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MARYLAND'S CLIMATE PATHWAY

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

Target

How Maryland can meet its climate goals of 60% reduction of GHG emissions by 2031 and attain a net-zero economy by 2045

Future

The benefits of this pathway extend beyond emissions reductions to improved air quality, job creation, cost-savings, and more

Global

By achieving Maryland's climate targets the State can set a national and global example for how a state can go all-in on climate action

University of Maryland School of Public Policy Center for Global Sustainability

Maryland Department of the Environment

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MARYLAND'S CLIMATE PATHWAY

AN ANALYSIS OF ACTIONS THE STATE CAN TAKE TO ACHIEVE MARYLAND'S NATION-LEADING GREENHOUSE GAS EMISSIONS REDUCTION GOALS

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

Affiliations:

Center for Global Sustainability, University of Maryland, College Park

Kathleen M. Kennedy

Alicia Zhao

Steven J. Smith

Kowan O'Keefe

Bradley Phelps

Shannon Kennedy

Ryna Cui

Camryn Dahl

Sarah Dodds

Shawn Edelstein

Eshna Ghosh

Yang Ou

Aishwary Trivedi

Jared Williams

Nathan Hultman

Regional Economic Studies Institute, Towson University

Shelby Francis

Daraius Irani

Ruisha Praisa

Amber Taylor

Nicholas Wetzler

Department of Geographical Sciences, University of Maryland, College Park

George Hurtt

Lei Ma

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Maryland
Department of
the Environment

Wes Moore, Governor
Aruna Miller, Lt. Governor

Serena McIlwain, Secretary
Suzanne E. Dorsey, Deputy Secretary

Foreword by Secretary Serena McIlwain

On behalf of the Maryland Department of the Environment (MDE), I am honored to present *Maryland's Climate Pathway* report. This report provides a comprehensive and ground-breaking analysis of Maryland's opportunity to address climate change while building a new, green economy. MDE and our sister agencies are hard at work implementing policies to meet Maryland's nation-leading climate goals and achieve environmental justice for all Marylanders. Please join us in this work with your feedback and support.

Maryland is already a leader in addressing climate change. We have reduced climate pollution faster than almost any other state. Our climate change law has the country's most ambitious reduction goals. We are requiring manufacturers to offer more zero-emission cars and trucks. We are providing incentives for individuals and businesses to purchase zero-emission vehicles and charging equipment. We are developing regulations to guide large buildings to improved energy efficiency and large landfills to reduced methane emissions. We are doing a lot. It's time to do even more.

MDE partnered with our state's leading scientists at the University of Maryland's Center for Global Sustainability (CGS) to develop this report and identify a pathway to achieve Maryland's ambitious climate goals. CGS's analysis found that Maryland <u>can</u> achieve its climate goals while creating net economic benefits and job growth. CGS's analysis shows that Maryland will enjoy hundreds of millions of dollars in economic and public health benefits while creating thousands of new jobs as we accelerate our transition to a clean energy economy. This report lays a foundation for a just and equitable climate response that will help build greener, healthier communities across the state.

We welcome your input on *Maryland's Climate Pathway* report. MDE will host listening sessions during the summer to inform our thinking and next steps to confront the climate crisis. In December, based on your feedback, we will publish a final plan to reduce climate pollution 60% by 2031.

Addressing climate change is the defining environmental challenge of our time. Together, we are meeting this challenge every day, with so much work already underway and more to come.

Serena McIlwain
Secretary
Maryland Department of the Environment

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LIST OF ACRONYMS AND ABBREVIATIONS

ACC	Advanced Clean Cars
ACT	Advanced Clean Trucks
AMI	Advanced Metering Infrastructure
ATP	Active Transportation Program
BEPS	Building Energy Performance Standards
BIL	Bipartisan Infrastructure Law
CAFE	Corporate Average Fuel Economy
CCS	Carbon Capture and Sequestration/Storage
CDR	Carbon Dioxide Removal
CES	Clean Electricity Standard
CGS	Center for Global Sustainability
COBRA	Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool
CORE	Clean Off-Road Equipment Voucher Incentive Program
CO_2	Carbon Dioxide
CPCN	Certificate of Public Convenience and Necessity
CSD	California Department of Community Services and Development
CSNA	Climate Solutions Now Act
CSP	Conservation Stewardship Program
DHCD	Maryland Department of Housing and Community Development
EIMA	Energy Infrastructure Modernization Act
EOR	Enhanced Oil Recovery
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
EUI	Energy Use Intensity
EV	Electric Vehicle
GCAM	Global Change Analysis Model
GDP	Gross Domestic Product
GGRA	Greenhouse Gas Reduction Act
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Emissions Reporting Program
GPI	Genuine Progress Indicator
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HVAC	Heating, Ventilation, and Air Conditioning
ICE	Internal Combustion Engine

IPPU	Industrial Processes and Product Use
IRA	Inflation Reduction Act
ISEW	Index of Sustainable Economic Welfare
ITC	Investment Tax Credit
IUI	Inclusive Utility Investment
kWh	Kilo-Watt Hour
LIEEP	Limited Income Energy Efficiency Program
LMI	Low and Moderate Income
MAC	Marginal Abatement Cost
MCPS	Montgomery County Public Schools
MDE	Maryland Department of the Environment
MDOT	Maryland Department of Transportation
MEA	Maryland Energy Administration
MEW	Measured Economic Welfare
MMTCO2e	Million Metric Tons of Carbon Dioxide Equivalent
MSRP	Manufacturer's Suggested Retail Price
NHTSA	National Highway Traffic Safety Administration
NO_2	Nitrogen Dioxide
OCED	Office of Clean Energy Demonstrations, U.S. Department of Energy
ODS	Ozone-Depleting Substances
OPC	Ordinary Portland Cement
PAYS®	Pay As You Save
PLC	Portland Limestone Cement
PM2.5	Particulate Matter 2.5 microns in diameter and smaller
PSC	Maryland Public Service Commission
PTC	Production Tax Credit
PV	Photovoltaic
REC	Renewable Energy Certificates
REMI PI+	Regional Economic Models, Inc. PI+
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standard
SEIF	Strategic Energy Investment Fund
SF_6	Sulfur Hexafluoride
SNAP	Significant New Alternatives Policy
SLCP	Short-lived Climate Pollutants
TPB	Transportation Planning Board
TPE	TurningPoint Energy

TTF	Transportation Trust Fund
VMT	Vehicle Miles Traveled
V2G	Vehicle-to-Grid
ZEV	Zero-Emission Vehicle

EXECUTIVE SUMMARY

KEY FINDINGS:

- The *Maryland's Climate Pathway* report demonstrates how Maryland can meet its ambitious climate goals of 60% reduction of greenhouse gas emissions by 2031 relative to 2006 levels, and attain a net-zero economy by 2045, all while realizing health and economic benefits for Marylanders, including improved air quality, new jobs, and household cost savings.
- Maryland can do this through the coordinated implementation of current and new policies across each sector of the economy, combined with a strong federal partnership and a broader all-of-society approach that integrates actions from cities, counties, local jurisdictions, business and industry leaders, community organizations, and more.
- The first step is fully implementing the policies already in place in Maryland. As of 2020, Maryland had already achieved half of the reductions needed—36.7 MMTCO2e of the 73.3 MMTCO2e to meet the 2031 target. Full implementation of existing policies can achieve another 26.0 MMTCO2e by 2031, leaving one fifth of the reductions left—a gap of 10.6 MMTCO2e that must be filled by new policy action.
- This analysis offers a pathway to success to fill this gap and achieve the economy-wide 60% goal, illustrating potential actions across all sectors with additional reductions, including 3.6 MMTCO2e from transportation, 2.3 MMTCO2e from electricity generation, and 1.6 MMTCO2e from buildings.
- Additional policies from the agriculture, waste, and industrial sectors, including critical reductions in methane, are needed to achieve the 2031 target and support broad economic, social, and environmental benefits for Marylanders. Taking these steps now to achieve the 2031 goals will also place Maryland on a pathway toward its 2045 goal of net-zero emissions.
- At its full potential, this pathway delivers substantial health, employment, and economic benefits to Maryland's people and further bolsters the leadership and ability of the State's economy to be globally competitive. New policy action will deliver even more health benefits through improved air quality and reduced respiratory ailments, especially for vulnerable populations—the equivalent of $1.09-$2.44 billion in health benefits by 2031. These benefits extend to the economy with the projected cumulative creation of more than 16,000 new jobs and increased personal income by nearly $1.5 billion by 2031.
- Maryland can also draw from the substantial resources being generated through federal partnerships, including the Inflation Reduction Act of 2022, which catalyzes and funds critical actions at state and local levels. With these actions, the State of Maryland can achieve its goals—and build a better future for Maryland by extending resources, cost-savings, new jobs, cleaner air, safer homes and roads, food security, and more.

Maryland's Climate Pathway

Maryland has set a bold and ambitious vision for its future: thriving communities, a clean and vibrant economy powered by the jobs of the 21st Century, enhanced health, and other benefits shared by all. As part of this vision, the State of Maryland has committed in statute to reshaping its economy towards delivering highly ambitious and forward-looking climate goals. The Climate Solutions Now Act (CSNA) sets Maryland's sights high—in fact, the highest in the United States—with a goal of a 60% reduction in greenhouse gas (GHG) emissions by 2031 relative to 2006 levels and a net-zero emissions economy by 2045.

The rapid, clean, affordable, and just energy and economic transition needed to achieve these goals will be challenging, but it is possible. This report, Maryland's Climate Pathway, sets forth a pathway to meet the CSNA goal through an all-of-society approach combined with a suite of actions across all economic sectors and GHGs, while realizing additional economic, health, and environmental benefits for Marylanders. Such actions include those from the Maryland General Assembly and the executive branch; counties, cities, tribal governments, and communities; industries and businesses, universities, and other organizations; and, especially critical, partnership with the federal government. In achieving this pathway, Maryland can also serve as a global example of an all-of-society approach on climate that integrates these measures to enable bold action to mitigate GHG emissions, prepare for the heightened impacts of climate change, and transition to a sustainable and low-carbon economy.

Maryland has consistently maintained its strong commitment to investing in its people, vibrant economy, diverse communities, and natural environment. It is one of the nation's most densely populated states, with over 6 million residents. The State boasts a tapestry of landscapes, from the Appalachian Mountains to the Chesapeake Bay and the Atlantic Ocean coastline. The economic mix comprises cutting-edge biotechnology, advanced healthcare, bustling government institutions, renowned educational establishments, and robust manufacturing. However, amid this prosperity, the unfolding threat of climate change casts a shadow over Maryland's people and ecosystems. Rising sea levels and extreme weather events like heavy rainfall, heat waves, and floods are causing substantial property damage, disrupting transportation and utilities, and endangering public health.

These burdens are not endured equally. Vulnerable communities, including low-income populations, people of color, and those residing in flood-prone areas, face the brunt of these impacts. Their safety, health, and economic well-being are at heightened risk as they contend with the intersections of heat, air pollution, and limited access to vital infrastructure. Beyond these most vulnerable groups, all Marylanders can be impacted, through poor air quality, real health dangers for even healthy individuals, substantial amounts of lost workdays and school days, curtailed recreational opportunities, and more. Maryland will need to navigate these challenges and more, to deliver the necessary rapid, clean, affordable, and just energy and economic transition to ensure these vulnerable communities are protected.

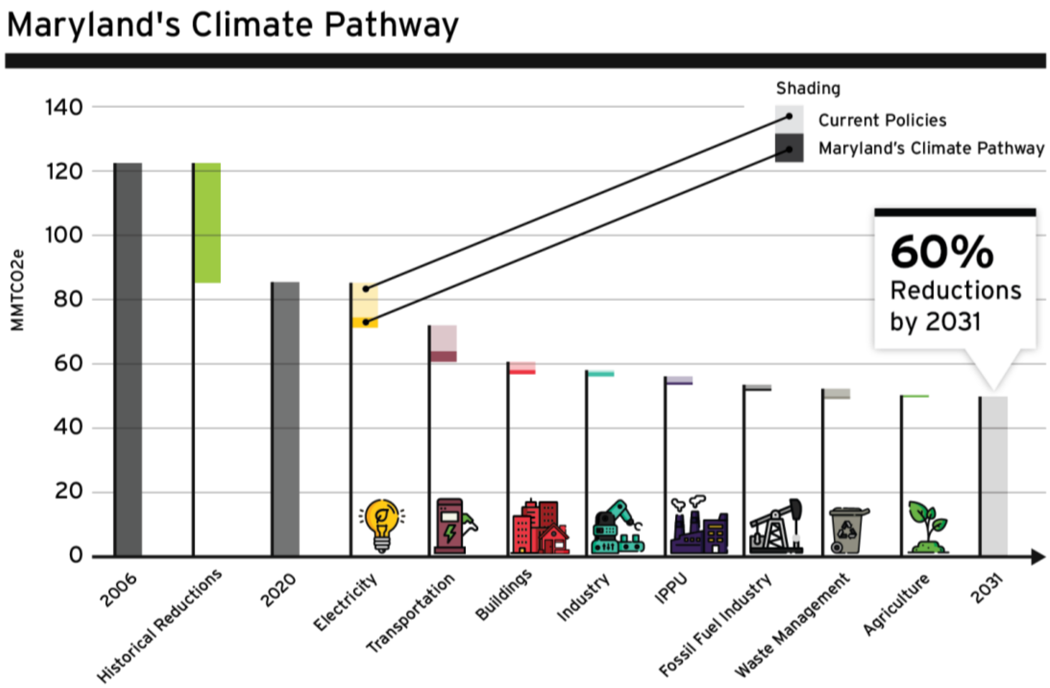

Figure ES.1. GHG emissions reductions by sector under Current Policies and the additional policies included in Maryland's Climate Pathway to reach the State's goal of 60% emissions reduction by 2031.

Maryland's Climate Pathway, as outlined in this report, represents a comprehensive approach to meeting the State's goals. The State is already recognized as a climate leader due to its existing policies, which are poised to make significant emissions reductions. By implementing additional measures, Maryland can achieve its 2031 goal and pave the way toward net-zero emissions by 2045. This modeled pathway results from a rigorous process involving collaboration between the State and local governments, research institutions in Maryland, and years of modeling cultivation to develop a first-of-its-kind analysis of an all-of-society approach. This report's analytical team worked closely with the Maryland Department of the Environment (MDE) and other state agencies and stakeholders to identify the most effective and feasible policies for Maryland. Through this approach, they analyzed the potential emissions reductions and identified the most efficient path to meet the State's GHG reduction targets. The strategy employed in this report combines a globally recognized integrated assessment model with a thorough evaluation of individual policies and climate actions across all sectors and society to ensure the accuracy and consistency of the pathway.

The analysis presents two scenarios. The "Current Policies" scenario quantifies the impact of existing federal and state-level actions on emissions reductions in Maryland. The "Maryland's Climate Pathway" scenario adopts a comprehensive approach involving actions and reductions across every sector. It incorporates all existing policies from the "Current Policies" scenario and introduces additional measures to bridge the gap to the State's climate targets. To meet the State's goals, Maryland's Climate Pathway involves both the extension and expansion of existing policies, as well as the introduction of new policies that will lead to deeper reductions.

Maryland's Climate Pathway

Full implementation of Current Policies puts Maryland on track to reduce emissions by 51% in 2031 relative to the 2006 baseline, leaving a gap of 10.6 MMTCO2e (million metric tons of carbon dioxide (CO_2) equivalents) to reach the 2031 target (Figure ES.1.). Historical efforts had already achieved 36.7 MMTCO2e of reductions as of the most recent state emissions inventory in 2020 (Figure ES.1.). However, under current policies, emissions stop declining by 2040 and resume growth through mid-century. This occurs because: many current policies at both the State and federal levels expire before 2040; as policy support is withdrawn, emissions reductions slow or reverse in many sectors; the demand for energy services continues to increase. CO_2 removal approaches are not a part of the pathway to the 2031 goal, because the 60% reduction target applies to gross emissions, therefore, does not include any negative emissions. Removal approaches are included in the model in later years to demonstrate the pathway's trajectory toward achieving the 2045 net-zero target.

The largest contributions to reductions in Maryland's Climate Pathway come from the electricity sector (Section 2.1) and the transportation sector (Section 2.2), but the pathway will require action across all sectors of the Maryland economy to achieve the needed emission reductions to reach Maryland's climate goals (Table ES.1). Additionally, the Pathway includes an economy-wide cap-and-invest program as a supporting policy that achieves the last 4.8 MMTCO2e of emissions reductions to close the gap in 2031 and help to fund future emissions reductions programs.

Sectors	Mitigation Strategies	Current & Potential Policy Approaches
	Provide market incentive for cost-effective mitigation	• Implement a cap and invest program
	Shift the electricity grid to clean generation	• Expand Renewable Portfolio Standard (RPS) to reach 100% clean electricity • Implement and raise awareness of IRA incentives, including tax credits and direct pay for clean energy production in low-income communities
	Shift PJM electricity grid to clean generation	• Strengthen the Regional Greenhouse Gas Initiative (RGGI) target to zero emissions by 2040
	Reduce passenger vehicle use	• Adopt new smart growth strategies • Increase public transit opportunities and access to safe walking/biking paths • Incentivize remote work, when possible
	Shift passenger vehicle fleet to ZEVs	• Achieve Advanced Clean Cars II targets • Implement and educate on IRA incentives • Implement electric vehicle (EV) infrastructure investments from BIL
	Shift freight trucking fleet to ZEVS	• Achieve Advanced Clean Trucks & Advanced Clean Fleets targets • Implement and educate on IRA & BIL incentives
	Electrify nonroad fuel usage	• Set new standards for equipment in construction, lawn care, warehouses, etc.
	Improve building efficiency	• Implement Building Energy Performance Standards and EmPOWER program • Implement and raise awareness of IRA incentives, including consumer tax credits for energy efficiency and clean energy upgrades • Set enhanced standards for new buildings
	Electrify all appliances	• Set zero-emission appliance standards • Set clean heat standards • Set all-electric construction standards
	Electrify industrial processes	• Implement EmPOWER program • Adopt Buy Clean policies (i.e. cement)
	Explore alternative fuels & energy sources	• Implement and raise awareness of IRA's hydrogen and CCS tax credits • Facilitate cement fuel switching
	Reduce HFC emissions	• Achieve AIM Act targets for HFC reductions • Achieve Maryland's HFC regulations
	Enhance efficiency in cement material	• Set new construction standards to reduce excessive use of cement • Adopt Buy Clean policies that prioritize cement products with high clinker replacement factor
	Reduce natural gas consumption	• Achieve policies across all consuming sectors
	Prevent and repair emissions leaks	• Implement Maryland natural gas methane regulation • Implement IRA methane fee
	Reduce methane from landfills	• Implement Maryland landfill methane regulation
	Divert and redirect waste	• Realize Maryland Sustainable Materials Management • Incentivize and facilitate composting • Prioritize circular economy policies
	Reduce methane emissions from enteric fermentation and manure management	• Incentivize best practices • Facilitate knowledge sharing

Table ES.1. Mitigation strategies for 2031 in Maryland's Climate Pathway by sector and policy approaches that can contribute to these essential strategies. See relevant sections 2.1-2.9 for details on specific policies.

BENEFITS OF CLIMATE GOAL ACHIEVEMENT

The REMI PI+ model, a comprehensive economic modeling tool, was used to analyze the potential impacts of Maryland's Climate Pathway on the State's economy. It is projected to create new job opportunities across various sectors. Investments in renewable energy, energy efficiency, and other clean technologies would support local businesses and contribute to workforce development. Maryland can foster innovation, attract new industries, and drive economic growth by investing in sustainable infrastructure and transitioning to cleaner energy sources. The transition will foster further innovation and technological advancement that can lead to new industries and increased competitiveness, resulting in job opportunities and economic benefits in emerging sectors.

Implementing energy efficiency measures as part of the Pathway would also lead to significant energy savings for households, businesses, and the public sector, which could be reinvested in the economy, stimulating additional economic activity and benefiting Maryland residents. While the REMI PI+ model's estimates are based on assumptions and data inputs, its findings suggest that Maryland's Climate Pathway has the potential to bring about positive economic changes. It would foster sustainable growth, job creation, and technological innovation while addressing the urgent need to mitigate climate change.

EQUITY AND IMPLEMENTATION CONSIDERATIONS

Successfully achieving the policies outlined in the Maryland's Climate Pathway scenario hinges on the full implementation of federal, state, regional, and local policies and realization of substantial and sustained benefits for the broad public and communities that can ensure Maryland's clean future. To realize this vision, it will be essential to support equitable access to the incentives and benefits included in the Pathway and the widespread adoption of key mitigation strategies across economic sectors and people's daily lives. These actions can be taken across all sectors, including:

Electricity. Decarbonizing the electricity sector is a central component of success, not only for reducing emissions within the sector, but also for enabling the decarbonization of other sectors, such as transportation, buildings, and industry, where electrification is a key solution. This shift is essential, but to realize the emissions reductions needed in the electricity sector based on our model, several critical policies and regulatory actions will need to be implemented. Importantly, to achieve 100% clean energy sources by 2035, coal phaseout and grid stability need to be prioritized to secure the renewable energy transition. Maryland can also leverage its involvement with the Regional Greenhouse Gas Initiative to set a cap for net-zero by 2040. Finally, the deployment of renewables, particularly solar photovoltaics, will need to accelerate rapidly in the near term. These actions raise particular challenges within the sector to ensure this transition is equitable through programs such as community solar and to ensure that imported electricity from outside of Maryland is clean, so that emissions reductions outside of State borders can also be accounted for in the State GHG Inventory.

Transportation. Maryland has shown climate leadership in the transportation sector by moving to adopt standards like Advanced Clean Cars II and passing the Maryland Clean Trucks Act. Yet, barriers still need to be overcome to achieve the transition to electric vehicles (EVs) and the infrastructure required to support them. Access to charging stations, affordability of EVs, and addressing range anxiety are key concerns. Additionally, reducing vehicle miles traveled (VMT) and promoting alternative modes of transportation, such as e-bikes and public transit, are important strategies to reduce emissions. However, challenges exist in terms of infrastructure, financing, and public perception of these modes. Ensuring equitable implementation of these strategies is also a significant challenge, as it is crucial to address the needs and accessibility of underserved communities.

Buildings. One of Maryland's priorities in the building sector is building electrification and efficiency measures. This involves transitioning to higher-efficiency electrical appliances and utilizing a cleaner electricity grid to reduce emissions. However, challenges arise regarding access and affordability for all individuals, particularly low-income homeowners and renters. Integrating renewable energy sources into building electrification also poses scalability, grid stability, and storage capacity challenges. Retrofitting older buildings to accommodate zero-emission appliances, such as heat pumps, can be complex and may require significant modifications. Additional concerns include historic preservation requirements, upfront costs, and installation disruptions. Overcoming these challenges requires targeted policies, support for low-income households, and coordination between policymakers, manufacturers, consumers, and energy providers.

Industry. Decarbonizing the industrial sector has historically been one of the toughest goals to accomplish due to policy limitations and technical challenges. Removing the Greenhouse Gas Reduction Act's exemption for the manufacturing sector will be a key step in facilitating emissions reductions within the sector. Additional research, funding, and multi-stakeholder support are needed to deploy and improve solutions such as electrification through heat pumps and resistive heating, zero-carbon fuels like hydrogen, and utilizing alternative sources of high heat such as solar thermal. Special effort will also be needed to address emissions from non-combustion sources such as cement and HFC's. Even with these actions, residual emissions from this sector may require offsetting through natural sinks or CO_2 removal methods, and, to meet the State's goals, other sectors may need to decarbonize rapidly to ensure the scalability of negative emissions.

Waste. Waste management policies are an opportunity for Maryland to achieve both emissions reductions and co-benefits to Marylanders through improved environmental health. Waste diversion policies can help the State reduce methane emissions and reduce the amount of waste that accumulates in landfills. To create better waste management policies, Maryland can improve data on waste sources and composition; address barriers to waste diversion policies like composting; adjust the inventory accounting methodology for waste incineration; and look for opportunities to achieve wastewater emissions reductions.

Agriculture. Maryland's farmers have already taken significant action to reduce non-CO_2 GHG emissions from agricultural soils as part of the State's commitment to a healthy Chesapeake Bay. Taking additional action in Maryland's agricultural sector will help the State preserve the largest commercial industry for years to come. The biggest problem in the agricultural sector is the potent GHG, methane. It will also be essential to employ best practices to manage agricultural soils as a carbon sink, in concert with the State's forests, Maryland's largest carbon sink, to maintain and expand natural methods of carbon sequestration to support the State's net-zero goals.

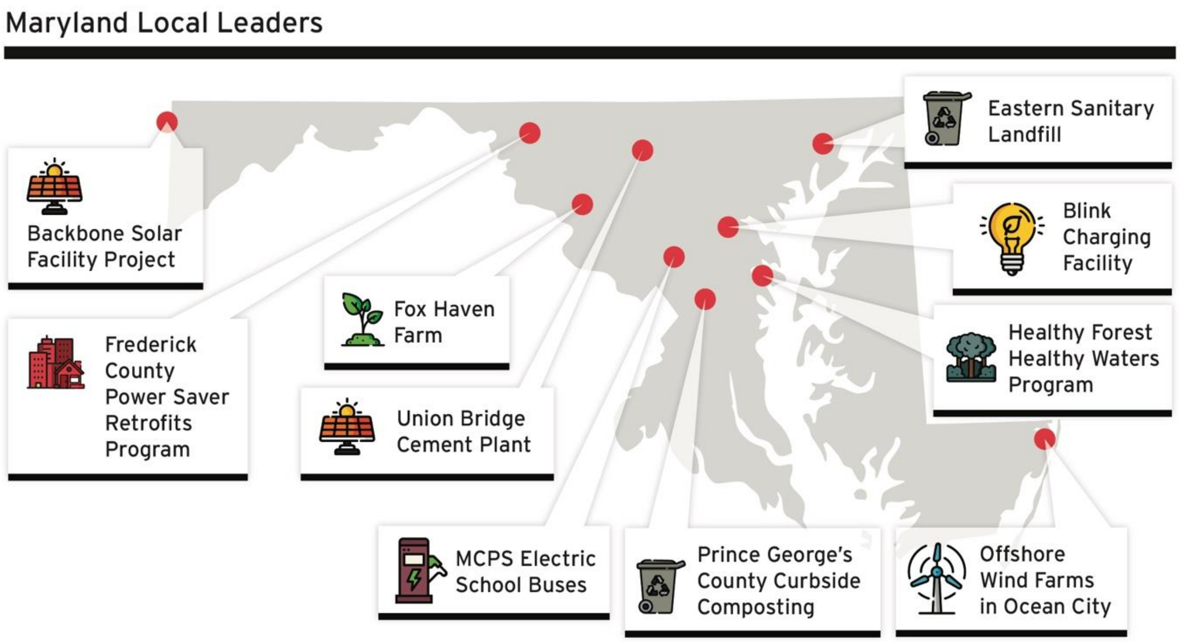

Figure ES.2. Maryland community leaders as highlighted in the implementation sections and case studies throughout the report to demonstrate how Maryland's Climate Pathway is already underway.

CONCLUSION

Achieving the 2031 goal will require immediate and sustained effort across Maryland's entire economy and at all governance levels. It will first require effective, collaborative implementation of current policies, in partnership with the federal government and the State's other governance levels including counties and cities. Through the pathway presented in this report, Maryland can achieve the 2031 target, set itself on a path to net-zero, and establish new policies that can create over 6,600 new jobs and provide up to $667 million of annual health benefits from co-pollutant reduction.

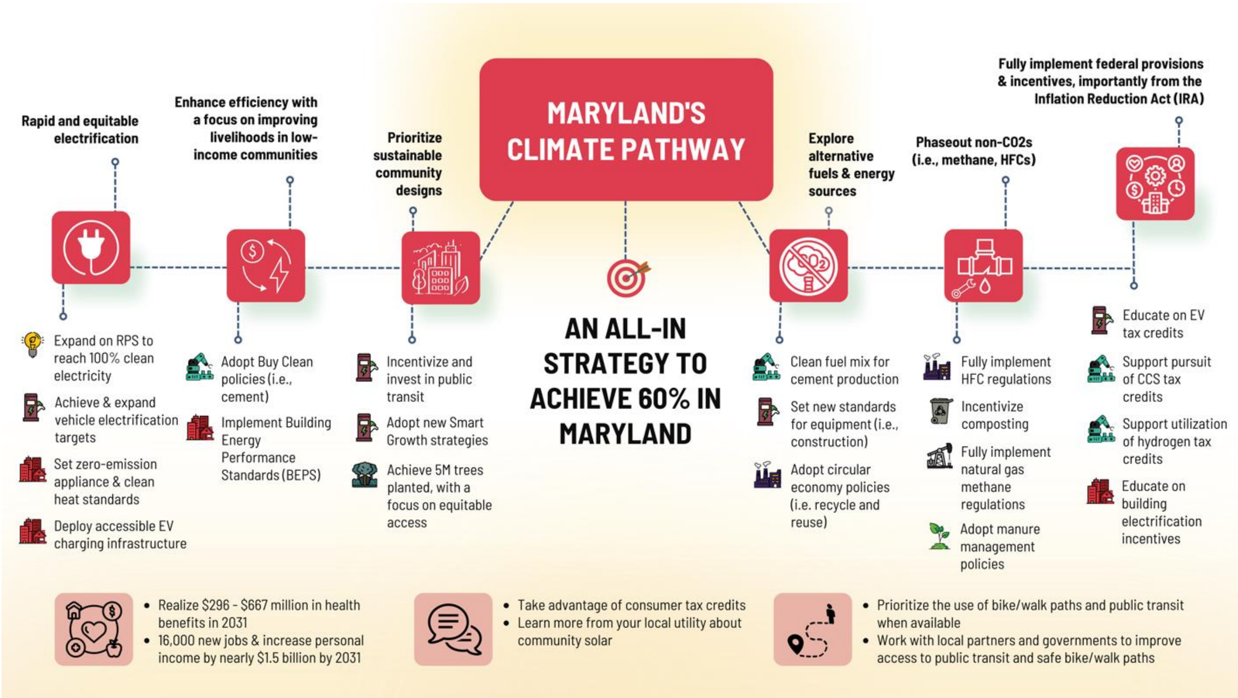

Figure ES.3. Key mitigation strategies and policy opportunities featured in the report that enable Maryland to achieve its 2031 goal.

As we embark on this path, additional collaboration and analysis will be required to sharpen our understanding of opportunities and implementation across several key areas, such as agriculture, forestry, and land use, and policy implementation challenges. In addition, enhanced discussion, analysis, and collaboration will be helpful to better structure and manage Maryland's transition to high renewables penetration and phasing down of natural gas distribution systems, particularly in planning for the post-2030 period. Stakeholder engagement and broad-based efforts involving government, community groups, businesses, and individuals will be crucial for achieving Maryland's climate action goals and can be supported by public outreach campaigns, engagement with businesses, and prioritizing equity and community involvement in policy development and implementation.

This Pathway shows that through working together, Maryland's ambitious 2031 climate goal is within reach. Achieving it will provide substantial benefits to Marylanders and will set the State squarely on a path to achieve its 2045 net-zero emissions goal. Maryland's Climate Pathway offers an initial comprehensive, all-of-society view of how the State can not only reach its goals but also set an example in the United States and world of how to develop a new, healthy, and vibrant economy that works for all residents.

