Appendix B – Greenhouse Gas Quantification (SAIC)

Final Report

Analysis of Greenhouse Gas Emission Reductions

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Prepared for: Maryland Department of the Environment
By: Science Applications International Corporation
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ABBREVIATIONS AND ACRONYMS

ACEEE	American Council for an Energy-Efficient Economy
AFW	Agriculture, Forestry & Waste
AP-42	EPA Compilation of Air Pollutant Emission Factors
BAU	Business as Usual
CAMD	Environmental Protection Agency Clean Air Markets Division
CAP	2008 Maryland Climate Action Plan
CEMS	Continuous Emission Monitoring System
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
DNR	[Maryland] Department of Natural Resources
eGRID	Emissions & Generation Resource Integrated Database
EGUs	Electricity Generating Units
EIA	Energy Information Administration
EPA	United States Environmental Protection Agency
ES	Energy Supply
GHG	Greenhouse Gas
GWP	Global Warming Potential
MANE-VU	Mid-Atlantic/Northeast Visibility Union
DHCD	Maryland Department of Housing and Community Development
N_20	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NO_X	Nitrogen Oxide
RCI	Residential, Commercial, Industrial
REC	Renewable Electricity Certificate
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standard
SO_2	Sulfur Dioxide
TLU	Transportation & Land Use
USDA	United States Department of Agriculture

UNITS OF MEASURE

CO_2e	Carbon Dioxide Equivalent
DBH	Diameter at Breast Height
GWh	Gigawatt Hour
kWh	Kilowatt Hour
MMBTU	Million British Thermal Units
$MMTCO_2e$	Million Metric Tons of Carbon Dioxide Equivalent
MWh	Megawatt Hour
tCO_2e	Metric Tons Carbon Dioxide Equivalent
VEH-H	Vehicle-hour
VMT	Vehicle Miles Traveled
WASD	Weighted Average Source Distance

EXECUTIVE SUMMARY

Introduction and Project Overview

In April of 2007, Governor Martin O'Malley established the Maryland Commission on Climate Change (Commission) through Executive Order 01.01.2007.07. The Order charged the Commission with developing a Climate Action Plan (CAP) to discuss the drivers and consequences of climate change, to outline necessary preparations for its ensuing impacts on the State, and to establish firm benchmarks and timetables for policy implementation. The Maryland CAP was completed in 2008. The CAP consists of a variety of climate policies designed to reduce the state's greenhouse gas (GHG) emissions in from different sectors and emission sources. Shortly thereafter, the Greenhouse Gas Emissions Reduction Act of 2009 (GGRA) codified Maryland's GHG reduction goal of 25 percent by 2020 from a 2006 baseline into state law.

In 2010, the Maryland Department of the Environment (MDE) hired Science Applications International (SAIC) to review, evaluate and update the 32 quantifiable climate policies[1] that comprise the 2008 Maryland CAP to help determine the State's progress toward meeting the GGRA goal. The CAP contains the following four groups of quantifiable climate policies:

- Residential, Commercial, and Industrial Policies (RCI)
- Energy Supply (ES)
- Agriculture, Forestry, and Waste (AFW)
- Transportation and Land Use (TLU)

After discussing interrelated aspects of various policies, MDE aggregated several policies and asked SAIC to review and evaluate 22 distinct CAP policies. SAIC reviewed and evaluated the policies by taking the following actions:

1) **Policy Documentation and Analysis**: SAIC reviewed and documented 14 existing GHG policies. SAIC also added its own analysis and recommendations for improving the accuracy of measuring and tracking GHG emission reduction progress toward the goals of these policies.

2) **Policy Re-quantification**: SAIC re-modeled or re-quantified the projected GHG emission reductions in 2012, 2015, and 2020 for 8 climate policies. SAIC based its re-quantification of emissions on updated science and methodologies, new tools, and or current implementation trends. SAIC transparently documented its methodology, data sources, and assumptions for these revised GHG emission reduction projections.

3) **Air Quality Co-benefit Quantification**: SAIC quantified the air quality co-benefits in 2012, 2015, and 2020 associated with the 22 climate policies. This entailed quantifying the criteria

[1]This excludes the ten "cross cutting" policies within the 2008 Maryland CAP.

pollutant impacts of 18 of the 22 climate policies – 4 policies did not have quantifiable air quality co-benefits.

4) **Water Quality Co-Benefit Quantification:** SAIC quantified the water quality co-benefits of the 22 policies in 2012, 2015, and 2020. Specifically, SAIC modeled the impact to nitrogen deposition to the Chesapeake Bay as a result of implementing the 22 climate policies.

5) **Policy Overlap Analysis:** SAIC conducted a climate policy overlap analysis that assessed the interactions between the climate policies. In other words, this policy overlap analysis removes any "double counting" of emissions. The overlap analysis was limited to the 8 policies that SAIC re-quantified, however, since these 8 policies were some of the most effective policies in terms of GHG emission reductions, this overlap analysis is likely takes into account most of the potential overlap amongst the policies.

Report Organization

This report summarizes the findings of SAIC's review and analysis of the 22 policies contained in Maryland's 2008 CAP. The report is organized into the following 6 Chapters:

- Chapter 1: Residential, Industrial, and Commercial Policies
- Chapter 2: Energy Supply Policies
- Chapter 3: Agriculture Forestry and Waste Policies
- Chapter 4: Transportation and Land Use Policies
- Chapter 5: Policy Overlap Analysis
- Chapter 6: Water Quality Co-benefits Analysis
- Appendix – Equations Used to Estimate GHG Reductions and Air Quality Co-benefits

The methodology, assumptions, findings, and analysis related to the projected GHG and criteria pollutant emission reductions for each climate policy are contained in sub-chapters within Chapters 1 through 4. In these sub-chapters, the effect of each policy on GHG and criteria pollutant emissions is considered independently of all other policies. In Chapter 5, double counting of emission reductions between the different policies is identified, quantified, and subtracted to yield an estimate of total emission reductions across policies. In addition, SAIC has provided MDE with the raw data and detailed technical inputs for each of the 22 policies in a separate series of supporting documents. The appendix provides a list, without accompanying context, of all the equations used per policy.

Project Approach

GHG Emissions Review and Analysis

SAIC reviewed the Original Methodology and GHG emission reduction results of 14 policies by reviewing the prior MDE contractor's reports and data files. SAIC then reconstructed and documented the GHG quantification methodologies used for each of the 14 individual policies listed in Table E.1.

Table E.1- Policies Reviewed and Analyzed

Policies Reviewed and Analyzed
Energy Supply (ES)
ES 8 - Efficiency Improvements & Repowering Existing Plants
Agriculture, Forestry & Waste (AFW)
AFW 1 - Forest Management for Enhanced Carbon Sequestration
AFW 3 - Afforestation, Reforestation & Restoration of Forests & Wetlands
AFW 4 - Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land
AFW 5 - "Buy Local" Programs
AFW 6 - Expanded Use of Forest & Farm Feedstocks & By-Products for Energy Production
AFW 7b - In-State Liquid Biodiesel Production
AFW 8 - Nutrient Trading with Carbon Benefits
Transportation & Land Use (TLU)
TLU 2 - Land Use & Location Efficiency
TLU 3 – Transit
TLU 5 - Intercity Travel
TLU 8 - Bike & Pedestrian Infrastructure
TLU 9 - Incentives, Pricing & Resource Measures
TLU 10 - Transportation Technologies

Re-Quantification of GHG Emission Reductions

Since Maryland's 2008 CAP was completed, the dynamics affecting many of the climate policies within it have shifted or changed, and in many cases the policies themselves have significantly evolved through further definition of the specific measures comprising each policy. SAIC was tasked with remodeling the GHG reduction estimates for a select number of policies in order to improve the accuracy of the GHG reduction estimates. The approach to recalculating the GHG reduction estimates varied depending on the policy, although our general approach was to estimate emission reductions in each forecast year (2012, 2015, and 2020) as the difference between emissions with and without the policy in that forecast year. Thus expected "business-as-usual" (BAU) developments, such as the general trend towards cleaner sources of electricity generation (e.g., natural gas), are captured over the forecast horizon. The year 2006 was used as the policy baseline, in the sense that we included all regulations and policies in place in or before 2006 (such as Maryland's Healthy Air Act) in our analysis. We excluded policy/regulatory developments that occurred after 2006 (except, of course, the specific policy to be analyzed). By using this approach, MDE will be able to subtract the emission reduction estimates we projected for each year from its separately-developed BAU emission forecast (also generated using a 2006 baseline) to project GHG emission levels as a result of the implementation of the full suite of policies.

The above-described general methodological approach was tailored to meet the requirements of each individual policy. The specific factors that determined how each policy was remodeled included whether or not there were substantive changes to the focus of the policy since the release of the 2008 CAP, whether or not a more accurate methodological approach existed, and whether or not updated data sets existed. Table E.2 summarizes the policies that SAIC re–quantified and the basis for the re-quantification.

It should be noted that a number of the policies include GHG emission reductions resulting from the decreased consumption of electricity. Because Maryland imports approximately 30 percent of its electricity from electric generating plants outside Maryland, policies that reduce the State's electricity consumption impact emissions both within and beyond the State's boundaries. We have included both the in-state and out-of state emission reductions in our reduction projections. Within the detailed policy analyses presented in Chapters 1 through 4, we have also broken down the in-state and out-of-state reductions separately.

The individual policy descriptions provide more detail on the specifics of how each policy was recalculated.

Table E.2- SAIC Re-Quantified Policies (All Emission Reduction Estimates Are Presented Prior to Adjustment for Overlaps Between the Policies)

Policy Number	Policy Option	Basis for Re-Quantification	Original 2020 Results ($MMTCO_2e$)	Re-Estimated 2020 Results ($MMTCO_2e$)	Difference ($MMtCO_2e$)
RCI-1	Improved Building and Trade Codes	Updated Data	2.4	5.4	3.0
RCI-4	Government Lead-By-Example	Narrowing of Policy Focus, Methodology Revision	1.3	0.2	(1.1)
RCI-10	EmPOWER Maryland*	Narrowing of Policy Focus, Methodology Revision	11.9	5.4	(6.5)
ES-3	Greenhouse Gas (GHG) Cap-and-Trade	Updated Data, Methodology Revision	16.96	12.3	(4.66)
ES-7	Renewable Portfolio Standard (RPS)**	Methodology Revision	13.8	3.0	(10.8)
AFW-2	Managing Urban Trees and Forests for GHG Benefits	Methodology Revision	1.9	1.3	(0.6)
AFW-9	Waste Management through Source Reduction (SR) and Advanced Recycling	Updated Data	29.27	6.0	(23.27)
TLU-6	Pay-As-You-Drive (PAYD) Insurance	Revised Assumptions	3.4	0.03	(3.37)

* New policy subsumes RCI 2, 3, 7, 10, and 11 from original analysis. Original Results are the sum of those policies
**New policy subsumes ES 1, 2, 5, and 7 from original analysis. Original results are the sum of those policies.

Air Quality Co-benefits Analysis

Based on the GHG emission reductions predicted by MDE's prior contractor, SAIC assessed the air quality benefits of all 22 policies and quantified the air quality co-benefits for 18 of the 22 policies as described in Table E.3 below. The remaining 4 policies did not produce any air quality co-benefits.

Table E.3- Air Quality Co-benefits Analysis

	Air Quality Co-benefits
Residential, Commercial & Industrial (RCI)	
RCI 1 - Improved Building & Trade Codes	Yes
RCI 4 - Improved Design, Construction, Appliances & Lighting	Yes
RCI 10 - EmPOWER Maryland	Yes
Energy Supply (ES)	
ES 3 - GHG Cap-and-Trade	Yes
ES 7 - Renewable Portfolio Standard	Yes
ES 8 - Efficiency Improvements & Repowering Existing Plants	Yes
Agriculture, Forestry & Waste (AFW)	
AFW 1 - Forest Management for Enhanced Carbon Sequestration	No
AFW 2 - Managing Urban Trees & Forests	Yes
AFW 3 - Afforestation, Reforestation & Restoration of Forests & Wetlands	Yes
AFW 4 - Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land	Yes
AFW 5 - "Buy Local" Programs	Yes
AFW 6 - Expanded Use of Forest & Farm Feedstocks & By-Products for Energy Production	No
AFW 7b - In-State Liquid Biodiesel Production	Yes
AFW 8 - Nutrient Trading with Carbon Benefits	No
AFW 9 - Waste Management & Advanced Recycling	Yes
Transportation & Land Use (TLU)	
TLU 2 - Land Use & Location Efficiency	Yes
TLU 3 – Transit	Yes
TLU 5 - Intercity Travel	Yes
TLU 6 - Pay-As-You-Drive Insurance	Yes
TLU 8 - Bike & Pedestrian Infrastructure	Yes
TLU 9 - Incentives, Pricing & Resource Measures	Yes
TLU 10 - Transportation Technologies	No

Policy Overlap Analysis

SAIC treated each policy independently of all others when developing the GHG emissions reduction estimates summarized in Table E.2. Similarly, the air quality co-benefit estimates for the policies listed in Table E.3 were developed by treating each policy separately. Thus both the GHG and air quality estimates for a given policy represent the emission reductions that can be expected to occur if the policy is implemented *by itself*.

However if, as is the State of Maryland's intent, the various policies are implemented together, the resulting total emission reductions will *not* equal the sum of the reductions estimated for each policy. Rather, the various policies will interact with each other such that their combined impact on emissions will not equal the sum of their individual impacts. In some cases (particularly in the energy supply and residential, commercial and industrial sectors) the various policies compete with each other, and hence their combined impact is less than the sum of their individual impacts. In other cases (particularly in the transportation and land use sector), policies may interact synergistically as well as competitively, with the result that their combine impact may be greater than their sum of their individual impacts.

Therefore SAIC conducted an "overlap analysis" in order to assess, both qualitatively and quantitatively, the interrelationships between policies and their combined impact on GHG emissions and air quality co-benefits. In the case of GHG emissions, the overlap analysis focused on the eight policies SAIC re-estimated, as listed in Table E.2. In the case of the three AFW and TLU policies (AFW-2, Urban Trees; AFW-9, Waste Management; and TLU-6, PAYD Insurance), SAIC concluded that there were no significant overlaps or synergies. However, significant overlaps were identified and quantified in the case of the five RCI and ES policies (RCI-1, Improved Building and Trade Codes; RCI-4, Government Lead-By-Example; RCI-10, EmPOWER Maryland; ES-3, GHG Cap and Trade; and ES-7, Renewable Portfolio Standard (RPS)). The overlaps, or double counting, between these five policies occur mainly as a result of the two policies (RCI-10 and ES-3) that specify emission reduction goals *without* specifying the methods to be used to achieve those goals. These two policies in effect allow market forces to determine the specific methods that will be used to meet the goals. To the extent that the policies that *do* specify the methods to be used to meet their goals (RCI-1, RCI-4, and ES-7) may help meet the numeric goals of the market-based policies, the impact of the former "method-specific" policies on emissions may in effect be subsumed under the latter market-based policies. Consider, for example, the interactions between ES-3 (GHG Cap and Trade) and ES-7 (RPS). ES-3 sets a quantitative limit on emissions but without specifying how the market must meet that limit. When such a policy is combined with the RPS policy, which specifies explicit targets for the market penetration of renewables, then meeting the explicit RPS targets will also help the market to meet the emissions cap. Since there are no constraints specifying how the cap is to be met, the emission reductions caused by the RPS will count towards meeting the cap. In such a situation, the GHG impacts of the RPS are effectively subsumed under the cap-and-trade policy.

By dividing the GHG emission reductions estimated for each RCI and ES policy into three components (in-State electricity sector reductions, out-of-state electricity sector reductions, and reductions from direct combustion of fossil fuels in the RCI sector), and then carefully identifying overlaps within each component, SAIC quantified the extent of the overlap between the RCI and ES policies. The results of this quantitative analysis are summarized in Section 4 below.

Water Quality Co-benefits Analysis

Two types of models are required to estimate the quantity of atmospheric nitrogen that is transported to the Chesapeake Bay. One model is required to estimate the atmospheric transport, dispersion, transformation, and deposition of nitrogen species; and a second is required to estimate the delivery of deposited nitrogen to the Bay. The CALPUFF and SPARROW models were selected for this analysis because they have been used by the Maryland Department of Natural Resources and other agencies to analyze nitrogen load reductions, and have provided results that are consistent with other established modeling approaches, such as the Chesapeake Bay Program HSPF (Hydrologic Simulation Program - Fortran) watershed model. A brief description of the two models used in this analysis is as follows:

CALPUFF – This model simulates the effects of time- and space-varying meteorological conditions and pollutant transport, transformation, and removal. It uses surface, upper air, and precipitation observations as recorded at National Weather Service stations; and nitrogen oxide (NO_X) emissions obtained from the U.S. Environmental Protection Agency's (EPA) National Emissions Trends inventory (NEI). CALPUFF predicts monthly average deposition flux rates (wet and dry).

SPARROW (SPAtially Referenced Regressions on Watershed) - This hydrologic flow and nutrient transport model is used to estimate the nitrogen delivery to the Bay by simulating the migration of nitrogen over the land surface and within the stream system. It uses nutrient and land-characteristic parameters as input data. Further details of this analysis are discussed in Chapter 6.

Summary of Report Findings

Table E.4 summarizes the results of SAIC's quantitative analyses of GHG emissions reductions for the eight policies we re-estimated. The first column of this table presents the estimated 2020 emission reductions for the eight policies, summed to the sector level. The emission reduction totals shown in the first column have *not* been adjusted to reflect the interactions or overlaps between the different policies. The second column of the table presents SAIC's estimates of the overlap within each sector. Finally, the last column of the table subtracts the estimated overlaps from the unadjusted emission reduction estimates shown in the first column, to yield estimates of the actual emission reductions that would occur if all eight policies were to be implemented.

Table E.4. Summary of Overlap Estimates, and Unadjusted and Adjusted GHG Emission Reductions, Across All Sectors in 2020

Sector	Unadjusted Total Reductions in 2020 ($MMTCO_2e$)	2020 Overlap Estimate ($MMTCO_2e$)	Adjusted Total Reductions in 2020 ($MMtCO_2e$)
RCI	11.00	4.11	6.89
ES	15.30	3.04	12.26
RCI & ES	26.30	10.75	15.55
AFW	7.29*	0.00	7.29*
TLU	0.03	0.00	0.03
Grand Total	**33.62**	**10.75**	**22.87**

*Includes 1.32 $MMTCO_2e$ of carbon sequestration.

As Table E.4 indicates, overlap between the different policies is limited to the five RCI and ES policies; the three AFW and TLU policies do not have significant overlaps. Overlap accounts for 36 percent of the unadjusted GHG reductions (i.e., 4.11 out of 11.00 million metric tons carbon dioxide equivalent (MMTCO_2e)) in the RCI sector alone, and 20 percent of the unadjusted reductions (3.04 out of 15.30 MMTCO_2e) in the ES sector. Because a significant amount of overlap occurs not only *within* but acrossthe RCI and ES sectors, the estimated overlap for the RCI & ES sectors combined (see third row of Table E.4) exceeds the sum of the overlap for each sector considered separately. Overlap accounts for 41 percent of the unadjusted reductions (10.75 out of 26.3 MMTCO_2e) in the RCI and ES sectors combined. Across all four sectors (RCI, ES, AFW and TLU), overlap between the policies represents 32 percent (10.75 out of 33.62 MMTCO_2e) of the total unadjusted reductions. Taking this overlap into account, SAIC estimates the total GHG reductions that would result from the implementation of all eight policies as 22.87 MMTCO_2e in 2020. The five RCI and ES policies account for 68.0 percent of this total; the two AFW policies contribute 31.9 percent; and the single TLU policy accounts for the remaining 0.1 percent of the total reductions.

The GHG emission reductions associated with the 22 policies that SAIC evaluated are summarized by policy category in Table E.5 below. In addition to providing the unadjusted sums of the emission reductions for each sector and for all 22 policies, this table also provides sector and grand totals adjusted for overlaps in the RCI and ES sectors, as estimated by SAIC and presented in Table E.4.

Table E.5. Summary of GHG Emission Reductions in 2020

Sector/Policy	2020 GHG Emission Reductions (MMTCO_2e)
Residential, Commercial and Industrial (RCI)	
RCI-1: Improved Building and Trade Codes	5.40
RCI-4: Government Lead-By-Example	0.20
RCI-10: EmPOWER Maryland	5.40
RCI Unadjusted Total	**11.00**
RCI Total Adjusted for Overlap	**6.89**
Energy Supply (ES)	
ES-3: GHG Cap and Trade	12.26
ES-7: Renewable Portfolio Standard	3.04
ES-8: Efficiency Improvements & Repowering Existing Plants	4.90
ES Unadjusted Total	**20.20**
ES Total Adjusted for Overlap	**12.26**
Agriculture, Forestry & Waste (AFW)	

Sector/Policy	2020 GHG Emission Reductions ($MMTCO_2e$)
AFW-1: Forest Management for Enhanced Carbon Sequestration	0.09
AFW-2: Managing Urban Trees & Forests	1.32
AFW-3: Afforestation, Reforestation & Restoration of Forests & Wetlands	0.62
AFW-4: Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land	26.54
AFW-5: "Buy Local" Programs	0.03
AFW-6: Expanded Use of Forest & Farm Feedstocks & By-Products for Energy Production	0.54
AFW-7b: In-State Liquid Biodiesel Production	0.17
AFW-8: Nutrient Trading with Carbon Benefits	0.14
AFW-9: Waste Management & Advanced Recycling	5.97
AFW Unadjusted Total	**34.10**
Transportation & Land Use (TLU)	
TLU-2: Land Use & Location Efficiency	0.96
TLU-3: Transit	0.45
TLU-5: Intercity Travel	0.02
TLU-6: Pay-As-You-Drive Insurance	0.03
TLU-8: Bike & Pedestrian Infrastructure	0.15
TLU-9: Incentives, Pricing & Resource Measures	1.84
TLU-10: Transportation Technologies	0.20
TLU Unadjusted Total	**3.65**
Unadjusted Grand Total	**68.95**
Grand Total Adjusted for Overlap	**53.30**

Air Quality Co-benefits Findings

Each individual policy summary contains a projection of criteria pollutant co-benefits (emission reductions) in 2012, 2015, and 2020 that will result from the policy's implementation. The quantification methodology, assumptions, data sources, and findings are explained for each policy. Table E.6 summarizes SAIC's estimates of criteria pollutant emission reductions. In addition to presenting the estimated reductions for each policy and the sum of the reductions by sector and across all sectors, Table E.6 also provides grand total emission reductions adjusted for overlaps.[2]

[2] Please note that while GHG reductions are expressed in metric tons, in keeping with standard practice in the U.S. for pollution and contaminant analyses, short tons are used in the air quality co-benefit sections of the policy chapters, the air quality section of the overlap analysis in Chapter 5, and the Chesapeake Bay co-benefits analysis in Chapter 6.

Table E.6. Summary of Criteria Pollutant Emission Reductions in 2020[3]

		SO_2 (Tons)	NO_x (Tons)	CO (Tons)	VOC (Tons)	PM10 (Tons)	PM2.5 (Tons)
	Residential, Commercial & Industrial (RCI)						
RCI-1	RCI 1 - Improved Building & Trade Codes	2,700.00	1,300.00	1,300.00	1,900.00	2,000.00	1,300.00
RCI-4	RCI 4 - Improved Design, Construction, Appliances & Lighting	19.00	30.00	34.00	3.00	27.00	24.00
RCI-10	RCI 10 - EmPOWER Maryland	590.00	200.00	340.00	49.00	780.00	680.00
	RCI Total	**3,309.00**	**1,530.00**	**1,674.00**	**1,952.00**	**2,807.00**	**2,004.00**
	Energy Supply (ES)						
ES-3	ES 3 - GHG Cap-and-Trade	17,000.00	5,700.00	220.00	45.00	2,100.00	1,900.00
ES-7	ES 7 - Renewable Portfolio Standard	510.00	-81.00	1.00	9.00	410.00	380.00
ES-8	ES 8 - Efficiency Improvements & Repowering Existing Plants	8,400.00	-2,500.00	-1,200.00	-68.00	1,000.00	870.00
	ES Total	**25,910.00**	**3,119.00**	**-979.00**	**-14.00**	**3,510.00**	**3,150.00**
	Agriculture, Forestry & Waste (AFW)						
AFW-1	AFW 1 - Forest Management for Enhanced Carbon Sequestration						
AFW-2	AFW 2 - Managing Urban Trees & Forests	300.00	450.00			2,400.00	
AFW-3	AFW 3 - Afforestation, Reforestation & Restoration of Forests & Wetlands	273.00	410.00			2,200.00	
AFW-4	AFW 4 - Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land	523.00	784.00			4,182.00	

[3] In cases where a range of reduction estimates existed the high figure was used in this table.

		SO_2 (Tons)	NO_x (Tons)	CO (Tons)	VOC (Tons)	PM10 (Tons)	PM2.5 (Tons)
AFW-5	AFW 5 - "Buy Local" Programs	0.22	9.50	220.00	10.00	0.37	0.35
AFW-6	AFW 6 - Expanded Use of Forest & Farm Feedstocks & By-Products for Energy Production						
AFW-7b	AFW 7b - In-State Liquid Biodiesel Production	8.90	-7.60	952.00	85.00	1.50	1.40
AFW-8	AFW 8 - Nutrient Trading with Carbon Benefits						
AFW-9	AFW 9 - Waste Management & Advanced Recycling	890.00	2,200.00	290.00		131.00	
	AFW Total	**1,995.12**	**3,845.90**	**1,462.00**	**95.00**	**8,914.87**	**1.75**
	Transportation & Land Use (TLU)						
TLU-2	TLU 2 - Land Use & Location Efficiency	15.00	620.00	14,000.00	660.00	25.00	23.00
TLU-3	TLU 3 – Transit	8.70	370.00	8,500.00	397.00	15.00	14.00
TLU-5	TLU 5 - Intercity Travel	0.60	26.00	600.00	28.00	1.00	1.00
TLU-6	TLU 6 - Pay-As-You-Drive Insurance	1.00	44.00	1,000.00	47.00	1.70	1.60
TLU-8	TLU 8 - Bike & Pedestrian Infrastructure	4.60	200.00	4,500.00	210.00	7.80	7.30
TLU-9	TLU 9 - Incentives, Pricing & Resource Measures	37.00	3,300.00	43,000.00	2,500.00	140.00	74.00
TLU-10	TLU 10 - Transportation Technologies						
	TLU Total	**66.90**	**4,560.00**	**71,600.00**	**3,842.00**	**190.50**	**120.90**
	Total for all Policies	**31,281.02**	**13,054.90**	**73,757.00**	**5,875.00**	**15,422.37**	**5,276.65**
	Total Adjusted for Overlaps	**22,000.00**	**15,000.00**	**75,000.00**	**5,900.00**	**13,000.00**	**3,300.00**

Chesapeake Bay Co-benefits Findings[4]

The nitrogen load reduction to the Chesapeake Bay from select climate policies for years 2012, 2015, and 2020 was estimated using the SPARROW (**SPA**tially **R**eferenced **R**egressions on **W**atershed) spreadsheet tool. The input into the SPARROW spreadsheet consisted of total NO_X emission reductions for policies re-estimated and re-documented by SAIC, adjusted for overlap. The SPARROW modeling results therefore represent the combined benefits to the Chesapeake Bay from all of the policies.

The SPARROW modeling analysis predicts that theoverall total nitrogen load reductions to the Chesapeake Bay (from all states) will be in the range of 0.94 to 0.95 million pounds in 2012. The total nitrogen load reductions will increase to the range of 1.13 to 1.14 million pounds in 2015, and increase again to the range of 1.26 to 1.5 million pounds in 2020. For the state of Maryland, the range of nitrogen load reductions in 2012 is predicted to be between 114 to 116 thousand pounds. In 2015, the range of load reductions is predicted to increase to between 145 to 148 thousand pounds, and increase again to the range of 184 to 290 thousand pounds in 2020.

[4] As noted in footnote 3 above, short tons are used here and in the Chesapeake Bay co-benefits analysis in Chapter 6.

Chapter 1: Residential, Commercial, and Industrial (RCI) Policies

The following RCI Policies were analyzed:

- RCI-1: Improved Building & Trade Codes
- RCI-4: Improved Design, Construction, Appliances, and Lighting
- RCI-10: Energy Efficiency Resources Standard (new policy subsumes RCI-2, 3, 7, 10, and 11 from original analysis).

Summary of RCI Findings for 2020

Table 1.1 presents the 2020 GHG emission reduction estimates for the above-listed three policies. As the Table indicates, Policies RCI-1 and RCI-10 are projected to yield the vast majority of the emission reductions in the RCI sector; each of these policies accounts for 49 percent of the sum of reductions across all policies. It should be noted that there are significant overlaps in the projected emission reductions not only across the three RCI policies, but between the RCI and ES policies. These overlaps arefurther discussed and quantified in Chapter 5.

Table 1.1. Summary of GHG Emission Reductions from the RCI Policies in 2020

Sector/Policy	2020 GHG Emission Reductions (MMTCO$_2$e)
Residential, Commercial and Industrial (RCI)	
RCI-1: Improved Building and Trade Codes	5.40
RCI-4: Government Lead-By-Example	0.20
RCI-10: EmPOWER Maryland	5.40
RCI Total (Unadjusted for Overlaps)	**11.00**

Table 1.2 presents the projected 2020 reductions in criteria pollutant emissions for the three RCI policies. As this table indicates, Policy RCI-1 yields the majority of the reductions in all pollutants. As is the case for GHGs, there are significant overlaps in the criteria pollutant emissions reduction estimates; the reader is referred to Chapter 5 for a discussion and quantification of these overlaps.

Table 1.2. Summary of Criteria Pollutant Emission Reductions from the RCI Policies in 2020[5]

		SO_2 (Tons)	NO_x (Tons)	CO (Tons)	VOC (Tons)	PM10 (Tons)	PM2.5 (Tons)
	Residential, Commercial & Industrial (RCI)						
RCI-1	RCI 1 - Improved Building & Trade Codes	2,700.00	1,300.00	1,300.00	1,900.00	2,000.00	1,300.00
RCI-4	RCI 4 - Improved Design, Construction, Appliances & Lighting	19.00	30.00	34.00	3.00	27.00	24.00
RCI-10	RCI 10 - EmPOWER Maryland	590.00	200.00	340.00	49.00	780.00	680.00
	RCI Total	**3,309.00**	**1,530.00**	**1,674.00**	**1,952.00**	**2,807.00**	**2,004.00**

[5] As noted in footnote 3, in keeping with standard practice in the U.S. for pollution and contaminant analyses, short tons are used in the air quality co-benefit sections of the policy chapters.

Technical Notes

PROMOD IV Model

The RCI policies rely on the PROMOD IV Model for their results. The PROMOD *IV* Model is Fundamental Electric Market Simulation software that incorporates extensive details in generating unit operating characteristics, transmission grid topology and constraints, unit commitment/operating conditions, and market system operations. PROMOD IV algorithms can be exercised in several modes, depending upon the scope, time frame, and simulation resolution that align with the decision focus. The model can assess a variety of electric market components including:

- Locational marginal price for forecasting
- Valuation
- Transmission congestion analysis
- Environmental analysis
- Generation and transmission asset valuation
- Fuel strategy
- System reliability

More information on the PROMOD IV Model can be found on their website: http://www1.ventyx.com/analytics/promod.asp

Mid-Atlantic/Northeast Visibility Union (MANE-VU) Future Emissions Inventory

All of the air quality co-benefit analyses for the RCI policies utilize the MANE-VU Future Emissions Inventory[6]. The MANE-VU Future Emissions Inventory represents a collaborative effort among northeastern and mid-Atlantic states to develop regionally consistent emissions inventories that account for projected growth and expected emissions control measures. The inventories for 2009, 2012, and 2018 are used by the states as they develop state implementation plans to meet national ambient air quality standards and progress goals to reducing regional haze. More information on MANE-VU can be found on the following website: (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory).

[6]http://www marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

Policy No.: RCI-1

Policy Title: Improved Building and Trade Codes and Beyond-Code Building Design and Construction in the Private Sector

SAIC was tasked with reviewing the RCI-1 policy analysis which was conducted by a prior MDE contractor (Original Methodology) and revising the methodology to include Maryland-specific data and/or other enhancements. SAIC subsequently recalculated the GHG emission reductions associated with RCI-1based upon its recommended methodology (Revised Methodology). SAIC also quantified the air quality co-benefits associated with RCI-1. SAIC's revised policy findings are described below:

1.0. GHG EMISSION REDUCTIONS

The goal of Policy RCI-1 is to improve the energy efficiency of residential and commercial buildings by ensuring rapid adoption of new building codes published by the International Code Council (ICC). Specifically, under the statewide building code known as the Maryland Building Performance Standards (MBPS), local jurisdictions with building code authority are required to adopt the most up-to-date codes within six months of their promulgation. The new codes are issued every three years, with the most recent issuance in 2009 (the 2009 International Energy Conservation Code (IECC)). Thus new codes are expected in 2012 (2012 IECC), 2015 (2015 IECC), and 2018 (2018 IECC).

Table RCI-1.1- Projected GHG Emission Reductions Resulting from RCI-1

Emissions Category	GHG Reductions ($MMTCO_2e$)		
	2012	2015	2020
RCI-1 Total	**0.6**	**1.9**	**5.4**
Residential Buildings:	**0.2**	**0.6**	**1.7**
Natural Gas	0.0	0.1	0.4
Distillate Oil	0.0	0.0	0.1
Biomass	0.0	0.0	0.1
In-State Electricity	0.1	0.3	0.7
Imported Electricity	0.0	0.1	0.4
Commercial Buildings:	**0.4**	**1.3**	**3.8**
Natural Gas	0.1	0.2	0.7
Distillate Oil	0.0	0.0	0.1
Biomass	0.0	0.0	0.0
In-State Electricity	0.2	0.7	1.9
Imported Electricity	0.1	0.3	1.0

Note: Totals may not equal sum of parts due to independent rounding.

1.1. Summary of Methodology

SAIC reconstructed and reviewed the Original Methodology, and found this methodology to be mathematically sound. Therefore, although we updated and/or improved a number of the data inputs (see Section 1.3); we retained the Original Methodology as the basis for developing our revised estimates. The Original Methodology followed in this report involved four steps, as follows:

1. Based on projections of new housing starts and commercial floor space, calculate the number of new and existing residential housing units, and commercial floor space, affected by the improved building codes in each year;

2. Calculate the total energy saved in each year by the buildings affected by the code in that year (from Step 1);

3. Split the total yearly energy savings calculated in Step 2 by energy/fuel type (e.g., electricity, natural gas, distillate oil, etc.);

4. By applying appropriate carbon dioxide equivalent (CO_2e) emission factors to the energy savings estimates from Step 3 (summed between 2009 and year i), and summing across all fuel/energy types, calculate the GHG emission reductions from all buildings built of renovated to code in each projection year i (where I equals 2012, 2015, or 2020).

Each of the above steps is documented in detail in the Detailed Explanation of GHG Emission Methodology Section below.

1.2. Rationale for GHG Emission Methodology

The selected method is essentially the same as the Original Methodology. It is a straightforward calculation that is mathematically correct. Data inputs to the methodology were updated and "Marylandized" to the extent possible.

1.3. Difference between Original and Revised Methodologies and Results

The Maryland Department of Housing and Community Development currently estimates that Maryland's adoption of 2009 IECC resulted in average energy efficiency improvements over the prior code (2006 IECC) of 15 percent, and that the next code (2012 IECC) will yield improvements of 30 percent relative to IECC 2006. These efficiency improvements differ from those estimated by the prior contractor and used in the Original Methodology.

Furthermore, we identified opportunities to update and/or improve some of the other input data used originally, including, most importantly, the ratio of major building renovations to new builds. The latter ratio, which is used in the methodology to determine the number of major building renovations conducted according to code in each year, was set equal to 1 in the Original Methodology as a "placeholder assumption," but based on actual permit data for Baltimore County we were able to estimate a new ratio for the residential sector. Unfortunately, when we attempted to use the same data source to estimate a ratio for the commercial sector, the result proved unreasonably large (4.4, a ratio which would imply more than one complete renovation of the entire existing building stock over the 10-year forecast period). Based on e-mail communication with Baltimore County staff, we suspect that some commercial buildings are covered by multiple renovation permits due, e.g., to multiple retail establishments undergoing renovation in the same mall or shopping center. Therefore, rather than using the ratio implied by the commercial permit data, we applied the residential permit ratio to the commercial as well as the residential sector. Our estimate of the ratio, based on the Baltimore County residential permit data, was significantly larger than the original placeholder assumption (1.5 vs. 1.0). However, whereas the prior contractor assumed that energy savings from building renovations would match those from new buildings, SAIC assumed that the energy savings from renovations would on average equal half that of the savings from new buildings.

As noted in the key assumptions for the Original Methodology, although RCI-1 applies to buildings undergoing both major and minor renovations, at least in the latter case "there would be a wide variety of measures implemented with a range of possible energy savings." We cannot in fact distinguish major from minor renovations based on the available data, but believe that energy savings from renovations will vary from levels equaling the energy savings from new buildings, all the way to negligible levels. The assumption that renovations will, on average, generate half the savings available from new buildings represents the midpoint of this range.

We considered the possibility that energy savings due to the renovation of historical buildings would average less than standard building renovations, but based on discussions with MDE it was agreed that historical renovations will not necessarily yield reduced savings. There is evidence that in at least some cases historical building renovations lead to very significant savings, so we retained the assumption that renovations would generate half the savings available from new buildings for historical as well as standard renovations.

Other inputs were also changed based on new and/or updated sources. It should be noted that while our projections of new housing starts were in the same ballpark as the projections used in the Original Methodology, we projected much larger additions to commercial floor space than the prior contractor (our estimates ranged from 4 to 6 times greater than the original estimates). The source of the original commercial floor space projections is not clear; our projections are based on U.S. aggregate projections from the Energy Information Administration's (EIA) Annual Energy Outlook 2010, scaled to Maryland based on the ratio of Maryland's 2003 total commercial floor space to the U.S. total. Furthermore, whereas the Original Methodology included an assumption that only 70 percent of new and renovated buildings would comply with the new codes, we assumed 100 percent compliance based on feedback from the Maryland Department of Housing and Community Development. The increased compliance, coupled with the increase in the commercial floor space projections, more than offset our use of smaller electricity emission factors than those used in the Original Methodology, resulting in forecasted emission reductions that are significantly larger than the reductions projected by the prior contractor.

