% of households are electrified by 2030 (starting from baseline of 31%), 100% by 2040. This action assumes the low-income (LI) population affected include 263,489 single-family and 184,374 multi-family for a total of 447,863 households.[69] These estimates are from the Maryland Department of Housing and Community Development (MD DHCD).

All-Electric Building Code Expansion (AEC scenario): This action uses the same building code upgrade assumptions as those used for Montgomery and Howard County in the Current Policies case, but extends the building code to the entire state, as described for the Current Policies case in section 4. This action assumes that all new buildings and major renovations (which are assumed to occur in one percent of buildings each year) are all-electric. Sales of heat pumps are increased by a factor proportional to the number of new buildings in each year.

Building Energy Performance Standards Expansion (BEP scenario): This scenario assumes that the full 20 percent reduction in direct emissions in buildings over 35,000 square feet is achieved by 2030 (instead of only partial achievement of that goal, as assumed in the Current Policies Scenario). As in the Current Policies Scenario, 40 percent of reductions in commercial buildings are assumed to come from building re-tuning, 12 percent are assumed to come from building envelope improvements, and 48 percent are assumed to come from electrification of space heating and water heating equipment. For residential buildings, 80 percent of reductions come from electrification and 20 percent from building envelope improvements. Buildings with floor area of 10,000 square feet and larger are assumed to be electrified by 2045.

EmPOWER Restructuring (EMP scenario): Starting in 2025, fossil fuel equipment stocks are reduced by 1.9 percent each year, replaced by sales of equivalent electric equipment. The electricity energy efficiency reductions assumed in the Current Policies Scenario are removed, except for the reductions achieved prior to 2024 (because it is assumed that EmPOWER funding is redirected to electrification) plus the following reductions in electricity use resulting from the EmPOWER low-income household mandate for 2024-2026:

- 2024: 36,899 MWh
- 2025: 50,127 MWh
- 2026: 69,621 MWh

Zero NOx Appliance Standards (ZNX scenario): Assumes that the sales shares of all fossil fuel residential and commercial space heaters and water heaters go to zero on the following schedule:[70]

- 2027: residential water heaters
- 2029: space heaters
- 2031: commercial water heaters

Expansion of Zero NOx (EZN scenario): Extends Zero NOx standards to residential and commercial cooking and residential clothes drying. This action assumes that the sales shares of these types of fossil fuel equipment go to zero in 2035.

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[69] Maryland Low-Income Market Characterization Report

[70] Based on schedule adopted by the Bay Area Air Quality Management District in California (undated), "Air District Appliance Rules – Furnaces and Water Heaters".

Combined Buildings Policies (CBG scenario): This Buildings scenario, which is part of the Additional Actions Scenario, combines all the above actions, removing overlaps. These overlaps include at least some of the electrification in LI households and buildings covered by BEPS being achieved through EmPOWER, and the fact that Zero NOx standards result in 100% space and water heating equipment going full electric after 2031. Before the ZNX phase-in dates, sales are adjusted for the heat pump sales estimated in the AEC, BEP, LIE, and BEP scenarios. After the 2029-2031 phase in dates for ZNX, all fossil fuel sales space heating and water heating sales are converted to heat pump sales. (Electric resistance heater sales are kept at baseline levels).

Residential sector energy demand decreases by about 38 percent between 2023 and 2045, and by 40 percent by 2050, as shown in Figure 5-7, with residential space and water heating, as well as other residential end uses, dominating overall energy use. Space heating and other energy use are the largest uses of energy overall in the commercial sector, which experiences similar declines in overall net energy use, by 36 percent between 2023 and 2045, and by 39 percent to 2050 (Figure 5-8). Electricity demand increases modestly in both buildings sectors under the Additional Actions case, as shown in Figure 5-9 and Figure 5-10.

Figure 5-7: Residential Sector Energy Demand by End Use, Additional Actions Case

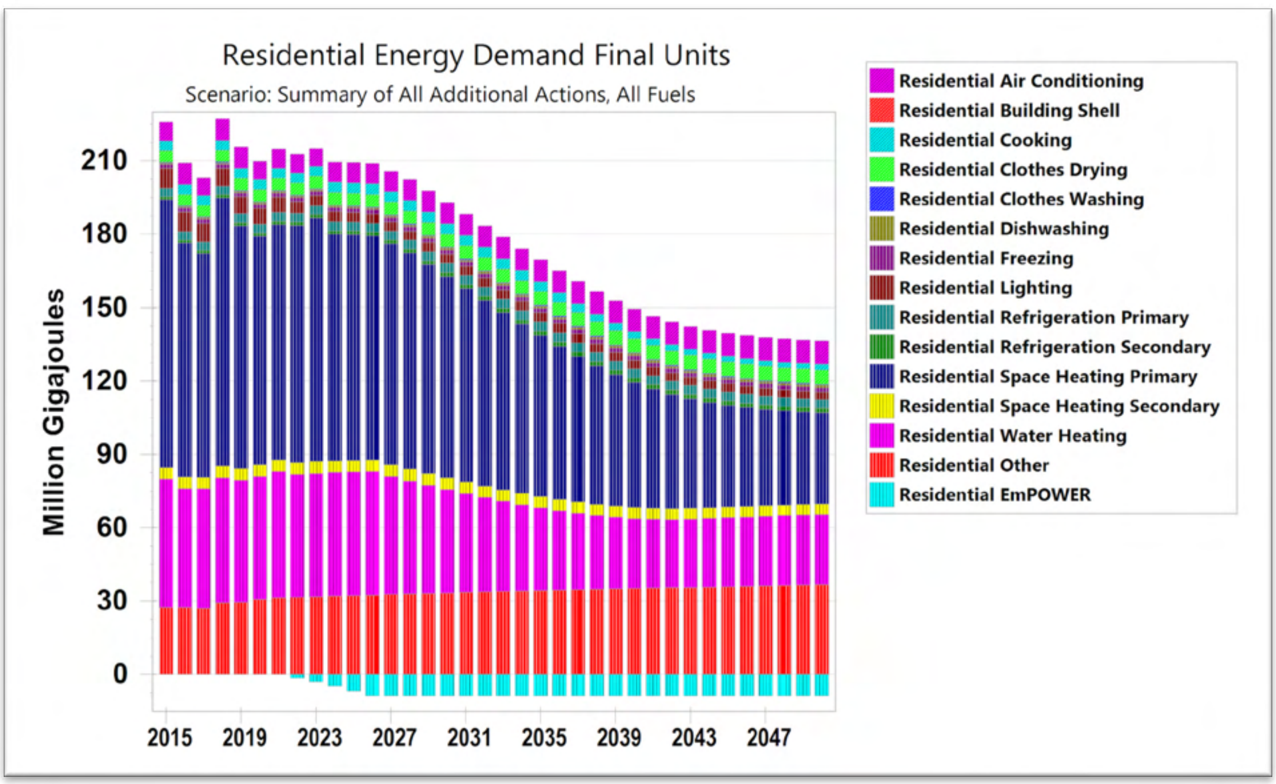


Figure 5-8: Residential Sector Energy Demand by End Use, Additional Actions Case

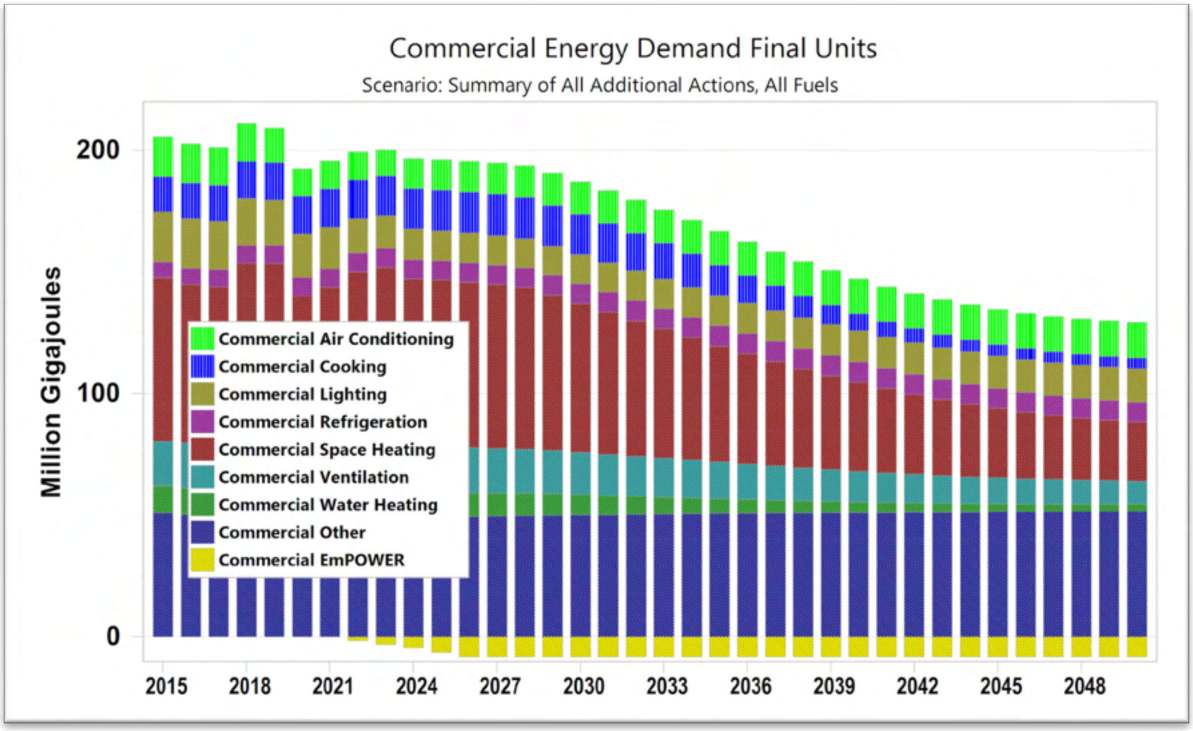


Figure 5-9: Residential Sector Electricity Demand by End Use, Additional Actions Case

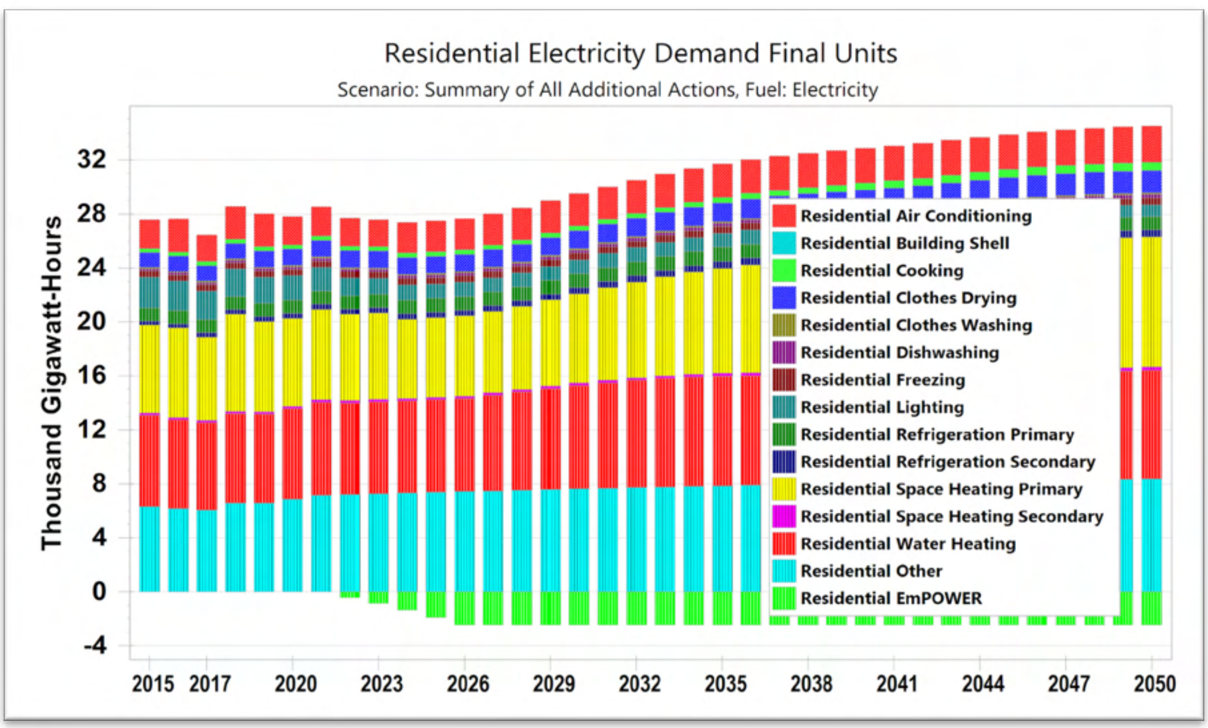
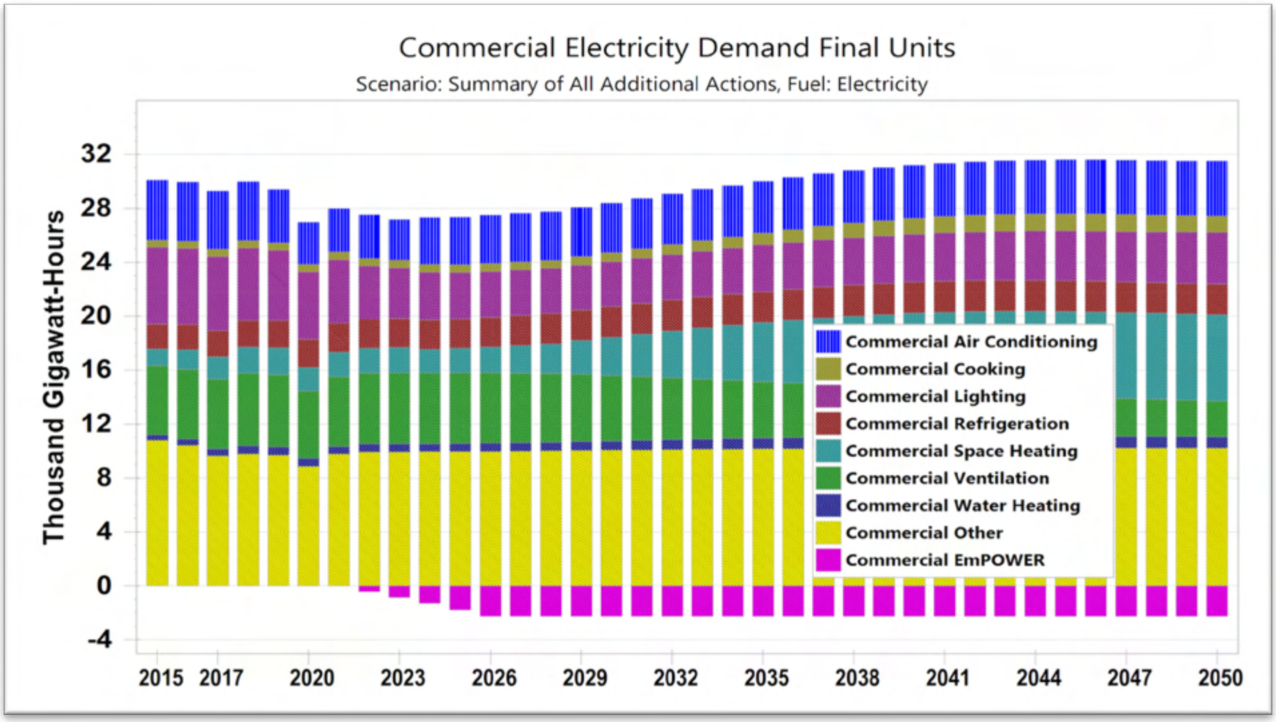
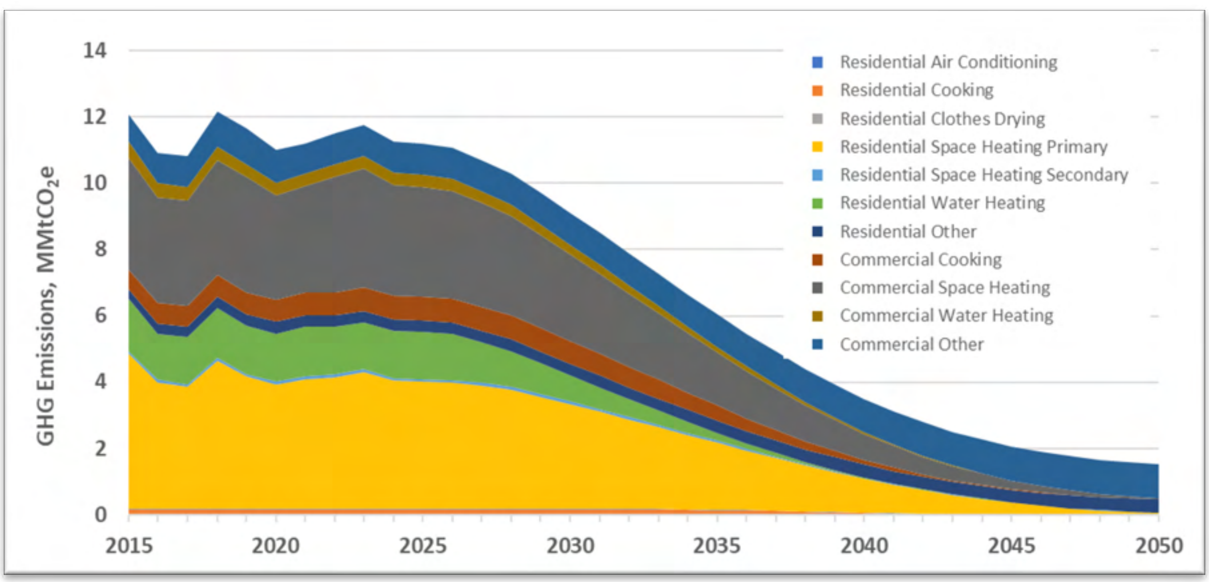


Figure 5-10: Commercial Sector Electricity Demand by End Use, Additional Actions Case



As a result of electrification of appliances and equipment, overall GHG emissions in the buildings sectors decline to about two $MMtCO_2e$ by 2045, and even less in 2050, versus nearly 12 $MMtCO_2e$ in 2023, as shown in Figure 5-11.

Figure 5-11: Overall Buildings Sector GHG Emissions by End Use, Additional Actions Case



5.2.3 Transportation

Actions related to some, but not all, of the Transportation segments are reflected in the list of individual "scenarios" below, the results of which are compiled into an overall **Transportation Summary scenario**, which itself is a component of the full Summary of Additional Actions case.

Key assumptions for the Transportation sector in the Additional Actions case are as follows:

- The scenario builds on the considerable expansion in deployment of electric LDVs (essentially all sales are electric by 2035), and HDVs (near 50 percent of sales by the late 2030s) already in the Current Policies case by extending electrification in the HDV class beyond the 2030s. The Additional Actions Scenario also incorporates diversion of about half of an assumed total reduction of 20 percent of vehicle miles traveled (VMT) by 2031 (and 25 percent by 2050) to other powered transit modes (trains, buses, and e-bikes) with the remainder of the VMT reduction assumed transferred to foot and bike traffic or otherwise resulting from denser development, carpooling, additional emphasis on working from home, and other approaches.
- Electrification of buses, rail travel (passenger and freight) and other transport equipment, with the notable exceptions of planes in the aviation sector (although electrification of ground equipment at airports is assumed to accelerate) and the marine shipping sectors, also builds on the Current Policies case by increasing the rate of and/or extending the deployment of electric vehicles and devices.

Key results for the Transportation sector in the Additional Actions case, emphasizing results in 2031, are as follows:

- Overall emissions from transportation in 2031 fall to 20.3 $MMtCO_2e$ annually, a reduction of 2.1 $MMtCO_2e$ relative to the Current Policies case (Figure 5-12 and Figure 5-13).
- Transit buses are not electrified as fast as the LDV fleet, resulting in increased emissions from the transit bus fleet. Therefore, non-intuitively, emissions reductions in the Additional Actions case are limited in future years relative to the Current Policies case. The result is that there is a shift of some VMT from electric cars to diesel buses, although this effect is more than balanced by GHG reductions in other subsectors (Figure 5-13).
- HDV energy use decreases markedly as the subsector is electrified (Figure 5-14).
- Emissions from the aviation sector (except for airport operations) and from the marine shipping sector follow the Current Policies case, except half of jet fuel is assumed to be replaced with sustainable aviation fuel. In general, those subsectors are difficult to decarbonize without a national/international effort.
- Transportation electricity use rises from near-zero in the early 2020s to about 22 TWh by 2050 as a result of the aggressive electrification included in the Additional Actions case (Figure 5-15).