MARYLAND'S CLIMATE PATHWAY

AN ANALYSIS OF ACTIONS THE STATE CAN TAKE TO ACHIEVE MARYLAND'S NATION-LEADING GREENHOUSE GAS EMISSIONS REDUCTION GOALS

KEY FINDINGS:

- The *Maryland's Climate Pathway* report demonstrates how Maryland can meet its ambitious climate goals of 60% reduction of greenhouse gas emissions by 2031 relative to 2006 levels and attain a net-zero economy by 2045, all while realizing health and economic benefits for Marylanders, including improved air quality, new jobs, and household cost savings.
- Maryland can do this through the coordinated implementation of current and new policies across each sector of the economy, combined with a strong federal partnership, and a broader all-of-society approach that integrates actions from cities, counties, local jurisdictions, business and industry leaders, community organizations, and more.
- The first step is fully implementing the policies already in place in Maryland. As of 2020, Maryland had already achieved half of the reductions needed—36.7 MMTCO2e of the 73.3 MMTCO2e to meet the 2031 target. Full implementation of existing policies can achieve another 26.0 MMTCO2e by 2031, leaving one fifth of the reductions left—a gap of 10.6 MMTCO2e that must be filled by new policy action.
- This analysis offers a pathway to success to fill this gap and achieve the economy-wide 60% goal, illustrating potential actions across all sectors, with additional reductions including 3.6 MMTCO2e from transportation, 2.3 MMTCO2e from electricity generation, and 1.6 MMTCO2e from buildings.
- Additional policies from the agriculture, waste, and industrial sectors, including critical reductions in methane, are needed to achieve the 2031 target and support broad economic, social, and environmental benefits for Marylanders. Taking these steps now to achieve the 2031 goals will also place Maryland on a pathway toward its 2045 goal of net-zero emissions.
- At its full potential, this pathway delivers substantial health, employment, and economic benefits to Maryland's people and further bolsters the leadership and ability of the State's economy to be globally competitive. New policy action will deliver even more health benefits through improved air quality and reduced respiratory ailments, especially for vulnerable populations—the equivalent of $1.09-$2.44 billion in health benefits by 2031. These benefits extend to the economy with the projected cumulative creation of more than 16,000 new jobs and increased personal income by nearly $1.5 billion by 2031.
- Maryland can also draw from the substantial resources being generated through federal partnerships, including the Inflation Reduction Act of 2022, which catalyzes and funds critical

actions at state and local levels. With these actions, the State of Maryland can achieve its goals and build a better future for Maryland by extending resources, cost-savings, new jobs, cleaner air, safer homes and roads, food security, and more.

1. INTRODUCTION

To realize its vision for thriving communities, a clean and vibrant economy with jobs for the future, enhanced health, and other benefits shared by all, the State of Maryland has committed in statute to achieving ambitious climate goals. The Climate Solutions Now Act (CSNA) sets Maryland's sights high—in fact, the highest in the United States—with a 60% reduction in climate pollutants by 2031 relative to 2006 levels and a net-zero emissions economy by 2045. Realizing these goals will not only benefit Marylanders directly but will also put the State on a path to do its part to help the nation and the world address the critical challenges of climate change.

The rapid, clean, affordable, and just energy and economic transition needed to achieve these goals will be challenging, but it is possible. This report sets forth a pathway that demonstrates how a suite of actions can be taken, across all economic sectors and all greenhouse gases (GHGs), to reach the goals set forth in the CSNA—and also highlights the many benefits of achieving them for Maryland's people and economy. It shows an all-of-society approach, with policies and actions across the entire state contributing to success. Such actions include those from the Maryland General Assembly and the executive branch; counties, cities, tribal governments, and communities; industries, businesses, institutions, and other organizations; and especially critical, those in partnership with the federal government.

1.1 THE CRITICAL CHALLENGE OF CLIMATE CHANGE FOR MARYLAND

Located in the Mid-Atlantic region of the United States, Maryland is a diverse state known for its rich history, vibrant cities, and varied landscapes, from the Appalachian Mountains to the Chesapeake Bay to the Atlantic Ocean. Maryland is home to approximately 6 million residents, which, because of its small size, makes it one of the most densely populated states in the country. The State's economy is also diverse, encompassing sectors such as biotechnology, healthcare, government, education, and manufacturing.

Maryland's people and economy face significant threats due to climate change, with many communities located in places that are vulnerable to climate impacts such as sea level rise, heat waves, floods, and droughts that often interact with other stresses, such as air pollution. Ecosystems and the parts of the economy dependent on them are also facing pressures. The State's extensive shoreline, including the Chesapeake Bay, makes the State particularly susceptible to coastal flooding, storm surges, and erosion. Rising sea levels intensify the risk of inundation, endangering coastal communities, critical infrastructure, private buildings, and valuable ecosystems. Furthermore, increased frequency and intensity of extreme weather events, such as flooding, heavy rainfall, and heat waves, can lead to costly property damage, disruptions to transportation and utilities, and public health risks. Vulnerable communities, including low-income populations, people of color, and those living in areas prone to flooding or the intersections of heat, air pollution, and lack of access to infrastructure, bear the brunt of these impacts. These individuals also face heightened risks to their safety, health, and economic well-being because of the impacts of climate change. Beyond these most vulnerable groups, all Marylanders can be impacted, through poor air quality, real health dangers for even healthy individuals, substantial amounts of lost work days and school days, curtailed recreational opportunities, and more. A comprehensive pathway to achieve Maryland's GHG reduction goals will prioritize the resilience and mitigation efforts needed to protect these vulnerable communities and ensure a safe, sustainable, and equitable future for all Marylanders.

1.2 ACHIEVING A BETTER FUTURE IN MARYLAND THROUGH PARTNERSHIP ON CLIMATE ACTION

The State's commitment to climate leadership sets the bar high both nationally and globally. Maryland has established the most aggressive state-level GHG emissions reduction goals in the United States to date, including a 60% reduction in gross emissions by 2031 and net-zero emissions by 2045. Maryland can achieve this goal through an all-of-society approach that incorporates climate considerations into all relevant decisions across government, business, industry, and partner organizations, and charts a path toward a sustainable and resilient future.

Maryland's leadership on climate and Maryland's ability to reach its goals are rooted in already strong actions taken by the State Legislature and the Executive Branch, as well as counties, cities, universities and research institutions, investors, health organizations, faith groups, and more. However, achieving the new 2031 and 2045 goals requires an even stronger set of actions across the economy. This climate action pathway will further accelerate progress towards emissions reductions; drive economic growth in diverse communities; protect Maryland's fragile ecosystems and the communities dependent on them; and ensure a better world for generations to come.

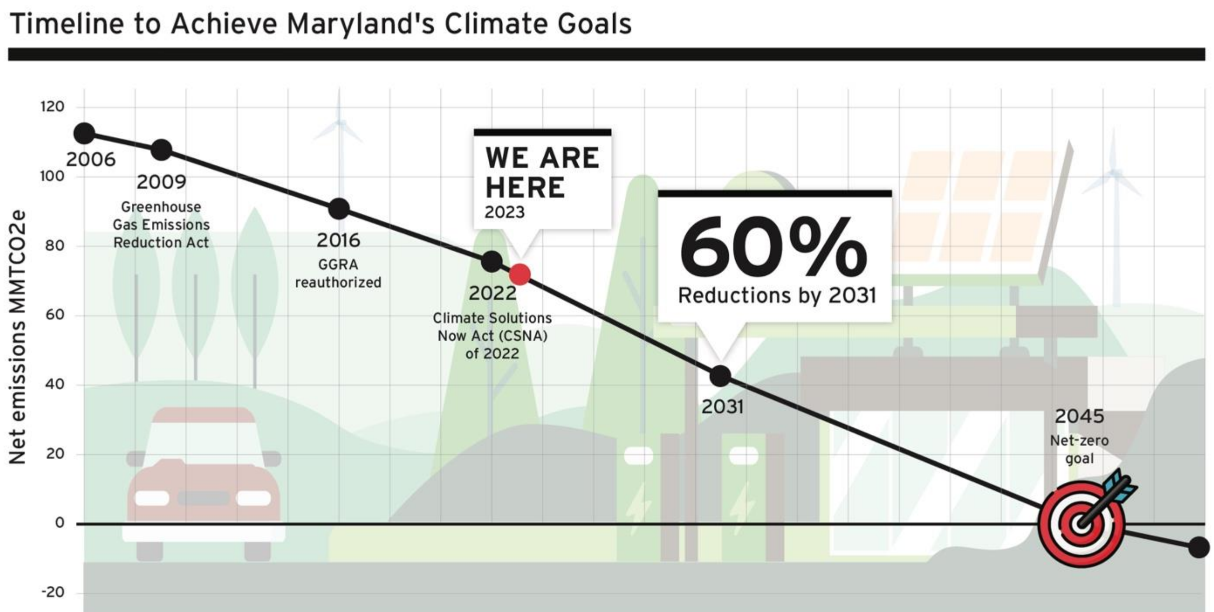

Figure 1.1. Timeline with milestones set by Maryland for achieving climate goals.

Achieving these climate goals will be good for Maryland's communities, health, and economy. These goals also support a larger set of actions across the United States and world to accelerate the transition of the national and global economy toward a new, cleaner, and better future. The transformed economy will grow in different ways than in the past and with different technologies and industrial strategies. Maryland's leadership on climate will, therefore, support economic growth and transformation here at home to equip the State's economy to thrive and compete effectively in the future.

Maryland will undertake these actions in partnership with the federal government. Both will benefit from and support the ambitious national climate strategy and goals of the United States. The United States has set a goal of reducing its emissions by 50-52% from 2005 levels by 2030 and to net zero by 2050. Achieving these national goals will be possible through a combination of existing policies, including recent comprehensive legislation from the federal government, plus new and accelerated actions from states, cities, businesses, federal regulatory agencies, and civil society across the United States. In addition, the substantial federal funding enabled by legislation and other forms of partnership with the federal government will be a strong and essential pillar supporting Maryland's ability to achieve its goals. In 2022, Maryland set the most ambitious state-level climate targets in the country, making Maryland a prime example of how leadership on climate change at the state and local levels can support broader action.

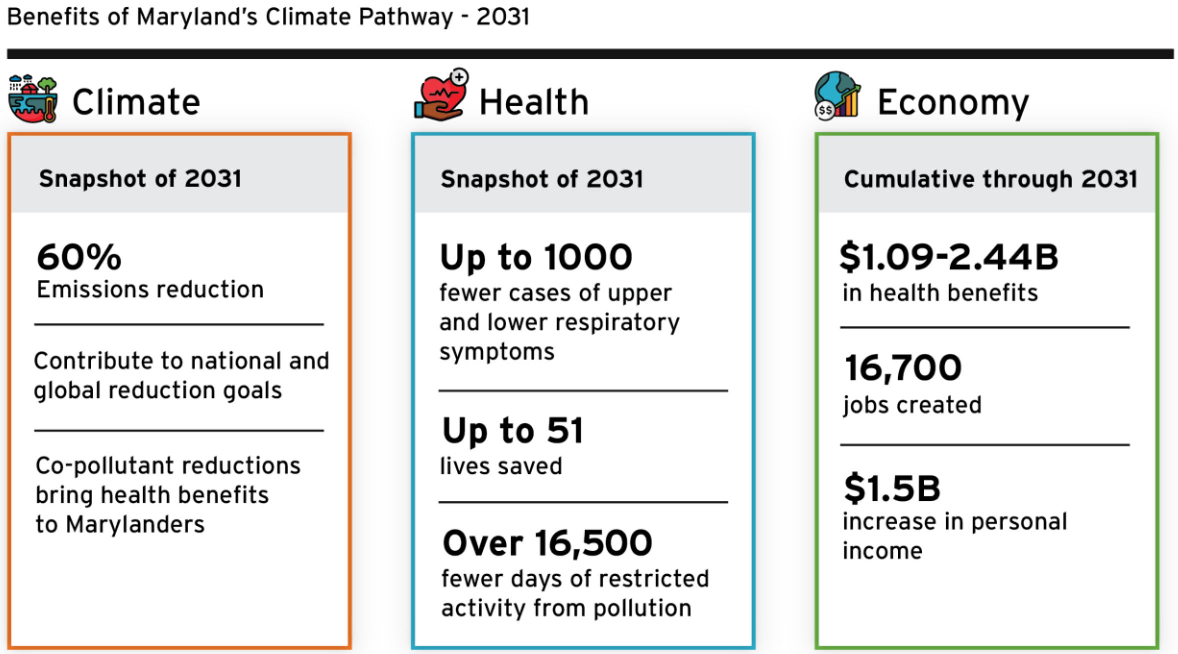

Figure 1.2. Summary of climate, health, and economic benefits to Marylanders.

Achieving the State's climate goals requires a holistic approach that considers the interconnection between the economy, environment, and health and social well-being of Maryland. Environmental benefits, such as reducing GHG emissions, conserving natural resources, and preserving ecosystems, are crucial for safeguarding Maryland's unique biodiversity and ensuring a sustainable future for generations to come. At the same time, it is essential to foster economic prosperity by capitalizing on clean energy investments, promoting sustainable industries, and creating green jobs. These commitments not only drive economic growth but also enhance the quality of life for Marylanders through increased employment opportunities, innovation, and technological advancements. Moreover, prioritizing health and social benefits is essential to ensure that climate action is inclusive and equitable, addressing the needs and vulnerabilities of marginalized communities, promoting social justice, fostering community resilience, and improving access to clean air and water.

The pathway presented here draws from these diverse and mutually reinforcing climate solutions. Through this combined, interconnected pathway of sectors and actors, the State can deliver benefits to its own residents and also develop and enhance best practices to shape a sustainable future for the planet.

1.3 MARYLAND’S CLIMATE PATHWAY

Maryland's current policies already position it as a climate leader, with key measures primed to contribute significant emissions reductions. Additional policies will help achieve the 2031 goal and put the State on track to reach net-zero emissions by 2045.

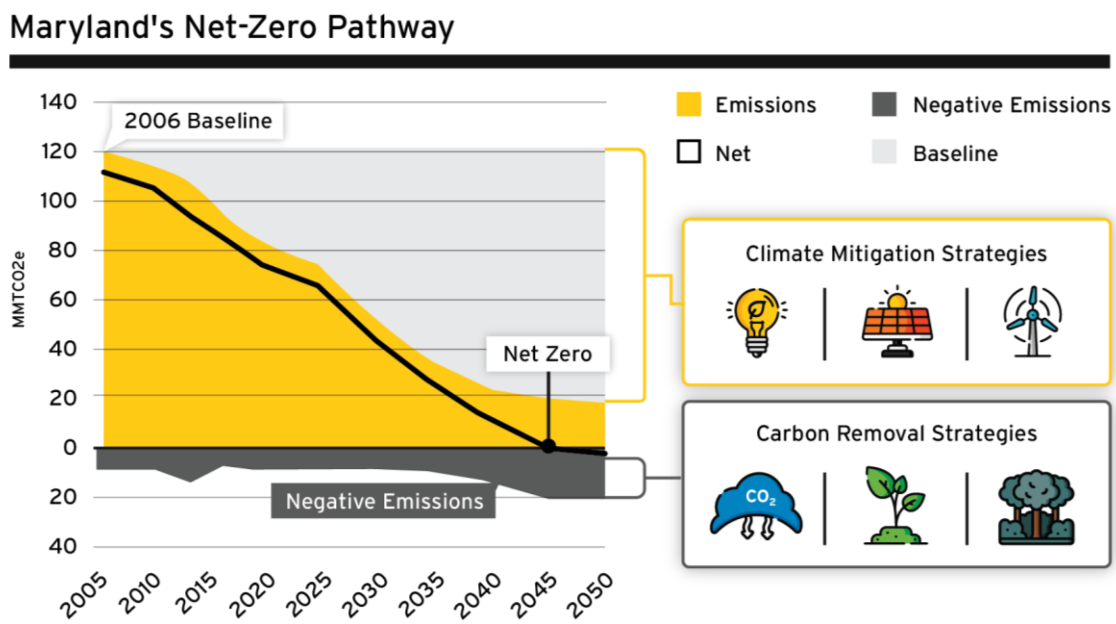

Figure 1.3. Emissions trajectory to reach Maryland's net-zero target in 2045.

Built on a multistage process and quantitative strategy to understand the opportunities for action, this report modeled how those opportunities would evolve within Maryland in the context of the national and global economy, and assessed the impacts of those actions in 2031 in terms of emissions reductions and other benefits to the State. First, the analytical team engaged in an iterative, consultative process with the Maryland Department of the Environment (MDE) and other State agencies and stakeholders, to scope the set of potential federal, state, and local policies in Maryland and to identify those policies that may be most effective and feasible given Maryland's specific situation. As part of a new policy platform, these policies are analyzed to project emissions reductions and determine the most efficient pathway to meet the legislated GHG reduction targets.

This strategy couples a United States-wide 50-state version of the well-known, vetted, and open-source global integrated assessment model GCAM (Global Change Analysis Model) with a set of bottom-up analyses to account for potential additional emissions reductions driven by U.S. states and sub-state actions and to ensure consistency with the State of Maryland's GHG inventory methodologies. By integrating bottom-up aggregation tools and data analysis into a global model with national and state resolution, this approach enables a robust evaluation of individual policies and climate actions within specific sectors (for further elaboration, see, for example, Hultman et al 2019, Zhao et al 2021, Zhao et al 2022).[1–4]

The *Maryland's Climate Pathway* analysis applies an all-of-society approach to help the State of Maryland identify a pathway to achieve Maryland's 2031 and 2045 goals. The analysis integrates all major climate-related policies across each sector, at both federal and non-federal levels, along with existing, currently in-force policies by Maryland's State government, and considers implementation barriers and opportunities from local governments, community organizations, and the private sector. We present two scenarios – one quantifying the impact of existing policies in the "Current Policies" scenario, and one that includes the additional effects of a suite of potential new policies across all-of-society in the "Maryland Climate Pathway" scenario.

- The **Current Policies** scenario models all existing federal-and-state-level actions contributing to Maryland's emissions reductions, including the climate-smart application of the federal Inflation Reduction Act (IRA). In addition, this scenario models Maryland's key policies contributing to major emissions reductions, which include Maryland's Renewable Portfolio Standard (RPS), the forthcoming adoption of the Advanced Clean Cars (ACC) II rule, Building Energy Performance Standards (BEPS), and more (see Section 2, Pathways to State Targets). However, Current Policies only achieve 51% GHG reductions by 2031 relative to 2006, leaving a gap in reaching the State's 60% reduction goal.

- The **Maryland's Climate Pathway** scenario incorporates an all-of-society approach to achieving 60% reductions by 2031 from 2006 levels, with a comprehensive suite of actions and reductions from best practices across every sector of the economy. It includes all modeled policies from the Current Policies scenario, as well as additional policies that enable the State to meet its climate targets. (See the technical appendix for more detailed information on the modeling and analysis.)

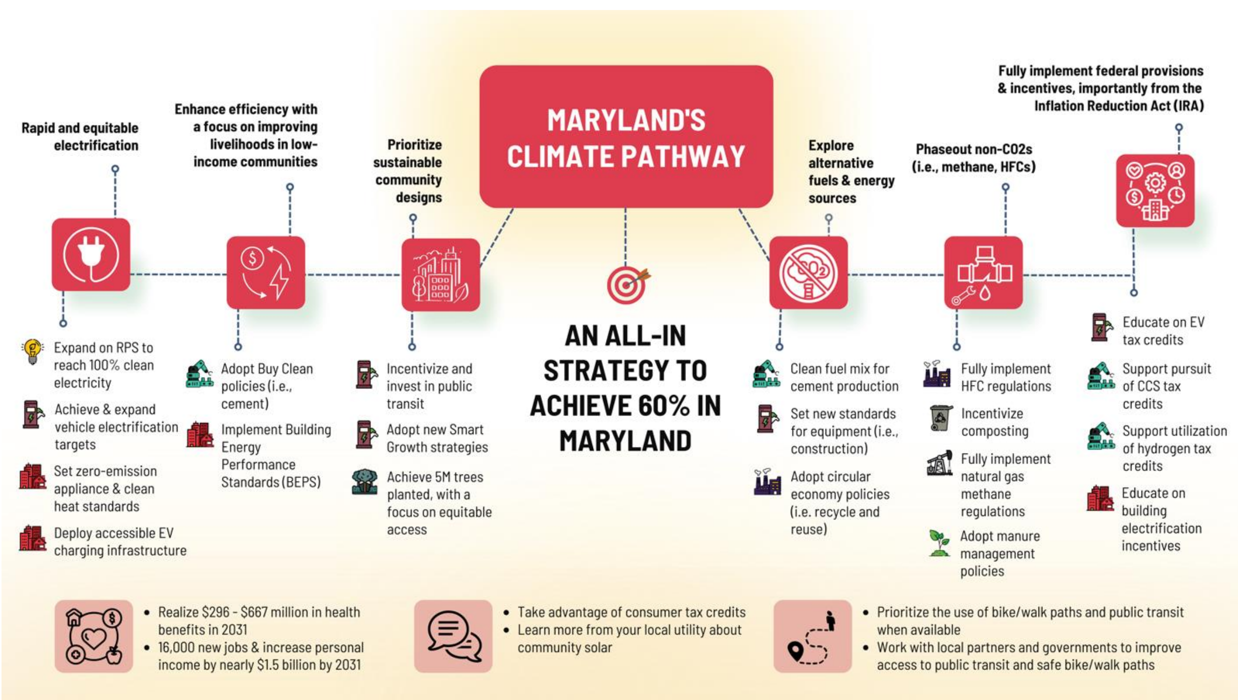

Figure 1.4. Key mitigation strategies and policies to achieve Maryland's Climate Pathway.

This pathway would enable Maryland to achieve 60% reductions below 2006 levels in GHG emissions by 2031 and put the State on a trajectory to meet its 2045 net-zero goal. Through 2031, most reductions occur from the electricity, transportation, buildings, and industry sectors. Additional policies would be needed in the agriculture and waste sectors to realize the reductions needed. To ensure progress toward net-zero by

2045, ongoing investment in the protection, management, and expansion of Maryland's natural and working lands is also critical. This report presents the climate pathway to 2031 by breaking down each sector's contribution to reductions, key policies needed, and any sub-sector actions necessary for implementation. Following the sector breakdowns is a description of the benefits associated with the pathway, including job growth, improvement in air quality, health benefits, and cost savings.

This analysis was led by the Center for Global Sustainability (CGS) at the University of Maryland, in partnership with MDE. As a next step, MDE and CGS will convene a series of public workshops and provide other methods for interested parties to comment on the proposed pathway. Following the open comment period, MDE will deliver a final policy framework and plan at the end of 2023.

2. PATHWAY TO STATE TARGETS

This report analyzes greenhouse gas (GHG) emissions reductions in two modeled scenarios for the State of Maryland — reductions under **Current Policies** and reductions under **Maryland's Climate Pathway**. Maryland's Climate Pathway includes additional policies necessary to meet the requirements for the State's ambitious goals established in the Climate Solutions Now Act (CSNA) of 60% GHG emissions reduction by 2031 and net-zero GHG emissions by 2045.

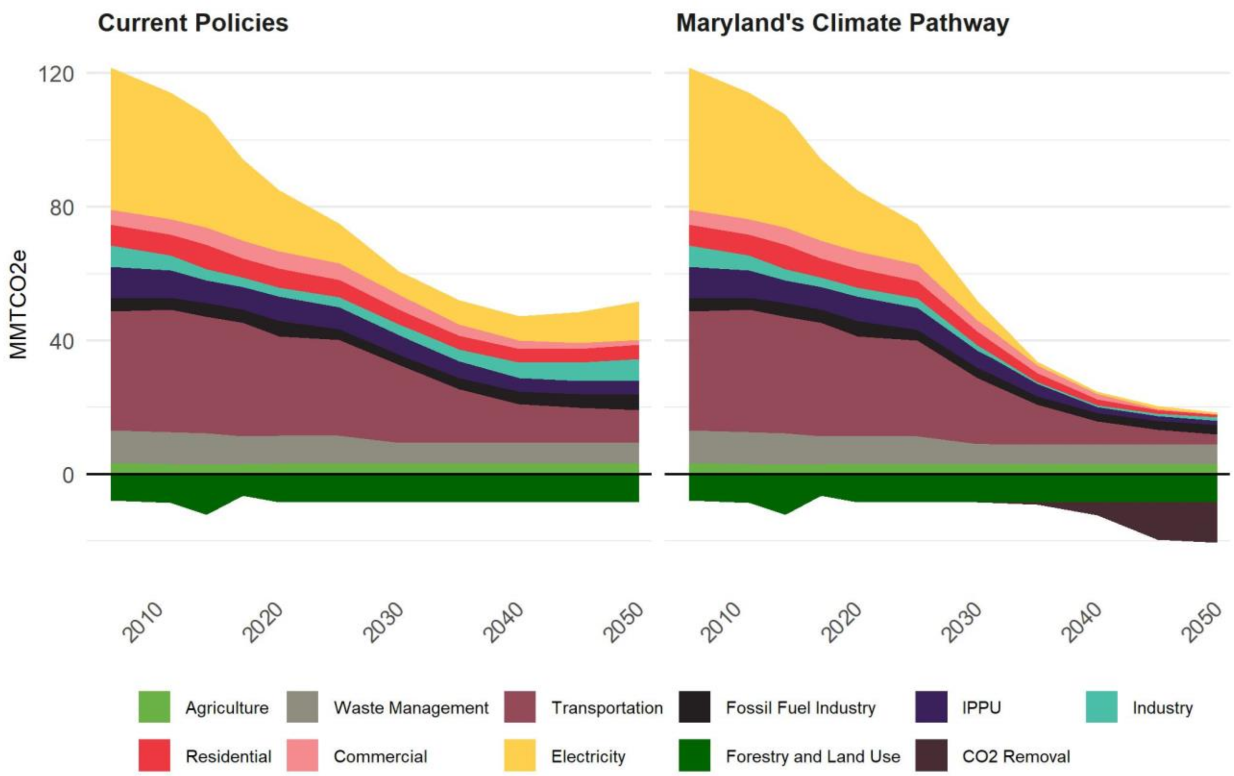

Figure 2.1. Economy-wide GHG emissions and removals broken down by sector under Current Policies and Maryland's Climate Pathway scenario.

Full implementation of Current Policies puts Maryland on track to reduce emissions by 51% in 2031 relative to the 2006 baseline, leaving a gap of 10.6 MMTCO2e (million metric tons of CO_2 equivalents) to reach the 2031 target. Historical efforts had already achieved 36.7 MMTCO2e of reductions as of the most recent State emissions inventory in 2020. However, under Current Policies, emissions stop declining by 2040 and resume growth through mid-century. This occurs because: many existing policies at both the State and federal levels expire before 2040: as policy support is withdrawn, emissions reductions slow or reverse in many sectors; and the demand for energy services continues to increase. To meet the State's goals, Maryland's Climate Pathway involves both the extension and expansion of existing policies to avoid this reversal in the Current Policies scenario, as well as the introduction of new policies that lead to deeper reductions. Natural and technological CO_2 removal approaches are not a part of the pathway to the 2031 goal, because the 60% reduction target applies to gross emissions, therefore, does not include any negative emissions. Removal approaches are included in later years to support achievement of the 2045 net-zero target.

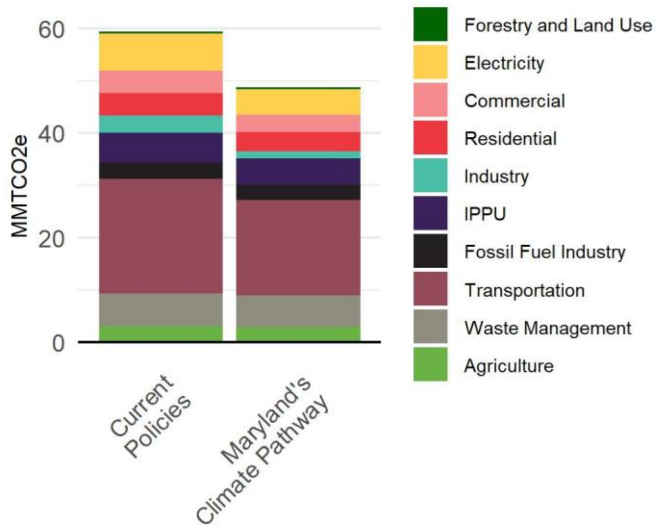

Figure 2.2. Remaining gross emissions by sector in 2031 under the Current Policies and Maryland's Climate Pathway scenarios.

The largest contributions to reductions in Maryland's Climate Pathway come from the electricity sector (Section 2.1) and the transportation sector (Section 2.2), but this Pathway requires action across all sectors of the Maryland economy to achieve the needed emission reductions. Additionally, Maryland's Climate Pathway includes an economy-wide cap-and-invest program as a supporting policy that achieves the last 4.8 MMTCO2e of emissions reductions needed to meet the 2031 target and can help fund future emissions reductions programs.

Cap-and-Invest Program

A cap-and-invest program sets a limit on the amount of emissions across the economy and auctions off the allowed emissions, such that all actors are incentivized to pursue emission reduction strategies that cost less than purchasing the emission allowance. The proceeds from the sales of these allowances are then re-invested within the State, potentially providing relief to sectors or individuals who are less able to pay for reductions, or funding state programs and infrastructure to support the green transition. Within this analysis, a high-level, theoretical cap-and-invest program incentivizes the least-cost emission reductions across all sectors of the economy within the model. Certain emissions sources that were analyzed exogenously were not included in the cap due to modeling constraints, including hydrofluorocarbons (HFCs) and agriculture. As this is a theoretical program that does not exist today, additional analyses will be needed to determine costs associated with the cap and specific details around how the cap would be implemented within the context of Maryland. No specific policy for reinvestment of funds is modeled in this analysis, but ensuring that investment is used effectively and equitably to support the State's goals will be a key policy challenge for this program.

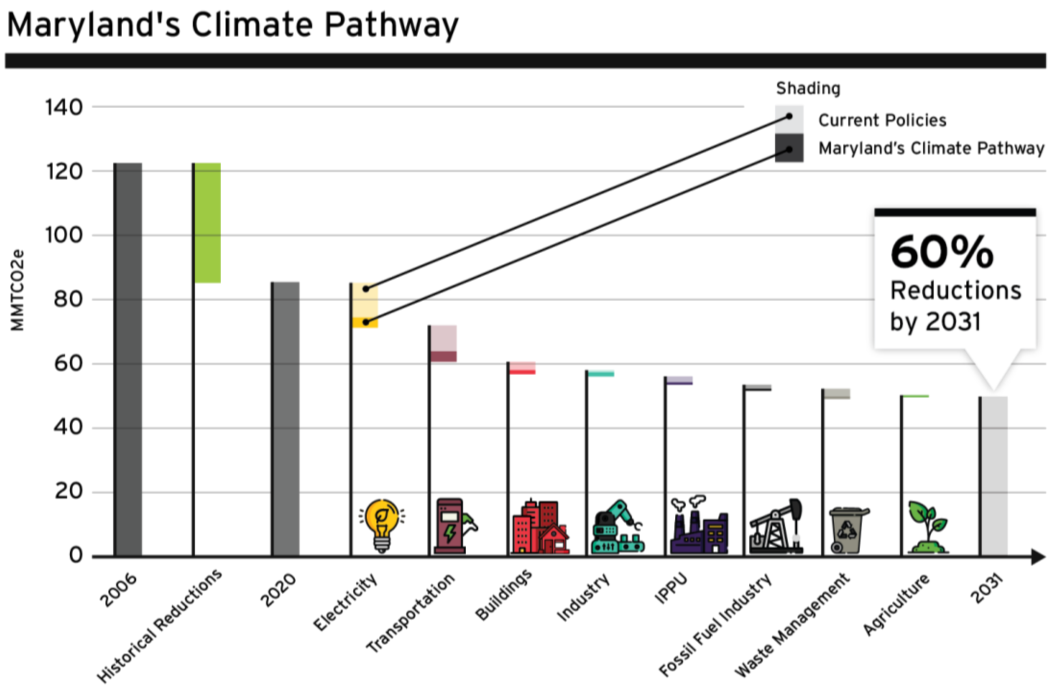

Figure 2.3. GHG emissions reductions by sector under Current Policies and in Maryland’s Climate Pathway to reach the State’s goal of 60% emissions reduction by 2031. Each bar from left to right indicates the emissions reductions achieved in that category. Darker shades indicate reductions achieved through new policies introduced in Maryland’s Climate Pathway in a given sector, and lighter shades of the same color indicate reductions achieved under Current Policies in that sector.

