Integrating Climate and Air Quality Planning in Maryland: Phase I

Applying NESCAUM's Multi-Pollutant Policy Analysis Framework

Prepared by
NESCAUM

March 20, 2009

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NESCAUM is an association of the eight northeast state air pollution control programs. Its staff provides technical guidance and policy advice to its member states.

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Executive Summary

This report was undertaken by the Northeast States for Coordinated Air Use Management (NESCAUM) and the Maryland Department of the Environment (MDE), with funding by the MDE. MDE's goal is to start developing a long-term ability to concurrently analyze policy and market impacts of air quality and climate programs. Recognizing that climate change will become the major environmental policy driver over the next decade, MDE seeks to employ analytical approaches and techniques developed by NESCAUM that evaluate least-cost policy pathways for achieving Maryland's climate goals while also yielding benefits to help the State address its other air quality challenges, such as ozone, particulates, air toxics, and regional haze.

MDE sees this study is seen as the first phase of a multi-year effort. The study's focus was to take the initial steps to employ NESCAUM's framework in Maryland. Over the long term, MDE anticipates building in-house capacity so that it can engage in multi-pollutant planning using the tools that NESCAUM employs. By doing so, MDE will be able to quantify the public health and economic benefits of multi-pollutant measures in a new manner that augments existing traditional planning techniques and metrics.

ES-1. Integrating Air and Climate Planning in Maryland

As today's environmental and public health challenges become more complex, states are recognizing the limits of the existing air quality management framework and the importance of moving to a more integrated, multi-pollutant, economy-wide approach. NESCAUM has recently developed an integrated, regional Multi-Pollutant Policy Analysis Framework that consists of a series of regional models linked together for analyzing energy, air quality, and economic and public health impacts in the Northeast.

In this Phase I effort, NESCAUM and MDE built qualitative and quantitative capabilities for multi-pollutant analyses in Maryland. Of particular interest were the multi-pollutant co-benefits resulting from implementing specific key features outlined in Maryland's Climate Action Plan. NESCAUM tailored the Northeast Market Allocation Model (NE-MARKAL) to reflect Maryland-specific conditions, and developed a reference case scenario that accounted for Maryland's Renewable Portfolio Standards (RPS). NESCAUM then provided preliminary analysis of implementing the Regional Greenhouse Gas Initiative (RGGI) program as described in the Maryland Healthy Air Act, and the Maryland Clean Cars Act. Using outputs from NE-MARKAL, NESCAUM then conducted a preliminary health benefits assessment using the Co-Benefits Risk Assessment Model (COBRA). These analyses demonstrate the tools and approaches that MDE can use in the future to evaluate potential policy initiatives.

ES-2. Methods and Approach

This study analyzed recently adopted climate mitigation policies using the NE-MARKAL energy and environmental modeling framework. NESCAUM developed three basic scenarios: a reference case, a scenario characterizing RGGI, and a scenario examining the Clean Cars Act. Next, NESCAUM examined a more stringent carbon cap scenario and then re-visited the Clean Cars Act, accounting for the lifecycle emissions of transportation fuels. Results from the reference scenario, which accounts for the State's

RPS and the power sector provisions of the Healthy Air Act, provided the basis for examining how the chosen policy scenarios were predicted to change energy consumption patterns, technology choices and, as a result, environmental outcomes.

After building the policy scenarios into the NE-MARKAL framework, NESCAUM conducted the modeling work and summarized key environmental and energy effects. Concurrent with the energy modeling work, NESCAUM developed a process to integrate the NE-MARKAL model with the COBRA model. NESCAUM used the modeled NE-MARKAL emission changes as inputs into COBRA to monetize the public health benefits associated with the chosen climate policy scenarios.

ES-3. Results

Chapter Two details the representation of RGGI and the Clean Cars Act in the modeling exercise and the associated NE-MARKAL modeling results. The predicted results indicate that RGGI is a modest carbon cap and not a significant driver of renewable energy, as greenhouse gas (GHG) reductions are predicted to be accomplished primarily by adding new gas-fired power generation. The model predicted that a more stringent cap on GHG emissions provides a strong incentive for renewable energy, especially from wind projects, which under the more stringent cap is predicted to account for 2.5 gigawatts of electricity generation by 2029.

The Clean Cars Act, which sets a GHG standard for light-duty vehicles, affects decision-making for the transportation sector differently, depending on whether the analysis accounts for the life cycle emissions from transportation fuels. Without life cycle accounting under the Clean Cars Act, the primary effect is predicted to be a shift away from gasoline and diesel in favor of significant increases in ethanol consumption. After accounting for life cycle emissions, however, the Clean Cars standard is predicted to be met by a much broader range of technology options and fuel choices. There is still a predicted shift away from gasoline and diesel, but compressed natural gas usage is also predicted to drop off sharply due to upstream emissions associated with its production and transportation. Another significant difference between the two analyses of the Clean Cars Act is the much heavier dependence on plug-in hybrid electric vehicles in the life cycle emissions scenario.

ES-4. Next Steps

Because this is a preliminary analysis, NESCAUM has started to identify three areas where there are opportunities for future study. First, NESCAUM recommends expanding the analysis to include the other modules of the NESCAUM Multi-Pollutant Policy Analysis Framework, and to explore more policy scenarios contained in Maryland's Climate Action Plan. Second, hand in hand with a more rigorous analysis, NESCAUM recommends that analytical enhancements should be pursued, as follows: (1) NESCAUM hopes to revisit the power sector assumptions and, in consultation with MDE, continue to refine the model's assumptions about this sector; (2) NESCAUM and MDE found that the predicted rate of declining gasoline consumption was non-intuitive. To address this, NESCAUM would like to examine the transportation sector data and constraints, and assess in coordination with MDE on where and if to place a lower bound gasoline consumption; (3) The relationship between high electricity prices induced by a carbon cap and increased deployment of industrial sector combined heat and power (CHP) should be examined in more detail and expanded to the commercial sector; (4) The interaction between ethanol incentives and emissions of nitrogen oxides (NOx) should be further examined. Third, efforts should be focused on how to build capacity in-house at MDE so that it can engage in multi-pollutant planning using the suite of the tools within the NESCAUM Framework.

1. INTRODUCTION

1.1. Air Quality and Climate Planning in Maryland

The State of Maryland has made strides in addressing its air quality challenges. By mid-2007, the Maryland Department of the Environment (MDE) had completed and submitted to the U.S. Environmental Protection Agency (EPA) its State Implementation Plan (SIP) to attain the eight-hour, 0.08 parts per million (ppm) National Ambient Air Quality Standard (NAAQS) for ozone. By early 2008, it had completed and submitted its SIP for the annual fine particulate matter ($PM_{2.5}$) NAAQS of 15 $\mu g/m^3$.

In light of recent scientific studies supporting more health protective standards, the U.S. EPA promulgated lower, more protective $PM_{2.5}$ and ozone NAAQS in 2006 and 2008, respectively. Maryland is currently involved in planning efforts in-state and within the greater Mid-Atlantic and Northeast regions to attain those new health-based standards. The MDE is working on policies that can further reduce Maryland's emissions, as well as with states in the Ozone Transport Region and eastern U.S. to mitigate pollution that originates upwind of Maryland.

In April 2007, Governor Martin O'Malley signed an Executive Order establishing the Maryland Commission on Climate Change (the Commission). The Commission's principal charge is to develop a Plan of Action (the Climate Action Plan) to address the drivers of climate change, prepare for its likely impacts in Maryland, and establish goals and timetables for implementation. In August 2008, the Commission issued its Climate Action Plan. The Commission has established the following science-based goals for reducing greenhouse gases (GHG) emissions in Maryland. All goals use a 2006 base year:

- 10 percent reduction by 2012
- 15 percent reduction by 2015
- 25 to 50 percent reduction by 2020
- 90 percent reduction by 2050

Maryland has already taken some important early actions toward reaching these goals, as described in the following sections.

1.1.1. The Healthy Air Act

Adopted as State law in 2006, the Healthy Air Act includes a provision for Maryland to join the Regional Greenhouse Gas Initiative (RGGI), a groundbreaking cap-and-trade program designed to reduce carbon dioxide (CO_2) emissions from power plants in participating states in the Northeast and Mid-Atlantic. The Maryland allocation in RGGI is expected to reduce CO_2 emissions by approximately 8.7 million tons by 2020. Maryland participated in RGGI's first auctions of CO_2 allowances in 2008.

1.1.2. The Clean Cars Act

Maryland's Clean Cars Act, adopted in 2007, requires implementing the California Clean Cars program (CA LEV). By requiring more rigorous emissions standards beginning in vehicle model year 2011, the program is expected to yield reductions in GHG emissions in Maryland as early as 2010, achieving reductions of approximately six million metric tons by 2020.[1]

1.1.3. EmPOWER Maryland Program

Launched by Governor O'Malley in July 2007 and codified by the General Assembly in its 2008 session, the EmPOWER Maryland Program is designed to reduce per capita electricity use by Maryland consumers by 15 percent in 2015. This could reduce GHG emissions by roughly seven million tons in 2020.

1.1.4. The 2008 Legislative Session

Nearly all of the Commission's Early Action recommendations for legislation were adopted as law in the General Assembly's 2008 session. Significant early reductions will be achieved through the following 2008 laws:

- EmPOWER Maryland Energy Efficiency Act of 2008
- Regional Greenhouse Gas Initiative – Maryland Strategic Energy Investment Program
- High Performance Buildings Act of 2008
- Renewable Portfolio Standard Percentage Requirements – Acceleration

The Maryland General Assembly adopted other laws designed to reduce GHG emissions in 2008 that were not part of the Commission's Early Action recommendations. These include: increased grants and tax incentives for solar and geothermal installations; a law to spur development around transit stations; low interest loans for energy efficiency projects; and establishment of the Maryland Clean Energy Center.

Taken together, these programs will provide reductions not only in CO_2, but also in air toxics, nitrogen oxides (NOx), sulfur dioxide (SO_2), and volatile organic compounds (VOCs). Over the next few years, Maryland will continue assessing and developing policies and programs to further reduce GHG emissions and make progress towards its climate goals.

1.2. The Need for Integrated Multi-Pollutant Planning

Under the federal Clean Air Act, states have been required to prepare their plans and programs to mitigate each air pollutant problem discretely. This has tended to encourage a single-pollutant planning mindset. However, motor vehicles, power plants, and other fossil fuel combustion sources can contribute to the formation of ground level ozone, fine particle pollution, mercury and acid deposition, and climate change by

[1] This assumes that the EPA, upon reconsideration, approves California's request for a waiver of preemption under Section 209 of the Clean Air Act.

emitting NOx, SO_2, VOCs, primary particulate, mercury (Hg), and CO_2. As today's environmental and public health challenges become more complex, states are recognizing the limits of the existing air quality management framework and the importance of moving to a more integrated, multi-pollutant, economy-wide approach.

Integrated multi-pollutant planning has the potential to be a more economical way to address environmental and public health issues. By looking at multiple air quality goals concurrently and by identifying potential control approaches and their environmental, public health, energy, and economic impacts together, a more complex set of policy questions emerges that can then be addressed. Multi-pollutant planning can identify tradeoffs of implementing one strategy over another, help set priorities and appropriate planning horizons, allow for more informed decisions, and ultimately provide more regulatory certainty. It can help assess unintended consequences of various control approaches and identify the best mix of policies and controls, given the mandate to protect public health and the environment.[2]

In June 2007, the federal Clean Air Act Advisory Committee recommended that governments adopt a comprehensive statewide air quality planning process and move from a single to a multiple pollutant approach in managing air quality.[3] The U.S. Environmental Protection Agency (EPA) has initiated pilots in four states that are already engaging in statewide planning.[4]

While many states have taken steps towards multi-pollutant planning and analysis for criteria pollutants, few are integrating GHG, mercury, and other air toxics. The modeling potential technological evolution, corresponding emission reductions, and possible co-benefits associated with multi-pollutant programs is complex and must be performed using regional-scale tools of appropriate detail. The Northeast States for Coordinated Air Use Management (NESCAUM) has developed such modeling capabilities and is currently engaged with some of its member states in multi-pollutant analytical techniques.

1.3. NESCAUM's Multi-Pollutant Analysis Framework

To assist states in moving to an integrated multi-pollutant planning approach, NESCAUM has developed a Multi-pollutant Policy Analysis Framework (MPAF), illustrated in Figure 1-1. It brings together and uses a series of models to integrate energy, climate, and air quality planning. The MPAF contains models that deal with: (1) energy economics -- the Northeast Market Allocation Model (NE-MARKAL) -- and regional economic impacts -- the Regional Economic Models, Inc. (REMI); (2) air quality and acid deposition -- the Community Multi-scale Air Quality Modeling System (CMAQ); and (3) health effects -- the Benefits Mapping and Analysis Program (BenMAP)[5] or the Co-Benefits Risk Assessment Model (COBRA).

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[2] Weiss, Leah, Manion, M. Kleiman, G., James, C. Building Momentum for Integrated Multipollutant Planning; Northeast States' Perspective. *J. Air &Waste Manage. Assoc.*; May 2007, 25-29.

[3] Recommendations to the Clean Air Act Advisory Committee: Air Quality Management Subcommittee. Phase II Recommendations, June 2007. See: http://epa.gov/air/caaac/aqm/phase2finalrept2007.pdf

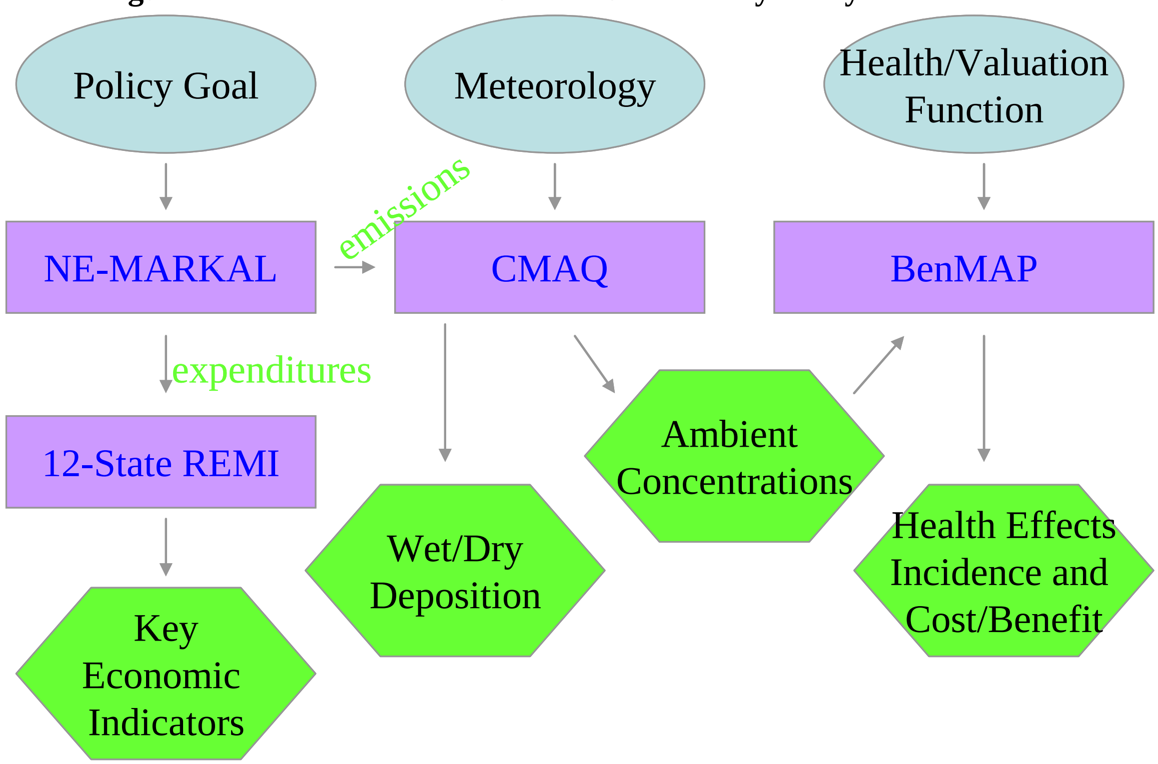
[4] See: http://www.epa.gov/air/aqmp/

[5] Abt Associates. 2007. Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP 2.4.8 US Version. Available at: http://www.epa.gov/air/benmap/download.html

The centerpiece of the framework is the NE-MARKAL model. NE-MARKAL is an energy model that simulates least-cost approaches to achieving pollution reductions. The model covers 11 Northeast states plus the District of Columbia,[6] and characterizes electricity generation, transportation, and the industrial, residential and commercial building sectors over a 30 year time horizon.

NESCAUM's framework provides a range of outputs. In addition to assessing potential emissions reductions, it allows the user to input the emissions reductions data into other models, thus providing data on potential air quality and health benefits. It also links the energy model to a regional economic model that estimates economic metrics, such as gross state product, jobs, and household disposable income. These types of economic indicators are important for states to garner support for prospective regulatory programs. NESCAUM is currently engaged in pilot projects, using its multi-pollutant analysis framework, with environmental agencies in Massachusetts and New York.

Figure 1-1 – NESCAUM's Multi-Pollutant Policy Analysis Framework



1.4. Project Goals and Tasks

The overarching goal of this project is to start developing a long-term ability at MDE to analyze policy and market impacts of air quality and climate programs and technologies concurrently. Specifically, MDE recognizes the general shift in environmental policy focus over the past few years from criteria air pollutant to climate

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[6] The jurisdictions covered in the NE-MARKAL model include: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.

change. Anticipating that climate change will be the major policy driver over the next decade, MDE wants to employ NESCAUM's framework from a climate-centric perspective, and evaluate least-cost policy pathways that can achieve Maryland's climate goals while also yielding benefits that can help the State address its other air quality challenges (i.e., ozone, fine particulate, regional haze, and air toxics goals). Over the long term, MDE also wants to be able to quantify the public health and economic benefits of such multi-pollutant measures in a manner that can augment the existing, more traditional emission reduction metrics. Furthermore, MDE wishes to build capacity so that staff can, in the future, engage in multi-pollutant planning using some of the tools that NESCAUM employs.

In this Phase I effort, NESCAUM initiated efforts to build qualitative and quantitative capabilities for multi-pollutant analyses in Maryland. Of particular interest were the multi-pollutant co-benefits resulting from implementing specific key features outlined in Maryland's Climate Action Plan.

In Phase I, NESCAUM tailored the NE-MARKAL model to reflect Maryland-specific conditions. NESCAUM developed a NE-MARKAL reference case scenario containing Maryland's Renewable Portfolio Standards (RPS), and provided preliminary analysis of two key policy initiatives: the RGGI program as described in the Healthy Air Act and the Maryland Clean Cars Act. Using outputs from NE-MARKAL, NESCAUM then conducted a preliminary health benefits assessment using COBRA.

The tasks for this project were as follows, and are discussed in further detail in Chapters Two and Three:

1. Identify air quality targets and climate-specific policies and programs, and characterize them for use in the NE-MARKAL model.

For this task, NESCAUM provided a list of model assumptions regarding economic factors, fuel cost, growth, and demand projections, current technology stocks, and future technology characterizations. NESCAUM provided a set of technical potential and policy constraints that, in combination with the other inputs, determined the future technology evolution for Maryland through the least-cost optimization model.

2. Develop the reference scenario.

To start the analysis, an appropriate reference scenario was developed against which subsequent policies and their benefits were measured. NESCAUM developed and provided a detailed reference scenario that was defined by future projections of technological evolution, multi-pollutant emissions trajectories, and total system costs. The reference scenario was reviewed by MDE staff to assess future growth and trends, subsequently adjusted, and approved.

3. Conduct NE-MARKAL model policy run and quantify co-benefits.

NESCAUM applied its framework to analyze the identified two key policy initiatives described above, comparing these two policies to the reference scenario. NESCAUM evaluated the lowest-cost options for meeting the RGGI carbon caps in Maryland and explored the implications for Maryland of RGGI-induced changes in fuels and technologies in the electricity sector on levels of criteria pollutants and overall energy use. NESCAUM also reviewed results for the Maryland Clean Cars Act scenario.

Estimates of criteria pollutant emission changes and associated health benefits were developed.