1.4. GHG Emission Calculations

Step 1: Calculate the Total Number of New and Existing Buildings Affected Each Year:

The number of *new* buildings built in each year subject to the MBPS code is simply equal to our forecast of the number buildings built (new plus renovations requiring a permit) times a fraction representing the percentage of local jurisdictions adopting the code (see Equation 1 below). Since local jurisdictions are required to adopt the new codes within six months of their promulgation, we assumed that *all* MD jurisdictions would adopt each new code with a minimal time lag at the beginning of the year of its issuance (see Subsection 2.3, "Assumptions," for a justification of this assumption). Given this assumption, the number of new buildings built to code in each year is equal to the number of new buildings built in each year (i.e., $NBA_{i,t}$ in Equation 1 becomes equal to $NBB_{i,t}$, with $LGAR_i$ set equal to 1 in all years). Our forecasts of the number of new housing units, and commercial floor space, built in each year were developed based on Maryland-specific historical data from the U.S. Census Bureau (in the case of the residential sector) and South Atlantic Census Division-specific data from the U.S. Energy Information Administration (commercial sector). The historic data was extended into the future based on national-level building projections from the Energy Information Administration's (EIA) 2010 Annual Energy Outlook (AEO) (see Subsection 2.2, Data and Data Sources, for additional details).

Once the number of *new* buildings or commercial floor space built to code in each year was determined, this number was multiplied by the estimated ratio of renovated to new buildings to determine the number of *existing* housing units and commercial floor space renovated according to code (see equation 2 below). As noted above, the ratio of renovations to new buildings was estimated based on permit data for Baltimore County. (An attempt to obtain similar permit data for other Maryland localities was not successful.)

The specific algorithms used to complete Step 1 were as follows:

$$NBA_{i,t} = (NBB_{i,t})(LGAR_i) \quad (1)$$

$$EBA_{i,t} = (R_t)(NBA_{i,t}) \quad (2)$$

Where

$NBA_{i,t}$ = Number of new housing units, or million square feet of commercial space, of type t (residential or commercial) built to code in year i

$NBB_{i,t}$ = Total number of new housing units, or million square feet of commercial space, of type t (residential or commercial) built in year i

$LGAR_i$ = Fraction of MD localities adopting new code in year i

$EBA_{i,t}$ = Number of existing housing units, or million square feet of commercial space, of type t (residential or commercial) undergoing major renovations according to code in year i

R_t = Ratio of renovated to new buildings, of type t (residential or commercial)

Step 2: Calculate Energy Saved by Buildings Built to Code in Each Year:

In order to estimate the total energy savings resulting from the adoption of new codes in each year, the number new and renovated housing units, or commercial floor space, built or renovated to code (as determined in Step 1) was multiplied by the average estimated energy consumption of each building (in mmBtus per housing unit or square foot of commercial floor space). The latter energy consumption estimates, for 2006 (AEU_t in Equation 3 below), were derived using EIA and Census Bureau data (see Section 2.2). The resulting baseline energy consumption estimates were then multiplied by our estimates of the fractional energy savings generated by the specific IECC code in place in the given year (e.g., the fractional energy savings for 2017 was based on estimated energy savings for 2015 IECC). The fractional energy savings for the 2009 IECC and 2012 IECC were based on the estimates provided by the Maryland Department of Housing and Community Development (DHCD). Since the 2012 IECC, unlike the 2009 IECC, did not account for non-code compliance, we reduced the DCHD's energy savings estimate for the 2012 IECC based on an assumed 70 percent code compliance rate (the same assumption used by the Center for Climate Strategies(CCS)). We then assumed the energy savings to be achieved by the 2015 and 2018 IECCs would be the same as that produced by the 2012 IECC.

The specific algorithm used to complete Step 2 was as follows:

$$ES_{i,t} = [(ESG_{i,t})(NBA_{i,t}) + (RESEN)(ESG_{i,t})(EBA_{i,t})](AEU_t) \quad (3)$$

Where

$ES_{i,t}$ = Energy saved by new and renovated buildings of type t (residential or commercial) built to code in year i (mmBtus)

$ESG_{i,t}$ = Energy saved via adoption of new code by buildings of type t (residential or commercial) in year i (fraction)

RESEN = Energy saved through renovation of existing buildings, as a fraction of energy saved by new buildings

AEU_t = Average current energy use of buildings of type t (residential or commercial) (mmBtus/square foot or unit/year)

Step 3: Calculate Electricity and Direct Fuel Savings from Buildings Built to Code in Each Year:

In the third step, the total energy savings estimated in Step 2 are categorized according to specific fuel/energy type. In addition, that portion of the total savings representing electricity is adjusted upward to take into account savings resulting from the reduction in losses due to transmission, distribution, and on-site power plant use.

In equations 4 and 5 below, the total energy savings from Step 3 are split into electricity savings (Equation 4) and direct fossil fuel use savings (Equation 5) using forecasts of the future breakdown of energy consumption in Maryland's residential and commercial sectors. The forecasts were developed based on EIA base year (2006) energy consumption data for Maryland. The base year data was projected into the future using the national-level percentage growth forecasts from EIA's 2010 AEO. By applying relative (percentage) growth trends from the AEO to Maryland-specific base year data, the forecasts were in effect normalized to represent Maryland.

The specific algorithms used to complete Step 3 were as follows:

$$E_i = (ES_{i,r})(1+TD)(RE_i) + (ES_{i,c})(1+TD)(CE_i) \quad (4)$$

$$FS_{i,t} = (ES_{i,r})(RFF_{i,t}) + (ES_{i,c})(CFF_{i,t}) \quad (5)$$

Where

E_i = Total electricity saved by buildings built/renovated to code in year i (mmBtus)

$FS_{i,t}$ = Total direct fuel saved by buildings built/renovated to code in year i (mmBtus), by fuel type t (e.g., natural gas, distillate oil, etc.)

$ES_{i,r}$ = Energy saved by new and renovated residential buildings built/renovated to code in year i (from Equation 3, in mmBtus)

$ES_{i,c}$ = Energy saved by new and renovated commercial buildings built/renovated to code in year i (from Equation 3, in mmBtus)

TD = Electricity losses due to transmission and distribution (fraction)

$RFF_{i,t}$ = Fraction of total energy savings by residential buildings of fuel type t (natural gas, distillate oil, etc.), in year i

$CFF_{i,t}$ = Fraction of total energy savings by commercial buildings of fuel type t (natural gas, distillate oil, etc.), in year i

RE_i = Fraction of total energy savings by residential buildings in the form of electricity

CE_i = Fraction of total energy savings by commercial buildings in the form of electricity

Step 4: Calculate Emission Reductions from Buildings Built to Code in Each Year:

In Step 4, the yearly electricity and fossil fuel savings calculated in Step 3 were summed across years and converted to GHG emission reductions using appropriate emission factors. The resulting fuel-specific savings were summed across all fuel/energy types to yield total emission reductions from buildings built or renovated in each year. The fossil fuel emission factors were derived from the U.S. Environmental Protection Agency's Mandatory Reporting Rule. Emission factors for methane and nitrous oxide were converted to a carbon dioxide equivalent (CO_2e) basis and then added to the carbon dioxide (CO_2)emission factors to yield factors covering all relevant GHG on a CO_2e basis. The electricity emission factors were developed through a modeling analysis of Maryland's electricity sector (see Section 2.2 for more details on the modeling analysis). Separate electricity emission factors were developed for imported and in-state generated electricity; a forecast of the percentage of Maryland's total electricity demand to be met by imports provided by MDE was used to split the total electricity savings into in-state and imported electricity prior to the application of the two separate electricity emission factors.

The specific algorithm used to complete Step 4 was as follows:

$$ER_i = (EEFIS_i)\left[\sum_{y=2009 \text{ to } i} (E_y)(FIS_y)\right] + (EEFOS_i)\left[\sum_{y=2009 \text{ to } i} (E_y)(1-FIS_y)\right] + \sum_{2009 \text{ to } i,\, t} (FS_{y,t})(FEF_t) \quad (6)$$

Where

ER_i = Total emission reductions from buildings built/renovated to code in year i (metric tons CO_2e)

FEF_t = Emission factor for fuel type t (metric tons/mmBtu)

FIS_y = Fraction of total electricity from in-state generators in year y (where y is a year between 2009 and i)

$EEFIS_i$ = Electricity emissions factor for in-state generators in year i (metric tons CO_2e/mmBtu)

$EEFOS_i$ = Electricity emissions factor for out-of-state generators in year i (metric tons CO_2e/mmBtu)

1.5. GHG Emission Data and Data Sources

Step 1 Data and Sources:

Table RCI-1.2- Step 1 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
$NBB_{i,t}$	Residential: Number of new MD housing units built in year i	2009: 14,418 2010: 25,217 2011: 19,808 2012: 24,643 2013: 25,865 2014: 26,162 2015: 27,535 2016: 28,912 2017: 29,289 2018: 29,709 2019: 30,241 2020: 30,140	U.S. Census Bureau, American Community Survey 2006 EIA Annual Energy Outlook (AEO) 2010 – Table A4	1
	Commercial: New floor space (million square feet) built in MD in year i	2009: 43 2010: 36 2011: 31 2012: 31 2013: 34 2014: 37 2015: 40 2016: 42 2017: 43 2018: 44 2019: 44 2020: 45	EIA Commercial Building Energy Consumption Survey (CBECS) 2003 – Table A4 U.S. Census Bureau Population Estimates 2003 EIA AEO 2010- Table A5	2
$LGAR_i$	Fraction of localities adopting code	100%	DHCD input (via email correspondence)	
R_t	Ratio of renovated to new buildings	1.5 for both residential and commercial buildings	Email communication with Regional Information Center Baltimore Metropolitan Council	Ratios presented are based on residential permit data for Baltimore County (3rd largest County in terms of population in MD)

Notes:

1. The percent change from the historic number of U.S. households in 2006 to each of the projection years was calculated from the AEO 2010 projections (AEO Reference Case Table 4). These percentages were then applied to the actual number of MD households in 2006 (from the American Community Survey conducted by the U.S. Census Bureau). The result was a projection of the number of new houses to be built in each year between 2006 and 2020, scaled to Maryland.

2. Historical data for 2003 commercial square footage in the South Atlantic census division was obtained from the EIA CBECS 2003 data (Table A4; this is the most recent data available). The values for the South Atlantic division were scaled to Maryland by multiplying by the ratio of the 2003 MD population to the total South Atlantic division's population. The resulting total 2003 floor space estimate for Maryland was then divided by the corresponding total for the U.S. as a whole. This fraction was then applied to the AEO 2010 projections (AEO Reference Case Table 5) of total new floor space additions for the U.S. as a whole. The result was a projection of new commercial floor space for the years 2009-20, scaled to Maryland.

<u>Step 2 Data and Sources:</u>

Table RCI-1.3- Step 2 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
$ESG_{i,t}$	Fractional energy savings	2010-12: 15% 2013-15: 30% 2016-18: 45% 2019-20: 60% Note the values are the same for residential and commercial buildings	2009 and 2012 values based on estimates of percentage savings for IECC 2009 and IECC 2012 provided by MD DHCD Subsequent values based on straight extrapolation of 15% improvement for the IECC 2009 and 2012 to IECC 2015 and 2018	1
AEU_t	Residential: MD energy use (million Btus/housing unit in 2006)	87.1	U.S. Census Bureau, American Community Survey 2006 EIA State Profiles – Maryland, 2006	2
	Commercial: MD Energy usage (mmBtus/million square feet in 2006)	125,782	EIA CBECS 2003 – Table A4 U.S. Census Bureau Population Estimates 2003 EIA AEO 2010-Table A5	3
RESEN	Energy saved by renovating existing buildings, as a fraction of energy saved by new buildings	0.5	SAIC assumption	

Notes:

1. Each new code is assumed to appear in the middle of the year; e.g., IECC 2012 is assumed to appear in July 2012. Furthermore, because local governments are given 6 months to adopt each new code, it is further assumed that the code does not begin to affect energy consumption until the beginning of the year *following* its promulgation. Thus IECC 2009 begins to affect energy use in 2010; IECC 2012 affects energy use beginning in 2013, etc.

2. Average energy use per housing unit was computed by dividing net residential energy consumption (from EIA's State Energy Profiles 2006) by the number of housing units in Maryland (from the 2006 American Community Survey by the U.S. Census Bureau).

3. Average energy use per million square feet in Maryland was computed as follows. First, 2003 EIA CBECS data for all commercial buildings in the South Atlantic division was apportioned to MD by estimates of the ratio of the 2003 MD population to South Atlantic division (from the U.S. Census Bureau). Then the 2003 MD CBECS data was scaled to 2006 based on the average annual U.S. percent increase in total commercial floor space from AEO 2010 (see note 2 from previous table for additional information). Finally, net commercial energy consumption (from EIA State Profiles Maryland, 2006) was divided by the estimate for 2006 MD commercial floor space.

Step 3 Data and Sources:

Table RCI-1.4- Step 3 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
TD	Transmission and Distribution (T&D) losses	8%	"Ten-Year Plan (2009-2018) of Electric Companies in Maryland." Maryland Public Service Commission. February 2010. <http://webapp.psc.state.md.us/intranet/Reports/2009-2018%20Ten%20Year%20Plan.pdf>	
RE_i	Fraction of residential energy that is electric	2009: 45% 2010: 45% 2011: 47% 2012: 47% 2013: 46% 2014: 46% 2015: 46% 2016: 47% 2017: 47% 2018: 47% 2019: 47% 2020: 48%	2006 Baseline data: EIA State Energy Data System – Maryland, Table 8 Projections: EIA AEO 2010, Supplemental Table 5	1
CE_i	Fraction of commercial energy that is electric	2009: 56% 2010: 56% 2011: 56% 2012: 57% 2013: 57% 2014: 57% 2015: 57% 2016: 57% 2017: 57% 2018: 58% 2019: 58% 2020: 58%	2006 Baseline data: EIA State Energy Data System – Maryland, Table 8 Projections: EIA AEO 2010, Supplemental Table 5	2

Variable	Definition	Value(s)	Source(s)	Notes
$RFF_{i,t}$	Fraction of residential energy use that is fuel type t	See Table RCI-1.2 below	2006 Baseline data: EIA State Energy Data System – Maryland, Table 8 Projections: EIA AEO 2010, Supplemental Table 5	1
$CFF_{i,t}$	Fraction of commercial energy use that is fuel type t	See Table RCI-1.3 below	2006 Baseline data: EIA State Energy Data System – Maryland, Table 8 Projections: EIA AEO 2010, Supplemental Table 5	2

Notes:

1. AEO Reference Case Supplemental Table 5 was used to obtain residential energy/electricity consumption by fuel type for the South Atlantic census division. The percent change in consumption by fuel type from the historic year 2006 to each of the projection years was then calculated from the AEO 2010. These percentages were then applied to the baseline MD energy consumption data by fuel type in 2006 (from EIA's State Energy Data System – Maryland, Table 8). Finally, the relative (percent) contribution of each fuel type to Maryland's total projected energy consumption in each year was calculated by dividing the consumption of the given fuel type by the total fuel consumption.

2. The same process was used as described in note 1 where commercial values were selected instead of residential values.

Table RCI-1.5- Residential Sector Energy Section Consumption, Percent of Net Energy (%)

		Petroleum			Biomass
Year	Natural Gas	Distillate Fuel Oil	Kerosene	LPG	Wood
2009	39	9	1	2	4
2010	40	9	1	2	3
2011	39	8	1	2	3
2012	39	8	1	2	3
2013	40	8	1	2	3
2014	40	8	1	2	3
2015	40	8	1	2	3
2016	41	7	0	2	3
2017	40	7	0	2	4
2018	40	7	0	2	4
2019	40	7	0	2	4
2020	40	6	0	2	4

Table RCI-1.6- Commercial Sector Energy Section Consumption, Percent of Net Energy (%)

			Petroleum		Biomass
Year	Coal	Natural Gas	Distillate Fuel Oil	LPG	Wood and Waste
2009	0	38	4	1	1
2010	0	38	4	1	1
2011	0	38	4	1	1
2012	0	37	4	1	1
2013	0	37	4	1	1
2014	0	37	4	1	1
2015	0	37	4	1	1
2016	0	38	3	1	1
2017	0	38	3	1	1
2018	0	37	3	1	1
2019	0	37	3	1	1
2020	0	37	3	1	1

Step 4 Data and Sources:

Table RCI-1.7- Step 4 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
FIS_i	Fraction of electricity from in-state generators	0.71 throughout forecast period	PSC communication	
$EEFIS_i$	In-state electricity emission factor (tonnes CO_2e/mmBtu)	2009: 0.1968 2010: 0.1968 2011: 0.2175 2012: 0.1745 2013: 0.1642 2014: 0.1552 2015: 0.1607 2016: 0.1498 2017: 0.1490 2018: 0.1424 2019: 0.1191 2020: 0.1225	PROMOD output, see below	
$EEFOS_i$	Emission factor for imported electricity (tonnes CO_2e/mmBtu)	2009: 0.2077 2010: 0.2077 2011: 0.2036 2012: 0.1951 2013: 0.1882 2014: 0.1849 2015: 0.1788 2016: 0.1748 2017: 0.1708 2018: 0.1693 2019: 0.1654 2020: 0.1625	PROMOD output, see below	
FEF_t	Emission factor for fuel type t	See Table 3 below for CO_2e emission factors by fuel type.	CO_2 emission factors: Mandatory Reporting Rule (MRR), Table C–1 to Subpart C of Part 98 CH_4 and N_2O emission factors: Mandatory Reporting Rule (MRR), Table C–1 to Subpart C of Part 98 Global Warming Potentials (GWP): 100-Year values in the IPCC Second Assessment Report(SAR) (Note: The IPCC SAR 100-Year GWPs have been adopted by the EPA's Mandatory GHG Reporting program)	Distillate Fuel Oil emission factor average values presented in MRR (No. 1-2 and 4-6).

SAIC developed the in-state and out-of-state electricity emission factors using the PROMOD production cost model. PROMOD is a well-known electricity dispatching model. To develop the emission factors SAIC used the model to simulate the operation of the PJM system under expected conditions for hourly demand, generator characteristics, fuel cost, emission costs, and transmission limitations to energy transfer across the PJM system. We used generator-specific emissions rates developed from historical Continuous Emissions Monitoring (CEMS) data. Also, we simulated the PJM system operation under two change cases: a 1 percent and a 2 percent reduction in PJM load. Our reported emissions rates are an average of the marginal emission rates for the two change cases. That is, we calculated the difference between the total CO_2 emissions in Maryland (or PJM system) for the Base Case and the total CO_2 emissions in Maryland for the 1 percent load reduction case. Dividing the decremental CO_2 output by the change in load gave us the marginal CO_2 emissions rate for Change Case 1. Then we did the same for the 2 percent load reduction case relative to the Base Case to compute a marginal CO_2 emissions rate for the 2 percent load reduction case. We averaged the two marginal CO_2 emissions rates to develop the above-documented CO_2 emissions factors in each forecast year.

Table RCI-1.8- CO_2, CH_4, N_2O and CO_2e Emission Factors for Different Fuel Types in the Maryland Fuel Supply

Fuel	CO_2**e Emission Factor (kgO2e/mmBTU)**
Coal Mixed (Commercial Sector)	95.99
Natural Gas	53.08
Distillate Fuel Oil	74.30
Kerosene	75.45
LPG	63.23
Biomass, wood and wood residuals	95.77

For coal mixed (commercial sector), coal and coke methane (CH_4) and nitrous oxide (N_2O) emissions factors were used for the conversion to CO_2e. For distillate fuel oil, kerosene and LPG, petroleum CH_4 and N_2O petroleum emission factors were used for the conversion to CO_2e. For biomass, wood and residuals, and biomass, solid products, biomass fuels solid CH_4 and N_2O emission factors were used for the conversion to CO_2e. Global Warming Potential (GWP) values were selected from the 100-year values in the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR) in order to be consistent with the reporting methodology required for United Nations Frameworks Convention on Climate Change (UNFCCC) National Communications. (Note: The IPCC SAR 100-Year GWPs have been adopted by the EPA's Mandatory GHG Reporting program.)

1.6. GHG Emission Assumptions

- The growth in the number of residential buildings and commercial floor space in MD will follow the national-level trends (as forecasted by EIA in the Annual Energy Outlook).
- MD's share of the total commercial floor space in the South Atlantic Census Division is equal to MD's share of the population in the Division.
- 2015 IECC and 2018 IECC will, like 2009 IECC 2009 and 2012 IECC, continue to generate 15 percent improvements in the energy efficiency of compliant residential and commercial buildings.

- The energy saved by renovating existing buildings will be equal to 0.5 of the energy saved by renovating new buildings.
- Electricity transmission and distribution losses average 8 percent for MD (based on the Maryland Public Service Commission's "Ten-Year Plan (2009-2018) of Electric Companies in Maryland," June 2010)).
- Compliance rates for all the new codes will equal 100 percent (this assumption is based on feedback from the Maryland Department of Housing and Community Development).
- Building codes appear at the midpoint of the year they are due (i.e., July 1), and are adopted by local governments 6 months after they appear. Thus each new code begins to affect energy consumption in the year following its appearance. Buildings undergoing renovations significant enough to require permits will be able to achieve the same level of energy savings as new buildings; e.g., buildings renovated in 2010 will, like buildings built in 2010, achieve a 15 percent savings in energy as a result of the renovations. It should however be emphasized that this assumption does *not* imply that renovated buildings are undergoing the same level of efficiency improvements as new buildings, or that the renovated buildings are as efficient as the new buildings. For new buildings, the energy efficiency improvements being achieved are in relation to the 2006 IECC. For *renovated* buildings, the efficiency improvements are relative to whichever code was in effect *at the time the building was originally built.* Thus, returning to our preceding example, a building built in 1950 that is renovated in 2010, is assumed to achieve a 15 percent savings in efficiency relative to a very low efficiency baseline (the baseline in place in 1950). Such a building, while generating a 15 percent improvement in efficiency, will not be as efficient as a new building built according to code in 2010. The assumption of equal *relative* efficiency improvements is thus designed to capture the fact that a renovation, being limited in scope, cannot bring a building up to the same average level of efficiency as a new building. The assumption of equal *relative* energy savings between new and renovated buildings is in effect a simplifying assumption (and is the same assumption applied by CCS); any attempt to improve upon this assumption would require more detailed data characterizing the buildings undergoing renovations in the State of Maryland.

1.7. GHG Emission Analysis and Recommendations

As documented in Section 1.6 above, a significant number of major assumptions were necessary to enable the calculation of emission reductions. The development of new data and Maryland-specific projections, e.g., on the number of new houses and commercial floor space, building code compliance rates, and electricity transmission and distribution (T&D) losses, would enable significant improvement in the accuracy of the emission reduction estimates.

2.0. AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from RCI-1 are shown within Table RCI-1.9. All numbers for the criteria pollutants reflect a single year of emissions.

Table RCI-1.9- Emissions Reductions of Criteria Pollutants Associated with RCI-1 (tons per year)

	Across Maryland			Across Entire Domain		
Pollutant	**2012**	**2015**	**2020**	**2012**	**2015**	**2020**
SO_2	320	1,000	2,700	1,400	3,900	8,900
NO_X	130	420	1,300	410	1,200	3,800
CO	110	370	1,300	150	480	1,700
VOC	170	550	1,900	170	560	1,900
PM10-primary	180	580	2,000	230	730	2,400
PM2.5-primary	120	410	1,300	150	510	1,600

These numbers were compared against the MANE-VU inventories for 2012 and 2018 (Table RCI-1.10). The 2018 emissions were estimated by interpolating between the 2015 and 2020 estimates. Because all the values in 2012 are less than one percent, Table RCI-1.10 indicates that the criteria pollutant emissions reductions associated with this policy alone would be unlikely to improve air quality in the early years. Because the energy savings from this policy occur not only for those buildings that are newly built or renovated in each year x, but also for all buildings built or renovated between 2009 and year x, emission reductions steadily increase over time. By 2018 Table RCI-1.10 shows that emissions inventory reductions of 1 and 2 percent would be observed within Maryland for sulfur dioxide and particulate matter.

Table RCI-1.10- Percentage Reduction in Emissions Inventory Associated with RCI-1

	Across Maryland		Across Entire Domain	
Pollutant	**2012**	**2018**	**2012**	**2018**
SO_2	<1%	2%	<1%	<1%
NO_X	<1%	<1%	<1%	<1%
CO	<1%	<1%	<1%	<1%
VOC	<1%	<1%	<1%	<1%
PM10-primary	<1%	1%	<1%	<1%
PM2.5-primary	<1%	2%	<1%	<1%

Local reductions in sulfur dioxide (SO_2) emissions could result in reduced acid rain and less formation of sulfate particulate matter downwind of Maryland. Local reductions in particulate matter emissions would improve local ambient particulate matter concentrations and improve visibility.

2.2. Summary of Air Quality Co-Benefits Methodology

The PROMOD model results are used to estimate the decreased fuel consumption (in mmBtu) at various plants based on the policy's estimate of electricity consumption reduction. The plant emissions reductions are calculated by multiplying each power plant's decreased fuel consumption by the plant-specific emission factors (lb pollutant/mmBtu), and then emissions reductions are totaled over the whole domain.

2.3. Air Quality Co-Benefit Calculations

Calculate Emissions Factors Associated with Marginal Power Plant Reductions

1. From the 2009 EPA Clean Air Markets Division (CAMD) data sets, calculate the SO_2 and NO_X emissions rates per mmBtu for coal-fired power plants in EPA Regions 2, 3, 4, and 5.

2. From the 2007 Mid-Atlantic Regional Air Management Association (MARAMA) inventory for Maryland and surrounding states (DC, DE, NJ, PA, VA, and WV), find the Carbon Monoxide (CO), Volatile Organic Compound (VOC), PM10, and PM2.5 emissions rates per mmBtu for coal-fired power plants that are listed in the database.

3. Use EPA Compilation of Air Pollutant (AP-42) emissions factors for oil and natural-gas fired utility boilers. Assume no emissions from renewable and nuclear plants.

4. Calculate the emissions factors for each power plant (lb/mmBtu).

5. Calculate the emissions for each plant for base load, 1 percent reduction and 2 percent reduction by multiplying the emission factors by the change in fuel consumption rates (in mmBtu/yr) from

the PROMOD model (years 2012, 2015, and 2020—see Section 1.5, "Step 2 Data and Sources" for additional details on the PROMOD model runs referred to here).

6. If the SO_2 or NO_X emissions for Maryland power plants exceeded the Healthy Air Act limits, reduce the base load emissions to those permit limits and compute the 1 percent and 2 percent reductions as a fraction of the base load using the ratios of fuel consumption rates.

7. Sum the fuel consumption rates and the pollutant emissions in the base load, 1 percent reduction case, and 2 percent reduction case across all plants (years 2012, 2015, and 2020). Do this for both Maryland and for the entire modeling domain.

8. Compute the emissions per percent load reduction and the fuel consumption per percent load reduction for the 1 percent and 2 percent cases. Average the 1 percent and 2 percent cases.

9. Calculate the marginal electricity emissions factors (lb pollutant/mmBtu change) as the emissions per percent load reduction divided by the fuel consumption per percent load reduction.

Calculate Emissions Reductions Associated with Fuel/Electricity Consumption Reductions

1. Use the marginal electricity emissions factors.

2. Use AP-42 emission factors for commercial boilers, residential boilers, and residential wood stoves (catalytic).

3. Multiply the calculated reductions in fuel consumption (mmBtu), from the GHG emission reduction methodology (Section 1.4) by the emission factors (lb/mmBtu) to calculate the emission reductions.

2.4. Air Quality Co-Benefit Data and Data Sources

The following data sources were used for the analysis:

- PROMOD Model: (http://www1.ventyx.com/analytics/promod.asp)
- Maryland's Healthy Air Act (http://www.mde.maryland.gov/programs/Air/Documents/26-11-27_MD_Healthy_Air_Act.pdf)
- AP-42 (http://www.epa.gov/ttn/chief/ap42/index.html)
- CAMD 2009 (http://camddataandmaps.epa.gov/gdm/)
- Cite MARAMA's 2007 Regional Emissions Inventories (http://www.marama.org/RegionalEmissionsInventory/2007BaseCase/index.html)

- MANE-VU Emissions Inventory (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory)

3.0 INTERACTION WITH OTHER POLICIES

The discussion of policy interactions is provided in Chapter 5.

Policy No.: RCI-4

Policy Title: Government Lead-By-Example

SAIC was tasked with reviewing the RCI-4 policy analysis which was conducted by a prior MDE contractor (Original Methodology) and revising the methodology to include Maryland-specific data and/or other enhancements. SAIC subsequently recalculated the GHG emission reductions associated with RCI-4 based upon its recommended methodology (Revised Methodology). SAIC also quantified the air quality co-benefits associated with RCI-4. SAIC's revised policy findings are described below:

1.0. GHG EMISSION REDUCTIONS

RCI-4 is designed to demonstrate howMaryland and municipal and county governments can "Lead by Example" by adopting policies that improve the energy efficiency of new and renovated public buildings, facilities and operations. For its RCI-4 analysis, MDE asked SAIC to quantify the GHG reductions associated with the Energy Performance Contracts (EPC) program and the Generating Clean Horizons (GCH) program. The GHG emission reductions expected from these programs are summarized below:

Table RCI-4.1- Estimated GHG Emission Reductions Resulting from RCI -4

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
RCI-4 Total	0.1	0.2	0.2
EPCs	0.1	0.1	0.1
In-State Electricity	0.0	0.0	0.0
Imported Electricity	0.0	0.0	0.0
Natural Gas	0.0	0.0	0.0
GCH	0.1	0.1	0.1
Biomass/Landfill Gas (LFG)[1]	0.0	0.0	0.0
Wind	0.1	0.1	0.1
Solar	0.0	0.0	0.0

Note: Totals may not equal sum of parts due to independent rounding.

[1] Net impact of increased use of biomass and landfill gas was a slight increase in emissions due to higher emissions per unit energy than traditional fuel mix.

Table RCI-4.2- Change in Energy Use

Sector	Electricity Use Reductions or Change to Renewable (GWh)		
	2012	2015	2020
RCI-4 Total	**171**	**274**	**409**
EPCs (Savings)	72	98	98
In-State Electricity	51	70	70
Imported Electricity	21	29	29
GCH (Renewables)	99	175	310
Biomass/LFG	11	20	36
Wind	85	144	247
Solar	3	12	27

Note: Totals may not equal sum of parts due to independent rounding.

Table RCI-4.3- Change in Fuel Use

Sector	Natural Gas Reductions (Trillion BTUs)		
	2012	2015	2020
RCI-4 Total	**.5**	**.6**	**.6**
EPCs	.5	.6	.6

Note: Totals may not equal sum of parts due to independent rounding

1.1. Summary of GHG Emission Methodology

Policy RCI-4 contains multiple elements to help the State of Maryland government "Lead by Example" in improving energy efficiency and use of renewable energy. This analysis models two distinct elements of RCI-4. First, the Energy Performance Contracts (EPC), result in direct energy savings. The Revised Methodology provides a break-down of EPC savings by natural gas, in-state electricity, and out-of-state electricity. The GHG benefits from current and expected EPCs were calculated as follows:

1. Calculate total expected energy savings for existing and expected EPC projects;
2. Calculate in-state and out-of-state emission reductions in each projection year.

The Generating Clean Horizons (GCH) project involves a power purchasing agreement, and commitment to install solar power. The Revised Methodology estimates the effect of the GCH project on total State of Maryland government electricity emissions. The policy as modeled dictates that through its power purchasing agreement, the State's electricity mix will meet the state's Renewable Portfolio Standard (RPS). The GHG benefits from the Generating Clean Horizons project were calculated as follows:

1. Calculate expected electricity consumption for the state of Maryland government in each projection year;

2. Calculate total projected renewable energy contributions in each projection year, less any pre-existing renewable energy contributions;

3. Calculate emission reductions in each project year.

Each of the above steps is documented in detail in the following subsection.

1.2. Rationale for GHG Emission Methodology

The selected method is a straightforward application of our standard emission factors to the energy savings goals of the EPCs and the renewable goals of Maryland's RPS.

1.3. Difference Between Original and Revised Methodology and Results

The Original Methodology modeled emissions reductions and energy savings from RCI-4 based on the policies proposed at that time. Since the original analysis, RCI-4 has evolved from a focus on Leadership in Energy and Environmental Design (LEED) building standards and government-wide goals to include two specific programs in the implementation phase: Energy Performance Contracts and Generating Clean Horizons.

The Revised Methodology was developed to quantify the emissions reductions and energy savings from the EPC and GCH programs specifically. These programs were not explicitly modeled within the original analysis, and therefore SAIC developed methodologies to calculate emissions reductions expected to be achieved through these programs.

1.4. GHG Emission Calculations

Energy Performance Contracts

Step 1: Calculate Total Energy Saved

MD's estimated energy savings resulting from the fourteen existing EPCs (65 million kWh, 450,000 mmBTU) were used as a starting point for this analysis. In addition, MDE provided data on the expected costs of four additional projects, and expected energy savings for one of these projects (15.7 million kWh, 70,673 mmBTU). The anticipated energy savings for the additional three projects without energy savings estimates were calculated based on their expected cost.

SAIC calculated the kWh and mmBTU savings per dollar of the fifteen projects for which energy savings data was provided as follows:

$$KWH\$ = KWH_{15} / Cost_{15}$$

And

$$mmBTU\$ = mmBTU_{15} / Cost_{15}$$

Where

KWH$= average kilowatt hours saved per program dollar cost, for all fifteen EPC projects for which data was provided (KWh/$)

mmBTU$ = average mmBTU saved per program dollar cost, for all fifteen EPC projects for which data was provided (mmBTU/$)

$Cost_{15}$ = total approximate cost of all fifteen EPC projects for which data was provided ($)

KWH_{15} = total electricity saved for all fifteen EPC projects for which data was provided (KWh)

$mmBTU_{15}$ = total thermal energy saved for all fifteen EPC projects for which data was provided (mmBTU)

SAIC then calculated the total energy savings for each year as the sum of the savings from the 15 projects with known savings (14 existing projects and 1 forecast project) and the 3 additional projects, using the following formula:

$$KWH_y = [KWH_{15} + (KWH\$ \times \sum_i NEW\$_{i,y})] \times (1+TL)$$

And

$$mmBTU_y = mmBTU_{15} + (mmBTU\$ \times \sum_i NEW\$_{i,y})$$

Where

KWH_y = total electricity saved for all EPC projects in year *y* (KWh)

$mmBTU_y$ = total thermal energy saved for all EPC projects in year *y* (mmBTU)

$NEW\$_i$ = forecast cost of each new project ($s)

TL = transmission losses (8%)

Step 2: Calculate Emissions Reductions

Emissions reductions accrue under three categories for the EPC program: natural gas combustion, in-state electricity, and out-of-state electricity. Natural gas emissions reductions were calculated as follows:

$$ERNG_y = mmBTU \times (53.08/1000)$$

Where

$ERNG_y$ = total annual emissions reductions from natural gas savings per year *y* (tCO_2e)

53.08 = emissions factor for natural gas ($kgCO_2e/mmBTU$)

1000 = conversion factor from kilograms to metric tons

Emissions reductions associated with in-state electricity production were calculated as follows. Note that unlike the constant emissions factor used for natural gas, the electricity emissions factors have been adjusted based on the anticipated fuel mix in each year.

$ERIE_y$ = (KWH/1000) x $EFIE_y$ x 0.71

Where

$ERIE_y$ = total annual emissions reductions from in-state produced electricity per year *y* (tCO_2e)

$EFIE_y$ = emissions factor for in-state electricity production in year *y* (tCO_2e/MWh)

1000 = conversion factor from kilowatts to megawatts

0.71 = proportion of electricity produced in-state

Emissions reductions associated with out-of-state electricity production were calculated as follows:

$EROE_y$ = (KWH/1000) x $EFOE_y$ x (1 – 0.71)

Where

$EROE_y$ = total annual emissions reductions from out-of-state produced electricity per year *y* (tCO_2e)

$EFOE_y$ = emissions factor for out-of-state electricity production in year *y* (t CO_2e/ MWh)

Generating Clean Horizons

SAIC calculated the emissions reductions associated with the Generating Clean Horizons program by forecasting State electricity consumption, and assuming that the program would result in the State meeting the renewable portfolio standard.

<u>Step 3: Calculate expected electricity consumption for the State of Maryland government in each projection year</u>

SAIC used the following equation to calculate the expected electricity consumption in each projection year for the government of the State of Maryland:

MD_y = [MD_{2009} x (MAC_y / MAC_{2009})] x (1 + TL)

Where

MD_y = projected electricity consumption, including losses for the State of Maryland's government in year *y* (KWh)

MD_{2009} = reported electricity consumption for the State of Maryland's government in 2009 (KWh)

MAC_y = EIA projection of mid-Atlantic electricity consumption for the commercial sector in year *y* (quadrillion BTU)

MAC_{2009} = EIA reported mid-Atlantic electricity consumption for the commercial sector in 2009 (quadrillion BTU)

TL = transmission losses (8%)

Step 4: Calculate additional renewable energy to meet RPS

The RPS goals specified renewable energy production from Tier 1 and Tier 2 sources. For this analysis, SAIC modeled only the Tier 1 sources, because Maryland already exceeds its Tier 2 standard, and no additional electricity from these sources is required. The Tier 1 interim goals were calculated as follows:

$$SE_y = SS_{2011} + [(SS_{2020} - SS_{2011}) / 9] (y - 2011)$$

Where

SE_y = percent of total State electricity from solar sources in year *y* (%)

SS_y = solar electricity standard in year *y*

9 = yearly increments between 2011 and 2020

y = year being modeled

And

$$NSE_y = NSS_{2011} + [(NSS_{2020} - NSE_{2011}) / 9] (y - 2011) - BNS$$

Where

NSE_y = percent of total State electricity from non-solar Tier 1 sources in year *y*

NSS_y = non-solar Tier 1 standard in year *y*

9 = yearly increments between 2011 and 2020

BNS = baseline non-solar Tier 1 renewable electricity produced in 2008

Step 5: Calculate Adjusted Marginal GHG Emissions Rate

SAIC calculated adjusted marginal GHG emission rates for solar and non-solar Tier 1 renewable energy as follows:

$$AMER_i = \sum_{m=1}^{12} \sum_{j=1}^{4} PR_j * MEF_{m,j} * MER_m \quad (2)$$

Where

$AMER_i$ = Adjusted Marginal GHG Emissions Rate for Year i (million metric tons CO_2e per MWh)

m = month

j = Resource

PRj = Percentage of Resource j (wind, biomass, landfill gas, or hydro; solar is calculated separately)

MEF_{mj} = Monthly Energy Factor for month m for resource j (% of annual energy produced in month m)

MER_m = Marginal GHG Emissions Rate for month m (million metric tons CO_2e per MWh)

Step 6: Calculate emission reductions in each project year.