Beyond 2031: Reaching Net-zero

Maryland’s climate goals are ambitious not only because of the speed of reduction required, but also because of their scope. Both the 60% emissions reduction goal in 2031 and the net-zero goal in 2045 are for all GHGs, not just carbon dioxide. Some of these non-CO_2 emissions are particularly difficult to abate, which, together with residual fossil CO_2 emissions, means that emissions sinks must be developed to offset residual emissions across the economy. These offsetting activities can include natural sinks from land use (Section 2.9) as well as technological CO_2 removal from negative emissions technologies. In Figure 2.1, natural sinks are represented by the “Forestry and Land Use'' category, and technological removals are represented as “CO2 Removal.” In total, Maryland’s Climate Pathway includes 20.0 MMTCO2e of negative emissions in 2045 — 8.8 MMTCO2e from natural sinks and 11.2 MMTCO2e from technological removals. To achieve that quantity of negative emissions, cultivation of natural sinks and development of negative emissions technologies must be pursued well before 2045 if they are to reach the required levels in time. Enhancing land sinks will require significant afforestation and conservation efforts; expansion of best practices in agriculture and forestry to increase soil and standing carbon stocks; proactive management of coastal ecosystems; and improved measurement and monitoring practices to track success. Technological sinks will require investment in innovation, support for demonstration and deployment phases, and appropriate financial mechanisms as technologies mature, including research and development funding, carbon markets, impact investing, public-private partnerships, green bonds and climate funds, and philanthropic funding. Both will benefit from the development of scientific and legal frameworks to ensure that net sequestration is rigorously monitored and verified over time.

Methodology

The primary analytical tool used in this analysis is a 50-state version of the Global Change Analysis Model (GCAM), which is described more fully in Section 2 of the Technical Appendix. GCAM is a global, open-source integrated assessment model that links the human and Earth systems and has been widely utilized to assess global, national, and subnational climate change and climate mitigation pathways. Here, GCAM is used to model changes in the electricity, transportation, buildings, and industry sectors of Maryland. The fossil fuel industry, waste management, agriculture, and forestry and land use sectors are partially or wholly analyzed outside of GCAM due to modeling and data limitations. The modeling assumptions are described in the Technical Appendix.

GHG emission results are calibrated to the 2020 Maryland GHG inventory the last available year of historical data. GCAM generates results in 5-year time steps, so emission results for 2031 are calculated as a linear interpolation between 2030 and 2035. Non-emissions data is not interpolated; therefore 2030 data is sometimes referenced in discussions about the 2031 target. Global warming potentials (GWPs) with a 20-year time horizon are used throughout the report to convert non-CO_2 gases to CO_2-equivalents, as required in the CSNA.[5] This effectively emphasizes the potency of short-lived climate pollutants (SLCPs), such as methane, compared to 100 year GWPs, which were used in Maryland's GHG inventory prior to the CSNA requirement. Therefore, sources of SLCPs are particularly important to address as drivers of overall emissions in sectors such as agriculture, fossil fuel, and waste management under this accounting requirement.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

This analysis assumes full implementation of all modeled policies in the Current Policies and Maryland's Climate Pathway scenarios. This means that these results represent the uppermost potential for emissions reductions achievable under these policies (see Section 2.10 for sensitivity analysis of incomplete policy implementation). Significant effort through supportive policies, regulations, and community engagement is therefore necessary to reach the modeled emissions reductions. It is also important to address equity concerns about how a given policy is implemented, which is often not represented within the model structure itself. Particular challenges for implementation of key policies with regard to these issues are noted for each sector under *Considerations for Policy Implementation*. These sections are not intended to provide a complete analysis of these concerns, which is beyond the scope of this work, but rather to briefly describe challenges and opportunities for a given policy. Each consideration is motivated by a mitigation strategy the modeling results suggest is needed to reach the State's goals and addresses concerns that go beyond the scope of the model.

2.1 ELECTRICITY SECTOR

MODELED POLICIES: CURRENT POLICIES SCENARIO

In the Current Policies scenario, the major policies modeled in the electricity sector include Maryland's Renewable Portfolio Standard (RPS), the Regional Greenhouse Gas Initiative (RGGI), and renewable energy incentives from the federal Inflation Reduction Act (IRA). We also assume planned retirements of coal-fired power plants in Maryland and relicensing of existing nuclear generation facilities at Maryland's Calvert Cliffs station.

Maryland's RPS works to increase the production of renewable energy sources, such as solar, wind, hydropower, and other alternatives to fossil fuels. The RPS requires electricity utilities and suppliers to meet a prescribed minimum portion of their retail electricity sales with various renewable energy sources, which have been classified within the RPS Statute as Tier 1 and Tier 2 renewable energy sources.[6] In the Clean Energy Jobs Act of 2019, Maryland's RPS increased the amount of renewable energy that electricity suppliers must procure from renewables to at least 50% from Tier 1 renewable energy resources by 2030.[6] Additionally, there is a carve-out that requires that 14.5% of retail electricity sales come from solar resources by 2030. The RPS initially allowed no more than 2.5% (500MW) from offshore wind, but then changed to require additional procurement of at least 1,200 MW from offshore wind projects. Maryland will surpass this new RPS target, with over 2,000 MW of total offshore wind capacity expected to come online after 2025.[6,7] Due to modeling constraints, the RPS requirements were modeled as separate requirements on generation within Maryland and within the larger PJM region rather than as a single policy, which effectively represents the purchase of renewable energy certificates (RECs) for imported power. Future analysis may refine this policy representation.

RGGI is a multi-state cap-and-invest cooperative effort by 12 Northeast and Mid-Atlantic states to reduce carbon dioxide (CO_2) emissions from power plants with a goal to cut power plant emissions 30% below 2020 levels by 2030.[8] Through this initiative, the states issue CO_2 allowances that authorize regulated sources to emit one short ton of CO_2. Once every three months, RGGI auctions off these allowances to power plants and reinvests the proceeds in member states.

Coal phaseout is already underway in Maryland. As of 2023, all coal-fired power plants are in the process of retiring or switching to other fuel sources in the next few years.[9,10] However, a number of the states in the PJM Interconnection do not have plans to fully phase out coal power, including West Virginia, Kentucky, Illinois, Pennsylvania, Indiana, Ohio, and Michigan. This has a potential impact on the State's climate progress because Maryland is currently a net importer of power and accounts for the emissions from imported power using the average emissions rate of the rest of the PJM interconnection.

Maryland has one operating nuclear plant, Calvert Cliffs Nuclear Power Plant, in Lusby, Maryland. It has two operating reactors that can produce up to 1,790 MW of zero-emissions energy.[11] Both reactors have been relicensed with the Unit 1 reactor operating through 2034 and Unit 2 operating through 2036, and, in this analysis, are assumed to be relicensed for continued operation through 2050.[11] This assumption is in line with the State's previous assumptions in the 2030 GGRA Plan,[12] but could impact the generation mix modeled here post-2034.

The IRA allocates $30 billion in clean energy production tax credits (PTC) for taxable business entities and direct pay to certain tax-exempt entities, including local governments and many nonprofits.[13] The PTC offers a base tax credit of 2.75 cents per kWh for clean energy projects under 1 MW and 0.5 cents per kWh for projects greater than 1 MW.[14] Eligible entities can receive PTC bonuses for siting in energy communities which will be heavily affected by a transition away from fossil fuels, meeting domestic content minimums, and meeting wage and apprenticeship requirements.[14] The IRA also allocates $10 billion in investment tax credits (ITC) for the same eligible entities. The base ITC is 30% of the total qualifying project cost for projects under 1 MW and 6% of the total qualifying project cost for projects greater than 1 MW. Eligible entities can also receive ITC bonuses for siting in energy communities, meeting domestic content minimums, and meeting wage and apprenticeship requirements, as well as siting in low-income communities, and for qualified low-income residential building or economic benefit projects.[14] To accommodate the influx in clean energy supply, the IRA provides $5 billion for energy infrastructure reinvestment projects.[13] Qualifying projects will retool, repower, repurpose, or replace energy infrastructure that has ceased to operate; or enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or anthropogenic emissions of GHGs.[13] Finally, the IRA expands and extends the 45Q tax credit which incentivizes the use of carbon capture and storage (CCS).[13] With the passage of the IRA, the tax credit now provides up to $85 per ton of CO_2 permanently stored and $60 per ton of CO_2 used for enhanced oil recovery (EOR) or other industrial purposes.[15]

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

In Maryland's Climate Pathway, all current policies listed above were included with the addition of more ambitious policies needed to reach the State's goals. Additional policies in this sector include a strengthened RGGI target of zero GHG emissions by 2040 and a clean electricity standard (CES) requiring 100% of in-state electricity to be produced from clean sources by 2035.

MODELING RESULTS

Decarbonizing the power grid will be critical as electrification ramps up in end-use sectors. In 2031, the electricity sector achieves GHG emissions reductions of 83% below 2006 levels under the Current Policies scenario and 89% under Maryland's Climate Pathway scenario, delivering the largest emissions reductions of all sectors.

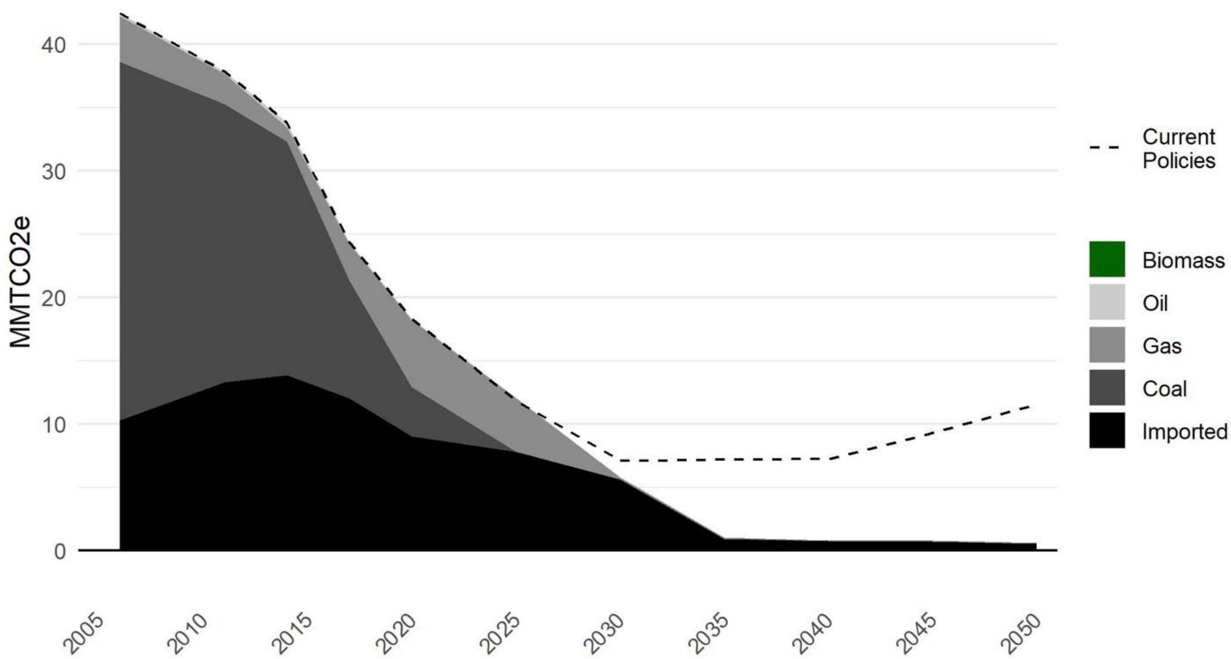

Figure 2.4. Electricity sector GHG emissions over time in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison.

In both scenarios, coal power is assumed to phase out by 2025, per datasets from EIA-860,[16] Global Energy Monitor's Global Coal Plant Tracker,[17] the U.S. Environmental Protection Agency (EPA) NEEDS database,[18] and the announcement of the Warrior Run facility's retirement by AES.[19] In-state generation meets the RPS target of 50% by 2030 and complies with the current RGGI target, with federal tax incentives lowering the costs of renewables. In Maryland's Climate Pathway, natural gas is rapidly displaced by renewable sources by 2031 under more stringent requirements from RGGI and the CES and the early retirement of natural gas plants as a result of the cap-and-invest program. All remaining natural gas plants are equipped with carbon capture and sequestration (CCS) technology by 2035, which would be supported by the recently proposed EPA rule on power plant emissions.[20] The majority of remaining emissions come from natural gas generation and electricity imported from surrounding states. Due to the rapid electrification in end-use sectors, the demand for electricity grows by over 20% from today's levels by 2031, a level of growth comparable to electricity demand increases seen in Maryland in the 1990s.[21]

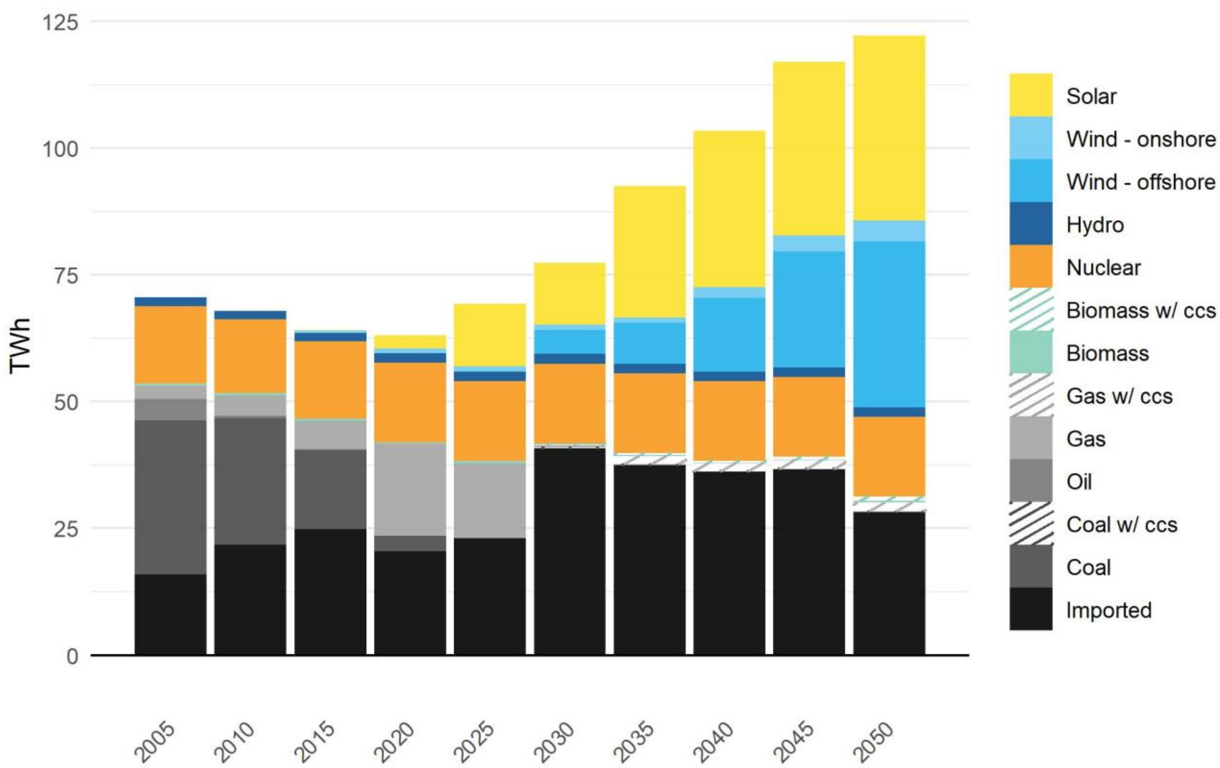

Figure 2.5. Electricity generation mix in Maryland over time in Maryland's Climate Pathway, including imported electricity from the PJM grid.

Zero/Low Emissions Technologies

Under Maryland's Climate Pathway, both wind and solar generation increase fivefold by 2031, with solar accounting for 33% of in-state generation and wind accounting for over 15%. Offshore wind represents over 80% of total wind generation in 2031, reaching an estimated capacity of 2.2 GW in 2035. Nuclear generation is held constant at 2020 levels, due to the relicensing of Calvert Cliffs through 2050.

Fossil Fuel Technologies

With the phaseout of coal by 2025, the only major remaining in-state source of emissions is natural gas. By 2031, natural gas generation in Maryland's Climate Pathway falls by over 95% from today's levels, accounting for less than a 2% share of in-state generation, compared to a 15% share under the Current Policies scenario. This drop in natural gas generation is driven by the cap-and-invest program, which begins in 2030 and forces the retirement of natural gas power plants earlier than what would have occurred under the CES.

Imported Electricity

Imported electricity from surrounding PJM states makes up over half of the electricity demand in Maryland in 2031 and contributes to over 95% of the remaining emissions in the power sector. In this pathway, although Maryland achieves its renewable and clean energy targets for in-state generation, the rapid expansion of solar and wind from current levels in this scenario is not sufficient to meet the growth in electricity demand from end-use sectors and to make up for reductions in natural gas generation. This means that Maryland must also increase imports from other states. The amount of imported electricity will depend on the relative cost of in-state vs out-of-state generation and the rate at which new generation can be built in-state to supply increased demands from electrification. Further increases of in-state deployment of clean energy sources in the near term, beyond what is included in this scenario, would decrease the need for imports.

Beyond 2031

To meet the net-zero goal, renewables deployment continues to ramp up, reaching over 75% of in-state generation by 2045. Additional wind generation is predominately offshore at almost 90% of total wind generation, reaching over 6 GW in capacity, which is close to the 8.5 GW target that Maryland has set.[22] As electrification of end-use sectors continues to increase, electricity consumption also grows by about 50% from 2031 levels by 2045, primarily driven by increased consumption in the transportation sector. Natural gas with CCS is introduced in the 2030s and contributes to 2% of in-state generation by 2045. Residual emissions from natural gas after the implementation of CCS are due to imperfect capture rates, which are generally expected to be, at most, 95%. Biomass with CCS is also introduced in the 2030s, though it plays a minor role, making up less than 1% of the generation mix in 2045. To help meet electricity demand, imported electricity from surrounding states continues at a level slightly higher than the modeled value for 2030.

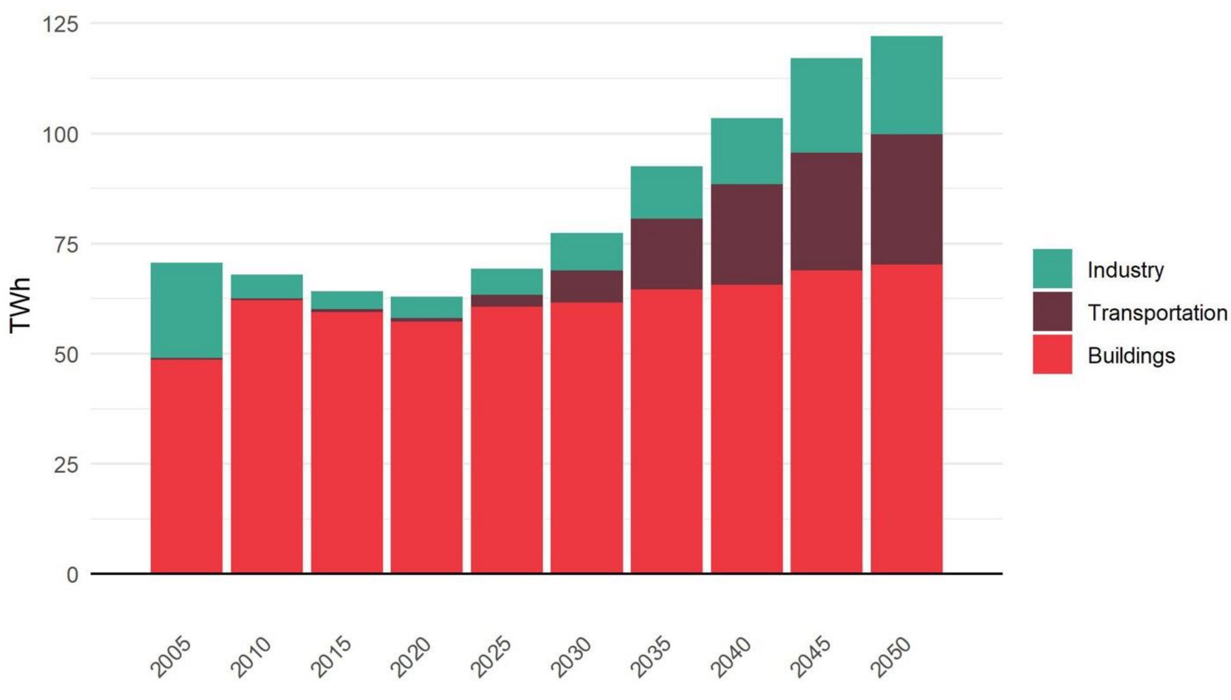

Figure 2.6. Electrical energy consumption by sector in Maryland's Climate Pathway.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

Decarbonizing the electricity sector is critical not only for reducing emissions within the sector, but also for enabling the decarbonization of other sectors such as transportation, buildings, and industry, where electrification is a key solution. This shift is essential for technologies such as electric vehicles (EVs), electric heating and cooling in buildings, and electrification of industrial processes. To facilitate this transition, several critical policies and regulatory actions will need to be implemented across the State. Importantly, coal phaseout and grid stability need to be prioritized to achieve 100% clean energy sources by 2035. Maryland can also leverage its involvement with RGGI to set a zero-emissions cap by 2040. Finally, deployment of renewables, particularly solar photovoltaics (PVs), will need to accelerate rapidly in the near term. Central challenges for these actions will be to ensure this transition is equitable through programs such as community solar, and to ensure that imported electricity is clean so that emissions reductions outside of State borders can also be accounted for in the State GHG Inventory.

IRA Implementation

The IRA allocates billions in federal funds to accelerate the clean energy transition. Maryland can leverage these funds to achieve its own emissions reduction goals. Extending and expanding the federal clean energy PTC and ITC for the next 10 years provides long-term stability and confidence, removing a previous deterrent to investment.[23] The tax credits also include bonuses for domestic production of renewables and siting renewables in energy communities, providing opportunities for Maryland to spur job creation and prioritize equity. Additionally, for the first time, the IRA also allows for tax-exempt organizations to take advantage of tax credits through direct payments.[24] This opens new possibilities for the Maryland State government and local governments to build out renewable resources themselves, as well as to educate and support other tax-exempt organizations in the State to help them receive these benefits. Because the tax credits are not capped, Maryland should work to take advantage of the credits to the greatest extent possible.

To achieve an equitable implementation of the IRA benefits, it is essential to keep in mind disadvantaged communities that are greatly affected by climate change and bear disproportionate environmental burdens, as well as energy communities that are at risk of being left out of the renewables transition. Maryland can leverage IRA provisions, including the Greenhouse Gas Reduction Fund and the Energy Infrastructure Reinvestment Program, to bring clean jobs and clean electricity to disadvantaged areas.[25,26] Maryland can also utilize the loans made available by the Energy Infrastructure Reinvestment Program to support coal phaseout by 2025 and revitalize energy communities whose livelihoods are tied to declining fossil fuels.

Ensuring Grid Stability Through the Renewable Energy Transition

To replace coal and other fossil fuels, Maryland needs to achieve a rapid deployment of renewable technologies that ensures a resilient grid in response to growing demand and concerns of instability. Many states, including Maryland,[27] have begun implementing grid management and grid modernization policies to support increasing variable renewable generation. For example, Illinois's Energy Infrastructure Modernization Act (EIMA) authorized up to $3.3 billion in funding for advanced metering infrastructure

(AMI) and other grid investments and established a performance-based mechanism for ROE rate determination.[28] Maryland's Public Service Commission (PSC) found that such performance- based rates may be helpful, if carefully implemented, in facilitating the achievement of the State's ambitious goals for electrification, renewable development, pipeline replacement, development of new consumer solutions, grid resiliency, and other State goals.[29]

Maryland can help prepare the grid for increased demand through investment and deployment of new technologies, including central and distributed storage and microgrids.[30] Recently, Maryland enacted the Maryland Energy Storage Program that established energy storage targets to accelerate deployment: 750 MW by year's end 2027; 1.5 GW through 2030; and 3 GW through 2033.[31] This follows the establishment of an Energy Storage Pilot Program which required the State's four investor-owned utilities to solicit offers to develop energy storage projects and submit to the PSC for approval.[32] One ongoing energy storage project, the Talen Energy project in Baltimore, is projected to store 20 MW of energy with the potential to expand in the future.[33] These energy storage additions can play an important role in grid stability as renewables come online, but it should be noted that when storage is connected to the wider grid rather than to a dedicated renewables project, the energy it provides is only as clean as the grid mix. Microgrids can improve supply and grid resilience by providing generation during extreme weather events, independent of an impacted grid.[34] For example, the California Public Utilities Commission implemented the Microgrid Incentive Program in 2021 to fund clean energy microgrids with a $200 million budget.[35] However, there are technical and financial barriers to the widespread adoption of both of these technologies. As they have yet to be rapidly deployed, more research and development are necessary to achieve cost competitiveness.[34]

Leveraging Interstate Collaboration through RGGI

Setting RGGI on a path to zero emissions by 2040 is central to meeting the State's ambitious 2031 goal. This is dependent on agreement by the other RGGI states, and Maryland will need to work in partnership with other leading states to push for more ambitious targets. Through Maryland's Strategic Energy Investment Fund (SEIF), the mechanism by which the State invests RGGI auction proceeds, Maryland has an opportunity to direct additional funds to further solar deployment through programs such as community solar operated by the Maryland Energy Administration (MEA). In doing so, the State can consider environmental justice alongside the added capacity and CO_2 emissions savings for every dollar invested by SEIF.

Solar Co-Siting and Co-Adoption

Solar siting is another critical factor for achieving sufficient deployment of renewables, as deployment of solar requires significant land area, which can lead to land conversion or competition with other land uses. However, there are many opportunities to expand co-siting of solar within Maryland to address this concern, including agrivoltaics;[36] leveraging unused lands at airports;[37] establishing community solar with the help of hospitals;[38] and deploying solar on closed landfills and other brownfields.[39] Some states, including New York and, more recently, California, have also increased their authority to approve utility-scale renewable energy projects.[40] Since the passage of the law in NY in 2020 that gave the state final approval over new projects, many more utility-scale projects have been approved.[40] It is important to keep in mind, however, that different policy instruments are appropriate for different states, as factors such as population and long-term support for solar help explain variations in adoption among states.[41]

There is also an important potential for synergy between adoption of residential solar and EVs, which could support a larger buildout of distributed solar through efforts such as the Solar Canopy Program operated by MEA.[42–44] Research on adoption trends showed that adoption of EVs and residential solar follow different trends, necessitating a different approach for each to ensure co-adoption of both is supported.[45–47] Solar adoption was strongly correlated with housing variables, such as housing type, value, and ownership, as opposed to race or income.[45] EV adoption was better explained by economic variables such as income and wealth.[45] Thus, it is particularly important to consider trends and drivers of solar and EV adoption, along with implications for energy equity, when promoting adoption of EVs and residential solar.

Interconnection Challenges

Interconnection is the process of connecting power generation and storage projects to the local grid or transmission system. This process can sometimes be costly, at times requiring upgrades to the broader network or construction of additional infrastructure at the point of interconnection, particularly for variable renewable resources like solar.[48] Given the need for rapid deployment of solar, wind, and other renewables, and storage to meet Maryland's goals, having expeditious interconnection processes is paramount. A recent report focusing on Massachusetts[49] outlined particular issues with interconnection queues, noting that considering one project at a time and placing all upgrade costs (referred to as cost causation) on the proposed project can cause delays and lead to project withdrawals. Another recent report on the PJM grid[50] outlined how the backlog and delays of the PJM interconnection queue could affect Maryland's ability to meet its renewable goals. It is important to note that PJM will be employing a new process for its interconnection queue going forward, which will evaluate many projects at once in a cluster-based approach.[51] However, the extent to which the backlog is filled and new projects are quickly studied and approved will be a deciding factor for renewables growth in Maryland.

Inventory Accounting Methodology

Maryland's GHG accounting methodology calculates emissions from imported electricity based on the average carbon intensity of the rest of the PJM grid. This diverges from the accounting methodology of the State's RPS, which allows out-of-state renewable generation to count toward the standard. This means that emission reductions from imported electricity requires either high ambition from all PJM states (those participating in and outside of RGGI) to lower the emissions intensity of the entire grid, or adjustment in state accounting methodology to allow for time-matched RECs. The use of time-matched RECs means that imported electricity would be uniquely matched with a renewable generation source that is producing electricity at the time of the import through the newly created PJM hourly tracking system.[52]

Partnerships for Equity, Access, and Benefits

Collaboration across private and public sectors, communities, and civil society has been proven to help expedite decarbonization efforts, gain support and funding for renewable energy projects, deploy new innovations in the clean energy field, and help ensure equity, access, and affordability to low-income communities.[53] Recently, Maryland permanently adopted a less restrictive and more equitable statewide community solar program.[54] At least 40% of the power output from community solar projects will be set aside for low-and-middle income (LMI) subscribers (except when subscribers totally own the system), aligning the State's community solar program with the federal Justice40 initiative.[54][55] Through these collaborations between local utilities and solar facilities, all Maryland residents can pay to access solar-generated electricity, help advance renewable energy, and save money on utility bills, while extending savings and access to historically marginalized residents that may not own their residence.[56] A deliberate focus on community solar access for low-income Marylanders is important, as, historically, renewable energy benefits have been primarily realized by high-income residents.[57] One key recommendation to prevent this is ensuring early adoption, which Maryland is already working to accomplish through their pilot program. As this pilot program takes permanent form, more collaboration will still be needed to answer critical questions on deployment, participation, and program evaluation.[57]

CASE STUDY: OFFSHORE WIND ON MARYLAND'S COASTS

In an effort to meet its renewable energy goals and generate enough clean energy to power thousands of homes, the State of Maryland has begun developing four offshore wind projects off the coast of Ocean City, MD. These offshore wind projects are planned at 2,022.5 MW of offshore wind capacity, enough to power 600,000 average Maryland homes and accelerate the achievement of Maryland's renewable energy goals over their 20-30-year lifespans. While these projects are planned for operation in 2026, they are not yet permitted or under construction.[58]

Not only will these wind turbines create new sources of more environmentally friendly energy, they are also expected to create about 12,000 direct full-time equivalent job opportunities in Maryland. Because installation of offshore wind projects is far more complex than a land wind project, Maryland residents will benefit from the substantial job opportunities in building and operating the State's wind projects. Wind jobs can support sustainable local economies and careers across a variety of skills and expertise, including transportation of raw materials and supplies, production and assembly, installation, and maintenance. To realize a successful offshore wind industry in Maryland, training centers and resources must be economically and locationally accessible to all Marylanders, including the most vulnerable communities, and access to diverse and accessible career pathways must be expanded for the next generation of workers who will lead the clean energy transition.

2.2 TRANSPORTATION SECTOR

MODELED POLICIES: CURRENT POLICIES SCENARIO

In the Current Policies scenario, modeled policies in the transportation sector include the Advanced Clean

Cars (ACC) II rule, the Advanced Clean Trucks (ACT) rule, and comprehensive smart growth policies that improve travel efficiency and reduce vehicle miles traveled (VMT). Federal policies impacting transportation include electric vehicle (EV) and sustainable fuel tax credits from the IRA; EV infrastructure investments from the Bipartisan Infrastructure Law (BIL); and Corporate Average Fuel Economy (CAFE) standards.

Maryland is adopting the ACC II rule this year, requiring manufacturers to continuously increase the share of zero-emission vehicles (ZEVs) they sell within the State until reaching 100% of passenger car and light truck sales by 2035.[59] The ACC II rule was originally adopted in California, but has now been adopted by multiple other states, including Maryland. The California ACT regulation similarly requires manufacturers to make zero-emission trucks an increasing percentage of their annual sales from 2024 through 2035.[60] The Maryland ACT requires Maryland to adopt this regulation effective in 2027.