4. Final results and report, assessing technology transfer needs, and next steps.

As part of Phase I and based on the NE-MARKAL results, NESCAUM has detailed in this report the evolution of various technologies that are key to Maryland's multi-sector economy, along with disaggregated investment and fuel costs and emissions information. Preliminary analysis, using the COBRA health benefit assessment tool, has provided an estimate of the order of magnitude of the health benefits that may result from the Clean Cars Act policies due to any $PM_{2.5}$ reductions. These analyses did not result in any absolute or conclusive set of findings per se, but rather, established the tools and an approach that MDE can use as policy initiatives are proposed in the future.

The study has limitations that are inherent to the NE-MARKAL model. The results of NE-MARKAL derive from the wide array of input assumptions, which include such things as technology costs, resource availability and energy demand. The model will, however, provide insights into how these input assumptions affect the economics of the regional energy system. The pathways projected by the model fail to reflect individual or societal behavior associated with risk aversion, uncertainty or informational bias.

Other limitations of this specific study can be addressed in future work. For example, NESCAUM could further develop (i.e., provide more detailed or comprehensive data) and calibrate the analytical tools so that more policies and programs can be analyzed. Such future work could include linking to regional-scale economic models (REMI) and regional-scale air quality models (CMAQ) for more robust assessments of macroeconomic indicators (e.g., household income, jobs, gross state product), as well as more detailed environmental benefits and public health assessments (BENMAP). In addition, investigations of interactions among different policies should be performed because, in reality, multiple policies will be put in place. Multi-policy scenario analyses can help improve our understanding of which approaches may work well in concert versus those that do not. This report discusses these potential analyses using NESCAUM's integrated framework that MDE could pursue as part of its air quality planning process

2. AIR QUALITY AND ENERGY ANALYSIS

2.1. The NE-MARKAL Model

The centerpiece of NESCAUM's integrated modeling framework is a Northeast U.S.-specific version of the Market Allocation (MARKAL) model.[7] NE-MARKAL is an economy-wide model that encompasses the entire energy infrastructure of the Northeast states. It can model all energy demand and supply in the transportation, commercial, industrial, residential, and power generation sectors.[8]

As an engineering cost model, NE-MARKAL calculates a least-cost combination of energy technologies available to meet energy demand in each sector. The model contains highly-detailed depictions of energy technologies and their associated economic factors, so each technology combination generated is based on the relative costs of the various energy technology options and constraints on the energy system. For example, for the region's power generation infrastructure, the model includes a detailed, bottom-up characterization with unit-by-unit specification of power plants down to 25 MW.[9] Renewable generation capacity is specified with characterization of new renewable generation potential and resources provided by the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL). The transportation sector includes detailed characterizations of light-duty and heavy-duty vehicles.[10] NE-MARKAL's industrial sector is characterized for major regional and GHG-intensive industries, and the residential and commercial building sector covers the majority of GHG emissions resulting from buildings.

The NE-MARKAL model draws from several authoritative data sources.[11] Foremost of these is the Energy Information Administration's (EIA) National Energy Modeling System (NEMS), used to produce the Annual Energy Outlook (AEO). Technology characterizations have been extracted from the NEMS, along with data on base year technology stocks, resource supply options, and the sectoral growth rates used in developing demand projections for each model region (state). Other data sources include: the State Energy Data System (SEDS), which provides final energy use for each demand sector by fuel type; Gross State Product data from the Bureau of Economic Analysis; EIA's three sectoral energy consumption surveys; and the EPA's eGRID emissions database. NESCAUM has and continues to update and improve NE-

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[7] For information on the MARKAL model, see Loulou, R., G. Goldstein, and K. Noble. The MARKAL Family of Models, Energy Technology Systems Analysis Programme (ETSAP), October 2004.

[8] NE-MARKAL currently includes the six New England states, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Washington, D.C.

[9] NE-MARKAL can accommodate power plants less than 25 MW if the data are available.

[10] Light-duty transportation technologies have been largely taken from a recent study of "off-the-shelf" advanced technology vehicle options for the State of California that has been supplemented with NEMS technologies. See: Reducing Greenhouse Gas Emissions from Light-duty Motor Vehicles, September 2004. Northeast States Center for a Clean Air Future (NESCCAF), Boston, MA.

[11] A more detailed description of the NE-MARKAL model and its inputs and assumptions is provided at: http://www.nescaum.org/topics/ne-markal-model We focus here on providing an overview of the model, its capabilities, and the types of data sources that were used to develop NE-MARKAL inputs.

MARKAL's underlying databases with data provided by state agencies and regional experts.

As a linear programming model that optimizes outcomes based on cost, NE-MARKAL's strength is in exploring the relative cost-effectiveness of meeting various policy goals such as limits on CO_2 emissions or minimum performance requirements on vehicles. NE-MARKAL, in contrast to REMI, is not a general equilibrium model of the economy that forecasts the price, output and welfare effects—gains or losses of producer and consumer surplus—associated with the introduction of policy instruments. It is, however, one of the few models of its kind that considers all energy-consuming sectors and characterizes energy use, emissions of GHGs and criteria air pollutants, technology deployment, and costs at a high level of detail.

2.2. Assumptions and Methodology

NESCAUM has developed a set of NE-MARKAL modeling scenarios to support the State of Maryland's multi-pollutant planning efforts. Appendix A documents the baseline assumptions of the model, including base year demand by sector and projections extending to 2029. Technologies available to the model are also detailed, providing estimates of investment costs and efficiencies. In addition, initial model constraints on fuel share and technology penetration rates are provided. In consultation with MDE, NESCAUM reviewed the default input assumptions for Maryland and made necessary updates. Key updates included ensuring the NE-MARKAL list of power plants matched data provided by MDE and representing the Healthy Air Act controls on coal power plants.

2.2.1. Reference Case

The reference case provides the basis for comparison of different policy scenarios within the modeling framework. The model determines sector-by-sector fuel consumption for each three-year model time period, beginning in 2002. In this work, some policies already in place in Maryland were built into the reference case, including the Maryland RPS and some mandated controls within the power sector based on the Healthy Air Act. These are detailed in Section 6 of Appendix A.

After developing the reference scenario, NESCAUM built the policy scenarios for analyses. This study focused on two specific policies: RGGI and the Clean Cars Act. An additional characterization of each policy was investigated to demonstrate model sensitivity to the policy assumptions. For the RGGI analysis, a more aggressive power sector cap was examined. For the Clean Cars Act scenario, life cycle emissions factors were also provided as contrast to the original CO_2 default factors that presume carbon neutrality of biomass.

2.2.2. The Healthy Air Act and the Regional Greenhouse Gas Initiative

The Healthy Air Act requires Maryland to participate in the RGGI, the first mandatory market-based CO_2 emissions cap-and-trade program in the U.S. The 10 participating states, including Maryland, have agreed to cap CO_2 emissions from the power sector in 2008, requiring a gradual decrease over time until a 10 percent reduction in CO_2 to 2008 is achieved by 2018.[12] RGGI is composed of CO_2 budget trading programs in each of the participating states that are linked through CO_2 allowance reciprocity.

The RGGI cap was built into the NE-MARKAL database on a state-by-state basis. In NE-MARKAL, power plants were allowed to trade CO_2 allowances originating from any of the 10 participating states to demonstrate compliance with the state program governing the power sector. For purposes of modeling, the state programs essentially function as a single regional compliance market for power plant carbon emissions. After performing the NE-MARKAL modeling based on the RGGI's established goal, NESCAUM conducted an additional analysis, using a more aggressive, 30 percent reduction in the RGGI cap relative to 2008 CO_2 levels. The purpose of this run was to examine the evolution of Maryland's power generating mix under a more aggressive medium-term goal.

2.2.3. The Clean Cars Act

As follow up to a 2004 technical study by the Northeast States for a Clean Air Future (NESCCAF) on light-duty GHG emissions reductions, NESCAUM quantified the GHG emission reductions that would be achieved in the Northeast through adoption of the California light-duty motor vehicle GHG standards.[13] These standards mandate that CO_2 emissions decline 16 percent relative to 2002 levels by 2016. NESCAUM's analysis estimated state-specific CO_2 emissions from light-duty vehicles for 2009-2030 for the NESCAUM states. That work was used as a basis for estimating Maryland's GHG reductions under Maryland's Clean Cars Act. The analysis employed NE-MARKAL to explore pathways that would allow Maryland's light-duty vehicle fleet to achieve these reductions.

2.3. Results

2.3.1. Reference Case Results

Reference case results are presented in the following tables and figures. As previously described, the Maryland RPS is included in the reference case. NESCAUM made adjustments to the power sector to represent controls mandated by the Maryland Healthy Air Act. The 2002 and predicted 2029 results for fuel consumption shares by sector were tabulated with the corresponding time evolution plotted. The average annual growth of each fuel type within each sector is provided. Further details on the underlying assumptions presented for the reference case are available in Appendix A.

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[12] See: http://rggi.org/home

[13] "Northeast State GHG Emission Reduction Potential from Adoption of the California Motor Vehicle GHG Standards Summary of NESCAUM Analysis,".NESCAUM 2005. Available at: http://www.nescaum.org/documents/summary-of-nescaum-ca-ghg-reduction-analysis.pdf/.

Table 2-1 – End Use Demand Fuel Consumption Shares by Sector

	2002	Predicted 2029	Average Annual Growth
Commercial	15%	12%	1.9%
Industrial	21%	15%	0.4%
Residential	20%	16%	1.4%
Transportation	44%	35%	0.8%

Figure 2-1 – Predicted Commercial Sector Energy Consumption

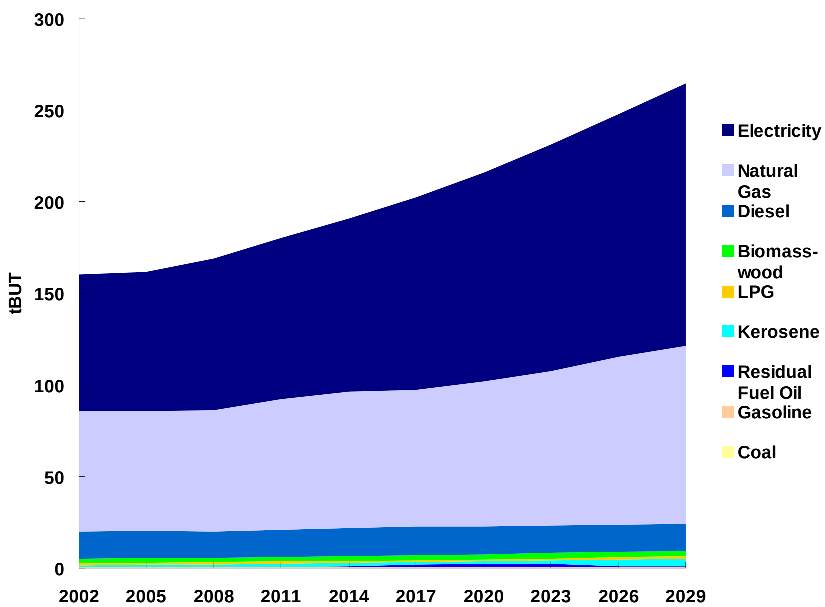


Table 2-2 – Commercial Sector Fuel Consumption Shares

	2002	Predicted 2029	Average Annual Growth
Wood	2%	0%	-12.9%
Coal	0%	0%	-0.1%
Diesel	9%	6%	0.1%
Electricity	47%	54%	2.4%
Gasoline	0%	0%	0.6%
Kerosene	1%	3%	7.7%
LPG	1%	0%	0.5%
Natural Gas	41%	37%	1.5%
Residual Fuel	0%	0%	1.4%

Figure 2-2 – Predicted Industrial Sector Energy Consumption

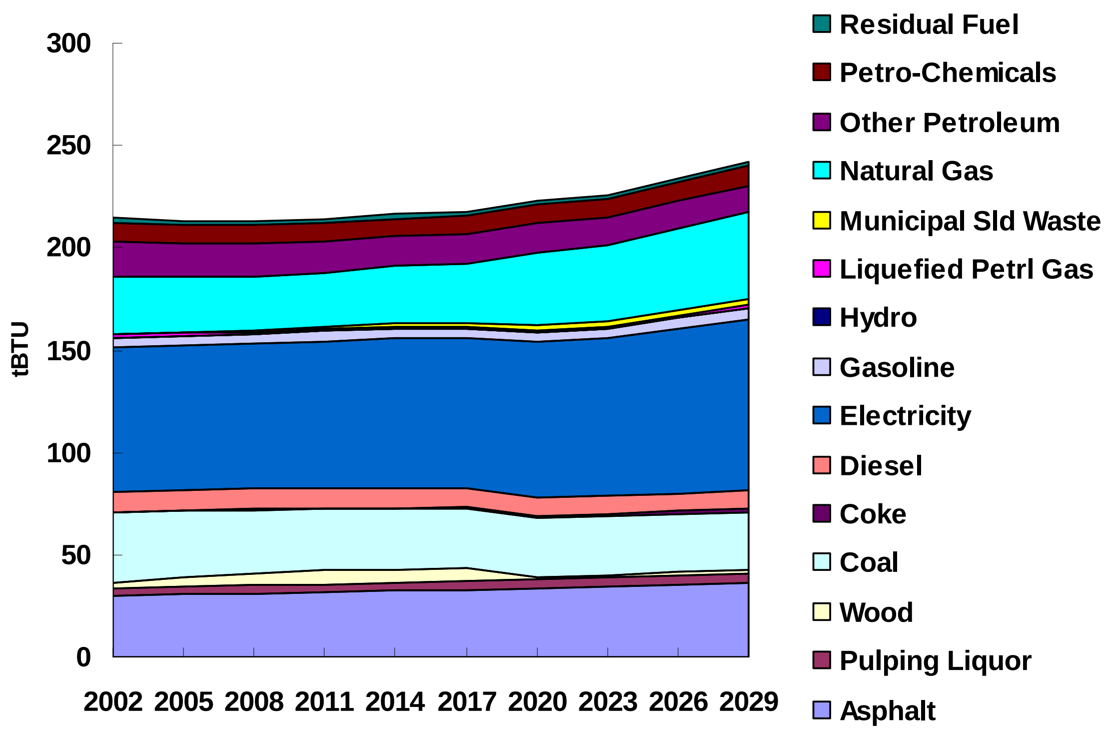


Table 2-3 – Industrial Sector Fuel Consumption Shares

	2002	Predicted 2029	Average Annual Growth
Asphalt	14%	15%	0.7%
Pulping Liquor	2%	2%	0.7%
Wood	1%	1%	-1.1%
Coal	16%	12%	-0.7%
Coke	0%	1%	11.5%
Diesel	5%	3%	-0.7%
Electricity	33%	35%	0.6%
Gasoline	2%	2%	0.7%
Hydro	0%	0%	~~
MSW	0%	1%	16.7%
Natural Gas	13%	17%	1.5%
Other Petroleum	8%	5%	-1.0%
Petro-Chemicals	5%	4%	0.0%
Residual Fuel	1%	1%	-1.1%

Figure 2-3 – Predicted Residential Sector Energy Consumption

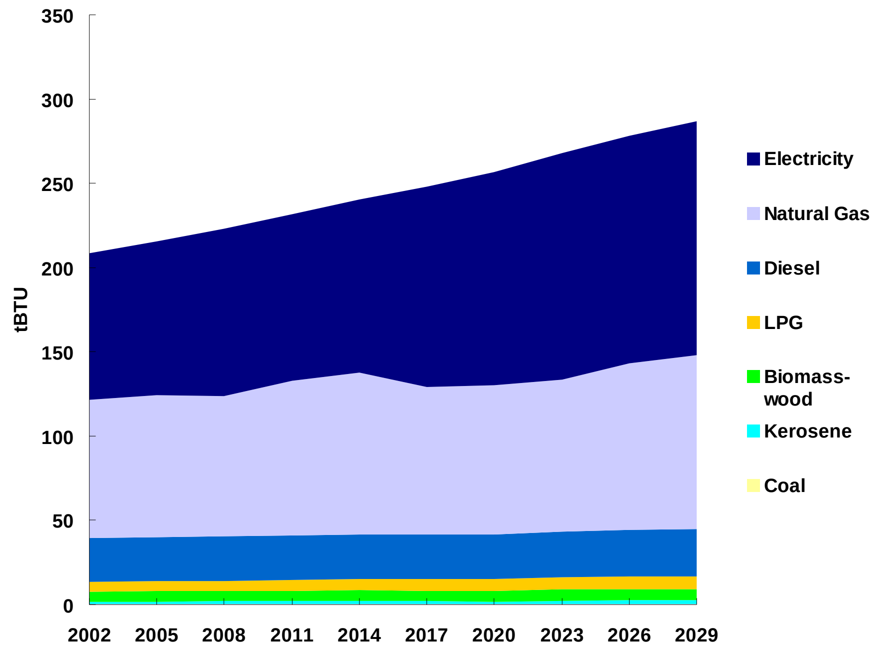


Table 2-4 – Residential Sector Fuel Consumption Shares

	2002	Predicted 2029	Average Annual Growth
Wood	3%	2%	0.5%
Coal	0%	0%	0.6%
Diesel	12%	8%	-0.1%
Electricity	42%	47%	1.9%
Kerosene	1%	1%	1.5%
LPG	3%	3%	1.2%
Natural Gas	39%	38%	1.3%

In the reference case, the model predicts growth in energy consumption for all sectors. Minor changes in the fuel shares are shown in the commercial, industrial, and residential sectors. The transportation sector provides the only substantial changes, with predicted increased use of compressed natural gas (CNG) and diesel fuel replacing the dominant gasoline contribution of the 2002 base year. As shown in Figure 2-5, use of conventional[14] gas internal combustion engines (ICE) is predicted to drop to zero between 2005 and 2020. Other technologies are predicted to gain in share over the same timeframe, with diesel (including both light- and heavy-duty classes) use representing the largest share of vehicle miles traveled (VMT) in 2029.

[14] Note the results reported in Figure 2-5 refer to vehicle model years up to 2005 as "conventional" ICE and those later than 2005 as "advanced" ICE.