Using the values SEy and NSEy, SAIC then calculated the emissions reductions associated with sourcing electricity from solar and non-solar Tier 1 sources. This was calculated as follows:

$ERSE_y = SE_y \text{ x } MDy \text{ x } AMER_{y,s}$

And

$ERNS_y = (NSE_y \text{ x } MDy \text{ x } AMER_{y,ns}) – \sum_i(NSE_{y,i} \text{ x } EF_i)$

Where

ERSE = total annual emissions reductions in year *y* from the use of solar electricity (tCO_2e)

$AMER_{y,s}$ = annual marginal emissions factor for avoided emissions from use of solar electricity in year *y* (tCO_2e/MWh)

ERNE = total annual emissions reductions in year *y* from the use of non-solar Tier 1 electricity (tCO_2e)

$AMER_{y,ns}$ = annual marginal emissions factor for avoided emissions from use of non-solar Tier 1 electricity in year *y* (tCO_2e/MWh)

$NSE_{y,i}$ = percent of non-solar Tier 1 electricity from renewable source *i* in year *y* (%)

EF_i = emissions factor for renewable source *i*

1.5. GHG Emission Data and Data Sources

Step 1 Data and Sources:

Table RCI-4.4- Step 1 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
KWH_{14}	Total annual KWh saved for fourteen existing EPC projects	65 million KWh	DGS communication	
$mmBTU_{14}$	Total annual mmBTU saved for fourteen existing EPC projects	450,000 mmBTU	DGS communication	
$COST_{14}$	Total approximate cost for all fourteen existing EPC projects	$135 million	DGS communication	
KWH_1	Total forecast annual KWh saved for new EPC project	15,740,945	DGS communication	
$mmBTU_1$	Total forecast annual mmBTU saved for new EPC project	70,673	DGS communication	
$NEW\$_i$	Forecast cost of new EPC project *i*	$5,800,000 $6,000,000 $5,200,000	DGS communication	
TL	Transmission Losses	8%	"Ten-Year Plan (2009-2018) of Electric Companies in Maryland." Maryland Public Service Commission. February 2010. <http://webapp.psc.state.md.us/intranet/Reports/2009-2018%20Ten%20Year%20Plan.pdf>	

Step 2 Data and Sources:

Table RCI-4.5- Step 2 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
53.08	Emissions factor for natural gas ($kgCO_2e/mmBTU$)	53.08	Mandatory Reporting Rule (MRR), Table C–1 to Subpart C of Part 98	
$EFIE_y$	Emissions factor for in-state electricity production in year *y* (tCO_2e/MWh)	2012: 0.595 2015: 0.548 2020: 0.418	PROMOD output, see below	1
$EFOE_y$	Emissions factor for out-of-state electricity production in year *y* (tCO_2e/MWh)	2012: 0.665 2015: 0.61 2020: 0.554	PROMOD output, see below	1
0.71	Proportion of electricity produced in-state	0.71	PSC communication	

Notes: (1) SAIC developed the in-state and out-of-state electricity emission factors using the PROMOD production cost model. PROMOD is a well-known electricity dispatching model. To develop the emission factors SAIC used the model to simulate the operation of the PJM system under expected conditions for hourly demand, generator characteristics, fuel cost, emission costs, and transmission limitations to energy transfer across the PJM system. We used generator-specific emissions rates developed from historical CEMS data. Also, we simulated the PJM system operation under two change cases: a 1 percent and a 2 percent reduction in PJM load. Our reported emissions rates are an average of the marginal emission rates for the two change cases. That is, we calculated the difference between the total CO_2 emissions in Maryland (or PJM system) for the Base Case and the total CO_2 emissions in Maryland for the 1 percent load reduction case. Dividing the decremental CO_2 output by the change in load gave us the marginal CO_2 emissions rate for Change Case 1. Then we did the same for the 2 percent load reduction case relative to the Base Case to compute a marginal CO_2 emissions rate for the 2 percent load reduction case. We averaged the two marginal CO_2 emissions rates to develop the above-documented CO_2 emissions factors in each forecast year.

Step 3 Data and Sources:

Table RCI-4.6- Step 3 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
MD_{2009}	Reported electricity consumption for State of Maryland government in 2009 (KWh)	2009: 1,455,031,107 KWh	Maryland State E-Footprint	Web Link
MAC_y	Projection of mid-Atlantic electricity consumption for commercial sector in year *y* (quad BTU)	2012: 0.57 2015: 0.5853 2020: 0.6158	EIA AEO2011, National Energy Modeling System	Web Link
MAC_{2009}	Reported electricity consumption for mid-Atlantic in year 2009 (quad BTU)	2009: 0.549	EIA AEO2011, National Energy Modeling System	Web Link
TL	Transmission losses	8%	Original CSS assumption	

Step 4 Data and Sources:

Table RCI-4.7- Step 4 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
SSy	Solar electricity renewable portfolio standard for year *y*	2011: 0.04% 2020: 1.5%	MD RPS Legislation*	
NSSy	Non-solar electricity renewable portfolio standard for year *y*	2011: 4.96% 2020: 16.5%	MD RPS Legislation*	
BNS	Baseline biomass and LFG Tier 1 renewable electricity produced in 2008	2012: 1.3% 2015: 1.3% 2020: 1.3%	EIA, Maryland Renewable Electricity Profile: 2008	Web Link

*RPS Legislation:
Senate Bill 595 (Electricity – Net Energy Metering – Renewable Portfolio Standard – Solar Energy), April 2007; House Bill 375 (Renewable Portfolio Standard Percentage Requirements – Acceleration), April 2008; Senate Bill 277 (Renewable Portfolio Standard – Solar Energy), May 2010. See http://webapp.psc.state.md.us/intranet/ElectricInfo/home_new.cfm.

Step 5 Data and Sources:

Table RCI-4.8- Step 5 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
$AMER_j$	Adjusted Marginal GHG Emissions Rate for Year i (million metric tons CO_2e per MWh)	Non-Solar Tier 1 2012: 0.645521 2015: 0.573826 2020: 0.454513 Solar 2012: 0.603850 2015: 0.558952 2020: 0.464188	Calculated	
PRj	Percentage of resource *j*		Public Service Commission of Maryland, Renewable Energy Portfolio Standard Report of 2010, February 2010. Ventyx Energy Velocity Database	See Note (1) for values
MEF_{mj}	Monthly energy factor for month *m* for resource *j* (% of annual energy produced in month *m*)		National Renewable Energy Laboratory, PV Watts Database National Renewable Energy Laboratory, Wind Integration Datasets,	See Note (2) for values
MER_m	Marginal GHG emissions rate for month *m* (metric tonnes CO_2e per MWh)		MarketPower™ simulation model and the Promod™ dispatch model	See Note (3) for values

Notes

(1) Energy mix

The annual Energy Mix is based on 2008 compliance data for the Maryland RPS and the mix of proposed renewables is based on the Ventyx Energy Velocity Database. New renewable energy is added in the following proportion: wind – 83.5 percent, biomass – 13.3 percent, landfill gas – 3.2 percent.

Table RCI-4.9- Annual Energy Mix

Resource	Energy Mix		
	2012	2015	2020
Wind	57.7%	67.5%	74.3%
Biomass	30.2%	23.7%	19.3%
LFG	6.8%	5.5%	4.5%
Hydro	5.3%	3.3%	1.9%

(2) Monthly energy production factor for month *m* for resource *j*

The Monthly Energy Production Factor provides the amount of energy produced in each month by a particular resource relative to the rest of the year. Wind, the main resource assumed to meet the RPS, produces more energy in the winter. The wind pattern is the average of several regional wind patterns.

Table RCI-4.10- Monthly Energy Production

Month	Monthly Energy Production				
	Wind	Biomass	LFG	Hydro	Solar
1	13.7%	8.3%	8.3%	8.3%	6.9%
2	12.0%	8.3%	8.3%	8.3%	7.9%
3	8.7%	8.3%	8.3%	8.3%	9.1%
4	7.6%	8.3%	8.3%	8.3%	9.2%
5	6.4%	8.3%	8.3%	8.3%	9.4%
6	4.1%	8.3%	8.3%	8.3%	9.5%
7	5.4%	8.3%	8.3%	8.3%	9.6%
8	4.6%	8.3%	8.3%	8.3%	9.0%
9	6.7%	8.3%	8.3%	8.3%	8.3%
10	10.5%	8.3%	8.3%	8.3%	9.0%
11	7.2%	8.3%	8.3%	8.3%	6.6%
12	13.1%	8.3%	8.3%	8.3%	5.5%

(3) Marginal GHG emissions rate for month *m*

Table RCI-4.11- Marginal GHG Emissions Rate for Month *m*

Month	Marginal GHG Emissions Rate (TCO_2e/MWh)		
	2012	2015	2020
1	0.8	0.7	0.4
2	0.7	0.6	0.5
3	0.8	0.5	0.4
4	0.8	0.6	0.6
5	0.4	0.5	0.5
6	0.5	0.6	0.5
7	0.5	0.6	0.5
8	0.4	0.5	0.4
9	0.4	0.5	0.5
10	0.6	0.5	0.4
11	0.6	0.5	0.5
12	0.9	0.7	0.4

Step 6: Data and Sources:

Table RCI-4.12- Step 6 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
EF_i	Emissions factor for renewable source *i* (tCO_2e/MWh)	Wind = 0 Biomass = 1.06 LFG = 0.53	Biomass: EIA, Annual Energy Outlook 2010 with Projections to 2035 LFG: see Natural Gas	Biomass: Web Link, converted from units $kgCO_2e/mmBTU$

1.6. GHG Emission Assumptions

- The cost effectiveness of future EPC projects will be equal to the cost effectiveness of the fourteen existing projects.
- EPC projects will recognize savings at the same level for all years in which they are operational
- New EPC projects will become operational in 2013
- All thermal energy savings come from natural gas.

- The proportion of electricity produced in-state will remain constant at 71 percent.
- The State of Maryland government's electricity consumption will increase at the same rate as the Commercial sector in the Mid-Atlantic region.
- The State's use of renewable energy will be met through a linear percentage increase in the proportion of energy from 2011 to 2020.
- The current rate of 1.3 percent biomass and landfill gas Tier 1 electricity would have remained constant in the baseline, and therefore does not accrue benefit to RCI-4.
- The mix of non-solar Tier I renewables begins with the actual mix reported in 2008 compliance data (1.3 percent from biomass and landfill gas (LFG) combined). New renewables are added based on the proportion of proposed renewable resources in the PJM region, derated based on resource-specific historical success rates. The mix of renewable resources chosen was 83 percent wind, 13 percent biomass, and 3 percent landfill gas.
- Electricity from solar and wind Tier 1 renewable resources do not produce emissions.
- Emissions from biomass and landfill gas do produce emissions.
- The EPCs will meet their energy savings goals, and the Generating Clean Horizon's program will meet its renewables usage goals.

2.0. AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from RCI-4 are shown in Table RCI-4.13.

Table RCI-4.13- Emissions Reductions Associated with RCI-4 (tons per year)

	Across Maryland			Across Entire Domain		
Pollutant	**2012**	**2015**	**2020**	**2012**	**2015**	**2020**
SO_2	16	17	19	570	720	670
NO_X	28	38	30	170	240	290
CO	19	25	34	40	53	83
VOC	1	2	3	3	4	5
PM10-primary	10	17	27	35	54	68
PM2.5-primary	9	16	24	25	39	56

These numbers were compared against the MANE-VU inventories for 2012 and 2018 (Table RCI-4.14). The 2018 emissions were estimated by interpolating between the 2015 and 2020 estimates. Because all the values are less than one percent, Table RCI-4.14 indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to improve air quality.

Table RCI-4.14- Percentage Reduction in Emissions Inventory Associated with Policy RCI-4

	Across Maryland		Across Entire Domain	
Pollutant	**2012**	**2018**	**2012**	**2018**
SO_2	<1%	<1%	<1%	<1%
NO_X	<1%	<1%	<1%	<1%
CO	<1%	<1%	<1%	<1%
VOC	<1%	<1%	<1%	<1%
PM10-primary	<1%	<1%	<1%	<1%
PM2.5-primary	<1%	<1%	<1%	<1%

2.2. Summary of Air Quality Co-Benefits Methodology

The PROMOD model results estimate the decreased fuel consumption at various plants based on marginal reductions in electricity consumption. The marginal plant emissions reductions are calculated by multiplying each power plant's decreased fuel consumption by the plant-specific emission factors (lb pollutant/mmBtu), and domain-wide emission factors are computed from the marginal calculations.

Then emissions reductions are computed by multiplying the policy's decrease in fuel consumption by the domain-wide emission factors. An assumption that electric generators would begin co-firing small quantities of biomass with coal did not lead to reduced emission factors. Emissions increases resulting from the development of landfill gas boilers were calculated by multiplying EPA's AP-42 emission factors by the increased electric demand on this sector. Additional emissions reductions from reduced natural gas consumption under EPCs were calculated using AP-42 emission factors.

2.3. Air Quality Co-Benefit Calculations

Calculate Emission Factors Associated with Marginal Power Plant Reductions

1. From the 2009 CAMD data sets, calculate the SO_2 and NO_X emissions rates per mmBtu for coal-fired power plants in EPA Regions 2, 3, 4, and 5.

2. From the 2007 MARAMA inventory for Maryland and surrounding states (DC, DE, NJ, PA, VA, and WV), find the CO, VOC, PM10, and PM2.5 emissions rates per mmBtu for coal-fired power plants that are listed in the database.

3. Use AP-42 emissions factors for oil and natural-gas fired utility boilers. Assume no emissions from renewable and nuclear plants.

4. Calculate the emissions factors for each power plant (lb/mmBtu).

5. Calculate the emissions for each plant for base load, 1 percent reduction and 2 percent reduction by multiplying the emission factors by the annual fuel consumption rates from the PROMOD model (years 2012, 2015, and 2020).

6. If the SO_2 or NO_X emissions for Maryland power plants exceeded the Healthy Air Act limits, adjust the base load emissions and adjust the 1 percent and 2 percent reductions by the fuel consumption rate ratios.

7. Sum the fuel consumption rates and the pollutant emissions in the base load, 1 percent reduction case, and 2 percent reduction case (years 2012, 2015, and 2020). Do this for both Maryland and for the entire modeling domain.

8. Compute the emissions, fuel consumption rates, and energy production per percent load reduction.

9. Calculate the marginal electricity emissions factors (lb pollutant/mmBtu change) as the emissions per percent load reduction divided by the fuel consumption rates per percent load reduction.

10. Calculate the marginal heat rates from electricity generating units (EGUs) (mmBtu/GWh) as the fuel consumption rate per percent load reduction divided by the energy production per percent load reduction.

Calculate Heat Input Reductions for EPCs

1. The total EPC energy savings (in GWh) are reported in Section 1.0

2. Multiply the total EPC energy savings for the year by the marginal heat rate from EGUs (mmBtu/GWh) for the same year to calculate the EPC heat input reduction.

Calculate Heat Input Reductions for GCHs

1. The GCH energy savings (in GWh) are reported in Section 1.0 for landfill gases, wind, and solar. Assume that co-firing coal-fired plants with less than 10 percent biomass does not significantly change the criteria pollutant emission factors (based on figure presented by Lesley Sloss of the International Energy Association(IEA) Clean Coal Centre at the 35th Annual EPA-Air & Waste Management Association (A&WMA) Annual Exchange in December 2010) from those for coal alone. Therefore, any generation capacity allotted to biomass in the GCH was treated with the same criteria pollutant emission factors that were used for PROMOD.

2. Multiply the GCH energy savings for landfill gases, wind, and solar by the marginal heat rate for EGUs for the same year to calculate the GCH heat input reduction.

Calculate Emissions Reductions Associated with RCI-4

1. Use the marginal electricity emissions factors for the electricity reductions.

2. Use AP-42 emission factors for commercial-size boilers.

3. Use AP-42 emission factors for landfill gas boilers, and assume that the GCH landfill gas boilers are all located within Maryland. To calculate the necessary landfill gas rates to meet electric demand, assume factors of 7 mmBtu/MWh for new boilers and 0.3 mmBtu/mcf landfill gases. Because landfill gas boilers would be replacing unspecified SO_2 and VOC emissions controls at the landfills but likely have negligible effects on total emissions changes, the SO_2 and VOC emissions increases were not computed.

4. Multiply the EPC and GCH heat input reductions (mmBtu) by the emission factors (lb/mmBtu) to calculate the emission reductions. Subtract out any emissions resulting from increased use of landfill gas boilers.

2.4. Air Quality Co-Benefits Data a and Data Sources

The following data sources were used for the analysis:

- PROMOD Model: (http://www1.ventyx.com/analytics/promod.asp)
- Maryland's Healthy Air Act (http://www.mde.maryland.gov/programs/Air/Documents/26-11-27_MD_Healthy_Air_Act.pdf)
- AP-42 (http://www.epa.gov/ttn/chief/ap42/index.html)
- CAMD 2009 (http://camddataandmaps.epa.gov/gdm/)
- Cite MARAMA's 2007 Regional Emissions Inventories (http://www.marama.org/RegionalEmissionsInventory/2007BaseCase/index.html)
- MANE-VU Emissions Inventory (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory)

3.0 INTERACTION WITH OTHER POLICIES

The discussion of policy interactions is provided in Chapter 5.

Policy No.: RCI-10 (Including RCI-2, 3, 7 and 11)

Policy Title: EmPOWER Maryland

SAIC was tasked with reviewing the RCI-10 policy analysis which was conducted by a prior MDE contractor (Original Methodology) and revising the methodology to include Maryland-specific data and/or other enhancements. SAIC subsequently recalculated the GHG emission reductions associated with RCI-10 based upon its recommended methodology (Revised Methodology). SAIC also quantified the air quality co-benefits associated with RCI-10. SAIC's revised policy findings are described below:

1.0. GHG EMISSION REDUCTIONS

RCI-10 (which incorporates and subsumes old policies RCI-2, RCI-3, RCI-7, and RCI-11 in addition to RCI-10) consists of the EmPOWER Maryland Act. EmPOWER Maryland, enacted in 2008, requires utilities and the Maryland Energy Administration (MEA) to reduce the state's per capita electricity consumption by 15 percent by 2015. The 15 percent reduction is to be achieved against a 2007 baseline. The GHG emission reductions expected from this policy are summarized below:

Table RCI-10.1- Estimated GHG Emission Reductions resulting from RCI -10

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
RCI-10 Total	**3.1**	**6.4**	**5.4**
Residential			
In-State Electricity	0.9	1.8	1.4
Imported Electricity	0.4	0.8	0.8
Commercial			
In-State Electricity	0.6	1.3	1.0
Imported Electricity	0.3	0.6	0.6
Industrial			
In-State Electricity	0.6	1.3	1.0
Imported Electricity	0.3	0.6	0.5

Note: Totals may not equal sum of parts due to independent rounding.

The reductions in electricity consumption expected from RCI-10 are presented in Table RCI-10.2. Note that although RCI-10 meets its final goal of a 15 percent reduction in per capita consumption in 2015, there is a slight increase in *total* electricity use reductions between 2015 and 2020. This increase reflects the fact that Maryland's population is projected to increase between 2015 and 2020; hence the 15 percent *per capita* reduction is applied to a larger population total in 2020 than in 2015. Note also that although the reduction in electricity consumption increases between 2015 and 2020, the GHG emission reductions projected for RCI-10 decline significantly over this same period (see Table RCI-10.1). The decline in emission reductions is the result of a corresponding decline in the projected marginal emissions factors for in-State and imported electricity, as Maryland and the U.S. as a whole shift towards cleaner burning fuels and renewable.

Table RCI-10.2- Change in Electricity Use

Sector	Electricity Use Reductions (GWh)		
	2012	2015	2020
RCI-10 Total	**5,103**	**11,279**	**11,746**
Residential	2,092	4,624	4,816
Commercial	1,531	3,384	3,524
Industrial	1,480	3,271	3,406

Note: Totals may not equal sum of parts due to independent rounding.

1.1. Summary of GHG Emission Methodology

The Revised Methodology used by SAIC to estimate GHG reductions for this policy is simple and straightforward, consisting of the following three steps:

3. Calculate electricity savings from each sector (residential, commercial, and industrial) in each projection year (2012, 2015, and 2020);
4. Calculate in-state and out-of-state emission reductions in each projection year;
5. Calculate total emission reductions across all sectors and geographic boundaries.

Each of the above steps is documented in detail in the following subsection.

1.2. Rationale for GHG Emission Methodology

The selected method is a straightforward application of our standard emission factors to the EmPOWER Maryland electricity savings goal.

1.3. Difference Between Original and Revised Methodology and Results

Since at the time the original emission reduction estimates were developed Policies RCI-2, RCI-3, RCI-7, RCI-10 and RCI-11 were all separate, the Original Methodologies applied at that time are no longer relevant, or an efficient approach, to calculating reductions for the single combined policy. Therefore SAIC developed a new Revised Methodology. It is important to recognize that the new combined policy consists exclusively of the EMPOWER Maryland act; therefore other emission reduction measures contained in the original set of policy estimates for RCI-2, RCI-3, RCI-7, RCI-10, and RCI-11 are not covered or considered in the Revised Methodology.

1.4. GHG Emission Calculations

Step 1: Calculate Electricity Savings from RCI-10:

Since EmPOWER Maryland's goal is a 15 percent reduction in per capita electricity consumption, to be met in full by 2015, total electricity savings in 2015 and 2020 is simply 0.15 times Maryland's 2007 per capita electricity consumption, multiplied by projections of the state's population in those years. By 2012 we assume Maryland will have progressed approximately halfway towards the goal; hence savings in 2012 are set equal to 7 percent of the State's 2007 per capita electricity consumption. The total electricity savings in each of the three years are assumed to be distributed across the three sectors (residential, commercial, and industrial) in accordance with the current distribution of electricity use by sector (as provided to us by MDE).

The specific algorithm used to calculate total electricity savings by year and sector is as follows:

$$ES_{i,s} = (P_i)(EC_{2007}/P_{2007})(SG_i)(SF_s) \quad (1)$$

Where

$ES_{i,s}$ = Total reduction in electricity consumption (in MWh) in year i, for sector s (where s is residential, commercial, or industrial)

EC_{2007} = Total MD electricity consumption in 2007, including losses (in MWh)

P_{2007} = MD population in 2007 (in MWh)

P_i = MD projected population in year i

SG_i = RCI-10 electricity saving's goal for year i (fraction)

SF_s = Fraction of total saving's goal to be met by each sector s (where s is residential, commercial, or industrial)

Step 2: Calculate In-State and Out-of State Emission Reductions for Each Sector:

Once total electricity savings by year and sector are computed in Step 1, these savings estimates are converted to emission reduction estimates by applying the appropriate electricity emission factors. The electricity emission factors were developed through a modeling analysis of Maryland's electricity sector (see Section 2.2 for more details on the modeling analysis). Separate electricity emission factors were developed for imported and in-state generated electricity; aPSC-supplied forecast of the percentage of Maryland's total electricity demand to be met by imports was used to split the total electricity savings into in-state and imported electricity prior to the application of the two separate electricity emission factors.

The specific algorithm used to complete Step 2 was as follows:

$$ERIS_{i,s} = (ES_{i,s})(FIS_i)(EEFIS_i) \quad (2)$$

$$EROS_{i,s} = (ES_{i,s})(1-FIS_i)(EEFOS_i) \quad (3)$$

Where

$ERIS_{i,s}$ = In-State emission reductions in year i (in metric tons CO_2e) for sector s (where s is residential, commercial, or industrial)

$EROS_{i,s}$ = Emission reductions from imported electricity in year i (in metric tons CO_2e) for sector s (where s is residential, commercial, or industrial)

FIS_i = Fraction of total electricity from in-state generators in year i

$EEFIS_i$ = Electricity emissions factor for in-state generators in year i (metric tons CO_2e/MWh)

$EEFOS_i$ = Electricity emissions factor for out-of-state generators in year i (metric tons CO_2e/MWh)

Step 3: Calculate Total Emission Reductions Across All Sectors and Boundaries:

Finally, in Step 3 total emission reductions for RCI-10 in each of the projection years (2012, 2015 and 2020) are computed by summing the in-state and out-of-state reductions across all sectors.

1.5. GHG Emission Data and Data Sources

Step 1 Data and Sources:

Table RCI-10.3- Step 1 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
EC_{2007}	Total MD electricity consumption in 2007	69,299,682 MWh	MD Public Service Commission*	
SG_i	Electricity savings goal	2012: 7% 2015: 15% 2020: 15%	EmPower Goal	The 2012 goal is estimated at approximately half the EmPower Goal of a 15% reduction by 2015
P_i	MD state population in year i	2007: 5,610,000 2012: 5,902,000 2015: 6,086,840 2020: 6,339,290	U.S. Census Bureau** MD Dept. of Planning, Demographic and Socio-economic Outlook***	The 2007 value is based on a linear interpolation of data for 2000 and 2009, from the U.S. Census Bureau. The 2012 data is based on a linear interpolation of projections from 2010 and 2015 from the MD Dept. of Planning's website. The 2015 and 2020 projections are from the MD Dept. of Planning
SF_s	Fraction of goal contributed by each sector	Residential=41% Commercial=30% Industrial=29%	ACEEE****	The fractions represent current electricity use by sector

*From the Excel spreadsheet "2007 and 2008 per capita consumption data."

**U.S. Census Bureau, http://quickfacts.census.gov/qfd/states/24000.html

***MD Department of Planning, http://planning.maryland.gov/msdc/county/stateMD.pdf. (We used the website rather than the Dept. of Planning's spreadsheet "2015 EmPOWER Targets and Population" because the former source is more recent--February 2009 vs. July 2008).

****American Council for an Energy-Efficient Economy (ACEEE), "Energy Efficiency: The First Fuel for a Clean Energy Future; Resources for Meeting Maryland's Electricity Needs," February 2008, http//www.aceee.org/research-report/e082.

Step 2 Data and Sources:

Table RCI-10.4- Step 2 Data and Sources

Variable	Definition	Value(s)	Source(s)	Notes
FIS_i	Fraction of electricity from in-state generators	0.71 throughout forecast period	PSC communication	
$EEFIS_i$	In-state electricity emission factor	2012: 0.595 tonnes/MWh 2015: 0.548 tonnes/MWh 2020: 0.418 tonnes/MWh	PROMOD output, see below	
$EEFOS_i$	Emission factor for imported electricity	2012: 0.665 tonnes/MWh 2015: 0.61 tonnes/MWh 2020: 0.554 tonnes/MWh	PROMOD output, see below	

SAIC developed the in-state and out-of-state electricity emission factors using the PROMOD production cost model. PROMOD is a well-known electricity dispatching model. To develop the emission factors SAIC used the model to simulate the operation of the PJM system under expected conditions for hourly demand, generator characteristics, fuel cost, emission costs, and transmission limitations to energy transfer across the PJM system. We used generator-specific emissions rates developed from historical CEMS data. Also, we simulated the PJM system operation under two change cases: a 1 percent and a 2 percent reduction in PJM load. Our reported emissions rates are an average of the marginal emission rates for the two change cases. That is, we calculated the difference between the total CO_2 emissions in Maryland (or PJM system) for the Base Case and the total CO_2 emissions in Maryland for the 1 percent load reduction case. Dividing the decremental CO_2 output by the change in load gave us the marginal CO_2 emissions rate for Change Case 1. Then we did the same for the 2 percent load reduction case relative to the Base Case to compute a marginal CO_2 emissions rate for the 2 percent load reduction case. We averaged the two marginal CO_2 emissions rates to develop the above-documented CO_2 emissions factors in each forecast year.

1.6. GHG Emission Assumptions

1. The 15 percent electricity savings goal specified in the EmPOWER Maryland Act is to be achieved by 2015. We assume that this goal will be met, and that Maryland will reach the approximate halfway point (i.e., a 7 percent savings) by 2012.

2. Reductions are assumed to mirror current electricity use by sector

2.0. NAAQS CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from RCI-10 are shown within Table RCI-10.5. All numbers for the criteria pollutants reflect a single year of emissions.

Table RCI-10.5- Emissions Reductions of Criteria Pollutants Associated with RCI-10 (tons per year)

	Across Maryland			Across Entire Domain		
Pollutant	**2012**	**2015**	**2020**	**2012**	**2015**	**2020**
SO_2	490	730	590	18,000	32,000	20,000
NO_X	230	530	200	4,700	9,200	8,300
CO	29	70	340	670	1,300	1,900
VOC	6	15	49	49	97	97
PM10-primary	270	680	780	1000	2,300	2,000
PM2.5-primary	250	620	680	720	1,600	1,700

These numbers were compared against the MANE-VU inventories for 2012 and 2018 (Table RCI-10.6). The 2018 emissions were estimated by interpolating between the 2015 and 2020 estimates. Table RCI-10.6 indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to improve air quality except through the reductions in SO_2 and later reductions in Maryland’s PM2.5 emissions.

Table RCI-10.6- Percentage Reduction in Emissions Inventory Associated with RCI-10

	Across Maryland		Across Entire Domain	
Pollutant	**2012**	**2018**	**2012**	**2018**
SO_2	<1%	<1%	2%	3%
NO_X	<1%	<1%	<1%	<1%
CO	<1%	<1%	<1%	<1%
VOC	<1%	<1%	<1%	<1%
PM10-primary	<1%	<1%	<1%	<1%
PM2.5-primary	<1%	2%	<1%	<1%

Local and regional reductions in SO_2 emissions could result in reduced acid rain and less formation of sulfate particulate matter. This may result in more nitrate particulate matter formation and subsequent deposition to the Chesapeake Bay. Reductions in primary PM2.5 emissions within Maryland may lower ambient levels slightly and also improve visibility.

2.2. Summary of Air Quality Co-Benefits Methodology

The PROMOD model results estimate the decreased fuel consumption at various plants based on marginal reductions in electricity consumption. The marginal plant emissions reductions are calculated by multiplying each power plant's decreased fuel consumption by the plant-specific emission factors (lb pollutant/mmBtu), and domain-wide emission factors are computed from the marginal calculations.

Then emissions reductions are computed by multiplying the policy's decrease in fuel consumption by the domain-wide emission factors.

2.3. Air Quality Co-Benefit Calculations

Calculate Emissions Factor Associated with Marginal Power Plant Reductions

1. From the 2009 CAMD data sets, calculate the SO_2 and NO_X emissions rates per mmBtu for coal-fired power plants in EPA Regions 2, 3, 4, and 5.

2. From the 2007 MARAMA inventory for Maryland and surrounding states (DC, DE, NJ, PA, VA, and WV), find the CO, VOC, PM10, and PM2.5 emissions rates per mmBtu for coal-fired power plants that are listed in the database.

3. Use AP-42 emissions factors for oil and natural-gas fired utility boilers. Assume no emissions from renewable and nuclear plants.

4. Calculate the emissions factors for each power plant (lb/mmBtu).

5. Calculate the emissions for each plant for base load, 1 percent reduction and 2 percent reduction by multiplying the emission factors by the change in fuel consumption rates (in mmBtu/yr) from the PROMOD model (years 2012, 2015, and 2020—see Section 1.5 for additional details on the PROMOD model runs referred to here).

6. If the SO_2 or NO_X emissions for Maryland power plants exceeded the Healthy Air Act limits, reduce the base load emissions to those permit limits and compute the 1 percent and 2 percent reductions as a fraction of the base load using the ratios of fuel consumption rates.

7. Sum the fuel consumption rates and the pollutant emissions in the base load, 1 percent reduction case, and 2 percent reduction case across all plants (years 2012, 2015, and 2020). Do this for both Maryland and for the entire modeling domain.

8. Compute the emissions per percent load reduction and the fuel consumption per percent load reduction for the 1 percent and 2 percent cases. Average the 1 percent and 2 percent cases.

9. Calculate the marginal electricity emissions factors (lb pollutant/mmBtu change) as the emissions per percent load reduction divided by the fuel consumption per percent load reduction.

10. Calculate the marginal heat rate (mmBtu/MWh) as the marginal fuel consumption change divided by the marginal electricity generated.

Calculate Emission Reductions Associated with Fuel/Electricity Consumption Reductions

1. Use the marginal electricity emissions factors and the marginal heat conversions.

2. Multiply the calculated reductions in electricity demand (MWh) as computed in Step 1 of the GHG emission reduction methodology (see Section 1.4) by the marginal heat rates (mmBtu/MWh) and by the emission factors (lb/mmBtu) to calculate the emission reductions.

2.4. Air Quality Co-Benefits Data and Data Sources

The following data sources were used for the analysis:

- PROMOD Model: (http://www1.ventyx.com/analytics/promod.asp)
- Maryland's Healthy Air Act (http://www.mde.maryland.gov/programs/Air/Documents/26-11-27_MD_Healthy_Air_Act.pdf)
- AP-42 (http://www.epa.gov/ttn/chief/ap42/index.html)
- CAMD 2009 (http://camddataandmaps.epa.gov/gdm/)
- Cite MARAMA's 2007 Regional Emissions Inventories (http://www.marama.org/RegionalEmissionsInventory/2007BaseCase/index.html)
- MANE-VU Emissions Inventory (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory)

3.0 INTERACTION WITH OTHER POLICIES

The discussion of policy interactions is provided in Chapter 5.

Chapter 2: Energy Supply (ES) Policies

The following ES Policies were analyzed:

- ES 3: GHG Cap and Trade
- ES 7: Renewable Portfolio Standard
- ES 8: Efficiency Improvements & Repowering Existing Plants

ES Policy Findings

Table 2.1 presents the 2020 GHG emission reduction estimates for the above-listed three policies. As the table indicates, Policy ES-3, the GHG Cap and Trade policy, is projected to yield the majority of the emission reductions in the ES sector; this policy accounts for 61 percent of the sum of reductions across all policies. It should be noted that there are significant overlaps in the projected emission reductions not only across the three ES policies, but between the ES and RCI policies. These overlaps are further discussed and quantified in Chapter 5.

Table 2.1. Summary of GHG Emission Reductions from the ES Sector in 2020

Sector/Policy	2020 GHG Emission Reductions ($MMTCO_2e$)
Energy Supply (ES)	
ES-3: GHG Cap and Trade	12.26
ES-7: Renewable Portfolio Standard	3.04
ES-8: Efficiency Improvements & Repowering Existing Plants	4.90
ES Total (Unadjusted for Overlaps)	**20.20**

Table 2.2 presents the projected 2020 reductions in criteria pollutant emissions for the three ES policies. As this table indicates, Policy ES-3 yields the majority of the reductions in all pollutants. As is the case for GHGs, there are significant overlaps in the criteria pollutant emissions reduction estimates; the reader is referred to Chapter 5 for a discussion and quantification of these overlaps.

Table 2.2. Summary of Criteria Pollutant Emission Reductions from the RCI Policies in 2020

		SO_2 (Tons)	NO_x (Tons)	CO (Tons)	VOC (Tons)	PM10 (Tons)	PM2.5 (Tons)
	Energy Supply (ES)						
ES-3	ES 3 - GHG Cap-and-Trade	17,000.00	5,700.00	220.00	45.00	2,100.00	1,900.00
ES-7	ES 7 - Renewable Portfolio Standard	510.00	-81.00	1.00	9.00	410.00	380.00
ES-8	ES 8 - Efficiency Improvements & Repowering Existing Plants	8,400.00	-2,500.00	-1,200.00	-68.00	1,000.00	870.00
	ES Total	**25,910.00**	**3,119.00**	**-979.00**	**-14.00**	**3,510.00**	**3,150.00**

Technical Notes:

PROMOD IV Model

The ES policies rely on the PROMOD IV Model for their results. The PROMOD *IV* Model is Fundamental Electric Market Simulation software that incorporates extensive details in generating unit operating characteristics, transmission grid topology and constraints, unit commitment/operating conditions, and market system operations. PROMOD IV algorithms can be exercised in several modes, depending upon the scope, time frame, and simulation resolution that align with the decision focus. The model can assess a variety of electric market components including:

- Locational marginal price for forecasting
- Valuation
- Transmission congestion analysis
- Environmental analysis
- Generation and transmission asset valuation
- Fuel strategy
- System reliability

More information on the PROMOD IV Model can be found on their website: http://www1.ventyx.com/analytics/promod.asp

MANE-VU Future Emissions Inventory

All of the air quality co-benefit analyses for the ES policies utilize the MANE-VU Future Emissions Inventory[7]. The MANE-VU Future Emissions Inventory represents a collaborative effort among northeastern and mid-Atlantic states to develop regionally consistent emissions inventories that account for projected growth and expected emissions control measures. The inventories for 2009, 2012, and 2018 are used by the states as they develop state implementation plans to meet national ambient air quality standards and progress goals to reducing regional haze. More information on MANE-VU can be found on the following website: (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory).

[7]http://www marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

Policy No.: ES-3

Policy Title: Greenhouse Gas (GHG) Cap-And-Trade (C&T)

SAIC was tasked with reviewing the ES-3 policy analysis which was conducted by a prior MDE contractor (Original Methodology) and revising the methodology to include Maryland-specific data and/or other enhancements. SAIC subsequently recalculated the GHG emission reductions associated with ES-3based upon its recommended methodology (Revised Methodology). SAIC also quantified the air quality co-benefits associated with ES-3. SAIC's revised policy findings are described below:

1. GHG EMISSION REDUCTIONS

The Regional Greenhouse Gas Initiative (RGGI) is the first market-based regulatory program in the United States to reduce carbon dioxide emissions. Ten Northeastern and Mid-Atlantic states, including Maryland, have capped and will reduce CO_2 emissions from the power sector 10 percent by 2018[8]. ES-3 embodies the RGGI carbon dioxide reduction goals for the state of Maryland.Table ES-3.1 below illustrates projected CO_2e emissions reductions in Maryland as a result of the RGGI program. By 2020, total GHG emissions reductions are 12.26 $MMTCO_2e$.

Table ES-3.1- GHG Emission Reductions Resulting from ES-3

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
Maryland	7.81	9.29	12.26

1.1. Summary of GHG Emission Methodology

SAIC estimated the emissions reduction due to RGGI by calculating the difference between projected Maryland electricity emissions and the RGGI cap for each year of the study period.

1.2. Rationale for GHG Emission Methodology

Since Maryland is part of RGGI and RGGI is based on an annual emissions cap emissions reductions were quantified by calculating the difference between forecasted emissions without RGGI and the RGGI cap.