In addition to adopting emerging technologies and building out infrastructure to support such technologies, Maryland's Department of Transportation (MDOT) also aims to improve travel efficiency and reduce VMT in a comprehensive approach to decarbonization in the transportation sector. MDOT's existing strategies include transitioning to cleaner and more efficient public transportation; expanding public transit systems and intercity systems; investing in bike and pedestrian infrastructure; and achieving the GGRA Smart Growth program's compact development goal.[12] Maryland achieved its 75% compact development goal (as defined in the technical appendix[61]) for the 2011-2020 planning period and is working to continue efforts on land use location efficiency to reduce VMT and combustion of fossil fuels.[12] MDOT is also pursuing strategies that are not modeled here explicitly, including on-road technology for traffic management; projects to expand freight and rail capacity; transportation demand management; all-electronic tolling, drayage truck and BWI airport parking shuttle bus replacements; electrification of the State passenger vehicle fleet; and a all 2024 requirement for zero-emission school bus purchases.

The IRA provides a $4,000 tax credit for used light-duty EVs and a $7,500 tax credit for new light-duty EVs, subject to income limitations.[13] To be eligible for the full credit, new vehicles must also undergo final assembly in North America; exceed domestic critical mineral and battery component sourcing thresholds; have a battery capacity of at least 7 kWh; and have a manufacturer's suggested retail price (MSRP) below $80,000 for vans, SUVs, and pickup trucks, or $55,000 for other vehicles. The IRA also extends biofuel, sustainable aviation fuel credits, and other clean fuel incentives ranging from $0.20 to $1 per gallon for biofuels and $0.35 to $1.75 per gallon for sustainable aviation fuels. The credits vary for each fuel based on the emissions factor.[13] In addition to the tax credits, the IRA also allocates $300 million for a sustainable aviation fuel grant program to develop and apply various technologies to the production, transportation, blending, and storage of aviation fuels.[13] The BIL invested $7.5 billion in EV charging infrastructure, $5 billion in school bus electrification, and $1.6 billion in transit bus electrification.[62]

CAFE standards set by the National Highway Traffic Safety Administration (NHTSA) regulate how far vehicles can travel on a gallon of fuel, with separate standards for light-duty vehicles and medium-and-heavy-duty vehicles.[63] Federal CAFE standards for light-duty vehicles increased in 2022, requiring that new vehicles sold in the United States average at least 40 miles per gallon.[64] The updated CAFE standards will increase fuel efficiency 8% annually for vehicle model years 2024 and 2025 and 10% annually for vehicle model year 2026.[64] The EPA recently announced new, more ambitious proposed tailpipe emissions standards to further reduce emissions from light-duty and medium-duty vehicles, starting with model year 2027, but these are not modeled here because they are only proposed, not yet adopted.[65]

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

In Maryland's Climate Pathway, all current policies above were included, with some additional policies also modeled. Additional policies in this sector include VMT reductions based on targets set by other leading states, such as Colorado, as well as California's Advanced Clean Fleets rule, which is assumed to help facilitate achievement of the ACT targets in the near-term. The VMT reductions modeled in Maryland's Climate Pathway represent decreasing passenger-miles traveled. The Advanced Clean Fleet standards operate by driving EV sales of freight trucks after 2035, reaching 100% electric truck sales by 2040. Some electrification of nonroad gasoline usage is also assumed in consumption by lawncare and other commercial equipment.

MODELING RESULTS

In 2031, the transportation sector achieves GHG emissions reductions of 38% below 2006 levels under the Current Policies scenario and 49% under Maryland's Climate Pathway scenario. The majority of emissions reductions occur in on-road vehicles, the dominant source of emissions in the sector.

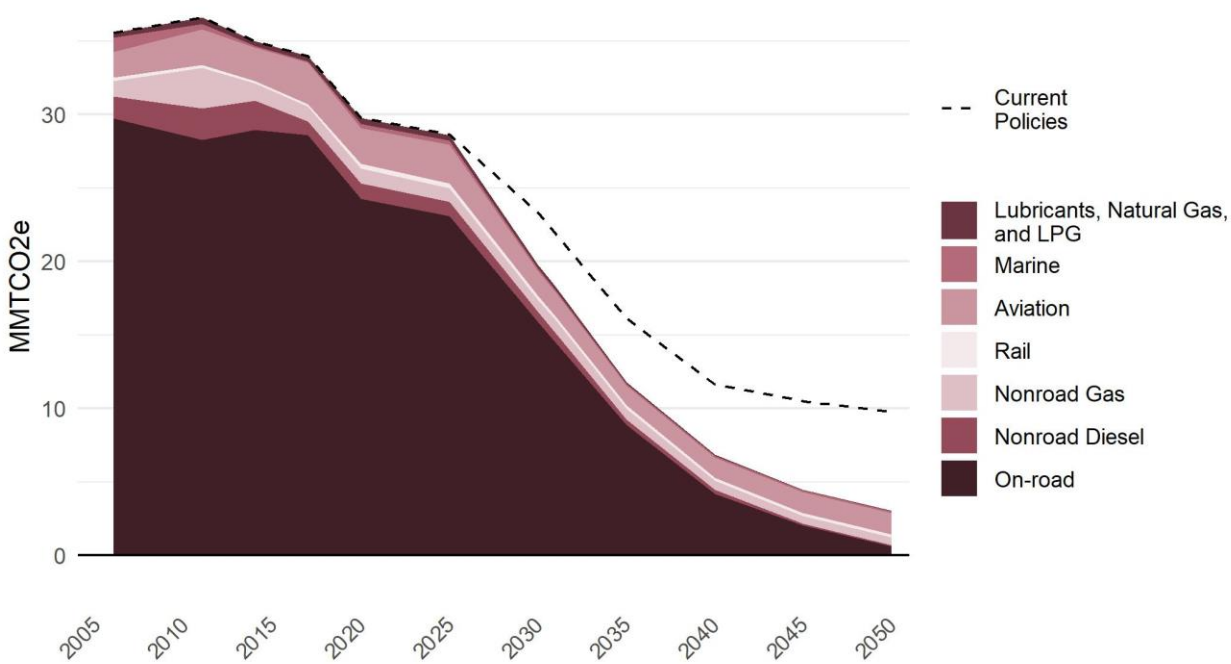

Figure 2.7. Transportation sector GHG emissions over time in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison.

In both scenarios, Maryland achieves the ACC II and ACT targets starting in 2027, with federal EV tax incentives and investments lowering the costs of EVs. At the same time, CAFE standards increase the efficiency of new on-road internal combustion engine (ICE) vehicles, as well as the deployment of EVs. The Advanced Clean Fleets policy is also implemented, complementing ACT to drive freight truck sales to 100% EVs by 2045. Smart growth and transportation demand management policies reduce personal vehicle travel through ridesharing and mode switching to public transit, biking and walking.[66] These changes are presented here in passenger miles traveled, which encompasses any movement of a person over a single mile via any transportation mode. Similarly, changes in freight tonnage movement are presented in ton-miles traveled, which encompasses transportation of one metric ton of freight over a single mile via any transportation mode. Although passenger miles and ton-miles are not equivalent to VMT, the percentage changes between model years can be interpreted in terms of percentage changes in VMT. With additional policies in Maryland's Climate Pathway scenario, passenger miles in personal vehicles are further reduced through additional smart growth transportation policies, and ton-miles are reduced for freight trucks due to the cap-and-invest program, resulting in reduced diesel consumption through service demand reductions and mode shifts. See *Considerations for Policy Implementation* below for more information on policies that could contribute to these reductions.

Passenger Vehicles: Cars, SUVs, and Trucks

Passenger car, SUV, and truck ZEV sales reach 54% by 2030 and 100% by 2035 in Maryland's Climate Pathway, achieving Maryland's ACC II target. In the near term, battery EVs dominate, and hydrogen-powered fuel-cell EVs play a minor role. While passenger miles grow with economic development in 2025, smart growth policies and the cap-and- invest program reduce passenger miles in 2030. As a result, passenger miles increase by 0.6% annually from 2020 to 2030 on average, compared to 2% annually under Current Policies.

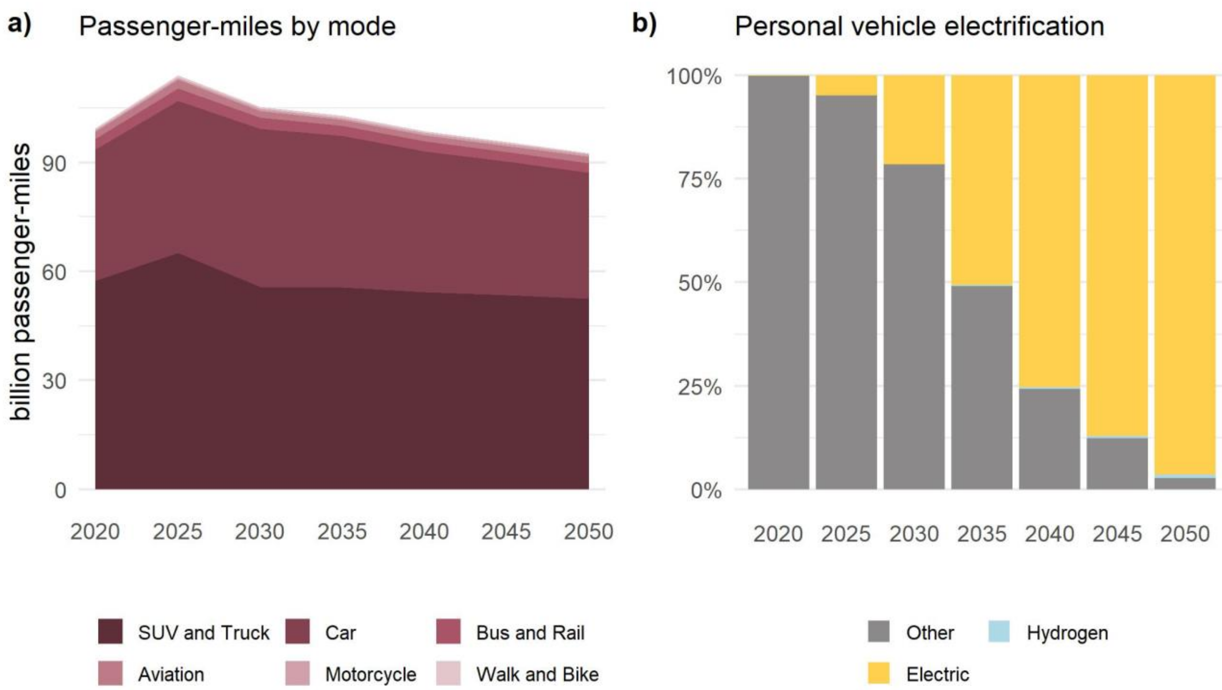

Figure 2.8. Overview of passenger transportation in Maryland's Climate Pathway showing a) passenger-miles traveled by mode in Maryland over time, and b) the percentage of passenger-miles traveled in cars, SUVs, and trucks by fossil-fueled vehicles and ZEVs.

Freight Trucks

Freight truck ZEV sales reach 30-50% by 2030, and 40-75% by 2035, depending on truck type, achieving Maryland's ACT target. In the near term, battery EVs dominate, and hydrogen-powered fuel-cell EVs play a minor role. While ton-miles supplied by freight truck service grow with economic development in 2025, the cap-and-invest program reduces freight truck service in 2030, in order to rapidly reduce diesel use and decarbonize the sector. As a result of these drivers, ton-miles traveled in freight trucks increase by 0.9% annually from 2020 to 2030 on average, compared to 1.5% under Current Policies.

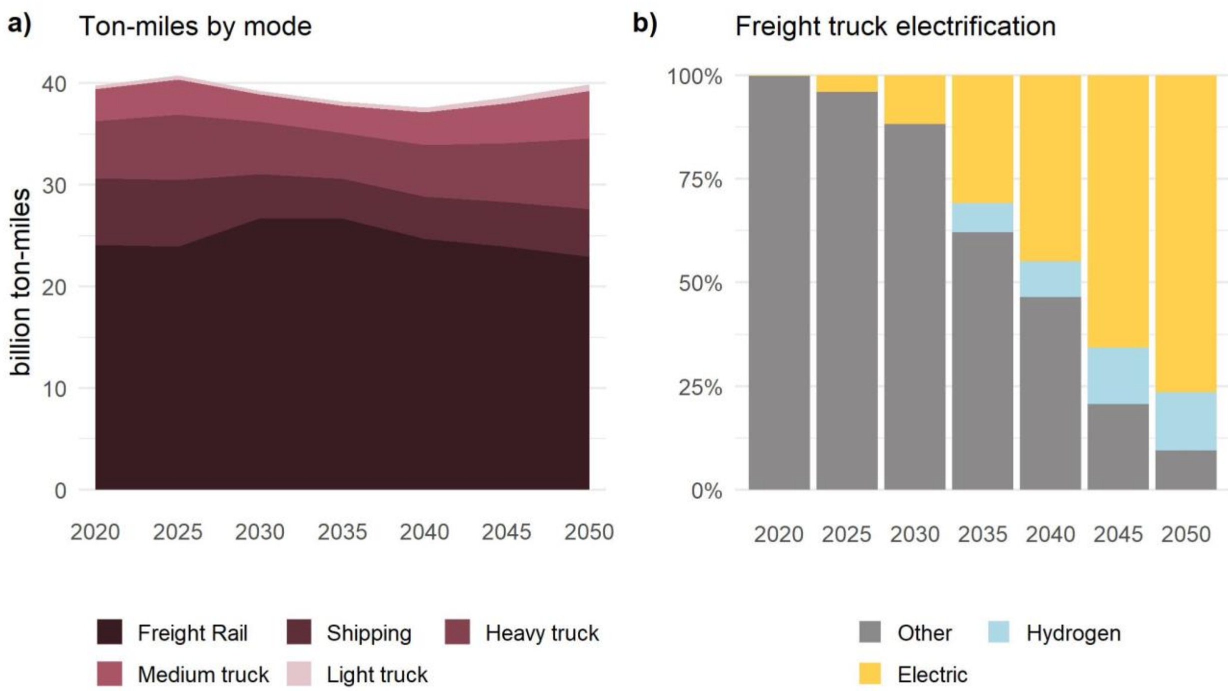

Figure 2.9. Overview of freight transportation in Maryland's Climate Pathway showing a) freight service in billion ton-miles by mode in Maryland over time and b) the percentage of freight trucking in ton-miles by fossil-fueled vehicles and ZEVs.

Nonroad Fuel Usage

Emissions from nonroad gasoline and diesel usage are not modeled directly in these scenarios. Nonroad gasoline usage (primarily by lawn and garden equipment) is assumed to remain constant at 2020 levels in the Current Policies scenario, and decarbonize linearly to 50% of 2020 levels by 2045 in Maryland's Climate Pathway. No specific policies are modeled to achieve this, but policy drivers could include decreased intensity of lawn and garden management, electrification of equipment, or both. Nonroad diesel usage (primarily by construction, mining, and other industrial equipment) was assumed to follow the same reduction trend as freight trucks.

Beyond 2031

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

CONSIDERATIONS FOR POLICY IMPLEMENTATION

Maryland has demonstrated climate leadership by adopting the ACC II standards and passing the Maryland Clean Trucks Act, yet there remain many implementation barriers to achieving the rate of electrification needed in the transportation sector. Reducing VMT and shifting modes of transportation are also important strategies to reach the reductions shown here. Equitable implementation of both of these strategies will also be a key challenge for this sector.

IRA Implementation

Given the complexity of the IRA incentives related to transportation, the State has a pivotal role in delivering those benefits to Marylanders. To receive a tax credit for a qualifying purchase of a vehicle, consumers must be aware of their eligibility and familiar with the rules, forms, and application processes. Maryland can aid in this process by educating consumers on available opportunities. Particular attention should be paid to LMI communities with targeted engagement. Purchasing habits and dealership proximity should be kept in mind given that research has demonstrated socioeconomic and racial disparities for EV purchases and dealership access, respectively.[102] The State could expand Montgomery County's Electrified Dealer Program as one way to disseminate necessary IRA information, focusing on underserved communities. To further push EV adoption, Maryland should address charging infrastructure concerns, a barrier to many potential consumers, including communities of color.[103] Specific funds in the IRA, through the Tax Credit for Alternative Refueling Property, help cover the cost of EV charging infrastructure in low income and rural census tracts.[104] Leveraging these funds in tandem with funds the State is already receiving from the BIL[105] for EV charging infrastructure could further incentivize Marylanders to adopt EVs.

Maryland can also look to other states, like Colorado, that have added additional state incentives, on top of IRA provisions, to bring in more federal dollars.[106,107] Given that the IRA tax credits are non-refundable, Maryland could offer rebates for those who do not qualify, further promoting EV adoption. The State can also create regulations that support EV adoption, such as requiring new homes to be EV charger-ready to save consumers money on costly retrofits.[108] Finally, the State can leverage IRA funding to aid in electrifying its own vehicle fleet by utilizing Clean Heavy-Duty Vehicle grants and the Commercial Clean Vehicle Tax Credit. To electrify local government fleets, the State can also educate and support municipal governments, schools, and others applying for these funds.[109]

Electric Vehicle Adoption

For Maryland to increase its sales of EVs and achieve the full potential of ACC II, the State will need to find ways to lower the cost of EVs in a way that is equitable for all Maryland residents. Currently, Maryland offers an excise tax credit of up to $3,000 for EV purchases, while other states, such as New Jersey,[67] Colorado,[68] and Connecticut,[69] provide higher rebates that range from $5,500 to $8,000. Increasing Maryland's rebates and the amount of funding for the program would align the State with others pursuing similar goals and prevent sales from flowing to neighboring states with less stringent targets. This is a key risk for Maryland's ACC II regulation, as the purchase of non-EVs in surrounding states that have less stringent targets (aka "sales leakage") could lead to lower numbers of EVs than if all sales were covered by the in-state targets. It is critical to track where EVs are sold and the total number of EVs on the road, as California does, to ensure Maryland's transportation sector is truly decarbonizing and meeting its targets.

Another key policy consideration in this sector is the impact of increasing vehicle electrification on gas tax revenue and its traditional use for road maintenance. As increasing adoption of EVs reduces fuel sales, alternative sources of funding will need to be found. Detailed studies and pilot programs at both the state[70–73] and federal[74–76] levels have addressed this issue and identified potential solutions, including shifting to a VMT tax, taxing kWh at commercial EV charging stations, and the introduction of more targeted taxes and fees based on vehicle weight, time of day, and location.[74,77–79] Addressing this concern will be crucial to maintain and expand investment in the Transportation Trust Fund (TTF), which is primarily funded by fuel tax revenue, but can also be a key avenue to support the transition away from emitting vehicles by funding EV infrastructure, bike lanes, and walkability.[66]

Realizing the Advanced Clean Truck Rule

Another critical challenge for emissions reductions in this sector is achieving the full potential of the ACT rule. The ACT goals are very ambitious, given that the current market for ZEV trucks is close to zero at present, and the rule will not be implemented until 2027. The steep increase in ZEV sales to reach 30-50% by 2030 will require early and rapid action from manufacturers, as well as government incentive programs to reach this target. ZEV costs and availability will be a constraint for this sector, and policies will be needed to bring down costs in order to ensure sufficient deployment of ZEV trucks. The needs of low- and middle-income communities and small business operators must be met through various incentive and outreach programs, including funds described in the IRA implementation section below, to ensure a just transition. In addition, Maryland's bill to implement ACT expands funding from FY 2024 through 2027 to at least $10 million in grants for medium- and heavy-duty ZEVs or zero-emission heavy equipment. Because EV charging infrastructure suitable for freight vehicles must also be built and expanded in Maryland and throughout the wider region to make this transition feasible, Maryland should partner with surrounding states to support interstate freight transportation. One caveat with Maryland's ACT regulation is its requirement of a thorough needs assessment prior to implementation, which could delay realization of the rule.[80] The assessment must analyze factors such as the number of charging stations needed, how utilities could fulfill new demands, economic feasibility, etc. Through this assessment, the bill also lays the groundwork for transitioning medium- and heavy-duty vehicles in the State fleet to ZEVs.

Zero-Emission Vehicle Supply Chains

Recent analysis from the Department of Energy classifies many materials necessary for ZEVs as critical or near-critical supply risks, including key components of batteries and fuel cells such as lithium, cobalt, nickel, and platinum.[81] If future supplies of these materials are limited, it will be essential to both reduce the overall need for ZEVs by reducing personal vehicle use, and to reduce the materials intensity of vehicles by building smaller and lighter vehicles to make the most of available supply. Lighter-weight vehicles require less energy to go the same distance as heavier vehicles, meaning material requirements are reduced.[82] Encouraging drivers to switch from SUVs and trucks to cars, or cars to e-bikes where appropriate, can dramatically reduce the total quantity of critical materials needed to support transport electrification.[83,84] Circular economy approaches that ensure materials are recovered and reused can also help alleviate supply-chain constraints.[85]

Electrifying Nonroad Fuel Use

Nonroad engines, reliant on either diesel or gasoline, play important roles in numerous industries. As of 2020, the largest portions of Maryland's emissions in this category come from lawn and garden equipment, construction and mining equipment, and industrial equipment. In each of these areas, opportunities for electrification are expected to grow in years ahead. Market research projects the global electric lawn mower market to grow at a rate of over 6% annually over the next five years.[86] Households can be incentivized to trade in their gas lawn mowers for electric models through programs like Southern California's rebate of up to $250.[87] Purchasers of large, commercial grade electric mowers can take advantage of federal IRA tax credits worth 30% of total cost.[88] Significant potential for emissions reductions also exists in electrifying construction equipment, which is currently dominated by diesel fuel. A rapid annual growth rate of 22% through 2027 is expected in the electric construction equipment industry, although continued investment in fast charging technology will likely be necessary to realize this growth.[89] Again, California serves as a potential model for incentivizing the purchase of more expensive electric equipment through its Clean Off-Road Equipment Voucher Incentive Project (CORE).[90]

Beyond Vehicle Electrification

Relying solely on vehicle electrification is insufficient to meet the targets for reducing GHG emissions. The Climate Change Mitigation Study conducted by the Transportation Planning Board (TPB) revealed that the Greater Washington D.C., region (including Prince George's, Frederick, and Montgomery Counties) needs to achieve a 15-20% reduction in per capita driving (light-duty VMT) below the 2030 baseline forecast, as outlined in the current transportation plan.[91] Maryland has an uphill battle. Total annual VMT steadily rose from 2014 through 2019 in Maryland, though there was a 17% reduction in VMT in 2020 due to the COVID-19 pandemic and associated restrictions.[66] VMT in Maryland increased in 2021, although not to pre-pandemic levels, and increased only slightly in 2022. It is unknown if this slower growth reflects a longer-term trend. Establishing a comprehensive and accurate system to measure and track individual vehicle mileage across a diverse range of vehicles and roadways is complex and may face resistance from the public, particularly if it involves imposing additional costs or changing established practices.[92] Addressing these challenges requires effective communication, stakeholder engagement, and a well-designed framework that promotes fairness, transparency, and public acceptance.

Smart Growth and Zoning Reform

Smart growth and zoning reform to reduce VMT are key areas where local and county-level action will be essential and can offer additional opportunities to preserve open space, farmland, natural beauty, and critical environmental areas. Strategies that can contribute to reduced VMT include densification and "upzoning,"[93] mixed-use development,[94] transit-oriented development,[95] parking reform,[96,97] and programs targeting behavior change.[98] However, it is crucial to implement these reforms using best practices that minimize potential drawbacks, such as traffic congestion, inequitable access to infrastructure, disruption of existing communities, and increased pollution.[99,100] Previous development of transportation systems, such as the interstate highway system, often happened at the expense of marginalized communities. Future development should seek to redress these harms rather than exacerbate them.[101]

Partnerships for Equity, Access, and Benefits

The promotion of bike lanes and walkability as alternatives to driving is an increasingly popular transportation strategy.[110] This can be achieved through various measures including government funding for "complete streets" with protected space for biking and walking, as well as bike-share programs or e-bike rebates and incentives.[107,111–113] Additionally, restricting car access on roads and reclaiming street space for pedestrians through "Open Streets" can contribute to a more walkable environment.[114] However, the lack of current infrastructure, lack of available governmental financing, limited retail interest, and the influence of the auto industry pose challenges to implementation of these initiatives. Changing public perceptions toward alternative modes of transportation is also a significant factor. On the positive side, promoting bike lanes and walkability offers numerous benefits, including improved health resulting from a more active lifestyle and lower maintenance costs for roads.[115] California's Active Transportation Program (ATP), which aims to enhance active modes of transportation throughout the state, is a notable example of this approach.[116] The 2023 Cycle 6 of the ATP is expected to include about $650 million in funding for as many as 100 potential projects.[116] Most recently, Minnesota passed a transportation funding bill that addresses the negative climate impact of highway expansion and increases VMT by requiring state agencies to make investment decisions consistent with GHG and VMT reduction goals.[117] It further requires cities to establish climate action plans and forecasts related to GHG emissions and VMT, including from land use.[117]

CASE STUDY: MONTGOMERY COUNTY PUBLIC SCHOOLS' ELECTRIC SCHOOL BUSES

Climate change and concerns about student and community health are driving school bus electrification mandates around the country, including in Maryland. The CSNA requires all new school bus purchases and contracts to be electric by 2025. Montgomery County Public Schools (MCPS) and Highland Electric Fleets (Highland) recently implemented the country's single largest deployment of electric school buses at Walter Johnson High School, upgrading 326 school buses to electric by 2025. On a business-as-usual day, MCPS diesel buses use approximately 17,000 gallons of diesel fuel, emitting GHGs and other harmful matter from tailpipes. Replacing the diesel bus fleet with electric buses will help Montgomery County achieve its target of reducing GHG emissions 80% by 2027 and 100% by 2035.

The partnership between Highland and MCPS will not only deliver cleaner, healthier transportation for students and local communities, but will also support electric grid reliability with vehicle-to-grid (V2G) services and the nation's first use of electric school buses to provide synchronized energy reserves. During the 2021-2022 school year, MCPS installed 25 electric buses. In the 2023 school year, another 61 buses will be delivered, and electric infrastructure will be installed at three more transportation depots.

CASE STUDY: ELECTRIC VEHICLE CHARGING DEPLOYMENT & JOB CREATION IN MARYLAND

Blink Charging actively collaborates with local governments, businesses, and organizations to identify suitable locations for charging infrastructure installations. One of their main facilities is based in Bowie, MD, where they engage in local hiring initiatives by partnering with electricians, contractors, and technicians to ensure the successful deployment and maintenance of their charging stations.[118] These collaborations not only stimulate economic growth but also help to upskill and train individuals in the emerging clean energy sector, fostering a skilled workforce for the future. Blink Charging has called for increased capacity from their Bowie manufacturing facility by 40,000 units by 2024.[118]

To realize Maryland's climate goals, a comprehensive charging network is needed to facilitate the increased adoption of EVs and enable a shift away from traditional combustion engines. Blink Charging provides an example of how establishing partnerships with various stakeholders, including local governments, businesses, property owners, utilities, and industry leaders can deploy charging solutions that will more seamlessly integrate into existing infrastructure. This collaborative approach can ensure the availability of charging stations in key locations, such as residential areas, workplaces, retail centers, and public spaces, making EV ownership more viable and convenient.

2.3 BUILDINGS SECTOR

MODELED POLICIES: CURRENT POLICIES SCENARIO

In the Current Policies scenario, modeled policies from buildings include the EmPOWER Maryland Energy Efficiency Act, the Building Energy Performance Standards (BEPS) required by the CSNA, and the IRA.

The EmPOWER Maryland Energy Efficiency Act was established in 2008 and promotes money-saving energy efficiency programs in Maryland for businesses and consumers.[119] EmPOWER programs are managed by Maryland's five largest electric utilities and two largest natural gas utilities, with the exception of programs for low-income customers, which are managed by the Maryland Department of Housing and Community Development (DHCD). Various programs include lighting and appliance rebates, heating, ventilation, and air conditioning (HVAC) rebates, Home Performance with Energy Star, Energy Star New Homes, combined heat and power grant programs and other efficiency services and measures for residential and commercial facilities.[119] The EmPOWER Maryland Limited Income Energy Efficiency Program (LIEEP) helps residents of limited-income households install energy conservation materials in their homes at no charge. Overall, the EmPOWER program aimed to achieve an annual energy savings goal of 2% gross energy sales, which the CSNA increased to 2.25% for 2025-2026 and to 2.5% beginning in 2027.[5] The Maryland PSC continues to require utilities to establish further programs to encourage and promote the efficient use of energy.

Under the CSNA, the Maryland Department of the Environment (MDE) was tasked with developing BEPS for buildings larger than 35,000 square feet.[120] These standards are expected to establish benchmarking requirements as well as energy usage reduction and emissions reduction targets. Covered buildings are required to achieve a 20% reduction in direct greenhouse gas (GHG) emissions by 2030 compared with

2025 levels and net-zero direct GHG emissions by 2040.[120] The buildings covered by BEPS will have different energy use intensity (EUI) requirements, depending on property type.

The IRA includes several incentives for reducing emissions in the buildings sector. The IRA provides $9 billion in consumer home energy rebate programs, with a specific focus on low-income consumers for energy efficiency retrofits and electrification of appliances.[13] The IRA also extends, increases, and modifies the new energy efficiency home tax credits.[24] Additionally, the IRA provides $35 billion over ten years in consumer tax credits for energy efficiency and clean energy upgrades including heat pumps, rooftop solar, and electric HVAC.[24] For commercial buildings, the IRA allows certain expenses associated with qualifying efficiency improvements to be tax deductible.

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

The policies above, as well as additional policies, were all modeled in Maryland's Climate Pathway scenario. Additional modeled policies in this sector include a zero-emission appliance standard, zero-emissions construction standard, and strengthened energy efficiency standards. The zero-emission appliance standard, which covers space and water heating appliances in residential and commercial buildings, begins in 2027 and takes full effect by 2030. The zero-emission construction standard, to be implemented in 2027, covers all new residential and commercial buildings, increasing electrification of the building sector. The EmPOWER energy savings goal is held constant at 2.5% annual savings through 2045.

MODELING RESULTS

The buildings sector achieves GHG emissions reductions of 20% relative to 2006 levels under the Current Policies scenario and by 35% under Maryland's Climate Pathway scenario in 2031, through a combination of energy efficiency and electrification measures. Over two-thirds of the emissions reductions in this sector occur in residential buildings.

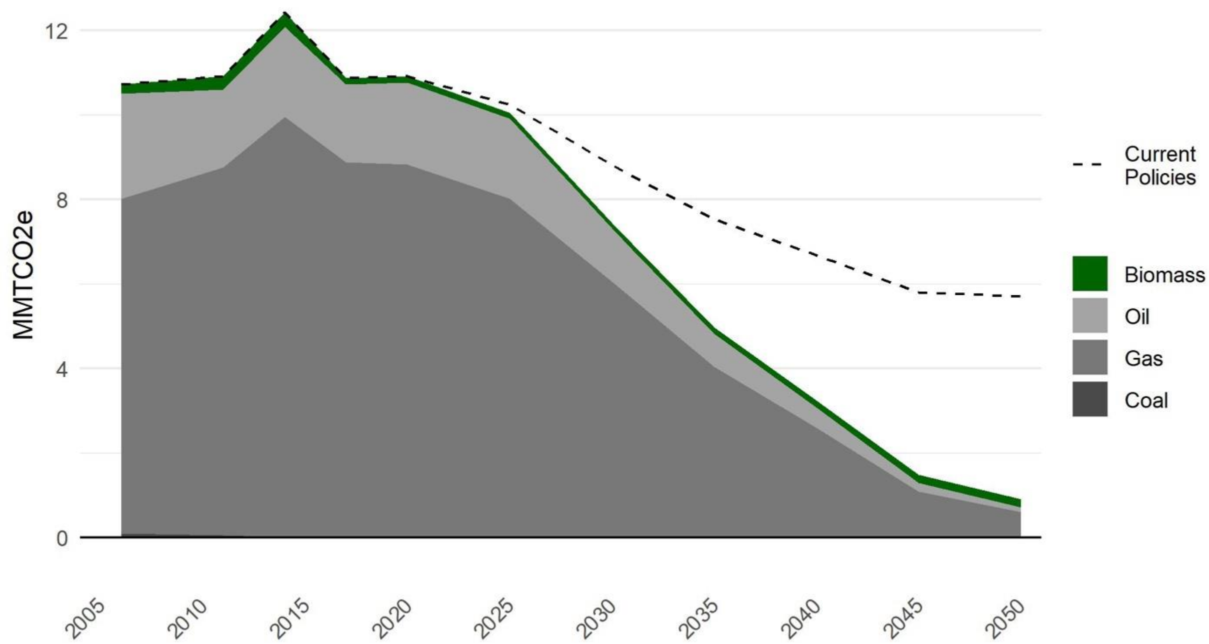

Figure 2.10. Buildings sector GHG emissions over time in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison.