Figure 2-4 – Predicted Transportation Sector Energy Consumption

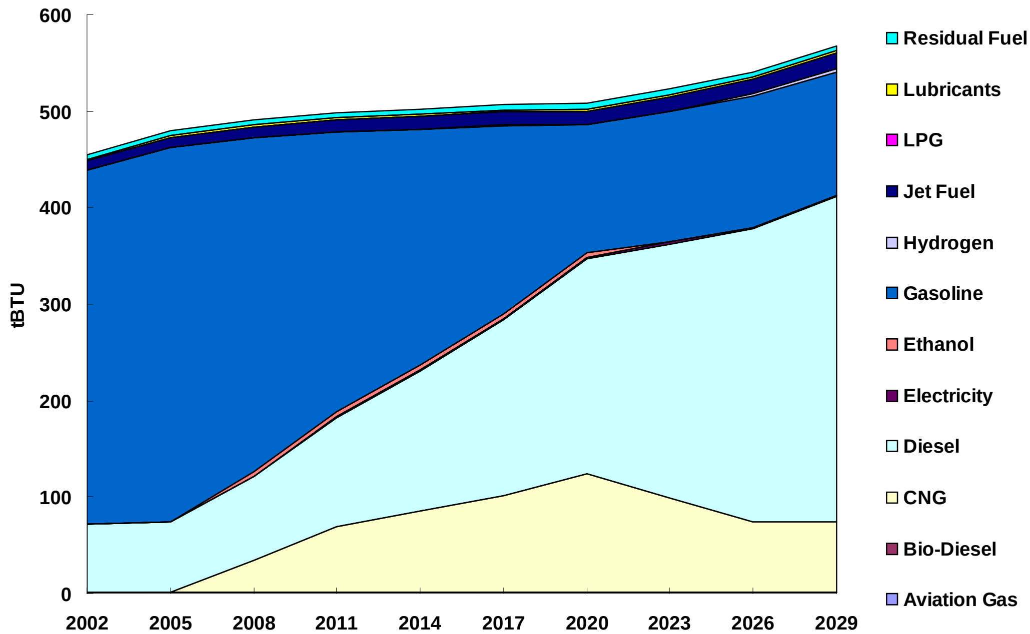


Table 2-5 – Transportation Sector Fuel Consumption Shares

	2002	Predicted 2029	Average Annual Growth
Aviation Gas	0%	0%	1.2%
Biodiesel	0%	0%	0.1%
CNG	0%	13%	18.7%
Diesel	16%	59%	6.0%
Electricity	0%	0%	2.1%
Ethanol	0%	0%	~~
Gasoline	81%	22%	-3.8%
Hydrogen	0%	1%	31.2%
Jet Fuel	2%	3%	1.7%
Liquefied Petroleum	0%	0%	~~
Lubricants	0%	0%	1.2%
Residual Fuel	1%	1%	1.2%

Figure 2-5 - Predicted Transportation Sector Technology Deployment

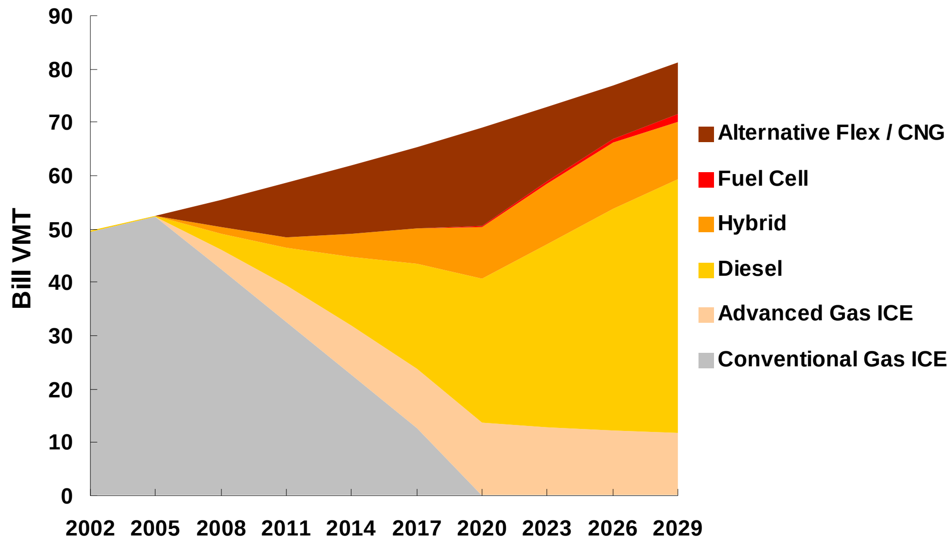


Figure 2-6 - Predicted Electricity Generation

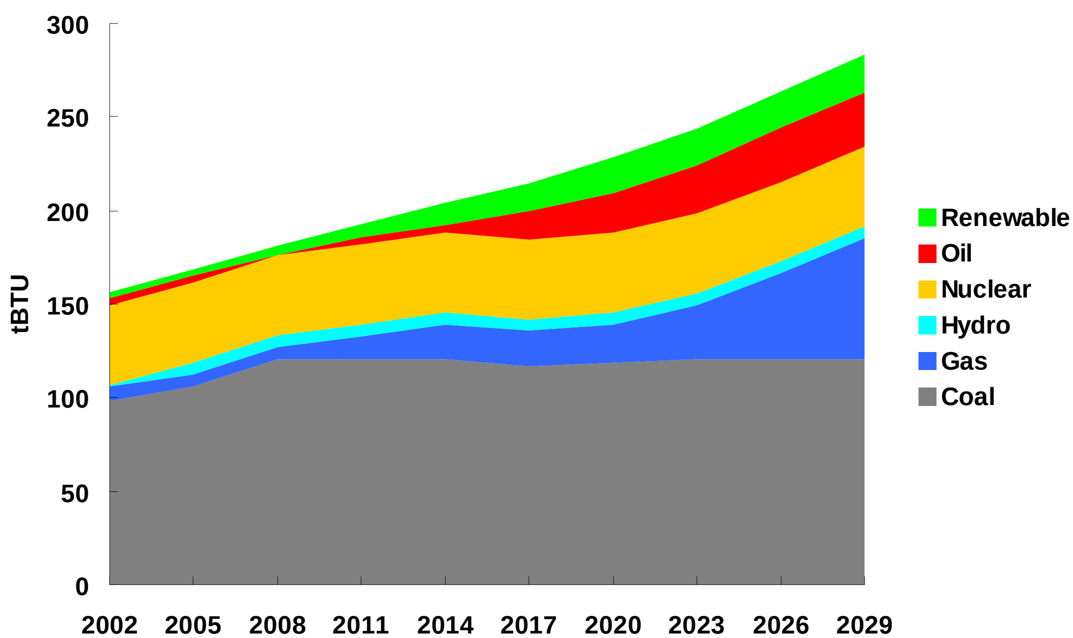
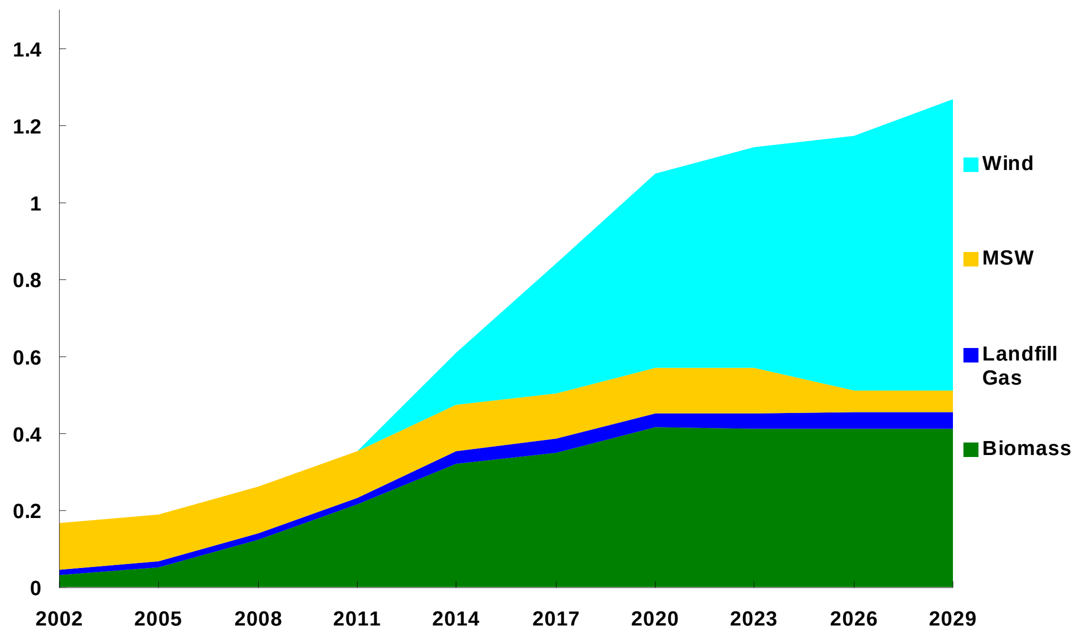


Figure 2-7 - Predicted Renewable Electricity Generation



To satisfy growing demand for energy, the reference case predicts increased power generation from gas, oil, and renewable energy facilities (Figure 2-6). Coal-fired and nuclear generation are predicted to remain stable throughout the modeling period. Renewable energy sources are predicted to be dominated by biomass and wind production, as illustrated in Figure 2-7. The predicted rapid deployment of wind is due in to the economic competitiveness it garners relative to other renewable sources.

Table 2-6 summarizes the economic input assumptions NE-MARKAL considers when comparing the cost effectiveness of various energy technologies.[15] As shown in the table, wind technologies in NE-MARKAL are classified by three characteristics: wind class, on/off shore and distance from transmission lines. For on-shore wind turbines, distance 1 indicates less than 20 miles from a 68kV high voltage transmission line, and distance 2 corresponds to wind potential located more than 20 miles away from high voltage lines. Off-shore distance classification use the same distances, except measured as nautical miles. Classes 4 through 5 indicate wind speeds roughly between 14.5 and 16.5 mi/hr and Classes 6 through 7 represent speeds between 16.5 and 24.5 mi/hr. If there is a direct upper bound on the technology's market penetration, it is listed in the far right two columns. Instead of limiting the biomass technologies directly, NE-MARKAL uses a biomass resource supply curve to limit the penetration of technologies that use biomass. The supply curves for biomass are documented in Appendix A. In cases where there is a direct upper bound on the technology's market penetration, it is listed in the far right two columns.

[15] Investment cost and fixed O&M are in terms of $2002/kW; variable O&M is in terms of $2002/tBTU.

Table 2-6 – Renewable Generation Cost / Resource Assumptions

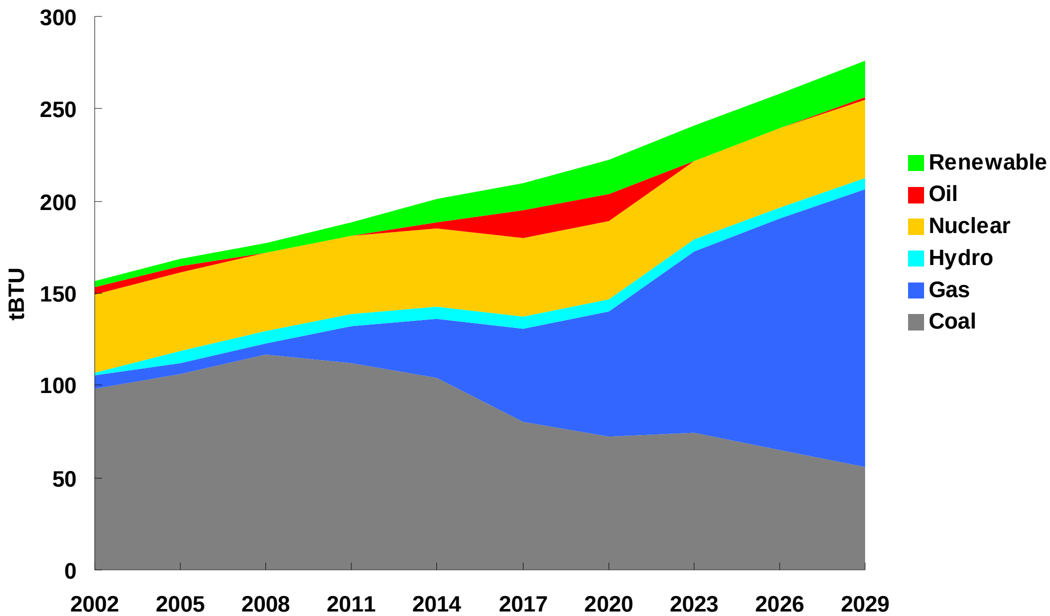
		Investment Cost					Normalized Cost			Bound (MW)	
		2002	2011	2029	Fixed O&M	Variable O&M	2002	2011	2029	2002	2029
Sld Biomass Gasification		1,838	1,838	1,080	69	3.9	3.9	3.9	3.9		
Sld Biomass Direct Combustion		1,745	1,745	975	55	2.9	3.0	3.0	2.9		
Biogas from Waste		1,846	1,846	1,360	37	2.9	3.0	3.0	3.0		
Crop Gasification		1,943	1,943	1,943	69	3.9	3.9	3.9	3.9		
Crop Direct Combustion		1,652	1,652	1,652	55	2.9	3.0	3.0	3.0		
MSW Direct Combustion		3,401	3,401	3,401	46	4.9	4.9	4.9	4.9		
Landfill w/ Collection		1,420	1,420	1,420	24	0	0.0	0.0	0.0	48	77
Landfill w/o Collection		2,056	2,056	2,056	34	0	0.1	0.1	0.1	0	8
Centralized Solar		5,803	4,552	3,292	17	0	3.0	2.4	1.7		
Commercial Solar		6,197	4,513	3,353	20	0	3.6	2.7	2.0		
Residential Solar		7,291	5,784	4,171	25	0	4.3	3.4	2.5		
On-Shore	Wind Class 4-5 Dist1	1,270	1,092	633	7	1	1.5	1.4	1.3	73	607
	Wind Class 4-5 Dist2	1,533	1,356	897	7	2	2.2	2.1	2.0	0	39
	Wind Class 6-7 Dist1	1,270	1,092	633	7	1	1.7	1.6	1.5	5	5
	Wind Class 6-7 Dist2	1,533	1,356	897	7	1	1.7	1.7	1.5	-	-
On-Shore	Wind Class 4-5 Dist1	2,008	2,008	1,583	7	2	2.3	2.3	2.2	1,137	1,266
	Wind Class 4-5 Dist2	2,272	2,272	1,846	7	2	2.4	2.3	2.2	30	189
	Wind Class 6-7 Dist1	2,008	2,008	1,583	7	1	1.8	1.8	1.7	140	240
	Wind Class 6-7 Dist2	2,272	2,272	1,846	7	1	1.9	1.9	1.7	203	9,314

In Table 2-6, the normalized cost summarizes the economic and engineering data considered when NE-MARKAL evaluates competing technology options, such as the efficiency, availability factor, cost data, and the discount rate. A lower normalized cost indicates that NE-MARKAL will favor a given technology when performing a model run. Over the short- and medium-term, wind technologies have significantly lower normalized costs than the solar and biomass technologies owing to economic assumptions and primarily to the high fixed cost for solar generation compared to wind. Electricity generation from landfill gas is mainly limited on the fixed upper bound assumed for this technology.

2.3.2. The Regional Greenhouse Gas Initiative Scenario

The NE-MARKAL model predicts that the RGGI cap on the power sector will be met primarily by substituting coal-fired electricity generation with gas generating units. By 2029, gas-fired generation is predicted to account for 55 percent of the state's electric power generation, up from 23 percent in the reference case. Based on the 2002 share of five percent, this represents an average annual growth rate of 14 percent. Meeting the RGGI cap would also require a substantive shift away from coal-fired electricity generation, which was predicted to account for 20 percent of the power sector's electricity sales by 2029, compared to a 43 percent share in the reference case. The model indicates that the shift away from coal would take place at an average annual rate of 2.6 percent. Aside from the noticeable switch away from coal in favor of gas-fired generation, there were no other significant changes to the State's grid mix required to meet the RGGI cap. Figure 2-8 and Table 2-7 summarize the predicted evolution of the grid under RGGI.

Figure 2-8 – Predicted Power Sector Electricity Generation



The predictions for renewable generation projects remain identical to the reference case, accounting for seven percent of the state's electricity by 2029. This predicts that RGGI, as currently designed, would fail to encourage new renewable energy development. It also predicts that the State's RPS would play the key role in fostering development of renewable energy. This finding prompted the subsequent analysis of a more aggressive carbon cap to further examine policy interactions between Maryland's RPS and the RGGI cap. It is important to note that, while nuclear generation as a share of the total is predicted to decline in absolute terms, the level of generation is predicted to remain constant as nuclear plants serve base load.[16]

[16] Note that information regarding expanded generation at the Calvert Cliffs Nuclear facility was not available at the time of this modeling exercise and was not included as part of the reference case assumption.

Table 2-7 – Power Sector Electricity Generation Shares

	Fuel	2002	Predicted 2029
Reference	***Coal***	*63%*	*43%*
	Gas	*5%*	*23%*
	Hydro	1%	2%
	Nuclear	27%	15%
	Oil	2%	10%
	Renewable	2%	7%
RGGI	***Coal***	*63%*	*20%*
	Gas	*5%*	*55%*
	Hydro	1%	2%
	Nuclear	27%	15%
	Oil	2%	0%
	Renewable	2%	7%

Figure 2-9 – Predicted Power Sector Electricity Generation under a More Aggressive Cap (30% below 2008 by 2029)

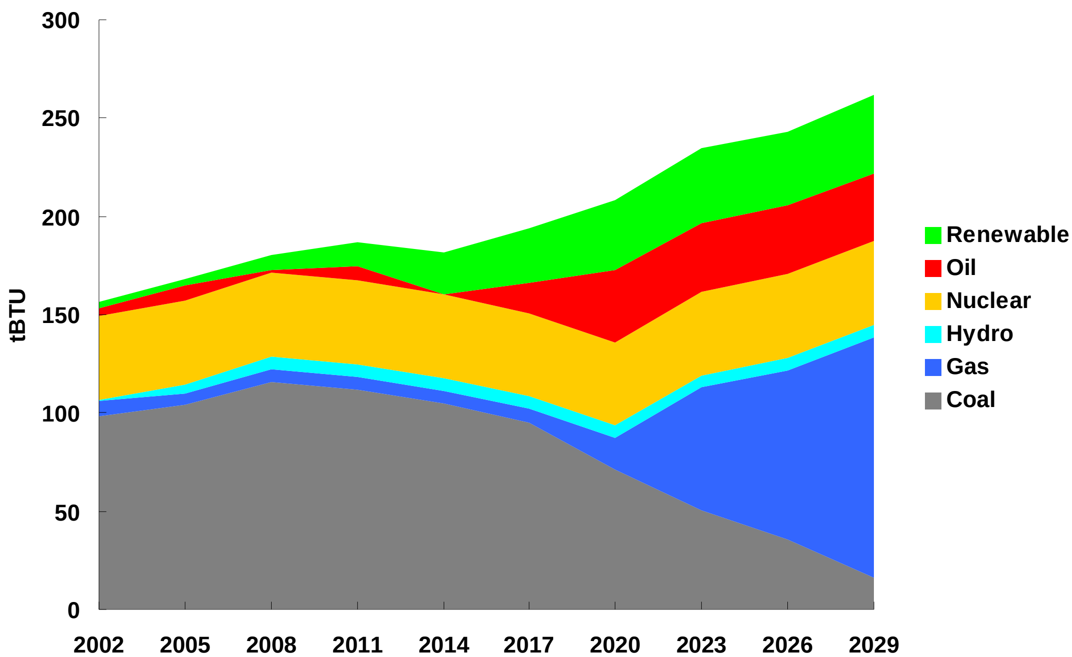


Table 2-8 - Electricity Generation Shares under a More Aggressive Cap (30% below 2008 by 2029)

	Fuel	2002	Predicted 2029
Aggressive CO_2 Cap	**Coal**	63%	11%
	Gas	5%	32%
	Hydro	1%	3%
	Nuclear	27%	19%
	Oil	2%	21%
	Renewable	2%	16%

Figure 2-9 and Table 2-8 summarize the grid mix over the modeling timeframe under a more aggressive cap in the RGGI region of 30 percent GHG reductions by 2030 relative to 2008 levels. The model responded to this hypothetical GHG cap scenario by implementing renewable electricity to a much larger extent, accounting for more than twice the share of generation in 2029, compared to the RGGI scenario. With an average annual rate of growth of 10 percent, renewable projects were predicted to be the second fastest growing source of electricity in Maryland under this more aggressive cap. The declining share of coal to 11 percent of the State's generation by 2029 represents an average annual decay rate of 7.5 percent. Though coal generation is predicted to be declining, generating capacity is not being taken offline. Under this scenario, growth in gas-fired generation is moderated in comparison to the RGGI cap, growing at an average annual rate of 13 percent to account for 32 percent of the electricity generated in-state. It is important to note that the actual generation level of nuclear plants remains the same, but with modest increases in electricity sales, the percentage of electricity being generated from nuclear declines. Also note in the case of the more aggressive GHG cap, electricity generation in the power sector declines somewhat relative to RGGI.

Figure 2-10 – Renewable Electricity Generation Analysis under a More Aggressive GHG Cap

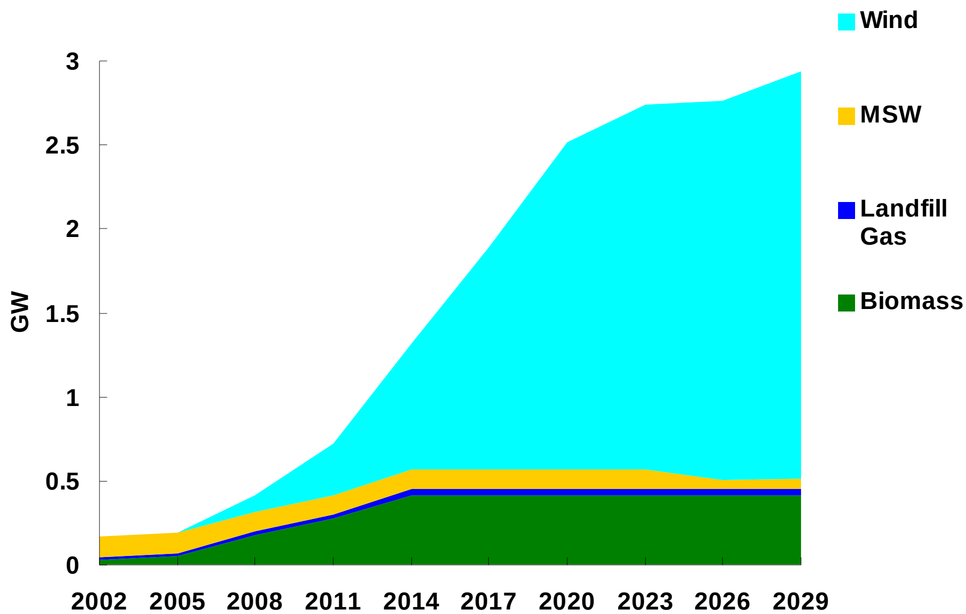


Figure 2-10 presents the various types of renewable generation predicted to be deployed in Maryland when faced with the more aggressive GHG cap on the power sector. Total new renewable capacity by 2029 is predicted to be 3 GW, with wind accounting for 2.5 GW. In-state wind capacity was predicted to grow at an average annual rate of 16 percent, which is faster in percentage terms than any other source of electricity generation. The rapid deployment of wind is likely due in large part to the economic competitiveness it garners relative to other renewable sources.