Figure 5-12: GHG Emissions in the Transportation Sector, Additional Actions Case

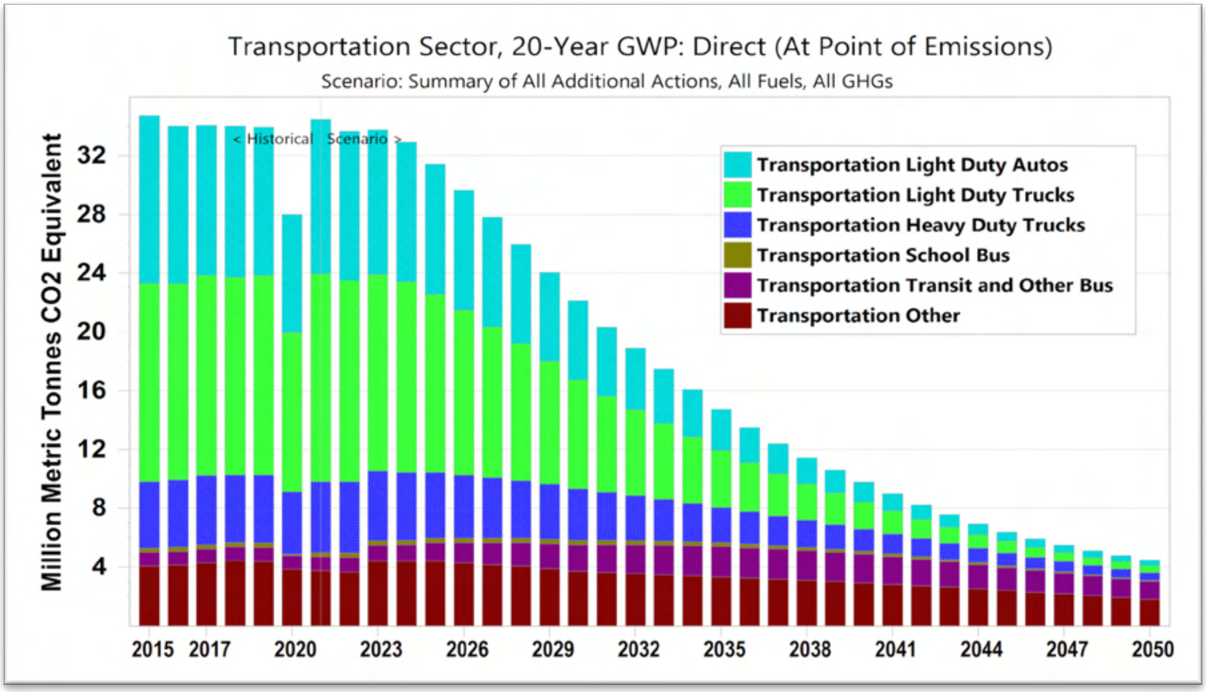


Figure 5-13: Additional Actions Changes in GHG Emissions for Transportation Sector

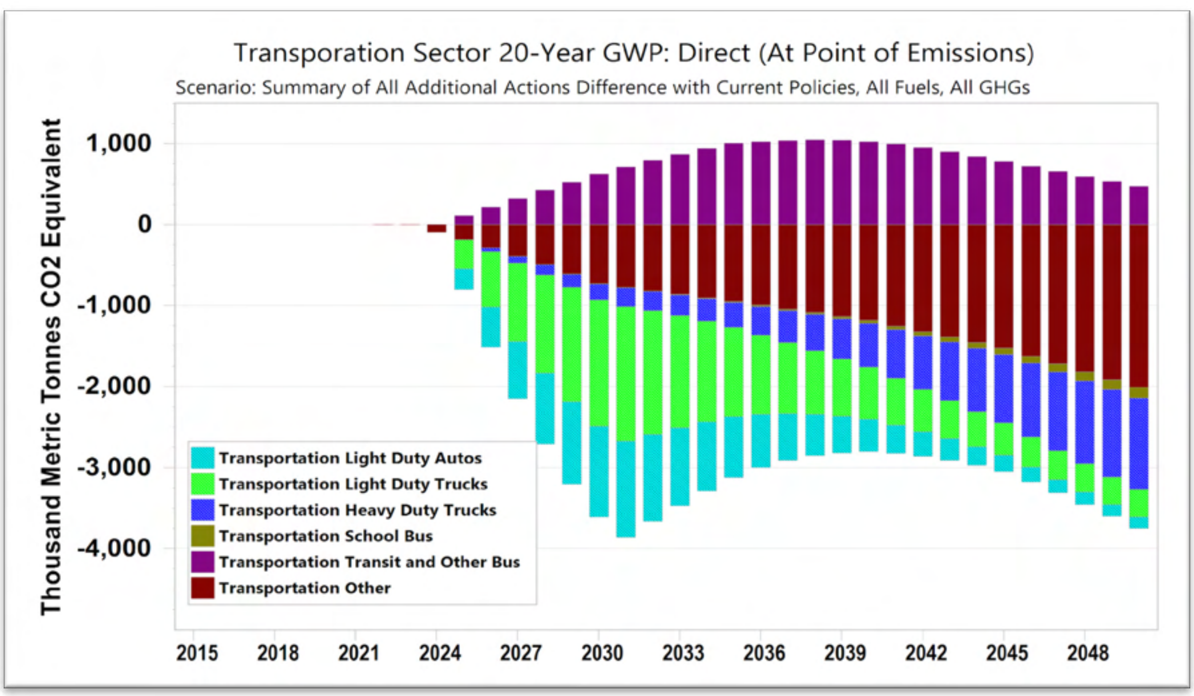


Figure 5-14: Incremental Transportation Energy Demand in Additional Actions Case

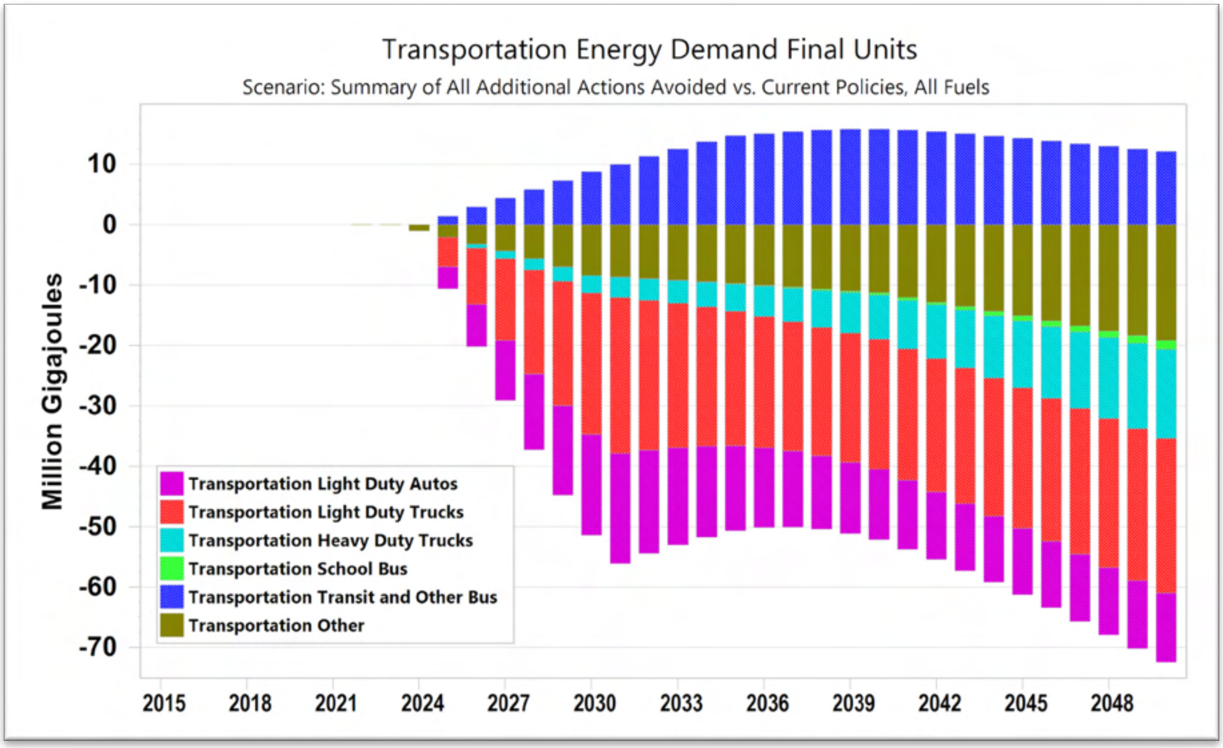
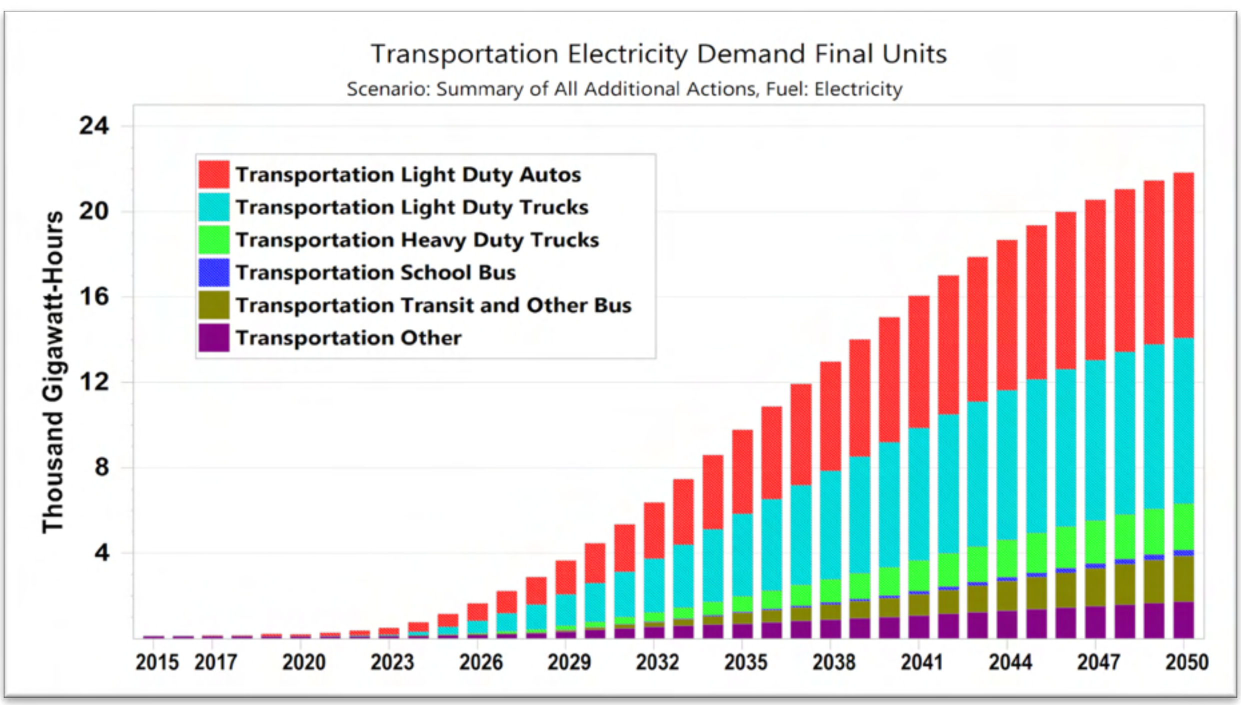


Figure 5-15: Transportation Electricity Demand in Additional Actions Case



Below we describe the transportation options included in the Additional Actions Case in greater detail and provide results and key assumptions by subsector.

The **VMT Reduction (VMR scenario)** assumes that light duty auto (LDA) and light duty truck (LDT) VMT (but not heavy-duty truck VMT) are reduced by 20% relative to the RPL case as of 2031, starting in 2025, and continues to decrease to 75% of Current Policies case levels by 2050. Of the 20% VMT reduction, some is shifted to passenger rail (Amtrak, MARC, Purple Line), some to e-bikes, and some to buses. The remainder of the 20/25 percent of VMT shifted by 2031/2050 are assumed to be accounted for by several factors: more trips on foot or (non-E) bike, in part due to denser development; increased vehicle occupancy (carpooling); a continuation of the trend toward working from home; and other changes that do not add to energy use. Initial assumptions for moving VMT include the following shifts:

- Increases in occupancy of MARC and the Purple Line by a factor of two by 2031 and an increased number of MARC and Purple Line trains by a factor of two by 2031 and three in 2050, with only the increase in trains affecting energy use. This shifts about 0.45 percent of VMT (very roughly) by 2031. Passenger-miles traveled on MARC are at this point a rough estimate based on data publicly available, and could be refined in consultations with MARC, MDOT, and/or others.
- Increased rate of growth of e-bike VMT such that e-bike VMT increases by about 40 percent by 2031 and more than doubles by 2050, relative to the reference case. This shifts about 0.30 percent of VMT (very roughly) by 2031 and could come from a combination of increased e-bike purchases and/or increased usage of bikes purchased as assumed in the Current Policies case.
- Shift additional LDV VMT to buses by doubling the capacity factor of transit and other (non-school) buses in service now by 2031,[71] doubling the number of transit and other bus VMT by 2035, with bus VMT nearly tripling by 2050, relative to the Current Policies case. The number of transit and other buses are assumed to be proportional to the changes in bus VMT (that is, the miles driven per bus per year stays the same). We assume that the number and travel miles of school buses—which accounted for an estimated 20 percent of all buses by number in recent years—remain roughly as they are now.
- The combination of additional rail, e-bike, and (mostly) bus passenger travel will account for about half of the 20 percent VMT reduction by 2031 (and 25 percent reduction in 2050), meaning that the other half of the reduction will need to come from a combination of non-motorized transport, additional carpooling, and reduction of transportation needs by a variety of land-use and other measures.

The changes noted above result in an overall increase in energy use by buses, relative to the Current Policies case, as is shown in Figure 5-16. There are also increases in e-bike and passenger rail (MARC and Purple Line) energy use as well, but those additional energy demands sum to only a few percent of the additional energy required by buses shown. Even with the increase, the additional energy needs in buses are more than offset by the reduction in energy use by light duty vehicles, as shown in Figure 5-17. This LDV energy use offset, particularly in later years, is mostly of electricity use, which is mostly from renewable sources, and will therefore has limited effect on GHG emissions in the later years of the modeling period. The reason that savings in LDV electricity use dominates the pattern shown in Figure 5-17 post-2035 is that the LDV stocks will have substantially turned over to electricity use based on Current Policies case trends.

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[71] At present we have statistics on the total number of bus registrations in Maryland, about 23,000 (2015-2020), and an estimate of the number of school buses, at 7,200. We list the non-school buses as "Transit and Other". Ideally, it would be useful to ultimately model the use of transit buses separate from other buses, such as coaches for hire, when more detailed data on the number and annual miles traveled for transit versus other buses are available.

Figure 5-16: Transit Bus Energy Use in the Additional Actions Case Relative to the Current Policies Case

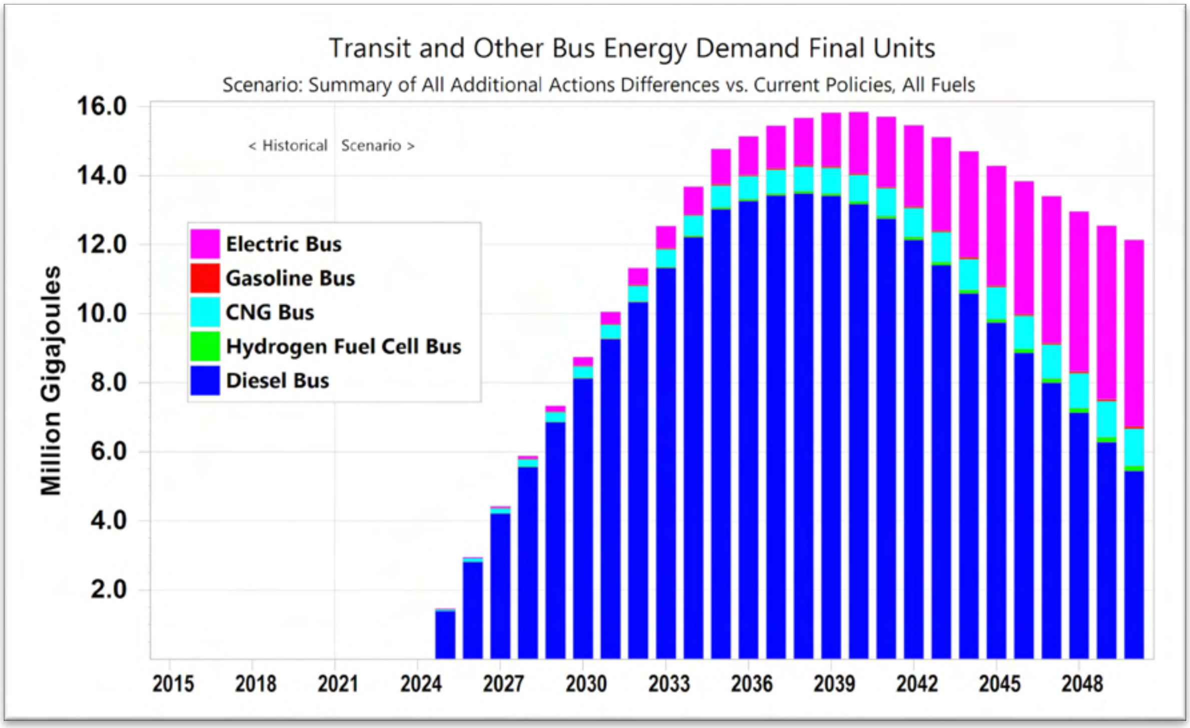
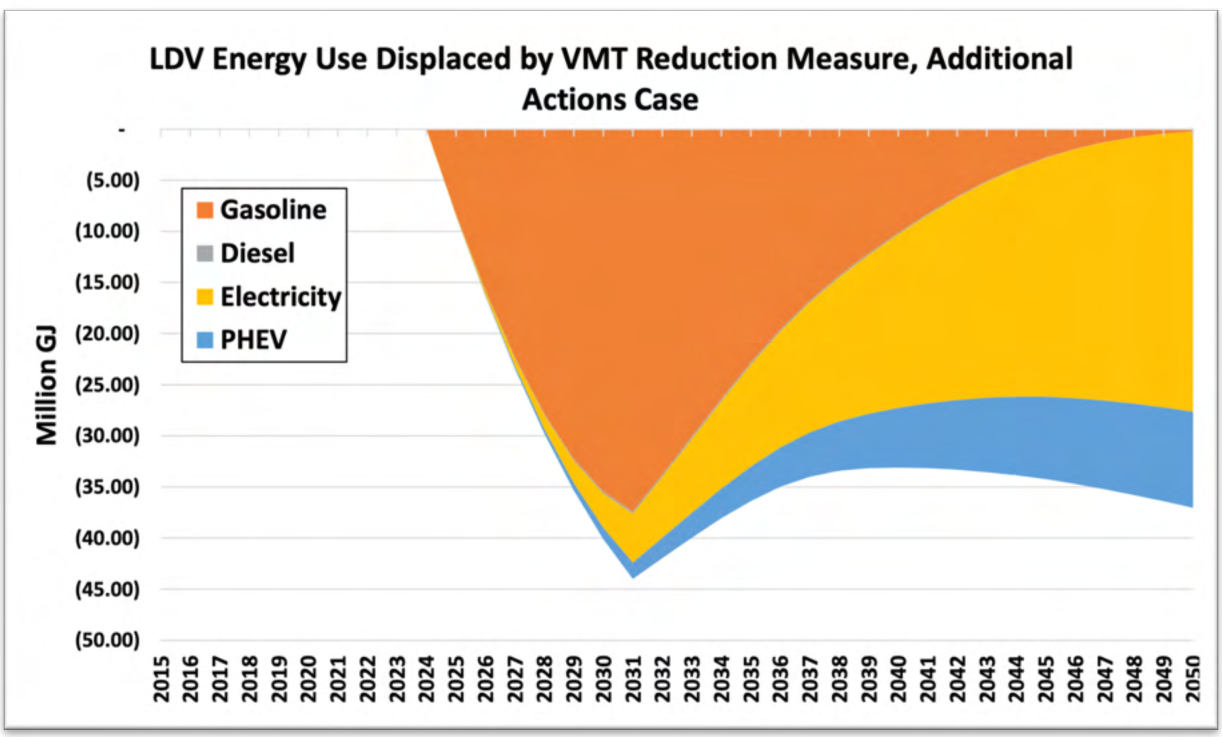


Figure 5-17: Light Duty Vehicle Energy Use in the Additional Actions Case Relative to the Current Policies Case



The **Additional HDV, Bus, and Heavy Equipment Electrification (HVE) scenario** assumes that truck electrification, rather than plateauing in 2035 as in the Current Policies case, reaches 80 percent (sum of electric plus PHEV) of vehicles sold in 2036, and continues through 2050, reaching essentially 100 percent (sum of battery electric vehicle (BEV), diesel PHEV, gasoline PHEV) of sales by that year. Note that this assumption will not affect 2031 results. This scenario also includes an increase in the sales fraction of transit and other buses that are electric to 80 percent in 2050 (from 50 percent in the reference case). Electric school buses capture virtually all sales by 2050. In addition, the stock of agricultural and construction equipment increases in the Additional Actions case to 80 percent electric by 2050 (from 20% in the reference case), and the stock of airport operations equipment changes over from mostly diesel-fueled to 90 percent electric by 2050. The vehicle electrification elements of this scenario change reduce direct transportation sector 2031 emissions modestly in the Additional Actions case because of increased rate of electrification before 2031. With buses, for example, the stock of electric buses in 2031 increases from 6.7% in the Current Policies case to 9.1% in the HVE scenario and in the Additional Actions case.