1.3. Detailed Explanation of Methodology

SAIC first obtained annual Maryland electricity emissions projections from MDE for the study period. MDE produced the emissions projections based on 2006 emissions data from the EPA Clean Air Markets Division (CAMD). Since RGGI did not exist in 2006, the projections do not include any impacts from the RGGI program. MDE projected the 2006 emissions data using CAMD based output optimization assumptions, meaning that MDE didn't increase emissions greater than the actual capacity of the power plants in Maryland.

[8] http://www rggi.org/home

SAIC then acquired the projected RGGI cap for each year of the study period. The difference between the MDE emissions projections and the RGGI cap resulted in the total GHG emissions reductions.

1.4. Difference Between Original & Revised Methodologies and Results

The Original Methodology evaluated the RGGI at multiple dollar amounts ranging from $1 per ton to $7 per ton, assuming that allowances were auctioned. In some cases, states reduced emissions by more than required by the cap in order to avoid the cost of purchasing an allowance. The Revised Methodology assumed that all emissions in Maryland are reduced by exactly the amount required to meet the cap.

The Original Methodology used projected emissions data based on 2005 data. The Revised Methodology employed an emissions forecast based on 2006 data. The 2006 data is more representative of a typical year of emissions than the 2005 data, and is about 1 $MMTCO_2$ lower than the 2005 data.

1.5. GHG Emission Reduction Calculations

The emissions reductions were calculated as the difference between the forecasted emissions without RGGI and the RGGI cap:

$$TER_i = PE_i - RC_i \quad (1)$$

Where

TER_i = Total GHG emission reductions in year i for ES-3 (million metric tons CO_2e)

PE_i = Projected Emissions without RGGI for year i, (million metric tons CO_2e)

RC_i = RGGI Cap for year i, (million metric tons CO_2e)

Table ES-3.2: GHG Emissions with and without RGGI

Emissions Category	GHG Emissions (Million Metric Tons CO_2e)		
	2012	2015	2020
Projected Emissions (without RGGI)	41.83	42.46	42.88
RGGI Cap*	34.02	33.17	30.62
Maryland GHG Reductions from RGGI	7.81	9.29	12.26

*The RGGI cap is held constant at 34.02 million metric tons CO_2e between 2009 and 2014. However, beginning in 2015 the cap is decreased over time. This tightening of the cap beginning in 2015 is reflected in the above values shown for the cap.

1.6. GHG Emission Data and Data Sources

- Projected Emissions (PE_i) without RGGI are from MDE, and are based on 2006 in-state Maryland electricity emissions of 32.16 $MMTCO_2e$ from the EPA's Clean Air Markets Division, http://www.epa.gov/airmarket/emissions/
- RGGI Cap (RC_i) data is from the Regional Greenhouse Gas Initiative website and was converted to metric tons using 0.9072 metric tons per short tons. http://www.rggi.org/design/overview/cap

1.7. GHG Emission Assumptions

The following assumptions were used in the analysis:

- MDE's emissions projections are based on 2006 data.
- MDE chose 2006 as the base year because the Greenhouse Gas Emissions Reduction Act Requires a 2006 baseline. Furthermore, the 2006 data best represents typical emissions in Maryland and Maryland's GHG reduction targets are relative to 2006.

1.8. GHG Emission Analysis and Recommendations

Based on this analysis, RGGI has the potential to result in substantial savings.

2. AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

Table ES-3.3 presents the emissions changes that would have occurred if the ES-3 policy had not been adopted. They were calculated based on the emissions increases in criteria pollutant emissions expected if the Project Emissions listed in the first row of Table ES-3.2 occurred instead of the RGGI Cap emissions in the second row. The relationships are based on the increased power requirements at specific fossil fuel-fired power plants as calculated in the PROMOD model runs.

Table ES-3.3. Emissions *Increases* of Criteria Pollutants Associated with the Absence of Policy ES-3 (tons per year)

	Across Maryland			Across Modeling Domain		
Pollutant	**2012**	**2015**	**2020**	**2012**	**2015**	**2020**
SO_2	14,000	12,000	17,000	520,000	560,000	605,000
NO_X	6,800	9,000	5,700	140,000	160,000	250,000
CO	200	230	220	4,800	4,400	8,900
VOC	42	48	45	360	320	460
PM10-primary	2,000	2,300	2,100	7,400	7,700	9,300
PM2.5-primary	1,800	2,100	1,900	5,200	5,500	6,700

These numbers were compared against the theoretical base MANE-VU inventories for 2012 and 2018 in Table ES-3.4. The 2018 emissions were estimated by interpolating between the 2015 and 2020 estimates.

The theoretical base inventory represents the case where RGGI had not been adopted (MANE-VU emissions estimates plus emissions increases listed in Table ES-1.4). Table ES-3.4 indicates that the criteria pollutant emissions reductions associated with this policy alone would likely affect SO_2, NO_X, and particulate matter emission levels across all years by substituting high sulfur coal burning with other energy types.

Table ES-3.4- Percentage Reductions Associated with Policy ES-3 from *Theoretical Base* Emissions Inventory

	Across Maryland		Across Modeling Domain*	
Pollutant	**2012**	**2018**	**2012**	**2018**
SO_2	12%	15%	34%	39%
NO_X	5%	7%	9%	15%
CO	<1%	<1%	<1%	<1%
VOC	<1%	<1%	<1%	<1%
PM10-primary	2%	2%	<1%	<1%
PM2.5-primary	4%	4%	1%	1%

* Note that emissions reductions are scaled against the adoption of RGGI in Maryland. Therefore, the percentages reflect the case where other states (even those outside the RGGI domain) adopt commensurate measures.

Reductions in SO_2 emissions could result in reduced acid rain and less formation of sulfate particulate matter across the entire domain. Local and regional reductions in NO_X emissions could improve local ambient ozone concentrations on days when the ozone formation rates are NO_X-controlled. Local reductions in PM10 emissions would result in improved air quality in Maryland. The PM2.5 reductions would result in improved air quality and reductions in regional haze.

2.2. Summary of Air Quality Co-Benefits Methodology

The PROMOD model results are used to estimate the increased power generation (as a percentage of the base load) at various power plants based on the estimate of increased CO_2 production in Maryland without the RGGI policy. The plant emissions increases are calculated by multiplying each power plant's increased fuel consumption by the plant-specific emission factors (lb pollutant/ percent change in power generation), and then emissions increases for the absence of policy are totaled over the whole domain.

Note that these calculations make two major assumptions, in addition to those introduced by the PROMOD modeling:

- The calculations assume that the replacement power is generated by means other than fuel burning (i.e., biomass and landfill gas burning does not replace the fossil fuel firing).
- Policy improvements in Maryland are reflected as decreased fossil fuel-fired generation in other States that fall within the PROMOD modeling domain (extending as far west as Illinois).

Because the PROMOD modeling exercise and the MANE-VU emission inventories already reflect adoption of the RGGI compact, the numbers in Table 5 reflect percentage reductions from an inventory that reflects emissions as if the RGGI policy had not been initiated.

2.3. Air Quality Co-Benefit Calculations

Calculate Emission Factors Associated with Marginal Power Plant Changes

1. From the 2009 CAMD data sets, calculate the SO_2 and NO_X emissions rates per mmBtu for coal-fired power plants in EPA Regions 2, 3, 4, and 5.

2. From the 2007 MARAMA inventory for Maryland and surrounding states (DC, DE, NJ, PA, VA, and WV), find the CO, VOC, PM10, and PM2.5 emissions rates per mmBtu for coal-fired power plants that are listed in the database.

3. Use AP-42 emissions factors for oil and natural-gas fired utility boilers. Assume no emissions from renewable and nuclear plants.

4. Calculate the emissions factors for each power plant (lb/mmBtu).

5. Calculate the emissions for each plant for base load, 1 percent reduction and 2 percent reduction by multiplying the emission factors by the change in fuel consumption rates (in mmBtu/yr) from the PROMOD model (years 2012, 2015, and 2020—see Section 2.2 above for additional details on the PROMOD model runs referred to here).

6. If the SO_2 or NO_X emissions for Maryland power plants exceeded the Healthy Air Act limits, reduce the base load emissions to those permit limits and compute the 1 percent and 2 percent reductions as a fraction of the base load using the ratios of fuel consumption rates.

7. Sum the Maryland CO_2 production rates and the pollutant emissions in the base load, 1 percent reduction case, and 2 percent reduction case across all plants (years 2012, 2015, and 2020). Do this for both Maryland and for the entire modeling domain.

8. Compute the emissions per percent load reduction and the Maryland CO_2 production rate per percent load reduction for the 1 percent and 2 percent cases. Average the 1 percent and 2 percent cases.

9. Calculate the marginal electricity emissions factors (lb pollutant/ton CO_2 change) as the emissions per percent load reduction divided by the Maryland CO_2 production rate per percent load reduction.

Calculate Emissions Increases Associated with Fuel/Electricity Consumption Changes if ES-3 Was Not Adopted

1. Use the marginal electricity emissions factors.

2. Multiply the calculated changes in Maryland CO_2 production from Table 1 by the emission factors (lb/ton CO_2 change) to calculate the emission increases.

Calculate Emissions Percentage Reductions Associated with ES-3 from Theoretical Base Emissions Inventory

1. The co-benefits of other GHG policies in this study were compared directly against the MANE-VU emissions inventory. However, the RGGI policy was already incorporated into the MANE-VU estimates and represents a significant change in the MANE-VU inventories (e.g., Table 4's 2012 value for SO_2 was 50 percent of the MANE-VU inventory).

2. The MANE-VU inventories reflect emissions projections with the assumption that RGGI was implemented. The numbers in Table 4 represent the additional emissions that would have occurred if RGGI was not adopted. The total of the MANE-VU inventory and Table 4 should reflect the theoretical base emissions inventory.

3. The numbers in Table 4 were divided by the theoretical base emissions inventory to calculate the percentage reductions.

2.4. Air Quality Co-Benefits Data and Data Sources

The following data sources were used for the analysis:

- PROMOD Model: (http://www1.ventyx.com/analytics/promod.asp)
- Maryland's Healthy Air Act (http://www.mde.maryland.gov/programs/Air/Documents/26-11-27_MD_Healthy_Air_Act.pdf)
- AP-42 (http://www.epa.gov/ttn/chief/ap42/index.html)
- CAMD 2009 (http://camddataandmaps.epa.gov/gdm/)
- MARAMA's 2007 Regional Emissions Inventories (http://www.marama.org/RegionalEmissionsInventory/2007BaseCase/index.html)
- MANE-VU Emissions Inventory (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory)

3.0 INTERACTIONS WITH OTHER POLICIES

The discussion of policy interactions is provided in Chapter 5.

Policy No.: ES-7

Policy Title: Renewable Portfolio Standard (RPS)

SAIC was tasked with reviewing the ES-7 policy analysis which was conducted by a prior MDE contractor (Original Methodology) and revising the methodology to include Maryland-specific data and/or other enhancements. SAIC subsequently recalculated the GHG emission reductions associated with ES-7 based upon its recommended methodology (Revised Methodology). SAIC also quantified the air quality co-benefits associated with ES-7. SAIC's revised policy findings are described below:

1.0 GHG EMISSION REDUCTIONS

The Maryland Renewable Energy Portfolio Standard (RPS) has the potential to contribute to significant reductions in GHG emissions. Table 1 illustrates the projected GHG reductions from the Tier 1[9] standard. The current Tier 1 standard is to supply 20 percent of 2022 electricity from renewable resources, two percent of which would come from solar energy (Solar Carveout). The 2020 goal is 16.5 percent from non-solar Tier 1 resources and 1.5 percent from solar resources. In 2020, this is expected to result in 2.56 $MMTCO_2e$ savings from non-solar resources and 0.48 $MMTCO_2e$ savings from solar resources, compared to a scenario without an RPS.

There is also a Tier 2[10] standard, which requires energy to come from large hydroelectric or waste-to-energy facilities. This is not modeled here as the requirement is satisfied with existing facilities and therefore does not result in any additional reductions.

Table ES-7.1- GHG Emission Reductions as a Result of ES-7

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
Current Tier 1 Non-Solar	1.16	1.90	2.56
Solar Carveout	0.04	0.14	0.48
Total Current RPS	1.19	2.04	3.04

1.1. Summary of GHG Emission Methodology

SAIC's methodology is based on the assumption that new renewable resources built to fulfill the RPS would be displacing the marginal electricity resource. The marginal electricity resource is the last electricity resource called upon to meet electricity demand, assuming that resources are dispatched in order of cost with the least expensive resources dispatched first. For example, during periods of low

9 The Maryland Tier 1 Renewable Portfolio Standard requires electricity suppliers to provide 20 percent of in-state retail electricity sales from renewable resources such as wind, solar, and biomass by 2022. The requirement began in 2006 at 1 percent, and increases gradually to 20 percent by 2022. Two percent of the final requirement is to come from solar resources.

10 The Maryland Tier 2 Renewable Portfolio Standard requires electricity suppliers to provide 2.5 percent of in-state retail electricity sales from hydroelectric power other than pumped storage and waste-to-energy facilities. The requirement began in 2006 at 2.5 percent and remains in place through 2018. After 2018 there is no Tier 2 requirement.

demand, such as at night, the marginal electricity resource is coal, which has a low variable cost. When demand is higher, such as in the middle of the day in the summer, more expensive resources such as natural gas plants are dispatched to meet the additional demand. Thus, when new electricity is added to the system, it displaces the marginal resource, the resource that would have been the final unit to be dispatched.

SAIC's methodology was to first determine the emissions rates for the marginal resources associated with Maryland power consumption. Then, the marginal emissions rates were multiplied by the quantity of renewable energy required by the RPS to calculate the total GHG emissions avoided.

1.2. Rationale for GHG Emission Methodology

SAIC chose to calculate reductions in emissions based on marginal emissions rates rather than based on coal plant emissions rates. Marginal emissions rates were chosen because it was assumed that additional renewables would replace energy at the margin, which is a mix of coal and gas fired power, depending on the season and time of day.

1.3. Detailed Explanation of GHG Emission Methodology

SAIC first used a dispatch model to estimate the marginal emissions rate associated with Maryland power consumption for the period of the study. Since the RPS program allows the acquisition of resources from surrounding states, the entire PJM market was modeled. To simulate power market operations SAIC used a customized PowerBase™ database, the MarketPower™ simulation model and the Promod™ dispatch model, all distributed by Ventyx. The PowerBase™ database is updated by SAIC to make the database consistent with our knowledge of the North American power markets.

The MarketPower™ model performs a chronological economic dispatch of the multiple, interconnected market areas, simulating all loads and resources, transmission interconnections, and unit outages on an hourly basis. The model simulates the mothballing of un-economic plants and produces an optimized generic capacity expansion plan. The Promod™ model uses the capacity expansion plan and a detailed hourly simulation of the power markets to produce the hourly, monthly, and annual average emissions rates for individual market areas.

The monthly marginal emissions rates for each year were extracted from the dispatch model results. Monthly rates were chosen because wind in PJM, the primary renewable resource, produces more energy in winter months than in summer months. The emissions rates were applied to the energy projected to be produced from renewable resources for each of the study years. SAIC also calculated the emissions associated with biomass and landfill gas resources and reduced the projected emissions savings by those amounts.

1.4. Differences Between Original & Revised Methodologies and Results

The main difference between the CCS and SAIC methodologies is that CCS assumed renewable electricity would be replacing electricity produced by coal plants, while SAIC assumed that it would be replacing electricity produced by a mix of coal and natural gas plants.

CCS estimated GHG reductions from the RPS by comparing the difference in GHG emissions rates from coal plants to GHG emissions rates from a mix of Tier 1 renewable resources, mainly wind. The difference in emissions rates was multiplied by the energy displaced by the RPS to determine net GHG savings.

SAIC's methodology was to apply emissions rates associated with the marginal electricity resource dispatched to meet Maryland power consumption. SAIC chose the marginal resource because it is the resource that would be displaced by new renewable resources. During periods of low demand, such as at night, the marginal electricity resource is coal. When demand is higher, such as in the middle of the day in the summer, more expensive resources such as natural gas plants are called upon to meet the additional demand. Thus, over the course of a month, the average marginal resource is a mix of coal and natural gas plants. SAIC then multiplied the marginal emissions rates by the quantity of renewable energy required by the RPS to calculate the displaced GHG emissions.

The emissions reductions calculated by SAIC are lower than those calculated by CCS. This is because the GHG emissions rate for coal plants is much higher than the rate for natural gas plants. CCS used the higher coal plant GHG emissions rate to calculate emissions reductions, while SAIC used a rate based on the marginal electricity resource, which is a mix of gas and coal plants, and therefore lower than an emissions rate based solely on coal.

1.5. GHG Emission Calculations

The total emissions reductions for each year was calculated as a product of the target RPS percentage, the energy demand, and the marginal emissions rate adjusted for monthly renewable energy production profiles, less any emissions produced by the renewable energy.

$$TER_i = ED_i * TRP_i * AMER_i /1000 - REE_i \quad (1)$$

Where

TER_i = Total GHG emission reductions in year i for Policy ES-7 (million metric tons CO_2e)

ED_i = Energy Demand for year i (GWh)

TRP_i = Target RPS Percentage for year i (% of energy consumed)

$AMER_i$ = Adjusted Marginal GHG Emissions Rate for Year i (million metric tons CO_2e per MWh)

$$AMERi = \sum_{m=1}^{12} \sum_{j=1}^{4} PRj * MEFm,j * MERm \quad (2)$$

Where

m = month

j = Resource

PRj = Percentage of Resource j (wind, biomass, landfill gas, or hydro; solar is calculated separately)

MEF_{mj} = Monthly Energy Factor for month m for resource j (% of annual energy produced in month m)

MER_m = Marginal GHG Emissions Rate for month m (million metric tons CO_2e per MWh)

REE_i = Renewable Energy Emissions for year i

$$REEi = \sum_{j=1}^{4} EDi * TRPi * PRj * ERj \quad (3)$$

Where

ER_j = GHG Emissions Rate for resource j (million metric tons CO_2e per MWh)

1.6. GHG Emission Data and Data Sources

Energy Demand

- The Energy Demand (ED_i) for Maryland is from the projected demand in *Maryland's Ten Year Plan (2009 – 2018) of Electric Companies in Maryland,* reduced by five percent to account for sales that are exempt from the RPS.
- Public Service Commission of Maryland, *Maryland's Ten Year Plan (2009 – 2018) of Electric Companies in Maryland,* February 2010. http://www.eia.doe.gov/cneaf/electricity/epm/table5_4_b.html

Table ES-7.2- Projected State Energy Demand (GWh)

	Energy Demand (GWh)		
	2012	2015	2020
Maryland Electricity Demand	62,472	64,084	68,569

Target RPS Percentage

Source:

- The RPS standards and associated annual Target RPS Percentage requirements (TRP_i) are listed in Table ES-7.3. Also included is the Total RPS Energy Demand, which is the product of the State Energy Demand (ED_i) and the Target RPS Percentage Requirement.

Table ES-7.3- Target RPS Percentage and Energy Demand

Standard	RPS Requirement		
	2012	2015	2020
Current Tier 1 Non-Solar	6.4%	10.1%	16.5%
Solar Carveout	0.1%	0.4%	1.5%
Total Tier 1 RPS	6.5%	10.5%	18.0%
Total RPS Energy Demand (GWh)	4,061	6,729	12,342

Sources:

- Database of State Incentives for Renewables and Efficiency Website, http://www.dsireusa.org/
- Maryland Commission on Climate Change (MCCC), *Maryland Climate Action Plan*, 2008. http://www.mdclimatechange.us/

Marginal GHG Emissions Rate

Table ES-7.4- Monthly Marginal GHG Emissions Rates (MER_m)

Month	Marginal GHG Emissions Rate (TCO_2e/MWh)		
	2012	2015	2020
1	0.8	0.7	0.4
2	0.7	0.6	0.5
3	0.8	0.5	0.4
4	0.8	0.6	0.6
5	0.4	0.5	0.5
6	0.5	0.6	0.5
7	0.5	0.6	0.5
8	0.4	0.5	0.4
9	0.4	0.5	0.5
10	0.6	0.5	0.4
11	0.6	0.5	0.5
12	0.9	0.7	0.4

Source:

- MarketPower™ simulation model and the Promod™ dispatch model

Energy Mix

The annual Energy Mix is based on 2008 compliance data for the Maryland RPS and the mix of proposed renewables is based on the Ventyx Energy Velocity Database. New renewable energy is added in the following proportion: wind – 83.5 percent, biomass – 13.3 percent, landfill gas – 3.2 percent. Table ES-7.5 displays the renewable energy mix and the associated energy production.

Table ES-7.5- Percentage Energy Mix (PRj) for the Tier 1 RPS Requirement and associated energy production

Resource	Energy Mix		
	2012	2015	2020
Energy Percentage			
Wind	57.7%	67.5%	74.3%
Biomass	30.2%	23.7%	19.3%
LFG	6.8%	5.5%	4.5%
Hydro	5.3%	3.3%	1.9%
Energy Production (GWh)			
Wind	2,307	4,371	8,412
Biomass	1,206	1,535	2,179
LFG	274	354	511
Hydro	212	212	212

Sources:

- Public Service Commission of Maryland, *Renewable Energy Portfolio Standard Report of 2010*, February 2010.
- Ventyx Energy Velocity Database

Monthly Energy Factor

The Monthly Energy Factor (MEF_{mj})provides the amount of energy produced in each month by a particular resource relative to the rest of the year. Wind, the main resource assumed to meet the RPS, produces more energy in the winter. The wind pattern is the average of several regional wind patterns.

Table ES-7.6- Monthly Energy Factor

Month	Monthly Energy Production				
	Wind	Biomass	LFG	Hydro	Solar
1	13.7%	8.3%	8.3%	8.3%	6.9%
2	12.0%	8.3%	8.3%	8.3%	7.9%
3	8.7%	8.3%	8.3%	8.3%	9.1%
4	7.6%	8.3%	8.3%	8.3%	9.2%
5	6.4%	8.3%	8.3%	8.3%	9.4%
6	4.1%	8.3%	8.3%	8.3%	9.5%
7	5.4%	8.3%	8.3%	8.3%	9.6%
8	4.6%	8.3%	8.3%	8.3%	9.0%
9	6.7%	8.3%	8.3%	8.3%	8.3%
10	10.5%	8.3%	8.3%	8.3%	9.0%
11	7.2%	8.3%	8.3%	8.3%	6.6%
12	13.1%	8.3%	8.3%	8.3%	5.5%

Sources:

- National Renewable Energy Laboratory, PV Watts Database, http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/.
- National Renewable Energy Laboratory, Wind Integration Datasets, http://www.nrel.gov/wind/integrationdatasets/eastern/methodology.html.

1.7. GHG Emission Assumptions

The mix of renewables begins with the actual mix reported in 2008 compliance data. New renewables are added based on the proportion of proposed renewable resources in the PJM region, derated based on resource-specific historical success rates. The mix of renewable resources chosen was 83 percent wind, 13 percent biomass, and 3 percent landfill gas.

Wind and hydro are assumed to have an emissions rate of 0. Biomass and landfill gas are assumed to have emissions rates of 1.0612 tCO_2/MWh and 0.5306 tCO_2/MWh, respectively

1.8. GHG Emission Analysis and Recommendations

The addition of renewable electricity displaces gas and coal electricity, which generally have higher GHG emissions than renewable electricity. Wind, solar, and hydroelectric resources all have zero emissions. Landfill gas and biomass resources have relatively higher emissions, but due to their smaller contribution to the projected renewable electricity portfolio, the ultimate affect is a reduction in GHG emissions. Thus, this analysis illustrates the potential of moderate GHG emissions reductions due to the Tier 1 RPS.

2.0 AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from ES-7 are shown within Table 7. All numbers for the criteria pollutants reflect a single year of emissions. Because the landfill gas boilers were assumed to be built in Maryland (in order to meet Maryland's RPS) to replace other boilers that may have higher efficiencies or more effective controls (e.g., Selective Catalytic Reduction (SCR)), the emissions reductions of criteria pollutants within Maryland were not always greater than zero.

Table ES-7.7- Emissions Reductions of Criteria Pollutants Associated with ES-7 (tons per year)

	Across Maryland			Across Entire Domain		
Pollutant	**2012**	**2015**	**2020**	**2012**	**2015**	**2020**
SO_2	280	330	510	9,900	14,000	18,000
NO_X	-9	71	-81	2,500	4,100	6,900
CO	-6	2	1	350	570	1,600
VOC	3	7	9	28	45	85
PM10-primary	140	300	410	570	1,000	1,800
PM2.5-primary	130	270	380	390	740	1,400

These numbers were compared against the MANE-VU inventories for 2012 and 2018 (Table 8). The 2018 emissions were estimated by interpolating between the 2015 and 2020 estimates. Table 8 indicates that the criteria pollutant emissions reductions associated with this policy alone would likely only affect SO_2 emission levels in the early years by substituting high sulfur coal with other energy types. By 2018 Table 8 shows that small emissions inventory reductions for sulfur dioxide and particulate matter could be achieved through the RPS policy.

Table ES-7.8. Percentage Reduction in Emissions Inventory Associated with ES-7

	Across Maryland		Across Entire Domain	
Pollutant	**2012**	**2018**	**2012**	**2018**
SO_2	<1%	<1%	1%	2%
NO_X	<1%	<1%	<1%	<1%
CO	<1%	<1%	<1%	<1%
VOC	<1%	<1%	<1%	<1%
PM10-primary	<1%	<1%	<1%	<1%
PM2.5-primary	<1%	1%	<1%	<1%

Reductions in SO_2 emissions could result in reduced acid rain and less formation of sulfate particulate matter across the entire domain. Local reductions in particulate matter emissions would improve local ambient particulate matter concentrations and improve visibility.

2.2. Summary of Air Quality Co-Benefits Methodology

The PROMOD model results estimate the decreased fuel consumption at various plants based on marginal reductions in electricity consumption. The marginal plant emissions reductions are calculated by multiplying each power plant's decreased fuel consumption by the plant-specific emission factors (lb pollutant/mmBtu), and domain-wide emission factors are computed from the marginal calculations.

Then emissions reductions are computed by multiplying the policy's decrease in fuel consumption by the domain-wide emission factors. An assumption that electric generators would begin co-firing small quantities of biomass with coal did not lead to reduced emission factors. Emissions increases resulting from the development of landfill gas boilers were calculated by multiplying EPA's AP-42 emission factors by the increased electric demand on this sector.

2.3. Air Quality Co-Benefit Calculations

Calculate Emissions Factors Associated with Marginal Power Plant Reductions

1. From the 2009 CAMD data sets, calculate the SO_2 and NO_X emissions rates per mmBtu for coal-fired power plants in EPA Regions 2, 3, 4, and 5.

2. From the 2007 MARAMA inventory for Maryland and surrounding states (DC, DE, NJ, PA, VA, and WV), find the CO, VOC, PM10, and PM2.5 emissions rates per mmBtu for coal-fired power plants that are listed in the database.

3. Use AP-42 emissions factors for oil and natural-gas fired utility boilers. Assume no emissions from renewable and nuclear plants.

4. Calculate the emissions factors for each power plant (lb/mmBtu).

5. Calculate the emissions for each plant for base load, 1 percent reduction and 2 percent reduction by multiplying the emission factors by the change in fuel consumption rates (in mmBtu/yr) from the PROMOD model (years 2012, 2015, and 2020—see Section **2.2** for additional details on the PROMOD model runs referred to here).

6. If the SO_2 or NO_X emissions for Maryland power plants exceeded the Healthy Air Act limits, reduce the base load emissions to those permit limits and compute the 1 percent and 2 percent reductions as a fraction of the base load using the ratios of fuel consumption rates.

7. Sum the fuel consumption rates and the pollutant emissions in the base load, 1 percent reduction case, and 2 percent reduction case across all plants (years 2012, 2015, and 2020). Do this for both Maryland and for the entire modeling domain.

8. Compute the emissions per percent load reduction and the electric generation per percent load reduction for the 1 percent and 2 percent cases. Average the 1 percent and 2 percent cases.

9. Calculate the marginal electricity emissions factors (lb pollutant/MWh change) as the emissions per percent load reduction divided by the electric generation per percent load reduction.

Calculate Emissions Reductions Associated with Fuel/Electricity Consumption Reductions

1. Use the marginal electricity emissions factors.

2. Assume that co-firing coal-fired plants with less than 10 percent biomass does not significantly change the criteria pollutant emission factors (based on figure presented by Lesley Sloss of the IEA Clean Coal Centre at the 35th Annual EPA-A&WMA Annual Exchange in December 2010) from those for coal alone. Therefore, any generation capacity allotted to biomass in the RPS was treated with the same emission factors that were used for PROMOD.

3. Use AP-42 emission factors for landfill gas boilers, and assume that the RPS landfill gas boilers are all located within Maryland. To calculate the necessary landfill gas rates to meet electric demand, assume factors of 7 mmBtu/MWh for new boilers and 0.3 mmBtu/mcf landfill gases. Because landfill gas boilers would be replacing unspecified SO_2 and VOC emissions controls at the landfills but likely have negligible effects on total emissions changes, the SO_2 and VOC emissions increases were not computed

4. Multiply the calculated quantities of renewable electricity generation (MWh) from Table 5 by the emission factors (lb/MWh) to calculate the emission reductions.

2.4. Air Quality Co-Benefits Data and Data Assumptions

The following data sources were used for the analysis:

- PROMOD Model: (http://www1.ventyx.com/analytics/promod.asp)
- Maryland's Healthy Air Act (http://www.mde.maryland.gov/programs/Air/Documents/26-11-27_MD_Healthy_Air_Act.pdf)
- AP-42 (http://www.epa.gov/ttn/chief/ap42/index.html)
- CAMD 2009 (http://camddataandmaps.epa.gov/gdm/)
- Cite MARAMA's 2007 Regional Emissions Inventories (http://www.marama.org/RegionalEmissionsInventory/2007BaseCase/index.html)

- MANE-VU Emissions Inventory (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory)

3.0 INTERACTION WITH OTHER POLICIES

The discussion of policy interactions is provided in Chapter 5.

Policy No.: ES-8

Policy Title: Efficiency Improvements and Repowering of Existing Power Plants

SAIC was tasked with reviewing the ES-8 policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits associated with ES-8. SAIC's findings are described below:

1.0 GHG EMISSION REDUCTIONS

The purpose of ES-8 is to improve efficiency at existing power plants and repower existing coal plants with natural gas. The goals for this policy include advocating for regulations to incentivize efficiency improvements, such as setting a carbon price or the EPA developing new regulations to install carbon reducing technology.

The potential GHG reductions were analyzed for two aspects of the Efficiency Improvements and Repowering of Existing Power Plants policy. The first was co-firing biomass at existing coal plants, reaching eight percent of energy input by 2015. The second was repowering several coal plants with natural gas-fired combined cycle (NGCC) technology by 2020. Table ES-8.1 illustrates the GHG emission reductions resulting from ES-8:

Table ES-8.1- GHG Emission Reductions Resulting from ES-8

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
Biomass Cofiring	1.2	2.0	2.0
Coal Plant Repowering	0.5	1.4	2.9

1.1. Summary of GHG Emission Methodology

The reduction in GHG emissions from the co-firing coal with biomass option was determined by calculating the emissions produced by the eight percent of coal generation to be replaced by biomass generation. This is the quantity of emissions avoided. To calculate the GHG reductions from repowering existing coal plants with NGCC, the emissions between coal and natural gas were compared and the net reduction that switching 30 percent of coal plants to natural gas would produce was calculated.

1.2. Rationale for GHG Emission Methodology

This methodology of displacing coal with other fuel sources was chosen as a straightforward way to calculate potential emissions savings of repowering plants. The differences in emissions rates were applied to the fuel quantities to determine emissions reductions.

1.3. Detailed Explanation of GHG Emission Methodology

To evaluate the biomass co-firing option, it was assumed that co-firing would begin in 2010 and increase linearly until 2015, when it would contribute to eight percent of energy input at existing coal plants. The emissions from co-fired biomass were compared to coal plants to determine the quantity of GHG reductions.

For the calculation of GHG reductions from repowering existing coal plants with NGCC, it was assumed NGCC would replace coal at a rate of three percent a year beginning in 2011. Ultimately, the goal is to repower 30 percent of eligible coal stations as NGCC by 2020. As in the biomass analysis, coal emissions were compared with NGCC emissions to determine the quantity of GHG reductions.

1.4.GHG Emission Calculations

The same methodology to calculate emissions reductions for the Biomass Co-firing Option was used to calculate emission reductions from the Coal Plant Re-Powering Option:

1. For each year of the study, the coal electricity production was multiplied by the percentage assumed to be replaced by the alternative fuel (either natural gas or biomass) to calculate the total coal fueled generation replaced.

   $$CGR_i = CG_i * PR_i \qquad (1)$$

   Where

   CGR_i = Coal Generation Replaced for year i (GWh)

   CG_i = Coal Generation for year i (GWh)

   PR_i = Percentage of coal generation Replaced for year i (%)

2. Then, the quantity of Coal Generation Replaced was multiplied by the emissions rate for coal to determine the quantity of coal emissions reduced.

   $$CER_i = CGR_i * CER_i \qquad (2)$$

   Where

   CER_i = Coal Emissions Reduction for year i ($MMTCO_2e$)

   CGR_i = Coal Generation Replaced for year i (GWh)

   CER_i = Coal Emissions Rate ($MMTCO_2e$ per GWh)

3. Next, for the Coal Plant Re-Powering Option, the quantity of the replacement natural gas generation (which is the equal to the coal generation replaced) was multiplied by the emissions rate for natural gas to determine the amount of emissions increased by the alternative fuel. This step was unnecessary for the Biomass Co-firing Option because biomass was assumed to have an emissions rate of 0.

   $NGE_i = CGR_i * NGER_i$ (3)

   Where

   NGE_i = Natural Gas Emissions for year i ($MMTCO_2e$)

   CGR_i = Coal Generation Replaced for year i (GWh)

   $NGER_i$ = Natural Gas Emissions Rate ($MMTCO_2e$ per GWh)

4. Finally, the difference between the quantity of emissions reduced by the decrease in coal use and the quantity of emissions augmented by the increase in natural gas use or biomass use (assumed to be 0) determined the net amount of emissions reductions.

   Coal Plant Repowering Option: $NER_i = CER_i - NGE_i$ (4)
   or

   Biomass Cofiring Option: $NER_i = CER_i$ (5)

   Where

   NER_i = Net Emissions Reduction for year i ($MMTCO_2e$)

   CER_i = Coal Emissions Reduction for year i ($MMTCO_2e$)

   NGE_i = Natural Gas Emissions for year i ($MMTCO_2e$)

1.5. GHG Emission Data and Data Sources

- EIA Annual Energy Outlook 2007
- Maryland Commission on Climate Change, *Climate Action Plan,* Appendix D, Greenhouse Gas & Carbon Mitigation Working Group Policy Option Documents, August 2008. Available at http://www.mde.state.md.us/programs/Air/ClimateChange/Documents/www.mde.state.md.us/assets/document/Air/ClimateChange/Appendix_D_Mitigation.pdf

- Maryland Power Plant Research Program (PPRP). 2006. The Potential for Biomass Co-firing in Maryland. Available at http://esm.versar.com/PPRP/bibliography/PPES_06_02/PPES_06_02.pdf

1.6. GHG Emission Assumptions

Table ES-8.2- Table of Assumptions and Inputs

Table of Assumptions and Inputs		2012	2015	2020
CCS Base Case Forecast (before policies are enacted)				
	Coal Generation (GWh)	25,901	25,901	25,901
	Natural Gas Generation (GWh)	1,006	1,006	1,006
	Coal Emissions ($MMTCO_2e$)	24.98	24.86	24.66
	Natural Gas Gross Emissions ($MMTCO_2e$)	0.6	0.6	0.6
	Coal Emissions Rate ($MMTCO_2e$/GWh)	0.0010	0.0010	0.0010
	Natural Gas Emissions Rate ($MMTCO_2$/GWh)	0.0006	0.0006	0.0006
Biomass Co-Firing Option				
	Co-Firing Target Percentage	5%	8%	8%
	Coal Generation Replaced by Biomass (GWh)	1,243	2,072	2,072
	Coal Emissions Reduction ($MMTCO_2e$)	1.2	2.0	2.0
Coal Plant Repowering Option				
	Repowering Target Percentage	6%	15%	30%
	Coal Generation Replaced by Natural Gas (GWh)	1,554	3,885	7,770
	Coal Emissions Reduction ($MMTCO_2e$)	1.5	3.7	7.4
	Natural Gas Emissions Increase ($MMTCO_2$)	1.0	2.3	4.5
	Net Emissions Reduction ($MMTCO_2$)	0.5	1.4	2.9

The Original Methodology assumed that historical generation and emissions quantities would remain constant and that all increases in demand would be met with imports. It also assumed biomass to have zero GHG emissions.

1.7. GHG Emission Analysis and Recommendations

The Original Methodology assumed that biomass has net zero GHG emissions. This is not consistent with MDE's policy on biomass, which is to quantify biomass emissions from combustion. To reflect MDE's policy accurately, this analysis should include biomass GHG emissions.

The Original Methodology did not analyze the potential GHG reductions from efficiency improvements. Emissions savings could result from decreased station load and/or improved heat rate. Plant-wide efficiency measures could reduce the energy requirements of plant operations, thereby increasing net output per unit of fuel. Process improvements could potentially increase the efficiency of the power generation process and reduce net plant heat rate. Improvements in efficiency and heat rates would reduce the quantity of GHG emissions per unit of generation. These improvements would also be consistent with recent EPA best available control technology guidance related to the Clean Air Act Prevention of Significant Deterioration and Title V GHG Tailoring Rule.

Finally, the Original Methodology's assumption that biomass could replace 8 percent of the coal consumed by Maryland's coal-fired power plants may be unrealistic in light of the fact that only two of the State's coal units have existing Title V permits for co-firing. A more realistic assumption could be developed by assessing the potential for biomass co-firing at these two units.

2.0 AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

Although the policy introduces measures for reducing CO_2 emissions, this policy will have less significant effects on criteria pollutant emissions. Introduction of small amounts of biomass to the feed at coal-fired plants does not significantly change the criteria pollutant emission factors (based on figure presented by Lesley Sloss of the IEA Clean Coal Centre at the 35th Annual EPA-A&WMA Annual Exchange in December 2010) from those for coal alone.

The estimated emissions reductions from Policy ES-8 are shown within Table ES-8.3. All numbers for the criteria pollutants reflect a single year of emissions. As a policy to repower Maryland's electricity generators, all of the emissions changes were assigned to Maryland and not the surrounding states. The emissions changes are due to replacement of Maryland's coal-fired power plants (already complying with the Healthy Air Act) with NGCCs (assuming water-steam injection controls).