In both scenarios, Maryland implements EmPOWER's energy efficiency standards and BEPS at the State level, aided by federal incentives and rebates for electrification and efficiency. For BEPS, both electrification and EUI improvements are modeled. Additional policies in Maryland's Climate Pathway scenario accelerate the phaseout of natural gas and petroleum so that over 90% of new appliance sales are zero-emission by 2031.

Residential Buildings

As zero-emission appliance standards and zero-emission construction standards kick in, the share of electricity increases to almost 60% of total residential energy consumption in 2031, while natural gas consumption falls to 31%. Biomass and biofuels stay about the same and play a minor role in the near term. At the same time, total residential building energy use falls by 15% from today's levels due to efficiency measures from EmPOWER and from electrification.

Commercial Buildings

Commercial buildings also electrify rapidly due to the standards mentioned above, as well as requirements under BEPS (which apply to half of the commercial building space and a small fraction of residential buildings in Maryland). The share of electricity increases to 70% of total commercial energy consumption in 2031, while natural gas consumption falls to 25%. At the same time, commercial building energy use decreases by 6% from today's levels due to efficiency measures from EmPOWER and the BEPS EUI requirement.

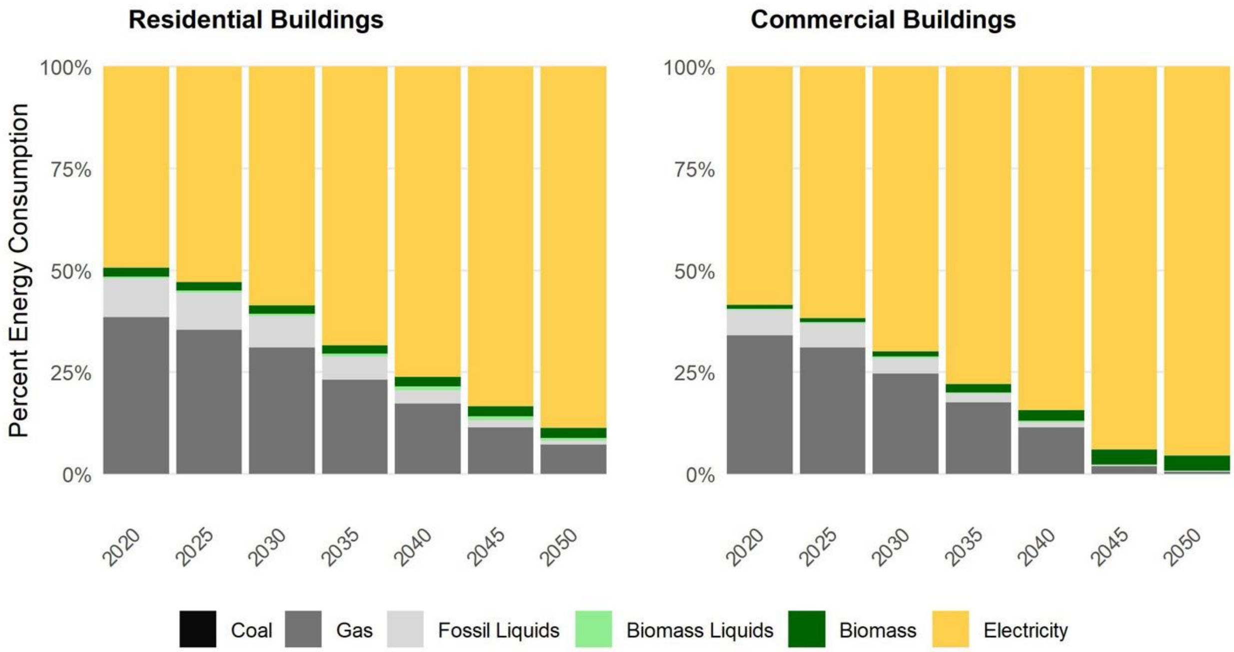

Figure 2.11. Percent energy use by fuel in residential and commercial buildings in Maryland over time.

Beyond 2031

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

CONSIDERATIONS FOR POLICY IMPLEMENTATION

One of the key priorities for Maryland to achieve its climate goals is building electrification and efficiency measures, which utilize both the higher efficiency of electrical appliances and the increasingly clean electricity grid to reduce emissions. Electrification can be achieved through standards such as BEPS, zero-emission appliance standards, a clean heat standard, and other similar measures. However, several challenges must be addressed to realize these standards, including access and affordability, integration of renewable energy sources, and the unique considerations of electrifying older buildings. Additionally, promoting equity and ensuring a sustainable and inclusive transition will be crucial aspects of each of these policies. Maryland has many opportunities to address these challenges through a targeted and coordinated effort by policymakers, manufacturers, consumers, and energy providers to accelerate the transition to a zero-emission future in buildings.

IRA Implementation

Fully utilizing the federal funds made available by the IRA will be crucial for Maryland to achieve the building electrification and efficiency improvements necessary to meet its climate goals.[137] Efforts to raise public awareness and distribute information about incentives widely will be key, as some organizations, communities, and individuals may not be aware that they qualify for a given provision, leaving federal funds unused and emissions reductions unrealized. A previous study on the Earned Income Tax Credit found that approximately 25% of eligible individuals did not claim the credit, often due to informational complexity and poor communication about the program.[138] Multiple organizations have created guidebooks on how to unlock incentives and improve communication about the IRA,[23] but even with such guides, individuals and businesses still face difficulty understanding the benefits of the act. Tailoring information so that every demographic can access the IRA's benefits, despite administrative and language barriers, will be key for successful implementation.

Another barrier to electrification addressed by the IRA is an insufficient number of trained contractors who can install and maintain electric appliances. The IRA's Home Energy Efficiency Contractor Training program allocates $200 million in grants directly to states to support the training of contractors.[13] Maryland can apply for these grants and potentially provide additional incentives for partner businesses and homeowners who hire contractors from the State's training program. This will support both green job growth within the State and building electrification. State-run contractor training programs could also be used to expand access to home energy efficiency and electrification improvements for low-income individuals who face higher energy burdens from outdated heating and cooling systems.

Zero-Emission Appliances in All Buildings

Older buildings may have limited physical space or inadequate ventilation systems, which can pose challenges for the installation and operation of zero-emission appliances. Retrofitting these buildings to accommodate these appliances—such as heat pumps—can be complex and costly.[121] Additionally, building owners or tenants may have concerns about disruptions during installation, higher upfront and maintenance costs, or the perception that new technologies may not be compatible with historic preservation requirements.[122] However, zero-emission appliances are critical, not only to achieving environmental goals but to create healthier homes. As gas-fired appliances are a significant source of nitrogen oxides (NOx) and methane, switching to zero-emission appliances will reduce the amount of harmful pollutants in homes, saving lives and reducing respiratory illnesses.[122] To ensure equitable and affordable access to zero-emission appliances, Maryland may consider additional support and incentives to alleviate these concerns and deliver health benefits for low-income homeowners and renters, who often face higher indoor air pollution levels.[123]

Building Electrification and Renewable Energy

The integration of renewable energy sources to power these appliances poses challenges and opportunities in terms of scalability, grid stability, and storage capacity.[124,125] To ensure building electrification can be accomplished successfully, Maryland should consider the steps mentioned in Section 2.1 to help the grid handle the influx in demand. Integrating electric vehicles (EVs) in buildings with bidirectional charging can also play an important role by making building energy loads more flexible.[126,127] To enable this, codes and covenants that restrict placement or use of EV charging in residential areas may also need to be re-considered. For example, New York State recently signed into law the Electric Vehicle Rights Act that prevents homeowners' associations from prohibiting EV charging stations.[128] Incentives will also need to be considered to compensate BEV owners who participate in such bi-directional charging programs for potential acceleration of battery degradation.[129]

Weatherization and Building Shell Efficiency Standards

One way to reduce the impact of building electrification on the electricity grid is to pair electrification with weatherization and building shell improvements to reduce overall demand. A notable example of this is the Low-Income Weatherization Program in California, which aims to provide solar PV systems and energy efficiency upgrades to low-income households, at no cost to residents, through revenues from the State's cap-and-trade program.[130] Another potential way to reduce building electricity demand is through enhanced building shell standards such as LEED[131] or Passive House[132] certification for new buildings. LEED certifications are a commonly utilized energy efficiency standard, but some research has found that lower levels of LEED certification do not perform better than non-LEED certified buildings.[133] On the other hand, new buildings with Passive House standards may reduce space heat consumption by around 80% and total primary energy consumption by approximately 50%.[134] However, these standards are not as widely adopted in new buildings as LEED.

Affordability and Financial Incentives

Zero-emission appliances often have higher upfront costs compared to emitting appliances, making it difficult for some building owners to afford the transition. Financial incentives, such as rebates, tax credits, or grants, can help offset the higher upfront costs associated with purchasing and installing such appliances, making them more accessible and affordable for LMI consumers.[122,123] The IRA has allocated billions of dollars in incentives to encourage adoption of zero-emission appliances through rebate programs and tax credits.[24] To facilitate adoption and ensure effective usage and maintenance, Maryland can update building codes and regulations to accommodate these appliances and offer education and training to building occupants and workers who will be needed to install and maintain them.[122] Recently, California adopted a zero-emission appliance building code to include electric heat pumps as a baseline technology, requiring new homes and buildings to either be equipped with at least one heat pump for space or water heating or face higher energy efficiency requirements.[135]

Scaling up deep energy retrofits is another key way to address both energy efficiency and electrification, but they can be difficult to implement properly. Barriers include a lack of government support, financing mechanisms, information gaps, and resistance to new technology.[136] However, government supported retrofit programs can reduce or eliminate retrofit costs and disseminate necessary information about energy savings and health benefits that can motivate retrofit adoption.[136]

Clean Heat Standards

Another policy that can spur adoption of zero-emission appliances is a Clean Heat Standard. One example is Vermont's recently passed Affordable Heat Act, which created a clean heating standard where utilities receive credits for energy efficient technologies, but pay if they don't meet certain goals to reduce fossil fuel usage.[139] In addition to moving existing buildings away from fossil fuel usage, clean heat policies can also reduce air pollution and improve health outcomes. In New York City, clean heat programs were found to reduce indoor air pollution, but challenges remain to ensure that low-income communities who are disproportionately impacted by pollution can access these benefits.[140]

Partnerships for Education, Economic, and Health Benefits

By expanding educational initiatives and community engagement efforts, Maryland can empower residents to embrace zero-emission appliances. Cooking with natural gas stoves can exacerbate respiratory problems—a more prevalent problem for low-income households that often lack access to proper indoor ventilation.[141] Organizations in Maryland, such as Action in Montgomery, are working to educate residents on the health and economic benefits of removing natural gas appliances from their homes by measuring harmful pollutants in their homes and discussing the effects of poor indoor air quality.[142] Maryland can also take advantage of IRA provisions for these communities, such as the EPA Greenhouse Gas Reduction Fund that focuses specifically on providing emission reduction and air pollution abatement solutions to disadvantaged communities.[24] Additionally, as Maryland approaches net-zero emissions, there will come a point where natural gas distribution infrastructure, particularly for residential buildings, becomes physically and/or financially unsustainable.[143] Financial mechanisms will need to be in place to assist LMI households to make the transition to electric technologies under these adverse conditions and ease the burden of higher energy prices.[144]

Maryland can also collaborate with utilities to develop programs that promote the use of zero-emission appliances, such as time-of-use pricing, demand response programs, or special rates for customers using energy-efficient and zero-emission appliances, making it financially advantageous for consumers. For example, Inclusive Utility Investment (IUI) programs provide upfront capital to pay for energy efficiency and electrification upgrades.[145] The cost is then recovered through fixed charges on the customer's utility bill. One example of an IUI program is the Pay As You Save (PAYS®) system, designed to be effective for LMI individuals, which enables program participants to capture the savings of the investment through lower energy bills, even as the utility recovers its costs.[146] Two utility companies, Ouachita Electric in Arkansas and Amaren Missouri in Missouri, have created energy savings programs based on the PAYS® model, with Amaren Missouri currently operating their program with a $15 million budget.[146] Adopting such programs can help alleviate equity concerns and enable Maryland to promote a more inclusive and sustainable transition to electric heating, cooling, and appliances.[145]

CASE STUDY: FREDERICK COUNTY POWER SAVER RETROFITS PROGRAM

A critical challenge for building electrification and energy efficiency policies is ensuring that low-income individuals are able to reap the benefits of these improvements, since upgrades often have high upfront costs. To combat this, Frederick County's Division of Energy and Environment has a grant from the MEA for a Power Saver Retrofits program. This program is designed for LMI households and will provide a free assessment of a home's energy use and what improvements could be made to conserve energy. After the assessment has been completed, work can be done to make environmental improvements, such as stopping drafts, reducing electricity or heating fuel use, installing heat pumps, etc., at no cost to the homeowners and occupants.

This program addresses two facets of energy efficiency—reducing emissions and reducing costs. Homeowners must have a gross household income of less than 85% of median income for Frederick County, based on family size, to be eligible for this program, aiding individuals who do not have readily available funds to afford the capital costs of energy. The Power Saver Retrofits Program allows Maryland residents to make environmentally friendly changes to their homes that they may not be able to afford otherwise, bringing Maryland one step closer to achieving its ambitious climate goals while helping low-income residents.

CASE STUDY: ACTION IN MONTGOMERY

For more than 20 years, Action In Montgomery (AIM) has been training and developing local leaders to deeply engage people in their congregations, schools, and neighborhoods to build the subnational power necessary to address the most pressing issues affecting residents' quality of life. AIM works across race, socioeconomic background, geography, and faith to drive specific changes, including over $1.2 billion for affordable housing, quality after-school programming in 14 low-income elementary schools, $30 million to renovate community centers in historic African American neighborhoods, and more.

For years, AIM has been working with tenants on issues of chronic respiratory illness, which have consistently been connected to vermin and toxic mold. AIM has begun to realize that "natural" gas appliances may also be negatively impacting local quality of life. These appliances emit nitrogen dioxide (NO_2), which causes asthma and affects brain development, so leaders and organizers have begun measuring NO_2 levels in their homes. In approximately half of the apartments measured, results often found NO_2 levels that are more than twice what the EPA says is dangerous for outdoor air quality. To date, AIM has measured 100 homes and is in the process of measuring many more.

This has been deeply concerning for residents, who have begun organizing to push for stronger regulations for electrification and efficient electric appliances in Maryland. They are meeting with Senators and Delegates and writing emails to legislators asking them to support more funding for electrification and weatherization in low-income housing, particularly multi-family housing. The tenants who have measured NO_2 and methane in their homes are very clear about the impacts of natural gas on health and in their communities and offer an important perspective that lawmakers and regulatory bodies are not otherwise hearing. The work that AIM is doing aligns with Maryland's goals of increasing renewable electricity and decreasing health disparities among residents and can therefore be used as an example of how to encourage action at the local level.

2.4 INDUSTRIAL SECTOR

MODELED POLICIES: CURRENT POLICIES SCENARIO

In the Current Policies scenario, modeled policies impacting emissions in the industrial sector include Maryland's EmPOWER program, federal hydrogen production tax credits (PTC), and carbon capture and storage (CCS) tax credits.[119] The EmPOWER program is managed through the PSC in partnership with energy providers to promote energy efficiency and conservation measures in Maryland buildings, including within the industrial sector.[119] The hydrogen PTC introduced in the IRA provides between $0.6 and $3 per kg hydrogen produced, depending on the carbon intensity of the production process and prevailing wage requirements.[13] The 45Q tax credit extended in the IRA provides $85/tCO_2$ for eligible facilities with CCS through 2030.[13] The credit also incentivizes direct air capture, with up to $180 per ton of CO_2 permanently stored and $130 per ton of CO_2 captured and used, including for activities such as enhanced oil recovery. The IRA also reduces the capacity requirements for eligible projects to receive the credits.

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

The policies described above, as well as additional policies, were all modeled in Maryland's Climate Pathway scenario. Additional policies for the industrial sector include "Buy Clean" standards, cement fuel switching, and inclusion in the economy-wide cap-and-invest program. The "Buy Clean" standards were used to drive increased efficiency, electrification, and CCS. Fuel switching from coal to natural gas and waste-derived fuel mixes was represented in the cement industry, in line with a previously published study by the authors on Maryland's manufacturing sector.[147] Finally, the sector was included in the economy-wide cap-and-invest program used to reach the 2031 target.

MODELING RESULTS

The industrial sector achieves GHG emissions reductions of 49% relative to 2006 levels under the Current Policies scenario and 79% under Maryland's Climate Pathway scenario by 2031. The industrial sector presents particular challenges for decarbonization because of the need for very high heat in some industrial applications that can be difficult to electrify. Instead, these applications may rely on alternative fuels, such as hydrogen or bio-based fuels, or continued use of fossil fuels with CCS. In Maryland, a key example of this is the cement industry, which is a major contributor to emissions within the industrial sector.

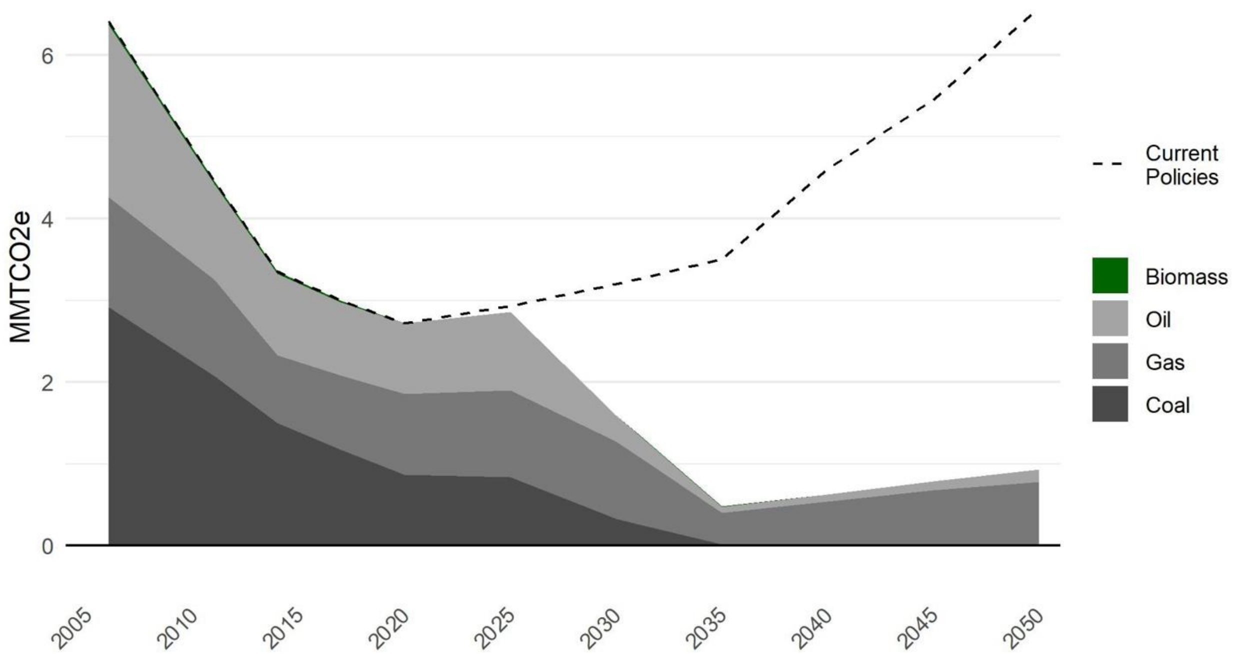

Figure 2.12. Industrial sector GHG emissions from fuel use in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison.

There are two cement plants in Maryland, one in Union Bridge and one in Hagerstown. Historical emissions from these plants have grown over time, and, without any action to prevent them, emissions are expected to continue rising with increasing demand as seen in the Current Policies scenario. However, both plants expect to switch the bulk of their production in 2023 to a type of cement known as Portland Limestone Cement (PLC), which has a lower clinker factor and correspondingly lower emissions.[147] This efficiency measure could help to stabilize overall fuel use while still allowing for some industry growth. Additionally, both plants are planning to reduce the carbon intensity of their fuel mix. The Union Bridge facility is planning to switch their primary fuel source from coal to natural gas in 2027, and the Hagerstown facility is planning to transition nearly half of its fuel use to a refuse-derived fuel mix within the next 5 years.[147] These corporate actions, combined with the effects of the economy-wide cap-and-invest program, are represented in Maryland's Climate Pathway. They result in a flattening of overall energy use by the cement industry and a transition away from coal to natural gas and bio-based fuels.

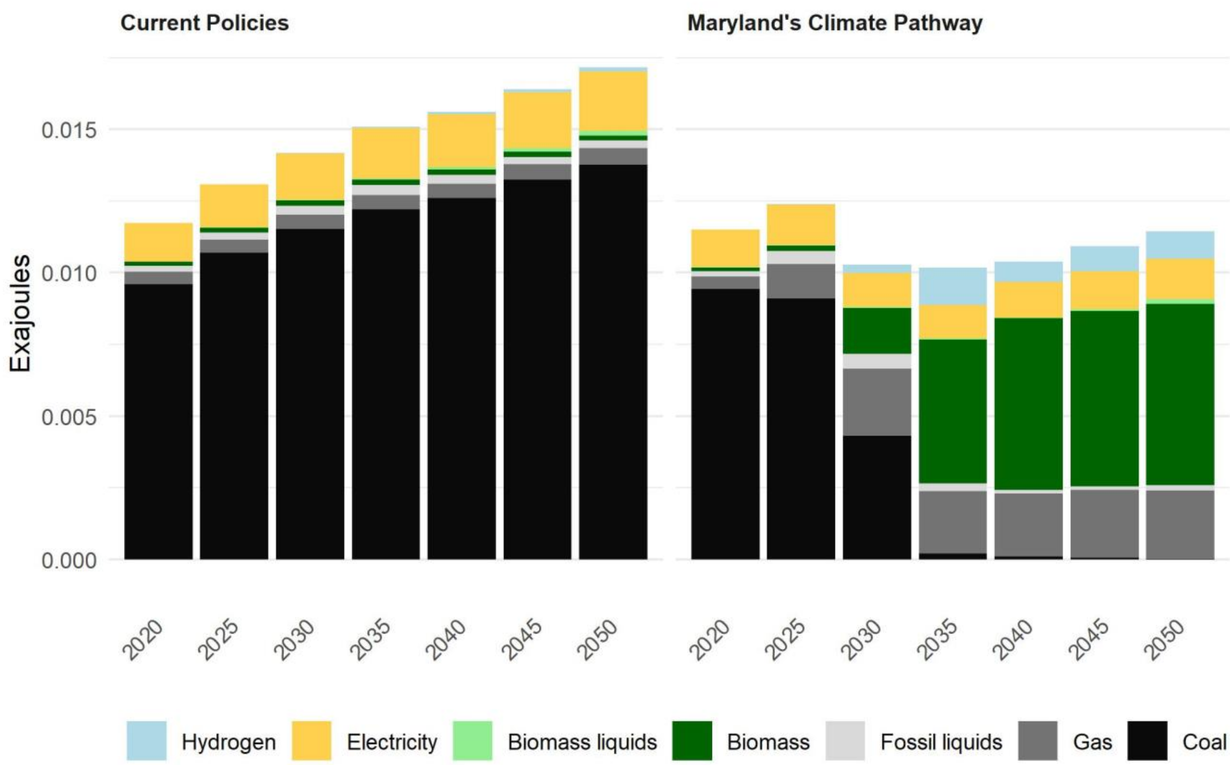

Figure 2.13. Cement sector energy consumption by fuel type under Current Policies and in Maryland’s Climate Pathway, where the sector pursues fuel switching based on current plans at the facilities and compliance with the economy-wide cap-and-invest program.

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

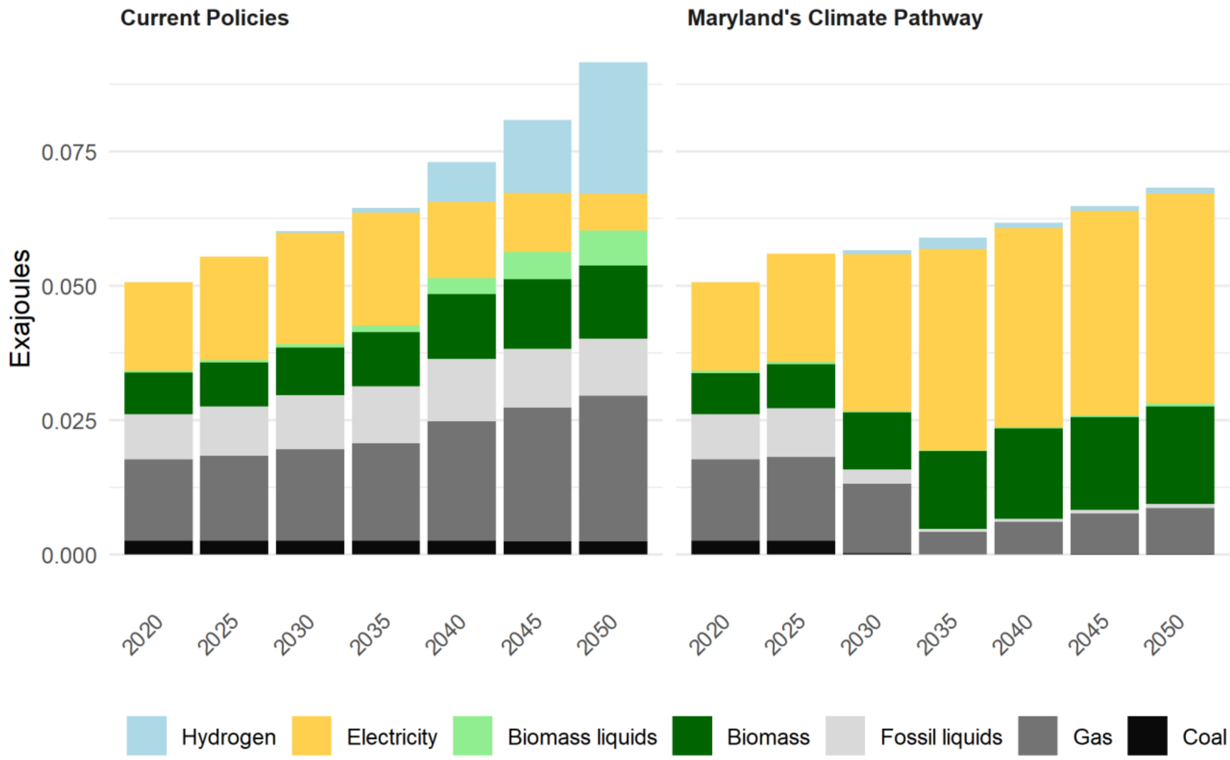

Figure 2.14. Energy consumption by fuel for non-cement industrial activities under Current Policies and under Maryland's Climate Pathway (not including CDR technologies, see below).

Beyond 2031

To reach net-zero, fossil fuels continue to be replaced by electrification and bio-based fuels. Continued use of natural gas with CCS will play a role in certain industries, potentially including cement. Overall energy use within the sector increases substantially in 2040 and 2045, due to the introduction of carbon dioxide removal (CDR) technologies to offset remaining emissions across the Maryland economy. CDR energy consumption peaks in 2045 at 37% of total industrial energy use.

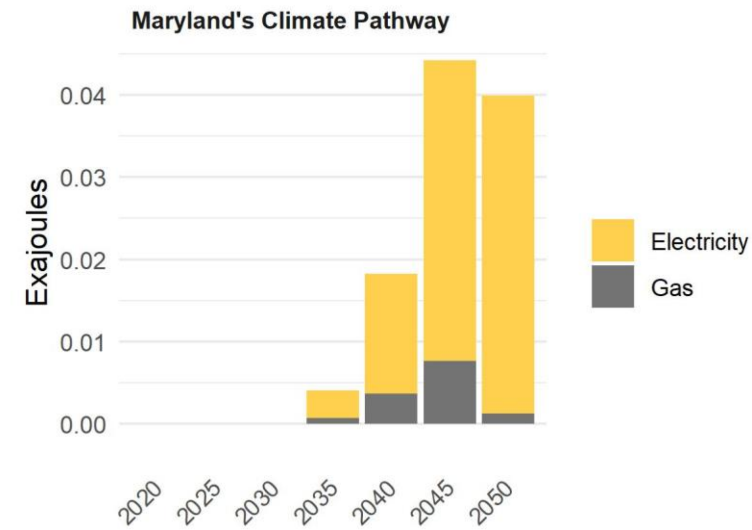

Figure 2.15. Energy consumption by fuel for carbon removal technologies as part of Maryland's Climate Pathway. Note that this energy use is shown here separately and is not included in the industrial energy consumption figures above.

This is a large deployment of CDR technologies in terms of overall magnitude and illustrates the substantial challenge to Maryland to reach net-zero GHG emissions in 2045. A range of CDR technologies and a combination of approaches could be used to help meet the net zero goal,[148] but it is unclear if these technologies will be available for large-scale deployment in the timeframe shown here. However, some approach will be needed to offset residual CO_2 and non-CO_2 emissions. Lowering the amount of residual emissions would also lower the amount of offset needed.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

The industrial sector faces several critical barriers to realizing the emissions reductions shown here, including a legal barrier created by the exemption for the manufacturing sector in the Greenhouse Gas Reduction Act of 2016 (GGRA) and technical barriers to reducing emissions from fuel usage in cement production and other high-heat processes. Even with these barriers, opportunities remain, including embracing a circular economy approach that improves product longevity and reusability and cultivating innovation within the sector to support clean manufacturing and improve Maryland manufacturers' competitiveness in future markets.

IRA Implementation

The IRA provides multiple catalysts that could make carbon-cutting manufacturing changes economically viable. First, net-zero fuel mixes are incentivized by IRA tax credits that could cut the cost of "green" hydrogen nearly in half.[157] Maryland can also work with technology developers, as well as industrial emitters themselves, to apply for grants through the Industrial Demonstrations Program to fund projects seeking to decarbonize industries with difficult-to-abate emissions.[158] Maryland and its cities can also apply directly for GHG Air Pollution Plans and Implementation Grants, which can be used to offset emissions in low-income and disadvantaged communities that may be especially impacted by polluting industries.[104] With numerous IRA-supported construction projects likely to take place in years to come, Maryland can further incentivize manufacturing emissions reductions by setting targets for the use of low-carbon materials during construction.