HDV electrification for trucks results in electric trucks comprising the majority of travel by heavy trucks by 2050. The trends shown in Figure 5-18 show the shift toward travel by electric and PHEV trucks nearing completion by 2050. Also, a factor in this figure is a shift in freight transport from road to rail, as described in the rail electrification scenario below. Overall, demand for diesel declines by over 90 percent between 2023 and 2050, while electricity use rises from zero in 2023 to nearly 8 million GJ or 2,200 GWh (Figure 5-19).

Figure 5-18: Distance Traveled by Heavy Duty Trucks by Type

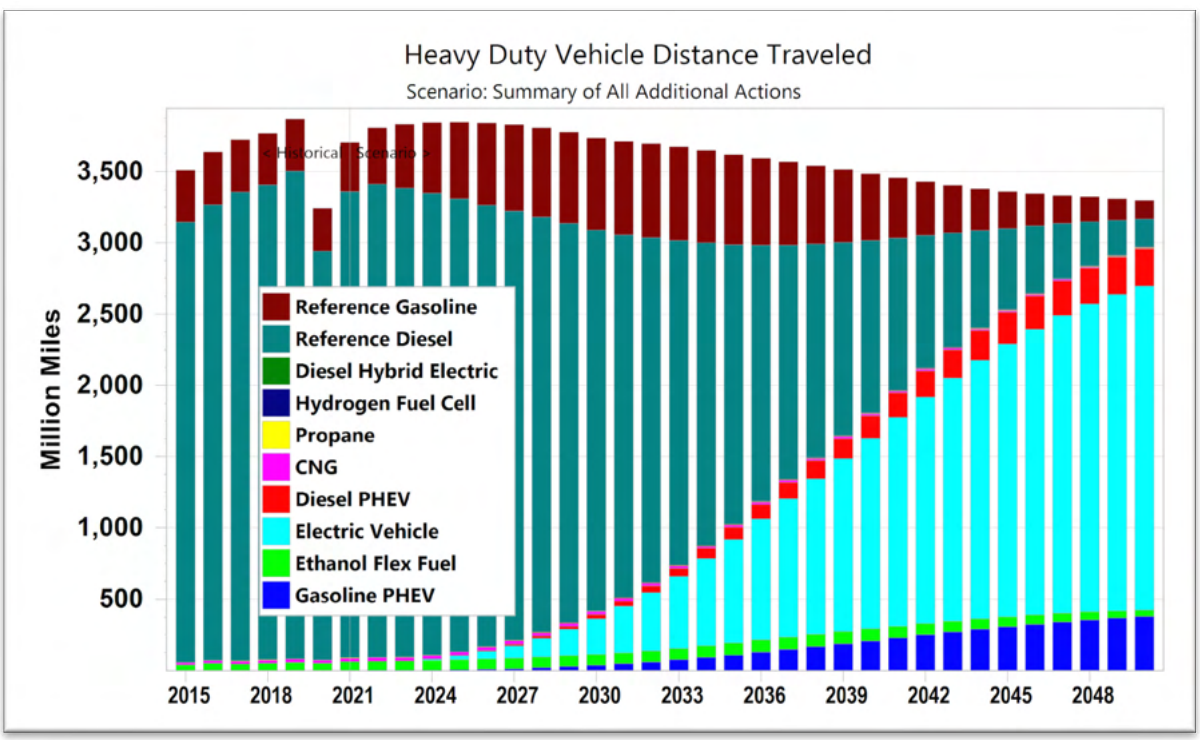
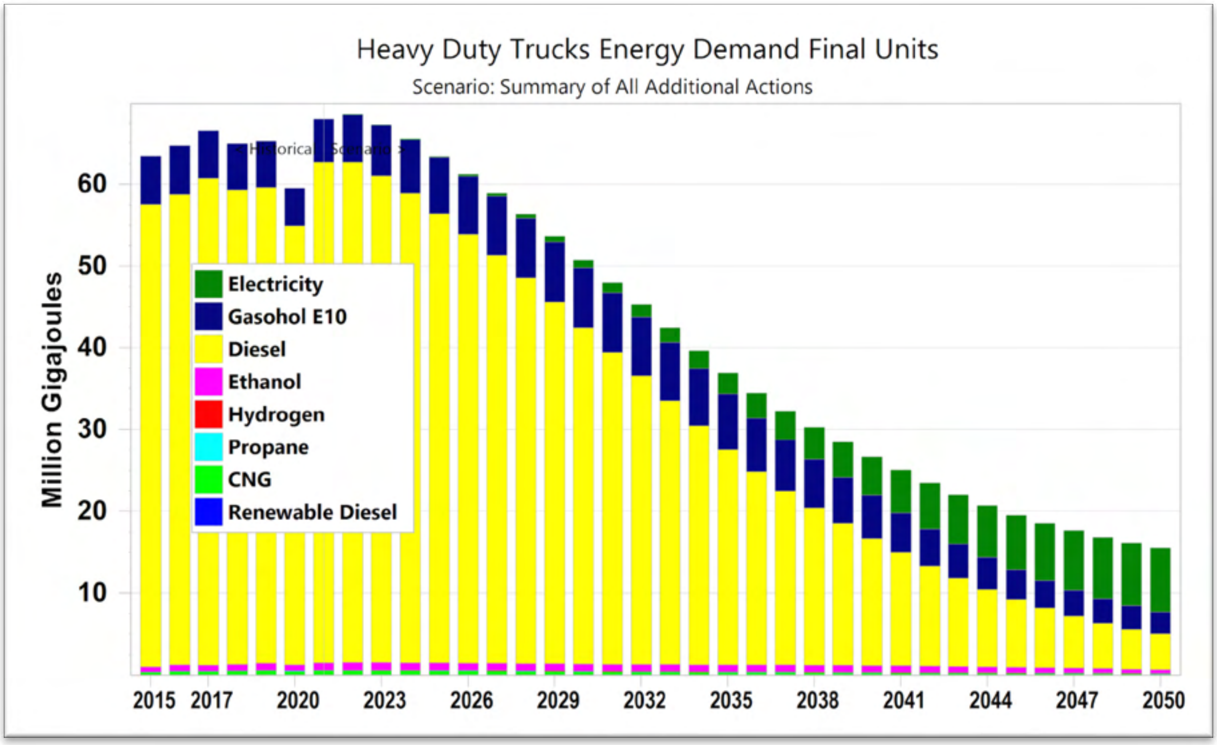


Figure 5-19: Energy Demand for Heavy Duty Vehicles (Trucks)



The **Rail Electrification (RLE scenario)** assumes that 50 percent of MARC is electrified by 2031 (up from an estimated 28 percent today on the Penn Line[72]), increasing to 100 percent by 2050. It also assumes that electrification of rail freight starts in 2025, reaches 25 percent by 2031, and increases to 75 percent by 2050. A key uncertainty here is the extent that Maryland can influence change in a national industry (of which Maryland's miles of rail are a small part). Figure 5-20 shows the pattern of energy use for the rail freight subsector over time in the Additional Actions case. Here energy use shifts to electricity but grows overall because rail is carrying more freight than in the Current Policies case. Figure 5-21 shows a similar pattern for passenger rail energy use. Here again overall energy use increases initially due to the shift in passenger travel from LDVs to rail, but then declines as electric trains, which have a lower energy intensity than diesel trains, become dominant.

In the **Freight Mode Shift (FMS scenario)** we assume that 10 percent of Maryland road freight is shifted to rail by 2031 (from the 2021 baseline) and increases to 25 percent by 2050. The shift is assumed to start in 2026, and results for energy use are indicated above.

[72] This is a very rough estimate that should be revised via research with MDOT and MARC operators.

Figure 5-20: Energy Demand for Rail Freight, Additional Actions Case

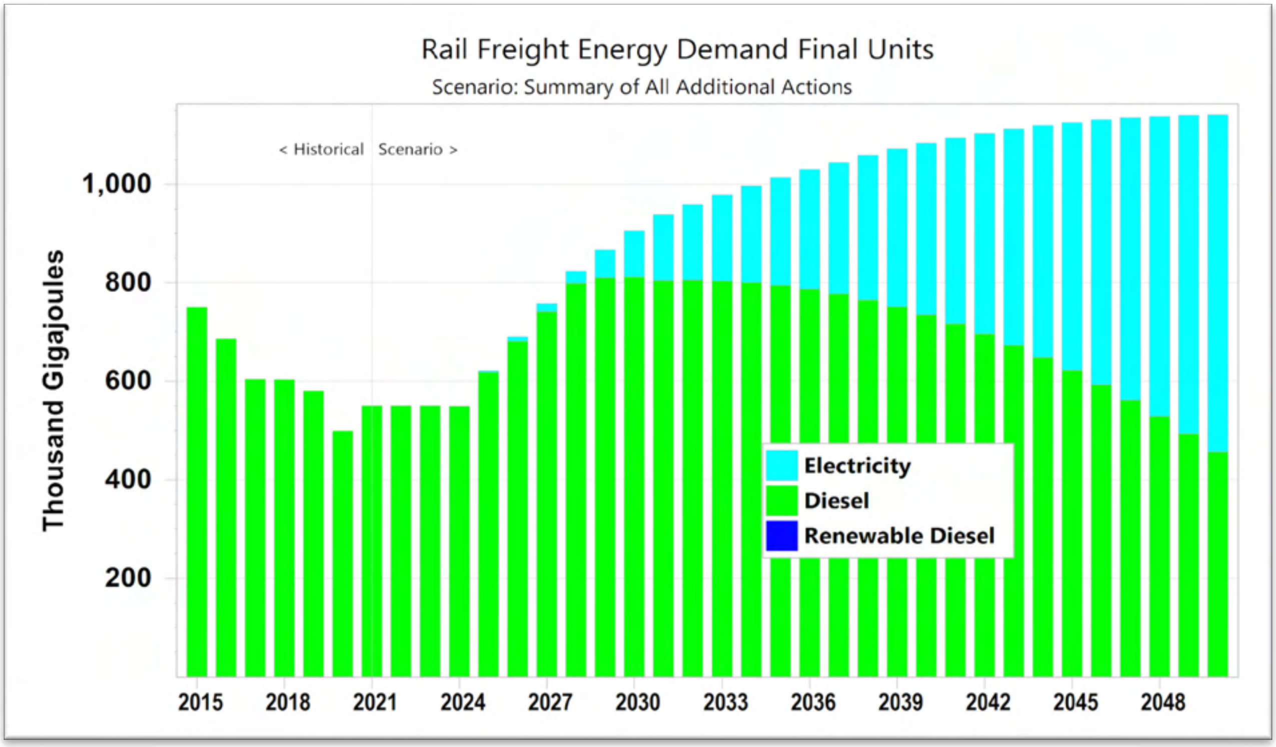
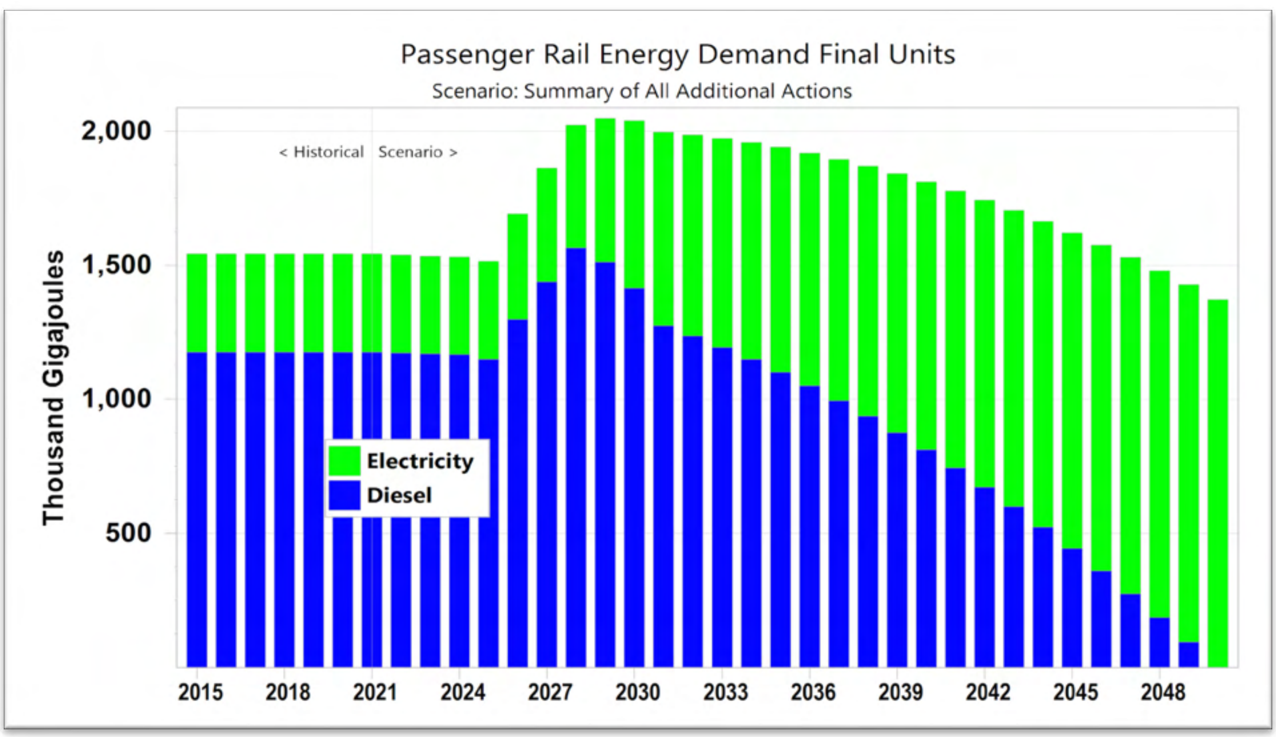


Figure 5-21: Energy Demand for Passenger Rail, Additional Actions Case

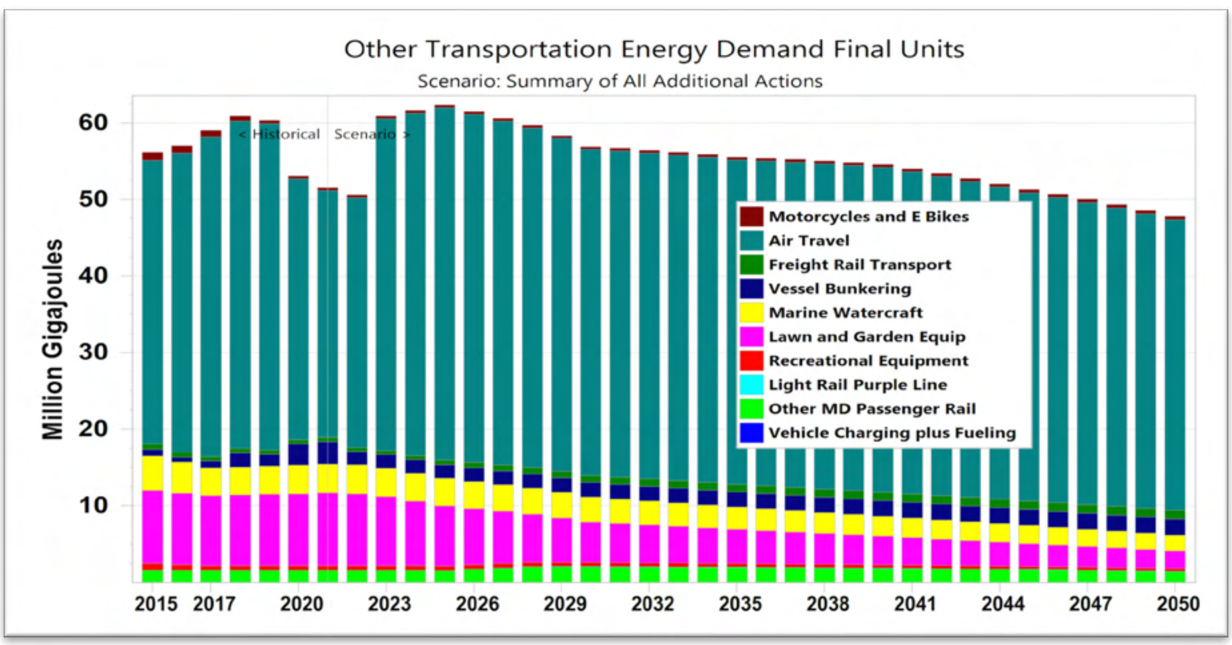


In the **Other Transportation Electrification (OTE scenario)**, we assume that electrification increases in marine watercraft and recreational equipment to 15 percent by 2030, and by 2050 increases to 70 percent of marine watercraft, and 50 percent of recreational equipment. In lawn and garden equipment, electrification increases to 50 percent by 2030 and 90 percent by 2050.

In the **Aviation Improvement (AVI scenario)**, we assume that the aircraft and operations improvements in the Federal Aviation Administration's *United States 2021 Aviation Climate Action Plan* are achieved, [73] increasing efficiency relative to the Current Policies case, and that 50 percent of jet fuel used is "sustainable aviation fuel" by 2050, as in one of the scenarios in the FAA report. As with rail freight, these improvements may be encouraged by Maryland, but will not occur without coordinated national and international action.

The net result of the above actions on energy use in the 'other' transportation subsectors is shown in Figure 5-22. Demand declines are relatively small overall due to increased activity in air transport. Changes in fuel use in other transport are more marked, however. Figure 5-23 shows the reduction in jet fuel use through the combination of energy efficiency improvements and switching to SAF, as well as a reduction in gasoline and diesel fuel use, partially offset by an increase in electricity use. It should be remembered that some of the other transportation modes will see increased activity due to higher ridership of rail and e-bikes. The shift of road freight to rail will reduce energy use in the road vehicle subsectors while increasing energy use in other transportation areas by a much smaller amount. Despite this interaction with the road transport subsectors, overall GHG emissions from the other transportation branches decrease by more than a factor of two between 2023 and 2050, as shown in Figure 5-24.

Figure 5-22: Energy Demand in Other Transportation Sectors, Additional Actions Case



[73] Federal Aviation Administration (FAA, 2021), *United States 2021 Aviation Climate Action Plan.*

Figure 5-23: Energy Demand by Fuel in Other Transportation Sectors, Additional Actions Case versus Current Policies

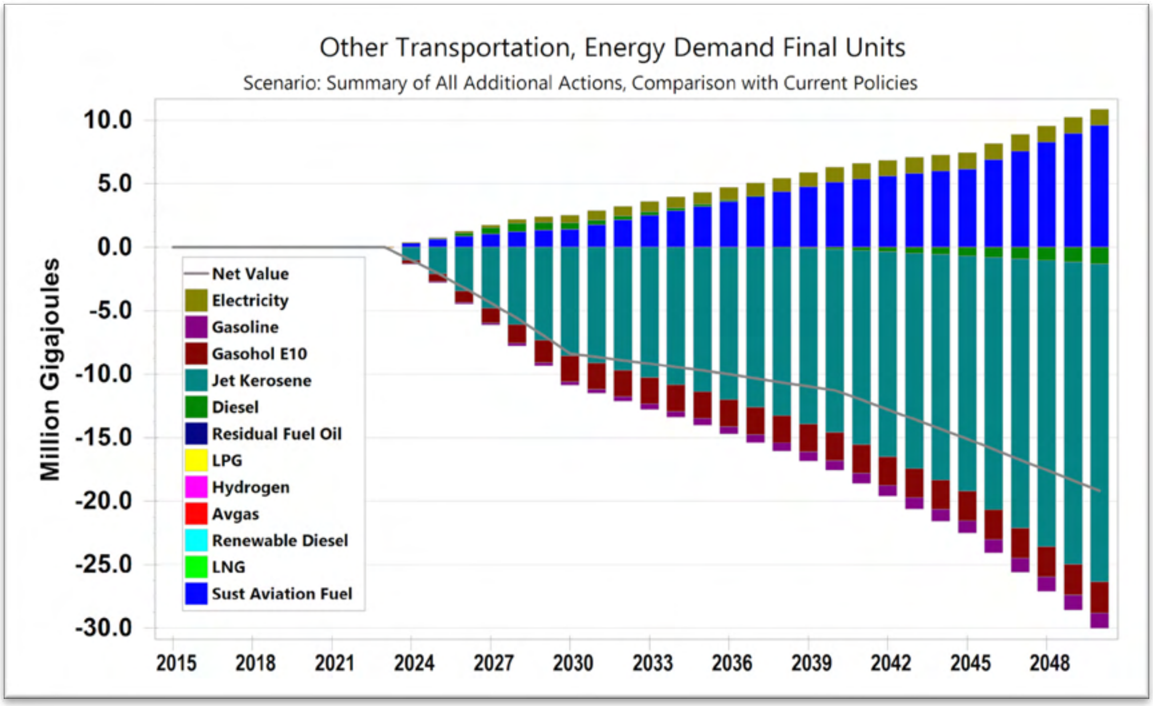
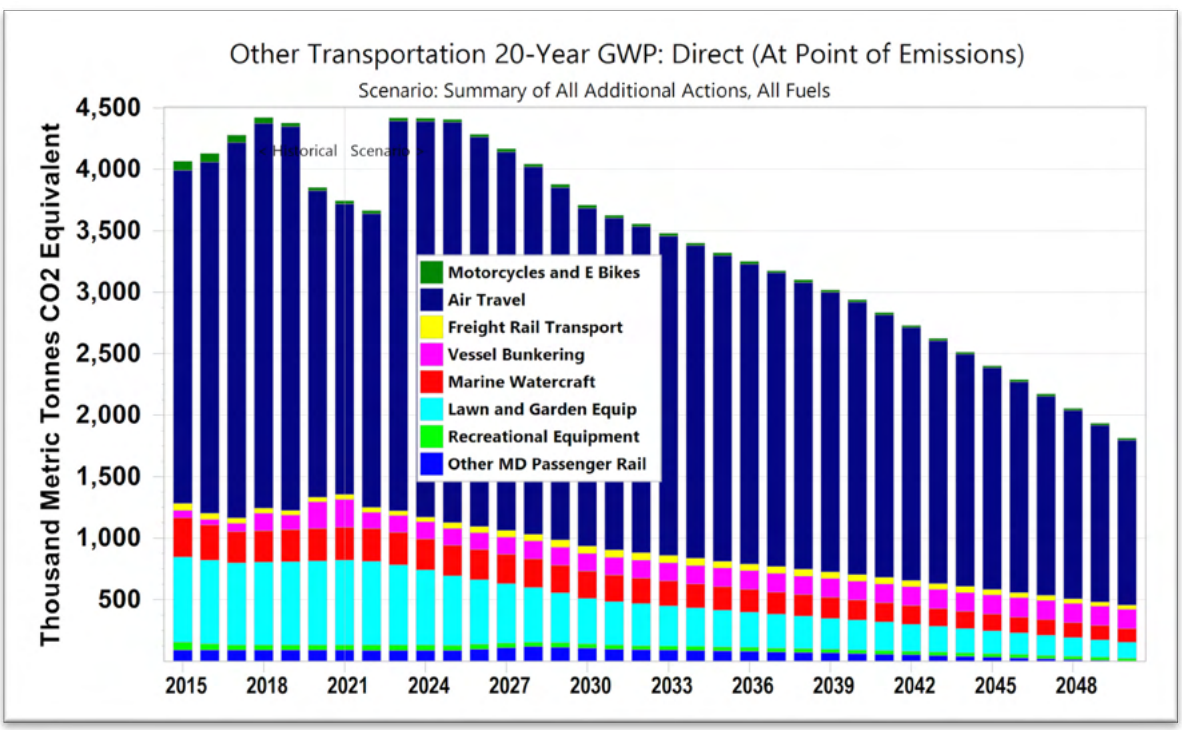