Table 2-9 – Predicted Changes in Electricity Sales Relative to Reference Case (2002-2029)

	Change in Electricity Sales (tBTU)		Change as a % of Reference Case	
	RGGI	RGGI+	RGGI	RGGI+
Commercial	-2	-1	-0.2%	-0.1%
Industry	1	-317	0%	-52%
Residential	-28	-21	-2%	-2%
Transportation	-5	-5	-17%	-17%

Table 2-9 summarizes the predicted sale of electricity to the end-use demand sectors. "Change in Electricity Sales" represents total electricity over the model timeframe of 2002 to 2009. "Change as a % of reference case" represents the absolute value of the total change divided by a given sector's reference case electricity consumption. In both capped scenarios, electricity prices are predicted to increase over time as the power sector invests in more expensive renewable and advanced conventional technologies. There is a small difference in electricity purchased in the commercial, residential and transportation sectors between the two sectors. Significant changes, however, occur in the industry sector under the more aggressive cap. As the stringency of the carbon cap is increased, the model predicts that the industrial sector would deploy gas-fired combined heat and power to defray the higher cost of electricity from the grid.

2.3.3. The Maryland Clean Cars Act Scenario

Figure 2-11 depicts Maryland's reference case Light-duty Vehicle (LDV) GHG emissions and the GHG emission level pursuant to the recently adopted Clean Cars Act. The Clean Cars Act leads to a net reduction (time-integrated) in GHG emissions over the modeling timeframe of 13 percent, which corresponds to a 15 percent reduction relative to 2008 levels by 2029.

The model predicts that the GHG reduction targets required by the Maryland Clean Cars Act are met by increasing the State's reliance on ethanol for transportation fuel, an increase representing eight percent of the total reference case energy consumption (see Table 2-10). In addition, the GHG reductions rely on smaller increases in the shares of electric and hydrogen vehicles. New hydrogen investments, however, are not predicted to be made until 2017. Total diesel and gasoline consumption is predicted to decline by nearly 10 percent relative to the overall reference case fuel consumption.

Figure 2-11 – Reference Case and Predicted Maryland Clean Cars Act CO_2 Emissions

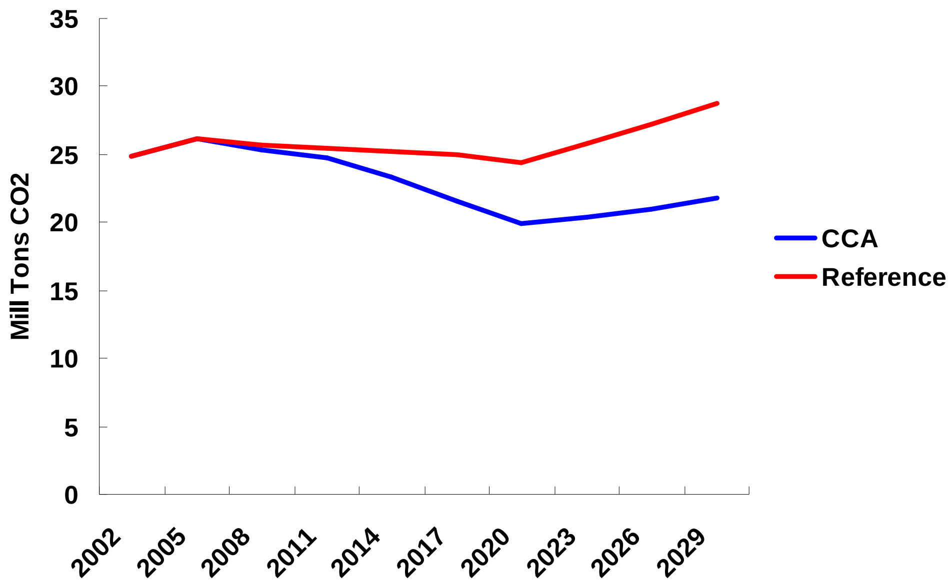
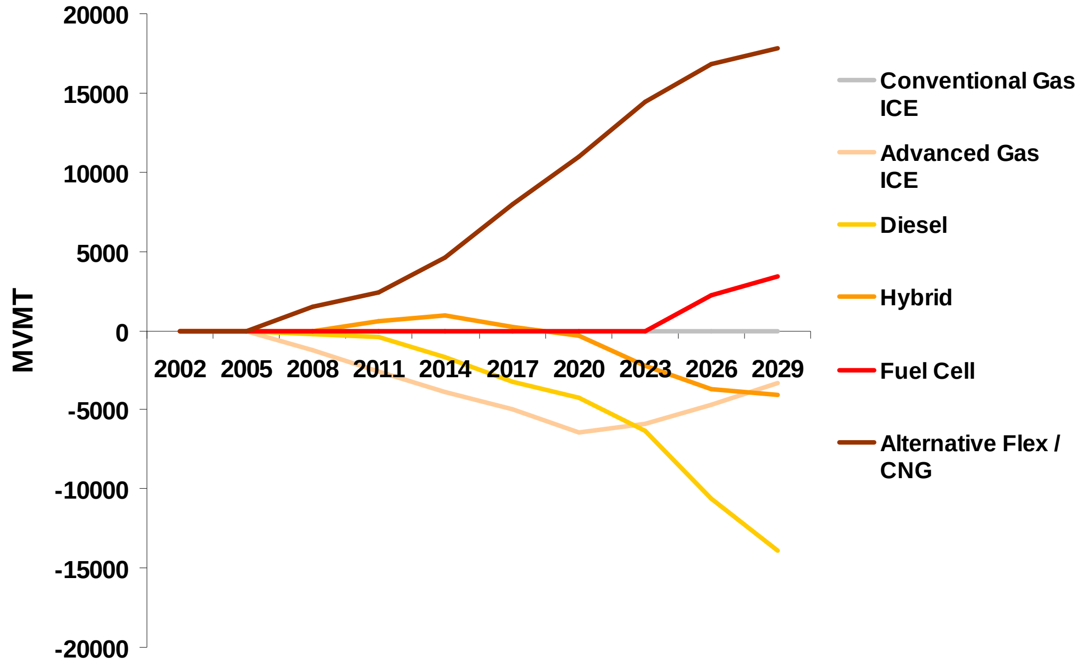


Table 2-10 – Predicted Transportation Energy Consumption Trends 2002-2029

	Change Relative to Reference 2002-2029 (tBTU)	Change as a % of Total Reference Case Consumption
Aviation Gasoline	0	0%
Biodiesel	0	0%
Compressed Natural Gas	0	0%
Diesel	-218	4%
Electricity	35	1%
Ethanol	403	8%
Gasoline	-240	5%
Hydrogen	17	0%
Jet Fuel	0	0%
Lubricants	0	0%
Residual Fuel Oil	0	0%

Figure 2-12 presents the predicted differences in technology choice relative to the reference case. Flex fuel ethanol (E85) vehicles show the most significant change in light-duty vehicle miles traveled. Vehicle miles traveled (VMT) by flex-fuel cars using ethanol are predicted to increase by 76.6 billion, or roughly 12 percent of the total miles traveled, in the reference case. Later in the modeled timeframe the market share for fuel cells increases by a modest amount, but this represents less than one percent of total VMT than in the reference case. The most significant declines in VMT are predicted to occur, as expected, in diesel and gasoline vehicles.

Figure 2-12 –Predicted Transportation Technology Deployment Change Relative to Reference



It is important to note that the analysis above uses emission factors that assume all biomass is carbon neutral. Given the widespread uncertainty of this assumption, and interest in the structure and implementation of a low carbon fuel standard, NESCAUM has conducted an analysis using life cycle emission factors for transportation fuels consumed in Maryland to assess how the light-duty vehicle fleet could meet the Clean Cars Act targets. Table 2-11 presents the original and life cycle factors employed in the modeling. The life cycle emission factors were calculated by NESCAUM using the GREET lifecycle emission calculator.[17] Life cycle emission factors account for the CO2e emissions produced throughout a fuel's various production stages as well as end-use consumption. For example, one possible life cycle emission factor for ethanol would account for emissions produced while cultivating, producing, and transporting the feedstock, processing the fuel at the plant, distributing the fuel by truck to refueling facilities and stations, distributing the fuel to consumers, and combusting the ethanol for end use.

Table 2-12 summarizes the predicted energy consumption trends as the light-duty vehicle fleet evolves to meet the Clean Cars Act, considering the life cycle emissions of each fuel. In this case, there are more dramatic shifts away from the carbon intensive fuels, i.e., diesel, compressed natural gas, and gasoline. The switch to cleaner fuels is not, as in the previous case, centered on one fuel (ethanol). Plug-in hybrids and, to a lesser extent, ethanol flex-fuel cars rise in importance when accounting for life cycle

[17] Details available at: http://www.transportation.anl.gov/modeling_simulation/GREET/index.html accessed February 2, 2009.

emissions. The increase in hydrogen transportation fuel also accelerates relative to the non-life cycle emission factor case.

Table 2-11 – Standard and Life Cycle Transportation Emission Factors (Thousand Tons/ tBTU)

	Original CO_2 Factor	Life Cycle Factor	% Increase
CNG	53.1	77.4	46%
Diesel	73.2	98.1	34%
Ethanol	10.5	76.5	627%
Gasoline	70.9	97.8	38%
LPG	62.3	82.3	32%
Diesel (20% Biodiesel)	59.7	85.9	44%
Biodiesel	27.5	36.9	34%

Table 2-12 – Predicted Transportation Energy Consumption Trends 2002-2029 (With Life Cycle Emission Factors)

	Change Relative to Reference 2002-2029 (tBTU)	Change as a % of Total Reference Case Consumption
Aviation Gasoline	0	0.0%
Biodiesel	0	0.0%
Compressed Natural Gas	-377	0.7%
Diesel	-86	0.2%
Electricity	180	0.3%
Ethanol	135	0.3%
Gasoline	-551	1.1%
Hydrogen	46	0.1%
Jet Fuel	0	0.0%
Lubricants	0	0.0%
Residual Fuel Oil	0	0.0%

3. HEALTH BENEFITS ANALYSIS

3.1. The COBRA model

To assess health benefits impacts for the Phase I effort, NESCAUM used the Co-Benefits Risk Assessment Model (COBRA).[18] COBRA, a screening tool, provides general predictions of monetized health impacts benefits resulting from specified emissions reductions measures. It uses source-receptor transfer coefficients to estimate $PM_{2.5}$ concentration differences between a reference case and a control scenario. Based on specified emissions reductions, the model estimates changes in primary and secondary PM concentrations, translates those changes into health benefits impacts, and then monetizes those impacts. COBRA is based on a simplified air quality model and relies on U.S. EPA's best estimates for health impact equations and valuations. It provides mean estimates of health impacts, rather than 95th percentile estimates that risk assessments routinely provide. Because COBRA is limited to analyzing PM concentrations, it does not consider health impacts that may result from changes in other atmospheric trace gases or air toxics. As a screening tool, results from COBRA should be viewed only as a rough approximation of benefits arising from emissions control policies.

3.2. Assumptions and Methodology

COBRA has two built-in inventories of 2010 and 2015. For this project, NESCAUM selected a baseline inventory year of 2010. We used emissions reductions outputs forecast for Maryland using the NE-MARKAL model from the Clean Cars Act scenario accounting for life cycle emissions and the RGGI scenario. Because the reference inventories are different between NE-MARKAL and COBRA, percent changes in emissions from NE-MARKAL output were used for the COBRA analyses. We looked at changes in emissions between the 2011 NE-MARKAL reference case and the 2029 model scenario endpoint.

Percent changes in emissions for three pollutants (NOx, SO_2 and VOC) were calculated for the reference case and the two policy scenarios. For the Clean Cars Act scenario, we focused on emissions changes in the light-duty transportation sector. Emissions for four different classifications within the sector were used as input to COBRA: diesel car, diesel truck, gasoline car, and gasoline truck. For the RGGI scenario, we focused on emissions changes in the power sector. Based on these emissions changes, COBRA predicted potential $PM_{2.5}$ reductions and their associated health outcomes on a county-specific basis.

The modeled changes in PM were assessed for consistency with actual ambient measurements. Based on measurements, annual average ammonium nitrate levels in urban areas in Maryland are about 2 $\mu g/m^3$. When Maryland's NOx emissions were zeroed out in COBRA, PM2.5 was predicted to decline by roughly 4 $\mu g/m^3$. This implies that COBRA may overestimate the benefits of NOx reductions by as much as a factor of two, but still provide reasonable screening capability.

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[18] Abt Associates. 2006. Co-Benefits Risk Assessment (COBRA) Screening Model. COBRA Version 2.1. For information contact: mulholland.denise@epa.gov

3.3. Results

3.3.1. Clean Cars Act

Emission in the transportation sector for the reference case and the Clean Cars Act life cycle CO_2 scenario were tracked in NE-MARKAL. Percent changes in modeled emissions from 2011 (nominally consistent with the 2010 COBRA reference inventory) to 2029 were calculated. These results were then input into COBRA to determine the associated PM reductions and associated health benefits.

For the 2010 base year inventory, the light-duty sector accounted for less than one percent of SO_2 and VOC emissions in Maryland, but more than a quarter of the NOx emissions. Accordingly, our analysis focuses on NOx and nitrates. In 2011, NOx emissions from the light-duty gasoline sector are much more important than the light-duty diesel sector. By 2029, the relative importance of diesel versus gasoline increases, as diesel-derived NOx emissions are predicted to increase (45 and 75 percent for policy and reference, respectively) while gasoline NO_x sources are predicted to decline markedly (50 and 33 percent for policy and reference, respectively). The overall reduction in NO_x by 2029 is 45 percent in the Clean Cars scenario, which is nearly twice the 27 percent reduction modeled in the reference case.

COBRA predicted $PM_{2.5}$ changes in all Maryland counties (Table 3-1). In the reference case, the benefit from emissions reductions in the transportation sector averaged 0.2 $\mu g/m^3$, ranging as high as 0.7 $\mu g/m^3$ in the most urbanized county. Under the Clean Cars Act scenario, average reductions were 0.3 $\mu g/m^3$, ranging as high as 0.8 $\mu g/m^3$. The health benefits associated with these predicted $PM_{2.5}$ reductions are \$0.6 billion for the reference case and \$0.7 billion for the Clean Cars Act. The bulk of these benefits are derived from avoided deaths, which were estimated at 95 and 109 people.

Table 3-1 – Predicted $PM_{2.5}$ Reductions from Emission Changes in COBRA ($\mu g/m^3$)

	Reference	Clean Cars	Reference	RGGI
Average	0.2	0.3	< 0.1	0.1
Median	0.2	0.2	< 0.1	0.1
Range	0.0 - 0.7	0.0 – 0.8		0.0-0.1

3.3.2. RGGI

An approach similar to what was employed for the Clean Cars Act was used to evaluate the potential emissions reduction and associated health benefits of RGGI relative to the reference case. While the Clean Cars Act scenario analyses focuses on light-duty transportation, the RGGI analysis tracks changes in the power sector. Based on the 2010 inventory in COBRA, power sector emissions of both SO_2 and NOx are substantial in Maryland. Emissions changes for these two pollutants were substantially less in the reference case than in the policy case. In the reference case, NOx emissions were predicted to increase two percent, with SO_2 emissions decreasing 20 percent. With RGGI in place, modeled reductions were 50 percent and 73 percent for NOx and SO_2, respectively.

These emissions changes were input into COBRA, which predicted very small reductions in $PM_{2.5}$ for the reference case and small changes under the RGGI scenario of 0.1 $\mu g/m^3$. The corresponding health benefits were valued at $4 million and predicted five avoided deaths for the reference case. Benefits were somewhat greater based on RGGI results, with benefits valued at $123 million and 19 avoided deaths predicted.

4. CONCLUSIONS AND NEXT STEPS

4.1. Conclusions

It is important to place this modeling exercise into context. The intent of NESCAUM's Multi-pollutant Policy Analysis Framework approach is to conduct iterative policy scenarios in order for decision-makers to understand potential interactions of various policy choices, given current and predicted characteristics of energy generation and use within a state. Specifically, the NE-MARKAL model calculates least-cost combinations of energy technologies available to meet energy demand in each sector. The analytical findings should not be construed to be conclusive, but rather instructive in understanding the dynamics that are predicted under various scenarios. In this manner, the analyses can inform decision-makers as they choose a mix of policies that best suit their needs and goals.

In this Phase I effort, NESCAUM worked with MDE staff to iteratively tailor and update NE-MARKAL's representation of Maryland's power sector. The two focus areas of the collaboration were: (1) ensuring that the power plants represented in NE-MARKAL were, in fact, operating and (2) characterizing the controls mandated by the Healthy Air Act. After this work was complete, the reference case was updated to reflect the appropriate changes in the power sector and Maryland's RPS. In potential future work, discussed below, we propose to further refine the power sector data for Maryland by cross-checking NE-MARKAL data with U.S. EPA's Clean Air Markets Division database of generating units and continuing to work with MDE staff to verify permitting specifics, fleet characterizations, and other state-specific data.

The reference case is based on the assumptions documented in Appendix A, which was prepared by NESCAUM at the beginning of the project and approved by MDE staff. In Maryland, the transportation sector represents the largest share of energy consumption, followed by the industrial and residential sectors and, finally, the commercial sector. The commercial sector energy consumption, however, is predicted to grow faster than any other sector, at an average annual rate of roughly 1.9 percent. In 2002, gasoline and coal at 29 and 26 percent, respectively, represented just over half of the primary inputs to Maryland's energy system. Other significant primary inputs in 2002 were natural gas, at 15 percent, and diesel and nuclear, both at 10 percent of the state's primary energy input. Each of the other sources tracked in NE-MARKAL represented less than two percent of primary energy consumption. By 2029, gasoline and coal are predicted to represent only 25 percent of the energy consumption. A major shift towards new light-duty diesel vehicles was predicted to drive the share of diesel fuel consumption up to 27 percent by 2029, while gasoline's share was predicted to decrease to only eight percent. As gas-fired generation is deployed to a greater extent over time in the reference case, the share of natural gas consumed in state is predicted to increase to 22 percent by the end of the model timeframe (2029). In the reference case, renewable generation is predicted to increase from just under 200 MW in 2002 to just over 1,200 MW by 2029. Among Maryland's renewable resources, wind and biomass represent the largest potential, and by 2029 is predicted to account for over 92 percent of renewable generation, at 60 and 32 percent, respectively, barring significant barriers to adoption.

The NE-MARKAL modeling predicts that the RGGI cap on the power sector (i.e., 10 percent reductions in GHG by 2029 from the 2008 baseline) would be met primarily by substituting coal-fired electricity generation with gas generating units, with gas-fired generation accounting for 55 percent of the state's electric power generation in 2029. The model also predicts a substantive shift away from coal-fired electricity generation, at an average annual rate of 2.6 percent. Given the favorable economics of building gas-fired power generation, the model predicted limited entry, relative to the reference case, of renewable power generation to the market under this scenario. Maryland's RPS, which was included in the reference case, is the primary driver fostering the development in renewable energy projects. An additional analysis was therefore undertaken to assess whether a more aggressive cap would foster the introduction of renewable power generation. Under a more aggressive cap in the RGGI region, i.e., a 30 percent reduction in GHG by 2029 relative to 2008 levels, the model predicted that increases in renewable electricity would be required, accounting for more than twice the share of generation in 2029, as compared to the RGGI scenario. With an average annual rate of growth of 10 percent, renewable projects were predicted to be the second fastest growing source of electricity in Maryland under this more aggressive cap.