Manufacturing Sector Exemption in the GGRA

A key barrier to emissions reductions in this sector is the manufacturing sector exemption created in the GGRA, which prohibits any regulation of GHG emissions from the manufacturing industry.[149] Legislation to remove this exemption would allow the sector to access benefits from cap-and-invest programs and improve regulatory coherency with federal initiatives. A previous study on the manufacturing industry also found that removing the GGRA exemption could provide much needed emissions reductions toward the state goals, while also improving regulatory certainty within the manufacturing industry.[147]

Cement Sector Fuel Use

The 2031 Pathway assumes fuel switching in the cement sector, particularly a complete switch from coal to natural gas at the Union Bridge cement facility —the largest single emitter in the industrial sector. However, this switch requires the construction of a 25-mile natural gas pipeline to transport fuel to the facility.[147] This has risks for both the State's near-term and long-term goals, as delays during construction or permitting could mean the switch does not happen by 2031. In addition, the required capital investment risks locking in fossil fuel infrastructure will be difficult to replace before the net-zero target in 2045. While carbon capture and storage (CCS) could offset this risk in the longer term, this is a costly solution that also comes with major infrastructure needs and challenges. A detailed analysis of decarbonization strategies for the cement sector can be found in *Manufacturing Sector Decarbonization Strategies and Impacts in the State of Maryland*.[147]

Industrial Heat Decarbonization

Decarbonizing industrial heat production is a particularly important challenge for this sector.[150] Improved heat management is one way to decrease emissions, where increased efficiency of distribution and usage leads to lower capital costs and fuel usage.[150] Electrifying heat sources, through heat pumps and resistive heating, is another avenue for industrial heat decarbonization.[150] However, this is usually suitable only for low-temperature heating needs. For high-temperature heat, zero-carbon fuels such as hydrogen can be used, and for particular applications like steelmaking, electric arc furnaces can provide high heat from a decarbonized source.[150,151] Lastly, appropriately employed solar thermal, geothermal, or advanced nuclear technologies for zero-carbon heat can support industrial heat decarbonization.[150]

Supporting Innovation in the Industrial Sector

Given the technical challenges associated with decarbonizing the industrial sector, further research and innovation are critical to achieving emissions reductions.[152,153] Decarbonization can be driven through research and development, competitive grants, innovation competitions, and regulatory structures. With adequate support for research and adoption, emerging technologies can help bridge the emissions gap in this sector. The U.S. Department of Energy Office of Clean Energy Demonstrations (OCED) recently issued a funding opportunity for approximately $6 billion to reduce industrial GHG emissions through transformational, commercial-scale demonstration projects. There are several other funding programs that support innovation for decarbonization of the industrial sector, but supportive policies also are needed from subnational governments to ensure industrial facilities are aware of opportunities and adopt new technologies as they become available.

Circular Economy

Prior research has demonstrated that applying circular economy principles has significant potential to support decarbonization of the industrial sector, with implications throughout the entire product lifecycle.[154] Interventions in the design and manufacturing stages can improve product longevity and reusability.[155] Utilization of byproducts and waste streams as industrial inputs can aid industry decarbonization by avoiding demand for virgin materials and fuels.[155] For example, research has found the mitigation potential of making cement recyclable can be quite high, depending on the clinker content and strength of the cement.[154,156] Circular economy in industry can also be promoted via the establishment of closed loop supply chains and creating requirements for disassembly of products at the end of their lifecycles.[155]

2.5 INDUSTRIAL PROCESSES AND PRODUCT USE

MODELED POLICIES: CURRENT POLICIES SCENARIO

In the Current Policies scenario, modeled policies impacting Industrial Processes and Product Use (IPPU) emissions include Maryland's HFC regulations, the federal American Innovation and Manufacturing (AIM) Act, and the 45Q federal tax credit for carbon capture and storage (CCS). Maryland's hydrofluorocarbon (HFC) regulations prohibit the use of certain HFCs in commercial air conditioning, aerosol propellants, chillers, foam products, and stationary refrigeration end-uses.[159] These HFC regulations are in line with the EPA's Significant New Alternatives Policy (SNAP) Program that evaluates and identifies substitutes for ozone-depleting substances (ODS) such as HFCs.[160]

The AIM Act empowers the EPA to reduce HFC emissions in line with the Kigali Amendment to the Montreal Protocol by phasing down production and consumption of HFC's, maximizing reclamation and minimizing releases from equipment, and facilitating the transition to next-generation technologies through sector-based restrictions.[161] The IRA designates $38.5 million in funding to carry out implementation of and compliance with the AIM Act, with $15 million set for competitive grants for innovative HFC reclamation and destruction technologies.[13] The 45Q tax credit extended in the IRA provides $85/t$CO_2$ for eligible facilities with CCS through 2030.[13]

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

All Current Policies above, in addition to new policies needed to reach the State's emission targets, were modeled in Maryland's Climate Pathway. The primary new policy modeled was inclusion of the IPPU sector in the economy-wide cap-and-invest program. Carbon capture and storage for cement emissions was also included as a possible way to achieve this cap starting in 2035.

MODELING RESULTS

GHG emissions from IPPU sources achieve 39% reductions relative to 2006 levels by 2031 under Current Policies and 47% reductions in Maryland's Climate Pathway. Historical emissions reductions in the IPPU sector are primarily due to the closure of the last steel production facility in the State in 2012.[147] The other major categories of emissions, cement process emissions, and ODS substitutes have grown over time.

Cement process emissions arise from the chemical reactions that occur when making clinker.[162] They do not stem from fossil fuel use and cannot be avoided without changing the recipe for cement. The emissions can be captured through CCS, but applications of CCS for cement are currently still in the demonstration phase, and neither of the two cement plants in the State has near-term plans for implementing CCS.[147] Therefore, cement CCS was not included as an abatement technology in Maryland's Climate Pathway until 2035, the first date when CCS might potentially be ready at one of the facilities. However, the Pathway still includes a reduction in cement emissions compared to Current Policies, because of lower process-related emissions. This can be achieved either through demand reductions that allow for lower production levels or through material efficiency measures, such as the switch to PLC at both facilities. PLC only allows for clinker replacement of up to 15%, but other types of clinker replacements, such as pozzolans, can replace up to 40% of clinker, potentially providing substantial reductions in emissions without requiring a decrease in production. These alternative types of cement may not be suitable for all applications, but transitioning as much production as possible toward alternate products can support near-term decarbonization and help the State reach its emission reduction goals.

Figure 2.16. GHG emissions from IPPU over time in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison.

The other major contributor to IPPU emissions are ODS substitutes, which are fluorinated gases (F-gases) that replace ODS in product applications such as refrigeration, air conditioning, and aerosols.[163] Current Policies at the State and federal level are expected to achieve substantial reductions in this category, but no additional reductions are modeled in Maryland's Climate Pathway.

Another F-gas, sulfur hexafluoride (SF_6), is used as an insulator in electricity transmission and distribution systems. While only very small amounts of SF_6 are released in these processes, it is the most potent GHG known to man and therefore still an important consideration for emissions.[164] Changes in SF_6 emissions were covered by the economy-wide cap-and-invest program, but no targeted reduction policies were modeled for this emission source.

Sources labeled as "Other" in Figure 2.16 include emissions from limestone and dolomite, soda ash, and ammonia and urea production. These sources were assumed to remain constant at 2020 levels, in line with historical trends.[165]

Beyond 2031

In order to meet the net-zero goal, cement production begins utilizing CCS for process emissions and any remaining fuel-use emissions. ODS substitute emissions continue to decline in accordance with the AIM Act requirements.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

Emissions from IPPU can be particularly difficult to address because of the nature of the emission sources. As in the industrial sector overall, one barrier to mitigation is the exemption for the manufacturing sector in the GGRA. Other challenges include tracking and reducing non-CO_2 emissions, offsetting residual emissions where no technological solution is currently available and creating financial mechanisms to enable those offsets through a robust and equitable cap-and-invest program.

Manufacturing Sector Exemption in the GGRA

The IPPU sector is also impacted by the exemption for the manufacturing sector created in the GGRA, as discussed in Section 2.4. Therefore, this sector could also benefit if the exemption were repealed.

ODS Substitute Opportunities

The largest sources of ODS substitute emissions in Maryland are refrigeration and air conditioning, which offer many opportunities to reduce emissions through cost-saving measures.[163,166] Encouraging collaboration between industry, academia, and government agencies can help disseminate information about the benefits of available substitutes and facilitate their adoption. California's regulations on monitoring and repair of AC/refrigeration leaks provide an example of proactive measures taken to deepen reductions from ODS substitute emissions.[167] Facilities with refrigeration systems containing over 50 pounds of high-GWP refrigerants are required to conduct periodic leak inspections, promptly repair leaks, and maintain service records on site. Additionally, service practices that minimize refrigerant emissions are mandated.[167] This approach ensures accountability and drives the reduction of emissions from AC/refrigeration systems.

Offsetting Residual Emissions with Removals

Because this sector consists of emissions sources that do not stem from fossil fuel use, it presents unique challenges for decarbonization. While the strategies outlined here can significantly reduce emissions, some residual emissions are expected even with ambitious reduction measures in place. Therefore, residual emissions from this sector must be offset by natural sinks or CO_2 removal to meet Maryland's 2045 net-zero goal. Other sectors must decarbonize even more rapidly to ensure that residual emissions do not exceed the ability of negative emissions to scale in the necessary timeframe.

Cap-and-invest Program

To offset difficult-to-abate emissions discussed above, it is critical to create a financial mechanism such as the cap-and-invest program in Maryland's Climate Pathway to incentivize removals. One example of such a program is the New York cap-and-invest program recently developed and implemented by the Department of Environmental Conservation and the New York State Energy Research and Development Authority.[168] It seeks to limit costs for economically vulnerable households, and maintain the competitiveness of New York industries, thereby enabling critical investments in clean energy while supporting vulnerable communities. The program sets an annual cap on GHG emissions, gradually reducing it to meet the New York Climate Act requirements of a 40% emissions reduction from 1990 levels by 2030 and an 85% reduction by 2050. Additionally, the program aims to create jobs and preserve competitiveness by increasing investments in industries that generate high-paying jobs, ranging from home retrofits. to EV charging installations, to green manufacturing. The program also prohibits the use of offsets and is designed to reduce co-pollutant burdens. At least 35% of the program's benefits will directly benefit disadvantaged communities, funding programs to improve air quality, reduce reliance on polluting power plants, retrofit homes and schools, and decarbonize transportation systems.[168]

Inventory Accounting Methodology

Another barrier to realizing the emission reductions shown here is lack of data on ODS substitute emissions at the State level. The Maryland GHG inventory accounts for ODS substitutes by downscaling national emissions based on the Maryland population. If Maryland is able to reduce emissions faster than the national average due to State-level policies, this progress will not be captured under the current inventory methodology.

CASE STUDY: UNION BRIDGE CEMENT PLANT

The Union Bridge Cement Plant, owned and operated by Heidelberg Materials, is committed to helping Maryland achieve its decarbonization goals through reducing emissions from cement production. While the manufacturing sector is currently exempted from emissions reduction requirements by the GGRA, the Union Bridge plant is still taking steps to reduce its emissions and collaborate with State and local entities to accomplish climate goals. In January, the plant transitioned from manufacturing Ordinary Portland Cement (OPC) to manufacturing PLC (except for a small percentage of specialty cement products) to reduce emissions by allowing 5% to 15% of clinker to be replaced by limestone. Heidelberg Materials understands that CCS technology will eventually become part of their carbon neutral strategy, but they are first taking steps to reduce their CO_2 intensity through their transition to PLC and planned switch to natural gas.

Heidelberg Materials has laid the foundation of their sustainability commitments through the establishment of global concrete promises. These promises include: (1) continuing to focus on heavy building materials that society needs, (2) committing to generate 50% of their revenue from sustainable products by 2030, (3) leading the industry by achieving a nearly 50% reduction in CO_2 emissions, to less than 400 kg CO2/metric ton of cement, by 2030, (4) making the transition a successful business case, and (5) driving the change for the benefit of their customers, shareholders, employees, and society.

2.6 FOSSIL FUEL INDUSTRY

MODELED POLICIES: CURRENT POLICIES SCENARIO

Emissions from the fossil fuel industry in Maryland consist largely of methane from the transportation and distribution of natural gas and emissions associated with the Cove Point LNG export facility. The cumulative impact of current emissions reduction policies in Maryland will drive a change in total natural gas consumption in Maryland and subsequently drive a change in methane emissions from the fossil fuel industry. It is assumed in this analysis that the future level of methane emissions from the fossil fuel industry in Maryland, in the absence of any direct policy action to reduce natural gas methane emissions, would be driven by the State's future level of natural gas consumption. Based on Maryland's total natural gas consumption in the Current Policies scenario, a baseline projection for fossil fuel industry emissions is then constructed from which reductions achievable through policies are subtracted.

In the Current Policies scenario, modeled policies impacting emissions from the fossil fuel industry include Maryland's natural gas methane regulation and the IRA's methane fee. Maryland's final natural gas methane emissions regulation establishes requirements to reduce vented and leaked emissions of methane from new and existing energy facilities.[159] The regulations require detection, testing, repair, reporting, and recordkeeping to achieve methane emissions reductions.

The IRA established the United States' first methane fee starting at $900 per metric ton of methane and increasing to $1,500 after two years, equivalent to $36 and $60 per metric ton of carbon dioxide equivalent, respectively.[169] This methane emissions fee only applies to specific facilities in the petroleum and natural gas industries that are required to report their GHG emissions to the EPA's Greenhouse Gas Emissions Reporting Program (GHGRP) and whose annual emissions total more than 25,000 MMTCO2e. Two Maryland facilities would meet these eligibility requirements for coverage under the IRA methane fee: Transco Station and Cove Point LNG Facility.[170,171] However, the policy language in the IRA also notes that if eligible facilities are in compliance with the EPA's oil and gas facility regulations, they will be exempt from the IRA methane fee.

The potential emissions reductions from Maryland's natural gas methane regulations and the IRA methane fee are estimated using the EPA's state-level marginal abatement cost (MAC) curves for reducing non-CO_2 emissions.[166] Using these MAC curves as percent reductions, the baseline projection allows for an estimation of the combined impact of both the State-level policy and the federal methane fee in a way that removes potential double counting of emissions reductions.

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

All Current Policies above were modeled in Maryland's Climate Pathway. Additionally, total natural gas consumption in Maryland will decline in the Pathway with the implementation of additional policies across the rest of the economy. This will, in turn, drive a further reduction in the baseline projection of methane emissions from the fossil fuel industry in Maryland, leading to significant reductions compared to those achievable with only Current Policies. We do not model additional policy actions in this sector beyond the additional methane reductions achieved through state-wide reduction in natural gas consumption.

MODELING RESULTS

The fossil fuel sector achieves GHG emissions reductions of 20% relative to 2006 levels under the Current Policies scenario and by 26% under Maryland's Climate Pathway scenario in 2031. The entirety of the difference in this sector's achievable reductions between the Current Policies scenario and Maryland's Climate Pathway scenario is the reduction in economy-wide natural gas consumption. This underscores the importance of an all-in approach to reduce emissions from all sectors of the economy.

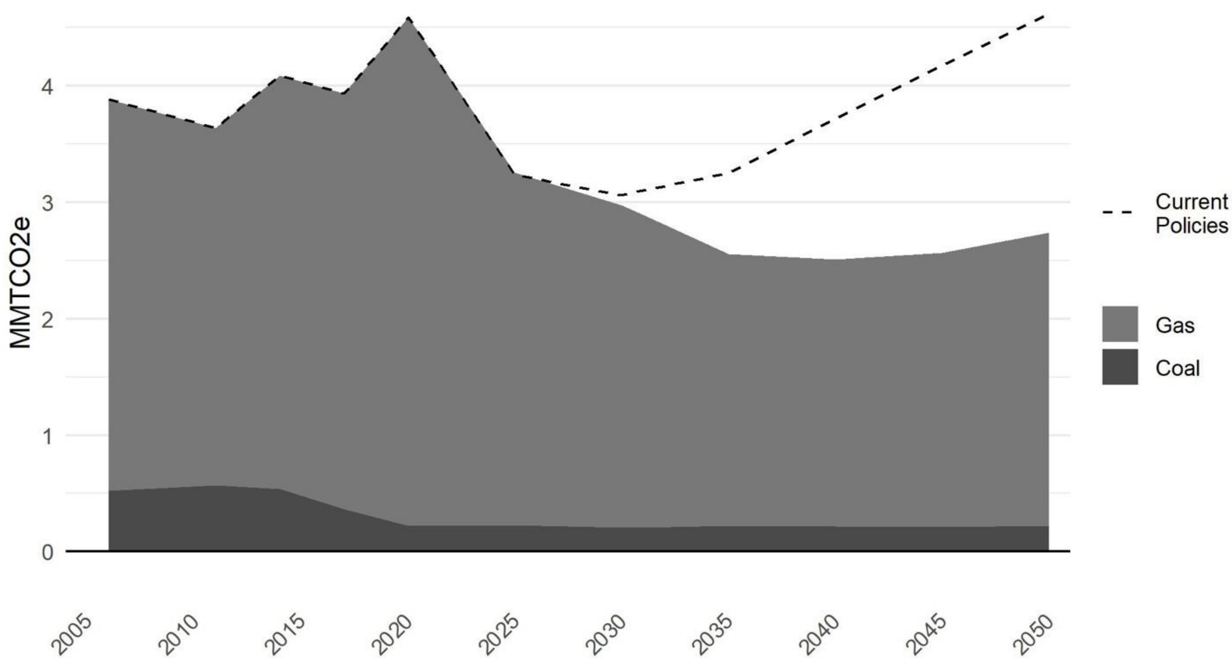

Figure 2.17. Fossil Fuel Industry GHG emissions over time in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison.

MAC curves are estimates of the quantity of emissions that can be abated through specific actions or technological improvements at given cost levels. In the case of methane emissions from the natural gas sector, these MAC curves include actions such as direct inspection and maintenance to focus on leak detection and repair in the transmission and distribution of natural gas. Significant emissions reductions in the natural gas industry can be achieved through direct inspection and maintenance at a net cost below $0 because the cost of taking these actions is lower than the price at which the saved natural gas can be sold. MAC curve actions also include replacing older equipment that is more prone to leaks. However, the firms in the fossil fuel industry that would bear these costs may be reluctant to invest in these technologies in the absence of financial or regulatory incentives.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

Emissions in this sector are primarily due to methane, which is emphasized in the State's accounting by using 20-year global warming potentials (GWPs) that account for larger impacts on emissions from SLCPs. However, quantifying potential methane emission reductions is challenging, and will likely only be exacerbated by increasing system fragility as natural gas usage declines. Additionally, the State's GHG inventory relies on per-mile emissions factors rather than measurements, making it difficult to accurately account for reductions as they are achieved.

BIL Implementation for Coal Mine Remediation

The BIL allocates $11.3 billion over the next 15 years to reclaim abandoned mine lands by eliminating dangerous environmental conditions and pollution caused by previous coal mining. The reclamation projects will include closing dangerous mine shafts, treating acid mine drainage, restoring water supplies damaged by mining, promoting economic opportunities, etc.[172] Some of this funding could be put toward reducing methane emissions from abandoned coal mines in Maryland, however, it is difficult to quantify an estimate of reductions that could be achieved from this action.

System Fragility Under Rapidly Declining Usage

A rapid decline in natural gas consumption means that natural gas customers remaining in the system would likely experience higher utility bills due to infrastructure costs being spread over a smaller customer base. This would have a disproportionate impact on LMI consumers and renters who are unable to switch to alternative energy sources because they don't own their own equipment or can't afford to electrify their equipment. Mitigation of cost impacts for LMI customers will become essential in these circumstances to ensure an equitable transition.[123] Research on methane leak detection and prevention strategies has also highlighted the challenges faced in pursuing these strategies as the system loses customers and has limited capital resources.[173] However, continuously expanding natural gas infrastructure would delay the inevitable transition to clean energy and could cause major economic losses from stranded assets.[143] Further research is needed on mid-transition system dynamics to address these issues effectively and determine the rate impacts on customers of lower system throughput.[143]

Cove Point LNG Terminal

Cove Point is a natural gas liquefaction, storage, and export facility located on the western shore of the Chesapeake Bay. Because the Cove Point terminal accounts for a significant portion of emissions in this sector, it would be useful to develop site-specific goals for reductions that take into account the characteristics of this facility. Emissions reduction practices and goals can vary by sites due to different site technologies and GHG emissions numbers, so effectiveness and costs will change.[173]

Inventory Accounting Methodology

The State's GHG inventory uses emissions factors, such as the quantity of emissions per mile of pipeline, to estimate the emissions in this sector. The absence of an actual measurement that could verify reductions due to decreases in natural gas consumption makes it difficult to account for these reductions accurately. If widespread monitoring of natural gas infrastructure were developed, this could serve the dual purpose of improving leak detection and mitigation, while also enabling more accurate accounting of emissions.

CASE STUDY: ABANDONED COAL MINES TO SOLAR ENERGY

A common question for the clean energy transition is what to do with leftover fossil fuel energy infrastructure. One way to do this is by transforming post-mining or reclaimed mining lands. Garrett County—the farthest west in Maryland—already has this transformation underway through community solar programs and development on abandoned coal mines, which were once one of the region's largest economic contributors. Most recently, Competitive Power Ventures (CPV) was granted a Certificate of Public Convenience and Necessity (CPCN) by the Maryland Public Service Commission to begin constructing the 200MW Backbone Solar Farm on 1,170 acres of land that was previously home to a coal mining site. The new solar farm will provide over 150 jobs during its 18-month construction process and will bring as much as $2.7 million in annual local tax revenues to benefit Garrett County. It will generate enough emission-free electricity to power an estimated 30,000 average Maryland homes, helping the State meet its clean energy targets of 14.5% solar energy by 2028 and 50% renewable energy by 2030. Projects like this are crucial, as they provide a way for communities that may otherwise be left out of the green transition to reap the benefits of predictable rates of clean, renewable solar energy and ensure that low-income communities have the same opportunities as wealthier communities to take advantage of these benefits.

2.7 WASTE MANAGEMENT

MODELED POLICIES: CURRENT POLICIES SCENARIO

In the Current Policies scenario, modeled policies impacting emissions from waste management include Maryland's landfill methane regulation, Sustainable Materials Management policy, and waste diversion programs.

The landfill methane regulations limit landfill gas methane emissions from municipal solid waste (MSW) landfills in Maryland.[174] Depending on their methane generation rate, MSW landfills will either need to install a landfill gas collection and control system (GCCS) or evaluate their surface methane emission rate. Analysis for the draft landfill methane regulations in Maryland shows a minimum and maximum estimate for emissions reduction attributable to these regulations.[175] For this analysis, it is assumed that the average of these minimum and maximum estimates is achieved. It is further assumed that the baseline to which this reduction is applied is a level that remains constant from the 2020 inventory value for landfill methane, due to increasing waste diversion efforts assumed to offset growth in MSW generation from a growing population.

Enacted through an executive order in 2017, Maryland's Sustainable Materials Management policy seeks to minimize the environmental impacts of materials management throughout their entire lifecycle through source reduction, reuse, and recycling.[176] To fulfill this executive order, MDE released voluntary statewide metrics and goals for achieving a sustainable materials management system, including a 10% reduction in the amount of waste generated per capita; a 1.2 MMTCO2e annual reduction of GHG emissions from materials management in 2035; a 4.3 trillion BTUs annual reduction in energy use from materials management in 2035, and more.[177] Maryland's Organics Recycling and Waste Diversion–Food Residuals provision requires specific entities that generate food residuals to separate organics from other solid waste and divert them from landfills to composting facilities. This policy aims to prevent waste before it occurs to reduce the amount of GHGs emitted from landfills, recover edible food, and improve Maryland's soils.

ADDITIONAL POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

In Maryland's Climate Pathway scenario, it assumed that annual waste diversion efforts drive an additional 10% reduction from the baseline methane emissions assumed in this sector through 2050. This is equivalent to a 0.4% annual increase in waste diversion from 2026-2050.

MODELING RESULTS

The waste management sector achieves 37% GHG emissions reductions relative to 2006 levels under Current Policies and 39% gross reductions in Maryland's Climate Pathway scenario by 2031.

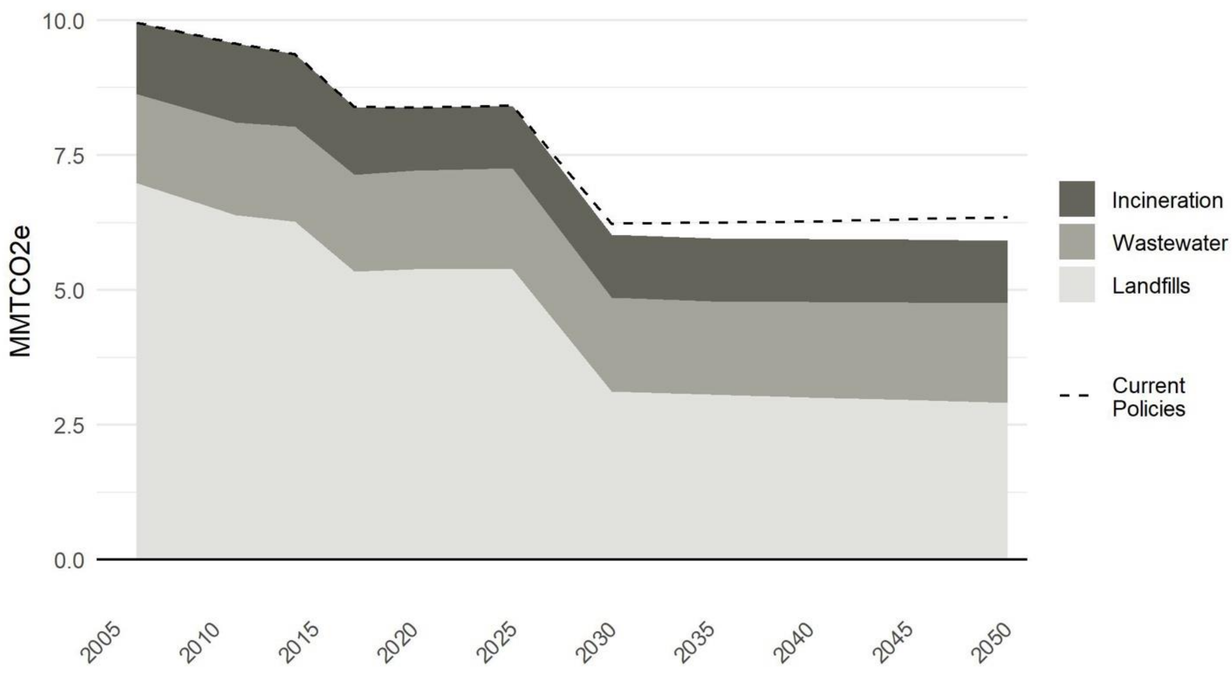

Figure 2.18. Waste sector GHG emissions over time in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

Waste management policies are an opportunity for Maryland to achieve both emissions reductions and co-benefits to Marylanders through improved environmental health. Waste diversion policies can help the State reduce methane emissions and the amount of waste that accumulates in landfills. To create better waste management policies, Maryland can apply principles from the zero-waste hierarchy, improve data on waste sources and composition, address barriers to waste diversion policies like composting, adjust the inventory accounting methodology for waste incineration, and look for opportunities to achieve wastewater emissions reductions.

The Zero-Waste Hierarchy

The zero-waste hierarchy provides an overarching framework for various waste management policies. Practices ranked from best to worst are: rethink/redesign, reduce, reuse, recycle/compost, material recovery, residuals management, and waste incineration, which can have negative impacts on human health.[178] This hierarchy provides guidance for implementing waste management policies, emphasizing the need to reduce and rethink the amount of waste produced in the first place before pursuing other strategies.[179] A similarly related waste management policy is the circular economy strategy mentioned in Section 2.4. A circular economy rejects the traditional make-to-waste format of most materials, instead focusing on keeping products in circulation for as long as possible, reducing the amount of materials that would otherwise go to the landfill.

Need for Improved Data

To improve waste management policies, it is essential to obtain accurate data on waste sources and composition. Efforts should be made to involve individuals, restaurants, and commercial sources in diverting organic waste to composting. Since landfill emissions and reduction potentials vary by site, a detailed analysis of Maryland landfills could help identify specific opportunities. Implementing programs such as landfill methane gas to energy projects, along with regulations, voluntary initiatives, and public education programs on zero waste strategies, can help drive progress. Addressing barriers, such as inaccessible composting programs, lack of information, and high costs of new technology, is also essential for successful waste diversion efforts.

Composting Barriers and Opportunities

While Maryland has several policies to reduce the amount of waste sent to landfills, it does not have a universal composting program. Howard County's voluntary composting program, Feed the Green Bin, which provides free composting bins to residents, is currently expanding the amount of eligible areas.[180] Prince George's County has similarly acted to increase composting in its communities through the Curbside Food Scraps Composting program, which gives composting materials in a phased rollout to eligible residents.[181] Recently passed legislation, SB 262, works to expand on-farm composting by allowing farmers who meet certain criteria to compost without a permit.[182] Despite such efforts to increase composting, there are several barriers to its widespread adoption. One challenge is ensuring rural communities and multi-family buildings, such as apartment complexes, have access to both composting materials and regular pickup.[183] Composting rates are also not equal between different demographics. Studies show that frequent composters often have higher incomes and education levels.[184] Citizen engagement is crucial to achieve higher composting rates, and Maryland can address barriers to engagement through educational programs and information campaigns.[184] Beyond the emissions reduction potential, composting can also reduce air pollution by reducing the amount of waste incineration in landfills.[185] The surrounding disadvantaged communities will then face lower air and water pollution levels. Compost also can help support carbon sinks, because it can be used as a soil amendment to increase tree growth and carbon sequestration.[186]

Wastewater Emissions Abatement

No reductions of methane emissions from wastewater treatment were included in these scenarios because there are no low-to-moderate-cost mitigation technologies currently available. Any operational improvements possible for current facilities that would reduce emissions should be identified and implemented. If research in the future identifies additional mitigation options, they should be pursued. This is particularly important, since wastewater methane emissions in the United States may currently be underestimated.[188,189]

Inventory Accounting Methodology

The State inventory accounting methodology for waste incineration is another important consideration for this sector. In the national standard accounting methodology used by the EPA, emissions from incineration are partially discounted because they come from biogenic sources, therefore are not net emitters.[187] Adjusting the State's methodology to be in line with the national standard could provide a more accurate measure of the impacts from this sector.

CASE STUDY: WHITE MARSH

To help meet Baltimore County's climate goal of 100% electricity derived from renewable sources by 2026, the county is implementing projects that recycle greenhouse gases produced at landfills. At the Eastern Sanitary Landfill in White Marsh, four electric generators are powered by the methane created from decomposing garbage. The project is run by Energy Power Partners, which operates 16 landfill gas-to-energy projects in the U.S. Pipes draw methane from the landfill, then combust it to create energy.

The landfill uses 5% of the methane to power the facility. The rest is sent to the power grid, enough to power 2,400 homes annually. Rather than venting methane into the air, this landfill reduces it, combusts it, eliminates it, and uses it for electricity. The process isn't perfect — sometimes landfills can't keep up with the volume of methane being produced. In that case, the landfill converts methane into carbon dioxide which is then released into the air. This isn't ideal, but it's better than releasing methane, which is a far more potent GHG than carbon dioxide. Reducing methane from these landfills is essential to achieving Maryland's climate goals, and this project is one example how the State can address this challenge.

2.8 AGRICULTURE

MODELED POLICIES: CURRENT POLICIES SCENARIO

Maryland's farmers have already taken significant action to reduce the environmental impact of agricultural operations as part of the State's commitment to a healthy Chesapeake Bay. Due to lack of available data to adequately represent the impact of current Maryland policies on GHG emissions from the agricultural sector, no agricultural emission reductions are included in the Current Policies scenario. Livestock populations are assumed to remain constant from their 2020 inventory level, and, by extension, so are emissions associated with livestock production. Similarly, N_2O emissions from livestock and agricultural soils are also assumed to remain constant over time. Note that carbon uptake by agricultural soils is not included here but is covered in Section 2.9.

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

In Maryland's Climate Pathway scenario, it is assumed that cost-effective reductions (those achievable at less than \$0 per tCO_2e) are achieved for methane emissions from livestock. These potential reductions are calculated using the EPA's state-level MAC curves for reducing non-CO_2 emissions from livestock.[166] The majority of cost-effective reductions in agriculture that are identified in the EPA MAC curves are attributable to methane from enteric fermentation in ruminants, along with a small contribution from manure management.

MODELING RESULTS

By 2031, the agriculture sector achieves 5% GHG emissions reductions relative to 2006 levels under Current Policies, due to pre-2020 reductions, and 9% reductions in Maryland's Climate Pathway scenario. The impacts of increased use of best practices for soil conservation management on nitrous oxide emissions, potentially expanding on the reductions seen here, will be examined in more detailed analysis that is underway.