Figure 5-24: GHG Emissions in Other Transportation Sectors, Additional Actions Case

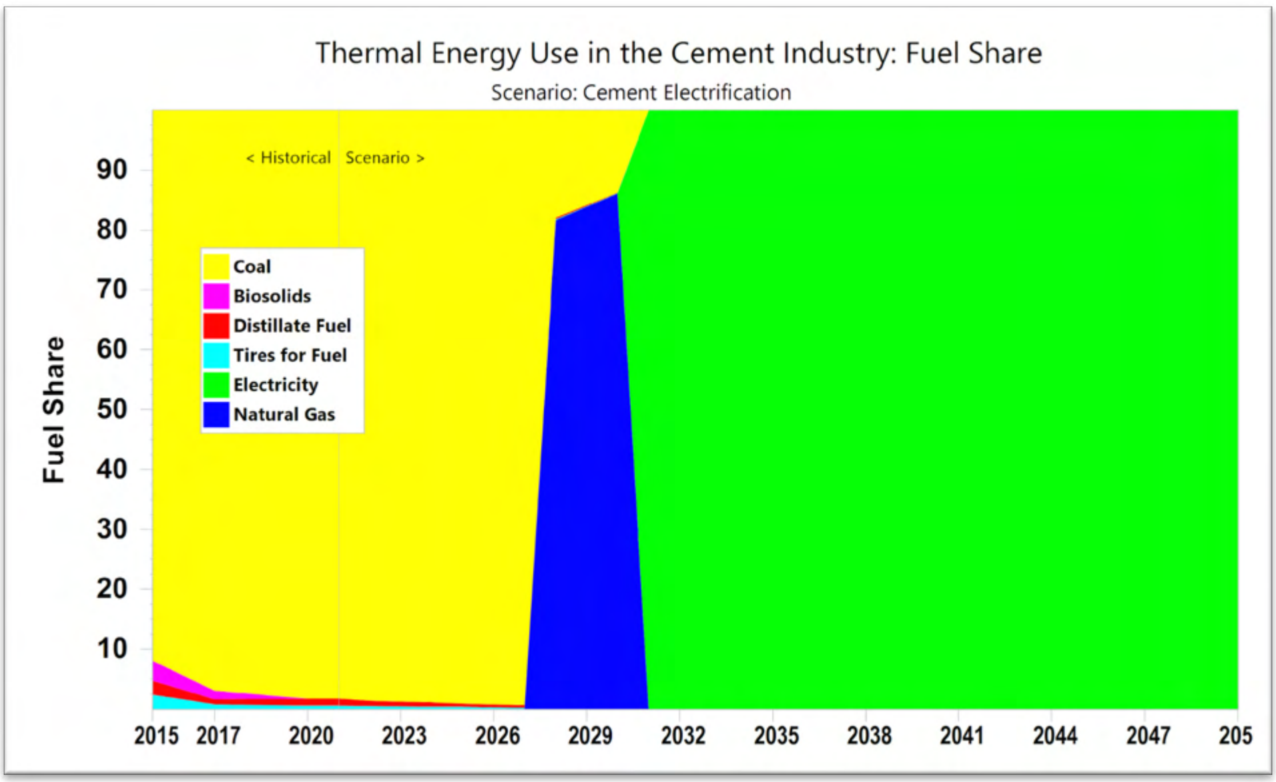


5.2.4 Industrial sector

The major emissions reductions strategies implemented in the LEAP model for the industrial sector are electrification of the cement sector, expanded use of "clinker" (the main component of cement) substitutes in cement blending, and energy efficiency improvements and electrification in non-cement industries.

In the **Cement Sector Electrification (CEM scenario)**, natural gas and coal used to provide heat in cement kilns is substituted with electricity. All the kilns operated by Maryland's two cement producers are assumed to be converted by 2031, resulting in the pattern of fuel share shown in Figure 5-25.

Figure 5-25: Fuel Share in the Cement Industry, Additional Actions Case



The **Cement Clinker Substitution (CCL) scenario** assumes expanded use of "clinker" (the main component of cement) substitutes in cement blending, with 35 percent of clinker substituted for by 2050. This results in proportionately reduced energy use for production of clinker in the cement industry.

The **Cement Sector Carbon Capture and Storage (CMC) scenario** progressively implements carbon capture and storage from cement kilns starting in 2035. Working in tandem with the CEM scenario, carbon capture and storage for cement kilns are much more energy efficient in electric-heated kilns because the carbon capture is applied to a gas stream which is near 100 percent CO_2 from limestone, rather than mixed with high levels of nitrogen and other combustion gases from burning coal or gas. Carbon capture and storage devices are assumed to be powered by electricity.

The **Industrial Energy Efficiency and Electrification (IEE) scenario** assumes energy efficiency improvements in electricity end-uses of 10 percent by 2050, relative to the Current Policies, case, in non-cement industries and for electricity use in the cement industry and assumes that 50 percent of motor fuel and natural gas use in non-cement industries is replaced with electricity by 2050.

Other options for reduction of industrial emissions are possible, including switching to production of CO_2-absorbing cement, but are not yet included in the Additional Actions Scenario, in part because they would require significant input from cement industry stakeholders to both assess their practicality and to estimate their impacts and cost-effectiveness.

Industrial sector GHG emissions in the Additional Actions case decline by about 1.1 $MMtCO_2e$ from 2023 levels by 2031, and by over 2.1 $MMtCO_2e$ by 2050 (Figure 5-26). Additional Actions case industrial emissions fall by about 0.95 $MMtCO_2e$ from Current Policies case levels by 2031, and by nearly 2.1 $MMtCO_2e$ by 2050 (Figure 5-27). These emissions reductions result from the transition to electricity and away from fossil fuels, as shown in Figure 5-28. Note that this figure also includes electricity use for carbon capture and storage in the Additional Actions case.

Additional emissions reduction of about 0.12 $MMtCO_2e$ in 2031, and about 1.6 $MMtCO_2e$ by 2050, result from the use of clinker substitutes in cement plus carbon capture and storage, as shown in Figure 5-29.

Figure 5-26: Industrial Sector GHG Emissions, Additional Actions Case

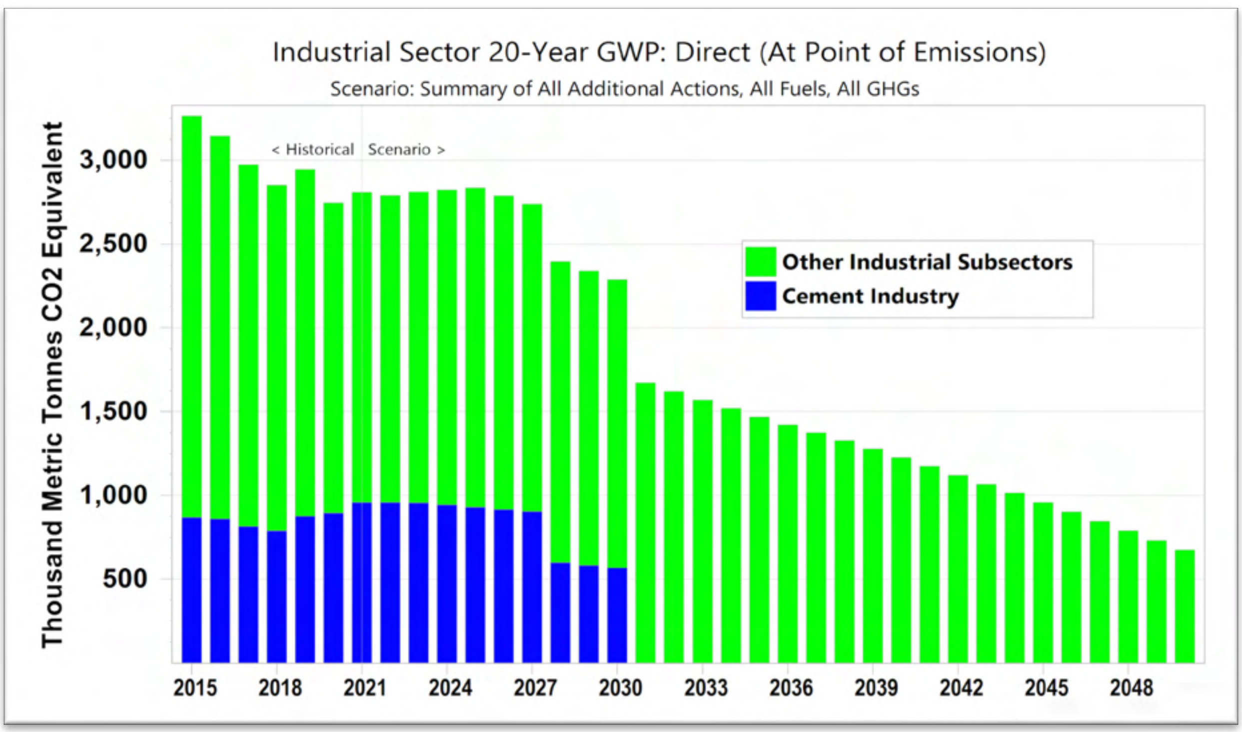


Figure 5-27: Difference in Industrial Sector GHG Emissions, Additional Actions Case versus Current Policies Case

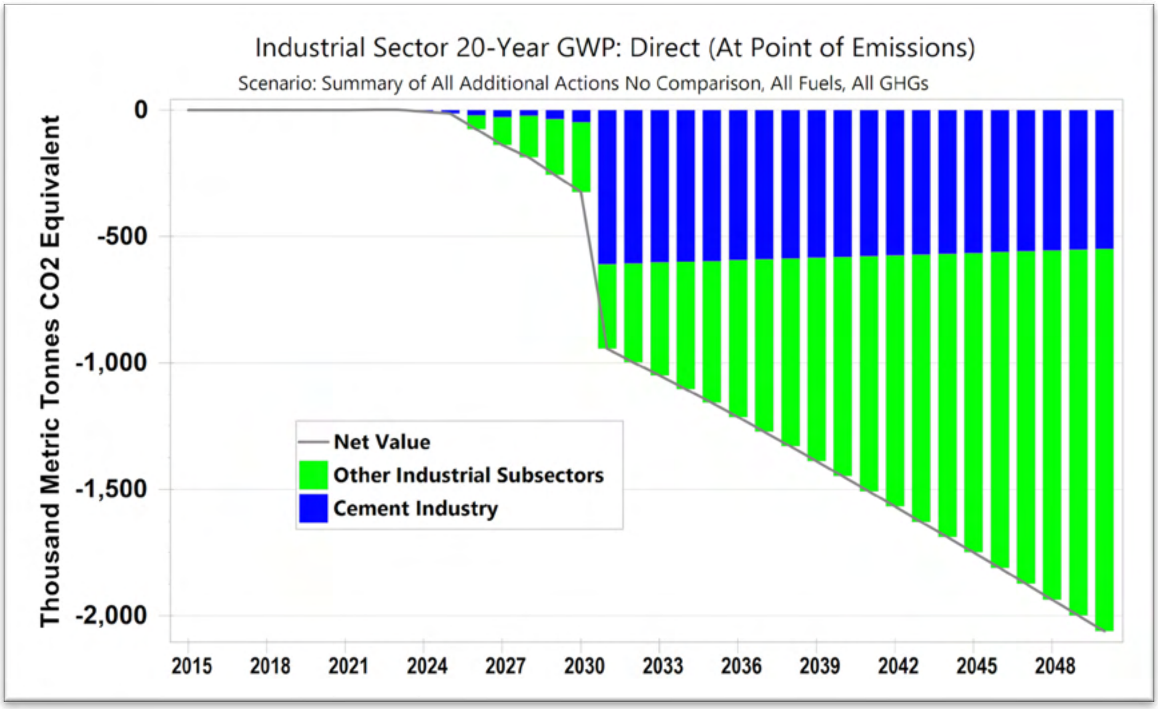


Figure 5-28: Difference in Industrial Sector Energy Demand, Additional Actions Case versus Current Policies Case

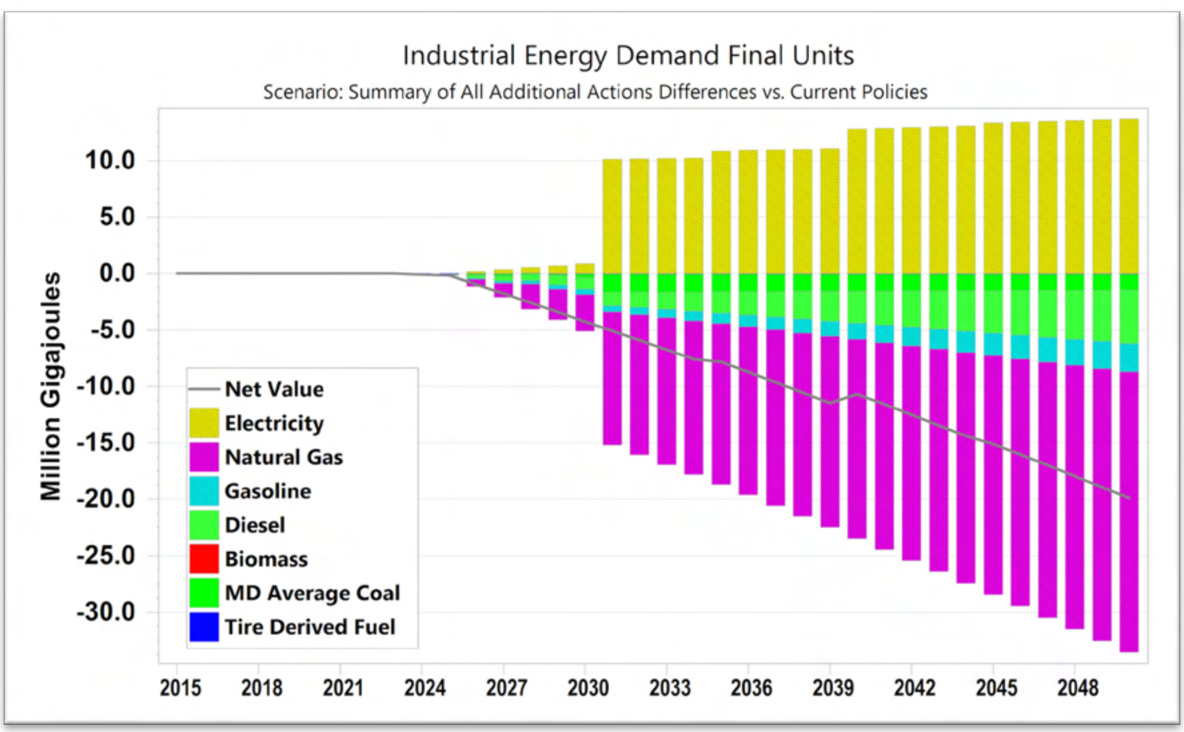
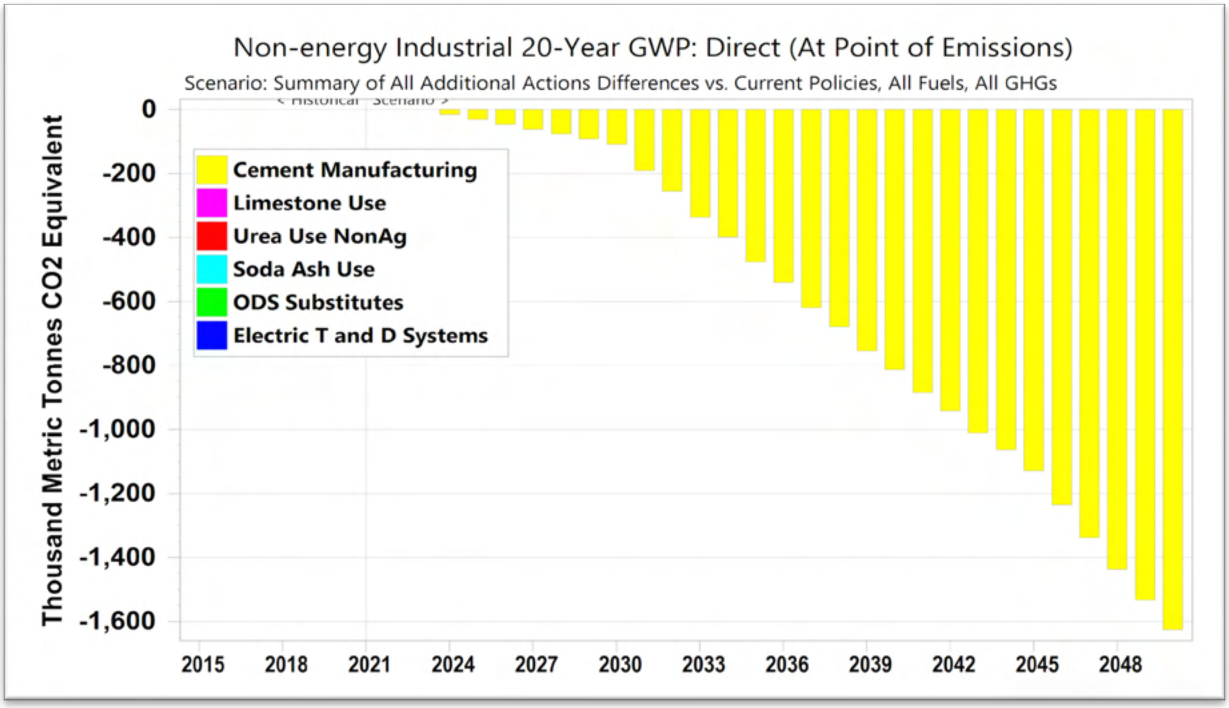


Figure 5-29: Difference in Non-Energy Industrial Sector GHG Emissions, Additional Actions Case versus Current Policies Case



5.2.5 Other sectors

Energy demand and GHG emissions are reduced in the Agriculture and Logging, as well as the Construction and Mining sectors, due to increased penetration of electric equipment in these sectors, as included with the HVE scenario under transportation, above. Figure 5-30 and Figure 5-31 show the reduction in diesel fuel use and increase in electricity use in both sectors, and Figure 5-32 and Figure 5-33 show the substantial reduction in GHG emissions in those sectors resulting from the changes in the Additional Action case.