The Clean Cars Act modeling exercise indicated that, for purposes of analyzing vehicle programs, it is critical to account for lifecycle emissions of transportation fuels. The initial analysis of the Clean Cars Act predicted that GHG reductions may be achieved by significantly relying on an increased share of corn-based ethanol consumption in Maryland's light-duty vehicle fleet. This result, however, presumes that biomass is carbon neutral. Due to the widely recognized uncertainty of this assumption, a second model run was performed, using emission factors in the transportation sector accounting for life cycle emissions associated with each major fuel source. Under this scenario, the model predicted use of a broader mix of clean transportation technologies that includes hybrids, flex fuel cars and fuel cells, to accomplish the Clean Cars Act goals

The analyses of RGGI and the Clean Cars Act from NE-MARKAL compare quite favorably to those presented in Maryland's Climate Action Plan. The Climate Action Plan's Executive Summary provides estimates of CO_2 reductions from RGGI and the Clean Cars Act of approximately 8.7 and 6 million metric tons by 2020. From the NE-MARKAL work, the estimated CO_2 reductions in 2020 relative to the reference case for RGGI were 10.4 million metric tons. In the light-duty vehicle sector, reductions in 2020 were modeled to be 4.5 million metric tons of CO_2. The relative agreement between these two independent analyses provides some confidence in the result.

4.2. Next Steps

Historically, air quality concerns have been addressed by states on a pollutant-by-pollutant basis. Each criteria pollutant and air toxic has required its own planning effort, as have efforts to address acid deposition and regional haze. Climate change is now taking center stage as the primary air pollution challenge of the century. A comprehensive multi-pollutant approach that integrates air quality goals with regional energy models could help to satisfy these multiple environmental requirements with limited available resources. To this end, NESCAUM and MDE collaborated to demonstrate use of two of the analytical tools that comprise NESCAUM's Multi-pollutant Policy Analysis Framework (MPAF).

We propose a second phase of the analysis presented in this report, in which NESCAUM adapts the full MPAF for use in Maryland. The tailored framework will enable policy analysts in Maryland, including the MDE, the Commission on Climate Change, the Maryland Energy Administration, and others to have access to or perform multi-pollutant assessments of various potential control strategies to simultaneously address multiple climate, energy, and air quality goals. In this expanded exercise, we would employ several tools and databases, including: NE-MARKAL; Regional Economic Model, Inc (REMI); Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System; Community Multi-scale Air Quality (CMAQ) model; and the Environmental Benefits Mapping and Analysis (BenMAP) program. Phase II of this project could include the following tasks:

- Identify emission reduction targets based on existing Maryland-specific and regional air quality goals for ozone, $PM_{2.5}$, acid deposition, and climate change;
- Employ NE-MARKAL to assess a suite of strategies and goals identified in Maryland's Climate Action and State Implementation Plans;
- Quantify the associated environmental, public health, and regional economic benefits associated with the identified strategies, and monetize a subset of these strategies;
- Use the project's findings to enhance model representations, promote use of integrated modeling frameworks, and promote integrated approaches to air quality planning in Maryland, the eight-state NESCAUM region, and other states outside the region.

4.2.1. Potential Phase II Strategies from Maryland's Climate Action Plan

As part of the suggested Phase II work outlined above, we recommend that mitigation strategies identified in Maryland's Climate Action Plan be reviewed and assessed as possible policies for scenario analysis in NE-MARKAL. Table 4-1 lists an initial set of strategies we propose to examine in Phase II. The strategies chosen represent those most suitable for analysis within the NE-MARKAL modeling framework.

In Phase I, the impact of each mitigation strategy was assessed independently. This type of scenario analysis serves to identify the magnitude of climate, air quality and energy impacts relative to the other strategies under examination. In Phase II, we propose to examine each scenario independently and then perform an analysis where multiple strategies are layered together. This approach can identify interactions between the strategies that may lead to climate, air quality and energy outcomes that differ from an analysis examining only one strategy at a time. For example, when RGGI is considered in isolation, the primary change within the power sector is a move away from coal towards gas-fired generation, a result presented earlier in this report. A model run that considers RGGI in light of other strategies, such as more aggressive renewable portfolio standards and demand-side management, may yield different results. This is an example of how the NESCAUM MPAF may be used to help decision-makers identify program synergies, and how we propose to further examine climate, air quality and energy impacts with MDE in a Phase II effort.

Table 4-1 – Suggested Phase II Mitigation Strategies

CAP Code	Program Description
CC-2	Statewide GHG Reduction Goals and Targets
CC-3	GHG Reduction Goals & Targets
CC-10	After Peak Oil
RCI-2	Demand-side Management & Energy Efficiency
RCI-3	Low Cost Loans for Energy Efficiency
RCI-7	More Stringent Appliance / Equipment Efficiency Standards
RCI-10	Energy Efficiency Resource Standard
RCI-11	Promotion & Incentives for Energy Efficient Lighting
ES-1	Promotion of Renewable Energy
ES-3	Cap and Trade
ES-5	Clean Distributed Generation
ES-7	Renewable Portfolio Standard
ES-8	Efficiency Improvements & Re-powering Existing Plants
ES-10	Generation Performance Standards
AFW-6	In-State Liquid Biodiesel Production
TLU-10	Transportation Technologies

4.2.2. Calibrating the Model and Expanding Use of the MPAF

In addition to expanding to multi-strategy analyses and interactions, Phase II work could also focus on model calibration for criteria pollutant emissions. This effort would require two primary elements. First, emission factors for represented technologies would need to be included if they are presently lacking in the model. Second, technologies and processes in NE-MARKAL would be mapped to source classification codes (SCC). This type of mapping will allow NESCAUM to calibrate Maryland's base-year emissions within NE-MARKAL to the 2002 Mid-Atlantic/Northeast Visibility Union (MANE-VU) criteria pollutant modeling inventory. A fully calibrated model would allow the use of air quality modeling and subsequent health benefits analysis.

After individual and collective strategy analyses have been conducted, the resultant criteria pollutant emissions could then be used as inputs for air quality modeling. This modeling would provide policy makers with an estimate of the potential air quality benefits that might be realized by implementing different strategy combinations. The approach would be tailored specifically to Maryland, with air quality results directly tied to emissions changes modeled in NE-MARKAL. Unlike the Phase I effort, which relied on relative emissions changes from MARKAL applied to U.S. EPA inventories in COBRA, Phase II could rely on baseline MANE-VU modeling inventories, emissions processed based explicitly on the NE-MARKAL results, and gridded chemical transport model output at a 12 km resolution (rather than county-level estimates from dispersion modeling source-receptor relationships). The model results would then feed into BenMAP, which would expand the health benefits analysis from $PM_{2.5}$ alone to include ozone.

4.2.3. Capacity Building

A final component of Phase II work would focus on capacity building within MDE. This would begin by communicating with relevant staff as to the interrelationships among sources, sectors, and emissions, and the multiple implications of air quality policies within the context of meeting air, energy, and climate goals. In addition, staff would learn about the tools and models that are part of the MPAF with the goal of expanding their ability to conduct policy analyses through implementation of the framework. NESCAUM and MDE would assess what types of training may be needed to employ the MPAF in future planning efforts.

Appendix A: NE-MARKAL Input Assumptions for Maryland

Appendix A: NE-MARKAL Input Assumptions for Maryland

This Appendix documents the baseline assumptions of the Northeast Market Allocation Model (NE-MARKAL). It includes information on base year demand by sector, and projections extending to 2029. Technologies available to the model are also detailed, as are their respective estimates of investment costs and efficiencies. Initial model constraints on fuel share and technology penetration rates are also provided.

A.1. Building Sector Input Assumptions

A.1.1. Commercial / Residential Demand Projections

In the NE-MARKAL modeling framework, the energy infrastructure is configured to meet the estimated demand for energy using the most cost-effective technologies and fuel sources. The initial base year (2002) demands, presented below for the commercial and residential sector, are estimated outside of the NE-MARKAL framework and represent a significant model input. The commercial sector Other/Non-Building is primarily composed of municipal scale energy consumption such as street lighting, municipal waste and water systems, and mass-transit systems.

Figure A.1: Commercial Sector Energy Demand

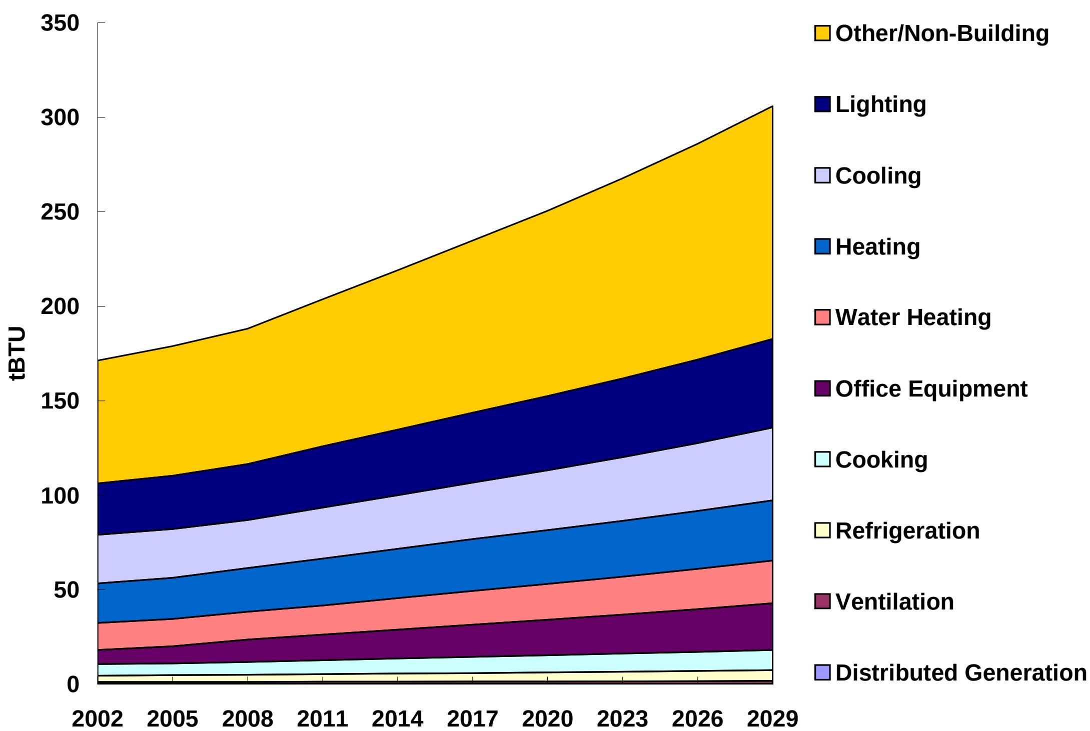


Table A.1: Commercial Sector Demand Growth

	Average Annual Growth 2002-2029	% 2002 Demand
Office Equipment	14.2%	4.4%
Other/Non-Building	7.3%	38.0%
Cooking	6.4%	3.6%
Lighting	6.3%	15.8%
Refrigeration	6.0%	2.0%
Water Heating	5.2%	8.4%
Ventilation	5.0%	0.6%
Heating	4.8%	12.2%
Cooling	4.6%	15.0%
Distributed Generation	1.0%	0.2%

Figure A.2: Residential Sector Energy Demand

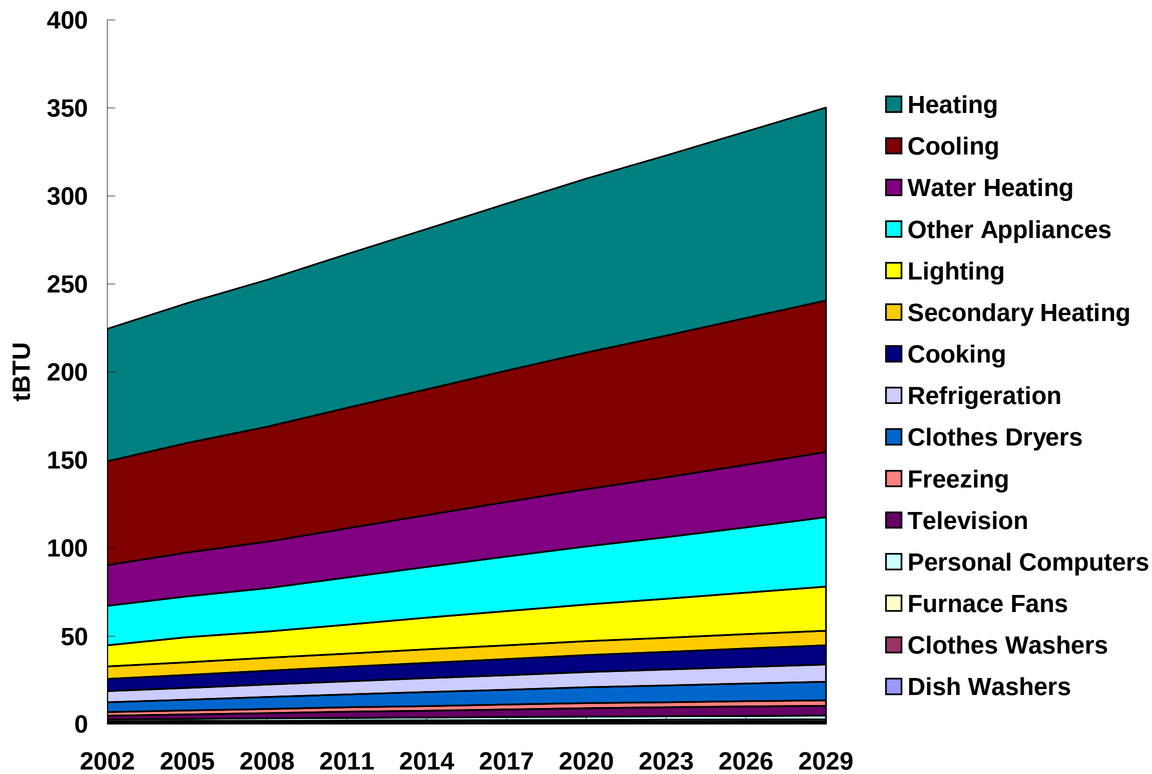


Table A.2: Residential Sector Demand Growth

	Average Annual Growth 2002-2029	% 2002 Demand
Television	12.0%	0.9%
Lighting	8.5%	5.4%
Personal Computers	7.4%	0.5%
Clothes Dryers	7.3%	2.5%
Dish Washers	7.2%	0.2%
Other Appliances	6.5%	10.0%
Furnace Fans	5.9%	0.3%
Clothes Washers	5.4%	0.2%
Water Heating	5.4%	10.3%
Cooking	5.3%	3.0%
Refrigeration	5.0%	2.8%
Cooling	4.3%	26.2%
Heating	4.2%	33.5%
Freezing	3.9%	1.0%
Secondary Heating	1.8%	3.2%

A.1.2. Demand Projection Methodology

Demand drivers were developed using data from the U.S. Department of Energy (DOE) Annual Energy Outlook (AEO) 2006 forecast of useful energy demand for the Northeast. After calculating the growth in useful energy demand relative to 2002, which is NE-MARKAL's base year, these growth factors are used to project the demand for energy in the commercial and residential sectors out to 2029. DOE's National Energy Modeling System (NEMS) provides a forecast of useful energy demand for the commercial sector and is used directly for developing the commercial demand drivers. NEMS does not provide a forecast of useful energy demand for the residential sector, so we constructed a customized forecast of residential energy demand based on AEO 2006 projections of device units in the residential equipment stock, final energy consumption by type of device, and the average base year efficiency of residential devices in each residential demand category.

A.1.3. Building Sector Demand Technologies

Tables A.3 and A.4 outline key assumptions made in NE-MARKAL regarding building technologies in the commercial and residential sectors. Technological and market innovation is represented by introducing more efficient or less expensive technologies over time. In Table A.3, the investment cost and efficiency ranges were prepared by comparing all technologies of a given type over the entire model timeframe. These tables provide a sense for our assumed range of market and technical innovation.

Table A.3: Commercial Technologies

		Efficiency		Investment Cost $/Mbtu	
Commercial Technology	# of Technologies	Min	Max	Min	Max
Electric Range	2	0.70	0.80	37	43
Gas Range	2	0.45	0.60	26	36
Beverage Machine	10	0.70	1.08	1,488	1,632
Centralized Refrigeration	10	1.82	1.95	947	955
Ice Machine	8	0.44	0.48	2,281	2,505
Reach in Freezer	10	0.56	0.69	2,206	2,832
Reach in Refrigerator	8	0.48	0.63	3,518	4,104
Refrigerated Vending Machine	11	0.48	0.65	3,487	3,692
Walk in Cooler	12	1.99	3.59	760	959
Walk in Freezer	10	0.73	1.09	2,498	2,788
Cooling Air Src HP	7	2.78	5.51	97	194
Centralized AC	7	2.81	5.86	45	143
Centrifugal Chiller	7	4.60	7.30	28	56
Cooling Ground Src HP	5	3.96	8.06	175	300
Gas-fired Chiller	6	1.00	2.20	52	75
Gas Heat Pump	3	0.62	0.70	181	181
Gas Rooftop AC	5	0.59	1.10	96	150
Electric Rooftop AC	6	2.60	4.40	61	80
Reciprocating Chiller	6	2.50	3.80	74	101
Wall Room AC	6	2.40	3.52	17	80
Air Src HP	7	1.88	3.17	97	194
Oil Boiler	4	0.73	0.84	17	19
Oil Furnace	3	0.76	0.80	9	10
Electric Boiler	2	0.94	0.94	20	22
Other Electric Packaged Sys	2	0.93	0.96	16	21
Ground Src HP	5	3.40	5.10	175	300
Natural Gas Boiler	5	0.70	0.85	20	37
Natural Gas Furnace	7	0.70	0.90	9	14
Gas HP	3	1.30	1.50	181	181
7000 CFM System	5	0.56	0.61	3,143	3,217
15000 CFM System	11	0.22	0.36	4,008	4,928
30000 CFM System	10	0.24	0.56	3,150	3,761
50000 CFM System	10	0.26	0.67	3,792	4,229
Oil Water Heater	2	0.73	0.78	27	41
Electric Water Heater	2	0.95	0.97	14	19
Natural Gas Water Heater	4	0.74	0.97	11	19

Table A.4: Residential Technologies

		Efficiency		Investment Cost $/Mbtu	
Residential Technology	# of Technologies	Min	Max	Min	Max
Electric Clothes Dryer	5	1.07	1.19	90.55	104.13
Gas Clothes Dryer	5	0.94	1.05	101.74	115.32
Electric Clothes Dryer	2	1.00	1.00	341.30	341.30
LPG Range	2	1.00	1.00	341.30	341.30
Gas Range	2	1.00	1.00	341.30	341.30
Electric Range	8	0.68	1.82	1124.69	2322.74
Electric Dish Washer	10	1.05	2.72	200.34	772.75
Electric Freezer	4	1.12	1.92	192.52	252.65
Florescent Light	4	3.68	3.68	1.84	2.03
Incandescent Light	2	0.99	0.99	0.24	0.24
Solid State Light	3	6.62	6.62	10.46	85.85
Electric Refrigeration	9	1.19	1.96	215.44	492.24
Central AC	11	2.93	5.86	411.02	1233.05
Air Src HP	14	2.93	5.51	273.33	503.49
Ground Src HP	10	13.80	27.50	604.19	1035.76
Gas HP	3	0.62	0.70	251.75	431.57
Room AC	6	2.87	3.52	59.60	164.41
Oil Furnace	5	0.80	0.86	30.79	37.63
Oil Radiator	7	0.80	0.97	47.89	62.43
Air Src HP	14	1.99	3.17	42.25	77.82
Electric Radiator	1	1.00	1.00	25.66	25.66
Ground Src HP	10	3.40	5.10	93.38	160.09
Kerosene Furnace	3	0.80	0.86	35.10	72.12
LPG Furnace	9	0.78	0.97	25.66	171.03
Natural Gas Furnace	9	0.78	0.97	25.66	171.03
Gas Heat Pump	3	1.30	1.50	38.91	66.70
Natural Gas Radiator	7	0.80	0.97	47.89	62.43
Wood Stove	1	1.00	1.00	29.08	29.08
Oil Water Heater	2	0.55	0.58	73.74	79.26
Electric Water Heater	18	0.86	2.40	33.87	174.20
LPG Water Heater	12	0.54	0.86	33.19	213.78
Natural Gas Water Heater	13	0.54	0.86	33.19	213.78

In Tables A.3 and A.4, efficiency is defined differently, depending on the technology type. The efficiency of devices such as radiators or furnaces is defined in the typical way as energy output divided by energy input. Lighting efficiency is defined as billion lumens per trillion British thermal units (tBTUs). Heat pumps and air conditioners are characterized by their coefficient of performance (COP).