Table ES-8.3- Emissions Reductions of Criteria Pollutants Associated with ES-8 (tons per year)

	Across Maryland			Across Entire Domain		
Pollutant	**2012**	**2015**	**2020**	**2012**	**2015**	**2020**
SO_2	2,600	5,000	8,400	2,600	5,000	8,400
NO_X	-460	-1,100	-2,500	-460	-1,100	-2,500
CO	-250	-610	-1,200	-250	-610	-1,200
VOC	-12	-30	-68	-12	-30	-68
PM10-primary	290	740	1,000	290	740	1,000
PM2.5-primary	260	660	870	260	660	870

These numbers were compared against the MANE-VU inventories for 2012 and 2018 (Table ES-8.4). The 2018 emissions were estimated by interpolating between the 2015 and 2020 estimates. Table ES-8.4 indicates that the criteria pollutant emissions reductions associated with this policy alone would significantly affect SO_2 emission levels by substituting high sulfur coal with natural gas. By 2018 Table ES-8.4 shows that emissions inventory reductions for sulfur dioxide and particulate matter could be achieved through the repowering policy.

Table ES-8.4- Percentage Reduction in Emissions Inventory Associated with ES-8

	Across Maryland		Across Entire Domain	
Pollutant	**2012**	**2018**	**2012**	**2018**
SO_2	2%	9%	<1%	1%
NO_X	<1%*	-2%	<1%*	<1%*
CO	<1%*	<1%*	<1%*	<1%*
VOC	<1%*	<1%*	<1%*	<1%*
PM10-primary	<1%	1%	<1%	<1%
PM2.5-primary	1%	2%	<1%	<1%

*The change was between -1% and +1%.

Reductions in SO_2 emissions could result in reduced acid rain and less formation of sulfate particulate matter downwind of Maryland. Increases in local NO_X emissions may result in higher local ozone concentrations. Local reductions in particulate matter emissions would improve local ambient particulate matter concentrations and improve visibility.

2.2. Summary of Air Quality Co-Benefits Methodology

The PROMOD model results estimate the decreased fuel consumption at various plants based on marginal reductions in electricity consumption. The marginal plant emissions reductions are calculated by multiplying each power plant's decreased fuel consumption by the plant-specific emission factors (lb pollutant/mmBtu), and Maryland coal-fired plant emission factors are computed from the marginal calculations.

Then emissions reductions are computed by multiplying the policy's decrease in coal consumption by the emission factors. An assumption that electric generators would begin co-firing small quantities of biomass with coal did not lead to reduced emission factors. Emissions increases resulting from the development of NGCCs in Maryland were calculated by multiplying EPA's AP-42 emission factors by the increased electric demand on this sector.

2.3. Air Quality Co-Benefits Calculations

Calculate Emissions Factors Associated with Marginal Power Plant Reductions

1. From the 2009 CAMD data sets, calculate the SO_2 and NO_X emissions rates per mmBtu for coal-fired power plants in EPA Regions 2, 3, 4, and 5.

2. From the 2007 MARAMA inventory for Maryland and surrounding states (DC, DE, NJ, PA, VA, and WV), find the CO, VOC, PM10, and PM2.5 emissions rates per mmBtu for coal-fired power plants that are listed in the database.

3. Calculate the emissions factors for each Maryland coal-fired power plant (lb/mmBtu).

4. Calculate the emissions for each plant for base load, 1 percent reduction and 2 percent reduction by multiplying the emission factors by the change in fuel consumption rates (in mmBtu/yr) from the PROMOD model (years 2012, 2015, and 2020—see section **2.2** for additional details on the PROMOD model runs referred to here).

5. If the SO_2 or NO_X emissions for Maryland power plants exceeded the Healthy Air Act limits, reduce the base load emissions to those permit limits and compute the 1 percent and 2 percent reductions as a fraction of the base load using the ratios of fuel consumption rates.

6. Sum the fuel consumption rates and the pollutant emissions in the base load, 1 percent reduction case, and 2 percent reduction case across all Maryland coal-fired plants (years 2012, 2015, and 2020).

7. Compute the emissions per percent load reduction and the electric generation per percent load reduction for the 1 percent and 2 percent cases. Average the 1 percent and 2 percent cases.

8. Calculate the marginal electricity emissions factors (lb pollutant/MWh change) for Maryland coal-fired plants as the emissions per percent load reduction divided by the electric generation per percent load reduction.

Calculate Emissions Reductions Associated with Fuel/Electricity Consumption Changes

1. Use the marginal electricity emissions factors (lb pollutant/MWh change). Multiply them by the coal generation reduction described in Table 2 to calculate the emissions reductions from Maryland's coal-fired power plants.

2. Assume that co-firing coal-fired plants with less than 10 percent biomass does not significantly change the criteria pollutant emission factors (based on figure presented by Lesley Sloss of the IEA Clean Coal Centre at the 35^{th} Annual EPA-A&WMA Annual Exchange in December 2010) from those for coal alone. Therefore, any generation capacity allotted to biomass co-firing was treated with the same emission factors that were used for PROMOD.

3. The AP-42 factor for CO_2 from natural gas-fired turbines was 110 lb/mmBtu, and this factor was used to calculate the heat rates (12300, 12000, and 11600 Btu/kWh in 2012, 2015, and 2020) of the NGCCs described in Table 2. The natural gas replacements of coal (GWh) were multiplied by the heat rates to calculate NGCC heat input (mmBtu). The AP-42 emission factors for natural gas-fired turbines with water-steam injection controls were multiplied by the NGCC heat input to calculate NGCC emissions.

4. Subtract the NGCC emissions increases from the coal-fired emissions reductions to calculate the overall emissions reductions from this policy.

2.4. Air Quality Co-Benefit Data and Data Sources

The following data sources were used for the analysis:

- PROMOD Model: (http://www1.ventyx.com/analytics/promod.asp)
- Maryland's Healthy Air Act (http://www.mde.maryland.gov/programs/Air/Documents/26-11-27_MD_Healthy_Air_Act.pdf)
- AP-42 (http://www.epa.gov/ttn/chief/ap42/index.html)
- CAMD 2009 (http://camddataandmaps.epa.gov/gdm/)
- MARAMA's 2007 Regional Emissions Inventories (http://www.marama.org/RegionalEmissionsInventory/2007BaseCase/index.html)
- MANE-VU Emissions Inventory (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory)

3.0 INTERACTION WITH OTHER POLICIES

This policy has the potential to interact with AFW-6, AFW-7b, and ES-3. AFW-6 stipulates greater use of biomass feedstocks from agricultural and forest residues, dedicated energy crops, and $CH_4$from manure and litter. As reported in Appendix D of the Maryland CAP,[11] AFW-6 overlaps with policy ES-8 which evaluates the GHG reduction benefits from increased biomass use at existing plants when economical. The analysis noted that the quantity of biomass needed for ES-8 may be limited by that needed for AFW-6. To avoid double counting, the 2008 Climate Action Plan allocated all emission reductions from biomass-to-energy production to ES-8.

Regarding AFW-7b, the first observation is that the goal to substitute fossil diesel with biodiesel is quite modest, and unlikely to cause much competition for feedstocks to co-fire in electricity generation. Secondly, while there is some potential for overlap in the feedstocks for co-firing to produce electricity and to produce biodiesel, it is most likely that the feedstocks for electricity generation will be mostly from forest residues, and those for biodiesel from agricultural crops like soybean. Lastly, the overarching assumption in all policies is that the individual policy goals will be achieved, which nullifies any remaining potential for overlap.

[11] Appendix D of the Maryland CAP, Greenhouse Gas & Carbon Mitigation Working Group: Policy Option Documents

ES-3 subsumes ES-8 since the cap specified in ES-3 encompasses both supply and demand side measures to reduce GHG emissions. Any action taken to implement ES-8 will thus be captured as part of the very wide policy possibilities of ES-3.[12]

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Chapter 3: Agriculture, Forestry, and Waste (AFW) Policies

The following AFW Policies were analyzed:

- AFW 1: Forest Management for Enhanced Carbon Sequestration
- AFW 2: Managing Urban Trees and Forests
- AFW 3: Afforestation, Reforestation and Restoration of Forests and Wetlands
- AFW 4: Protection and Conservation of Agricultural Land, Coastal Wetlands and Forested Land
- AFW 5: "Buy Local" Programs
- AFW 6: Expanded Use of Forest and Farm Feedstocks and By-Products for Energy Productions
- AFW 7b: In State Liquid Biodiesel Production
- AFW 8: Nutrient Trading with Carbon Benefits
- AFW 9: Waste Management and Advanced Recycling

AFW Policy Findings

Table 3.1 presents the 2020 GHG emission reduction estimates for the above-listed nine policies. SAIC developed the reduction estimates for AFW-2 and AFW-9; the estimated reductions for the other seven policies are from the CAP. As the table indicates, Policy AFW-4 is projected to yield the majority of the emission reductions in the AFW sector; this policy accounts for 78 percent of the sum of reductions across all policies. Policy AFW-9 accounts for an additional 18 percent of the emission reductions. The remaining seven policies combined account for only 4 percent of the sum of the reductions.

SAIC reviewed the two policies we re-estimated (AFW-2 and AFW-9) for overlaps; we did not identify any significant overlaps for these two policies (see Chapter 5). However, it is possible that the emission reduction estimates for the other seven policies overlap to some extent.

[12]Chapter 5 provides a more detailed discussion of the interaction between ES-3 and other ES policies, which is similar to the interaction with ES-8.

Table 3.1. Summary of GHG Emission Reductions from the AFW Sector in 2020

Sector/Policy	2020 GHG Emission Reductions ($MMTCO_2e$)
Agriculture, Forestry & Waste (AFW)	
AFW-1: Forest Management for Enhanced Carbon Sequestration	0.09
AFW-2: Managing Urban Trees & Forests	1.32
AFW-3: Afforestation, Reforestation & Restoration of Forests & Wetlands	0.62
AFW-4: Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land	26.54
AFW-5: "Buy Local" Programs	0.03
AFW-6: Expanded Use of Forest & Farm Feedstocks & By-Products for Energy Production	0.54
AFW-7b: In-State Liquid Biodiesel Production	0.17
AFW-8: Nutrient Trading with Carbon Benefits	0.14
AFW-9: Waste Management & Advanced Recycling	5.97
AFW Total (Unadjusted for Overlap)	**34.10**

Table 3.2 presents the projected 2020 reductions in criteria pollutant emissions for the nine AFW policies. As this table indicates, Policies AFW-2, AFW-3, AFW-4, and AFW-9 are all significant contributors to the emission reductions in SO_2, NO_X, and PM10, while AFW-7b accounts for the majority of the reductions in CO, VOC, and PM2.5. As discussed in Chapter 5, the criteria pollutant reduction estimates for the nine AFW policies do not appear to overlap either each other, or the reduction estimates for policies in other sectors, to any significant extent.

Table 3.2. Summary of Criteria Pollutant Emission Reductions from the AFW Policies in 2020

		SO_2 (Tons)	NO_x (Tons)	CO (Tons)	VOC (Tons)	PM10 (Tons)	PM2.5 (Tons)
	Agriculture, Forestry & Waste (AFW)						
AFW-1	AFW 1 - Forest Management for Enhanced Carbon Sequestration						
AFW-2	AFW 2 - Managing Urban Trees & Forests	300.00	450.00			2,400.00	
AFW-3	AFW 3 - Afforestation, Reforestation & Restoration of Forests & Wetlands	273.00	410.00			2,200.00	
AFW-4	AFW 4 - Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land	523.00	784.00			4,182.00	
AFW-5	AFW 5 - "Buy Local" Programs	0.22	9.50	220.00	10.00	0.37	0.35
AFW-6	AFW 6 - Expanded Use of Forest & Farm Feedstocks & By-Products for Energy Production						
AFW-7b	AFW 7b - In-State Liquid Biodiesel Production	8.90	-7.60	952.00	85.00	1.50	1.40
AFW-8	AFW 8 - Nutrient Trading with Carbon Benefits						
AFW-9	AFW 9 - Waste Management & Advanced Recycling	890.00	2,200.00	290.00		131.00	
	AFW Total	**1,995.12**	**3,845.90**	**1,462.00**	**95.00**	**8,914.87**	**1.75**

Policy No.: AFW-1

Policy Title: Forest Management for Enhanced Carbon Sequestration

SAIC was tasked with reviewing the AFW-1 policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits associated with AFW-1. SAIC's policy review and evaluation of the Original Methodology is below:

1.0 GHG EMISSION REDUCTIONS

AFW-1 seeks to encourage the management activities needed to keep forests healthy and vigorous on private and public forest lands in the state of Maryland. The overarching goal is to restore, enhance, and sustain the economic, social, and ecological values of these forests. Specific goals include: improving sustainable forest management on 25,000 acres of private land by 2020; improving sustainable forest management on all state-owned resource lands by 2020, and as per a recent policy update by the Maryland Department of Natural Resources (DNR); and third-party certify 50 percent of State-owned forest lands as sustainably managed. The policy also addresses invasive species.

The analysis quantified the increased carbon sequestration from forest management based upon the difference between intensively managed and non-managed stands of forests as modeled by the United States Department of Agriculture (USDA) Forest Service (USFS). The resulting GHG emission reductions from the enhanced sequestration of $CO_2$from forest management activities are as follows:

Table AFW-1.1. GHG Emission Reductions Resulting from AFW-1

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
Annual Carbon Sequestration from Sustainably Managed Forests	0.036	0.058	0.094

1.1. Summary of GHG Emission Methodology

The analysis used USFS data to compare the CO_2 removed from the air by intensively managed and normally managed forests. It then assumed that sustainably managed forests would behave similarly to intensively managed forests in terms of the amount of CO_2 removed from the air. An estimated acreage of state owned and private lands that would change their forest management practices as a result of AFW-1 was multiplied by an enhanced CO_2 rate of removal (carbon sequestration) to determine the GHG emission reductions. [13]

1.2. Rationale for GHG Emission Methodology

The methodology used determined a set of annual carbon storage values for different forest types in Maryland as described in Step 2 in the GHG Emission Calculation section below. The validity of this

[13]As detailed in 1.3.2, the actual factor used did not result from this methodology. It is unclear how the actual factor was determined.

approach is highly dependent upon the validity of the assumptions. The calculations of overall carbon benefits are inconsistent with the stated methodology of the prior contractor.

1.3. GHG Emission Calculations

The increased carbon sequestration from sustainable forest management was calculated as follows:

Step 1: Determine the Difference between Sequestration in Intensively Managed versus "Average" Loblolly stands

Assuming that intensively managed loblolly stands are equivalent to sustainably managed loblolly stands, the Original Analysis used USFS sequestration tables in GTR-NE-343,[14] and noted that intensively managed stands store 5 percent more carbon than average stands from years 0 through 90.

> Average Annual Sequestration = 1/90 (Sequestration at year 90 - Sequestration at Year 0)
>
> Difference = Average Annual Sequestration in Intensive Stands - Average Annual Sequestration in "Average" Stands (Expressed as a percentage difference = 5%)

Step 2: Applied Percentage Increase to Other Forest Types

Using USFS GTR-NE-343 data, determined the average annual sequestration (as in Step 1) for oak-hickory, oak-pine, and loblolly-shortleaf pine stands, to be 0.8, 0.604, and 0.662 tons carbon/acre/year, respectively. Applied the 5 percent increase from Step 1 proportionally according to forest distribution in Maryland of 63 percent oak-hickory, 10 percent oak-pine and 11 percent loblolly-shortleaf pine.[15]

> Enhanced Average Annual Sequestration per Forest Type = Carbon Storage of Forest Type * Percentage Increase (e.g., 0.8 * 1.05 for oak-hickory)
>
> Weighted Annual Sequestration per Forest Type = Fraction of Forest Type * Enhanced Average Annual Sequestration per Forest Type (e.g., 0.63 * 0.8 * 1.05 for oak-hickory)
>
> Average Annual Sequestration Across Forest Types = Sum of Annual Sequestration per Forest Type (for oak-hickory, oak-pine, and loblolly-shortleaf pine)
>
> Overall Average Annual Sequestration = 0.63 * 0.8 * 1.05 + 0.1 * .604 * 1.05 + 0.11 * 0.662 * 1.05 = 0.669 tons C/acre/year.

Step 3: Determined Annual Acreage for Applying Sustainable Forest Management Practices

Based on USFS Forestry Inventory Analysis data, determine the area of state owned forests to be 749,975 acres. To meet policy goals, simulated the linear implementation of sustainable forest management on 57,690 and 1,923 acres of existing state owned and private forests annually.

> Annual Target for Implementation (Public) = 749,975/13 = 57,960 acres

[14]Smith et al., Ibid.
[15]The citation provided in the prior analysis is incomplete. It is "USDA USFS Northern Global Change Program," available at http://www fs.fed.us/ne/global/pubs/books/epa/states/MD.htm," which is a site with several different documents. The particular document cited in the prior analysis is unclear.

Annual Target for Implementation (Private) = 25,000/13 = 1,923 acres

Step 4: Calculated Increased Carbon Sequestration

Used an implied (back calculated by SAIC) annual increase in carbon storage of 1.2 * 10^-7 $MMTCO_2e$/year over 2008 through 2020. (The Original Methodology appears to have made some calculation errors. The rate here should be 0.67 * 44/12 * 10^-6 = 2.46 * 10^-6 $MMTCO_2e$.)

1.4. GHG Emission Data and Data Sources

The quantification used data from USFS GTR-NE-343[16]

1.5. GHG Emission Assumptions

The assumptions made in the quantification of sequestered carbon are not all evident since a significant part of the methodology is not made explicit, as mentioned in Section 1.3 above. Those assumptions that appear to have been made are as follows:

- Intensively managed, high productivity stands are equivalent to sustainably managed stands of loblolly-shortleaf pines
- Annual carbon storage rates derived from the loblolly-shortleaf pine association can be applied to oak-hickory and oak-pine forest associations
- Both sets of assumptions above are likely to have resulted in overestimates of the GHG benefits of this policy

1.6. GHG Emission Analysis and Recommendations

The methodology attempts to estimate a carbon sequestration rate for different types of sustainably managed forests in Maryland by applying the factor derived from loblolly-shortleaf pines to the other types. The derivation of this rate was initially based upon 90 year average carbon storage values for intensively managed loblolly-shortleaf pine association to give a value of 0.579 tons carbon/acre/year. Then, the 5 percent value determined in Step 1 above, was applied to a 65 year average carbon storage value for loblolly-shortleaf pines without a clear rationale.

It is also unclear why, even if the 5 percent value is valid for the loblolly-shortleaf pine forest association, it would also apply to oak-hickory and oak-pine forest associations. Oak-hickory composes the majority of Maryland forests and loblolly-shortleaf pines a much smaller fraction. The justification for applying a rate determined from a less common forest type to a more common forest type is unclear, as is that for applying a conifer rate (loblolly-shortleaf pines) to a deciduous forest type (oak-hickory).

[16] The data sets included in this USFS document encompass several forest type and age classes within each type, and, are, as such too large for inclusion in this report itself. Step 2 above details the intermediate calculations used to derive the average annual sequestration.

In the future, it would be more accurate to derive annual carbon storage values for all forest types (loblolly-shortleaf pines, oak-hickory, and oak-pine) under sustainable management, possibly through comparison with similar management in other areas of the country or field trials. Then, these annual carbon storage values could be compared to the annual carbon storage values of the same forests under existing management to derive the increase in annual carbon storage under sustainable management. Finally, the difference could be multiplied to the acreage under planned sustainable management to determine the increase in carbon sequestration through the sustainable forest management of Maryland forests.

2.0 AIR QUALITY CO-BENEFITS

This policy has no significant National Ambient Air Quality Standards (NAAQS)co-benefits because, unlike other AFW policies (e.g., AFW-2, AFW-3 and AFW-4) it does not result in an increase in the area of forested land within the State. Since the geographic extent of the tree canopy does not change under this policy, there is no net change in pollutant removal. The approach used to quantify the air quality co-benefits of the various AFW forestry policies considers the benefit of additional forested acreage.

3.0 INTERACTION WITH OTHER POLICIES

AFW-1 involves improved forest management on private and public lands. While other AFW policies also involve interventions in forests, the nature of these policies is such that there is little to no interaction with AFW-1. AFW-3 includes afforestation and reforestation, but this involves adding or replacing lost forested areas, and not enhancing their management as in AFW-1. One component of AFW-4 is the conservation and protection of forests, especially upland forests most susceptible to conversion to settlements. This does not involve any change to the management of these forests, as in AFW-1. AFW-6 seeks to increase the use of forestry residues for use as a biomass feedstock, but AFW-6 does not include any forest management measures.

Policy No.: AFW-2

Policy Title: Managing Urban Trees and Forests for Greenhouse Gas (GHG) Benefits

SAIC was tasked with reviewing the AFW-2 policy analysis which was conducted by a prior MDE contractor (Original Methodology) and revising the methodology to include Maryland-specific data and/or other enhancements. SAIC subsequently recalculated the GHG emission reductions associated with AFW-2 based upon its recommended methodology (Revised Methodology). SAIC also quantified the air quality co-benefits associated with AFW-2. SAIC's revised policy findings are described below:

1.0 GHG EMISSION REDUCTIONS

Policy AFW-2 is designed to increase urban tree canopy (UTC) from 28 percent to 38 percent by 2020, enhancing green infrastructure, and improving urban wood recovery. The UTC reduces GHG emissions directly from new carbon sequestration resulting from the new trees and indirectly from the reduction in electricity used for cooling due to the shade and local climate effects of the trees. The GHG reductions are listed in Table AFW-2.1 below:

Table AFW-2.1: GHG Emission Reductions Resulting from AFW-2

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
AnnualCarbon Sequestration by Planted Trees	0.16	0.45	1.32
Reduced Electricity Demand for Cooling and Heating	*De minimis*		

1.1. Summary of GHG Emission Methodology

SAIC used an urban forestry model[17] to determine the year-to-year carbon sequestration and heating/cooling effects of a representative sample of tree species in Maryland. An average sequestration value for each year (from 2009 – 2020) was calculated and applied to the number trees needed each year to meet AFW-2 policy objectives. The methodology took into account the growth of the trees (and thus sequestration) from year to year. The heating/cooling effects of the new tress proved to be *de minimis*.

The following five steps were used to quantify GHG reductions for AFW 2:

Step 1. Identify a representative sample set of Maryland trees

Step 2. Determine the carbon sequestration per calendar year from 2008 through 2020 for each cohort of trees planted in a given year, and calculate an average annual GHG reduction

Step 3. Determine the number of trees that would need to be planted annually, based on the difference between the current UTC of 28 percent and the UTC policy target of 38 percent

[17] U.S. Department of Agriculture Forest Service's Center for Urban Forestry carbon calculator (CTCC)

Step 4. Determine the total GHG reductions from carbon sequestration for 2012, 2015, and 2020 by multiplying the results of Step 2 and Step 3

Step 5. Determine the total GHG reductions from decreased electricity demand

1.2. Rationale for GHG Emission Methodology

The Center for Urban Forestry Carbon Calculator (CTCC) model was used because it is based on actual field measurements of a wide variety of trees in multiple regions of the country, thus enabling a more Maryland specific analysis, rather than a generic approach. The trees available for modeling for Maryland corresponded sufficiently well to the "Marylanders Plant Trees" recommended list, and provided specific annual values for GHG reductions as the trees grew over time. The i-Tree set of tools, also developed by USFS, would have been potentially more applicable, and are frequently used in municipal inventories of carbon sequestration by urban trees. However, policy AFW-2 involves trees to be mostly planted in the future, and with no clear manner of determining what those tree species will be. Since i-Tree requires the input of data on the trees to be analyzed, it was not possible to use i-Tree for this analysis, and CTCC, which comes pre-loaded with field data based on thousands of trees samples in urban settings, was used instead.

An alternative approach would be to apply an average sequestration rate derived from existing trees, but this has the large disadvantage of not accounting for the growth of trees. Since, under AFW-2, the trees would be planted in between 2008 to 2020, age-specific GHG reduction values are needed. It is necessary to know, for example, the sequestration of a red maple from 2008-2009 (year one to two), 2009-2010 (year two to three), 2010-2011 (year three to four), and so on, until 2020. Additionally, the chosen methodology allowed the determination of the GHG reduction per tree for each age cohort. By way of illustration, we were able to create data for red maples planted in 2008 and follow their annual sequestration until 2020, similarly for red maples planted in 2009 through 2020, those planted in 2010 through 2020, and so on.

Summing the carbon sequestration benefits of all the tree species over each calendar year provided a good estimation of what the average GHG reduction benefits would be over time, providing policy makers with continuous annual GHG sequestration, critical to tracking policy benefits over time, and, naturally providing the same information for the key years of 2012, 2015, and 2020. This analysis can also be easily extended beyond 2020 with minimum effort, which is an advantage for policymakers considering the extension of this policy.

1.3. Difference Between Original & Revised Methodologies and Results

The Original Methodology used a current and policy target UTC of 40.1 percent and 50 percent, respectively, and thus determined that 20 percent more urban trees (or 22 million trees) were needed.[18]Assuming uniform tree planting in between 2008 and 2020 indicated a planting rate of 1.7

[18]The prior analysis misinterpreted the "2020 Forest Conservation Goals for Maryland Summary" of November 2007, which states that 50% of the areas developed before 1984 should have urban canopy goals by 2020, and not that the policy goal is a UTC of 50%. The number of trees provided in the following source is 82.6 million: USFS. Urban and community forests of the Southern Atlantic region: Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia. Gen. Tech. Rep. NRS-50. Newtown Square,

million trees per year. Sequestration was calculated based on an implied sequestration rate of 0.0223 metric tons/tree/yr. The source of this factor is unclear.[19] GHG reductions from heating and cooling effects were determined with reference to a USFS study based on evergreen trees.[20] An implied GHG emissions reduction rate of 0.0635 mt/tree/yr (the source of which is not stated) was applied to the 1.7 million trees to be grown annually from 2008 through 2020. The overall GHG reduction was determined by adding the GHG reductions from carbon sequestration to the reductions associated with heating/cooling effects.

In contrast, the Revised Methodology used an urban forestry model[21] to determine the year-to-year carbon sequestration and heating/cooling effects of a representative sample of tree species in Maryland. The policy assumptions for current and future UTCs were 28 percent and 38 percent resulting in a lower baseline number of trees in the Revised Methodology, as opposed to 40 percent and 50 percent in the Original Methodology. The percentage difference between the initial and target UTC was 25 percent for the Original Methodology and is 37.5 percent for the Revised Methodology. Thus, the Revised Methodology projects an increase of 2.27 million new trees per year to meet the policy objectives, as compared to the 1.7 million trees per year projected in the Original Methodology. The requirement for these additional trees and a more justifiable average annual sequestration rate, which accounted for tree growth over time , resulted in substantially more GHG reductions from new sequestration. The Revised Methodology found the GHG reductions from reduced cooling and heating demands to be *de minimis*, in contrast to the Original Methodology which used an implied GHG reductions rate approximately three times larger than its own sequestration rate. The GHG reductions benefit in the Original Methodology for 2012, 2015, and 2020 are all approximately three times as high as the sequestration benefit, which is not possible. The extremely high GHG reductions benefit explains why the Original Methodology produced results higher than the Revised Methodology.

The Original Methodology predicted total GHG emission reductions of 0.7289, 1.1663 and 1.8952 MMTCO_2e for 2012, 2015, and 2020, respectively. The corresponding results for the Revised Methodology are 0.16, 0.45, and 1.32 MMTCO_2e for 2012, 2015, and 2020 respectively.

1.4. GHG Emission Calculations

The following Steps describe the quantification approach summarized in Section 1.1 above:

Step 1: Identify a Representative Sample of Maryland Trees:

PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 85 p. pp.41-42. http://www.nrs.fs fed.us/pubs/gtr/gtr_nrs50.pdf.

[19]2008. Maryland Commission on Climate Change. Climate Change Action Plan. Appendix D - Greenhouse Gas & Carbon Mitigation Working Group. p.17. The **implied value** of 0.0223 metric tons per tree per year was determined for the current analysis by dividing sequestration by the number of planted trees.
[20]E.G. McPherson and J.R. Simpson. 1999. CO_2 reduction through urban forestry: guidelines for professional and volunteer tree planters. USDA USFS Pacific Southwest Research Station. General Technical Report PSW-GTR-171.
[21]U.S. Department of Agriculture Forest Service's Center for Urban Forestry carbon calculator (CTCC)

The model used to determine GHG sequestration chosen was the USFS Center for Urban Forestry carbon calculator (CTCC), which includes pre-loaded sequestration values for numerous species of urban trees[22]. The CTCC is programmed in an Excel spreadsheet. It is designed to provide carbon-related information for a single tree located in one of sixteen U.S. climate zones. CTCC outputs can be used to estimate GHG benefits for existing trees or to forecast future benefits. Tree size data are based on growth curves developed from samples of 650 - 1000 street trees for each of about 20 predominant species per region. The CTCC uses biomass equations to derive total CO_2 stored, and annual CO_2 sequestration.[23] To determine effects of tree shade on building energy performance (heating and cooling), over 12,000 simulations were conducted using different combinations of tree sizes, locations, and building vintages. Effects of tree shade require user input of azimuth (compass direction of tree relative to house), distance of tree from house, housing vintage, heating equipment, and cooling equipment.

The "Marylanders Plant Trees" program provides a recommended list of tree species.[24] The first set of tree species considered for analysis were those common to the "Marylanders Plant Trees" list and the CTCC. Given that the carbon sequestration, as well as the shade and climate effects of trees are dependent upon their size and shape, this list was further refined to ensure that the selected trees for analysis were representative of as many of the following tree types as possible: deciduous (large, medium, small), broad leaf evergreen (large, medium, small), and conifers (large, medium, small). The list of species selected for analysis is listed in Table AFW-2.2 below.

[22]USDA Forest Service. Climate Change Resource Center - Urban Forests and Climate Change. http://www.fs.fed.us/ccrc/topics/urban-forests/ctcc/. SAIC considered the i-Tree set of tools developed by the USFS and collaborating organizations (http://www.itreetools.org/) for this analysis, but in the absence of data on the trees to be planted, it was not feasible to use it, and the CTCC, also developed by USFS was selected, since it includes field data on a number of tree species.
[23]The CTCC calculates volume from dbh, then weight using density values, next carbon as a known proportion of the mass of trees, and finally CO_2.
[24]Marylanders Plant Trees - Recommended Tree List for Marylanders Plant Trees. http://www.trees maryland.gov/pickatree.asp#trees

Table AFW-2.2. – List of Tree Species by Type Used for Modeling Average GHG Reductions and Inferred Age at Planting (Based on 2 inch dbh)

Tree Type	Tree Species	Inferred Age at Planting (years)
Broadleaf deciduous		
Large	Maple, Red (*Acer Rubrum*)	1
	Oak, Northern Red (*Quercus rubra*)	1
	Oak, White (*Quercus alba*)	3
	Oak, Willow (*Quercus phellos*)	4
	Sweetgum, American (*Liquidambar styraciflua*)	3
Medium	Birch, River (*Betula nigra*)	2
Small	Crabapple Spp. (*Malus spp.*)	2
Broadleaf evergreen		
Large	N/A	N/A
Medium	Magnolia, Southern (*Magnolia grandiflora*)	3
Small	Holly, American (*Ilex opaca*)	4
Conifer		
Large	Pine, Loblolly (*Pinus taeda*)	4
Medium	Redcedar, Eastern (*Juniperus virginiana*)	3
Small	N/A	N/A

<u>Step 2: Determine Carbon Sequestration Per Calendar Year:</u>

The first step in using the CTCC is determining the age of the trees at planting. Based on informal contacts with the Maryland Nursery and Landscape Association, a diameter at breast height (dbh) of 2 inches was assumed for newly planted trees. This 2 inch dbh was used to infer an age at planting using the CTCC. Then, the carbon sequestration was modeled using the CTCC for each of the tree species chosen, providing year-over-year data on GHG reductions for each species from 2008 through 2020, as shown in Table AFW-2.3. This table provides both the total carbon storage, which is cumulative sequestration over time, and annual sequestration. The annual sequestration was used for the subsequent steps of the calculations.

Table AFW-2.3. Annual GHG Sequestration for Chosen Tree Species from 2008 through 2020[25]

Carbon Storage Values from CUFR Calculator (kg CO_2/tree) and Carbon Sequestration Values (kg CO_2/tree)														
Tree Species		**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Maple, Red (*Acer Rubrum*)	Cumulative Storage	15.5	24.8	36.9	52	70.3	92	117.6	147.1	181	219.4	262.7	311.2	365.1
	Annual Sequestration		9.3	12.1	15.1	18.3	21.7	25.6	29.5	33.9	38.4	43.3	48.5	53.9
Oak, Northern Red (*Quercus rubra*)	Cumulative Storage	4.9	15.5	33.8	60.8	97.3	144	201.4	270.1	350.3	442.4	546.8	663.5	792.9
	Annual Sequestration		10.6	18.3	27	36.5	46.7	57.4	68.7	80.2	92.1	104.4	116.7	129.4
Oak, White (*Quercus alba*)	Cumulative Storage	8.1	18.7	35.4	51.3	91.4	132.6	183.9	246.2	320.3	407	507.1	621.4	750.6
	Annual Sequestration		10.6	16.7	15.9	40.1	41.2	51.3	62.3	74.1	86.7	100.1	114.3	129.2
Oak, Willow (*Quercus phellos*)	Cumulative Storage	13.9	31.4	57.5	93.1	138.9	195.2	262.6	341.5	432	534.4	648.8	775.5	914.3
	Annual Sequestration		17.5	26.1	35.6	45.8	56.3	67.4	78.9	90.5	102.4	114.4	126.7	138.8
Sweetgum, American (*Liquidambar styraciflua*)	Cumulative Storage	7.8	17.6	32.6	53.4	80.8	115.4	157.7	208.1	267.3	335.5	413.4	501.1	599.3
	Annual Sequestration		9.8	15	20.8	27.4	34.6	42.3	50.4	59.2	68.2	77.9	87.7	98.2
Birch, River (*Betula nigra*)	Cumulative Storage	8.5	21.2	41.9	71.9	112.8	165.6	231.8	312.3	408.4	521	651.3	800.3	968.8
	Annual Sequestration		12.7	20.7	30	40.9	52.8	66.2	80.5	96.1	112.6	130.3	149	168.5

[25]For each tree species, the top line is the annual carbon storage in kilograms per tree, and the second line is the annual sequestration calculated for every year after 2008. 2008 is the earliest possible year of planting, hence sequestration can only be calculated for the following year, and so on.

Carbon Storage Values from CUFR Calculator (kg CO_2/tree) and Carbon Sequestration Values (kg CO_2/tree)

Tree Species		**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Crabapple spp. (Malus spp.)	Cumulative Storage	3.5	14	34.9	67.7	112.9	170.7	240.8	322.8	416.3	520.7	635.7	760.6	895.1
	Annual Sequestration		10.5	20.9	32.8	45.2	57.8	70.1	82	93.5	104.4	115	124.9	134.5
Magnolia, Southern (*Magnolia grandiflora*)	Cumulative Storage	2.9	5.7	9.8	15.5	22.9	32.3	44	58	74.8	94.4	117.1	143.1	172.7
	Annual Sequestration		2.8	4.1	5.7	7.4	9.4	11.7	14	16.8	19.6	22.7	26	29.6
Holly, American (*Ilex opaca*)	Cumulative Storage	9.7	13.9	18.9	24.9	32	40.2	49.6	60.3	72.3	85.7	100.6	117.1	135.2
	Annual Sequestration		4.2	5	6	7.1	8.2	9.4	10.7	12	13.4	14.9	16.5	18.1
Pine, Loblolly (*Pinus taeda*)	Cumulative Storage	4	10	19.8	34	53.2	78	108.8	146	190.2	241.7	300.9	368.1	443.7
	Annual Sequestration		6	9.8	14.2	19.2	24.8	30.8	37.2	44.2	51.5	59.2	67.2	75.6
Redcedar, Eastern (*Juniperus virginiana*)	Cumulative Storage	9.5	18.2	30	45.2	63.8	86	111.9	141.6	175.3	212.9	254.7	300.7	350.9
	Annual Sequestration		8.7	11.8	15.2	18.6	22.2	25.9	29.7	33.7	37.6	41.8	46	50.2
Total Annual Sequestration			**102.7**	**160.5**	**218.3**	**306.5**	**375.7**	**458.1**	**543.9**	**634.2**	**726.9**	**824**	**923.5**	**1026**
Average Annual Sequestration			**9.34**	**14.59**	**19.85**	**27.86**	**34.15**	**41.65**	**49.45**	**57.65**	**66.08**	**74.91**	**83.95**	**93.27**

Step 3: Determine Annual Number of Trees to be Planted:

According to the DNR, the current UTC is 28 percent and Maryland-specific USFS data states the current number of urban trees as 82.6 million. Applying the policy target UTC of 38 percent, a 35.7 percent increase in trees would be required or 29.5 million trees more to reach 112 million trees by 2020. This would require an average annual planting of 2.27 million trees in urban areas.[26]

Number of trees needed per year ={(38-28)/28 = 35.7%}*82.6 million*1/13 = 2.27 million

Step 4: Determine Total GHG Reductions from Sequestration:

The average annual carbon sequestration determined in Step 2 was multiplied by 2.27 million trees (from Step 3) and converted to metric tons of $CO_2$to determine the annual GHG reduction for each cohort. This data is provided in Table AFW-2.4. The table shows the year of planting in the rows, and the calendar years in the columns. The values from left to right for "year of planting" rows 2008 through 2020 provide the annual sequestration values from the year of planting through 2020. To illustrate, the values from left to right in year of planting (row) 2008 provide the annual sequestration of trees planted in 2008 through 2020 (e.g., 63,250.45metric tons of $CO_2$is the annual sequestration in calendar year 2012 for the trees planted in 2008).

Determining the annual sequestration of all trees in a given years involves summing the values in a given calendar year (column). So, for calendar year 2012, the total annual sequestration is the sum of (all in metric tons of CO_2)63,250.45 (planted in 2008), 45,049.18(planted in 2009), 33,121.36(planted in 2010), and 21,193.55(planted in 2011), giving 162,614.55..

[26]Current and policy target UTC provided by MD DNR (email from Marian Honeczy of March 24th, 2011). Current tree population from: USFS. Urban and community forests of the Southern Atlantic region: Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia. Gen. Tech. Rep. NRS-50. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 85 p. pp.41-48. http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs50.pdf.