Figure 5-30: Construction and Mining Sector Energy Use, Additional Actions Case

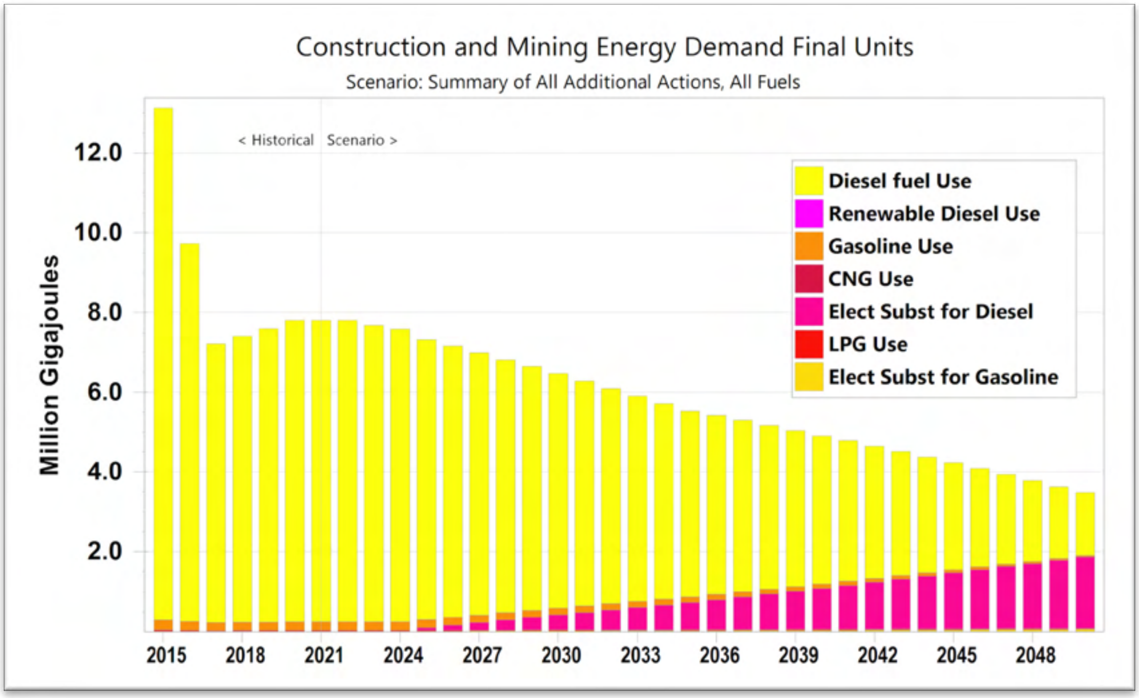


Figure 5-31: Agriculture and Logging Sector Energy Use, Additional Actions Case

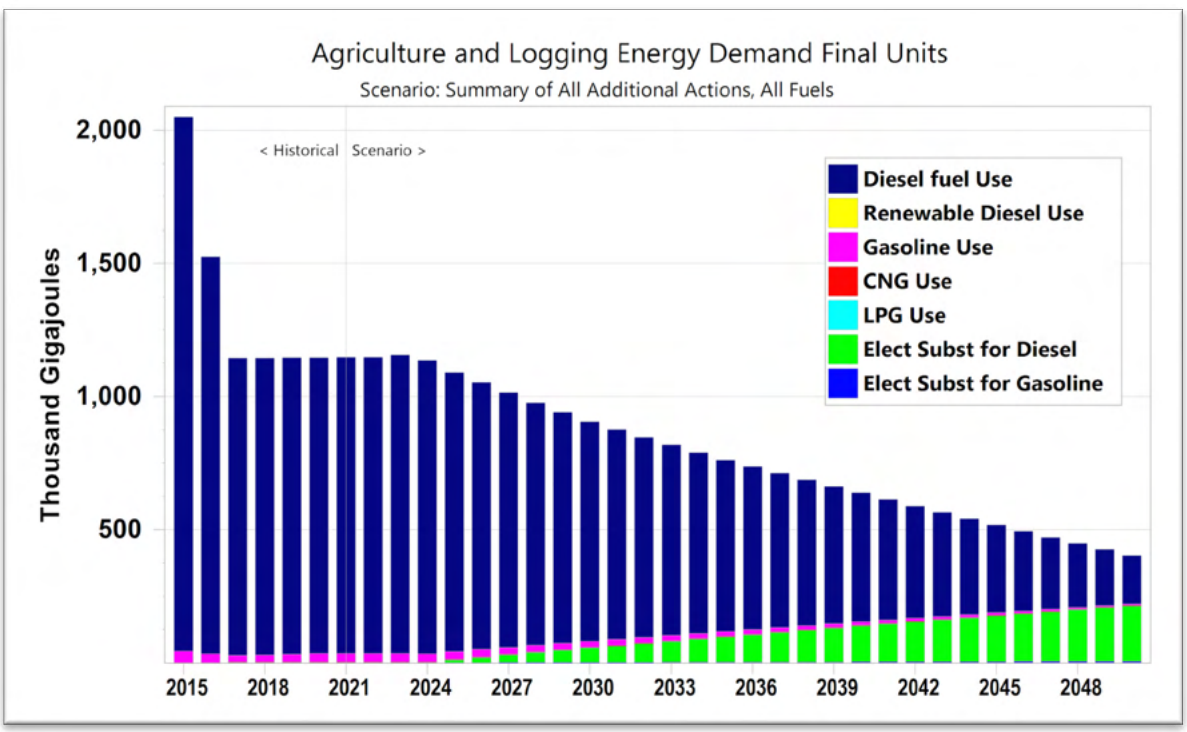


Figure 5-32: Construction and Mining Sector GHG Emissions, Additional Actions Case

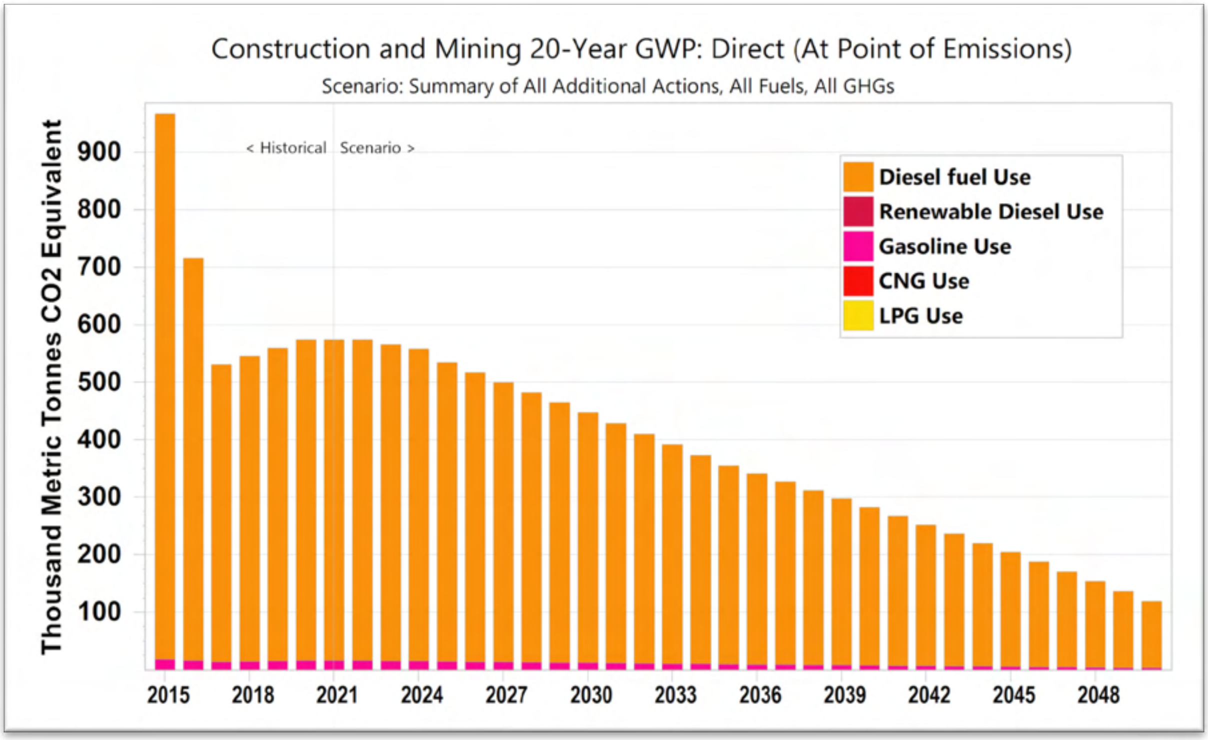
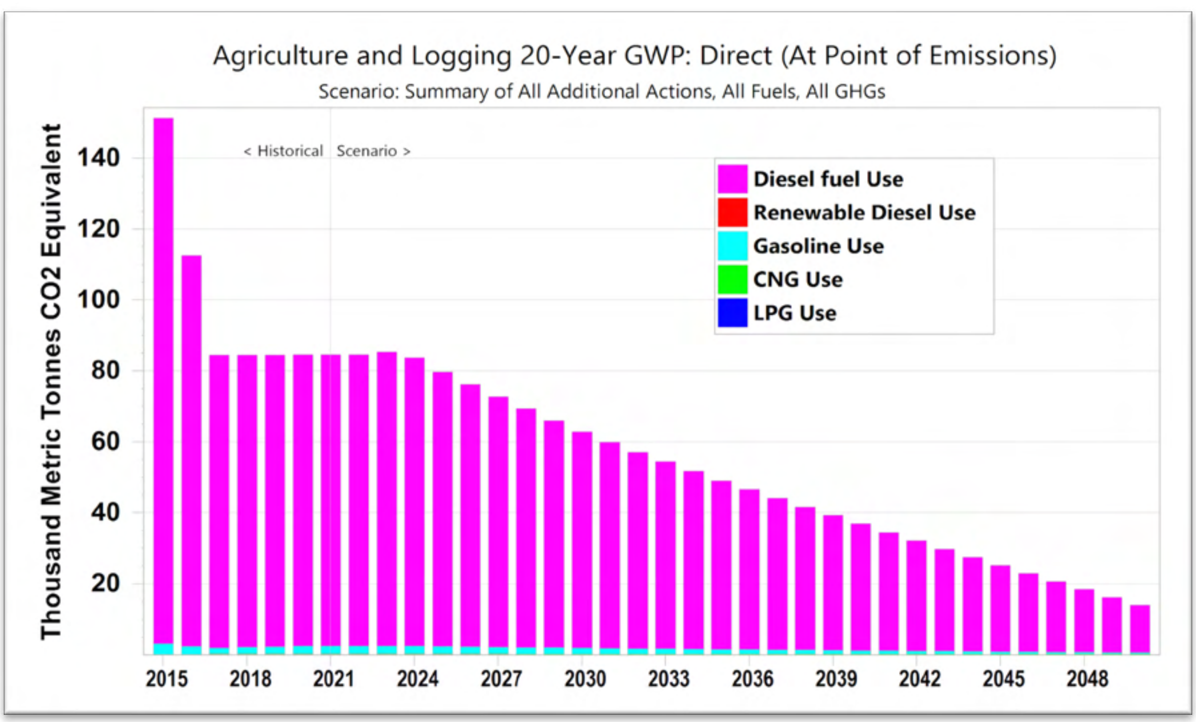


Figure 5-33: Agriculture and Logging Sector GHG Emissions, Additional Actions Case



5.3 Energy Supply

Key assumptions for the Energy Supply sector in the Additional Actions case are as follows:

- The scenario includes considerable expansion in deployment of utility (or independent power producer) solar relative to the Current Policies case and increases the pace in deployment of offshore wind generation and energy storage beyond the levels in the Current Policies case, particularly after 2031. For example, although offshore wind deployment reaches about 2.8 GW (gigawatts, or thousand megawatts) in both cases by 2031, it continues to grow to 13 GW by 2050 in the Additional Actions case, versus 3.0 GW in 2050 in the Current Policies case. Utility solar rises to nearly 6 GW by 2035 in the Additional Actions case, up from about 3 GW in the Current Policies case, and to 13.5 GW in 2050, versus 4.5 GW in 2050 in the Current Policies case.
- For modeling purposes, storage is assumed to use energy from offshore wind and utility solar for charging, and to store energy for eight hours.
- The scenario includes life extension for the two Calvert Cliffs nuclear units, which will therefore run at what is assumed to be full capacity beyond the end of the modeling period (2050).
- All fossil-fueled generation, as well as waste-to-energy plants, are taken offline by 2035 in the Additional Actions case. Sites of existing fossil-fueled generation could be used for renewable generation, energy storage, and/or transmission interties once the fossil plants are retired.
- The Additional Actions case includes considerable increases in rooftop solar (residential, commercial, industrial, and community solar) relative to the Current Policies case, through a set of assumptions including relaxed limits on deployment of net metering, improved procedures for siting and interconnection, homeowner/installer incentives, and other measures.
- Imported electricity is assumed to be effectively carbon-free by 2040, reflecting the achievement of regional goals in the PJM system through the Regional Greenhouse Gas Initiative.
- The powering of the Cove Point LNG liquefaction terminal, a major point source of GHG emissions, is assumed to be electrified in 2030, eliminating natural gas combustion in gas turbines that drive compressors for LNG liquefaction.

Key results for the Energy Supply sector in the Additional Actions case, emphasizing results in 2031 and beyond, are as follows:

- Overall emissions from energy supply fall from over 21 $MMtCO_2e$ in 2023 to less than 10 $MMtCO_2e$ by 2031, led largely by reductions in emissions from electricity generation, which in turn are due to increases in renewable generation and reduction of fossil generation (see Figure 5-34). By 2045, emissions from energy supply fall to 5.9 percent of 2023 levels, falling further to 5.4 percent of 2023 levels by 2050.
- Emissions from LNG exports are reduced to zero in 2031 because of the electrification of LNG liquefaction.[74]

[74] In practice, it is unlikely that emissions from the LNG plant will actually fall to zero—a better understanding of plant processes and fugitive emissions is required to more accurately estimate net reductions—but electrification will cause the vast majority of GHG emissions from the plant to be avoided.

- Output from rooftop solar reaches about 3.1 TWh (Terawatt-hours) by 2031 with almost 2.2 GW of generation capacity, about 5 percent of total electricity demand in that year (Figure 5-35). By 2050, rooftop solar output reaches 14.5 TWh, about 18 percent of electricity demand, from over 10 GW of capacity.
- Renewables become a much larger part of central-station generation by 2031, as coal-fired generation ends in the 2020s, and gas-fired and oil-fired generation are shut down by 2035. By 2045, renewables and nuclear are dominant, and Maryland becomes a net exporter of electricity in 2046. Some "Net Imports", meaning imports from other PJM states, are still needed, as shown in Figure 5-36, to balance load. The longer-term net result of the combination of the cases below is that almost all generation is renewable by 2045, and in-state generation is nearly sufficient to meet in-state requirements, even factoring in demand-side (and some supply-side) electrification. Figure 5-37 shows the evolution of generation capacity in the Additional Actions case. For reference, Figure 5-38 shows the differences in generation capacity between the Additional Actions and Current Policies cases.

Figure 5-34: Overall GHG Emissions from Energy Supply, Additional Actions Case

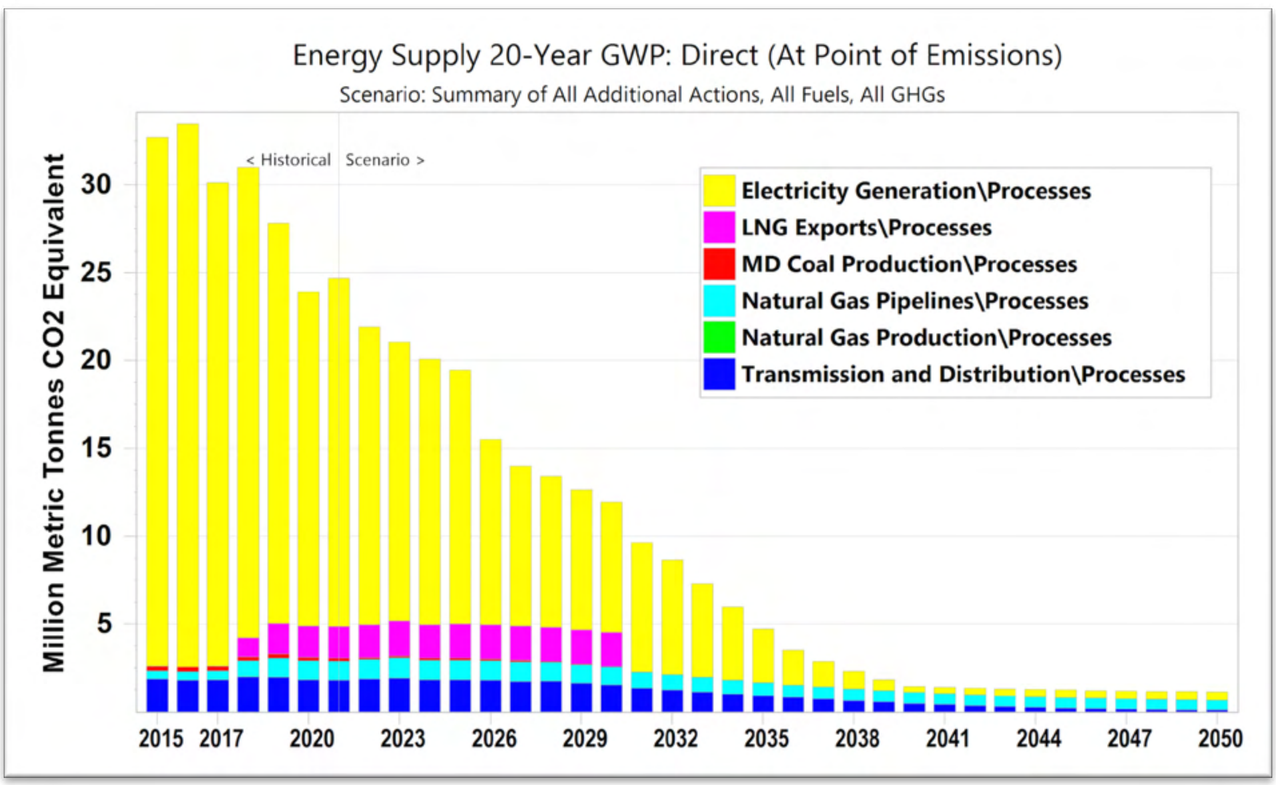


Figure 5-35: Rooftop Solar Electricity Outputs, Additional Actions Case

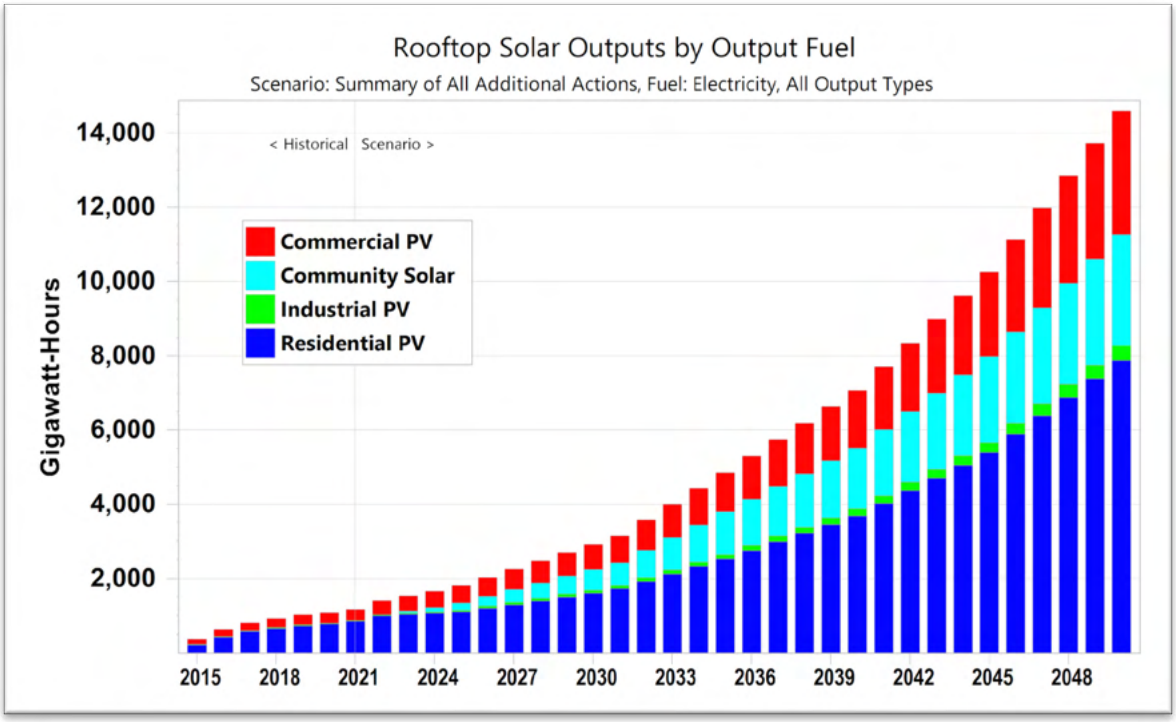
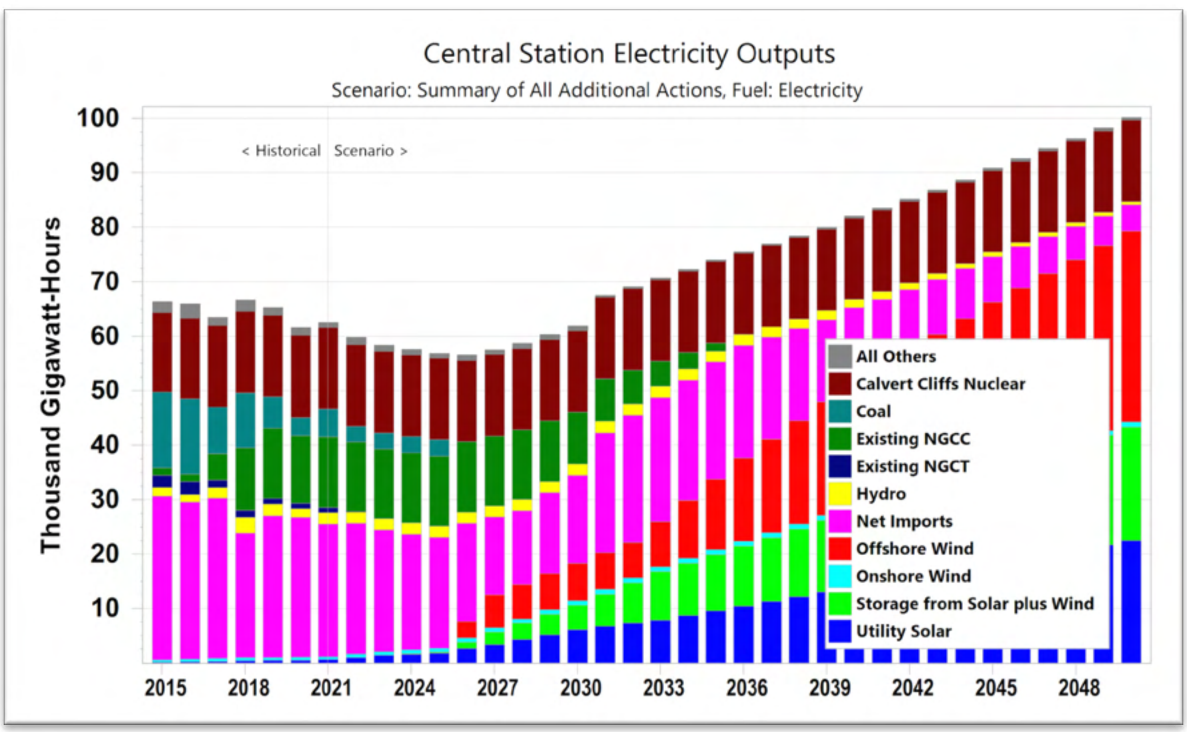


Figure 5-36: Central Station Electricity Outputs by Type of Generation, Additional Actions Case



Note: NGCC refers to natural gas combined cycle; NGCT refers to natural gas combustion turbine.