A.1.4. Technology/Fuel Share Constraints

Technology-specific penetration rates and fuel consumption shares were developed to ensure that initial year fuel consumption levels calibrated well with the historical 2002 values reported in AEO 2006. These calibration constraints were relaxed modestly over time to allow for some degree of fuel-switching and increased adoption of high efficiency technologies. These "relaxation factors" have a large impact on how flexible each of the sectors can be when deciding which technologies and energy sources are implemented to meet the demand for energy. When assessing stringent

TableA.5: Commercial Sector Shares Constraints

	2002	2029	Relaxation Factor
*** Space Heating**			
Lower limit of electricity use in commercial space heating	10.2%	9.2%	0.9
Lower limit of natural gas use in commercial space heating	73.3%	58.7%	0.8
Lower limit of distillate oil use in commercial space heating	16.4%	11.5%	0.7
Advanced technology limit for commercial space heating	0.0%	20.0%	
Technology upper limit for commercial GSHP	0.0%	20.0%	
*** Space Cooling**			
Lower limit of electricity use in commercial space cooling	97.8%	88.0%	0.9
Lower limit of natural gas use in commercial space cooling	2.2%	1.8%	0.8
Advanced technology limit for commercial space cooling	0.0%	20.0%	
Technology upper limit for window AC	10.7%	8.6%	0.8
Technology upper limit for rooftop AC	55.5%	44.4%	0.8
*** Water Heating**			
Upper limit of solar use in commercial water heating	20.7%	0.0%	
Upper limit of heat pump use in commercial water heating	20.7%	0.0%	
Lower limit of electricity use in commercial water heating	20.7%	18.7%	0.9
Lower limit of natural gas use in commercial water heating	70.4%	56.4%	0.8
Lower limit of distillate oil use in commercial water heating	8.8%	6.2%	0.7
Advanced technology limit for commercial water heating	0.0%	20.0%	
*** Cooking**			
Lower limit of electricity use in commercial cooking	6.2%	5.6%	0.9
Lower limit of natural gas use in commercial cooking	93.8%	84.4%	0.9
Advanced technology limit for commercial cooking	0.0%	20.0%	
*** Lighting**			
Technology share for commercial lighting - Incandescent	17.8%	0.0%	0.0
Technology share for commercial lighting - Fluorescent	72.7%	72.7%	1.0
Technology share for commercial lighting - HID	9.5%	9.5%	1.0
Advanced technology limit for commercial lighting	2.4%	25.0%	
*** Refrigeration**			
Technology share for commercial refrigeration - Centralized	58.6%	58.6%	1.0
Technology share for commercial refrigeration - Walk-in Cooler	21.6%	21.6%	1.0
Technology share for commercial refrigeration - Walk-in Freezer	6.4%	6.4%	1.0
Technology share for commercial refrigeration - Reach-in Refrigerator	1.7%	1.7%	1.0
Technology share for commercial refrigeration - Reach-in Freezer	2.4%	2.4%	1.0
Technology share for commercial refrigeration - Ice Machine	3.2%	3.2%	1.0
Technology share for commercial refrigeration - Beverage Merchandiser	2.3%	2.3%	1.0
Technology share for commercial refrigeration - Rfg. Vending Machine	3.8%	3.8%	1.0
Advanced technology limit for commercial refrigeration	0.0%	20.0%	

environmental policies, the model requires the freedom to explore scenarios that are very different from current energy consumption patterns. In these cases, the constraints in Tables A.5 and A.6 need to be relaxed. Between 2002 and 2029, the value of the constraint decreases or increases linearly depending on whether the constraint is being relaxed or tightened.

Table A.6: Residential Sector Share Constraints

Constraint	2002	2029	Relaxation Factor
*** Space Heating**			
Lower limit of electricity use in residential space heating	17.3%	15.6%	90.0%
Lower limit of natural gas use in residential space heating	49.7%	42.2%	85.0%
Upper limit of kerosene use in residential space heating	1.4%	1.5%	110.0%
Lower limit of LPG use in residential space heating	3.1%	2.8%	90.0%
Lower limit of distillate oil use in residential space heating	25.6%	23.0%	90.0%
Lower limit of woody biomass use in residential space heating	2.9%	2.6%	90.0%
Technology upper limit for residential GSHP	0.0%	5.0%	Not Used
Advanced technology limit for residential space heating	13.2%	10.0%	Not Used
*** Space Cooling**			
Lower limit of electricity use in residential space cooling	100.0%	90.0%	90.0%
Lower limit of natural gas use in residential space cooling	0.0%	0.0%	Not Used
Advanced technology limit for residential space cooling	0.0%	20.0%	Not Used
Technology upper limit for room AC	5.5%	50.0%	Not Used
Technology upper limit for heat pumps	34.4%	10.0%	Not Used
*** Clothes Washers**			
Advanced technology limit for residential clothes washers	0.0%	20.0%	Not Used
*** Dish Washers**			
Advanced technology limit for residential dishwashers	0.0%	10.0%	Not Used
*** Water Heating**			
Upper limit of solar use in residential water heating	0.0%	25.0%	Not Used
Lower limit of LPG use in residential water heating	0.8%	0.8%	90.0%
Lower limit of electricity use in residential water heating	38.3%	34.4%	90.0%
Lower limit of natural gas use in residential water heating	57.3%	45.8%	80.0%
Lower limit of distillate oil use in residential water heating	3.6%	2.5%	70.0%
Advanced technology limit for residential water heating	0.0%	20.0%	Not Used
*** Cooking**			
Lower limit of electricity use in residential cooking	29.9%	26.9%	90.0%
Lower limit of natural gas use in residential cooking	65.0%	58.5%	90.0%
Lower limit of LPG use in residential cooking	5.1%	4.5%	90.0%
Advanced technology limit for residential cooking	0.0%	10.0%	Not Used
*** Drying**			
Lower limit of electricity use in residential clothes drying	79.2%	71.2%	90.0%
Lower limit of natural gas use in residential clothes drying	20.8%	18.8%	90.0%
Advanced technology limit for residential clothes drying	0.0%	10.0%	Not Used
*** Refrigeration**			
Advanced technology limit for residential refrigeration	0.0%	20.0%	Not Used
*** Freezing**			
Advanced technology limit for residential freezing	0.0%	10.0%	Not Used
*** Lighting**			
Technology share for residential lighting - Incandescent	90.0%	70.0%	Not Used
Technology share for residential lighting - Fluorescent	10.0%	25.0%	Not Used
Advanced technology limit for residential lighting	0.0%	2.0%	Not Used

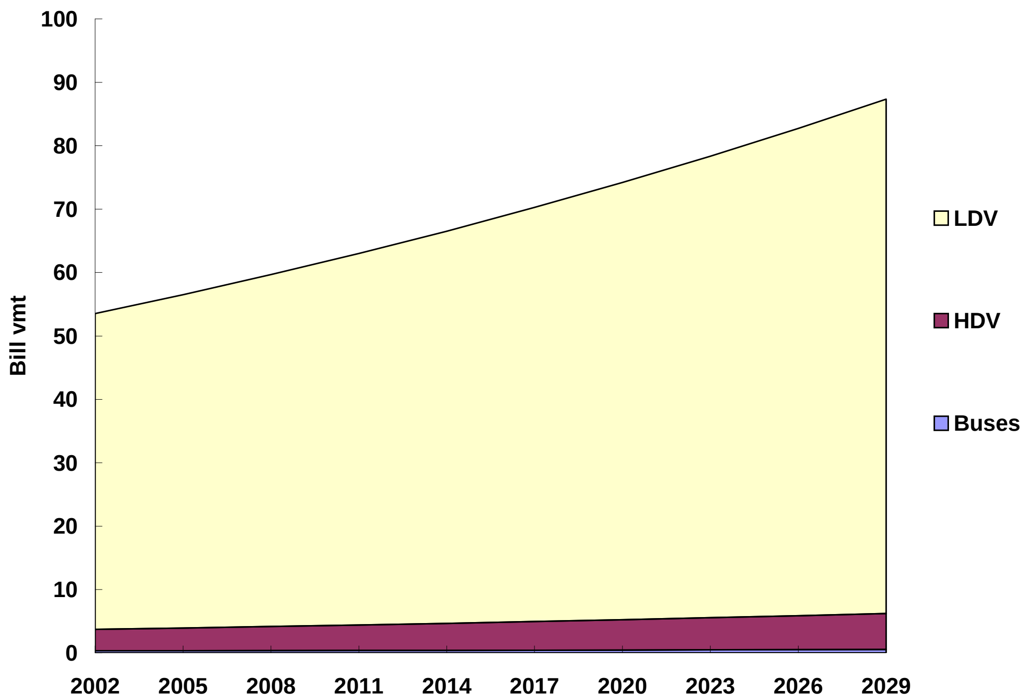
A.2. Transportation Sector Input Assumptions

For light-duty vehicles (LDV), heavy trucks and buses, 2002 state-level vehicle miles traveled (VMT) is derived from the Mid-Atlantic/Northeast Visibility Union's (MANE-VU's) mobile report. The demands are based on the MOBILE model's size classes, and were mapped to the NE-MARKAL size classes: small car, large car, small truck, large truck and mini-vans. The NE-MARKAL size classes were defined to take advantage of technical and economic data in a detailed study of currently available and emerging GHG reduction technologies.[19]

A.2.1. Transportation Demand Projections

Demand projections for LDVs, trucks, and buses were based on VMT projections extracted by NESCAUM from the MANE-VU[20] inventory data for 2009 and 2018, which were based on state-provided VMT projections. For LDVs, the average growth rate for all size categories was used. For trucks, an average of the Heavy Duty Gas Truck (HDGT), Medium Heavy Duty Diesel Vehicle (MHDDV), and Heavy Heavy Duty Diesel Vehicle (HHDDV) classes, weighted by the base year shares for these classes in each state, was used. For buses, the Heavy Duty Diesel Bus (HDDB) category growth rate was used.

Figure A.3: Vehicle Miles Traveled Demand Projection



[19] Reducing Greenhouse Gas Emissions from Light-duty Motor Vehicles, September 2004. Northeast States Center for a Clean Air Future (NESCCAF), Boston, MA

[20] MARAMA, Documentation of the 2002 Mobile Emissions Inventory for the MANE-VU States, Mid-Atlantic Regional Air Management Association, Baltimore MD, 2006, available online at: http://www.marama.org/visibility/Inventory%20Summary/final_mob_manevu_rpt.pdf

For the fuel-based other demands, growth projections are derived from the growth of the consumption of these fuels in AEO 2006 regional results. The exception is Other Diesel, because AEO diesel consumption is dominated by heavy trucks, a demand we track explicitly. The growth rate for Other Diesel is the AEO annual growth rate for the sum of freight rail and domestic shipping, the two largest components of diesel consumption after heavy trucks. This is a national average growth rate.

Figure A.4: Other Transportation Fuel Demands

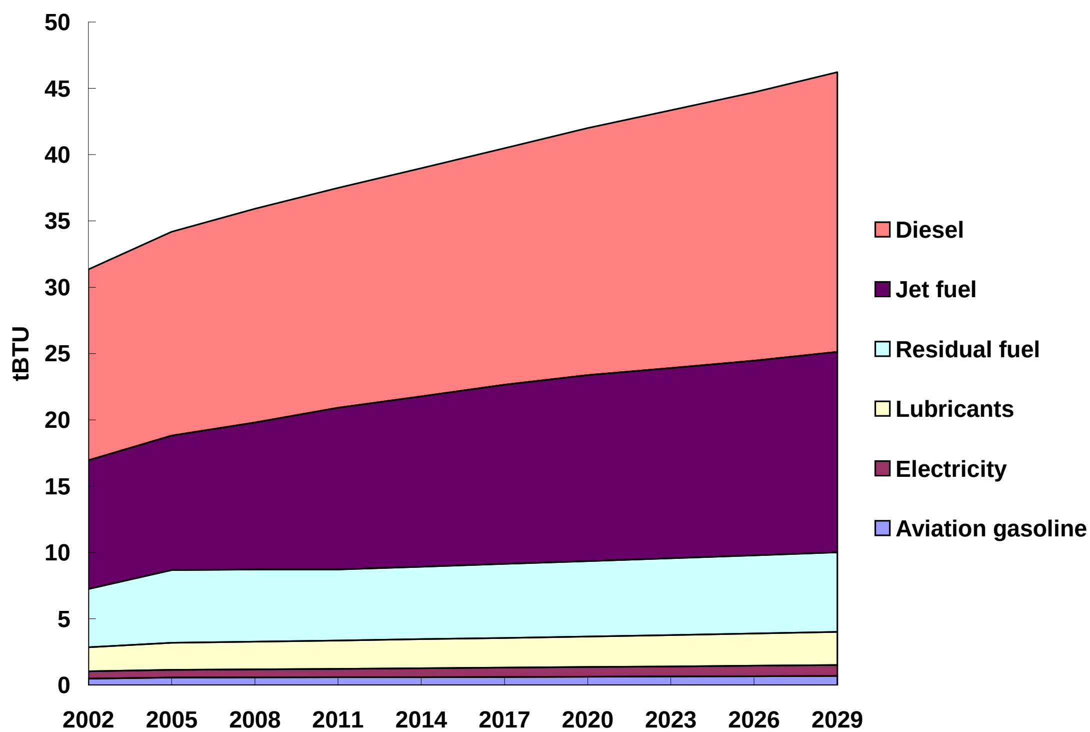


Table A.7: HDV Technical Characteristics

	Min MPG	Max MPG	Min Cost (2002$/mi/yr)	Max Cost (2002$/mi/yr)	Life
CNG Bus	4.3	8.6	5.0	11.4	15
Diesel Bus	3.9	4.7	3.5	11.4	15
Electric Bus	4.3	9.3	5.0	11.4	15
Gasoline Bus	7.1	11.1	4.7	11.4	15
Heavy Diesel Truck	5.8	6.9	2.9	11.3	25
Heavy Diesel Truck Adv	7.0	8.3	3.0	3.3	25
Heavy Gasoline Truck	5.8	5.8	2.9	11.3	25
Medium Diesel Truck	7.8	9.4	1.7	6.8	25
Medium Diesel Truck Adv	9.5	11.3	1.8	2.0	25
Medium Gasoline Truck	7.8	7.9	1.7	6.8	25

Each of the major vehicle classes represented in Tables A.7 and A.8 contains more than one technology depending on the model year. They list the range of costs and efficiencies associated with technologies in the transportation sector over the modeling timeframe.

Table A.8: LDV Technical Characteristics

	Min MPG	Max MPG	Min Cost (2002$/mi/yr)	Max Cost (2002$/mi/yr)	Life
CNG Minivan	17.2	17.2	2.2	2.3	15
Diesel Hybrid Minivan	42.7	42.7	2.7	2.7	15
Diesel Minivan	23.2	23.2	2.2	2.2	15
Electric Minivan	68.8	68.8	3.3	3.7	15
Ethanol Minivan	20.7	23.0	2.1	2.2	15
Gasoline Hybrid Minivan	31.1	36.2	2.4	2.6	15
Gasoline Minivan	17.2	23.6	2.1	2.3	15
Hydrogen FC Minivan	40.9	47.3	2.5	2.7	15
Lg CNG Car	19.7	19.7	2.5	2.5	15
Lg CNG Truck	13.3	13.3	2.4	2.5	15
Lg Diesel Car	26.0	26.0	2.3	2.3	15
Lg Diesel Hybrid Car	49.0	49.0	3.0	3.0	15
Lg Diesel Hybrid Truck	33.5	33.5	3.1	3.1	15
Lg Diesel Truck	17.7	17.7	2.5	2.5	15
Lg Electric Car	78.9	78.9	4.1	4.1	15
Lg Electric Truck	17.0	53.2	2.3	3.5	15
Lg Ethanol Flex Car	21.1	23.8	2.3	2.4	15
Lg Gasoline Car	19.7	30.1	2.1	2.6	15
Lg Gasoline Hybrid Car	35.7	41.6	2.6	2.8	15
Lg Gasoline Hybrid Truck	23.8	27.7	2.6	2.9	15
Lg Gasoline Truck	13.3	19.0	2.2	2.6	15
Lg Hydrogen FC Car	47.9	54.6	2.8	3.1	15
Lg Hydrogen FC Truck	28.1	36.9	2.7	3.2	15
Sm CNG Car	23.3	23.3	2.0	2.0	15
Sm CNG Truck	15.2	15.2	1.9	1.9	15
Sm Diesel Car	35.5	35.5	2.1	2.1	15
Sm Diesel Truck	23.4	25.2	1.8	1.8	15
Sm Electric Car	93.1	93.1	3.4	3.4	15
Sm Electric Truck	17.7	61.0	1.7	2.8	15
Sm Ethanol Flex Car	25.9	27.4	1.8	1.8	15
Sm Ethanol Truck	18.3	19.3	1.8	1.8	15
Sm Gasoline Car	23.3	33.0	1.7	2.0	15
Sm Gasoline Truck	15.2	21.8	1.7	1.9	15
Sm Hybrid Diesel Car	59.4	59.4	2.4	2.4	15
Sm Hybrid Diesel Truck	37.1	37.1	2.3	2.3	15
Sm Hybrid Gasoline Car	42.2	49.1	2.1	2.2	15
Sm Hybrid Gasoline Truck	27.1	31.5	1.9	2.1	15
Sm Hydrogen FC Car	60.1	65.9	2.2	2.5	15
Sm Hydrogen FC Truck	30.5	45.7	2.1	2.3	15

Table A.9 presents the default assumptions made about the evolution of the fleet technology mix for Maryland in the NE-MARKAL model. The share constraints change linearly between 2005 and 2029. The constraints govern the extent to which the fleet technology mix is allowed to change over time. As with the share constraints in both of the building sectors, these constraints govern how flexible the technology choices in the transportation sector are in response to climate and environmental policy scenarios.

Table A.9: Transportation Sector Technology Share Constraints

	2005	2029
Min Share of Diesel Bus in Transportation Buses	84.4%	67.5%
Min Share of Heavy Truck in Transportation Heavy Trucks	45.6%	43.4%
Min Share of Gasoline Truck in Transportation Heavy Trucks	30.6%	29.1%
Minimum Share of Big Car in Transportation LDV	28.3%	19.2%
Minimum Share of Small Truck in Transportation LDV	27.3%	33.8%
Minimum Share of Small Car in Transportation LDV	24.1%	16.3%
Minimum Share of Lg Truck in Transportation LDV	11.8%	16.7%
Max Share of CNG Bus in Transportation Buses	7.6%	8.4%
Minimum Share of Min Van in Transportation LDV	7.5%	13.0%
Max Share of Gasoline Bus in Transportation Buses	6.0%	6.6%
Max Share of DSL LDV in Transportation LDV	2.0%	10.0%
Max Share of CNG LDV in Transportation LDV	0.1%	1.0%

A.3. Industrial Sector Input Assumptions

A.3.1. Industry Sector Demand Projections

Industrial sector demand covers a generic set of process technologies in the manufacturing industries depicted in Figure 3.1.[21] DOE's Manufacturing Energy Consumption Survey (MECS) was used to map forecasted industrial energy consumption in AEO 2006 into a set of processes common to all industries modeled. These processes include process heating, steam usage, electro-chemical devices, machine drives, petro-chemical feed stocks and other industrial process demands.

[21] The National Energy Modeling System (NEMS) reports energy consumption by North American Industrial Classification System (NAICS) code for the manufacturing sector. Paper 322, Metal 3311-3313, Chemicals 325, Durables 332-336, Glass & Cement 3272-3273, Other Manufacturing.