Table AFW-2.4- Total Annual GHG Reductions from Sequestration (Metric Tons CO_2)

Year of Planting (rows)/Calendar Year (columns)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2008	21,193.55	33,121.36	45,049.18	63,250.45	77,530.82	94,535.18	112,241.18	130,875.82	150,005.73	170,043.64	190,576.82	211,729.09
2009		21,193.55	33,121.36	45,049.18	63,250.45	77,530.82	94,535.18	112,241.18	130,875.82	150,005.73	170,043.64	190,576.82
2010			21,193.55	33,121.36	45,049.18	63,250.45	77,530.82	94,535.18	112,241.18	130,875.82	150,005.73	170,043.64
2011				21,193.55	33,121.36	45,049.18	63,250.45	77,530.82	94,535.18	112,241.18	130,875.82	150,005.73
2012					21,193.55	33,121.36	45,049.18	63,250.45	77,530.82	94,535.18	112,241.18	130,875.82
2013						21,193.55	33,121.36	45,049.18	63,250.45	77,530.82	94,535.18	112,241.18
2014							21,193.55	33,121.36	45,049.18	63,250.45	77,530.82	94,535.18
2015								21,193.55	33,121.36	45,049.18	63,250.45	77,530.82
2016									21,193.55	33,121.36	45,049.18	63,250.45
2017										21,193.55	33,121.36	45,049.18
2018											21,193.55	33,121.36
2019												21,193.55
2020												21,193.55
Total Sequestered in Calendar Year	**21,193.55**	**54,314.91**	**99,364.09**	**162,614.55**	**240,145.36**	**334,680.55**	**446,921.73**	**577,797.55**	**727,803.27**	**897,846.91**	**1,088,423.73**	**1,321,346.36**

Step 5: Determine Total GHG Reductions from Reduced Electricity Demand:

The CTCC also provides GHG reductions from heating and cooling effects of trees with the input of specific assumptions, including GHG emissions factors. The CTCC was used to estimate GHG reductions using annual blended emissions factors (Maryland and PJM in CO_2e/kWh) determined by SAIC, and CTCC heating emissions factors, for each species of tree from Table AFW-2.2.[27] The GHG effects of the trees were small (in the order of 1-3 kg/tree/year) especially in the early years of tree growth. Even the trees at maximum age (i.e., in year 2020) provided very low GHG impacts as shown in Table AFW-2.5. The average GHG effect across all species was -1.2 kg CO_2e even at maximum age.[28] The corresponding value from Table AFW-2.3 for carbon sequestration is 93.3 kg CO_2e, an order of magnitude higher. Given the numerous assumptions in a study of this nature, it was determined that the heating and cooling effects were therefore *de minimis*, and that their final contribution would be negligible compared to the carbon sequestration.

Table AFW-2.5- GHG Reductions from Shade and Local Climate Effects (kg of carbon per tree) in Year 2020

Tree Species	GHG Reduction (kg CO_2/tree)
Maple, Red (*Acer Rubrum*)	-0.8
Oak, Northern Red (*Quercus rubra*)	8.2
Oak, White (*Quercus alba*)	5.7
Oak, Willow (*Quercus phellos*)	5.4
Sweetgum, American (*Liquidambar styraciflua*)	4.8
Birch, River (*Betula nigra*)	-0.3
Crabapple Spp. (*Malus spp.*)	-1.6
Magnolia, Southern (*Magnolia grandiflora*)	-11.4
Holly, American (*Ilex opaca*)	-1.7
Pine, Loblolly (*Pinus taeda*)	-7.2
Redcedar, Eastern (*Juniperus virginiana*)	-12.8
Average GHG Effect (kg CO_2/tree)	**-1.2**

[27]The input assumptions were azimuth=SE, distance of tree from house = 20-40 feet, housing vintage = 1950-1980, heating equipment = natural gas, and cooling equipment = heat pump. The azimuth was chosen based on repeating the energy analyses with all other factors remaining constant and using the azimuth which provided a GHG reduction value closest to the average of all different directions (N, NE, E, SE, S, SW, W, NW). The tree distance values were <20, 20-40, 40-60, and >60 feet. 20-40 was chosen based on size of lawns and general homeowner preferences. The housing vintage choices were <1950, 1950-1980, and >1980. The mid value was used. Heating and cooling equipment were chosen based on discussions with the U.S. Energy Information Administration (DOE).
[28]The negative value indicates that, on average, for the sample set of trees chosen, under the assumptions input to the model, the reduced energy for cooling due to shade, and heating due to windbreak effects, are outweighed by the increased heating needed due to shading in the winter (insulation). This is also possibly attributable to the differential efficiency of heating and cooling equipment, with the latter generally being more efficient.

1.5. GHG Emission Data and Data Sources

- Recommended Tree List for Marylanders Plant Trees (to determine list of trees for analysis)
- USFS CTCC pre-loaded sequestration values (to determine list of trees for analysis)
- Current UTC of 28 percent and target UTC of 38 percent determined from MD Forestry Service
- USFS General Technical Report NRS-50 (for number of urban trees)

1.6. GHG Emission Assumptions

This analysis uses the following assumptions:

- Current UTC is 28 percent and policy target UTC is 38 percent
- Data provided in USFS General Technical Report NRS-50 of 82.6 million urban trees is valid
- The sample set of trees (see Table 1) is a representative sample for the trees planted over the implementation of the policy
- The tree saplings will have an initial dbh of 2 inches
- The CTCC model which uses tree growth curves based on hundreds of samples of each species and thousands of heating/cooling simulations is applicable for the purposes of this analysis
- For estimating heating and cooling GHG reductions, the following parameters are valid: azimuth=SE, distance of tree from house = 20-40 feet, housing vintage = 1950-1980, heating equipment = natural gas, and cooling equipment = heat pump.

2. AIR QUALITY CO-BENEFITS

The estimated emissions reductions from AFW-2 are shown in the following table:

Table AFW-2.6- Emissions Reductions in Maryland Associated with AFW-2

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	120	190	300
NO_X	180	280	450
PM10-primary	930	1,500	2,400

These numbers were compared against the MANE-VU inventories for 2012 and 2018. The reductions for SO_2 and NO_X are all less than four-tenths of a percent, indicating that the co-benefits associated with this policy for those pollutants would be unlikely to improve air quality. The value for PM is 0.78 and 1.5 percent in 2012 and 2018, respectively and this policy could contribute to an improvement PM air quality.

Table AFW-2.7- Percentage Reduction in State Emissions Inventory Associated with AFW-2

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	0.11	0.31
NO_X	0.14	0.39
PM10-primary	0.78	1.5

2.1. Summary of Air Quality Co-Benefits Methodology

For AFW-2 the benefits to attainment/maintenance of the PM, NO_X, and SO_2 NAAQS is related to the amount of air pollutant that the trees will remove from the ambient air. The method for estimating these reductions was based on empirical data that was derived from an urban park. Emission reduction factors were derived from the park data and applied to the additional forest acreage resulting from this policy. The reductions were then compared to the projected statewide emission inventories to determine the significance of the reductions.

2.2. Rationale for Air Quality Co-Benefits Methodology

The methodology for determining co-benefits for the PM, NO_X, and SO_2 NAAQS was based on urban park data. This methodology was chosen because it was readily available and provided a simple and straightforward means to estimating the ambient air pollutant reductions. There may be models that produce estimates based on more details and considers more parameters; however, given the small reductions involved, the lack of detailed data, and the uncertainty associated with such models, it was not believed that the additional effort would produce more reliable estimates. It is recognized that using data derived from an "urban park" does not consider rural environments, tree species, forest density, site-specific meteorology, and other variables. But given the minimal reductions that are estimated it is unlikely that a more refined approach would produce more accurate estimates.

2.3. Air Quality Co-Benefits Calculations

The removal from the atmosphere of airborne pollutants by a 212 hectare urban park has been estimated to be 48, 9, and 6 pounds per day for PM, NO_X and SO_2, respectively. Pollutant reduction factors were derived as in the following example for PM:

> 48 lb-PM/212 hectare-day x 0.404 hectare/acre x 365 day/yr x .0005 ton/lb = 0.017 ton-PM/acre-yr

The reduction for each pollutant was the product of the pollutant reduction factor and the estimated additional acreage of forest. The calculation for PM in 2020 is as follows:

> 0.017 ton-PM/acre-yr x 250,000 acres = 4,200 ton-PM/yr

The potential co-benefit of those emission reductions listed in Table 6 is the absolute reductions in Table 5 compared to the statewide emission inventory.

2.4. Air Quality Co-Benefits Data and Data Sources

- **Urban park emissions.** Identified Benefits of Community Trees and Forests by Dr. Rim D. Coder, University of Georgia, October 1996
- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory
- Trees density.Dwyer, J.F., Nowak, D.J., Noble, M.H., and Sisinni, S.M. in review, Connecting People with Ecosystems in the 21st Century: An Assessment of our Nation's Urban Forests. Draft Urban Forest RPA.   It was cited on http://www.coloradotrees.org/benefits.htm
- Tree mechanism for removing pollutants. Encyclopedia of the Earth, http://www.eoearth.org/, Environmental effects of urban trees and vegetation

2.5. Air Quality Co-Benefits Assumptions

- It was assumed that all the "urban park" PM was PM**10**. Particle size distribution was not provided for PM in the "urban park" data.

3. INTERACTION WITH OTHER POLICIES

AFW-2 does not interact with any other AFW policies as it is the only policy which includes urban tree planting. While the emissions reductions benefits of the planted trees could be included aspotential measures under RCI-10 (Energy Efficiency Resource Standard) and ES-3 (GHG Cap and Trade), the analysis determined that the GHG reductions benefits from reduced heating and cooling are *de minimis*, and therefore the potential interaction with these policies is negligible.

Policy No.: AFW-3

Policy Title: Afforestation, Reforestation, and Restoration of Forests and Wetlands

SAIC was tasked with reviewing the AFW-3 policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits of this policy. The results of SAIC's review of the Original Methodology and the quantification of related co-benefits is below:

1.0. GHG EMISSION REDUCTIONS

As described in Appendix D of the Maryland CAP, AFW-3 seeks to increase forest cover through afforestation and reforestation in forests, agricultural areas, and wetlands. The goals are to offset the loss of 900 acres each month to development, (June 2008 through December 2020); establish riparian buffers at a rate of 360 miles/year to 2020 until 70 percent of all stream miles in the state are buffered, and increase wetland areas wherever feasible. Updated performance targets provided by the Maryland Department of Natural Resources (DNR) further elaborate upon these policy objectives to: establish or restore 16,678 acres of wetlands, protect 250,000 acres of forest by 2020, and afforest and/or reforest of 10,000 acres.

The analysis did not quantify the establishment or restoration of wetlands, rather, it calculated the carbon sequestration from afforestation to offset development as well as riparian buffers as follows:

Table AFW-3.1. Annual GHG Emission Reductions Estimated from AFW-3

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
AFW-3 Total	**0.217**	**0.366**	**0.624**
Afforestation to Offset Development	0.209	0.346	0.574
Riparian Buffer Afforestation	0.008	0.020	0.050

1.1. Summary of Methodology

The analysis used USFS data for forest types chosen as similar to current Maryland forests. It used different forest types to estimate the CO_2 removed from the air through "afforestation to offset development," and "riparian buffer afforestation". Using the acreages for both aspects of this policy, specific CO_2 rates of removal were applied to determine the GHG emission benefits.

1.2. Rationale for GHG Emission Methodology

The analysis used USFS General Technical Report GTR-NE-343 to determine carbon sequestration rates from afforestation for offsetting development and riparian buffers. Applying weighted rates based upon the composition of two broad areas for afforestation – offsetting development and riparian buffers – to the targeted acreages for afforestation provided estimates of carbon sequestration.

1.3. GHG Emission Calculations

The analysis quantified GHGs from two aspects of AFW-3:

- Afforestation to Offset Development
- Afforestation for Riparian Buffers

The methodologies employed for each aspect are discussed separately below.

A) Afforestation to Offset Development Calculations

<u>Step 1: Determine the Average Annual Sequestration for Different Forest Types</u>

The Original Analysis used USFS sequestration tables in GTR-NE-343 to determine average annual carbon sequestration in oak-hickory, oak-pine, and loblolly-shortleaf pine stands from year 0 to year 45, as 1.2, 1, and 0.9 tons carbon/acre/year.[29]

Average Annual Sequestration = 1/45 (Sequestration at year 45 - Sequestration at Year 0)

<u>Step 2: Create a weighted annual average of carbon sequestration.</u>

The Original Analysis used a forest composition for Maryland forests of 70 percent oak-hickory, 15 percent oak-pine, and 15 percent loblolly-shortleaf pine, and created a weighted annual average carbon sequestration rate from the average annual sequestration for oak-hickory, oak-pine, and loblolly-shortleaf pine stands (from Step 1), as follows:

Weighted Annual Sequestration per Forest Type = Fraction of Forest Type * Average Annual Sequestration per Forest Type (e.g., for oak-hickory = 0.7 * 1.2 = 0.84 tons/acre/year)

Average Annual Sequestration Across Forest Types = Sum of Weighted Annual Sequestration per Forest Type = 0.7 * 1.2 + 0.15 * 1 + 0.15 * 0.9 = 1.155 tons/acre/year

<u>Step 3: Determine the acreage in each year.</u>

Based on policy goals of offsetting 900 acres monthly, determined the annual target acreages for seven months in 2008 (program implementation began in June) and twelve months from 2009 through 2020. This resulted in 6,300 acres (900 acres * 7 months) for 2008, and 10,800 acres for all other years.

<u>Step 4: Calculate the annual and cumulative carbon sequestration for all program years.</u>

Multiply the per acre carbon sequestration rate determined in Step 2 by the acreage in each year (from Step 3) to give the annual carbon sequestration for all program years.

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[29] J.E. Smith, L.S. Heath, K.E. Skog, and R.A. Birdsey. 2006. Methods for calculating forest ecosystem and harvested carbon with standards estimates for forest types of the United States. USDA United States Forest Service (USFS) Northern Research Station. General Technical Report GTR-NE-343. http://www.treesearch.fs.fed.us/pubs/22954 (ne_gtr343.pdf)

Total Annual Sequestration (in a given year) = Average Annual Sequestration * CO_2/C mass ratio * Annual Acreage * 1 * 10^-6 MMt/Mt (e.g., for 2008 = 1.155 * 44/12 * 6,300 * 10^-6 = 0.027 $MMTCO_2e$)

B) Afforestation for Riparian Buffers Calculations

Step 1: Determined annual acreage for afforestation.

Using Chesapeake Bay Program goals for the afforestation of riparian areas of 900 miles per year by 2020 and assuming that 40 percent of these riparian buffers would be established in Maryland, determine an annual acreage for afforestation.[30]

Total Policy Acreage = 900 miles * 50 feet * 1.894*10^-4 miles/foot * 640 acres/square mile * 0.4 = 2,182 acres.

Annual Acreage = 2,182 acres / 13 years = 168 acres / year

Step 2: Determined the forest composition of riparian buffer areas

The analysis used by the prior contractor assumed that the forest composition of riparian buffer areas could be represented by a mix of 50 percent elm-ash-cottonwood and 50 percent loblolly-pine forest types. This assumption was based on the prior contractor's conclusion that the two most common species in riparian buffers statewide are loblolly pine and green ash.[31]

Step 3: Determine a weighted annual average carbon sequestration rate.

As in Step 1 and Step 2 of Section 1.3.2, use 45 year carbon storage rates of loblolly pines and elm-ash-cottonwood to determine a weighted annual average carbon sequestration rate of 0.9 tons C/acre/year.

Step 4. Determine the annual and cumulative carbon sequestration

As in step 4 of Section 1.3.2, multiply the per acre carbon sequestration rate (Step 3) by the acreage (Step 1) to produce the annual and cumulative carbon sequestration.

1.4. GHG Emission Data and Data Sources

The GHG emission quantification used data from:

- USFS GTR-NE-343
- Chesapeake Bay Program goals
- Maryland DNR Forest Service Research Report DNR/FS-01-01

[30] 2007. Chesapeake Bay Program. Chesapeake Bay Program Announces Forest Conservation Goals for Watershed. http://www.chesapeakebay net/press_ec2007forests.aspx

[31] April 2001. Maryland DNR Forest Service. Riparian Forest Buffer Survival and Success in Maryland, Maryland DNR Forest Service Research Report DNR/FS-01-01. http://dnrweb.dnr.state.md.us/download/forests/rfb_survival.pdf

1.5. GHG Emission Assumptions

- Offsetting of development acres would be completely achieved by afforestation without any part of the offsetting being done through reforestation.
- Composition of Maryland forests is 70 percent oak-hickory, 15 percent oak-pine, and 15 percent loblolly-shortleaf pine, and that afforestation would be implemented in these proportions.
- Afforestation in riparian buffers is equivalent, in carbon sequestration terms, to a 50 percent elm-ash-cottonwood and 50 percent loblolly-pine forest types. Equating riparian vegetation to this mix risks overestimating the GHG benefits, especially due to the use of loblolly-pine data.
- For both offsetting development and riparian buffers, assumed that average sequestration rates based on existing trees can be applied to newly planted trees and that this rate can be applied independent of tree age.

1.6. GHG Emission Analysis and Recommendations

AFW-3 encourages afforestation actions to offset development and to support riparian buffers. The analysis applied a per area sequestration rate from USFS General Technical Report GTR-NE-343 to determine the carbon sequestration. This method assumes that the trees would sequester carbon at the same rate over the life of the policy, and that these rates would be those of the simulated forest stands which form the basis of GTR-NE-343.

Within this policy, saplings are planted, grow and sequester carbon over different time spans, depending upon when they are planted. Maryland plans to use the predicted GHG emission reductions in 2012, 2015, and 2020 to measure its progress against the policy's ultimate goals. Determining accurate carbon sequestration values involves tracking the planting and growth of several age cohorts of trees, i.e., knowing for example the per acre sequestration of the oak-hickory forest type planted in 2008-2009 (first year of growth), 2009-2010 (second year of growth), 2010-2011 (third year of growth), and so on, until 2020. This analysis should be repeated for each age cohort, i.e., white oak forest type species planted in 2008 (growth over 2008-2020), those planted in 2009 (growth over 2009-2020) through 2020, and so on. Summing the carbon sequestration benefits of the various forest types over each calendar year would provide more accurate GHG reductions/carbon sequestration benefits on an annual basis, providing policy makers both with meaningful GHG reduction estimates for the key policy years of 2012, 2015, and 2020.

2.0 AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from AFW-3 are shown in the following table:

Table AFW-3.2- Emissions Reductions in Maryland Associated with AFW-3

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	92	160	273
NO_X	140	240	410
PM10-primary	740	1300	2200

These numbers were compared against the MANE-VU inventories for 2012 and 2018. The reductions for SO_2 and NO_X are all less than four-tenths of a percent, indicating that the co-benefits associated with this policy for those pollutants would be unlikely to improve air quality. The value for PM is greater than 1 percent in 2018 and this policy could contribute to an improvement PM air quality.

Table AFW-3.3- Percentage Reduction in State Emissions Inventory Associated with AFW-3

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	0.086	0.28
NO_X	0.10	0.34
PM10-primary	0.6	1.4

2.2. Summary of Air Quality Co-Benefits Methodology

The benefits to attainment/maintenance of the PM, NO_X, and SO_2 NAAQS in AFW 3 is related to the amount of air pollutant that the trees will remove from the ambient air. The method for estimating these reductions was based on empirical data that was derived from an urban park. Emission reduction factors were derived from the park data and applied to the additional forest acreage resulting from this policy. The reductions were then compared to the projected statewide emission inventories to determine the significance of the reductions.

2.3. Rationale for Air Quality Co-Benefits Methodology

The methodology for determining co-benefits for the PM, NO_X, and SO_2 NAAQS was based on urban park data. This methodology was chosen because it was readily available and provided a simple and straightforward means to estimating the ambient air pollutant reductions. There may be models that produce estimates based on more details and considers more parameters; however, given the small reductions involved, the lack of detailed data, and the uncertainty associated with such a models it was not believed that the additional effort would produce more reliable estimates. It is recognized that using data derived from an "urban park" does not consider rural environments, tree species, forest density, site-specific meteorology, and other variables. But given the minimal reductions that are estimated it is unlikely that a more refined approach would produce more accurate estimates.

2.4. Air Quality Co-Benefits Calculations

The removal from the atmosphere of airborne pollutants by a 212 hectare urban park has been estimated to be 48, 9, and 6 pounds per day for PM, NO_X and SO_2, respectively. Pollutant reduction factors were derived as in the following example for PM:

Equation 1: 48 lb-PM/212 hectare-day x 0.404 hectare/acre x 365 day/yr x .0005 ton/lb = 0.017 ton-PM/acre-yr

The reduction for each pollutant was the product of the pollutant reduction factor and the estimated additional acreage of forest. The calculation for PM in 2020 is as follows:

Equation 2: 0.017 ton-PM/acre-yr x 130,500 acres = 2,200 ton-PM/yr

The potential co-benefit of those emission reductions listed in Table 2 is the absolute reductions in Table 1 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefits Data and Data Sources

- Urban park emissions**:**Identified Benefits of Community Trees and Forests by Dr. Rim D. Coder, University of Georgia, October 1996

- Statewide emission inventory**:** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.6. Air Quality Co-Benefits Assumptions

- It was assumed that all the "urban park" PM was PM**10**. Particle size distribution was not provided for PM in the "urban park" data. Ignoring the larger PM, which may have been present, only raises the estimated reductions for PM**10**. Since those reductions are de minimis anyway, it does not change the conclusions.

- Research has shown that biogenic emissions produce NO_X limited atmospheric chemistry over the entire Eastern U.S. region. http://www.epa.gov/appcdwww/apb/biogenic.htm. Model uncertainties range from ± 50 percent for summertime isoprene emission estimates (the most important compound emitted from U.S. deciduous forests) to over a factor of 10 for some oxygenated VOC such as hexenol.

3.0 INTERACTION WITH OTHER POLICIES

AFW policies that could interact with AFW-3 are AFW-1 and AFW-4. AFW-1 involves improved forest management on private and public lands. AFW-3 includes afforestation and reforestation, but this involves adding or replacing lost forested areas, and not enhancing their management as in AFW-1. One component of AFW-4 is the conservation and protection of forests, especially upland forests most susceptible to conversion to settlements. This does not involve any addition of forests as in AFW-3, and instead focuses upon preventing the conversion of existing forests. There is thus no interaction with AFW-1 and AFW-4.

Policy No.: AFW-4

Policy Title: Protection and Conservation of Agricultural Land, Coastal Wetlands, and Forested Land

SAIC was tasked with reviewing the AFW-4 policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits of this policy. The results of SAIC's review of the Original Methodology and the quantification of related co-benefits is below:

1.0 GHG EMISSION REDUCTIONS

AFW-4 contains measures designed to conserve agricultural, forest, and coastal wetlands, as a means of mitigating and adapting to climate change. The measures included in policy AFW-4 include: (1) protecting 962,000 acres of productive agricultural lands ensuring no net loss by 2020,[32] (2a) retaining existing levels of forest cover in the Maryland at 2.6 million acres past 2020 and (2b) protecting an additional 250,000 acres of forest by 2020, (3) assessing coastal wetlands as a sink or source of GHGs and evaluating the impact of climate change upon the extent of coastal wetlands, and (4) protecting priority coastal zones using a living shoreline. The analysis quantified measures (1) and (2).

Table AFW-4.1- Annual GHG Emission Reductions Resulting from AFW-4

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
AFW-4 Total	**10.190**	**16.319**	**26.536**
(1) Protecting Agricultural Lands (962,000 acres)	0.106	0.170	0.276
(2a) Avoiding deforestation (250,000 acres by 2020)[33]	9.810	15.710	25.545
(2b) Sequestration in protected forests	0.274	0.439	0.715

1.1. Summary of GHG Emission Methodology

The analysis used estimates of the carbon in agricultural soils and in forest vegetation to determine how emissions of carbon dioxide into the air could be reduced through AFW-4. Maintaining agricultural lands and forests in their current form would prevent the emissions that occur when farms or forests are cleared. For agricultural lands, the analysis quantified the loss of carbon from the soils by multiplying the estimated carbon content of the soils by the area of agricultural lands targeted under the policy.

[32]This is the updated acreage from November 2010. The value in Appendix D was 1.2 million acres.
[33]The original analysis presented annual values in Table I-15 of Appendix D. The 2012 and 2015 values were determined using the cumulative totals up to that year.

There are two carbon benefits when forests are not cleared for development (or any other purpose), and both were quantified. The first benefit is that when forests are cleared, there is an immediate release of CO_2 into the atmosphere, therefore, when forests are not cleared, this CO_2 is not released to the atmosphere. This is calculated by determining the quantity of carbon in the area of the forest targeted by the policy.

The second carbon benefit relates to the continuous removal of CO_2 from the atmosphere by the forest vegetation through photosynthesis (also termed "carbon sequestration"). When the forest is cleared, this ongoing removal of carbon dioxide is lost. This loss is calculated by determining how fast carbon is absorbed by the forests and applying this rate of carbon removal to the forest areas targeted under the policy. The calculations for agricultural soils and forests are repeated for each year of the policy (2008-2020) and then added together to provide annual carbon benefits.

1.2. Rationale for GHG Emission Methodology

Protecting agricultural lands – The analysis assumed a soil carbon density and multiplied it by an annual rate of agricultural loss calculated to be 11,813 acres per year (see 1.3 A Step 1) and not the policy target for the avoided conversion of agricultural lands. As mentioned in the "Assumptions" section 1.5 Abelow, it is unclear why a calculated annual rate of agricultural land loss was used instead of an average annual conversion rate based on the life of the policy target of 962,000 acres (November 2010 update) or the 1.2 million acres specified in Appendix D of the Maryland CAP.[34]

Avoided deforestation – The analysis determined carbon density from United States Department of Agriculture (USDA) Forest Inventory and Analysis (FIA) data for non-soil total forest carbon and multiplied it by annual policy targets.

Sequestration in protected forests – The analysis determined a single sequestration rate using USDA GTR-NE-343 and applied it to annual policy targets for preventing forest conversion for development use.

1.3. GHG Emission Calculations

The Original Methodology quantified three aspects of this policy:

- Protecting agricultural lands
- Avoided deforestation
- Sequestration in protected forests

The methodologies employed for each aspect are discussed separately below.

A) Protecting Agricultural Lands

The following methodology was used to quantify GHG emission reductions from protected agricultural lands:

[34] Assuming linear implementation of the policy, the calculation would be 962,000/13 or 74,000 acres annually. With the CAP value of 1.2 million acres it would be 92,308 acres annually. The prior contractor used 11,813 acres annually.

Step 1: Determine agricultural land lost to development.

Citing the USDA National Resources Inventory (NRI) data, determined that the agricultural land lost to development is 11,813 acres/year.[35]

Step 2: Determine annual land lost to development.

Divided this 11,813 acres value by 13 (2008-2020) to give an annual loss of 909 acres of agricultural land to development.

Step 3: Assume that when agricultural land is converted to development, 50 percent of the land would be cleared, and that 75 percent of the soil carbon in the top eight inches of the soil would be lost.

Step 4: Assume a soil carbon content of 0.017 million metric tons of carbonper 1,000 acres.[36]

Step 5: Determine loss of soil carbon per acre.

From Step 3 and Step 4, determined a loss of soil carbon of 2.3375 * 10^-5 $MMTCO_2$ per acre when agricultural land is converted for development use.

From Step 4, 0.017 MMTC per 1000 acres = 1.7*10^-5 MMTC /acre

Loss of Soil Carbon Per Acre (as CO_2) = Soil Carbon Content * Fraction of Land Cleared * Fraction of Carbon Lost * CO_2/C mass ratio

Loss of Soil Carbon Per Acre (as CO_2) = 1.7*10^-5 MMTC * 0.5 * 0.75 * 44/12 = 2.3375 * 10^-5 $MMTCO_2$/acre.

Step 6: Determine avoided emissions from preventing the conversion of agricultural land to development.

Citing AFW-4 policy goals, multiplied the annual target for avoided agricultural land conversion (from Step 2) by the per acre soil carbon loss (Step 5) to determine the avoided emissions from preventing the conversion of agricultural land to development use.

Avoided Emissions = Annual Target for Avoided Land Conversion * Loss of Soil Carbon per acre

(For example for the first year, 909 acres of agricultural land not lost to development = 909 acres * 2.3375*10^-5 $MMTCO_2$/acre = 0.021 $MMTCO_2$)

B) Avoided Deforestation

The following methodology was used to quantify GHG emission reductions from avoided deforestation:

Step 1: Determine amount of land cleared for residential development.

Using American Housing Survey and NRI data for Maryland, determined that 67 percent of the land is cleared during conversion of forestland to residential development.[37]

[35]Currently available NRI data for Maryland states that the amount of land in crop production for Maryland decreased from 1,794,700 acres in 1982 to 1,616,000 acres in 1997, which is an annual rate of 11,913 acres. USDA Natural Resources Conservation Service (NRCS). NRI. Maryland. http://www.md nrcs.usda.gov/technical/nritext html

[36]The source of this value is unclear.

Step 2: Assumed that 100 percent of the non-soil total forest carbon would be lost in this 67 percent of the previously forested area.

Step 3: Determine a per acre value of non-soil forest carbon.

Citing FIA data for Maryland, and based upon Steps 1 and 2 above, determined a per acre value of 27.9 metric tons of non-soil forest carbon.

Non-soil forest carbon = Total Forest Carbon – Soil Carbon

Non-soil forest carbon = 73.9 - 25.5 = 48.4 metric tons carbon per acre[38]

Carbon lost from Forest to Development Conversion = Fraction of Land Cleared * Fraction of Carbon Lost * Non-soil Forest Carbon

Carbon lost from Forest to Development Conversion = 0.67 * 1 * 48.4 = 32.43 tons carbon per acre. (This value is different from the 27.9 used in the original analysis which could be attributable to the updating of the FIA data since the original study.)

Step 4: Determine the tons of CO_2 lost per acre from development.

Convert the 27.9 metric tons of carbon (from Step 3) to CO_2 to determine the tons of CO_2 lost per acre from forest converted to development.

CO_2 lost from Forest to Development Conversion = Carbon lost from Forest to Development Conversion * CO_2/C mass ratio = 27.9 metric tons C * 44/12 metric ton CO_2/metric ton C = 102.3 metric tons CO_2 per acre.

Step 5: Determine annual target acreages of avoided forest to residential conversion

Based upon policy goals of protecting 96,000 acres by 2012, and a total of 250,000 acres by 2020; determined yearly target acreages of 19,200 for 2008 through 2012 (96,000 divided by 5), and 19,250 for 2013 through 2020 (250,000 less 96,000, divided by 8).

Step 6: Determine tons of CO_2 avoided.

Multiplied the target annual acreages (from Step 5) with the tons of carbon dioxide that would be lost per acre (from Step 4) to determine the tons of carbon dioxide emissions avoided.

Avoided Emissions = Acreage * CO_2 "Lost" from Forest to Development Conversion (e.g., for 2008 = 19,200 acres * 102.3 metric tons CO_2 per acre = 1,964,160 tons CO_2 or 1.96 $MMTCO_2$)

C) Sequestration in Protected Forests

The following methodology was used to quantify GHG emission reductions from sequestration in protected forests:

Step 1: Citing FIA, use a forest distribution for Maryland of 63 percent oak-hickory types, 11 percent oak-pine and 10 percent natural loblolly-shortleaf pine stands.[39]

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[37]The source of how this 67% value was determined is unclear.

[38]The analysis did not provide details on the data used, but the current USDA Forest Inventory and Analysis (FIA) database provides a value of 73.9 metric tons per acre total forest carbon and 25.5 metric tons per acre soil carbon for public forests in Maryland. Source: USDA USFS FIA. http://www fia fs fed.us/Forest%20Carbon/default.asp.

[39] The exact source of this forest type distribution is unclear.

Step 2: Determine average annual carbon sequestration

The Original Analysis used USFS sequestration tables in GTR-NE-343 to determine average annual carbon sequestration for oak-hickory, oak-pine, and loblolly-shortleaf pine stands from year 25 to year 75, as 0.8, 0.7, and 0.5 tons carbon/acre/year.[40]

Average Annual Sequestration = 1/50 (Sequestration at year 75 - Sequestration at Year 25)

Step 3: Determined an average annual sequestration rate for forests not converted to development

The Original Analysis used a forest composition for Maryland forests of 70 percent oak-hickory, 15 percent oak-pine, and 15 percent loblolly-shortleaf pine, and created a weighted annual average carbon sequestration rate from the average annual sequestration for oak-hickory, oak-pine, and loblolly-shortleaf pine stands (from Step 3), as follows:

Weighted Annual Sequestration per Forest Type = Fraction of Forest Type * Average Annual Sequestration per Forest Type (e.g., for oak-hickory = 0.75 * 0.8 = 0.6 tons/acre/year)

Average Annual Sequestration Across Forest Types = Sum of Weighted Annual Sequestration per Forest Type = 0.75 * 0.8 + 0.15 * 0.7 + 0.15 * 0.5) = 0.78 metric tons C/acre/year[41]

In CO_2 terms = 0.78 * 44/12 = 2.86 tons CO_2 / acre / year

Step 4: Determine the annual and cumulative sequestration.

Multiplied the annual target acreages identified in Step 5 of Section B above by the weighted average annual sequestration rate from Step 3 to determine the annual and cumulative sequestration of forestlands not cleared for development use.

Annual Sequestration = Acreage * Average Annual Sequestration Across Forest Types (e.g., for 2008 = 19,200 * 2.86 * 1* 10^-6 $MMTCO_2$= 0.055 $MMTCO_2$)

1.4. GHG Emission Data and Data Sources

- USDA National Resources Inventory. Maryland. http://www.md.nrcs.usda.gov/technical/nritext.html#Crop%20and%20Pasture%20Trends
- J.E. Smith, L.S. Heath, K.E. Skog, and R.A. Birdsey. 2006. Methods for calculating forest ecosystem and harvested carbon with standards estimates for forest types of the United States. USDA United States Forest Service (USFS) Northern Research Station. General Technical Report GTR-NE-343. http://www.treesearch.fs.fed.us/pubs/22954 (ne_gtr343.pdf)

[40] J.E. Smith, L.S. Heath, K.E. Skog, and R.A. Birdsey. 2006. Methods for calculating forest ecosystem and harvested carbon with standards estimates for forest types of the United States. USDA United States Forest Service (USFS) Northern Research Station. General Technical Report GTR-NE-343. http://www.treesearch.fs.fed.us/pubs/22954 (ne_gtr343.pdf)

[41] This equation is implied from the existing analysis.

1.5. GHG Emission Assumptions

The assumptions are presented separately by each part of the analysis

A) Protecting Agricultural Lands - Assumptions

- 50 percent of the land is cleared upon conversion of agricultural land for development use
- Only carbon from soil is lost and that there would be no change in the levels of aboveground carbon stocks
- 75 percent of the soil carbon in the top eight inches of the soil is lost when agricultural land is converted to development use
- Soil carbon value is 0.017 million metric tons of carbon per 1,000 acres
- Although the policy goal is to maintain 962,000 acres of agricultural land, the analysis was conducted based upon a land conversion rate of 11,813 acres per year over the life of the policy (2008-2020)
- Policy implementation would be linear

B) Avoided Deforestation - Assumptions

- 67 percent of the land is cleared during conversion of forestland to residential development
- 100 percent of the vegetation carbon stocks would be lost in the event of forest conversion to developed uses
- No appreciable carbon sequestration would occur in soils or biomass following development
- Policy implementation would be linear

C) Sequestration in Protected Forests - Assumptions

- A single sequestration rate determined from oak-hickory, oak-pine, and loblolly-shortleaf pine forest types is applicable to the forest conservation efforts
- Policy implementation would be linear

1.6. GHG Emission Analysis and Recommendations

For calculating the emissions avoided by protecting agricultural lands, the assumed value used for soil carbon and its source is unclear. Soil carbon values for the non-urban to urban land use conversion are available in scientific literature.[42] A more accurate analysis would use more specific data.

To improve the accuracy of the agricultural findings for policy (1), SAIC recommends that 74,000 acres annually (based on a total goal of 962,000 acres of cropland over the life of the policy) be used in the calculations rather than the 11,813 acre value of yearly land converted from cropland to development use.

[42]For example, see "2002. Pouyata, R. et al. Soil carbon pools and fluxes in urban ecosystems . Environmental Pollution 116:S107-S118."

The approach to calculating the avoided deforestation is generally sound, based upon FIA data for the state of Maryland. However, both the avoided deforestation and sequestration analyses relied upon linear implementation of the initiatives, which, given the variety of implementation mechanisms proposed, is unlikely. The USDA GTR-NE-343 “look-up” tables are based upon the FORCARB model and likely lack the degree of accuracy sufficient for an analysis of this nature. Using values from limited forest types and extending them statewide provides a rough first approximation of sequestration. A more accurate analysis may be possible through the use of more detailed information on forest types and their sequestration rates.

2.0 AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from AFW-4 are shown in the following table:

Table AFW-4.2- Annual Emissions Reductions (based on Cumulative Acreage) in Maryland Associated with AFW-4

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	201	322	523
NO_X	301	482	784
PM10-primary	1,606	2,572	4,182

These numbers were compared against the MANE-VU inventories for 2012 and 2018. The reductions for SO_2 and NO_X are all less than four-tenths of a percent of the projected MANE-VU inventories, indicating that the co-benefits associated with this policy for those pollutants would be unlikely to improve air quality. The value for PM is greater than 1 percent of the projected MANE-VU inventory in 2018 and this policy could contribute to an improvement PM air quality.

Table AFW-4.3- Percentage Reduction in State Emissions Inventory Associated with AFW-4

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	0.19	0.54
NO_X	0.2	0.67
PM10-primary	1.3	2.6

2.2. Summary of Air Quality Co-Benefits Methodology

For Policy AFW-4 the benefits to attainment/maintenance of the PM, NO_X, and SO_2 NAAQS is related to the amount of air pollutant that the trees will remove from the ambient air. The method for estimating these reductions was based on empirical data that was derived from an urban park.[43] Emission reduction factors were derived from the park data and applied to the additional forest acreage resulting from this policy. The reductions were then compared to the projected statewide emission inventories to determine the significance of the reductions.