Figure 5-37: Central Station Electricity Generation Capacity, Additional Actions Case

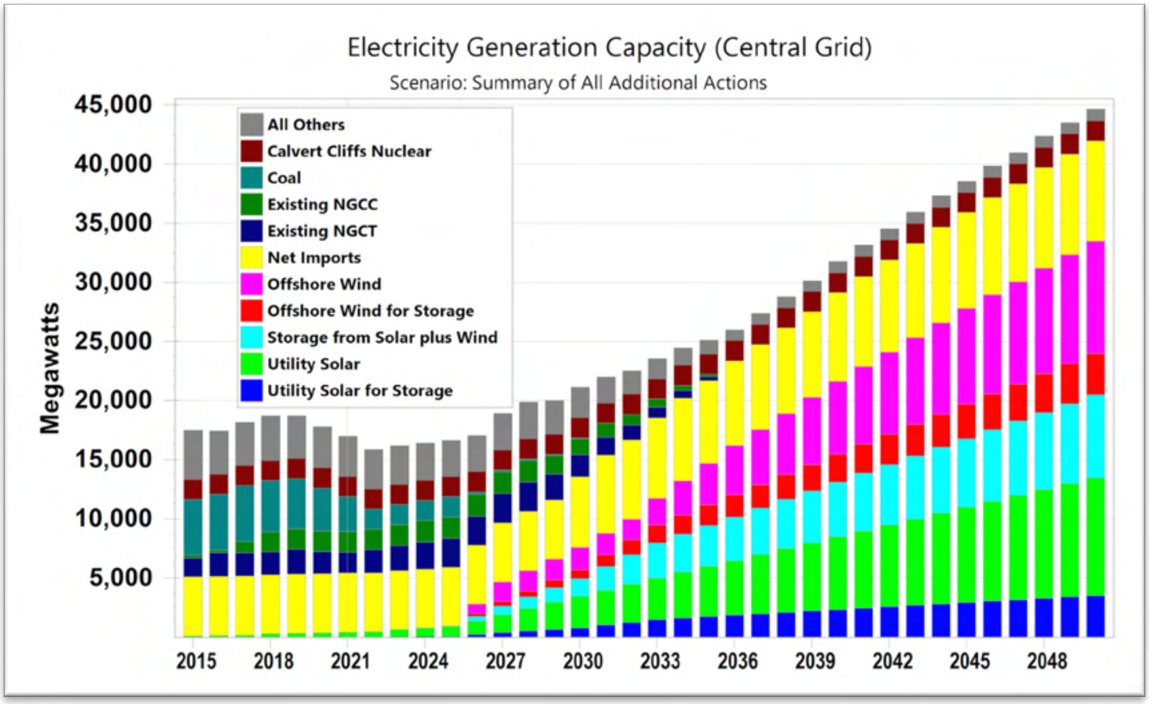
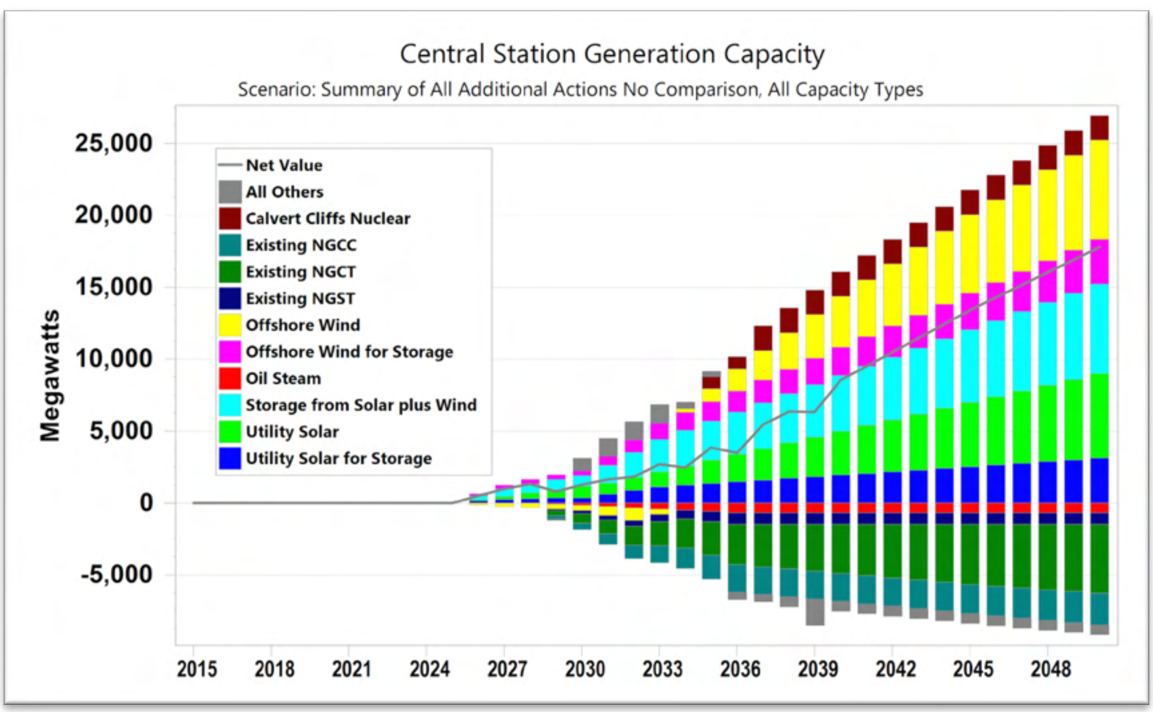


Figure 5-38: Differences in Central Station Electricity Generation Capacity, Additional Actions Case versus Current Policies Case

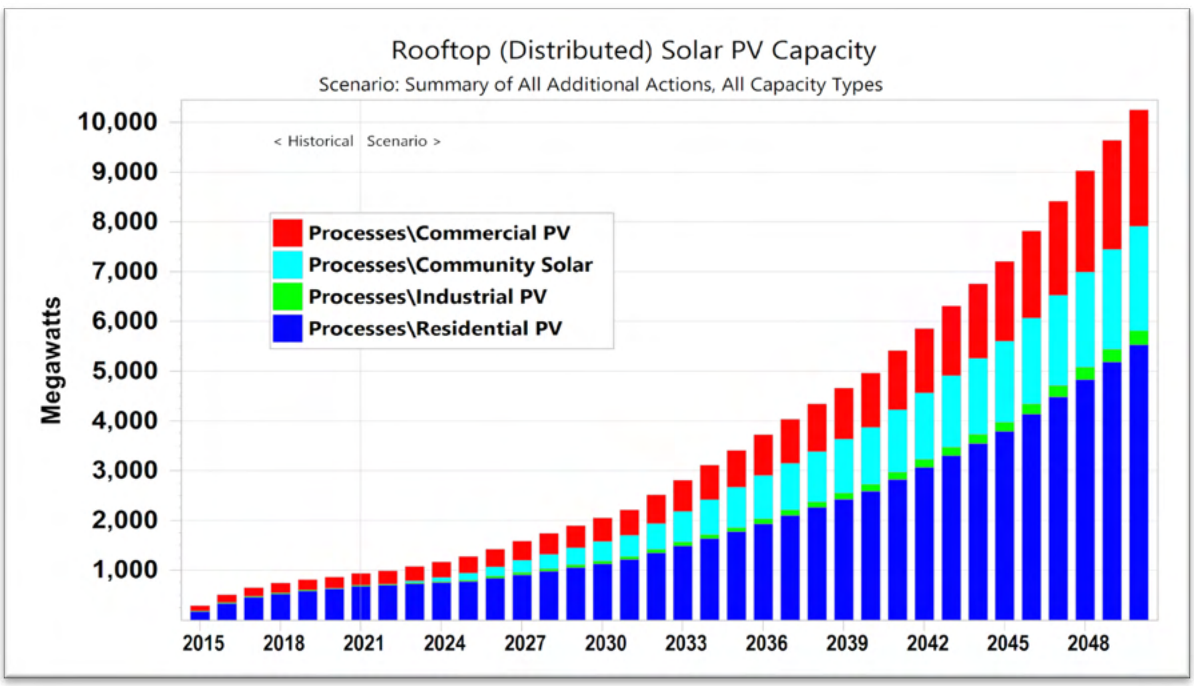


Additional details on each of the individual scenarios that sum to yield the Energy Supply actions result are provided in the subsections below.

5.3.1 Distributed Solar Generation

For the **Rooftop Solar Expansion (RSX) Scenario**, we assume that annual growth in rooftop solar after 2025 will be roughly a third higher than projected in the AEO2023 reference case over 2021-2050a, due to a combination of incentives, decreasing CAPEX for rooftop and community solar, willingness to raise net metering caps, support for siting of rooftop and community solar, and increased effort at developing the rooftop solar industry in Maryland. This results in total solar rooftop capacity (including community solar) of nearly 6000 MW by 2040, and over 10,000 MW by 2050. This case assumes that by 2050 community solar capacity is 1.5 times the 1500 MW (minus 100 MW for existing systems as of 2021) target used in the Current Policies case. These overall goals for rooftop solar imply that the state's net metering cap will need to be raised by about 2033, doubled to 6000 MW by the early 2040s, and more than tripled to over 10,000 MW by 2050. Figure 5-39 shows the trend in rooftop solar PV capacity corresponding to the Additional Actions case output trends in Figure 5-35, above.

Figure 5-39: Rooftop Solar Generation Capacity, Additional Actions Case



5.3.2 Central station generation

Several scenarios targeting GHG reductions for central station generation emissions sources are included in the Additional Actions case as follows.

The **Expanded Offshore Wind (OWX) scenario** assumes that offshore wind power development proceeds as per existing state goals, that is, rising to 8500 MW by 2040, but then continuing to rise to 11,000 MW by 2045 and 13,000 MW by 2050. Achieving these targets will depend on the offshore wind industry overcoming some of its current challenges,[75] as well as cooperation from offshore wind stakeholders. It will also likely require both the expansion of the lease areas available off the Maryland coast and a continued build-out of infrastructure for the offshore wind industry, including in Maryland and neighboring states.

For the **Utility Solar Expansion (USX)** scenario, we used a capacity additions trend which assumes the lifting of substantial restrictions on approval of proposed PJM (and local) solar interconnections such that the amount of capacity listed in the current PJM queue as "Active" (a little less than 4000 MW, including existing capacity) is deployed by 2031. This would allow annual deployment to increase linearly at about 500 MW additional MW added/year from 2025 through 2050, to over 13,000 MW by 2050.

In the **Calvert Cliffs Life Extension (NLX)** scenario, we assume that when the current operating licenses expire for both units at the Calvert Cliffs Nuclear Plant, in 2034 and 2036, they will have their lifetimes extended through at least 2050. We assume that additional CAPEX and operating costs will be required for the life-extended units. Extending the life of these units will require the agreement of the owners and operators of the plant, state agencies, the Federal Energy Regulatory Commission, the Nuclear Regulatory Commission, and likely other stakeholders. We recognize that life extension of these plants, assuming it can be done safely, will be a contentious issue for some Maryland stakeholders, but the plants constitute a large source of continuously available (if not readily load-following) power that would require many multiples of their 1,700 MW combined capacity to replace with other carbon-free electricity sources.

In the **Expanded Electricity Storage (ESX)** scenario, we assume that policies are implemented such that current state targets for storage deployment (3000 MW by 2033) are reached, and that a combination of decreasing electricity storage costs, state and federal incentives for deployment, and active assistance with siting results in a total of 7000 MW deployed by 2050. Note that this scenario also includes the assumptions of the OWX and USX cases, as renewables charging capacity is otherwise insufficient to charge as much storage as is included in the ESX scenario.

In the **Natural Gas Generation Retired (NGR)** case, we assume that natural gas-fired capacity in the state (combined cycle, steam turbine, and combustion turbine) are trended from their existing levels in the Current Policies case to zero as of 2036, starting in 2028. Oil-fired plants, which operate at very low-capacity factors even in the Recent Policies case, are assumed to be retired on the same schedule as well.

Retirement of Baltimore WTE (RWE) Assumes the state's two major Waste-to-Energy (WTE) plants, Wheelabrator Baltimore, and the Montgomery County plant, are retired at the end of 2030 from the Electricity Generation module. The heat currently provided by the Baltimore plant to the Baltimore Steam Loop will be provided by a new electric heat-pump district energy plant in the District Heat Provision module. As currently modeled in this scenario, the waste no longer used in the WTE plants is handled with a combination of landfilling and composting, with about 80 percent of landfill emissions captured and used as fuel gas for electricity generation. Note that this option also provides important air pollutant emissions reductions, including for low-income communities.

For the **RGGI Net Zero Generation by 2040 (RGZ)** case, we assume that the goal targeting zero CO_2e emissions from electricity generation is reached by the RGGI states, which covers all the states exporting power to Maryland. As a result, the emission factor for CO_2e per MWh of imported electricity falls to zero by 2040, with the phase-in period starting after 2025. Note that the emission factor trend is

[75] See, for example, Ivan Penn, Stanley Reed and Brad Plumer (2023), "What Ails Offshore Wind: Supply Chains, Ships and Interest Rates", *New York Times*, dated December 11, 2023.

entered as a “Key Assumption” in LEAP. It is possible that this scenario could be associated with an increase in import costs, although a review of the USDOE’s AEO2023 results for non-reference scenarios suggests it is not clear that a shift to renewables will actually result in higher costs. For example, in AEO2023 (the USDOE’s Annual Energy Outlook model) results, a scenario with low renewables (CAPEX) costs, but high deployment of renewables in PJM, yields lower overall generation and transmission costs in 2050 than in the Reference case. Note that because the implementation of this particular action depends on policy implementation in both Maryland and other states, it is only partially under Maryland’s control.

Two of the non-energy emissions reduction scenarios described below include an energy supply component that is modeled as the **New Biogas Capacity (NBG) scenario**. This scenario adds a total of about 24 MW of biogas and landfill gas-fired capacity in 2030, rising to about 72 MW by 2045. These plants are considered renewable generation but will add only modestly to overall renewable generation in Maryland.

The longer-term net result of the combination of the cases above is that almost all generation is renewable by 2040 and beyond, and in-state generation is sufficient to meet in-state requirements by 2046, even factoring in increased consumption from demand-side (and some supply-side) electrification. Even by 2035, only a small amount (2.9 percent) of Maryland’s in-state generation comes from fossil fuels. Therefore, in later years the fraction of Maryland’s overall electricity supply that is carbon-free is mostly dictated by the degree to which imports from PJM come from clean energy (nuclear, renewables, and a modest amount of biofuels such as landfill gas and biogas). Our assumption is that the effective CO_2e per MWh for power imported into Maryland will fall by about two-thirds in the Additional Actions case, leaving the state at above 90 percent clean energy for electricity generation in 2035.

5.3.3 Other Energy Supply

The **LNG Liquefaction Electrification (LNE) Scenario** assumes that starting in 2031 the Cove Point LNG plant will use electricity for its liquefaction train rather than burning natural gas in combustion turbines that drive compressors.

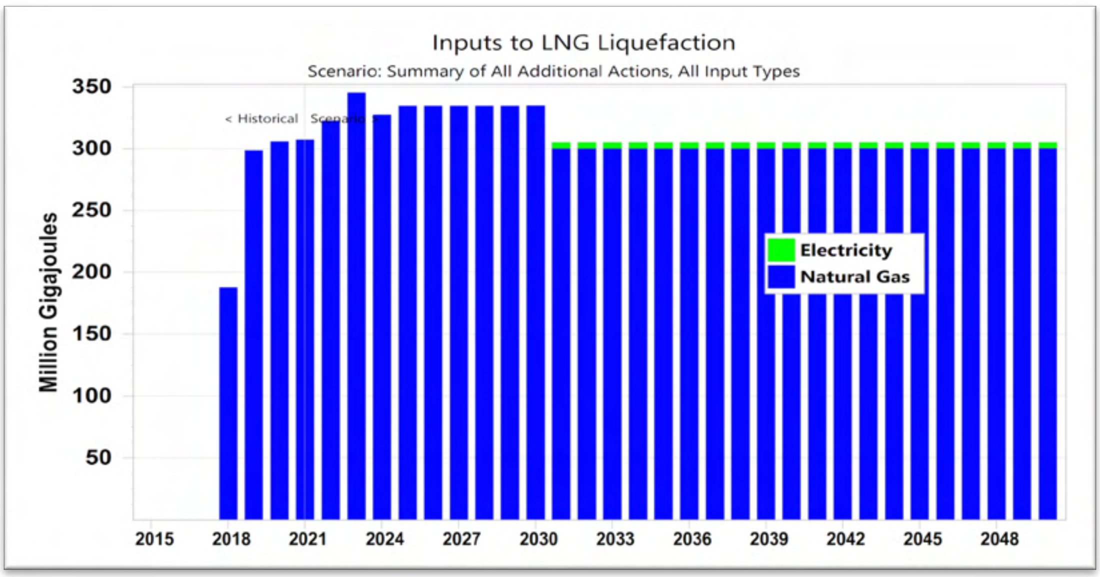
- This scenario is consistent with retiring gas-fired generation and provides significant GHG savings.
- Electrification is assumed to be implemented all at once, just before 2031, as Cove Point has just one liquefaction train. There may be ways of phasing in electrification that can be determined in discussions with Cove Point stakeholders.
- The investment costs for converting liquefaction machinery to run on electricity will be significant, on the order of $40 million, but natural gas savings (or, alternatively, additional LNG exports) will be significant, and there will also be significant offsetting O&M savings, as compressors driven by electric motors require less maintenance than gas-fired compressors.
- Electrification technologies for LNG liquefaction, based on our review of the literature, appear to be well into the commercialization stage.[76]

[76] For example, see GE Power (2022), "Reliable solutions for decarbonized LNG operations: Emission free. Efficient. Low maintenance". Another GE reference, GE Power Conversion (2022), "Freeport LNG, world largest all-electric liquefaction plant – Quintana Island, Texas, US", September 21, 2022, includes the following: "Freeport LNG, founded in 2002 and headquartered in Houston, is the world’s seventh largest LNG export company and the second largest in the United States. The company is focused on providing its customers with low carbon intensity LNG. In 2014, Freeport LNG received an authorization to construct a world-class natural gas liquefaction and liquefied natural gas export facility, designed to have a capacity to export 15.3 million metric tons per annum (MTPA), equivalent to approximately 2.2 billion standard cubic feet (Bscf) of gas per day.

- Note that our analysis to date has focused on GHG emissions from gas combustion to drive liquefaction trains. There are likely to also be fugitive emissions of natural gas (leakage of natural gas, which is mostly methane, from liquefaction equipment, gas/LNG handling equipment, and LNG storage), but we do not have estimates of these sources. Should these fugitive emissions sources prove significant on a CO_2e basis, it may be possible to design additional actions to reduce those emissions.