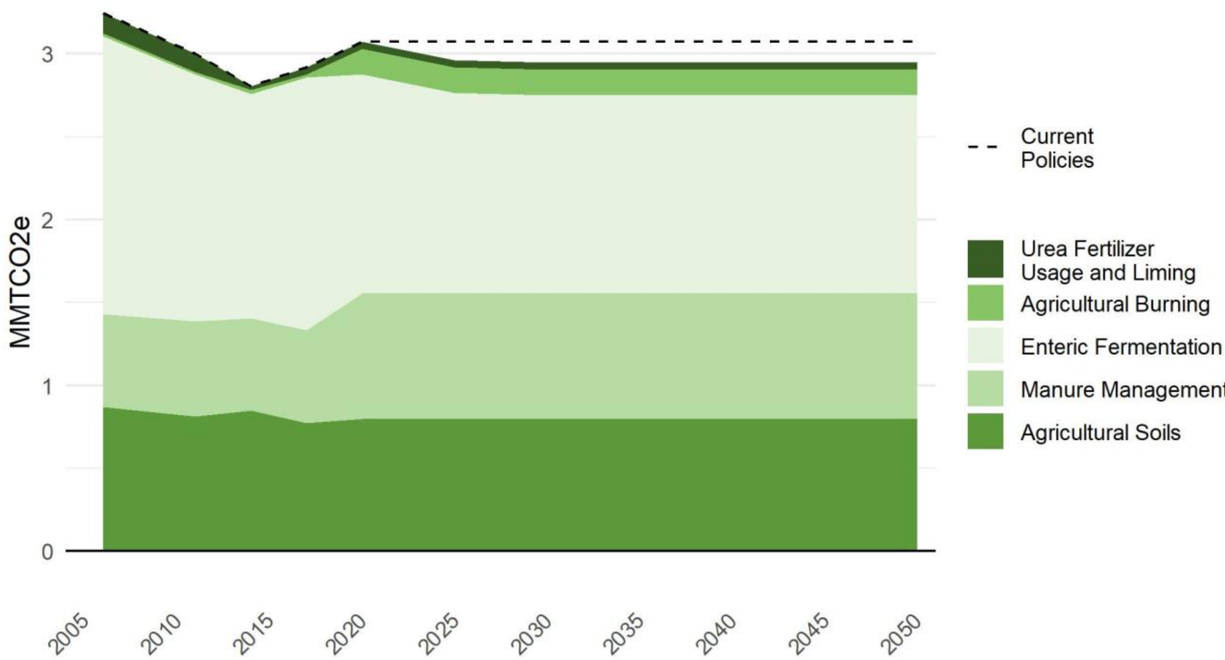

Figure 2.19. Agricultural sector GHG emissions over time in Maryland's Climate Pathway. Emissions under Current Policies are shown with the dotted line for comparison. The "agricultural soils" category only includes non-CO_2 GHG emissions.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

Taking additional actions focused on also reducing GHG emissions from Maryland's agricultural sector will help the State preserve its largest commercial industry for years to come. The largest contributor to GHG emissions in the agricultural sector is the potent GHG, methane. Methane has a large relative contribution, in part due to Maryland's use of 20-year GWP values to compute carbon-equivalent emissions. Funds from the IRA can also support action in the agriculture sector.

IRA Implementation

The IRA provides significant federal funding — $19.5 billion — to support the U.S. Department of Agriculture's conservation programs to yield climate mitigation benefits.[193] Through funding from the USDA's Natural Resources Conservation Service, Maryland will receive approximately an additional $80 million for Maryland's conservation programs over the next 5 years, starting in 2023. Through this funding, Maryland will be able to expand conservation efforts and implement new climate-smart practices. Two key IRA provisions, the Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP), provide additional support for Maryland agricultural producers to adopt climate-friendly agricultural practices and activities that directly reduce greenhouse gas emissions or increase carbon sequestration.[194]

Directions for Future Emission Reduction Efforts

Methane and nitrous oxide emissions from agriculture are particularly difficult to abate. However, there is substantial ongoing research in this area,[190] and, if new approaches are found to be effective, Maryland should activate policy support for adoption. There are also substantial potential synergies between efforts to reduce emissions from agricultural soils and manure management and existing programs to improve surface water quality in Maryland.[191,192]

CASE STUDY: FOX HAVEN FARM

Fox Haven Farm, LLC, in Jefferson is an organic farm, ecological retreat, and learning center that has been a pioneer in sustainable farming and land conservation practices to protect the health of Maryland's land, water quality, and wildlife habitat. Fox Haven Farm plays a vital role in promoting sustainable practices and environmental awareness within the community through various educational programs and hands-on experiences that educate participants about sustainable agriculture, regenerative practices, biodiversity, and the importance of environmental conservation. By fostering a connection between people and the land, Fox Haven Farm inspires and empowers individuals to make informed choices that contribute to a more sustainable and resilient future.

Critical to Maryland's climate pathway to a clean economy, Fox Haven Farm practices innovative carbon sequestration techniques in its soil management. Sequestering carbon in soil helps more water soak into the soil and plants, rather than being lost as runoff. Fox Haven Farm established over 500 acres as certified organic farmland, with 50 acres for rotational grazing of cows, which creates a natural source of organic fertilizer and carbon sequestration. Through the utilization of organic and natural fertilizers, reduced chemical pesticide usage, and integrated pest management techniques, Fox Haven Farm minimizes reliance on synthetic inputs and avoids the emissions associated with the production and use of these inputs.

Additionally, the farm practices crop rotation and cover cropping year-round to protect topsoil, rebuild nutrients, and diversify microscopic organisms in the soil. The farm champions effective manure management by utilizing compost from their kitchens, significantly reducing methane emissions. These practices have not only resulted in remarkable environmental stewardship and education, but also present a model for how Maryland's industry and community leaders can make a substantial impact in reducing emissions.

2.9 FORESTRY AND LAND USE

MODELED POLICIES: CURRENT POLICIES SCENARIO

In the Current Policies scenario, no specific policies were modeled for this sector due to modeling constraints and lack of data. However, Maryland does have many policies addressing forestry and land use activities in the State, including the Tree Solutions Now Act, the Forest Conservation Act, and the Maryland Department of Agriculture's (MDA's) Healthy Soils Program. The Tree Solutions Now Act of 2021 establishes a goal to plant and maintain 5 million additional native trees across Maryland by 2031, with 500,000 of them directed to urban and underserved areas.[195] Maryland's Forest Conservation Act, recently revised in the 2023 session of the Maryland General Assembly, works to minimize and mitigate the loss of Maryland's trees and forests during land development.[196] The State also funds adoption of agricultural best management practices to meet the goals of Maryland's Phase III Watershed Implementation Plan, including many that have the co-benefit of sequestering CO_2 in soils.[197] The Maryland Healthy Soils Programs promotes soil practices that increase biological activity and carbon sequestration in Maryland's soils.[198] Farmers receive incentives from the Department of Agriculture in the form of financial and technical assistance, education, and research.

ADDITIONAL MODELED POLICIES: MARYLAND'S CLIMATE PATHWAY SCENARIO

No additional policies were modeled in this sector. A number of areas where future policies and developments could expand land-based carbon sinks are discussed below.

MODELING ASSUMPTIONS

For both of the scenarios presented, emissions and removals in this sector were held constant over time after 2020 due to a lack of available detailed modeling for this sector. As more detailed analysis for these sectors is completed, the scenarios will be updated to reflect the best available data. While this sector will play a crucial role in maintaining and expanding natural sinks to help meet Maryland's 2045 net-zero goal, negative emissions are not included in the 2031 target, which is a gross emissions goal. Therefore, assumptions about the forest sink do not impact the analysis of Maryland's Climate Pathway to 2031.

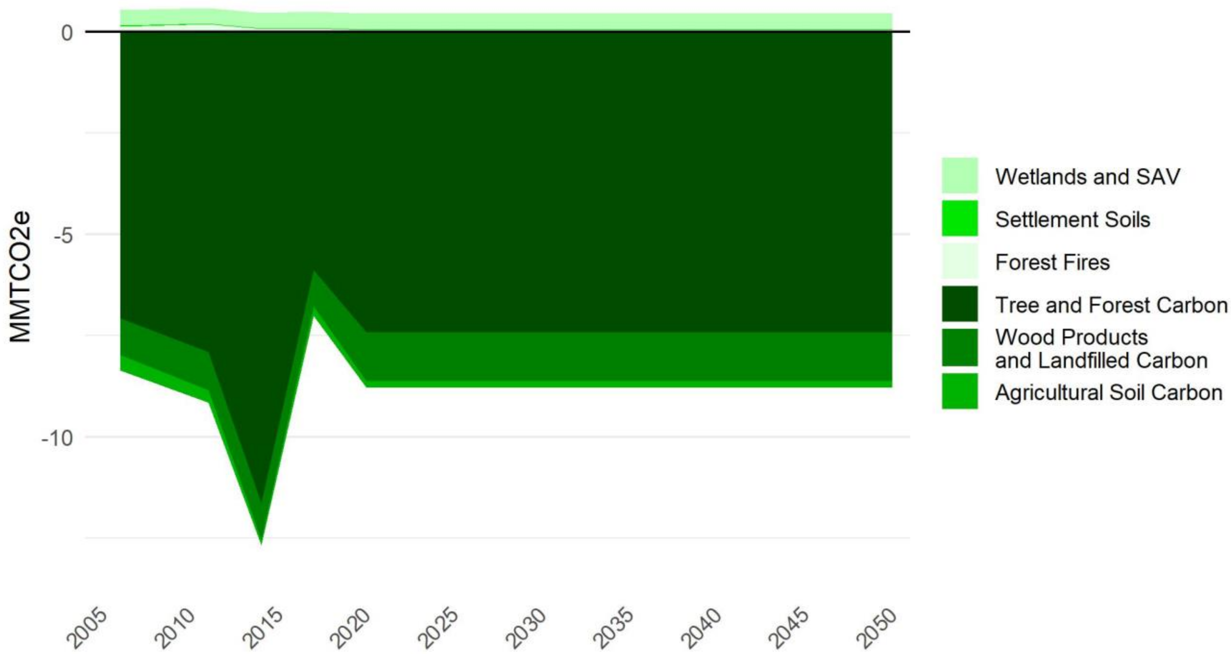

Figure 2.20. Forestry and Land Use GHG emissions and sinks in Maryland's Climate Pathway.

Forests in Maryland are currently a net carbon sink, with trees annually removing more CO_2 from the atmosphere than they emit. Preliminary estimates indicate that the dominant driver of the future forest sink will be from continued regrowth of Maryland's existing forests. The magnitude of the forest sink in 2045 will be influenced by a combination of several factors: a slowdown in carbon uptake as current forests mature; changes in forest management practices; and the net impacts of changes in climate and CO_2 concentrations, which include changes in temperature, precipitation, and any changes in disturbance frequency due to forest fires, pests, or disease.[199] Any continued forest clearing will subtract from the forest sink, while reforestation and tree planting programs will increase the forest sink.

Agricultural soils in Maryland are currently a carbon sink due to a relatively high rate of adoption of best management practices, such as low- and no-till, which reduce pollution runoff and improve water quality, particularly for the Chesapeake Bay.[200] Agricultural soils also contribute nitrous oxide emissions, a powerful greenhouse gas, due to fertilizer use, which is included in the Agriculture sector (Section 2.8).

CONSIDERATIONS FOR POLICY IMPLEMENTATION

The forestry and land use sector is a critical sector for offsetting emissions across the rest of the economy. As the largest annual net carbon sink in this sector, many policies focus on preserving, managing, and growing forests. Well-managed farmlands are another key focus for policies in this sector. It is important to understand the impact that other emission reduction policies can have on land use and management and the potential impact of these activities on one of Maryland's critical ecosystems, the Chesapeake Bay.

Biofuel Considerations and Trade-offs

Biofuels can be an important component of a policy for achieving emissions reductions if biofuel feedstocks can be sustainably produced. Biofuel feedstocks in Maryland would primarily come from forest residues, sustainably harvested fuelwood, or potentially dedicated biomass "crops," such as fast-growing tree species. Because these feedstocks would compete with natural-growth forest for land, there are potential tradeoffs between biofuel production and the continued growth of forests and land carbon sinks. If improperly managed, biofuels can also have a negative impact on land use, food security, water availability, and revenue.[201] However, there are still synergies with sustainable development goals, including water quality, soil quality, and biodiversity conservation.[201] To ensure that these synergies are realized, policies must promote the sustainable development of biofuels and management best practices to prevent adverse effects.

Long-lived Wood Products

As building demand continues to grow worldwide, increasing the utilization of wood in long-lasting harvested wood products can be a way to bolster carbon sequestration while simultaneously helping to decarbonize the building sector.[202] Mass timber is an engineered wood product that allows tall buildings to be built with wood, creating a low-carbon alternative to carbon-intensive building materials like concrete and steel.[203] One study found that average embodied GHG emissions of reinforced concrete buildings are 42.68% higher than that of mass timber alternatives.[204] One of the significant benefits of mass timber is the potential to not only replace high-emissions materials, but also to produce negative emissions through carbon sequestration for as long as the product lasts. However, there is a lack of consensus on the amount of sequestration from engineered wood products, as well as concerns over eventual CO_2 emissions when the wood decays.[204] Mass timber is an emerging technology that could be utilized in Maryland to reduce emissions in the building sector, but there may be tradeoffs with forest growth if wood is harvested unsustainably. Best practices in forestry management are therefore critical to reaping the benefits of mass timber while preventing deforestation and promoting the continued growth of forests.[205]

Protecting the Chesapeake Bay Ecosystem

As a coastal state and part of the Chesapeake Bay ecosystem, best practices for Maryland's climate goals will provide synergies between protecting its ecosystems and reducing GHG emissions. Current policies and programs in Maryland, such as the Healthy Soils Competitive Fund, already promote a range of improved soil management practices, including agroforestry.[206] Evaluation is underway to determine the GHG implications of the practices supported by these programs, in order to steer resources to those that maximize water quality benefits, minimize emissions, and increase soil carbon.

Another strong synergy between climate and water quality is blue carbon and related policies. Blue carbon ecosystems are coastal wetlands and submerged aquatic vegetation (SAV) that contain significant carbon stocks and fluxes. These ecosystems have the ability to store carbon but will also emit when degraded. Protecting coastal ecosystems, including wetlands, will therefore not only promote ecosystem health, but can also achieve emissions reductions.[207] Maryland has already implemented programs such as the

Resiliency Through Restoration Initiative to improve the health of coastal ecosystems to help protect communities from climate change impacts.[208] These programs can also result in increasing carbon sequestration. Despite the benefits, there are significant environmental and economic barriers to ecosystem restoration, including lack of funding, physical characteristics that decrease the likelihood of success (including sea level rise), economic interest in marine life (e.g., oysters), competition with existing land uses, and human disturbances.[207] The Maryland Wetlands and Waterways Protection Program currently works to protect wetlands and waterways from loss and degradation, which will prevent further ecosystem loss and help Maryland achieve its climate goals.[209] As more detailed analysis of blue carbon ecosystems is completed, the forestry and land use sector scenarios will be updated to reflect the best available data.

CASE STUDY: HEALTHY FORESTS, HEALTHY WATERS

The Maryland Forest Service, the Chesapeake & Atlantic Coastal Bay Trust Fund, the Alliance for the Chesapeake Bay, and the Maryland Forestry Foundations have collaborated over the last nine years to implement the largest tree planting program on private lands in the State of Maryland. The *Healthy Forests, Healthy Waters* Program provides participating landowners with a free, turnkey tree planting plan for an acre or more of land that they want to convert to a forest. The program is made possible by a grant from the Maryland Department of Natural Resources Chesapeake and Coastal Bays Trust Fund. From 2014-2020, the four collaborating organizations have completed five DNR Trust Fund funding grants to establish forest cover on private lands, resulting in 555 acres of new woodlands being planted on 140 parcels of land. In 2020, another DNR Trust Fund grant was awarded to the program, allowing an additional 208 acres of forest to be planted on 37 private land parcels.

Because forests are currently a net carbon sink in the State, maintaining and increasing forest coverage in Maryland is crucial to decreasing net GHG emissions. It's also important to recognize the synergies between maximizing water quality and reducing GHG emissions. Establishing new coverage will not only reduce the amounts of nutrients and sediments entering Maryland's waterways, but will aid in sequestering CO_2 from the atmosphere, which will help Maryland achieve its ambitious net-zero emissions goal. Tree planting programs in Maryland, such as Healthy Forests, Healthy Waters, can ensure that forests in the State remain a net carbon sink and contribute to maintaining the quality of important ecosystems such as the Chesapeake Bay.

2.10 LOW IMPLEMENTATION SENSITIVITIES

As discussed in *Considerations for Policy Implementation* throughout Sections 2.1-2.9, there are many uncertainties and challenges around the full implementation of the federal and State policies modeled in the core scenarios. To assess the impacts of these uncertainties on emission outcomes, we explore a set of sensitivities by assuming a less optimistic implementation of several State policies and IRA provisions under Maryland's Climate Pathway.

As shown below (Table 2.1), the Low Implementation scenario includes: delayed achievement of EV sales targets in ACC II and ACT; smaller VMT reductions; less electrification of nonroad fuel usage; fewer commercial buildings meeting the 2040 net-zero goal under BEPS; delayed compliance with zero emissions appliance standards and construction standards; slower deployment of solar and wind power; less waste diversion; no adoption of a cap-and-invest program; and a less optimistic implementation of IRA's clean energy tax credits and EV tax credits.[2] Moreover, it also assumes an overall low implementation of various IRA funds and provisions, which are not only drivers for emissions reductions on their own, but also powerful enabling policies that can help deliver the State's various policy targets. Failing to effectively utilize the IRA could make achieving these targets more costly and result in delays.

Policy	Target	Maryland's Climate Pathway	Low Implementation
ACC II	2030 EV sales target	54%	27%
	100% EV sales target year	2035	2045
ACT	2030 EV sales target	30%-50%	15%-25%
	40-75% EV sales target year	2035	2045
Nonroad fuel use	50% electrification by 2050	Yes	No
Smart growth	Annual average VMT growth from 2020 to 2030	0.6%	1.2%
BEPS	Share of commercial buildings hitting net-zero by 2040	50%	25%
Zero emissions appliance standards and construction standards	Compliance year	2027	2032
Solar & wind deployment	RPS target year	2030	2035
	CES target year	2035	2040
	RGGI target year	2040	2045
Waste management	Additional annual waste diversion	0.4%	0%
Cap-&-invest	Adoption	Yes	No

IRA	PTC ($26/MWh)	7.5% transferability deduction	15% transferability deduction
	ITC (30%)	7.5% transferability deduction	15% transferability deduction
	Clean vehicle credit effective value	$6,673	$3,337

Table 2.1. Summary of representation of low implementation of state and federal policies compared to Maryland's Climate Pathway.

MODELING RESULTS

Overall, the combined effect of low implementation of these policies leads to a gap of 10.2 MMTCO2e with the State's 2031 target. Without the cap-and-invest program alone, the policies in Maryland's Climate Pathway only achieve 56% emissions reductions in 2031, falling 4.8 MMTCO2e short of the State target. Additionally, without a carbon market created by the cap-and-invest program, CDR fails to deploy, and the State falls short of its 2045 net-zero goal. Although emissions still decline, the rate of decrease slows and net emissions in 2045 are 27.0 MMTCO2e in the Low Implementation scenario.

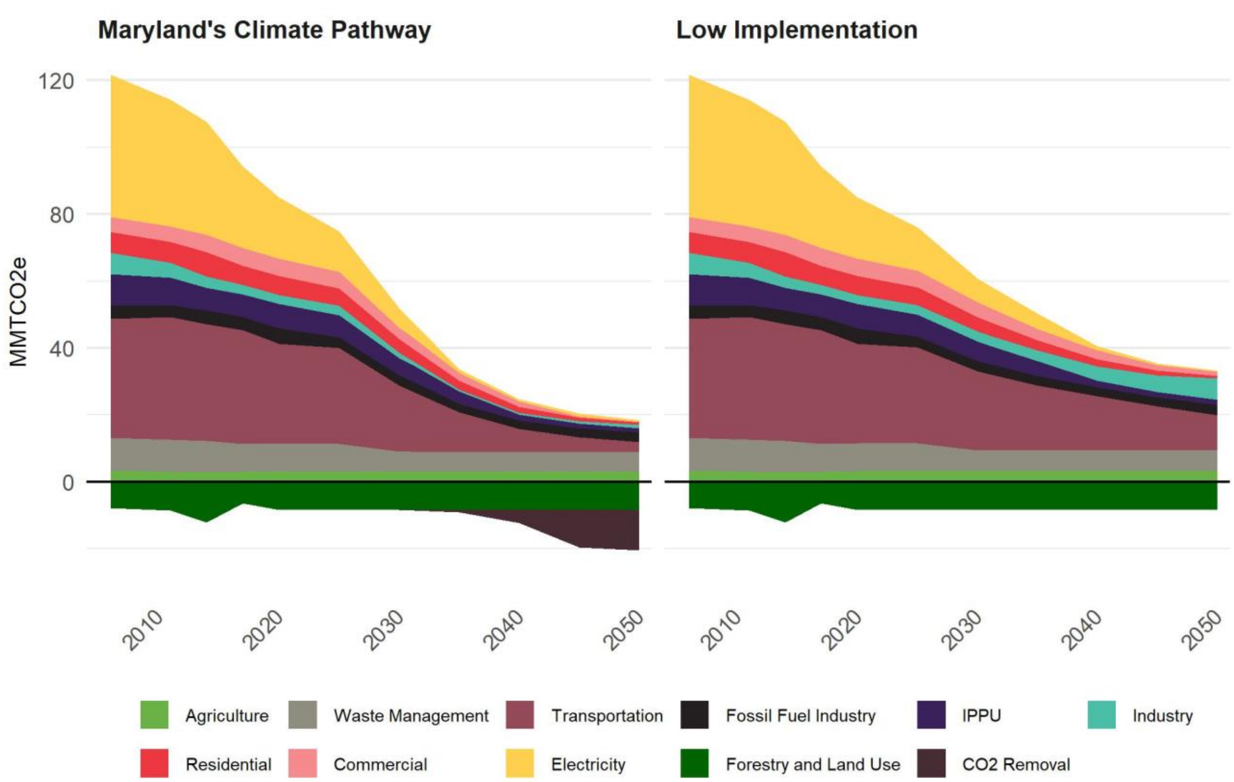

Figure 2.21. Economy-wide GHG emissions by sector in Maryland's Climate Pathway compared to Low Implementation of key policies.

Lower implementation of State and federal policies leads to a notably different electricity generation mix compared to Maryland's Climate Pathway. Delayed achievement of Maryland's clean energy targets in the Low Implementation scenario leads to a smaller build-out of renewables, continued unabated use of natural gas generation through 2040, and lower levels of imported electricity from the PJM grid. These changes are associated with a lower overall level of electricity consumption, so the electricity sector achieves 84% emissions reductions from the 2006 baseline by 2031 (compared to 89% reductions in Maryland's Climate Pathway), but because of lower electrification, emissions in end-use sectors are higher. It is important to note that substantial build-out of renewables is still required in the near-term, even with the delayed achievement of State targets. Therefore, grid stability with high renewables penetration will be a key challenge, even if State targets are not fully met, and addressing this challenge should be a priority for both the State and the wider PJM grid region.

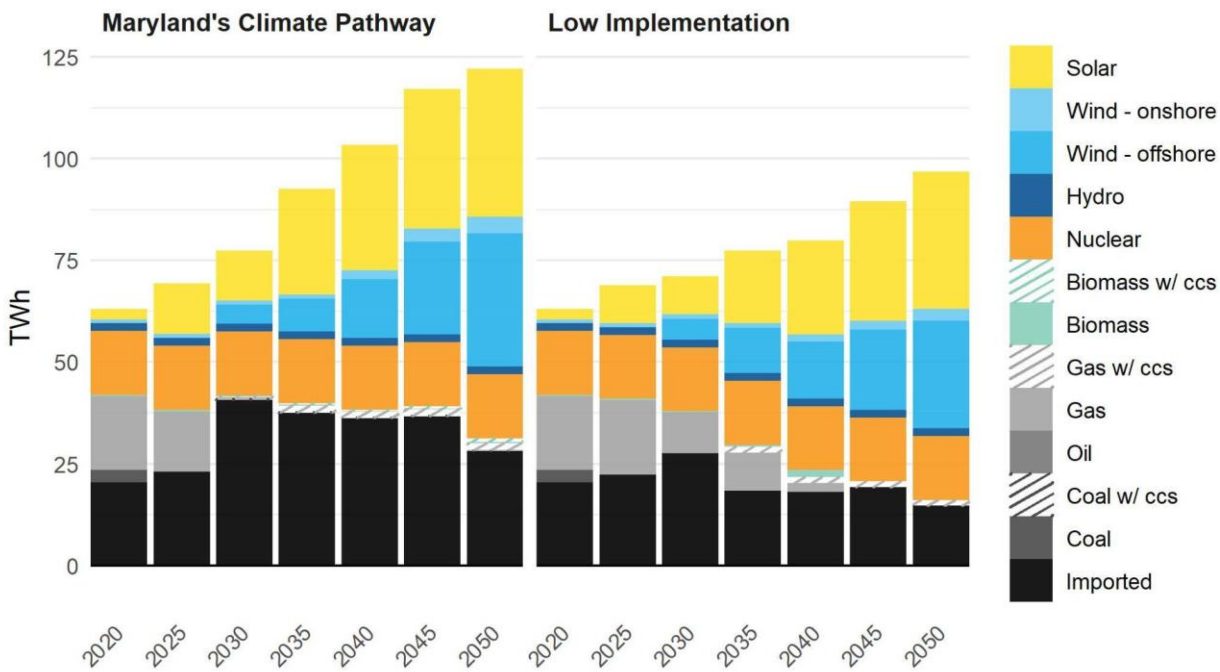

Figure 2.22. Electricity generation in Maryland's Climate Pathway compared to Low Implementation of key state-level policies.

Low Implementation of key policies leads to substantially lower electricity consumption overall, primarily due to reduced electrification in transportation and industry.

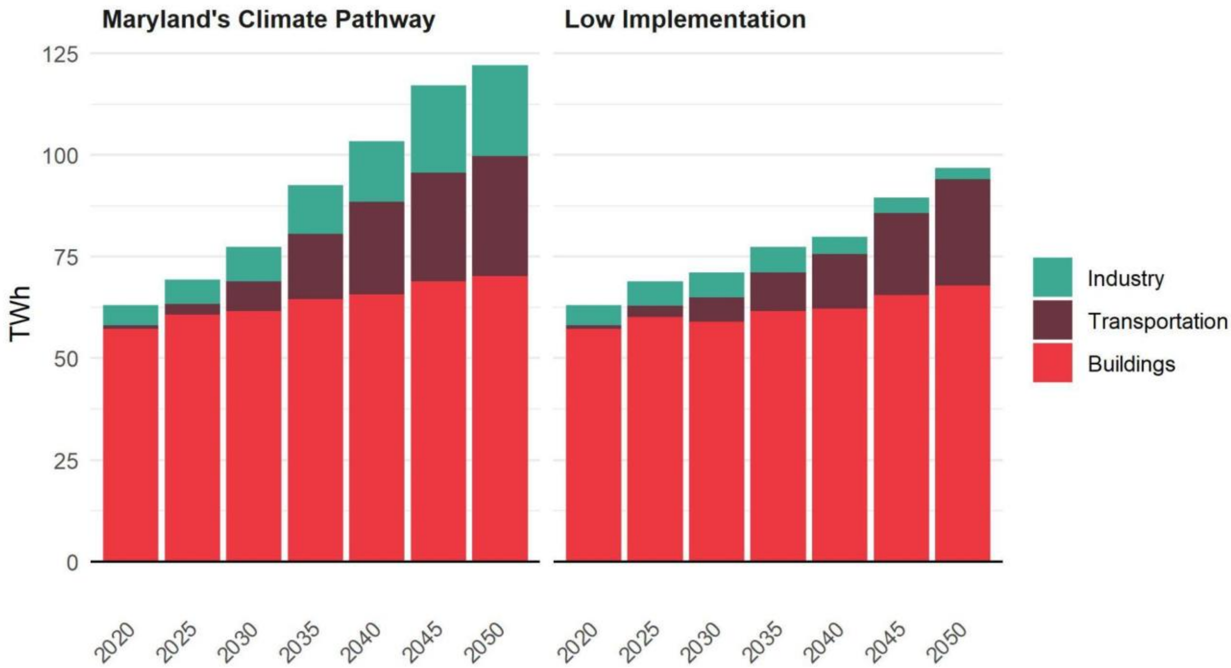

Figure 2.23. Electricity consumption by sector in Maryland's Climate Pathway compared to Low Implementation of key state-level policies.

The transportation sector sees significant changes under lower levels of policy implementation, achieving only 36% emissions reductions from 2006 levels by 2031, compared to 49% in Maryland's Climate Pathway. Potential sources of uncertainties that may affect transportation sector outcomes and achievement of targets include purchasing of internal combustion vehicles from states outside of Maryland; large-scale supply chain constraints on EVs or their components; and barriers that reduce access to and uptake of incentives such as the IRA tax credits. These instances are not modeled specifically in the sensitivity analysis presented here.

With Low Implementation of policies, passenger miles in personal vehicles (cars, SUVs, and passenger trucks) increases through 2030, then remain fairly constant through 2050, instead of declining, as seen in Maryland's Climate Pathway. Significant electrification still occurs for these vehicles, but it lags well behind rates seen in Maryland's Climate Pathway due to delayed achievement of state targets.

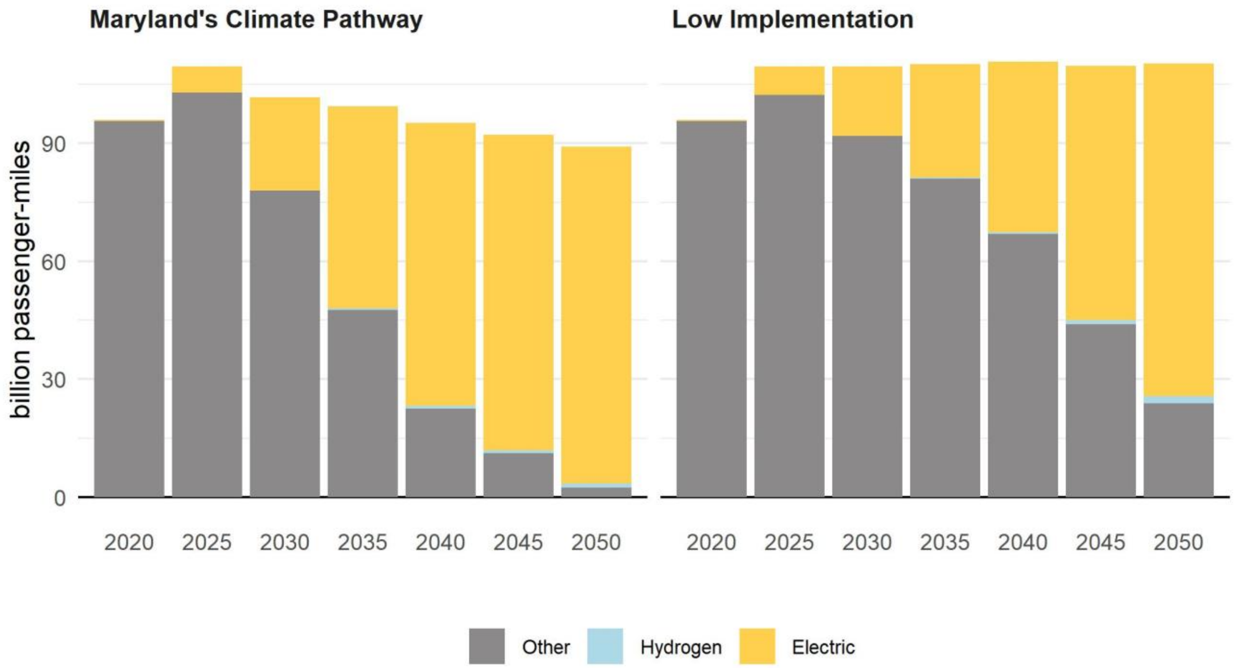

Figure 2.24. Personal vehicle use by fuel type in Maryland's Climate Pathway compared to low implementation of key State-level policies.