2.3. Rationale for Air Quality Co-Benefits Methodology

The methodology for determining co-benefits for the PM, NO_X, and SO_2 NAAQS was based on urban park data. This methodology was chosen because it was readily available and provided a simple and straightforward means to estimating the ambient air pollutant reductions. There may be models that produce estimates based on more details and considers more parameters; however, given the small reductions involved, the lack of detailed data, and the uncertainty associated with such a models it was not believed that the additional effort would produce more reliable estimates. It is recognized that using data derived from an "urban park" does not consider rural environments, tree species, forest density, site-specific meteorology, and other variables. But given the minimal reductions that are estimated it is unlikely that a more refined approach would produce more accurate estimates.

2.4. Air Quality Co-Benefits Calculations

The removal from the atmosphere of airborne pollutants by a 212 hectare urban park has been estimated to be 48, 9, and 6 pounds per day for PM, NO_X and SO_2, respectively. Pollutant reduction factors were derived as in the following example for PM:

48 lb-PM/212 hectare-day x 0.404 hectare/acre x 365 day/yr x .0005 ton/lb = 0.017 ton-PM/acre-yr

[43] Although this policy is more likely to impact rural forests than urban parks, both AFW-4 and urban parks represent similar vegetation (trees and grasses). Granted that there are likely to be differences in the air quality impacts of urban versus rural tree stands, there were no available studies indicating that calculation methods for AFW-4 should deviate from those for other AFW policies.

The reduction for each pollutant was the product of the pollutant reduction factor and the estimated additional acreage of forest that avoids deforestation as a result of Policy AFW 4. The calculation for PM in 2015 is as follows:

0.017 ton-PM/acre-yr x 153,750 acres = 2,572 ton-PM/yr

The potential co-benefit of those emission reductions listed in Table 2 is the absolute reductions in Table 1 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefits Data and Data Sources

- **Urban park emissions.** Identified Benefits of Community Trees and Forests by Dr. Rim D. Coder, University of Georgia, October 1996
- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.7. Air Quality Co-Benefits Assumptions

- It was assumed that all the "urban park" PM was PM10. Particle size distribution was not provided for PM in the "urban park" data.

3. INTERACTIONS WITH OTHER POLICIES

AFW policies that could interact with AFW-4 are AFW-1, AFW-3, and AFW-5. One component of AFW-4 is the conservation and protection of forests, especially upland forests most susceptible to conversion to settlements. AFW-1 involves improved forest management to enhance carbon sequestration on existing private and public lands, and while conserved lands could be targeted for improved forest management, the avoided carbon emissions from conversion (AFW-4), the sequestration in protected forests (AFW-4), and the enhanced carbon sequestration from improved management (AFW-1) are separate. The last category would only consist of the additional sequestration achieved through improved forest management. AFW-3 includes afforestation and reforestation, but this involves adding or replacing lost forested areas, and not preventing the conversion of existing forests. The implementation of the portion AFW-5 (Buy Local) calling for 80 percent of Maryland's food supply to be grownlocally by 2050 is related to the portion of policy AFW-4 that deals with protecting agricultural lands. However, since AFW-4 focuses

AFW-4 also has synergistic interactions with TLU-2 (Land Use & Location Efficiency), since TLU-2 encourages high density development and discourages urban sprawl, which will protect forests susceptible to conversion to settlements. Thus, TLU-2 and AFW-4 will have a synergistic effect, as noted in Chapter 5. Since the emissions reductions from these two policies are calculated using two distinct methodologies (reduced VMT for TLU-2 and the prevention of the release of carbon from cleared forests for AFW-4), the emission reductions for the two policies may be summed.

Policy No.: AFW-5

Policy Title: "Buy Local" Programs for Sustainable Agriculture, Wood and Wood Products

SAIC was tasked with reviewing the AFW-5 policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits of this policy. The results of SAIC's review of the Original Methodology and the quantification of related co-benefits is below:

1.0 GHG Emission Reductions

AFW-5, as described in Appendix D of the Maryland CAP and the November 2010 Maryland Commission on Climate Change Report Update, includes several measures designed to reduce GHGs associated with the production and transport of agricultural goods imported from other states or countries by replacing them with locally produced goods. The policy goals included in AFW-5 are: (1) increasing the number of local farmers' markets in Maryland 25 percent by 2015 and 50 percent by 2020, (2) increasing the locally grown and produced portion of food consumed by Marylanders to 80 percent by 2050, and (3) replacing 20 percent of imported wood with wood locally grown and processed by 2015 and 50 percent by 2050. The analysis quantified policy goal (1).

Table AFW-5.1- GHG Emission Reductions Resulting from AFW-5

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
AFW-5 Total	**.009**	**.015**	**0.031**

1.1. Summary of GHG Emission Methodology

The analysis estimated GHG reductions associated with increasing the number of local farmers' markets in Maryland by scaling up the results of a 2001 Iowa study by the Leopold Center entitled "Food, Fuel, and Freeways: An Iowa perspective on how far food travels, fuel usage, and GHG emissions[44]" that determined fuel usage and CO_2 emissions associated with different food systems in Iowa. Results of the Iowa study were scaled to Maryland by using a comparison of the two states' populations and linked to AFW- 5 using the percentage increase in farmers' markets called for in the policy.

1.2. Rationale for GHG Emission Methodology

[44]Pirog, R., Van Pelt, T., Enshayan, K., Cook, E., 2001, *Food, Fuel, and Freeways: An Iowa perspective on how far food travels, fuel usage, and greenhouse gas emission,* Leopold Center for Sustainable Agriculture, June 2001.

The methodology chosen for determining GHG reductions associated with AFW-5 focused on reductions in what is often called "food-miles." Food-miles represent the distance food travels from production to the consumer; locally produced food travels a shorter distance then conventionally produced food, resulting in transportation related GHG reductions. There is however a dearth of comprehensive studies of food-miles that could be used as the basis for estimating GHG reductions associated with local food production. The 2001 Leopold Center report, while Iowa-specific, is one of the only well documented U.S. studies available to use as a basis for estimating GHG reductions from food-miles. The analysis was based on the Leopold Center study because no comparable local Maryland-specific data was readily available.

1.3. GHG Emission Reduction Calculations

The methodology used to apply the results of the 2001 Leopold Center study to Maryland is described stepwise below.

Step 1: Determine annual fuel use and CO_2 emissions from a conventional food system

Citing the Leopold Center study discussed in Section 1.2 above, the analysis determined the annual fuel use and CO_2 emissions associated with transporting 10 percent of Iowa's total annual per capita consumption of 28 fresh produce items by the conventional tractor-trailer food system to be 368,102 gallons of diesel fuel resulting in 3,807 metric tons of CO_2.

Step 2: Determine annual fuel use and CO_2 emissions from a local food system

Citing the Leopold Center study, determined the annual fuel use and CO_2 emissions associated with transporting 10 percent of Iowa's total annual per capita consumption of the same 28 produce items (from step 1 above) by the local food system to be 49,359 gallons ofdiesel fuel resulting in 439 $mtCO_2$.

Step 3: Determine 2006 populations

Citing the US Census Bureau Quick Facts, determined the 2006 population of Iowa to be 2,982,085 and the 2006 population of Maryland to be 5,615,727.

Step 4: Determine a population conversion factor to compare Maryland's population to Iowa's

The analysis divided the Maryland population by the Iowa population from Step 3 to determine a population conversion factor of 1.88.

Step 5: Determine CO_2 emissions resulting from 10 percent of Maryland's food consumption of produce transported by a conventional food system

The analysis multiplied the Iowa conventional tractor-trailer food system CO_2 figure of 3,807 metric tons of CO_2 (Step 1) by the population conversion factor of 1.88 (Step 4) to determine CO_2 emissions resulting from 10 percent of Maryland's annual food consumption of select produce being transported through a conventional tractor-trailer food system to be 7,169 $mtCO_2$ per year.

Step 6: Determine CO_2 emissions resulting from 10 percent of Maryland's food consumption of produce transported by a conventional food system

The analysis multiplied the Iowa local food system CO_2 figure of 439 $mtCO_2$ (Step 2) by the population conversion factor of 1.88 (Step 4) to determine an estimate of CO_2 emissions resulting from 10 percent of Maryland's annual food consumption of select produce being transported through a local food system to be 826 $mtCO_2$ per year.

Step 7: Determine CO_2 reductions from sourcing 10 percent of Maryland's produce locally

The analysis subtracted the Maryland local food system CO_2 estimate of 826 $mtCO_2$ (Step 6) from the Maryland conventional tractor-trailer food system CO_2 estimate of 7,169 $mtCO_2$ (Step 5) to determine CO_2 reductions from sourcing 10 percent of Maryland produce locally to be 6,343 $mtCO_2$ per year.[45]

Step 8: Estimate the avoided CO_2 emissions from sourcing 100 percent of Maryland's produce locally

The analysis divided the CO_2 reductions from sourcing 10 percent of Maryland produce locally of 6,343 $mtCO_2$ (Step 7) by 10 percent to estimate CO_2 emissions avoided by sourcing 100 percent of Maryland's produce locally to be 63,426 $mtCO_2$ per year.[46]

Step 9: Determine the annual GHG emission reductions resulting from a 25 percent increase in the number of local farmers' markets by 2015

The analysis multiplied the estimate of total annual CO_2 emission reductions resulting from 100 percent local produce of 63,426 $mtCO_2$ (step 8) by 25 percent to determine that emission reductions of 15,856 $mtCO_2$ a year would result from a 25 percent increase in the number of local farmers' markets by 2015.[47]

Step 10: Determine the annual GHG emission reductions resulting from a 50 percent increase in the number of local farmers' markets by 2020

The analysis multiplied the estimate of annual CO_2 emission reductions resulting from 100 percent local produce production of 63,426 $mtCO_2$ (Step 8) by 50 percent to determine that emission reductions of 31,713 $mtCO_2$ a year would result from a 50 percent increase in the number of local farmers' markets by 2020.

1.4. GHG Emission Data and Data Sources

- Pirog, R., Van Pelt, T., Enshayan, K., Cook, E., 2001, *Food, Fuel, and Freeways: An Iowa perspective on how far food travels, fuel usage, and greenhouse gas emission,* Leopold Center for Sustainable Agriculture, June 2001.

- United States Census Bureau Quick Facts http://quickfacts.census.gov/qfd/index.html

45 The calculations in the "MD AFW Quantification" spreadsheet does not describe the fact that the Leopold Center study was based on 28 fruit and vegetable types and therefore give the impression that this figure covers all produce.

46 Resulting figure presented here varies slightly from the calculation described in this step due to rounding that occurred in the original calculations in the "MD AFW Quantification" spreadsheet. 63,426 $mtCO_2$ is the number that was used to determine the GHG reductions.

47 The emission reductions associated with AFW-5 calculated in the prior study actually give a theoretical estimate of reductions that would occur from sourcing different percentages of select produce locally and not reductions from an increase in the number of farmers markets; although the two items are linked they are not the same thing. This is further described in section 1.3.4.

1.5. GHG Emission Assumptions

The analysis makes the following assumptions:

- GHG reductions associated with transportation of produce are the chief source of quantifiable emission reductions associated with AFW-5.
- The relative food mix and assumptions about transport modes looked at in the Leopold Center study is an appropriate proxy for the Maryland food mix and food systems.
- A percentage increase in selected locally sourced produce is commensurate to the same percentage increase in the number of farmers' markets.
- The local region has the ability to supply the amount of agricultural products necessary to achieve the goals of AFW-5.

1.6. GHG Emission Analysis and Recommendations

To understand the effort necessary to reproduce the methodology in the Leopold Center paper to produce Maryland specific results, it is useful to understand the basic approach and some of the data sources used in that study. In order to estimate GHG emissions associated with both the Iowa conventional food system and the Iowa local food system, the Leopold Center began by estimating a per truck weighted average source distance (WASD)[48] for 28 different fresh fruit and vegetable commodities for each food system (conventional and local).

For the conventional food system the WASDs were determined by using USDA Agricultural Marketing Service data for the 28 selected produce items from the Chicago Terminal Market. The USDA data included the modes of transportation, origin, and amount consumed from each location of origin for the 28 items.[49]

To estimate the WASD associated with the Iowa local farm system (which includes farmer's markets and community supported agriculture programs) the study used data on total pounds of each of the 28 produce items delivered, delivery location, and address of growers. That data was collected from three local food projects that were all funded by the Leopold Center.

Iowa specific per capita annual consumption by weight of each of the 28 food commodities was also determined using USDA data. Assumptions were made about the mode of transport for each food system and the efficiency of that mode based on the data collected (tractor trailer was estimated for the conventional system and light truck for the local food system). That data was used in conjunction with the WASDs to determine the number of truckloads, resulting vehicle miles traveled and fuel necessary to transport 10 percent of Iowa's per capita consumption of the 28 selected commodities for each food system.

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[48] WASD is a figure that reports combined information on average miles from production to consumption for a product type (e.g., apples).
[49] The Leopold report states that the last year USDA collected this data was 1998. Similar data from 1998 is referenced in the Iowa study for the Jessup, MD Market Terminal.

While it would be possible given the appropriate data to reproduce the Leopold study in Maryland, it is important to recognize that there are GHG emissions related to how (e.g., organic vs. non-organic), where (e.g., in a heated greenhouse vs. a field), and when (e.g., in-season or out-of-season) food is produced, that may prove to be a more significant component of the carbon footprint of various food types than food-miles. In addition, the Leopold Study cites a 2001 report called "From Farm to Table: Making the Connection in the Mid-Atlantic Food System" which found that the average pound of produce distributed by the Maryland Market Terminal traveled 1,685 miles.[50] The 1,685 miles figure is only 47 miles higher than the average WASD reported in the Leopold study for the conventional food system. Therefore it may be that a Maryland version of the Leopold study would not produce significantly different results.

Further analysis of additional emissions benefits related to factors such as organic or non-organic may be challenging since there is no simple or standardized approach to their GHG quantification, and the necessary data is likely unavailable. As the body of knowledge in those areas develops, Maryland may want to develop more standard data sets that can be used to measure the efficacy of specific projects designed to increase consumption of local and sustainable food (and which may also be useful to researchers working on life-cycle analysis of local food).

The November 2010 Maryland Commission on Climate Change Report Update suggests that some of these measurement efforts are currently in development. Additional metrics such as annual increase in numbers of visitors to farmers' markets, number of participants in community supported agriculture programs, number of community gardens, and percentage of organic vs. non-organic food being distributed through government programs may also be useful but would likely require local partners to collect the data.

Finally it is also important to recognize that the majority of emission reductions associated with AFW-5 are based on avoiding transportation related GHG emissions that would occur outside of Maryland and should be noted as such.

[50] Hora, Matthew, and Jody Tick. 2001. "From Farm to Table: Making the Connection in the Mid-Atlantic Food System." Capital Area Food Bank of Washington D.C. report.

2.0. AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated criteria pollutant emission reductions from AFW-5 are shown in the following table:

Table AFW-5.2- NAAQS Emissions Reductions in Maryland Associated with AFW-5

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	0.06	0.11	0.22
NO_X	5.6	6.9	9.5
CO	74	120	220
VOC	4.3	6.1	10
PM10 – primary	0.25	0.29	0.37
PM2.5 – primary	0.13	0.19	0.35

These numbers were compared against the MANE-VU inventories for 2012 and 2018 in Table AFW-5.3. Because all the values are less than two-tenths of a percent, the table indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to significantly improve air quality.

Table AFW-5.3: Percentage Reduction in State NAAQS Emissions Inventory Associated with AFW-5

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	< .02	< .02
NO_X	< .02	< .02
CO	< .02	< .02
VOC	< .02	< .02
PM10-primary	< .02	< .02
PM2.5-primary	< .02	< .02

2.2. Summary of Air Quality Co-Benefits Methodology

The NAAQS co-benefits quantification methodology builds on the approach used in Section 1.0, and also applied the results of the 2001 Leopold Center study to Maryland as described below:

Step 1: Develop a co-benefit factor

A co-benefit factor was developed from the Leopold Center study discussed in 1.2 above. The annual fuel use and CO_2 emissions associated with transporting 10 percent of Iowa's total annual per capita consumption of 28 fresh produce items were determined to be 368,102 gallons ofdiesel fuel resulting in 3,807 metric tons of CO_2 and 49,359 gallons of diesel fuel resulting in 439 mtCO_2 for a conventional tractor-trailer food system and a local food system, respectively.

Step 2: Develop a fuel reduction factor

A fuel reduction factor was developed by calculating the ratio of the change in CO_2 to the change in fuel consumption (from Step 1) resulting in a factor of 1.06E-08 $MMTCO_2$/gal

Step 3: Determine fuel reductions

The fuel reduction factor in Step 2 was applied to the 2012, 2015, and 2020 CO_2 emission reductions of 0.009, 0.015, and 0.031 $MMTCO_2$ resulting in fuel reductions of 851,748, 1,419,580, and 2,933,798 gallons of fuel.

Step 4: Convert fuel reductions to Vehicle Miles Traveled (VMT)

Using a Heavy-Duty Truck Fuel Economy Presentation that cited 7.8 miles per gallon as the base fuel economy for Platform trucks, Delivery vans, Super-duty pickups, etc. (10,000 – 26,000 lbs gross vehicle weight (GVW)) the fuel reductions translated to 6.6, 11, and 23 million (mVMT) reductions in 2012, 2015, and 2020.

Step 5: Determine statewide VMT

Statewide VMT estimates of 55,631 and 78,989 mVMT were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

Step 6: Determine percent of statewide VMT reduced from fuel reductions

Determined that statewide VMT reductions in Step 4 represented 0.01, 0.02 and 0.03 percent of Maryland statewide VMT estimates, in 2012, 2015 and 2020, respectively.

Step 7: Calculate the NAAQS reductions

When those percent reductions from Step 6 are applied to the total state mobile source inventory, the NAAQS emission reductions listed in Table 1 are derived. The potential co-benefit of those emission reductions listed in Table 2 is the absolute reductions in Table 1 compared to the statewide emission inventory.

2.3. Air Quality Co-Benefits Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, American Institute of Certified Planners (AICP), Secretary, Maryland Department of Planning, November 15, 2010

- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

- **Fuel Efficiency for Trucks.** Policy Discussion – Heavy-Duty Truck Fuel Economy Presentation by Drew Kodjak, National Commission on Energy Policy 10th Diesel Engine Emissions Reduction (DEER) Conference August 29 - September 2, 2004

2.4. Air Quality Co-Benefits Assumptions

- It was assumed that the reduction in VMT would result in a proportional reduction in the mobile source inventory. The platform trucks, delivery vans, and super-duty pickups probably contribute more per VMT than light duty vehicles (LDV), which are the largest fraction of the total mobile source emissions. However, as shown in Table 2, the impacts of this policy are so small that even an order of magnitude increase in the emission contribution from those vehicles would still result in an insignificant impact.

- It was assumed that the reductions in VMT would occur in state but it is likely that they would be mostly out of state since it is a shift from imported to local goods. We had no basis for refining the estimate with the in-state/out-of-state proportions.

3.0 INTERACTION WITH OTHER POLICIES

The quantified portion of AFW-5 (increasing the number of farmers' markets in Maryland) will not affect other policies, nor will it be affected by other policies.

The implementation of the portion AFW-5 calling for 80 percent of Maryland's food supply to be grown locally by 2050 is related to the portion of policy AFW-4 "Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Lands" that deals with protecting agricultural lands. Implementation of the AFW-4 policy would contribute toward meeting the AFW-5 goal of 80 percent local food production (note that further study is required to determine the amount of land that would be necessary to fully meet the AFW-5 goal).

The portion of AFW-5 related to replacing the amount of imported wood products with locally grown wood products is related to policy AFW-1 "Forest Management for Enhanced Carbon Sequestration"; however, since this portion of AFW-5 was not quantified it will not affect the emission reduction estimates in AFW-1, rather, it should be seen as a complimentary measure that would help create the market for products built with sustainably harvested Maryland wood.

Policy No.: AFW-6

Policy Title: Expanded Use of Forest and Farm Feedstocks and By-Products for Energy Production

SAIC was tasked with reviewing the AFW-6 policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits of this policy. The results of SAIC's review of the Original Methodology and the quantification of related co-benefits is below:

1.0 GHG EMISSION REDUCTIONS

AFW-6 seeks to increase the utilization of biomass from urban and rural feedstocks, including processing by-products for generation of electricity, thermal energy, and transportation fuels. AFW-6 also seeks to reduce the amount of CH_4 emissions from livestock manure by installing manure digesters and implementing energy recovery projects.

AFW-6 contains several policy goals: 1) To increase use of agricultural residues and utilize 10 percent and 25 percent of available in-state agricultural residue biomass by 2015 and 2020, respectively, for electricity, steam, and heat generation; 2) To increase use of forest residues and utilize 10 percent and 25 percent of available in-state forest residue biomass by 2015 and 2020, respectively, for electricity, steam, and heat generation; 3) Increase energy crop use to utilize 50 percent of available in-state energy crop biomass for electricity, steam, and heat generation by 2020; and 4) Capture and use 50 percent of available CH_4 from livestock manure and poultry litter for renewable electricity, heat, and steam generation, by 2020.

Table AFW-6.1. Estimated GHG Emission Reductions Resulting from AFW-6[51]

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
AFW-6 Total	**0.13**	**0.24**	**0.54**
Biomass (Including Agricultural Residue, Forest Feedstocks, and Energy Crops)	0.12	0.22	0.50
Methane (CH_4) Utilization From Livestock Manure and Poultry Litter	0.01	0.022	0.04

[51] GHG Reduction numbers for 2012 and 2020 in this table come from the "Summary List of Recommended Priority Policy Options" on page 3 of Appendix D. GHG Reduction numbers for 2015 come from Table I-30 Summary of GHG Benefits and Costs for Biomass on page 58 of Appendix D and Table I-31 GHG Benefits for CH_4 Utilization from Livestock Manure on page 59 of Appendix D.

1.1. Summary of GHG Emission Methodology

Biomass GHG Benefits

To estimate the GHG benefit from this policy, the analysis first obtained the potential biomass feedstock production in 2020 from a Maryland DNR study.[52] The annual production was multiplied by the percentage increase in use needed each year from 2008 through 2020 to achieve the policy's biomass utilization goals. The yearly biomass feedstock production as determined for 2008 through 2020 was then multiplied by a factor to estimate the GHG benefits from the use of biomass instead of coal to generate electricity, heat, and steam.

CH_4 Utilization from Livestock Manure and Poultry Litter GHG Benefits

The GHG benefits of this aspect of AFW6 are two-fold – the reduction of CH_4 emissions and the emissions saved by producing electricity from the waste CH_4 instead of from conventional sources. The prior study used CH_4 emissions data from the Maryland GHG Inventory & Forecast[53] as a baseline. To obtain the quantity of CH_4 that could be captured, the estimated CH_4 emissions were first adjusted to reflect the partial efficiency of the collection process. Then, for each year of the policy period, the amount captured was uniformly increased from 2008 to 2020 to reach the goal of 50 percent capture and use by 2020. The annual amount of CH_4 captured each year was then used to determine the amount of electricity produced. The emissions normally produced for this quantity of electricity produced was then determined. The total GHG benefit was estimated as the sum of both the CH_4 captured and CO_2e offset as electricity.

1.2. Rationale for GHG Emission Methodology

To calculate the incremental GHG benefit from the use of biomass feedstocks in place of fossil fuel for the generation of electricity, steam, and heat, an emission reduction benefit factor was developed that was then multiplied by the estimated in-state biomass production potential. Then CH_4 avoided from the capture of CH_4 from livestock manure and chicken litter was calculated by multiplying an estimated collection efficiency factor to the potential CH_4 emissions generated from these agricultural sources. To calculate the incremental GHG benefit of the conversion of captured CH_4 to electricity, an energy recovery factor was applied to the mass of CH_4 captured and this value was multiplied by a Maryland-specific emission factor for electricity generation. The methodologies used appear to have been developed specifically for this measure in the absence of a standardized approach.

1.3. GHG Emission Reduction Calculations

The methodologies employed for calculating the GHG emission reductions for the biomass feedstock utilization goal and the CH_4 from livestock manure and poultry litter utilization goal are discussed separately below.

[52] Maryland DNR. 2006 (Mar.). The potential for biomass co-firing in Maryland. Prepared by Princeton Energy Resources International, LLC and Exeter Associates Inc. for the DNR Maryland Power Plant Research Program.
[53] Maryland GHG Inventory & Reference Case Projections 1990-2020, prepared by CCS.

Biomass GHG Benefits

The methodology for calculating GHG reductions associated with increasing the utilization of biomass to offset fossil fuel consumption[54] are described stepwise below.[55]

Step 1: Determine the amount of biomass available in 2020

The amount of biomass available in 2020 (in dry tons) from agricultural and forestry feedstocks were obtained from two studies,[56] and consisted of:

- 622,882 dry tons of agricultural residues[57]
- 251,019 dry tons of energy crop[58]
- 812,345 dry tons of forestry resides[59]

Step 2: Estimate the potential heat input

The amount of each residue available was multiplied by the heat content[60] of the residue to estimate the potential heat input (in MMBtu). The available heat input from biomass is estimated to be:

- 5,169,921 MMBtu from agricultural residue
- 3,689,979 MMBtu from energy crops
- 8,663,717 MMBtu from forestry residues

Step 3: Calculate the annual biomass utilization fraction

The potential heat input available from each biomass type was multiplied by the fraction necessary to satisfy the biomass utilization policy goals for each year. For agricultural and forestry residues, the yearly utilization fraction was calculated over two different time periods based on the policy goals. Each of the two utilization goals (10 percent by 2015 and 25 percent by 2020) were divided evenly between the goal years, resulting in a 1.25 percent additional

[54] The analysis assumed biomass will replace coal. This is based on the assumption that biomass will be used to replace coal in the RCI and electricity sector (where coal represents the majority of electricity generated)
[55] The quantification method described in Appendix D only lists the available mass and heat input from biomass residues in Maryland. The methods used to quantify the GHG reductions are described based on the calculations contained in the "MD AFW Quantification" spreadsheets.
[56] With the exception of available urban wood waste, the amount of biomass available in 2020 in Maryland was obtained from Maryland DNR. 2006 (Mar.). The potential for biomass co-firing in Maryland. Prepared by Princeton Energy Resources International, LLC and Exeter Associates Inc. for the DNR Maryland Power Plant Research Program. Available urban wood waste is based on analysis by Daniel Rider, Maryland DNR Forest Service.
[57] Agricultural residues include residues generated from corn, wheat, winter wheat, and barley crops.
[58] The amount of energy crop available is estimated based on the assumption that 25% of idle cropland in Maryland is used to grow switchgrass.
[59] Forestry feedstocks include residues generated from forest, mill, and urban residues
[60] Heat content of agricultural by-products sourced from above DNR Report, which references EIA (1999) Annual Electric Generator. Heat content for switchgrass is also sourced from the DNR Report, which references the EIA Annual Energy Outlook 2005 (Feb.), Table H1.

utilization fraction for each year between 2008 and 2015 and a 3 percent additional utilization fraction for each year between 2015 and 2020.[61,62]

A similar calculation was performed for energy crop utilization (50 percent by 2020) where a slower growth rate of 2 percent additional utilization fraction each year was assumed between 2008 and 2012, which ramped up to a 5 percent additional utilization fraction for each year between 2012 and 2020.[63]

Step 4: Calculate the GHG benefit from each biomass feedstock utilized

To obtain the GHG benefit from the utilization of each biomass feedstock for each year through the goal period, the heat input calculated in Step 3 above was multiplied by an emission factor (in tCO_2e/MMBtu)[64] quantifying the GHG benefit of replacing coal with biomass fuel. This emission factor (0.094 tCO_2e/MMBtu) was calculated by subtracting the emission factor for refuse-derived biomass fuel (0.0019 tCO_2e/MMBtu) from the emission factor for subbituminous coal (0.0959 tCO_2e/MMBtu).

Step 5: Determine the total GHG benefit from the use of biomass feedstocks instead of fossil fuels

The GHG benefits resulting from the utilization of agricultural and forestry residues and energy crops through the policy goal period were summed to obtain the total GHG benefit from the use of additional biomass feedstocks instead of fossil fuels.

CH_4 *Utilization from Livestock Manure and Poultry Litter GHG Benefits*

The methodology for calculating GHG reductions from the use of CH_4 from livestock manure and poultry litter for renewable electricity, heat, and steam generation is described stepwise below:

Step 1: Estimate the GHG benefits of CH_4 capture

The business as usual (BAU) CH_4 emissions generated from dairy, swine, and poultry sources were obtained from the Maryland GHG Inventory and Forecast[65] and the sum of these emissions was used as the starting point to estimate the GHG benefits of capturing the volumes of CH_4 targeted by the policy.

Step 2: Determine the CH_4 that could be captured annually

61 2012 Ag Residue Biomass (MMBtu) Utilized = (5,169,921 MMBtu) × (1.25% × 5); Note, 2012 is the 5th year of the goal period. The 1.25% additional utilization fraction is the result of (10% ÷ 8 years).

62 2012 Forestry Residue Biomass (MMBtu) Utilized = (8,663,717 MMBtu) × (1.25% × 5); Note, 2012 is the 5th year of the goal period. The 1.25% additional utilization fraction is the result of (10% ÷ 8 years).

63 2012 Energy Crop Biomass (MMBtu) Utilized = (3,689,979MMBtu) × (2.0% × 5); Note, 2012 is the 5th year of the goal period. The 2.0% additional utilization fraction is the result of (10% ÷ 5 years).

64 The emission factors utilized in these calculations were found in the "MD AFW Quantification" spreadsheets made available to MDE. The original data source of these emission factors was not noted in these spreadsheets.

65 Maryland GHG Inventory & Reference Case Projections 1990-2020, prepared by CCS released in 2008.

An assumed collection efficiency of 75 percent was applied to the CH_4 emissions from manure and poultry litter obtained in step 1 above to obtain the potential CH_4 that could be captured each year through 2020.[66]

Step 3: Calculate annual utilization factor

The potential quantity of CH_4 captured was then multiplied by a yearly utilization factor based on the policy target of achieving 50 percent collection in 2020. This yearly utilization fraction was calculated in a manner similar to the method described above in Step 3 of the previous methodology for biomass feedstock yearly utilization rates. For CH_4 capture, the 50 percent collection goal was divided evenly between 2008 and 2020 resulting in an annual additional increase in use of approximately 3.85 percent.[67]

Step 4: Estimate the amount of electricity produced from the captured CH_4

To estimate the amount of electricity produced (kWh) from the captured CH_4, the captured CH_4 each year was converted to its heat content (in Btus), and then multiplied by an energy recovery factor (17,100 Btu/kWh[68]).

Step 5: Estimate the total CO_2e associated with utilizing the captured CH_4 for electricity generation

The estimated amount of electricity produced for each year was converted to megawatt hours (MWh) by dividing by 1,000. The prior MDE contractor multiplied this value by the Maryland specific emission factor for electricity production from the U.S. Environmental Protection Agency's (EPA) Emissions & Generation Resource Integrated Database (eGRID, 0.587 tCO_2e/MWh) to estimate the total mass of CO_2e (tons) associated with utilizing the captured CH_4 for electricity.

Step 6: Determine the total GHG benefit

The total GHG benefit was estimated as the sum of both the CH_4 captured and CO_2e offset as electricity.

1.4. GHG EmissionData and Data Sources

Sources used in the previous analysis include:

Biomass GHG Benefits

- Maryland DNR. 2006 (Mar.). The potential for biomass co-firing in Maryland. Prepared by Princeton Energy Resources International, LLC and Exeter Associates Inc. for the DNR

[66] The 75% value is an assumed value based on engineering judgment. No applicable studies were identified at the time of this analysis that provided information on CH_4 collection efficiencies achieved using manure digesters (as it relates to collection of entire farm-level emissions).
[67] 2012 CH_4 (MMt CO_2e) Captured = (0.090 MMt CO_2e) × (3.85% × 5); Note, 2012 is the 5th year of the goal period. The 3.85% additional utilization fraction is the rounded result of (50% ÷ 13 years).
[68] The energy recovery factor assumed a 25% efficiency for conversion to electricity in an engine and generator set.

Maryland Power Plant Research Program. Available at http://esm.versar.com/pprp/bibliography/PPES_06_02/PPES_06_02.pdf

- Daniel Rider, Maryland DNR Forest Service, "Available urban wood waste."
- U.S. Energy Information Administration (1999) Annual Electric Generator. Form EIA-860B Database, Available at http://www.eia.doe.gov/cneaf/electricity/page/eia860b.html
- U.S. Energy Information Administration, Annual Energy Outlook 2005 (Feb.), Table H1. Available at ftp://ftp.eia.doe.gov/forecasting/0383%282005%29.pdf

CH_4 Utilization from Livestock Manure and Poultry Litter GHG Benefits

- Maryland GHG Inventory & Reference Case Projections 1990-2020, prepared by CCS, Available at http://www.mde.state.md.us/assets/document/Air/ClimateChange/AppendixC_Inventory.pdf
- U.S. Environmental Protection Agency, Emissions & Generating Resource Integrated Database, Available at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

1.5. GHG Emission Assumptions

Several assumptions were made in this analysis concerning the GHG benefits from displacing fossil fuels with biomass feedstocks in the generation of electricity, steam, and heat as well as the GHG benefits from utilizing CH_4 from livestock and poultry litter for renewable electricity, heat, and steam generation. Assumptions include:

Biomass GHG Benefits

- Biomass will replace only coal in the RCI and electricity sector through 2020.
- 25 percent of idle cropland (approximately 51,307 acres in Maryland) can be used to grow switchgrass (which translates to approximately 250,000 dry tons of switchgrass fuel).
- The quantity of available biomass will remain constant over the entire goal period.
- The upward bound of biomass feedstock utilization is feasible.
- Co-firing technology would be used through 2020.

CH_4 Utilization from Livestock Manure and Poultry Litter GHG Benefits

- The average collection efficiency of methane capture technology is 75 percent. This estimate was an assumed value based on an engineering judgment.
- The quantity of available methane will remain constant over the entire goal period.
- Conversion efficiency of methane to electricity is 25 percent in an engine and generator set.
- EPA's eGRID factor is an accurate representation of the electricity that the captured and converted methane will offset.
- The upward generation and collection of methane from livestock manure and poultry litter is feasible

1.6. GHG Emission Analysis and Recommendations

GHG emission reductions associated with AFW-6 are based on the utilization of biomass feedstocks instead of coal to generate electricity, steam, or heat, and the avoidance of CH_4 emissions from livestock manure and poultry litter and the utilization of that CH_4 to generate electricity, steam, or heat.

In terms of the potential biomass feedstock production estimate, several assumptions should be noted. First, the GHG benefit methodology assumes that both the utilization of biomass feedstocks will occur uniformly and that the supply of biomass feedstock will remain constant over the goal period. This may not occur as other factors, such as weather or the consumption of biomass feedstocks by other sectors, may change the amount of feedstocks available each year. The analysis notes that if shortfalls in the preferred biomass sources (agricultural resides, forestry residues, and energy crops) occur, feedstocks may be met by municipal solid waste (MSW) such as paper, cardboard, organics, and yard waste. Further analysis of the amount of MSW potentially available would be helpful, particularly in light of AFW-9 which aims to reduce MSW generated through source reduction and advanced recycling.

Another area that might benefit from further analysis would be the availability of various firing technologies through 2020. In the cost portion of this analysis, the analysis assumed that co-firing would be used through 2020. However, as technology advances, other options (such as gasification) may be more cost effective and energy efficient.

In terms of CH_4 recovery from livestock manure and poultry litter, it should be noted that as described above, the GHG benefit methodology assumes that both the use and supply of CH_4 will remain constant over the goal period. However, several factors could alter this CH_4 supply, such as a change in either the diet of dairy cows, swine, or poultry, or their overall population.

While the methodology for the CH_4 from livestock manure and poultry litter policy goal is relatively straightforward, Maryland may wish to revisit several assumptions. In particular, updated collection efficiency factors and energy recovery factors could be available. It was noted in the methodology that no applicable studies were identified that provided information on CH_4 collection efficiencies achieved using manure digesters, as it relates to collection of entire farm-level emissions. No citation was provided for the energy recovery factor used. However, offsets and renewable electricity certificates (RECs) markets have further developed since this analysis was first completed, and state and federal grant programs have helped promote the installation of digesters at farms. Updated data on system efficiencies could be available.

2.0 AIR QUALITY CO-BENEFITS

The air quality co-benefits of replacing fossil fuels or grid-based power with biomass is highly situation specific and difficult to estimate. Co-firing with some types of biomass—particularly wood chips and agricultural waste—are as likely to result in an increase as a decrease in PM, CO, or NO_X emissions. Although co-firing will tend to result in a reductionin SO_2 emissions, this reduction will be insignificant relative to the total statewide SO_2 emissions inventory. It was therefore assumed that co-firing coal-fired plants with less than 10 percent biomass will not significantly change the criteria pollutant emission factors (based not only on the above considerations, but on a figure presented by Lesley Sloss of the IEA

Clean Coal Centre at the 35th Annual EPA-A&WMA Annual Exchange in December 2010) from those for coal alone.

3.0 INTERACTION WITH OTHER POLICIES

AFW-6 aims to increase the use of biomass for generation of electricity, steam, and heat. As reported in Appendix D of the Maryland CAP,[69] AFW 6 overlaps with policy ES-8 which evaluates the GHG reduction benefits from increased biomass use at existing plants when economical. The analysis noted that the quantity of biomass needed for ES-8 may be limited by that needed for AFW-6. To avoid double counting, the 2008 Climate Action Plan allocated all emission reductions from biomass-to-energy production to ES-8. While AFW-9 seeks to reduce the quantity of MSW, and thus potentially lower the feedstock stream available for biofuel production, it is important to note that agricultural resides, forestry residues, and energy crops are the preferred feedstocks. The probability of having insufficient supplies of all these preferred sources, such that the reduction of MSW via AFW-9 would become material, is judged to be very low.

[69] Appendix D of the Maryland CAP, Greenhouse Gas & Carbon Mitigation Working Group: Policy Option Documents

Policy No.: AFW-7b

Policy Title: In-State Liquid Biofuels Production

SAIC was tasked with reviewing the AFW-7b policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits of this policy. The results of SAIC's review of the Original Methodology and the quantification of related co-benefits is below:

Note: *The original analysis of AFW-7b in Appendix D-1 of the Maryland CAP included quantification of GHG benefits associated with in-state production of ethanol (referred to as AFW7a) and bio-diesel (referred to as AFW7b).*[70]

1.0 GHG EMISSION REDUCTIONS

Policy AFW-7b seeks to promote sustainable in-state production and consumption of bio-diesel from agriculture and/or agroforestry feedstocks, to displace the use of fossil fuels in the production of bio-diesel.The policy goal of AFW 7 is to increase in-state bio-diesel production from Maryland non-food feedstocks to offset diesel consumption in the State by 2 percent in 2015 and 2.2 percent in 2020. This policy is linked to TLU-4, "Low Greenhouse Gas Fuel Standard".[71] The analysis predicted the following GHG reduction potential associated with replacing imported soy based biodiesel with non-food based biodiesel produced in Maryland:

Table AFW-7b.1- Estimated GHG Emission Reductions Resulting from AFW-7b[72]

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
AFW-7 Total	**0.099**	**0.127**	**0.167**
Bio-diesel Production	0.099	0.127	0.167
Ethanol Production	Not included		

[70]The ethanol portion of the analysis has been excluded here by direction of MDE. Ethanol was excluded due to concern over potential detrimental impacts on consumer food prices resulting from the use of food-based feedstocks as transportation fuels.