Figure A.5: Industry Demand

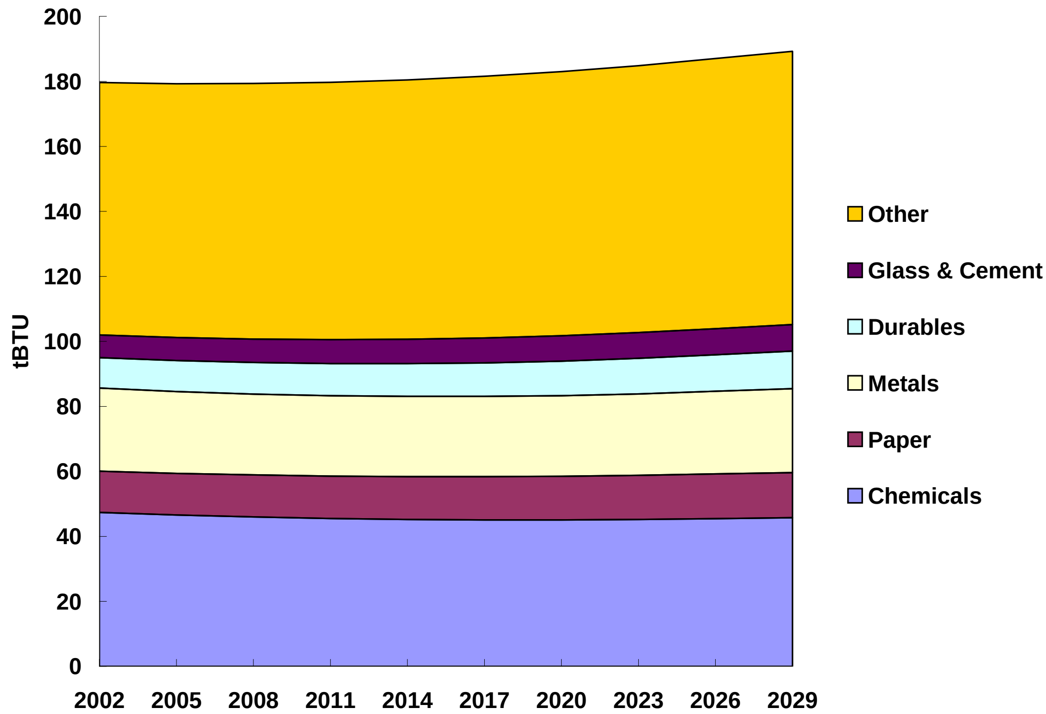


Table A.10: Industry Demand Growth

	Average Annual Growth 2002-2029	% 2002 Demand
Durables	2.3%	5.2%
Glass & Cement	1.9%	3.9%
Paper	1.0%	7.1%
Other	0.9%	43.2%
Metals	0.1%	14.2%
Chemicals	-0.4%	26.4%

A.3.2. Demand Projection Methodology

Unlike energy demand in the buildings sector, industrial demand drivers are based on AEO 2006 projections of final energy consumption rather than useful energy output. The drivers were constructed in a manner that would result in relatively flat industrial demand projections.

A.3.3. Industry Sector Fuel Share Constraints

Tables A.11 through A.16 outline the fuel share constraints that calibrate industrial sector fuel consumption to baseline 2002 data sources. Tables are also included describing how these constraints are relaxed over time to allow for fuel- and technology-switching. The shares indicate the minimum proportion of each fuel category consumed by each industrial process.

Table A.11: Chemical Sector Fuel Shares

FUEL		CHP	Machine Drive	Other	Petro Chemical Processes	Process Heat	Steam
Coal	2002	80.7%		9.0%			29.7%
	2029	72.6%		5.4%			17.8%
Diesel	2002	0.0%	0.0%	0.0%		0.2%	0.2%
	2029	0.0%	0.0%	0.0%		0.1%	0.1%
Electricity	2002		97.6%	47.7%		15.6%	0.4%
	2029		97.6%	47.7%		15.6%	0.4%
Low Tem Heat	2002						52.6%
	2029						52.6%
LPG	2002			0.000%	8.1%		
	2029			0.000%	7.3%		
MSW	2002						0.1%
	2029						0.1%
Natural Gas	2002	18.3%	2.4%	7.8%	30.5%	78.5%	15.3%
	2029	16.4%	1.9%	6.2%	24.4%	62.8%	12.3%
Other Petroleum	2002			34.5%			
	2029			27.6%			
Petro-Chemical Feedstocks	2002				61.4%		
	2029				49.1%		
Residual Oil	2002			1.0%		5.7%	1.7%
	2029			0.8%		4.6%	1.4%

Table A.12: Metal Manufacturing Sector Fuel Constraints

FUEL		Machine Drive	Other	Process Heat	Steam
Coal	2002		47.08%	38.48%	
	2029		28.25%	23.09%	
Diesel	2002	0.41%	1.06%	0.00%	
	2029	0.29%	0.74%	0.00%	
Electricity	2002	98.87%	37.66%	42.14%	12.58%
	2029	98.87%	41.42%	37.93%	13.84%
Low Tem Heat	2002				26.61%
	2029				26.61%
LPG	2002		0.00%		
	2029		0.00%		
Natural Gas	2002	0.72%	6.10%	19.01%	60.81%
	2029	0.58%	4.88%	15.21%	48.65%
Other Petroleum	2002		7.58%		
	2029		7.58%		
Residual Oil	2002		0.52%		
	2029		0.36%		

Table A.13: Durable Goods Manufacturing Sector Fuel Constraints

FUEL		CHP	Machine Drive	Other	Process Heat	Steam
Coal	2002	0.00%		0.00%		0.00%
	2029	0.00%		0.00%		0.00%
Diesel	2002			0.68%		2.03%
	2029			0.48%		1.42%
Electricity	2002		99.73%	89.58%	75.02%	
	2029		99.73%	71.66%	75.02%	
Low Tem Heat	2002					14.99%
	2029					14.99%
LPG	2002			0.00%		
	2029			0.00%		
Natural Gas	2002	9.27%	0.27%	8.75%	24.98%	59.12%
	2029	8.34%	0.22%	7.00%	19.98%	47.30%
Residual Oil	2002			0.99%		2.97%
	2029			0.80%		2.37%
Wood	2002	89.73%				20.89%
	2029	80.76%				20.89%

Table A.14: Paper Manufacturing Sector Fuel Constraints

FUEL		CHP	Machine Drive	Other	Process Heat	Steam
Coal	2002	50.58%	6.23%	45.94%		12.69%
	2029	45.52%	3.74%	27.56%		7.62%
Diesel	2002	0.58%		1.77%	2.89%	0.19%
	2029	0.52%		1.24%	2.02%	0.13%
Electricity	2002		91.33%	37.83%	9.99%	0.13%
	2029		91.33%	41.61%	10.99%	0.15%
Low Tem Heat	2002					73.26%
	2029					73.26%
LPG	2002			0.00%	0.00%	
	2029			0.00%	0.00%	
MSW	2002					0.45%
	2029					0.45%
Natural Gas	2002	3.10%	1.57%	10.19%	43.37%	3.18%
	2029	2.79%	1.26%	8.15%	34.70%	2.54%
Residual Oil	2002	4.01%	0.87%	4.28%	43.75%	3.38%
	2029	3.61%	0.70%	3.42%	35.00%	2.71%
Wood	2002	40.73%				6.71%
	2029	36.65%				6.71%

Table A.15: Glass & Cement Sector Fuel Constraints

FUEL		Machine Drive	Other	Process Heat	Steam
Coal	2002			90.57%	
	2029			54.34%	
Diesel	2002	2.30%	12.04%	0.24%	61.91%
	2029	1.61%	8.43%	0.17%	43.34%
Electricity	2002	97.51%	51.37%	4.52%	
	2029	97.51%	56.50%	4.97%	
Low Tem Heat	2002				4.90%
	2029				4.90%
Natural Gas	2002	0.20%	6.89%	4.67%	33.18%
	2029	0.16%	5.51%	3.74%	26.55%
Other Petroleum	2002		27.38%		
	2029		27.38%		
Residual Oil	2002		2.33%		
	2029		1.86%		

Table A.16: Other Industrial Sectors Fuel Constraints

FUEL		CHP	Machine Drive	Other	Process Heat	Steam
Coal	2002	0.00%		0.27%	0.26%	12.76%
	2029	0.00%		0.16%	0.15%	7.66%
Diesel	2002	0.00%	14.55%	19.83%	6.71%	32.09%
	2029	0.00%	10.19%	13.88%	4.69%	22.46%
Electricity	2002		85.30%	60.54%	42.58%	
	2029		85.30%	66.60%	46.84%	
Gasoline	2002			14.15%		
	2029			14.15%		
Low Tem Heat	2002					15.47%
	2029					15.47%
LPG	2002			0.00%		
	2029			0.00%		
Natural Gas	2002	9.27%	0.14%	4.64%	46.63%	25.49%
	2029	8.34%	0.11%	3.71%	37.30%	20.39%
Residual Oil	2002	0.00%		0.57%	3.83%	4.75%
	2029	0.00%		0.46%	3.06%	3.80%
Wood	2002	89.73%				9.44%
	2029	80.76%				9.44%

A.4. Power Sector Input Assumptions

For electricity only plants, the NE-MARKAL modeling approach is to represent individual plants down to a minimum size threshold, and aggregate the plants below that threshold. Technical and economic data are taken from Energy Information Administration (EIA) reports, NEMS, and eGRID.

There are two types of combined heat and power (CHP) applications considered in NE-MARKAL. The first is the independent or merchant CHP plant that primarily sells electricity to the grid and is not integrated into industrial processes. The heat (usually steam) they produce can be used in a range of low to medium temperature applications, including district heating, commercial/institutional buildings, or industrial manufacturing. These plants are modeled in the electricity sector in the same manner as the electricity generation technologies.

The second class of plants is the industrial CHP plant. These plants are more tightly integrated with the industrial processes they serve and often (but not always) use by-product fuels from industrial processing. The fuel consumption and residual capacity of these plants (and on-site generation) have been extracted from the NEMS industrial database and apportioned to the states according the State Energy Data System (SEDS) data, as are other industrial energy consumption data. The CHP end-use shares are derived from the MECS data. Specific CHP technologies are defined according to the fuel input. Technology characteristics are derived from the System for the Analysis of Global Energy Markets (SAGE) industrial technology database.

A.4.1. Existing Power Plants

The data sources for existing electricity generation plants and independent CHP generation technologies are EIA Forms 860 (existing and planned units), 767, 759/906 and 1. These data sources collectively list generating unit capacity, prime mover, fuel sources, location, plant operation and equipment design (including environmental controls), and fuel consumption and quality. For the larger investor-owned plants, these data also include non-fuel operating costs. Each survey form covers a unique universe of units covered. All units are covered by one or more of the forms. Key input assumptions for all existing plants for inclusion in our modeling are presented in Tables A.17 and A.18.

Because the EIA forms list every plant regardless of size, small plants must be aggregated to an appropriate level to obtain a manageable number of technologies that still adequately represent the diversity of existing plants and their differential use in the system. All existing generation units above a specified capacity threshold are represented as individual technologies, retaining all unit-specific information. This threshold is currently set at 25MW, but can be adjusted to obtain the desired level of detail in the sector.

Plants below the capacity threshold have been aggregated using the following characteristics[22] to define a plant type:

- Fuel input type
- Plant type (taken from the Electricity Capacity Planning (ECP) designations in NEMS)
- State/Region

For each grouping of aggregated plants, data for the representative MARKAL technology are derived by calculating a capacity weighted average of selected fields from the EIA forms and totaling other fields. The following fields have been averaged:

- Heat rate
- Annual capacity additions (added to fixed operation and maintenance (O&M) costs)
- Fixed O&M
- Variable O&M
- Capacity factor
- Availability
- Scrubber efficiency
- Nitrogen oxides (NOx) emission rate

The following fields were totaled:

- total of summer capacity
- total of winter capacity (used by adjusting the AF by season)

[22] Note that ECP designations separate coal units with and without scrubbers and by vintage. In addition, for coal units, the coal supply region providing the fuel input was used to further distinguish between units for aggregation purposes.

Table A.17: Existing Power Plants

Unit	Fuel	Efficiency	Capacity	Retirement Date	Availability
MD C P Crane:1.CBX.CSU	Coal / Biomass	33%	190	2032	82%
MD C P Crane:2.CBX.CSU	Coal / Biomass	34%	195	2032	82%
MD Gould Street:3.RFL.STO	Residual Oil	29%	103	2012	82%
MD Herbert A Wagner:1.RFL.STO	Residual Oil	30%	131	2012	82%
MD Herbert A Wagner:2.CBX.CSU	Coal / Biomass	33%	135	2032	82%
MD Herbert A Wagner:3.CBX.CSU	Coal / Biomass	35%	332	2032	82%
MD Herbert A Wagner:4.NGA.STG	Gas	26%	401	2012	82%
MD Perryman:GT1.DSL.CTO	Diesel	28%	52	2012	92%
MD Perryman:GT2.DSL.CTO	Diesel	28%	52	2012	92%
MD Perryman:GT3.DSL.CTO	Diesel	28%	52	2012	92%
MD Perryman:GT4.DSL.CTO	Diesel	28%	52	2012	92%
MD Perryman:GT5.OGX.CTX	Oil / Gas	28%	173	2035	92%
MD Riverside:4.NGA.STG	Gas	25%	79	2012	82%
MD Riverside:GT6.OGX.CTX	Oil / Gas	18%	133	2012	92%
MD Westport:GT5.NGA.CTG	Gas	18%	121	2012	92%
MD Vienna Operations:8.RFL.STO	Residual Oil	27%	156	2012	82%
MD R Paul Smith Power S:11.CBX.CSU	Coal / Biomass	29%	88	2032	82%
MD R Paul Smith Power S:9.CBX.CSU	Coal / Biomass	29%	28	2032	82%
MD Chalk Point LLC:3.RFL.STO	Residual Oil	35%	612	2015	82%
MD Chalk Point LLC:4.RFL.STO	Residual Oil	34%	612	2021	82%
MD Chalk Point LLC:GT2.DSL.CTO	Diesel	26%	35	2014	92%
MD Chalk Point LLC:GT3.OGX.CTX	Oil / Gas	26%	99	2031	92%
MD Chalk Point LLC:GT4.OGX.CTX	Oil / Gas	26%	99	2031	92%
MD Chalk Point LLC:GT5.OGX.CTX	Oil / Gas	26%	120	2031	92%
MD Chalk Point LLC:GT6.OGX.CTX	Oil / Gas	26%	120	2031	92%
MD Chalk Point LLC:SGT1.OGX.CTX	Oil / Gas	26%	93	2030	92%
MD Chalk Point LLC:ST1.CBX.CSU	Coal / Biomass	28%	341	2032	82%
MD Chalk Point LLC:ST2.CBX.CSU	Coal / Biomass	32%	343	2032	82%

MD Dickerson:2.CBX.CSU	Coal / Biomass	34%	182	2032	82%
MD Dickerson:3.CBX.CSU	Coal / Biomass	34%	182	2032	82%
MD Dickerson:GT2.OGX.CTX	Oil / Gas	26%	167	2032	92%
MD Dickerson:GT3.OGX.CTX	Oil / Gas	26%	167	2032	92%
MD Dickerson:ST1.CBX.CSU	Coal / Biomass	34%	182	2032	82%
MD Morgantown Generatin:3.DSL.CTO	Diesel	24%	65	2013	92%
MD Morgantown Generatin:4.DSL.CTO	Diesel	24%	65	2013	92%
MD Morgantown Generatin:5.DSL.CTO	Diesel	24%	65	2013	92%
MD Morgantown Generatin:6.DSL.CTO	Diesel	24%	65	2013	92%
MD Morgantown Generatin:ST1.CBX.CSU	Coal / Biomass	35%	624	2032	82%
MD Morgantown Generatin:ST2.CBX.CSU	Coal / Biomass	35%	620	2032	82%
MD Conowingo:1.HYD.HYC	Hydro	34%	48	2032	38%
MD Conowingo:2.HYD.HYC	Hydro	34%	36	2032	38%
MD Conowingo:3.HYD.HYC	Hydro	34%	48	2032	38%
MD Conowingo:4.HYD.HYC	Hydro	34%	48	2032	38%
MD Conowingo:5.HYD.HYC	Hydro	34%	36	2032	38%
MD Conowingo:6.HYD.HYC	Hydro	34%	36	2032	38%
MD Conowingo:7.HYD.HYC	Hydro	34%	36	2032	38%
MD Conowingo:8.HYD.HYC	Hydro	34%	65	2032	38%
MD Conowingo:9.HYD.HYC	Hydro	34%	65	2032	38%
MD Conowingo:10.HYD.HYC	Hydro	34%	65	2032	38%
MD Conowingo:11.HYD.HYC	Hydro	34%	65	2032	38%
MD Montgomery County Re:GEN1.MSW.MSW	MSW	20%	56	2035	90%
MD Calvert Cliffs Nucle:1.NUC.CNU	Nuclear	34%	865	2032	82%
MD Calvert Cliffs Nucle:2.NUC.CNU	Nuclear	34%	880	2032	82%
MD Brandon Shores:1.CBX.CSU	Coal / Biomass	32%	652	2032	82%
MD Brandon Shores:2.CBX.CSU	Coal / Biomass	33%	652	2032	82%
MD Rock Springs Generat:5.NGA.CTG	Gas	32%	185	2046	92%
MD Rock Springs Generat:6.NGA.CTG	Gas	32%	185	2046	92%
MD CTO.DSL.37	Diesel	24%	300	2013	92%
MD CTG.NGA.8	Gas	19%	128	2012	92%
MD CTX.OGX.5	Oil / Gas	33%	20.8	2015	92%
MD MSW.MSW.2	MSW	23%	2.6	2025	90%
MD HYC.HYD.2	Hydro	34%	19	2012	32%

Table A.18: Smaller Plants and CHP

Unit	Fuel	Efficiency	Capacity	Retirement Date	Availability
Combined Heat and Power Plants					
MD Sparrows Point:GEN1.NGA.STG	Natural Gas	18.5%	152	2012	82.0%
MD Sparrows Point:GEN2.NGA.STG	Natural Gas	18.6%	38	2012	82.0%
MD Sparrows Point:GEN3.NGA.STG	Natural Gas	16.2%	38	2012	82.0%
MD Sparrows Point:GEN4.NGA.STG	Natural Gas	16.2%	38	2012	82.0%
MD Wheelabrator Baltimo:GEN1.MSW.MSW	MSW	35.4%	57	2024	90.0%
MD AES Warrior Run Coge:GEN1.CBS.CSC	Coal / Biomass	32.0%	180		82.0%
MD Panda Brandywine LP:1.OGX.CCX	Oil / Gas	41.0%	230		87.0%
MD Panda Brandywine LP:2.OGX.CCX	Oil / Gas	41.0%	77		87.0%
MD Panda Brandywine LP:3.OGX.CCX	Oil / Gas	41.0%	77		87.0%
MD STG.NGA.1	Natural Gas	16.2%	1		82.0%
MD CTG.NGA.8	Natural Gas	29.1%	20		92.4%
MD MSW.MSW.1	MSW	33.2%	4		90.0%
Aggregations of Small Existing Plants/Technologies < 25 MW					
MD CSU.CBX.2	Coal / Biomass	22.9%	42	2012	82.0%
MD CSU.CBX.4	Coal / Biomass	28.4%	77	2012	82.0%
MD CSU.CBX.9	Coal / Biomass	22.0%	112	2012	82.0%
MD STG.NGA.3	Natural Gas	29.4%	34	2012	82.0%
MD CTO.DSL.141	Diesel	22.0%	352	2020	92.4%
MD CTG.NGA.6	Natural Gas	31.9%	59		92.4%
MD CTX.OGX.95	Oil / Gas	24.8%	364	2013	92.4%
MD HYC.HYD.6	Hydro	33.8%	19	2012	96.4%

A.4.2. New Power Plants

New conventional fossil and nuclear plants were characterized using NEMS data. Table A.19 presents the key parameter assumptions associated with new conventional generation technologies in NE-MARKAL. Investment cost and efficiency ranges represent the assumed decline in cost and efficiency increase over the modeling horizon.