The result of the electrification of LNG liquefaction is a decrease in natural gas use of about 35 million GJ per year and an increase in electricity use of about 5 million GJ, or 1.33 TWh, per year, as shown in Figure 5-40. Note that the natural gas input remaining beyond 2031, about 300 million GJ, is exported at the terminal as LNG, and is consumed outside Maryland.

Figure 5-40: Inputs to LNG Liquefaction, Additional Actions Case



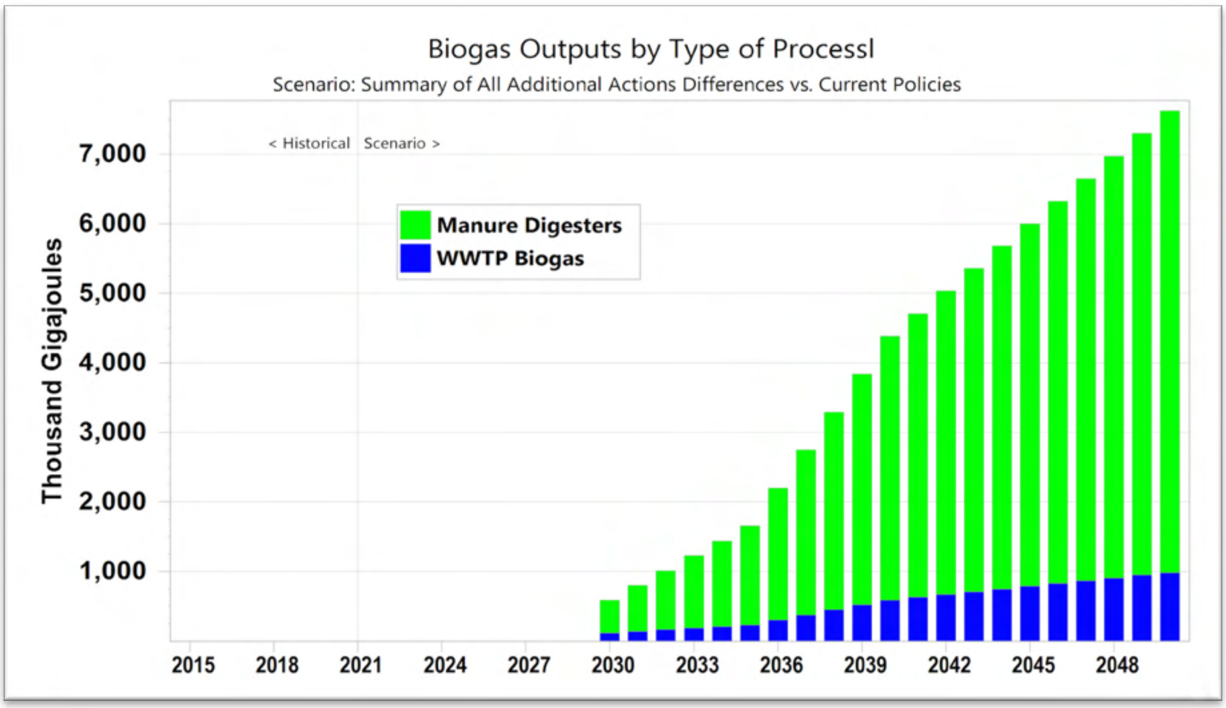
As part of this project, GE Power Conversion was awarded a contract to provide Freeport LNG with all-electric drivers for the three trains of the liquefaction facility's (LQF) refrigerant compressors. With 675 MW total electric power installed, Freeport LNG is the world's largest all-electric plant built to date." This reference lists the benefits of LNG plant electrification as follows, noting that in all cases "[d]ata may vary depending on manufacturer, site particular conditions, and market conditions":

- "Reduction of site combustion emissions by 90%, resulting in more savings on carbon taxes.
- Net production increase by over 6.5% – The use of electric power allows all the natural gas entering the facility to be turned into LNG.
- High flexibility, resulting in production increase – Thanks to a nearly constant amount of power throughout the year and fewer outage days, the eLNG plant can produce the equivalent of 10 to 15 days more of LNG per year (2.7% to 4.1 %).
- Help achieve reduced performance loss due to high temperatures – the production loss for a given installed specific power is estimated to be less than 2% of production per 5°C ambient temperature increase.
- For the Freeport LNG project, GE Power Conversion's electrical equipment is estimated to run 6 years before minor maintenance and 12 years before major one.
- Maintenance cost reduction – the maintenance of an electric system is estimated to cost approximately 30% less than for a turbine.
- Operational flexibility – Freeport LNG's concept of three motors per train also separates control of two refrigeration loop compressors from each other, which simplifies overall liquefaction operation control. The propane refrigeration compressor rotating speed can be adjusted without necessarily affecting the MR compressors, since they are not coupled to the same driver."

An additional reference is: Will Owen (2020), "The future is electric", *LNG Industry*, dated 08 July 2020 10:30.

An additional difference between the Additional Actions and Current Policies cases for other energy supply processes is that the Additional Actions case includes **Biogas Production** processes starting in 2030 to provide fuel for the biogas-fired generation described above. Biogas production from manure digesters and from wastewater treatment plants is assumed to start in 2030 and grow from about 0.6 million GJ annually in that year to 7.6 million GJ/yr by 2050, as shown in Figure 5-41.

Figure 5-41: Biogas Production, Additional Actions Case



5.4 Non-energy

The RWE case (described under section 5.3, Energy Supply, above), in which the two major waste-to-energy plants in Maryland are closed, creates the need to dispose of the municipal solid waste stream currently burned in the WtE plants. At present, in the Additional Actions case (which subsumes the RWE case) assumes those wastes will be added to Maryland landfills. In isolation, the RWE case results in an increase in emissions as the added landfill waste decomposes and increases methane emissions. However, the addition of increased composting and methane capture as described below, results in decreased emissions in the Additional Actions case relative to the Current Policies case. There is a tension between the goals of reducing emissions from WtE plants and the control of emissions from landfills. Maryland policymakers and climate planners must navigate not only the GHG emissions tradeoff, but also the local pollution impacts that disproportionately affect lower-income neighborhoods near the plants. Closing the WtE plants will require additional measures to keep GHG emissions from increasing.[77] Some of these non-energy sector additional actions (beyond the cement clinker substitution and cement carbon capture and storage scenarios described above) are described below.

Methane Capture from Landfills: Assumes that landfills in Maryland increase the rate at which methane is captured to 80% (from 75% under the Current Policies Scenario) by 2031. Also, all captured landfill gas is used for electricity generation, instead of a portion flared in the Current Policies Scenario. This adds 24 MW of additional landfill gas electricity generation capacity by 2050 over the 11.8 MW under the Current Policies Scenario.

Expanded Composting: Assumes that the state expands capacity for composting to 750,000 tons per year by 2045, and in parallel increases diversion rates, to manage the limit excess waste from the retirement of WTE generation (as described under Energy Supply above). This is an increase of more than 200,000 tons of composting capacity over the 2045 estimate in the Current Policies Scenario (estimated at 542,000 tons).

Biogas Production and Use: Assumes that capture and consumption of biogas (a mixture of methane and CO_2 produced from anaerobic waste treatment of livestock wastes and municipal wastewater) expands such that 70% percent of dairy and poultry wastes by 2045, and all municipal wastewater treated with anaerobic digestion (16.3% according to the MDE inventory), are covered by these systems. The biogas produced will be used to generate electricity for the central power grid, resulting in 46 MW of electricity generation capacity.

Enteric Methane Mitigation: Assumes that 100% of dairy and feedlot beef cattle will be given feed additives to reduce enteric methane production by 2045. The additive considered for this action is red seaweed (Asparagopsis), which has been shown to reduce emissions by 80%[78] for beef cattle and 50%[79] for dairy cattle. The additive has also been shown to reduce feed intake by cattle by as much as 14%, providing financial savings from reduced feed purchases for dairy/feedlot operators.[80]

Biofertilizer: Assumes that biofertilizer will be used on 80% of cropland currently using synthetic fertilizer by 2045. Biofertilizer products contain live microorganisms that when applied to soil, seeds, or plants improve nutrient availability and uptake, reducing the need for chemical fertilizers. The use of biofertilizer is estimated to reduce the need for synthetic nitrogen by 20%.

Soil Management Program: Assumes that conservation crop rotation and cover crop usage will be expanded to an additional 250,000 acres each by 2050.

Applying these additional actions results in total non-energy net emissions reductions shown in Figure 5-42. The non-energy actions above reduce non-energy GHG emissions and sinks to "net zero" by around 2040, at which point gross non-energy GHG emissions fall to the level of annual forest carbon sinks, just

[77] Note that our estimates of emissions from WtE plants count the biogenic (plant-derived) portion of the MSW burned in the WtE facilities as not contributing to net CO_2 emissions, but rather as a renewable fuel. The remainder of the carbon emissions are assumed to come from combustion of plastic wastes, and thus do contribute to net CO_2 emissions to the atmosphere. This approach is different than that used by MDE in its GHG inventories for the state but allows us to consistently estimate what fraction of biofuels are renewable and which are not. For biomass in general, an argument can be made that at least some biomass fuels are not produced sustainably, and result in a decrease in above- or below-ground carbon storage in plants and/or soils, but for the purposes of this report we assume that all biogenic carbon is from sustainable sources.

[78] Roque, et al. (2021). "Red seaweed (Asparagopsis taxiformis) supplementation reduces enteric methane by over 80 percent in beef steers".

[79] Roque, B. M., Salwen, J. K., Kinley, R., & Kebreab, E. (2019). Inclusion of Asparagopsis armata in lactating dairy cows' diet reduces enteric methane emission by over 50 percent. Journal of Cleaner Production, 234, 132-138.

[80] BusinessWire (2020). "Study Shows Dramatic Dual Reduction in Farmer Feed Costs and Cattle Methane Emissions Using Red Seaweed Supplement".

under eight $MMtCO_2e$. Compared with the Current Policies case, these additional non-energy actions reduce 2031 emissions by 0.85 $MMtCO_2e$, and 2050 emissions by 3.9 $MMtCO_2e$ (Figure 5-43).

Figure 5-42: Non-energy Emissions, Additional Actions Case

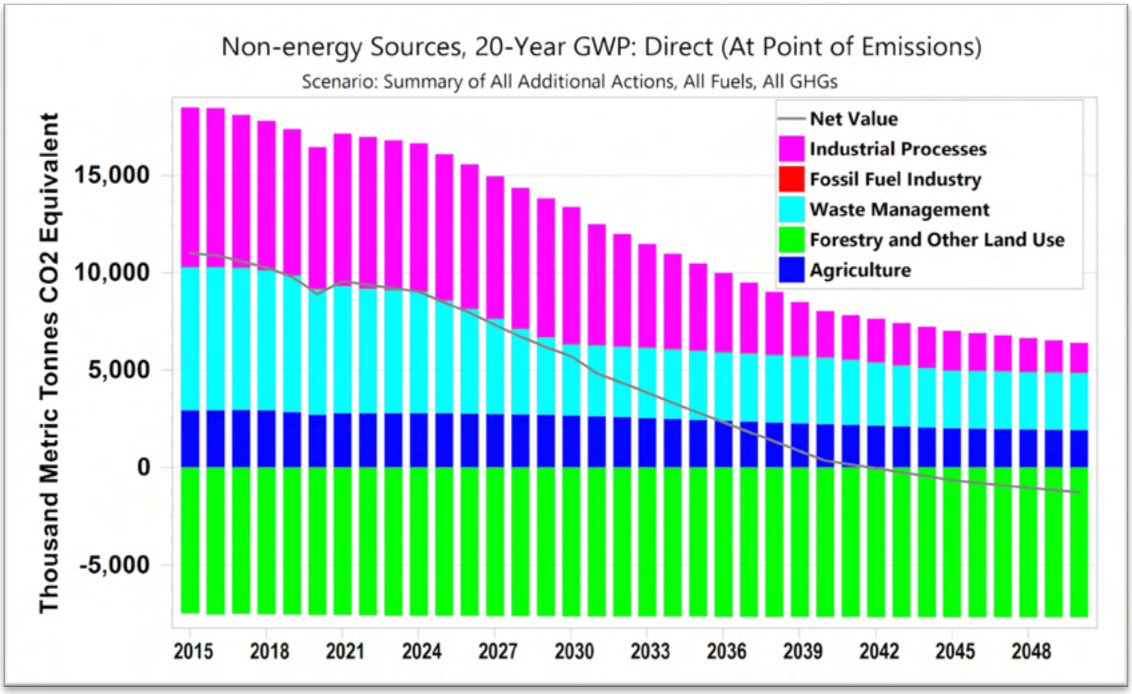
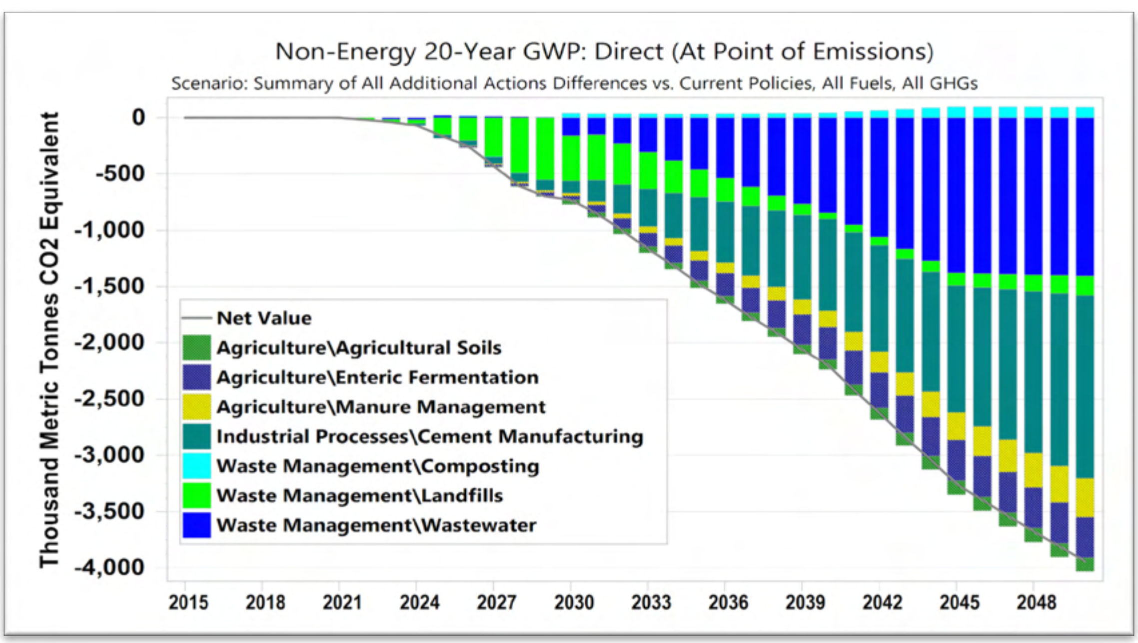


Figure 5-43: Non-energy Emissions, Additional Actions Case versus Current Policies Case



6. Potential Next Steps

The Maryland LEAP model described in this Report was built, starting with a version prepared earlier for MDE and with close involvement of a range of experts and stakeholders, for use as a tool to assist Maryland climate action planning processes. The work was intended as a first step to provide options for GHG emissions reductions in the state, and to ultimately lead to more detailed implementation planning. Potential next steps which could build on the work described here are detailed below, looking at potential further modeling, project planning and implementation elements of its climate action plan.

6.1 Elements and actions that could be added to modeling

Although CCS has worked to develop and model additional actions to reduce most major sources of GHG emissions in all sectors throughout the Maryland economy, we would certainly agree that the new actions in the Additional Actions case are far from exhaustive. The elements that follow are some of the measures that could be modeled in the future. [Additional modeling of non-energy options, modeling of sources not now in MDE inventory, such as methane emissions from the Baltimore coal transport terminal.

6.1.1 Carbon capture and storage

The modeling of carbon capture and storage in the current implementation of the Maryland LEAP model and GHG Strategy Tool is limited to adding carbon capture and storage to Maryland's two cement plants. It may be possible to model additional carbon capture and storage for other sources of fossil-based emissions, or, once technologies mature, to model the capturing of CO_2 from the air and sequestering it, creating a net carbon sink. Key unresolved issues for direct air capture include high costs, high energy use, and the long-term effectiveness of sequestration/storage. All of these are being actively researched by many groups around the world.

6.1.2 Reduction of emissions from natural gas compressor stations

Natural gas compressor stations could be electrified, just as LNG liquefaction trains are in the Additional Actions case. Although natural gas demand, as modeled, will decline to a very low level in Maryland as a result of the electrification of many residential, commercial, and industrial end-uses, overall natural gas throughput in Maryland declines only to about half 2021 levels by 2050 because natural gas still passes through to the LNG export terminal. Pipeline compressor use may decline as a function of in-state end-use demand, but as overall pipeline throughput decline is less severe, so presumably there would still be demand from pipeline compressors significant enough to warrant investigation of the prospects for electrification of compressors.

6.1.3 Methane emissions from coal storage

Methane emissions from coal mining, coal combustion, and shuttered coal mines are included in MDE's inventory of GHG emissions, as well as in the Maryland LEAP model described in this report. Not yet included in the model, however, or in MDE's inventories, is an accounting for methane emissions from coal handling and storage at power plants and industries, and at coal export facilities. Emissions from the two coal export terminals in the Port of Baltimore will be the most important sources of emissions from coal handling, given that coal use in electricity generation is waning rapidly in Maryland, and that industrial use of coal in the state is limited. Baltimore's coal exports have been increasing in recent years. 2023 will likely see exports in the range of 25 million metric tons from the two terminals, with total capacity of about 30 million short tons (or about 27 million metric tons).[81] Each of the two terminals accommodates coal storage piles on the order of 600-800 meters long and 200 meters wide, as well as rail yards for coal trains, berths for coal ships, and other coal storage and handling facilities. Figure 6-1 shows the trend in coal exports from the Port of Baltimore since 2010, and Figure 6-2 shows satellite photos of the two coal export facilities as of October 2022.[82]

Figure 6-1: Coal Exports from the Port of Baltimore since 2010

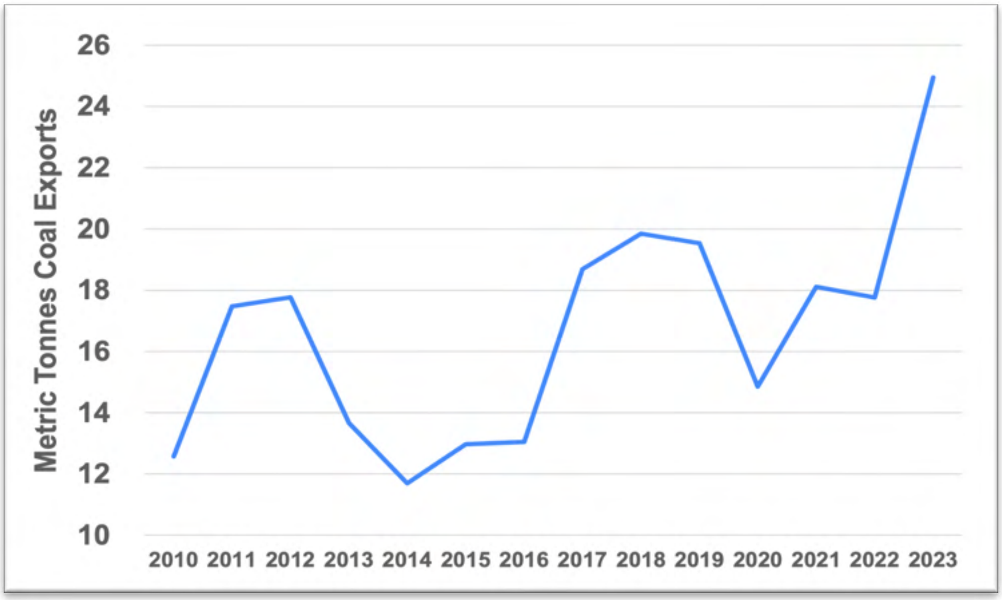
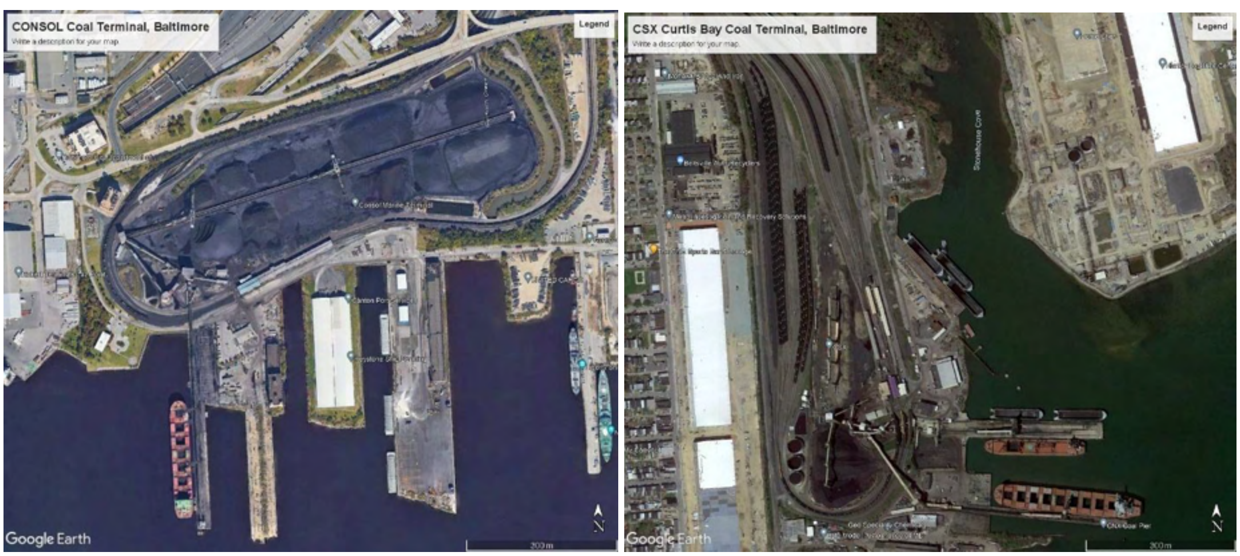


Figure 6-2: Port of Baltimore Export Terminals as of October 2022



81 Information on coal shipments from the Port of Baltimore from USDOE EIA Coal Data Browser. Capacities of coal export terminals in the Port of Baltimore are derived from websites of the companies running the terminals, namely CONSOL, "CONSOL Marine Terminals LLC -- Baltimore, Maryland", and CSX, "Curtis Bay Coal Piers in Baltimore, Md.".