Electrification of freight trucks is also substantially different with Low Implementation of policies. In this scenario, there is a much lower adoption of ZEV trucks, which results in larger emissions from the transportation sector.

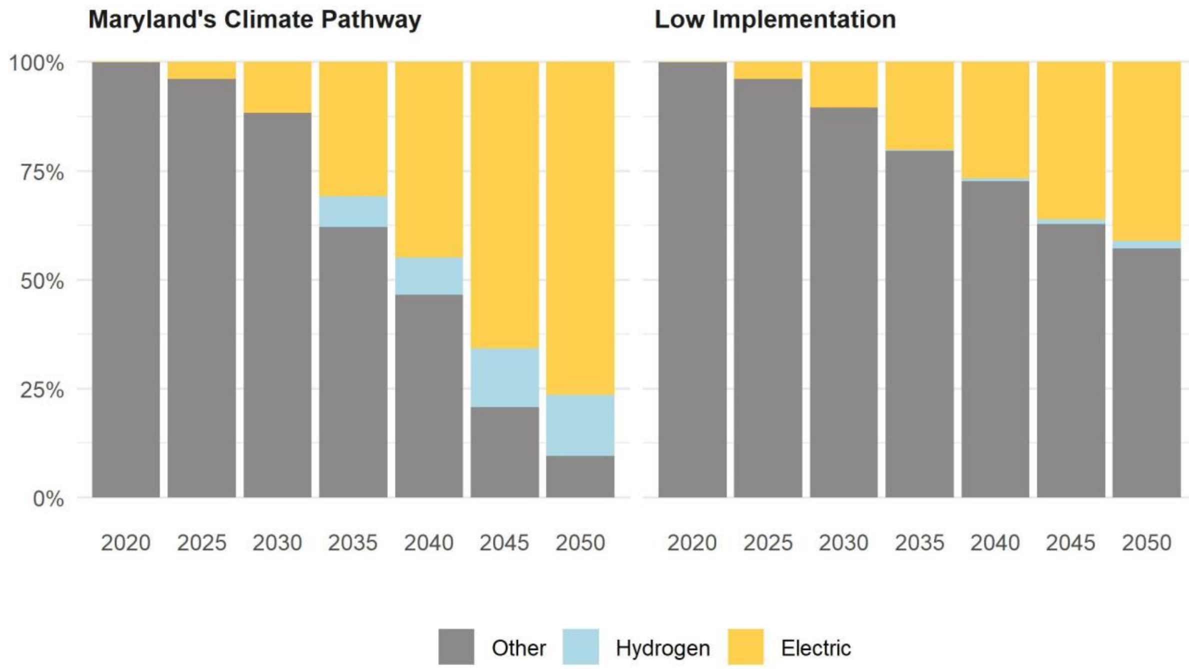

Figure 2.25. Freight trucking by fuel type in Maryland's Climate Pathway compared to Low Implementation of key policies.

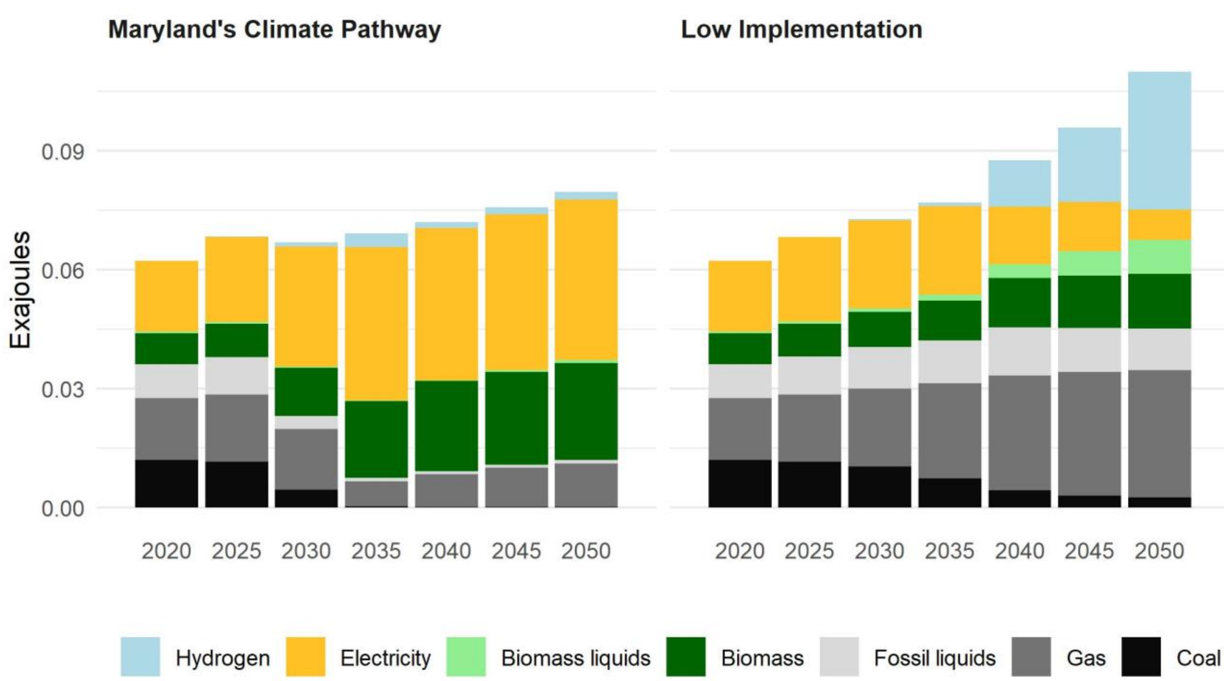

Figure 2.26. Industrial energy use by fuel type in Maryland's Climate Pathway compared to Low Implementation of key policies.

Without the cap-and-invest program there is less incentive for the industrial sector to shift to lower carbon fuels and energy technologies, and consumption of natural gas and fossil liquid fuels continues throughout the modeled period. This highlights the need to adopt policy measures to incentivize a shift to lower carbon options in the industrial sector in order to meet Maryland's emission goals.

Overall, the set of sensitivities with Low Implementation of State and federal policies leads to an emissions gap of 10.2 MMTCO2e in 2031. Closing this gap requires additional State actions and strategies to ensure Maryland's effective utilization of the IRA. Funds from the IRA, if applied correctly, can make it significantly easier to implement State policies.

3. BROADER SOCIETAL IMPACTS

HEALTH IMPACTS OF MARYLAND'S CLIMATE PATHWAY

In addition to reducing greenhouse gas (GHG) emissions, Maryland's Climate Pathway can yield significant benefits for air quality and public health through emissions reductions of co-pollutants. Overall, it delivers additional health benefits of $296 million to $667 million in 2031 compared to Current Policies.

These impacts were modeled using the EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).[210] A screening model used regularly in the research community,[211–213] COBRA is a free, easy-to-use EPA model employed as a preliminary analysis of health impacts and monetized benefits from environmental policy changes.[210] COBRA models the incidence rate and corresponding economic impact of twelve health outcomes due to five different co-pollutants. These co-pollutants include fine particulate matter 2.5 micrometers in diameter and smaller ($PM_{2.5}$) and precursor chemicals for $PM_{2.5}$, which COBRA converts in its calculations.

The added health benefits of Maryland's Climate Pathway scenario as compared to the Current Policies scenario in 2031 are summarized in Table 3.1. The largest contributors in terms of monetized benefits across the State are reductions in mortality, nonfatal heart attacks, and minor restricted activity days. More than 95% of the economic value is from reductions in mortality due to the high value of a statistical life.[214] Reductions in minor restricted activity days have the highest reduction in incidence rate, meaning the benefits are experienced by the largest number of people. The numbers in Table 3.1 represent the estimated number of avoided cases for each adverse health impact and the corresponding monetary savings due to the additional policies in Maryland's Climate Pathway scenario, beyond what is already included in Current Policies. While most incidence values represent impacts occurring in 2031, the avoided mortality is over the next 20 years (2031-2051).[214] For example, in the Pathway scenario, there would be approximately 32 fewer cases of Acute Bronchitis in 2031.

The benefits shown here represent a very conservative estimate of health benefits from fully realizing Maryland's Climate Pathway due to several methodological considerations. Some sectors, such as waste management, agriculture, and forestry and land use, were not modeled explicitly in GCAM. Because the pollutant changes used as COBRA inputs were derived from GCAM outputs, those sectors are not included in COBRA analysis. Further changes in pollutants resulting from off-model programs would likely result in positive health impacts as well, but they are not shown modeled here. Additionally, the benefits of enacting Current Policies are likely substantial, but these are not represented here because COBRA only captures impacts relative to a baseline, not the benefits of the baseline itself. For county-level results and more details on methodology, see Section 3 of the Technical Appendix. Future analysis can expand on these results to include greater detail on distributional impacts of health benefits and analyze benefits in future years.

Health Impact		Annual Incidence	Economic Value ($)
Total Health benefits	***low estimate***	-	***296,410,000***
	high estimate	-	***667,128,000***
Mortality (over 20 years, 2031-2051)	*low estimate*	*22.9*	*291,237,382*
	high estimate	*51.8*	*658,687,328*
Infant Mortality		0.13	1,826,414
Nonfatal Heart Attacks	*low estimate*	*2.24*	*394,669*
	high estimate	*20.8*	*3,664,189*
All Respiratory Hospital Admits		5.90	243,853
Cardiovascular Hospital Admits (except heart attacks)		5.12	290,866
Acute Bronchitis		31.7	22,322
Upper Respiratory Symptoms		575	28,059
Lower Respiratory Symptoms		403	12,437
Emergency Room Visits, Asthma		13.0	8,240
Minor Restricted Activity Days		16,550	1,657,283
Work Loss Days		2,818	636,750
Asthma Exacerbation		587	49,789

Table 3.1. Additional health benefits of Maryland's Climate Pathway scenario compared to Current Policies in 2031. Pollutant changes used as inputs for COBRA were linearly interpolated from GCAM output years 2030 and 2035. All Respiratory Hospital Admits include direct, asthma, and chronic lung disease summed into the total. Asthma Exacerbation includes cough, shortness of breath, and wheeze. Total Health Benefit Results are rounded to avoid communicating over precision in summing all of the health impacts.

The health benefits of policy action are not equally distributed across the State due to differences in population density and exposure to pollutant sources. This leads to well-known differences in health outcomes between different communities, with implications for environmental equity.[215,216] COBRA uses $PM_{2.5}$ concentration changes, determined within the COBRA model, to estimate the resulting health outcomes at the county level, which allows for a more granular analysis of State level policies.[214] Table 3.1 above is the aggregate totals of all the county-level results from the COBRA model. Figure 3.1 shows the reduction of $PM_{2.5}$ concentration in the Pathway scenario versus the Current Policies scenario in individual counties. For reference, the 2031 COBRA results show the county-level average concentration of $PM_{2.5}$ to be 6.95 µg/m^3 in the Current Policies scenario and 6.89 µg/m^3 in the Maryland's Climate Pathway scenario.

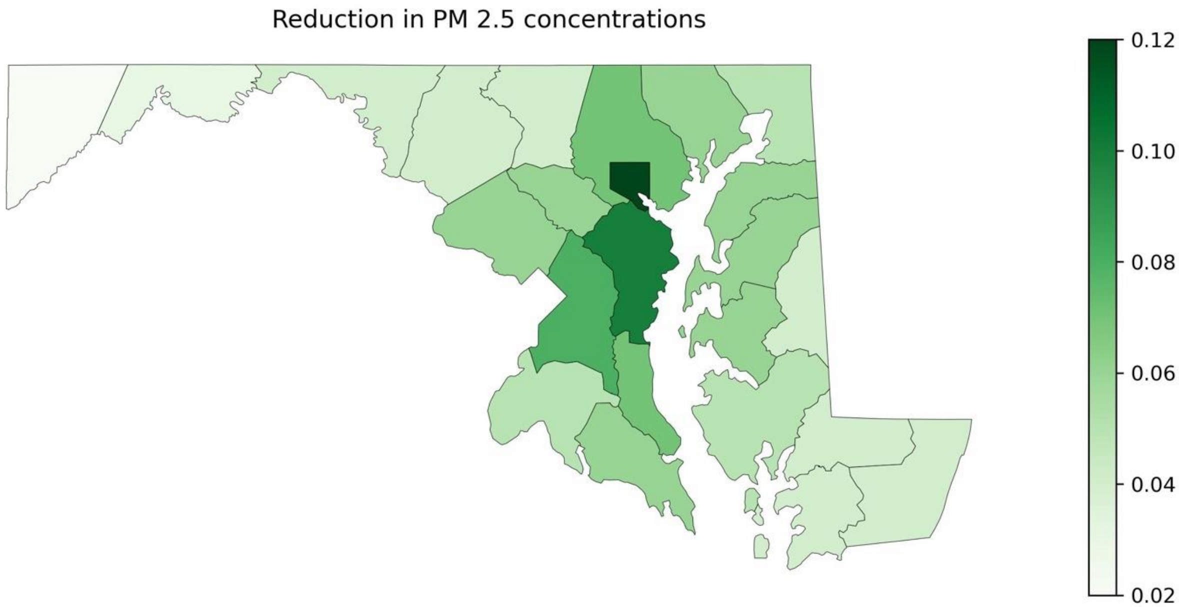

Figure 3.1. Reduction in $PM_{2.5}$ concentration (µg/m^3) by county in Maryland's Climate Pathway compared to Current Policies. Higher numbers indicate greater reductions and greater resulting health benefits.

The reductions in $PM_{2.5}$ tend to cluster on population centers where there are more sources of emissions, with particularly significant benefits accruing to communities in the Baltimore City area, which includes many historically disadvantaged communities. This remains true even when adjusted for population, with total health benefits showing a similar pattern. There are also notable benefits in counties along Maryland's Eastern Shore. Specifically, on a per capita basis, Baltimore City, Kent, Anne Arundel, and Talbot Counties have the greatest estimated total health benefits from the Pathway scenario. However, even Garrett County, a rural county in the western-most area of Maryland, is estimated to see significant total health benefits delivered in 2031 ($433,000 - $976,00), despite having the lowest $/person benefit.

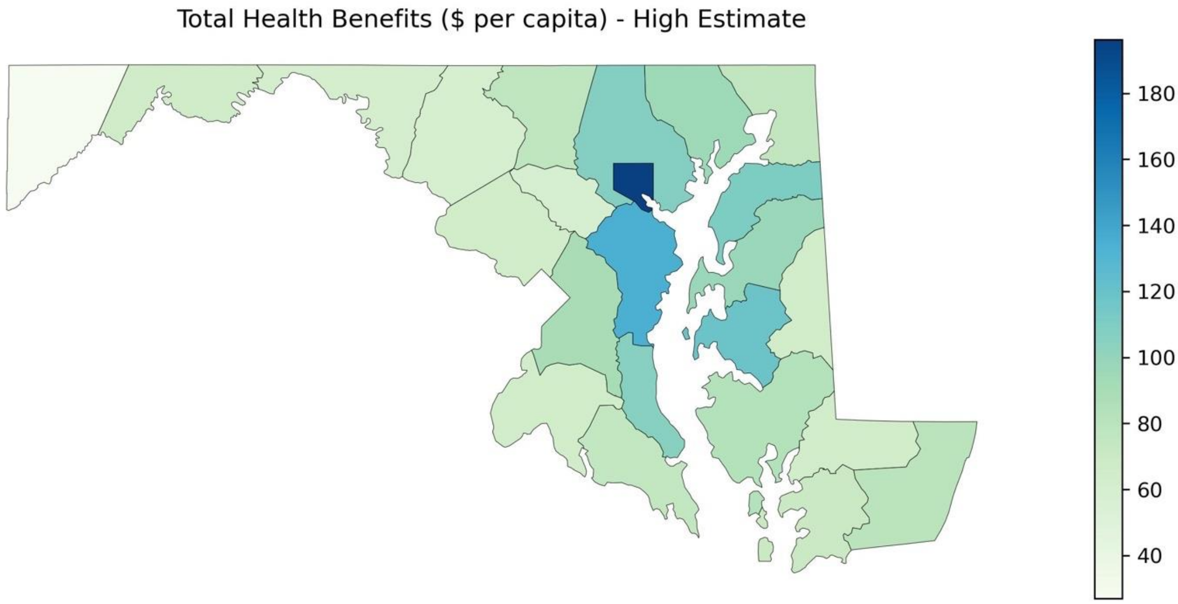

Figure 3.2. Total monetized health benefits in $/person realized through the additional policies in Maryland's Climate Pathway compared to Current Policies. Values are for the high estimate of benefits provided by COBRA.

There are also differences in the reduction of incidence rate for various symptoms and outcomes across counties. Prince George's County, a diverse county[217] that is densely populated with an estimated population of 1,031,691 in 2031, is expected to have 475 fewer work loss days in 2031 compared to the Current Policies scenario. Baltimore City, a focus area for environmental justice issues, such as pollution from waste incineration and from Baltimore Harbor, is estimated to have 96 fewer incidents of asthma exacerbation in 2031. Additionally, the Pathway scenario is anticipated to have the largest per capita reduction in asthma exacerbation in Talbot County, an Eastern Shore county with a small population compared to other Maryland counties. Washington and Worcester counties, along with Talbot, all of which are more rural, will see the greatest reduction in minor restricted activity days per capita. Minor restricted activity days are days in which activity is reduced, but not so far as missing work. Montgomery, Prince George's, and Baltimore counties, the most populous, are expected to see significant benefits in all categories. As shown in Figure 3.3, the incidence of upper respiratory symptoms is expected to reduce greatly for Baltimore City and the areas south and west of Baltimore.

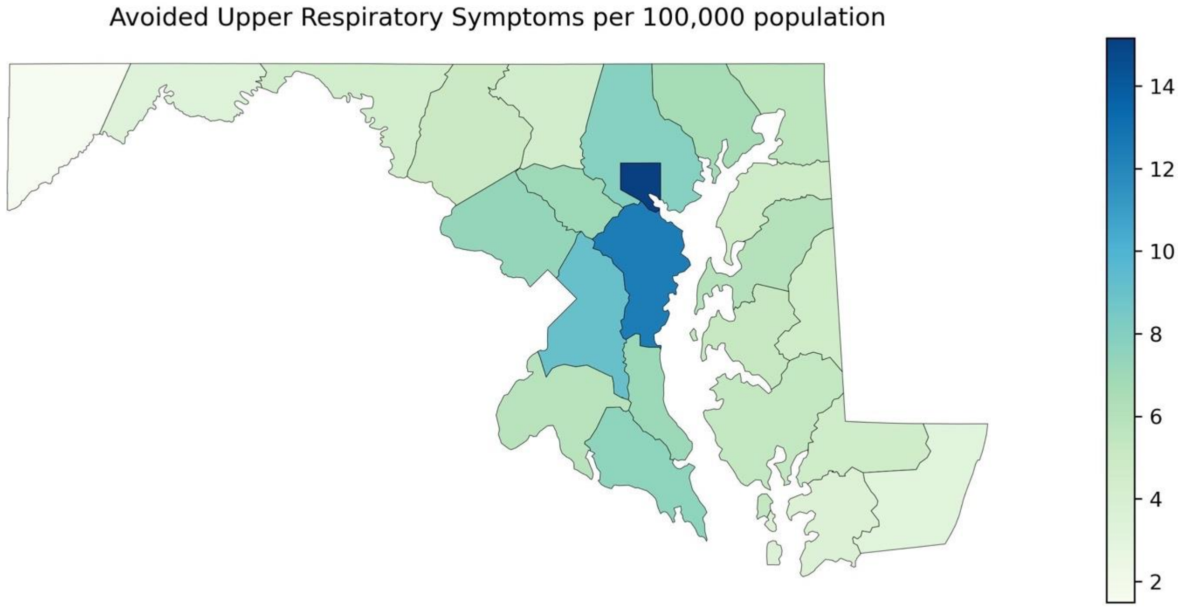

Figure 3.3. Reduction in incidence of upper respiratory symptoms by county in Maryland's Climate Pathway compared to Current Policies. Higher numbers indicate larger reductions, therefore fewer cases of symptoms.

The monetized benefits associated with these health improvements were also used as an input for modeling the overall economic impact of the Pathway scenario.

ECONOMIC IMPACTS OF MARYLAND'S CLIMATE PATHWAY

Meeting Maryland's climate targets can bring positive economic impacts to the State. In 2031, over 6,600 new jobs can be generated additionally under Maryland's Climate Pathway compared to Current Policies; total personal income increases by $611 million; and Gross Domestic Product (GDP) increases by $426 million.

The economic impacts of Maryland's Climate Pathway were evaluated with the REMI PI+ model, a high-end dynamic modeling tool used by various federal and state government agencies in economic policy analysis. It allows for the creation of a sophisticated model that is calibrated to the specific demographic features of the study, in this case, Maryland. This model enumerates the economic and fiscal impacts of each dollar earned and spent by the following: employees relating to the economic events; other supporting vendors (business services, retail, etc.); each dollar spent by these vendors on other firms; and each dollar spent by the households of the event's employees, other vendors' employees, and other businesses' employees. The REMI PI+ model also accounts for changes to the economy over time, including tax changes, inflation, recessions, and sequestration.

To estimate the impact of Maryland's Climate Pathway, the difference between the Current Policies and Climate Pathway scenarios was calculated in terms of capital costs, electricity generation costs, and energy consumption costs. These differences were entered into REMI PI+. Due to the broad industry scheme used in REMI PI+, the change in the cost of electricity generation was entered as a change in fuel costs under the Utilities sector. Changes in capital costs and energy consumption were also entered under the Utilities sector.

Table 3.2 summarizes the results of a forecast run in REMI PI+ of the economic benefits of Maryland's Climate Pathway compared to Current Policies. Results should be interpreted as changes from Maryland's standard regional control, which is the baseline forecast used in REMI PI+. Once changes in capital costs, energy consumption and electricity generation costs are entered, the model estimates what the shift from the baseline forecast would look like. Please note that the current REMI PI+ package used here does not estimate fiscal impacts. Future analysis can expand on these results to describe detailed sectoral and distributional impacts of climate action in Maryland.

Year	Employment	Personal Income	GDP
2024-2031, *average*	2091	$188,000,000	$37,000,000
2031	**6606**	**$611,000,000**	**$426,000,000**
2032-2045, *average*	7506	$915,000,000	$366,000,000

Table 3.2. Additional economic benefits of Maryland's Climate Pathway compared to Current Policies in terms of jobs created, personal income growth, and GDP growth. Results are shown specific to 2031, and as an annual average for 2024-2031 and 2032-2045.

Methodology

REMI PI+ is a dynamic model, meaning it analyzes the data over a given period and that future impacts are dependent on changes in the previous years. The main strength of the REMI PI+ model being dynamic is that it allows researchers to examine policy changes with respect to inflation and price effects. This method allows for increased demand and employment constraints from the previous years to shift inflation and wage changes in later years. The REMI PI+ model then allows researchers to look at the economic migration based on job opportunities within the region to estimate the labor that would seek to relocate as well as the potential for Maryland jobs to go to other states due to a shortage in labor demand.

REMI PI+ is built on a set of multipliers based on historical data created for each state by the Bureau of Economic Analysis. The model is based on the concept of input/output modeling. Within the model, an input or change to the economy is entered into the model. The model uses the multipliers to generate the potential economic impacts (jobs, output, and wages) that might result from this economic activity.

CONSIDERATIONS FOR POLICY IMPLEMENTATION

Equitable Access to Co-benefits

It is clear both from prior analysis of climate action and the specific results presented here that climate action also generates significant benefits from co-pollutant reductions.[218] However, the distributional impacts of these benefits can be more difficult to ascertain, and research has shown that vulnerable communities can be left behind unless intentional effort is made to center them.[219] The value of explicit focus on distributional impacts in decision-making frameworks, including understanding the spatial implications of proposed actions, has been demonstrated for multiple areas of climate action, including coal phaseout, grid decarbonization, and nature-based solutions.[219–221]

Measures of Economic Well-being

While GDP can be a valuable indicator for economic activity, it has well-known limitations that can be particularly pronounced in a climate context.[222] GDP may capture economic activity and output, but it does not provide a comprehensive understanding of the ecological impact and sustainability of such growth. As the global community grapples with the challenges of climate change, there is a growing recognition that alternative indicators that incorporate environmental factors are essential for assessing progress and guiding policy decisions toward a more sustainable future.

Efforts to improve upon GDP started in the 1970s with Measured Economic Welfare (MEW) and later the Index of Sustainable Economic Welfare (ISEW).[223] The Genuine Progress Indicator (GPI) was established in 1995 by the think tank Redefining Progress,[224] and it has been calculated for many countries and states.[224] Maryland was an early adopter of this measure as the first U.S. state to regularly calculate and track its GPI in addition to its GDP.[225] Considering the relationship between the economy, environment, society, and people's well-being, the GPI focuses on measuring more than just economic activity.[223] The Maryland Department of Natural Resources details three important principles for GPI: naming and deducting costs of environmental degradation, health effects, and loss of leisure time; accounting for income inequality; and measuring and including non-market benefits from the environment, economy, and society.[223]

This report presents GDP impacts due to its ubiquity as an indicator and lack of sufficient data to fully model the broader categories described above. However, adopting alternate indicators such as the currently calculated GPI to evaluate the impact of climate action could provide enhanced understanding of the economic, social, and environmental well-being benefits to Maryland communities.

4. BUILDING MARYLAND'S CLIMATE PATHWAY — TOGETHER

Achieving the 2031 goal will require immediate and sustained effort across Maryland's entire economy and at all governance levels. It will first require effective, collaborative implementation of current policies, in partnership with the federal government and the State's other governance levels including counties and cities. Nevertheless, even if fully implemented and maximum emissions reductions are achieved, these current policies only reach 51% reductions by 2031. Additional policies are therefore needed to meet the State target. Table 4.1 summarizes the reductions seen under Current Policies and in Maryland's Climate Pathway across sectors, showing where extra action is needed.

Sectors	Current Policies	Maryland's Climate Pathway
Economy-wide	51%	60%
Electricity	83%	89%
Transportation	38%	49%
Buildings	20%	35%
Industry	49%	79%
IPPU	39%	46%
Fossil Fuel Industry	20%	26%
Waste Management	37%	40%
Agriculture	6%	9%

Table 4.1. Summary of percent GHG emission reductions in 2031 relative to the 2006 baseline under Current Policies and in Maryland's Climate Pathway.

Even small reductions within a given sector can be critical to closing the gap between Current Policies and the State target. Additional actions must therefore be taken across all sectors to achieve the maximum mitigation potential. Table 4.2 summarizes by sector the mitigation strategies that are included in this report and the policy approaches that could enable them.

Sectors	Mitigation Strategies	Current & Potential Policy Approaches
	Provide market incentive for cost-effective mitigation	• Implement a cap and invest program
	Shift the electricity grid to clean generation	• Expand Renewable Portfolio Standard (RPS) to reach 100% clean electricity • Implement and raise awareness of IRA incentives, including tax credits and direct pay for clean energy production in low-income communities
	Shift PJM electricity grid to clean generation	• Strengthen the Regional Greenhouse Gas Initiative (RGGI) target to zero emissions by 2040
	Reduce passenger vehicle use	• Adopt new smart growth strategies • Increase public transit opportunities and access to safe walking/biking paths • Incentivize remote work, when possible
	Shift passenger vehicle fleet to ZEVs	• Achieve Advanced Clean Cars II targets • Implement and educate on IRA incentives • Implement electric vehicle (EV) infrastructure investments from BIL
	Shift freight trucking fleet to ZEVS	• Achieve Advanced Clean Trucks & Advanced Clean Fleets targets • Implement and educate on IRA & BIL incentives
	Electrify nonroad fuel usage	• Set new standards for equipment in construction, lawn care, warehouses, etc.
	Improve building efficiency	• Implement Building Energy Performance Standards and EmPOWER program • Implement and raise awareness of IRA incentives, including consumer tax credits for energy efficiency and clean energy upgrades • Set enhanced standards for new buildings
	Electrify all appliances	• Set zero-emission appliance standards • Set clean heat standards • Set all-electric construction standards
	Electrify industrial processes	• Implement EmPOWER program • Adopt Buy Clean policies (i.e. cement)
	Explore alternative fuels & energy sources	• Implement and raise awareness of IRA's hydrogen and CCS tax credits • Facilitate cement fuel switching
	Reduce HFC emissions	• Achieve AIM Act targets for HFC reductions • Achieve Maryland's HFC regulations
	Enhance efficiency in cement material	• Set new construction standards to reduce excessive use of cement • Adopt Buy Clean policies that prioritize cement products with high clinker replacement factor
	Reduce natural gas consumption	• Achieve policies across all consuming sectors
	Prevent and repair emissions leaks	• Implement Maryland natural gas methane regulation • Implement IRA methane fee
	Reduce methane from landfills	• Implement Maryland landfill methane regulation
	Divert and redirect waste	• Realize Maryland Sustainable Materials Management • Incentivize and facilitate composting • Prioritize circular economy policies
	Reduce methane emissions from enteric fermentation and manure management	• Incentivize best practices • Facilitate knowledge sharing

Table 4.2. Mitigation strategies for 2031 in Maryland's Climate Pathway by sector, and policy approaches that can contribute to these essential strategies. See relevant Sections 2.1-2.9 for details on specific policies.

With these and other policies, Maryland can achieve the 2031 target, set itself on a path to net-zero emissions, and generate additional benefits beyond Current Policies, including creating 6,606 new jobs in 2031, and providing up to $667 million in additional health benefits from co-pollutant reduction annually.

Much work still lies ahead. To achieve the Pathway analyzed in this report, it will be essential for Maryland to pursue an all-of-society approach to climate action, with engagement and efforts by State and local governments, as well as community groups, businesses, and individuals. In one step toward building this broad-based effort, MDE and CGS will convene a series of public workshops and provide other methods for interested parties to comment on the proposed Pathway. Following the open comment period, MDE will deliver a final policy framework and plan at the end of 2023. Once the final version of Maryland's climate plan has been adopted, further collaboration and engagement within and across sectors can help support and deliver the needed actions. Key strategies that could support this broad effort may include public outreach campaigns to raise awareness of eligibility for incentives and rebates; leveraging government's role as a convener to engage with businesses and industry around best practices; and sustained engagement with frontline communities to ensure that all policies are developed and implemented in a way that centers equity and ensures community backing.

Additional collaborative work across stakeholder groups will also be needed to support enhanced and more finely resolved planning for individual policies and sectors. This report identifies key areas for continued work to deepen the understanding of important sectors and strategies for meeting the State's climate goals. Near-term work can expand analysis on the agriculture and forestry and land use sectors, provide a more detailed assessment of distributional impacts of these pathways, and further explore the challenges associated with policy implementation in key areas to support development of a final State Plan by the end of 2023. Another important area for future work will be how to manage the transition described in this Pathway, including collaborative discussions across actors and analysis of how to ensure electricity grid reliability with high renewables penetration and growing demand, and how to phase down natural gas distribution systems in an equitable manner. The new Maryland Climate Change Commission Working Groups established by the CSNA will be a key avenue for addressing these and other concerns.

Future work across stakeholders can also explore new areas of policy that may be needed for longer-term goals. This could include sharpening our understanding of the possibilities for CO_2 removal and storage within the State, as well as assessing the need for new legal and financial frameworks to support deployment timelines that reach the levels modeled here by 2045. Materials and battery recycling, and other "circular economy" policies are another area that could support long-term decarbonization efforts, particularly in the industrial and waste management sectors. Finally, enhanced data collection on non-CO_2 emissions and mitigation potential could support deep decarbonization of certain difficult sectors. This could include developing tools to monitor F-gas emissions within the State, collecting site-specific data on landfills to enable targeted abatement measures, and monitoring pipeline systems to both track emissions and rapidly address leaks.

This analysis shows that through working together, Maryland's ambitious 2031 climate goal is within reach. Achieving it will provide substantial benefits to Marylanders and will set the State squarely on a path to achieve its 2045 net-zero emissions goal. Maryland's Climate Pathway offers an initial comprehensive, all-of-society view of how the State can not only reach its goals but also set an example in the United States and world of how to develop a new, healthy, and vibrant economy that works for everybody—and leaves no one behind.

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