Table A.19: New Power Plant Assumptions

	Investment Cost	Variable O&M	Fixed O&M	Efficiency	Availability
Scrbd Pulverized Coal 2010	1,305 - 1374	1.2	23.9	39 - 40 %	85%
Integrated Gas Comb Cycle 2010	1,313 - 1,561	0.7	33.5	43 - 47 %	85%
IGCC w/Sequestration 2010	1,589 - 2,279	1.1	39.5	35%	85%
Gas/Oil Steam Turbine 2005	1,024	0.5	32.2	36%	82%
Conv Combustion Turbine 2007	375 - 400	0.9	10.5	31%	92%
Adv Combustion Turbine 2007	315 - 379	0.8	9.1	38 - 40 %	92%
Conv Gas/Oil Comb Cycle 2008	548 - 585	0.5	10.8	47%	87%
Adv Gas/Oil Comb Cycle 2008	503 - 576	0.5	10.1	52 - 54 %	87%
Adv CC w/Sequestration 2010	864 - 1,149	0.7	17.3	40%	87%
Fuel Cells 2005	4,304	12.2	4.9	43%	87%
Advanced Nuclear 2013	1,990 - 2,255	0.1	63.6	33%	90%
Pumped Storage 2005	2,180	0.8	17.1	97%	10%
Distributed Generation-Base 2005	818	1.8	13.9	35%	50%
Distributed Generation-Peak 2005	982	1.8	13.9	32%	5%

A.4.3. Renewable Resources Characterization

A.4.3.1. Wind Resources

The National Renewable Energy Laboratory (NREL) provided NESCAUM with wind potentials for on- and off-shore resources and as a function of wind class (i.e., 3 through 7) and distance from grid transmission lines. NREL processed its standard state-level wind resource maps and transmission line data from PowerMap[23] for lines between 69 -

[23] Platts - Dec 2006 update.

345 kV, buffered to identify raw wind resource potential for 0-5, 5-10, 10-20, and >20 mile distance bands. The standard environmental, land use, and other exclusion criteria were then applied to the data to produce a developable resource potential. These criteria are provided in Table A.20.

Table A.20: Criteria for Defining Available Windy Land (numbered in the order they are applied)

Environmental Criteria	Data/Comments:
2) 100% exclusion of National Park Service and Fish and Wildlife Service managed lands	USGS Federal and Indian Lands shapefile, Jan 2005
3) 100% exclusion of federal lands designated as park, wilderness, wilderness study area, national monument, national battlefield, recreation area, national conservation area, wildlife refuge, wildlife area, wild and scenic river or inventoried roadless area.	USGS Federal and Indian Lands shapefile, Jan 2005
4) 100% exclusion of state and private lands equivalent to criteria 2 and 3, where GIS data is available.	State/GAP land stewardship data management status 1, from Conservation Biology Institute Protected Lands database, 2004
8) 50% exclusion of remaining USDA Forest Service (FS) lands (incl. National Grasslands)	USGS Federal and Indian Lands shapefile, Jan 2005
9) 50% exclusion of remaining Dept. of Defense lands	USGS Federal and Indian Lands shapefile, Jan 2005
10) 50% exclusion of state forest land, where GIS data is available	State/GAP land stewardship data management status 2, from Conservation Biology Institute Protected Lands database, 2004
Land Use Criteria	
5) 100% exclusion of airfields, urban, wetland and water areas.	USGS North America Land Use Land Cover (LULC), version 2.0, 1993; ESRI airports and airfields (2003)
11) 50% exclusion of non-ridgecrest forest	Ridge-crest areas defined using a terrain definition script, overlaid with USGS LULC data screened for the forest categories.
Other Criteria	
1) Exclude areas of slope > 20%	Derived from elevation data used in the wind resource model.
6) 100% exclude 3 km surrounding criteria 2-5 (except water)	Merged datasets and buffer 3 km
7) Exclude resource areas that do not meet a density of 5 km^2 of class 3 or better resource within the surrounding 100 km^2 area.	Focalsum function of class 3+ areas (not applied to 1987 PNL resource data)
Note - 50% exclusions are not cumulative. If an area is non-ridgecrest forest on FS land, it is just excluded at the 50% level one time.	

A.4.3.2. Renewable energy cost and resource bounds

Oak Ridge National Lab (ORNL) has estimated the availability and delivered price of six types of biomass resources for the U.S.[24] For agricultural residues, the delivered price includes the cost of collecting the residues, the premium paid to farmers to encourage participation, and transportation costs. Woody biomass and agricultural wastes were combined as one aggregated biomass resource, as the technology differences for application of these two biomass types are not significant.

Four biomass resource supply steps, described in Tables A.21 and A.22, were developed for each state, corresponding to each price step in the ORNL data. The first three price steps start in 2002, as they correspond to existing supplies of forest and urban wood waste residues. The final step corresponds to energy crops, which ORNL assumed are available by 2010. The final step was constructed such that half the potential energy crop supply is available in 2008, and the full energy crop potential is available in 2011.

Most of the increase at $50/dry ton is due to energy crops, which the ORNL data assume is all switchgrass due to its higher productivity. However, such a significant role for energy crops may not be the best assumption for Maryland. The ORNL methodology assumes that agricultural lands are used for energy crops, and it factors in some competition between food production and energy crops. We did not review the validity of these and other assumptions in ORNL's analysis to understand how adequately they characterize Maryland's potential for energy crops. Ideally, we would have wanted data to better characterize the likely supply and suitability of switchgrass, poplar, and other energy crops in Maryland.

Work is currently underway to revise our characterization of the biomass potential in the Northeast through a NESCAUM study examining a regional low carbon fuel standard. We expect that this analysis will provide useful information to better refine these assumptions in the future.

Table A.21: Maryland Renewable Energy Cost Assumptions

		Mill 2002$/tBTU		
	Start	Initial Cost	Cost 2029	% Change
Woody Biomass @ 20$/dt	2002	1.5	1.5	0.0%
Woody Biomass @ 30$/dt	2002	2.3	2.3	0.0%
Woody Biomass @ 40$/dt	2002	3.3	3.3	0.0%
Woody Biomass @ 50$/dt	2008	4.2	4.2	0.0%
Residential Wood	2002	15*	15*	0.0%
MSW**	2002			
Pulping Liquor**	2002			
Biodiesel Supply Curve 1	2005	5.0	6.1	22.1%
Biodiesel Supply Curve 2	2005	6.8	7.9	16.3%
Hydrogen Supply Curve 1	2005	29.0	24.2	-16.6%
Hydrogen Supply Curve 2	2014	53.9	56.6	5.1%

[24] Biomass Feedstock Availability in the United States: 1999 State Level Analysis, Marie E. Walsh, Robert L. Perlack, Anthony Turhollow, Daniel de la Torre Ugarte, Denny A. Becker, Robin L. Graham, Stephen E. Slinsky, and Daryll E. Ray (updated January 2000).

Table A.22: Maryland Renewable Energy Resource Potential Assumptions

		tBTU		
	Start	Initial Upper Bound	Upper Bound 2029	% Change
Woody Biomass @ 20$/dt	2002	2.8	2.8	0.0%
Woody Biomass @ 30$/dt	2002	4.7	4.7	0.0%
Woody Biomass @ 40$/dt	2002	6.7	6.7	0.0%
Woody Biomass @ 50$/dt	2008	8.9	8.9	0.0%
Residential Wood	2002	11.8	11.8	0.0%
MSW**	2002	16.0	62.9	293.6%
Pulping Liquor**	2002	3.6	4.3	20.5%
Biodiesel Supply Curve 1	2005	0.32	0.33	2.3%
Biodiesel Supply Curve 2	2005	0.18	0.18	2.3%
Hydrogen Supply Curve 1	2005	0.004	35.5	>> 100%
Hydrogen Supply Curve 2	2014	0.1	5.9	>> 100%

Data on municipal solid waste (MSW) were derived from the report "BioCycle, The State of Garbage in America, April 2006."[25] Initial biomass pulping liquor resource bounds were developed using SEDS data and then relaxed slowly over the model timeframe. Both MSW and pulping liquor are currently consumed at no cost. Residential wood has a high cost to prevent any large degree of fuel switching into the resource. Hydrogen supply curves were developed based on a forecast[26] of regional hydrogen production and investment costs out to 2050. Biodiesel supply and cost characteristics were constructed directly from the 2006 AEO.

[25] BioCycle, The State of Garbage in America, April 2006, available online at www.p2pays.org/ref/22/21411.pdf

[26] Hydrogen Demand, Production, and Cost by Region to 2050, ANL/ESD/05-2,

A.5. Fuel Price Input Assumptions

In NE-MARKAL, fuel price assumptions are taken directly from the AEO 2006 reference case forecast. Table A.23 summarizes key fuel price assumptions in each modeled sector.

Table A.23: Fuel Price Assumptions

Constant 2002 $/ Million Btu										
	2002	2005	2008	2011	2014	2017	2020	2023	2026	2029
Commercial Sector										
Coal	1.85	2.07	2.19	2.15	2.09	2.07	2.07	2.08	2.11	2.14
Diesel	5.77	9.59	9.97	9.47	9.40	9.64	10.02	10.33	10.61	10.78
Gasoline	10.59	16.96	15.84	14.76	14.61	14.81	15.37	15.64	15.88	16.09
Kerosene	4.85	7.96	8.03	7.48	7.37	7.45	7.66	7.84	7.96	8.07
LPG	6.73	11.04	10.90	10.30	10.17	10.54	11.19	11.65	12.03	12.43
Natural Gas	7.46	10.81	9.28	8.51	8.35	8.26	8.48	8.73	9.01	9.18
Residual Fuel Oil	3.86	8.32	7.37	6.61	6.57	6.58	6.91	6.86	7.13	7.18
Power Sector										
Diesel	5.40	8.98	9.09	8.35	8.28	8.52	8.87	9.15	9.36	9.53
Natural Gas	3.96	7.82	5.84	4.95	4.94	4.97	5.26	5.52	5.81	5.96
Nuclear Uranium	0.42	0.44	0.48	0.51	0.54	0.55	0.57	0.59	0.58	0.57
Residual Fuel Oil High Sulfur	0.28	0.48	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Residual Fuel Oil Low Sulfur	2.75	4.72	4.92	4.40	4.36	4.41	4.55	4.64	4.81	4.89
Coal	3.03	5.20	5.43	4.90	4.87	4.92	5.06	5.15	5.32	5.40
Industrial Sector										
Asphalt	3.09	4.88	4.74	4.33	4.28	4.46	4.23	4.81	4.69	5.16
Coal	1.85	2.07	2.19	2.15	2.09	2.07	2.07	2.08	2.11	2.14
Diesel	6.07	10.09	10.37	10.30	10.22	10.46	10.87	11.20	11.54	11.71
Gasoline	10.59	16.96	15.84	14.76	14.61	14.81	15.37	15.64	15.88	16.09
LPG	11.22	18.28	15.01	14.18	14.01	14.51	15.44	16.05	16.55	17.06
Natural Gas	4.48	8.75	6.71	5.71	5.60	5.55	5.82	6.10	6.40	6.59
Petroleum Feedstocks	2.69	4.25	4.15	3.87	3.84	3.87	3.94	4.03	4.12	4.18
Residual Fuel Oil	3.91	8.44	7.45	6.69	6.66	6.67	6.99	6.94	7.21	7.27
Residential Sector										
Coal	1.85	2.07	2.19	2.15	2.09	2.07	2.07	2.08	2.11	2.14
Diesel	8.24	13.69	13.34	12.26	12.17	12.52	13.10	13.50	13.81	14.02
Kerosene	5.30	7.97	8.14	7.58	7.48	7.56	7.77	7.94	8.06	8.17
LPG	14.80	21.80	21.75	20.56	20.29	20.99	22.32	23.26	24.00	24.71
Natural Gas	9.50	12.93	11.40	10.59	10.48	10.45	10.73	11.04	11.38	11.61
Transportation Sector										
CNG	6.85	11.81	10.20	9.42	9.41	9.41	9.68	9.94	10.21	10.36
Diesel	8.93	15.45	13.81	13.29	13.13	13.27	13.57	13.83	14.11	14.22
Ethanol	14.35	21.29	22.06	20.31	19.70	19.94	20.30	20.60	21.08	21.42
Gasoline	10.59	16.96	15.84	14.76	14.61	14.81	15.37	15.64	15.88	16.09
Jet Fuel	6.01	12.20	9.77	9.27	9.32	9.49	10.03	10.28	10.54	10.91
LPG	15.03	20.41	19.21	18.24	17.96	18.40	19.30	19.88	20.35	20.82
Residual Fuel Oil	3.52	4.77	7.14	6.36	6.27	6.36	6.54	6.81	7.06	7.24

A.6. State / Regional Policies & Regulations

The state and regional climate and air quality goals considered in the modeling strategy for Maryland include the Regional Greenhouse Gas Initiative (RGGI), greenhouse gas reductions associated with a version of the California Low Emission Vehicle (CA-LEV) program tailored to Maryland, Maryland's renewable portfolio standard requirements, and its Healthy Air Act. The following briefly explains our modeling approach for each of these goals.

A.6.1.1. State Renewable Portfolio Standards

The state's Renewable Portfolio Standards (RPS) requirements modeled for electric generators are taken from the Synapse assessment of the RGGI with the Integrated Planning Model (IPM).[27] Table A.24 presents how each state's RPS is currently being modeled.

Table A.24: State RPS Requirements

	Percentage of Load Required			
State Program	**2005**	**2010**	**2015**	**2020**
CT Class 1	0.78%	6.05%	6.09%	6.12%
MD Tier 1		**1.58%**	**3.14%**	**5.04%**
NJ- Class 1 Main Tier	0.00%	3.22%	5.55%	7.88%
NY- Main Tier		4.05%	6.43%	6.43%
PA - Tier 1 Main Tier		1.13%	3.02%	4.19%
MA	0.55%	2.72%	4.89%	7.06%
RI	0.00%	2.49%	7.97%	13.94%
NJ- Solar Tier (PV only)	0.01%	0.20%	0.41%	0.62%
PA - Solar Tier (PV only)	0.00%	0.01%	0.24%	0.49%

In NE-MARKAL, these requirements are modeled by introducing constraints that govern the minimum amount of electricity generated by renewable resources throughout the state. Our analysis assumes the lower bound on renewable generation remains at five percent between 2020 and 2029.

A.6.2. Maryland's Healthy Air Act

Maryland's Healthy Air Act was designed to bring Maryland into compliance with the National Ambient Air Quality Standards (NAAQS) for ozone and fine particulate matter by 2010. The Healthy Air Act limits mercury, NOx, and sulfur dioxide (SO_2) emissions from the coal-fired electric generators listed in Tables A.25 and A.26. In NE-MARKAL, the electricity sector is modeled at the generator level and currently includes representations of each unit listed below. The modeling framework is capable of accounting for emissions at various levels of detail. Currently, emissions from electricity generation are tracked at the sector level. It is straightforward to introduce emissions accounting for the plants below and impose the associated limits.

[27] Assumption Development Document: Regional Greenhouse Gas Initiative Analysis, prepared by ICF Consulting for Regional Greenhouse Gas Initiative (RGGI) Staff Working Group and Stakeholders, August 2006.

The two key modeling challenges were: (1) aligning the timing of the Healthy Air Act regulations to the NE-MARKAL time steps, and (2) representing seasonal NOx limits. NE-MARKAL runs in three-year time steps, starting in 2002 and ending in 2029. As a result, the years relevant to this modeling exercise (2009, 2010, 2012, and 2013) do not correspond exactly to the three-year intervals in NE-MARKAL (i.e., 2008, 2011, and 2014). Our approach was to calculate the average annual rate of decrease for each of these limits and use those rates to map the Healthy Air Act years onto the NE-MARKAL years.

Table A.25: Healthy Air Act SO_2 and NOx Limits

	Annual NOx Tonnage Limits		O_3 Season NOx Tonnage Limits		Annual SO_2 Tonnage Limits	
	1-Jan-09	1-Jan-12	1-May-09	1-May-12	1-Jan-10	1-Jan-13
Brandon Shores Unit 1	2,927	1,414	1,363	1,124	7,041	5,392
Brandon Shores Unit 2	3,055	1,519	1,449	1,195	7,347	5,627
C.P. Crane Unit 1	832	686	345	284	2,000	1,532
C.P. Crane Unit 2	894	737	385	317	2,149	1,646
Chalk Point Unit 1	1,415	1,166	611	503	3,403	2,606
Chalk Point Unit 2	1,484	1,223	657	542	3,568	2,733
Dickerson Unit 1	672	554	311	257	1,616	1,238
Dickerson Unit 2	736	607	333	274	1,770	1,355
Dickerson Unit 3	698	575	314	259	1,678	1,285
H.A. Wagner Unit 2	673	555	278	229	1,618	1,239
H.A. Wagner Unit 3	1,352	1,115	583	481	3,252	2,490
Morgantown Unit 1	2,540	2,094	1,053	868	6,108	4,678
Morgantown Unit 2	2,522	2,079	1,048	864	6,066	4,646
R. Paul Smith Unit 3	67	55	27	22	161	124
R. Paul Smith Unit 4	349	288	143	118	841	644
Totals	**20,216**	**14,667**	**8,900**	**7,337**	**48,618**	**37,235**

Table A.26: Healthy Air Act Mercury Limits

	Hg Emissions Rates (oz / tBTU Heat Input)		Hg Emissions Limits (lbs / yr)	
	1-Jan-10	1-Jan-13	1-Jan-10	1-Jan-13
Brandon Shores	21	10	94	46
C.P. Crane	37	18	26	13
Chalk Point	40	20	108	54
Dickerson	38	19	74	37
H.A. Wagner	25	12	68	33
Morgantown	27	14	127	66
R. Paul Smith	35	18	14	7

A.6.3. MD-LEV GHG reductions

Our analysis used the NE-MARKAL framework to examine Maryland's adoption of the CA-LEV program's GHG reductions targets. NESCCAF carried out a similar analysis for the New England states in 2006,[28] and we used the detailed technology characterizations and efficiency learning curves for LDVs that were developed to support this analysis. The 2006 study estimated potential carbon dioxide (CO_2) emission reductions from light-duty vehicles by adopting the CA-LEV standards in each New England state. This estimate was used to constrain the transportation sector emissions in the NE-MARKAL model. The NE-MARKAL analysis provides insights on how the transportation sector can achieve the program goals by evolving into a more efficient fleet in the least expensive way. Our approach was to extend this analysis to the Maryland vehicle fleet.

A.6.4. Regional Greenhouse Gas Initiative (RGGI)

The RGGI cap for Maryland is represented using the same assumptions as were used for the IPM analysis of RGGI. Maryland's annual CO_2 equivalent (CO2e) budget under the RGGI program[29] is presented in Table A.27. In the model, we represented this budget by introducing a power sector-wide constraint on CO_2 emissions consistent with the data in Table A.27.

Table A.27: RGGI CO2e Limits by State over Time

	Thousand tons CO_2							
	2008	2011	2014	2017	2020	2023	2026	2029
CT	9,702	9,702	9,622	8,975	8,732	8,732	8,732	8,732
DE	6,858	6,858	6,801	6,344	6,172	6,172	6,172	6,172
ME	5,397	5,397	5,352	4,992	4,857	4,857	4,857	4,857
MD	**34,019**	**34,019**	**33,736**	**31,468**	**30,617**	**30,617**	**30,617**	**30,617**
MA	24,186	24,186	23,984	22,372	21,767	21,767	21,767	21,767
NH	7,820	7,820	7,755	7,234	7,038	7,038	7,038	7,038
NJ	20,768	20,768	20,595	19,210	18,691	18,691	18,691	18,691
NY	58,342	58,342	57,856	53,966	52,508	52,508	52,508	52,508
RI	2,412	2,412	2,392	2,231	2,171	2,171	2,171	2,171
VT	1,112	1,112	1,103	1,029	1,001	1,001	1,001	1,001

For the modeling exercise, the reductions were derived assuming that 2020 levels would be at 10 percent below 2008 levels. We assumed that the RGGI cap remains in place for the remainder of the modeling horizon (i.e., through 2029) at 2020 levels.

[28] Expanding Regional Multi-Sector Carbon Trading to Include Transportation and Energy Efficiency. NESCCAF 2006

[29] Assumption Development Document: Regional Greenhouse Gas Initiative Analysis, prepared by ICF Consulting for Regional Greenhouse Gas Initiative (RGGI) Staff Working Group and Stakeholders, August 2006.