82 Images downloaded from Google Earth.

Estimating emissions from coal piles and related coal handling associated with export terminals is complicated, as it ideally involves consideration of many factors, including: the types of coal being handled, the size of coal particles, the size and shape of the coal pile, how long the coal is piled at the dock, how many ship loads are processed per year, and a number of other variables in addition to the annual throughput of the terminal. Methods for estimating methane emissions from coal handling, and specifically for coal terminals, are not well described in the literature we have identified to date. An article from 2000 entitled "An Improved Inventory of Methane Emissions from Coal Mining in the United States" estimated that emissions from coal handling overall in the US in 1995 totaled 0.98 million tons of methane.[83] 1995 coal production in the United States was 1.033 billion (short) tons, based on USDOE EIA statistics, suggesting that overall methane emissions from coal handling were about 1 kg of methane per metric ton of coal mined. Applying this value to Port of Baltimore coal throughput suggests that the upper bound for methane emissions from coal terminal operations for (for example) 2023 would be about 25,000 tons of methane, which would result in emissions on the order of 2 $MMtCO_2e$, if 20-year GWPs are used. This is likely a substantial over-estimate of the methane actually emitted during coal port activities in Baltimore, particularly as the coal exported from Baltimore spends only part of the time between when it is mined and when it leaves port in Maryland. However, even if emissions from exported coal within Maryland were an order of magnitude lower than the estimate, they would still be in the low hundreds of thousands of metric tons of CO_2e, which is significant relative to statewide emissions and emissions reduction goals, and thus bears future investigation.

6.1.4 Additional modeling of non-energy emissions abatement actions

There may be additional options for reduction of emissions or enhancement of carbon sinks in the non-energy sectors. Options include reduction of emissions from mineral soils, including those related to nitrogen fertilizer application; enhancement of forest carbon stocks in aboveground or below-ground biomass; and the production of biochar for use in carbon sequestration. The challenge in compiling a representative model of the costs and benefits of these options will hinge on determining which actions are applicable to Maryland, and finding reasonable estimates of how much emissions savings are possible per unit of activity (for example, per unit of land area) and how much the actions are likely to cost.

6.1.5 Modeling of the hosting of energy supply facilities at sites of shuttered power plants

Many existing or recently shuttered coal-fired power plants, as well as gas-fired facilities and, at some point, the Calvert Cliffs nuclear site, offer advantages for siting of renewable generation facilities (such as solar PV), energy storage, and/or transmission links to, for example, offshore wind farms. Modeling of specific transmission linkages is, as noted below, likely beyond what can be done conveniently in LEAP. However, it is well established that using these sites may affect the costs of implementing some renewable energy. In addition, some of the existing infrastructure at these sites, such as boilers at coal-fired power plants, could be retrofitted, for example, for thermal storage using technologies that are under development.

6.1.6 Additional detail throughout the model

LEAP allows the user to add essentially as much detail as needed to describe a given energy system. As such, it is possible, for example, to add different types of appliances and vehicles with different fuels, efficiencies, or other parameters, to consider different types of housing separately, or to be specific about the location of energy supply facilities. Decisions to add detail to the model, however, should be

[83] David A. Kirchgessner, Stephen D. Piccot, and Sushma S. Masemore (2000), "An Improved Inventory of Methane Emissions from Coal Mining in the United States", *Journal of the Air & Waste Management Association*, 50:11, 1904-1919.

informed by consideration of whether reliable data are available to derive modeling parameters, such as per-unit energy use and costs, and the extent to which additional detail is useful in the analysis of the policies that are to be evaluated.

6.2 Elements that could be refined in modeling

Any analytical model can be improved, given additional modeling resources and data obtained via research and/or consultation, and the Maryland LEAP dataset is no exception. Some of the elements of the model that could be refined are identified below.

6.2.1 Electricity Transmission Modeling

Although the Maryland LEAP model incorporates consideration of the timing of electricity generation and demand in modeling the electricity sector, our scenarios thus far have addressed the modeling of electricity transmission only to the extent of including significant electricity storage along with renewable generation, and in roughly estimating the cost of transmission improvements needed to support a mostly-renewables grid.[84] LEAP does have some capabilities for more detailed modeling of electricity transmission, but ideally climate action planning in Maryland should integrate detailed consideration of transmission planning with its emissions reduction actions. The state could use modeling similar to the type used by utilities and PJM, since there are many potential options for transmission upgrades (including avoided upgrades by emphasizing distributed power and storage) at many different costs. An example of this need is shown by objections by Maryland officials, including the Public Service Commission, to a recent PJM transmission plan, in which Maryland officials, in part, criticized PJM for not looking harder at other alternatives to its plan.[85] Thus, a key task for the future is to engage transmission planners, renewable generation stakeholders, and others to determine transmission project costs and alternatives as climate action planning in Maryland moves forward.

6.2.2 Improvement of cost estimates

Many of the cost estimates used to characterize the additional actions modeled have been, of necessity, derived from generic costs in the literature, or estimated roughly based on similar investments elsewhere. For costs that have a significant bearing on the overall investments required to make GHG emissions reduction actions reality, it may be useful to research Maryland-specific costs in more detail and solicit the input of local experts and other stakeholders.

6.2.3 Coordination with transportation modeling

There are several elements of the additional actions included in the existing Maryland LEAP model that would benefit from coordination and interaction with transportation modelers working in the state. To model the impacts and costs of transportation options more accurately for reducing GHG emissions, it may be useful to utilize Maryland transportation and traffic models. For example, they could be used to model how VMT reduction strategies would really affect the number of miles driven in light-duty

[84] As described in Appendix section 7.2, we are using an assumption of costing for additional needed transmission based on an estimate (with a very broad range) from an LBNL study, and keyed to the relative increase in renewable generation in the scenarios. Costs are based on the article/report "Improving estimates of transmission capital costs for utility-scale wind and solar projects to inform renewable energy policy", by Will Gorman, Andrew Mills, Ryan Wiser of Lawrence Berkeley National Laboratory, published in *Energy Policy*, Volume 135, December 2019, 110994.(preprint version). The LBNL study concludes "The average VRE LCOT range estimated in this study, $1–$10/MWh, represents a substantial expense in relation to the LCOEs of utility-scale wind ($29–$56/MWh) and solar ($36–$46/MWh)." We use $5/MWh as a starting assumption within this broad range, and convert it to cost per kW added.
[85] See, for example, Sean Wolfe (2023), "FERC approves PJM's $796M transmission plan, thwarting Maryland officials", *Power Grid International*, dated 11-13-2023.

vehicles, or how moving toward denser settlement patterns might affect the need for motorized transportation.

6.2.4 Refinement of costs of industrial emissions reduction actions

Specifically for certain industrial or energy supply actions, such as the application of electrification to the cement industry, the production of biogas, or the electrification of LNG liquefaction, it would be useful to be able to work with industrial stakeholders or other experts in the field (particularly where concerns about confidential commercial information are an issue) to better estimate the potential for and costs of emissions reduction in key industrial facilities in Maryland.

6.2.5 Refinement of load curves

The current LEAP model adapts an hourly weekend/weekday and seasonal set of load curves from the previous LEAP model. This might be improved through use of Maryland or PJM East load data from recent years, and by considering trends related to changes in technology over time that might shift load curves.

6.3 Sensitivity analyses

The structure of the Maryland LEAP dataset makes it possible to run a number of different sensitivity analyses to test the impacts of different assumptions on emissions reduction and/or net social costs and investment costs. Some that might be of interest include:

- Modeling the impact of changes in the capital costs of key types of renewable generation.
- Modeling the impact of changes in fuel prices (for example, motor fuels, natural gas, electricity imports/exports, or nuclear fuels).
- Testing different levels of penetration of devices in different sectors or changing the timing of implementation of actions.
- Testing the impacts of different device efficiencies on costs and benefits.
- Testing aggregate Additional Actions cases that include new actions, change the selection of actions included, or modify existing actions to test the impacts of those changes on overall social costs and on emissions reduction, and thus on action cost-effectiveness. In some cases, particularly where a scenario focuses on a specific sector or even facility, including or excluding the action modeled in the scenario will be straightforward. In other cases, adjusting the modeling will require more care, as when a change in one part of the model affects emissions or costs elsewhere. VMT reduction is a specific example, here, as the emissions and costs impacts of VMT reduction depend on which modes of transport must increase activity in order to carry more passengers, at what time light duty vehicle use is decreased in the cycle of vehicle electrification, which energy resources (diesel, gasoline, or electricity) are used more or less as a result of the policy, and the degree to which electric vehicles added and displaced are using electricity from carbon-free resources.

6.4 Additional work with stakeholders on the statewide model and measurement system

Whether adding new actions to the model, refining existing actions, or deciding upon and implementing sensitivity analyses, CCS is open and willing to work with Maryland stakeholders to help refine the model and to test new or modified actions.

6.5 Focus on modeling of specific actions to provide inputs to financial analysis for action planning

The goal of any future-oriented emissions modeling effort is to assist in framing and deploying policies, regulations, incentives, and other changes which bring about reductions in GHG emissions. As such, CCS hopes to be able to work with agencies and stakeholders tasked with implementing emissions reduction policies in Maryland to prioritize, develop, and implement plans for funding and carrying out climate policies.

Results from the modeling effort described in this Report can be used as a starting point for estimating the total investment funds required for a given policy at a given level of effort and quantifying the potential benefits of the policy. These results can inform the process of evaluating what types of funding sources are available and applicable to a policy, how financial flows of funds, including both outlays and financial benefits, might be distributed among project and program participants, and what inputs might be needed from state and federal agencies to make a project/program viable. In addition to facilitating the matching of sources and uses, the modeling effort supports translation of investment requirements for each action to tailored mechanisms and partnerships.

The results of this modelling are crucial in providing both the overall statewide context and costs and performance information as a starting point for the financial planning needed to make emissions reduction projects reality. However, the tools used in this study are in general not sufficient for the types of customized financial analyses needed for detailed development and implementation of GHG emissions reduction projects and programs. Put another way, the LEAP modeling is designed to compute the total net cost to the state as a whole (not just the government, but everyone) of purchasing, installing, and operating the different types of devices/vehicles/equipment/systems that will be needed to reduce emissions. As such, the modeling reported on here does not try to assign specific costs of specific actions to different stakeholders. Doing so would require designing in detail the policies to be implemented, which involves balanced consideration of stakeholder needs to make the program economically or otherwise attractive to all involved. The LEAP model and GHG Strategy Tool provide platforms for translating the financing needs analysis to the next level using more specific tools, such as developing financial spreadsheet analyses that are linked to the LEAP model and GHG Strategy Tool.

Once the overall totals for costs, such as those presented in this report, have been estimated, it is possible to start conversations with stakeholders as to how to make the investments needed. The balance among which stakeholders will make the investments varies by action. For example, for LNG terminal electrification, the entire investment would presumably be from the company operating the terminal, although that company might require some input from the state (in the form of financial and information resources, encouragement, or threat of action, for example) to make the project worthwhile. For residential and commercial electrification, some of the cost will be borne by homeowners and business owners, but some might come from State or utility rebates, or low-interest loans. For a huge expansion of bus and passenger train fleets, much or all of the investment will come from public agencies (state, federal, and/or local), likely in the form of bonds paid off in part by passenger fares. Rooted in this modeling analysis, work between agencies and stakeholders to design detailed actions and beneficial financial flows are some of the next steps to follow this Report.

7. Conclusions

7.1 Potential for MD to reach its climate goals

The modeling assessment of GHG emissions reductions suggests that without additional mitigation of emissions beyond Current Policies, Maryland will be well short of reaching its goal of reducing emissions 60 percent by 2031 from 2006 levels. Likewise, under current policies, Maryland will be well short of its goal of reaching net zero GHG emissions by 2045 (or 2050). Working with Maryland stakeholders and adapting/adopting ideas for further emissions reduction from other studies in Maryland and other jurisdictions, CCS used the LEAP and GHG Strategy Tool frameworks to assemble and model estimates of the benefits and costs resulting from a set of additional GHG emissions reduction actions.

Based on this, the composite Additional Actions case still would not quite meet the state's 60-percent-by-2031 goal but would achieve the 60 percent reduction goal by 2033. Similarly, although the Additional Actions case falls short of achieving net zero emissions by the end of the modeling period, it comes close, with Maryland's gross GHG emissions falling from 87 $MMtCO_2e$ in 2023 to under 15 $MMtCO_2e$ by 2050, yielding net emissions of about 7 $MMtCO_2e$ by 2050, after subtracting carbon sinks provided by forests, soils, and landfills.

Although these Additional Actions do not bring Maryland all the way to achievement of its GHG emissions reduction goals as laid out in current targets, they do, in our estimates, achieve much of what Maryland has set out to do. For the short-term goal—60 percent reduction in gross GHG emissions by 2031— it seems unlikely that emissions can be pushed down that far that fast. Coming up short of that goal, even if additional and aggressive actions are initiated in the next few years, seems likely not for lack of good intentions, but because the logistical difficulties. For example, even if the electricity sector could quickly be converted to renewable energy, substantially changing out buildings sector appliances and equipment, updating the buildings themselves, and changing out millions of vehicles, is extremely difficult to accomplish within seven years for a single state embedded in a national economy.

Accomplishing the transition required by Maryland's climate goals and aligned with the Additional Actions case will require the mobilization of funds, technology, and human capacity—including training people to work in an expanded set of clean energy occupations. In our view, this transition will simply take more time to organize and implement than Maryland has between now and 2031. That said, the benefits of making many of the changes consistent with the Additional Actions case are too significant to ignore, including both climate benefits and other accompanying benefits. Maryland should continue pushing forward the transitions required to meet its existing climate goals.

To achieve the additional GHG emissions reductions resulting from the Additional Actions case, tens of billions of dollars in investments will be required over the coming decades. But these actions would also avoid considerable outlays by Maryland consumers for fossil fuels, equal to about two thirds of all investment, and would have crucial ancillary benefits such as reductions in local air pollution and job creation in clean energy industries. These potentially large outlays notwithstanding, the overall net social costs of moving from the Current Policies case to the Additional Actions case are largely offset if a social cost of carbon in the range of \$50 per tCO_2e is included in the analysis, and are much more than offset if an SCC is set in the range of \$200 per tCO_2e, as has recently been proposed by the USEPA and others.

7.2 Key considerations in achieving GHG goals

Implementing both current policies and additional actions beyond current policies will require cooperation and, in some cases, compromise across stakeholders, Maryland agencies, jurisdictions within Maryland, and with other states and the Federal government. Below are some key considerations that will help make implementing GHG emissions reduction actions in Maryland a reality:

- Maintaining and building upon consistent climate change mitigation and related policies and funding on a statewide level, even as administrations change.
- Maintaining or expanding consistent climate change mitigation and related policies and funding on the federal level, especially as administrations change.
- Undertaking timely and informed discussions with stakeholders when designing and implementing GHG emissions reduction actions.
- Undertaking timely conversations and reaching agreements with stakeholder organizations that might end up harmed by emissions reduction actions. Natural gas utilities, vendors of fossil fuels, and those who sell and maintain internal combustion vehicles and equipment are key examples here, but there will likely be other stakeholders specific to some actions who will need to be negotiated with and, if possible, "made whole" to enable efficient deployment of climate mitigation actions.
- Working with vendors and installers of clean energy devices and equipment to make sure that economic incentives are in place (and barriers lowered) to enable the deployment of those devices as rapidly and affordably as possible.
- Reducing local, state, and federal level administrative and siting barriers to deployment of renewable energy systems, including providing incentives for those reluctant to host renewable energy systems to do so.
- Where needed, develop regulations, enforcement methods for regulations, and regulatory workforces sufficient to ensure that climate targets are met, and regulations are enforced. Examples might include assuring that electric vehicle sales meet targets (as fractions of overall sales) in the state, that buildings and energy systems within them meet or exceed standards, and that natural gas pipelines perform as required in terms of avoiding leakage.
- Developing and deploying training programs for clean energy equipment and system installers and recruiting workers to fill key positions—ranging from solar PV installers to planners in state agencies—to drive the transitions implied in the Additional Actions case.

7.3 Unknowns/uncertainties associated with current policies and additional actions

The results described in this report projecting the degree to which GHG emissions reduction actions might meet their targets are estimates, as is true of any analysis looking many years into the future. Some of the unknowns and uncertainties associated with these estimates include (but are certainly not limited to):

- Will the devices and equipment needed be ready at sufficient scale in the marketplace to be installed to meet climate goals?

- Relatedly, can markets for appliances, vehicles, and equipment be transformed fast enough to meet climate goals, and will the new electric products in the marketplace prove acceptable to consumers?
- How will changes in energy markets, many of which are affected by forces far outside Maryland's control, affect the economics of clean energy deployment? Note that changes in energy markets could either enhance or reduce the cost-effectiveness of clean energy investments.
- Will there be technological breakthroughs that make climate change mitigation goals easier to achieve?
- Will changes in governance at the state or federal level make achieving climate goals in Maryland easier or more difficult from, for example, legal and/or funding perspectives?
- Will the owners of major GHG emitting industries be willing to make changes to markedly reduce emissions, and if not, what inducements will make them willing to do so?
- Specifically, will a second life extension of the Calvert Cliffs nuclear units be applied for and permitted?

7.4 Beyond the Additional Actions case

There are sectors where additional reductions GHG emissions beyond the Additional Actions case are possible by 2031. Implementation may, in many cases, be limited by the logistical difficulties associated with agreeing upon, funding, mounting, and staffing aggressive programs in time to achieve the 2031 goal. This does not mean these programs cannot be implemented or should not be implemented, but it will be challenging for such programs to be mounted in time to meet the 2031 goal. Examples of potential further actions include very extensive deployment of building energy efficiency and electrification in low-income and other homes, implementing additional electrification in the transportation fleet by actively retiring internal combustion vehicles or repowering existing vehicles with battery electric systems, and much more stringent control of methane emissions from waste management and fossil fuel infrastructure.

For some energy end uses, such as aviation, international marine shipping, and, to a lesser extent, rail freight, it will be difficult for Maryland to make inroads on emissions reduction without more aggressive regional and/or national and/or international efforts to "decarbonize" those sectors. Efforts in these areas are certainly possible (for example, significant measures, based on national goals, are modeled in the Additional Actions case for the aviation sector), and Maryland could provide a key voice to help spur timely programs in those sectors. However, this study did not assess the difficulty, cost, or benefits of implementing these further actions.

Looking at implementation beyond 2031, there will likely be additional options for increased actions beyond those included in the Additional Actions case. Looking at recently available technologies and those under development, an even more complete and/or earlier transition to electrification throughout the economy is possible. There may be opportunities for increased and sooner deployment of renewable generation and electricity storage, building efficiency retrofits in the residential and commercial sectors may be more aggressive than anticipated, and carbon dioxide capture and storage/sequestration may have potential beyond the cement sector (only the cement sector is considered in the Additional Actions).

Many of these actions can help to address other significant social and environmental issues, including poverty and local air pollution/health challenges, as they contribute to GHG emissions reduction. It is inevitable that unexpected technological advances—such as the ability to wrap vehicles and buildings in solar PV films, battery cost or energy density improvements, or cost-effective carbon capture and storage—will aid in meeting climate change mitigation goals, albeit with unpredictable timing and effect. Therefore, it is crucial for Maryland to move forward to address its GHG emissions reduction goals in a way that is expeditious, flexible, makes use of city, county, state, federal, and private financial and other resources available, and involves key stakeholders, to both secure broad input on the implementation of actions and reduce potential for conflicts as actions are implemented.