[71] The GHG benefit of replacing standard diesel with bio-diesel was calculated as part of related action TLU-4, "Low Greenhouse Gas Fuel Standard". Pg. 91 of the MD Climate Action plan states that recommendation TLU-4 was withdrawn by the MD Commission on Climate Change pending further analysis and technological innovation.

[72] GHG Reduction numbers in this table vary from 2015 and 2020 numbers presented on page 68 of Appendix D but do agree with 2012 and 2020 numbers presented in the "Summary List of Recommended Priority Policy Options" on page 3 of Appendix D. The source of GHG-reduction numbers on page 68 is unclear.

1.1. Summary of GHG Emission Methodology

To estimate the GHG benefit from this policy, an upper limit potential for in-state non-food bio-diesel (in-state bio-diesel) production amounts was estimated for 2015 and 2020. The production amounts were then multiplied by the estimated "emission reduction benefit" of using in-state bio-diesel as opposed to imported soy based bio-diesel to determine emission reductions.[73] The GHG emission reduction benefit was calculated to be the difference between a lifecycle soy based bio-diesel emission factor and an estimate of GHG emissions associated with transporting in-state bio-diesel an average of 100 miles by diesel rail.[74]

The business as usual (BAU) fossil diesel consumption for Maryland for 2015 and 2020 was also used to estimate the volume of bio-diesel production necessary to displace 2 percent of fossil diesel in 2015 and 2.2 percent in 2020.[75]

1.2. Rationale for GHG Emission Methodology

To calculate the incremental GHG benefit of the use of Maryland grown non-food feedstocks over imported soy-based bio-diesel, an emission reduction benefit factor was developed that was then multiplied by the estimated in-state bio-diesel production potential. The methodology appears to have been developed specifically for this measure in the absence of a standardized approach.

1.3. GHG Emission Reduction Calculations

The methodologies employed for calculating the GHG emission reductions and for estimating the in-state bio-diesel production goals are discussed separately below.

In-State Biodiesel GHG Emission Benefits

The methodology for calculating GHG reductions associated with producing bio-diesel in Maryland from non-food feedstocks (as compared to importing soy based bio-diesel) are described stepwise below.

<u>Step 1: Estimate the upper limits of potential in-state bio-diesel produced from non-food feedstocks</u>

The upper limits of potential in-state bio-diesel that could be produced from non-food feedstocks (in 1,000 gallons) was estimated to total 17,571 in 2015 and 23,120 in 2020. Consisting of:

- 5,791,000 gallons from animal fats in both 2015 and 2020[76]
- 11,780,000 gallons from yellow grease in 2015[77]
- 12,329,000 gallons from yellow grease in 2020
- 5,000,000 gallons from algal oils in 2020

[73] That use of an "emission reduction benefit" multiplier to determine GHG reductions is not common practice in GHG accounting, a more standardized approach is discussed in 1.6.
[74] 100 miles is the distance from the center of MD to the border. In-state transportation emissions are assumed by CCS to be the only GHG emissions associated with in-state non-food feedstock bio-diesel.
[75] It is unclear if the assessment of available in-state non-food bio-diesel feedstocks was completed before or after the policy goals for 2015 and 2020 were set.
[76] Animal fats available were estimated based on the ratio of Maryland livestock and poultry slaughter and production to that of Minnesota.Calculations of these estimates are not clearly documented but are included in the excel spreadsheet "MD AFW Quantification", tab "7-Bio-diesel".
[77]Yellow grease was projected based on estimate of 14 pounds of restaurant grease per capita (using U.S. Census projections for Maryland) and 7.6 pounds of grease per gallon of bio-diesel.

Step 2: Estimate the GHG reduction benefit of in-state bio-diesel

The estimated reduction benefit of in-state bio-diesel was estimated by using a lifecycle emission factor for soy based bio-diesel of 7,261 metric tons of carbon dioxide equivalent (tCO_2e) per million gallons[78] and subtracting estimated transportation emissions associated with shipping in-state bio-diesel an average of 100 miles, to yield an "emission reduction benefit" of 7,207 tCO_2e per million gallons of in-state bio-diesel.

Emission reduction benefit formula: soybean lifecycle emission factor (EF) – (miles*fossil diesel EF)/ gallons of bio-diesel per short ton of soybeans*ton-miles per gallon of diesel = emission reduction benefit, or, 7,207 tCO_2e per million gallon = 7,261$mtCO_2e$ per million gallon – (100*(.01006 $mtCO_2e$)*10^6)/44.632 gal per ton*423 ton-miles

Step 3: Estimate 2015 emission reductions

The in-state bio-diesel emission reduction benefit, as determined in Step 2 above, was multiplied by the 2015 in-state bio-diesel production goal of 17,571,000 gallons, as determined in step 1 above, to estimate 2015 emission reductions associated with this action.

2015 GHG reductions of 126,634 tCO_2e= 17.571 MMgal * 7,207 tCO_2e/MMgal

Step 4: Estimate 2020 emission reductions

The in-state bio-diesel emission reduction benefit, as determined in Step 2 above, was multiplied by the 2020 in-state bio-diesel production goal of 23,120,000 gallons, as determined in step 1 above, to estimate 2020 emission reductions associated with this action.

2020 GHG reductions of 166,626 tCO_2e= 23.120 MMgal * 7,207 tCO_2e/MMgal

In-State Bio-diesel Production Goals

The methodology for calculating the in-state bio-diesel production goals is described stepwise below. Calculations for production goals show the amount of in-state bio-diesel production necessary to achieve the AFW-7b policy goals of increasing in-state biodiesel production to 2 percent in 2015 and 2.2 percent in 2020 as described in Section 1 above.

Step 1: Determine the BAU fossil diesel consumption in Maryland

The business as usual (BAU) fossil diesel consumption data for Maryland for 2015 (817 million gallons) and 2020 (941 million gallons) was identified.[79]

Step 2: Calculate bio-diesel production

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[78] The lifecycle emission factor for biodiesel is a 41% reduction from a lifecycle fossil diesel emission factor of 12,306 $mtCO_2e$ as presented in J. Hill, E. Nelson, D. Tilman, et al. 2006. Environmental, economic, and energetic costs and benefits of bio-diesel and ethanol biofuels. *Proceedings of the National Academy of Sciences* 103:11206–11210.

[79] Page 66 of the Maryland CAP Appendix D AFW7 lists the Maryland Draft Inventory & Forecast prepared by CCS as the data source used as "the starting point for quantifying the benefits of offsetting fossil diesel and gasoline consumption with bio-diesel".

The necessary bio-diesel production was calculated by multiplying BAU fossil diesel consumption in 2015, as determined in step 1, by 2 percent, and dividing by the heat content of bio-diesel as compared to fossil diesel (91 percent), for a production target of 18 million gallons.

18 million gallons=817million gallons*.02/.91

<u>Step 3: Determine the bio-diesel production necessary to achieve the AFW-7b policy objectives</u>

The necessary bio-diesel production needed to achieve the 2020 policy goal was calculated by multiplying BAU fossil diesel consumption in 2020, as determined in step 1, by 2.2 percent, and dividing by the heat content of bio-diesel as compared to fossil diesel (91 percent), for a production target of 23 million gallons.

23 million gallons=941million gallons*.022/.91

1.4. GHG Emission Data and Data Sources

Sources used in the analysis include:

- California Grain & Feed Association. "Evaluate the Cost and Usage of Various Fuels." http://www.cgfa.org/news.html

- Center for Energy and Environment "Identifying Effective Biomass Strategies: Quantifying Minnesota's Resources and Evaluating Future Opportunities," http://www.mncee.org/public_policy/renewable_energy/biomass/index.php

- Oak Ridge National Laboratory, Biomass Energy Data Book, Appendix A- Conversions. http://cta.ornl.gov/bedb/appendix_a.shtml

- Cleantech.com "Chevron turning California kitchen grease into biogas", November 21, 2006 http://cleantech.com/news/node/376

- Hill, Jason, Erik Nelson, David Tilman, Stephen Polasky, and Douglas Tiffany, 2006, "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences*, Vol. 103, no. 30 (July 25, 2006), http://www.pnas.org/content/103/30/11206.short

1.5. GHG Emission Assumptions

Several assumptions were made concerning the potential production volume of in-state bio-diesel over the goal period and the GHG benefit from displacing soy based bio-diesel with in-state bio-diesel. Assumptions include:

- In-state biodiesel would replace imported soy based bio-diesel.
- All available feedstock that does not serve as a food source will be used for fuel production.

- Two bio-diesel facilities, MD bio-diesel and Greenlight biofuels (in production at the time the CCS analysis was conducted), would be completed and online as scheduled.
- Maryland and Minnesota have similar livestock and poultry slaughter and production rates, which is the basis of potential animal fat feedstock production.[80]
- By 2020, algal bio-diesel technology would progress enough to be available to provide approximately 20 percent of bio-diesel production.
- Bio-diesel produced from animal fats, yellow grease, and algae feedstocks contain 91 percent of the usable energy of energy of fossil based diesel.
- The upward bound of the mix of feedstocks estimated in the previous analysis is feasible.
- Animal fats, algal oils, and yellow grease have negligible additional embodied energy compared to soybean feedstocks.
- The only GHG emissions associated with in-state bio-diesel produced with non-food feedstocks are transportation related.
- Transportation emissions associated with each million gallons of in-state non-food bio-diesel are equivalent to the proportional share of emissions that would result from transporting the necessary amount of soybean feedstock it would take to produce that fuel, 100 miles by diesel powered freight.

1.6. GHG EmissionAnalysis and Recommendations

GHG reductions associated with this measure are based on reductions in lifecycle emissions that would occur outside of Maryland and should be clearly identified as such when they are referenced. The 2008 Maryland CAP states that the entire policy option, AFW 7, "should not be included in the total GHG emission reductions or costs because of concern over food- and animal feed-based feedstocks".[81] The lifecycle nature of the biodiesel GHG reduction estimate further justifies its exclusion from cumulative GHG emission reductions that contribute to the State's GHG reduction targets.

The assumptions used to estimate the incremental GHG benefit of in-state non-food bio-diesel production over imported soy based bio-diesel need further analysis. The approach to determining the GHG reductions associated with in-state biodiesel should not be to take the difference between lifecycle GHG emissions associated with imported soy bio-diesel and subtract out distribution related transportation emissions that would occur in Maryland, but rather to compare the lifecycle GHG emissions associated with production of bio-diesel from different feedstocks (soybeans, yellow grease, animal fat, and algae), in addition to distribution related transportation emissions. The analysis assumes that, of these feedstocks, soybeans are the only feedstock that would produce GHGs during the production stage, which is unlikely.

Maryland could improve the methodology by utilizing a standardized approach. Such an approach could consist of estimating GHG emissions from imported bio-diesel based on a volume of fuel * emission factor calculation as a base case, and then subtracting GHG emissions from in-state bio-diesel (also calculated using a volume of fuel* emission factor approach) as the after case, rather than using an

[80] Accessed from MN's BioPower Evaluation Tool (report listed in data sources)

[81] Pg. 52

emission reduction benefit factor as described in Section 1.3 above. Note that this would still entail using lifecycle emission factors, and those factors may need to be developed for each of the in-state feedstocks.[82]

Additional analysis of the assumptions used to estimate in-state bio-diesel production capacity, presented in 1.5, is needed to add credibility to the emission reduction potential presented for this action. For example, the estimate of potential for algal bio-diesel does not appear to have a source. Additional review of bio-fuel capacities completed by the MEA for the Comprehensive Energy Plan may be helpful.[83]

Since the larger GHG benefit of replacing fossil diesel with biofuels (analyzed in TLU-4, "Low Greenhouse Gas Fuel Standard") is directly linked to this action, further research on in-state biofuel production would benefit from being conducted in conjunction with additional analysis of TLU-4.

Future analysis of GHG emissions from bio-diesel, in AFW-7b and in the Maryland statewide GHG inventory, could also include an assessment of biogenic CO_2 emissions. Biogenic CO_2 emissions associated with bio-diesel result from the combustion of materials derived from organic matter and from agricultural practices associated with growing the feedstocks.[84] Guidance for determining biogenic emissions associated with combustion of bio-diesel is included in the General Reporting Protocol of the Climate Registry (of which MDE is a member).[85] The Climate Registry requires separate reporting of biogenic emissions from both stationary and mobile sources in GHG inventories.

2.0 AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from AFW-7b are shown in the following table:

Table AFW-7b.2: Emissions Reductions in Maryland Associated with AFW-7b

	Statewide (tons/yr)	
Pollutant	**2015**	**2020**
SO_2	7.0	8.9
NO_X(Increases)	-9.0	-7.6
CO	823	952
VOC	83	85
PM10 - primary	1.9	1.5
PM2.5 - primary	1.3	1.4

[82]The May 2009 "EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels" EPA-420-F-09-024 available at http://www.epa.gov/oms/renewablefuels/420f09024.htm contains draft lifecycle GHG emission reduction results for soy and waste grease bio-diesel that could be used, but not algae and animal fats.
[83] Pg. 10, MD Commission on Climate Change's January 2010 "Update to Governor and General Assembly"
[84] The lifecycle emission factor for soy based biodiesel used by CCS assumed that the soy was produced on land that was already in production and therefore there were no biogenic emissions associated with land conversion.
[85] http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/

These numbers were compared against the MANE-VU inventories for 2012 (compared to 2015) and 2018 (compared to 2020) in Table AFW-7b.3. Because all the values are less than one-tenth of a percent, the table indicates that the criteria pollutant emissions reductions/increases associated with this policy would be unlikely to significantly improve or degrade air quality.

Table AFW-7b.3- Percentage Reductions in State Emissions Inventory Associated with AFW-7b

	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	< .1	< .1
NO_X(Increase)	< .1	< .1
CO	< .1	< .1
VOC	< .1	< .1
PM10-primary	< .1	< .1
PM2.5-primary	< .1	< .1

2.2. Summary of Air Quality Co-Benefits Methodology

The method is based upon the estimated change in statewide Vehicle Miles Traveled (VMT). It was assumed that the percentage reduction in Maryland's VMT would result in an equivalent percentage reduction in the state's mobile source emission inventory. The potential for improved air quality was estimated by comparing reductions in the mobile source inventory to estimates for the total statewide emission inventory.

2.3. Rationale for Air Quality Co-Benefits Methodology

Given the small role of VMT reductions due to car-based passenger-mile reductions a simple comparison (i.e., percentage) of change in the statewide emission inventory was used as the parameter for net co-benefit. The uncertainty and assumptions associated with a more detailed modeling approach would not produce a better result.

2.4. Air Quality Co-Benefits Emission Calculations

Statewide VMT estimates of 55,631 and 78,989 million VMT (mVMT) were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

As a result of AFW-7b, 90 and 115 million gallons of biodiesel (B20) will be used in the state in 2015 and 2020, respectively. Assuming an average diesel fuel use of 8 miles per gallon this would result in 720 and 920 million VMT traveled with biodiesel. This is equivalent to 1.2 and 1.4 percent of the estimate VMT for the state, 2015 and 2020, respectively.

It is estimated that a B20 (i.e., 20 percent) blend of biodiesel will reduce emissions of CO, VOC, SO_2, and PM by 11, 21, 100, and 10 percent, respectively. It will also increase NO_X emission by 2 percent. When those emission changes are applied to the fraction of the statewide mobile source inventory represented by 720 and 920 million VMT the emission reductions listed in Table 1 are derived. The potential co-benefit of those emission reductions listed in Table 2 is the absolute reductions (increase in the case of NO_X) in Table 1 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefits Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, AICP, Secretary, Maryland Department of Planning, November 15, 2010
- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory
- **Biodiesel Emission Factors.** Air Biodiesel Fact Sheet published by the Oklahoma Department of Environmental Quality. www.deq.state.ok.us/factsheets/air/biodieselfs.pdf

2.6. Air Quality Co-Benefits Assumptions

- The emission changes when replacing diesel with biodiesel varies with the fraction of biodiesel in the fuel. The Oklahoma fact sheet from which the emission changes were derived was based on a B20 (i.e., 20 percent biodiesel) blend. We assumed that the biodiesel used in Maryland would be a B20 blend.
- It was assumed that diesel trucks average 8 miles per gallon (mpg). It was reported that semi-trailer trucks average in the range of 5 – 7 mpg (on the road). Smaller diesel vans have average mpgs in the mid-teens. These would vary with city/highway driving, load being hauled, and many other factors. The 8 mpg factor was simply selected as a starting point and was not calculated.
- Emissions from production of the fuel were not considered due to a lack of information.

3.0 INTERACTION WITH OTHER POLICIES

The GHG benefits of AFW-7b could be captured under the Maryland Low-Carbon Fuel Standard policy TLU-4), if this policy had not been removed from consideration by the Maryland Commission on Climate Change (MCCC). Moving forward, specific GHG reductions associated with AFW-7b should not be reported independent of TLU-4, as that would constitute double counting.

Policy No.: AFW-8

Policy Title: Nutrient Trading with Carbon Benefits

SAIC was tasked with reviewing the ES-8 policy analysis which was conducted by a prior MDE contractor (Original Methodology). SAIC conducted a thorough examination of the methodologies, assumptions, data sources, and results and subsequently described the methodology and results as well as provided SAIC's observations and recommendations. SAIC also quantified the air quality co-benefits of this policy. The results of SAIC's review of the Original Methodology and the quantification of related co-benefits is below:

1.0. GHG EMISSION REDUCTIONS

AFW-8 is designed to reduce nitrogen loss from agricultural soils through improved agricultural practices that increase soil carbon sequestration and reduce the use of nitrogen fertilizers that release nitrous oxide (N_2O), a GHG with 310 times the effect (or global warming potential) of one unit of carbon dioxide (CO_2). AFW-8 achieves GHG emission reductions by increasing nitrogen fertilizer efficiency by 20 percent by implementing a nutrient trading scheme. The projected GHG emission reductions from AFW-8 are summarized below:

Table AFW-8.1- Estimated GHG Emission Reductions Resulting from AFW-8

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
Increased fertilizer efficiency by 20 per cent through nutrient trading	0.054	0.087	0.141

1.1. Summary of GHG Emission Methodology

Estimates of N_2O emission rates for fertilizer production and application to agricultural soils were used to determine how N_2O emissions could be reduced through AFW-8. Nitrogen additions to soil, such as fertilizer, drive underlying soil nitrification and de-nitrification cycles, which produce N_2O as a by-product. The emissions estimation accounts for the direct and indirect sources of N_2O emissions from agricultural soils due to fertilizer application. Direct N_2O emissions occur at the site of application and indirect N_2O emissions occur when the nitrogen applied at the site leaches to groundwater or moves in surface runoff and is transported off-site before entering the nitrification/de-nitrification cycle. These direct and indirect N_2O emissions were converted to a CO_2 equivalent emission factor on a per unit of nitrogen basis. The impact on lifecycle emissions of CO_2 that occur during the manufacture and transport of the fertilizer to the agricultural fields was also included in the analysis based on a known emission factor. The improved agricultural practices applied through AFW-8 would reduce the GHG emissions that occur when farmers apply fertilizer to their crops. This reduction was calculated by applying a 20 per cent decrease to the current fertilizer use value (expressed in tons of nitrogen) incrementally in a linear fashion over the policy period. The yearly avoided GHG emissions were calculated by multiplying the reduction in fertilizer use by the related GHG emission factors. The calculation was repeated for each year of the policy (2008-2020) and then summed as appropriate to obtain the GHG reductions in years 2012, 2015, and 2020.

1.2. Rationale for GHG Emission Methodology

N_2O emissions from nitrogen fertilizer use applied to land were calculated using the US Environmental Protection Agency's State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector. The SIT methodology applies emission factors developed for the United States to activity data for the agricultural sector. SIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. The activity data for fertilizer includes all potential uses in addition to agriculture, such as residential and commercial (e.g., golf courses).

In line with international GHG emission accounting practices, N_2O emissions from nitrogen fertilizer use applied to land were converted to carbon dioxide equivalents per unit element of fertilizer product (i.e., CO_{2e}/ kg nitrogen (N)) using the GWP. The GWP determines the relative contribution of a gas to the greenhouse effect. The GWP (with a time span of 100 years) of CO_2, CH_4 and N_2O is 1, 21, and 310, respectively (IPCC 1996).

The lifecycle GHG emissions factor from nitrogen fertilizer production and transport was not calculated, rather, a value was obtained from the scientific literature (an article by Wood and Cowie (2004)). The emissions factor value is the weighted mean for CO_2 emissions from commercial nitrogen fertilizer production (mineral extraction and fertilizer manufacture) and transport from the production facility to the farm. The CO_2 emission values are reported based on type of energy input (natural gas, electricity, distillate fuel, steam, coal, and gasoline) and summed to determine the total CO_2 emissions per ton of nitrogen. This value is believed to be low, as discussed in the analysis and recommendations section.

1.3. GHG Emission Reduction Calculations

The methodology employed for calculating the GHG emission reductions is described stepwise below.

<u>Step 1: Determine annual nitrogen use</u>

Citing Maryland Department of Agriculture (MDA) financial year data, the average annual nitrogen use was determined to be 108,019 tons.[86]

<u>Step 2: Determine Global Warming Potential (GWP) of N_2O</u>

Citing the IPCC Second Assessment Report, the global warming potential of N_2O as compared to CO_2 was determined to be 310.

[86]The total fertilizer use (expressed in tons of nitrogen) for years 2004 through 2006 was averaged to obtain the average annual nitrogen use value. Appendix D states that it was obtained from the MDA 1999-2000 to 2005-2006 data.

Step 3: Determine annual N_2O emissions from fertilizer applied to agricultural land in Maryland

Citing Appendix C (Maryland Inventory & Forecast data), the annual N_2O emissions from nitrogen fertilizer use that was applied to land was determined.[87]

Step 4: Determine GHG impact from fertilizer use

Using Step 2 and Step 3, the GHG impact from nitrogen fertilizer use applied to land was determined. The yearly N_2O emissions from nitrogen fertilizer use applied to land (Step 3) were multiplied by the global warming potential for N_2O (310) to determine the CO_2 equivalent emissions (Step 2).

Step 5: Determine average CO_2e emission factor for fertilizer use

Using Step 1 and Step 4, an average CO_2e emission factor for fertilizer use applied to land was determined. The yearly CO_2e emissions for nitrogen fertilizer applied to land (Step 4) were divided by the yearly total fertilizer use (Step 1). The 2000 through 2006 yearly values were averaged to obtain an average CO_2e emission factor of 5.75E-6 million metric tons CO_2equivalent per ton of nitrogen ($MMTCO_2e$/ton N).

Step 6: Determine a lifecycle CO_2 emission factor for the production and transport of fertilizer

Citing data from Wood and Cowie (2004), a lifecycle CO_2 emissions factor from the production and transport of nitrogen fertilizer was determined to be 0.778 tons CO_2 per ton of nitrogen.[88][89]

Step 7: Forecast fertilizer efficiency over time

Assumed the 20 per cent fertilizer efficiency improvements brought about by the nutrient trading program would increase linearly during the policy period (i.e., from 2 per cent in 2008 to 20 per cent in 2020).

[87] The values of N_2Oemissions for three line items (direct fertilizer, indirect fertilizer, and leaching/runoff) in the AFW Quantification spreadsheet were added for each year between 1990 and 2006 to obtain the annual N_2Oemissions for nitrogen fertilizer use that was applied to land. The emissions were estimated using the US EPA's State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document.

[88] This factor was taken from Table 5 of the Wood and Cowie publication entitled "Greenhouse gas emission factors for Ammonium Nitrate (AN), Calcium Ammonium Nitrate (CAN) and Mean N Fertilisers". The estimate provided for the United States (taken from West And Marland (2001)) was 857.5 grams of CO_2e per kilogram of nitrogen (gCO_2e /kgN)69 or 0.778 tCO_2e per ton of nitrogen (tCO_2e /tN).

[89] This factor is the weighted mean value for CO_2 emissions from energy use in commercial nitrogen fertilizer production and transport only. Carbon emissions from fossil fuels used in the production of the nitrogen fertilizers include emissions from mineral extraction and fertilizer manufacture (Bhat et al., 1994). Energy used in packaging was not included in the calculations because fertilizers used on farms are commonly sold and transported in bulk form.

Step 8: Determine the annual fertilizer reductions

From Step 1 and Step 7, the quantity of fertilizer reduction that would occur each year was determined. The total fertilizer use value of 108,019 tons nitrogen (Step 1) was multiplied by the per cent efficiency improvement for each year of the policy (Step 7).

Step 9: Determine the avoided GHG emissions from reduced fertilizer use

From Step 5 and Step 8, the avoided GHG emissions for nitrogen fertilizer use applied to the land was determined for each year of the policy period. The yearly nitrogen fertilizer reduction value (Step 8) was multiplied by the average CO_2e emission factor of 5.75E-6 $MMTCO_2$e/ton N (Step 5).

Step 10: Determine the avoided GHG emissions from the manufacture and transport of the fertilizer

From Step 6 and Step 8, the avoided GHG emissions for the manufacture and transport of nitrogen fertilizer was determined for each year of the policy period. The yearly fertilizer reduction value (Step 8) was multiplied by the carbon equivalent emissions factor of 0.778 tCO_2 per ton N (Step 6).

Step 11: Calculate the total annual GHG reductions

From Step 9 and Step 10, the total reduction in GHG emissions for each year of the policy period was determined. The avoided GHG emissions value for nitrogen fertilizer use applied to land (Step 9) was added to the avoided GHG emissions value for the manufacture and transport of nitrogen fertilizer (Step 10) for each year of the policy period. The yearly GHG reduction values were added as appropriate to determine the total reductions for years 2012, 2015, and 2020 as shown in Table AFW-8.1.

1.4. GHG Emission Data and Data Sources

The analysis used the following data sources:

- Bhat, M.G., English, B.C., Turhollow, A.F., Nyangito, H.O., 1994. *Energy in Synthetic Fertilizers and Pesticides: Revisited*. ORNL/Sub/90-99732/2. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Borjesson, P.I.I., 1996. *Energy Analysis of Biomass Production and Transportation.* Biomass Bioenergy, 11, pg. 305-318.
- Ruth, M., Selman, M., Marshall, L., Gasper, R. and Bagley, G., 2010, *Multiple Ecosystem Markets in Maryland: Quantifying the carbon benefits associated with nutrient trading*, Center for Integrative Environmental Research and World Resources Institute, August 2010.
- *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, IPCC Second Assessment Report, May 2000.
- Maryland Climate Action Plan, Appendix C, Inventory & Forecast data
- Maryland Department of Agriculture financial year data
- Mudahar, M.S., Hignett, T.P., 1982. *Energy and Fertilizer- Policy Implications and Options for Developing Countries.* International Fertilizer Development Center, Muscle Shoals, Alabama.
- West, T.O. and Marland, G., 2001. *A Synthesis of Carbon Sequestration, Carbon Emissions and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States.*Agriculture, Ecosystems and Environment. Volume 1812, pages 1-16.

- Wood, S. and Cowie A., 2004. *A review of greenhouse gas emission factors for fertiliser production.* Research and Development Division, State Forests of New South Wales, Cooperative Research Centre for Greenhouse Accounting. Available at http://www.ieabioenergy-task38.org/publications/GHG_Emission_Fertilizer Production_July2004.pdf

1.5. GHG Emission Assumptions

The following assumptions were made:

- The GHG emission reduction is achieved through a decrease in commercial nitrogen fertilizer use only.
- The efficiency improvements will increase linearly during the policy period.
- Business As Usual (BAU) fertilizer use will remain constant at 108,000 t/year during the policy period.
- Activity data for fertilizer includes all potential uses in addition to agriculture, such as residential and commercial (e.g., golf courses).[90]
- In the lifecycle CO_2 emissions factor, electricity is assumed to be the primary energy input required for power generation in the production of nitrogen fertilizer with a use rate of 10.5 MJ k Wh(e)$^{-1}$ (0.0105 GJ kWh(e)$^{-1}$).[91]
- In the lifecycle CO_2 emissions factor, demands for steam are assumed to be met by combustion of natural gas.[6]
- In the lifecycle CO_2 emissions factor, transportation of the nitrogen fertilizer from the production facility to the farms assumes an energy use of 0.7 and 1.4 MJ Mg^{-1} km^{-1} by railroad and truck, respectively.[92]
- In the lifecycle CO_2 emissions factor, transportation of the nitrogen fertilizer from the production facility to the farms assumes the distance of transportation is 800 and 160 km by railroad and truck, respectively.[93]

1.6. GHG Emission Analysis and Recommendations

The analysis is restricted to the reduction in N_2O emissions from commercial nitrogen fertilizer production, transport, and application. The analysis omits several other sources of GHG emissions from fertilizer and does not account for GHG reductions created from other types of agricultural improvement

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[90]The activity data was used in the calculation of annual N_2O emissions from nitrogen fertilizer that was applied to land.
[91]Bhat et al., 1994
[92]Borjesson, 1996
[93]Mudahar and Hignett, 1982

projects. Farmers often use multi-nutrient fertilizers that contain various amounts of phosphorus and potassium in addition to nitrogen. Lime is also a common soil amendment used in the agricultural industry and Concentrated Animal Feeding Operations (CAFOs) typically apply manure to fertilize their crops with minor additions of commercial fertilizer. The emissions from the production and application of these other compounds are not included in the analysis.

In addition, the analysis does not include the emission reductions from agricultural Best Management Practices (BMPs) that reduce nutrient runoff and sequester carbon in the soil. These BMPs include a variety of practices such as conservation tilling, cover crop use, forest buffers, grass buffers, nutrient management planning, manure management, and wetland restoration.[94] These omissions underestimate the GHG emissions and the avoided GHG emissions attributed to land application practices, which in turn underestimates the total reduction in GHG emissions for years 2012, 2015, and 2020, as reported in Table AFW-8.1. To some degree, this underestimate is counterbalanced by an over estimate of the calculated N_2O emissions from the SIT model, which used activity data for fertilizer that includes all potential uses in addition to agriculture, such as residential and commercial (e.g., golf courses). To what degree these estimates balance out is unknown.

The analysis used a value for the lifecycle CO_2e emissions factor from nitrogen fertilizer production and transport that was obtained from the scientific literature (an article by Wood and Cowie (2004)). It should be noted here that the value reported in the article is believed to be low. According to the authors, the reported value excluded N_2O emissions, which are significant in total GHG emissions. In other words, the value only accounts for the CO_2 emissions from the production and transport of nitrogen fertilizer. Regardless of the omission of N_2O emissions, the estimate is still considered to be relatively low according to the authors because it is significantly lower than the estimates for European fertilizers (ranging from 5,339.9 to 7,615.9 gCO_2e/kgN). The use of this low value in the analysis of the CO_2e emissions factor underestimates the yearly fertilizer reduction value, which in turn underestimates the total reduction in GHG emissions for years 2012, 2015, and 2020, as reported in Table AFW-8.1.

2. AIR QUALITY CO-BENEFITS

This policy has no NAAQS co-benefits.

3. INTERACTION WITH OTHER POLICIES

This policy does not appear to have significant overlap with other policies.

[94]Carbon benefits associated with seven agricultural BMPs were evaluated after Appendix D was produced. The study is entitled "Multiple Ecosystem Markets in Maryland: Quantifying the carbon benefits associated with nutrient trading", Center for Integrative Environmental Research and World Resources Institute, (August 2010).

Policy No.: AFW-9

Policy Title: Waste Management through Source Reduction and Advanced Recycling

SAIC was tasked with reviewing the AFW-9 policy analysis which was conducted by a prior MDE contractor (Original Methodology) and revising the methodology to include Maryland-specific data and/or other enhancements. SAIC subsequently recalculated the GHG emission reductions associated with AFW-9 based upon its recommended methodology (Revised Methodology). SAIC's revised policy findings along with its air quality co-benefits analysis are described below:

1. GHG EMISSION REDUCTIONS

AFW-9 encompasses the GHG reductions realized from increasing diversion of materials from landfill. There are several components to this policy:

- Source reduction, or preventing waste before it occurs, through process changes, transition to durables, extended producer responsibility, etc.;
- Increasing recycling and composting of various materials; and
- The end of life profile of the remaining discards: landfill or incineration.

SAIC analyzed the impacts in the year 2020 associated with reducing the combined amount to landfill and incineration for each material above the 2006 diversion rate by 10 percent, 20 percent, 30 percent, 40 percent and 50 percent respectively. The total GHG reductions from increased diversions from landfills and incineration over the 2006 baseline[95] is summarized in the table below. Green indicates a GHG reduction.

Table AFW-9.1- GHG Emission Reductions Resulting from AFW-9

Year 2020	GHG Reductions (Million Metric Tons CO_2e)				
Increased Diversion for each material over the 2006 baseline	10%	20%	30%	40%	50%
Total	(0.84)	(2.32)	(3.80)	(5.12)	(5.97)

[95] Data provided by MDE in "WARM CY 2006 v 2007.xls"

1.1. Summary of GHG Emission Methodology

GHG emissions reductions were estimated using the solid waste industry standard EPA Waste Reduction Model (WARM)[96]. EPA developed WARM to model the GHG impacts of solid waste and diversion practices of communities or organizations. The WARM Model compares GHG and energy baselines with alternate scenarios for landfilling, recycling, composting, incineration and source reduction of various materials.

1.2. Rationale for GHG Emission Methodology

The industry standard methodology to estimate greenhouse gas impacts from solid waste decisions remains the EPA WARM Model. The adoption of this methodology benefits from the detailed documentation and easy comparison to other efforts and scenarios modeled with the same software.

Version 10 of the WARM model was utilized for consistency with previously conducted modeling by MDE with the same software. The WARM model itself has been updated since, ostensibly making it a more accurate tool. Some revisions in WARM, version 11 include:

- Revised assumptions regarding capture of landfill gas based on system installation;
- Incorporated decay rate for organic materials;
- Detailed choices regarding moisture and landfill gas recovery; and
- Updated options for energy grid customized by State and landfill options.

However, at this time the benefits of resulting from updates were outweighed by the ability to limit the number of changing variables by staying with Version 10.

1.3. Detailed Explanation of GHG Emission Methodology

EPA's WARM Model is the result of an in-depth Life Cycle Analysis that looks to document the process of material discards and the impacts of that process. The process includes:

1) Extraction of minerals; ores; other raw materials and their initial processing;
2) Production of goods;
3) Hauling of the goods to markets
4) Consumer use; and
5) Their end of life or discard fate (reuse, recycling, compost, landfill, or incineration).

GHG emission impacts related to material discards stem from:

1) Energy consumption or combustion of fuels used to extract, process, transport, use or dispose of a material;
2) Greenhouse gas emissions from processing or manufacture of goods;
3) Landfill Emissions – Methane;
4) Incineration Emissions – Carbon Dioxide and Nitrous Oxide; and

[96] http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home html

5) Carbon Sequestration.

WARM is a comparative tool, showing GHG reductions for a scenario with respect to a baseline. While Source Reduction is an option in the WARM model any year 2020 waste prevention that occurs with respect to the standard 2020 generation case also needs to account for the *increase* in materials generation as compared to 2006 as projected due to factors such as population growth.

The materials analyzed were the total quantity of waste generated in the state of Maryland. Therefore this includes tons of Municipal Solid Waste (MSW) exported in the analysis, but not those imported.

1.4. GHG Emission Reduction Calculations

Waste Projections

The waste generated figures were based on the Solid Waste Tonnage Reports from permitted solid waste acceptance facilities and the Maryland Recycling Act (MRA) Tonnage Report[97]. Discards and population statistics for the years 2005 to 2008 were used to calculate a per capita waste discard value in ton/year. This was used in conjunction with population projections from the Maryland Department of Planning to forecast the actual discards for each future year.

$$\text{Population}_{2020} \times \text{Ton/Person/Year} = \text{Tons/Year}$$

Source Reductions

Maryland creates incentives for preventing waste before it is created by offering Source Reduction Credits for specific initiatives such as grasscycling[98]. Based on the Source Reduction credits for 2005 and 2008 of 3.43 percent and 3.64 percent, respectively, it was projected that the same increase would occur annually until 2020. A compounded Source Reduction Credit of 4.56 percent for the year 2020 was calculated.

$$SR_{\text{Annual Increase}} = \{(SR_{2008}/SR_{2005}) - 1\} / 3 \text{ years}$$

$$= \{(3.64\%/3.43\%) - 1\} / 3 \text{ years}$$

$$= 2.04\% \text{ increase in Source Reduction per Year}$$

$$SR_{2020} = \{(SR_{\text{Annual Increase}} \times 14 \text{ years}) + 1\} \times SR_{\text{Baseline (2006)}}$$

$$= \{(2.04\% \times 14) + 1\} \times 3.55\%$$

$$= 4.56\% \text{ Source Reduction in the Year 2020}$$

Waste Characterization

Available data on amount of materials discarded, recycled, landfilled and incinerated were tracked and obtained, but the specific materials and their fate impact the greenhouse gases generated or reduced. In

[97] Data provided by MDE: 2009 MRA Totals.xls

[98] Grasscycling is the practice of leaving grass cuttings on the lawn to decompose when mowing, In contrast to collecting the clippings to compost or landfill them.

order to estimate quantities of each of the materials for input into the WARM model figures from EPA's Municipal Solid Waste Generation, Recycling, and Disposal in the United States 2008[99] were used to estimate the quantities of each waste generated that were both generated and source reduced in Maryland in the year 2020.

Recycling

Baseline recycling for the year 2006 was determined from actual tonnage data[100] (see GHG Emission Data and Data Sources Section 1.5 below).

1.5. GHG Emission Data and Data Sources

The analysis benefitted from data that was tracked since the 2008 Climate Action Plan. Updated waste statistics compiled from the Annual Maryland Recycling Act (MRA) Tonnage Reporting Surveys informed the waste projections. Data from the Source Reduction Credit Reporting System was utilized to more conservatively estimate future Source Reduction Credits and their impact.

Key Input data for the policy:

Waste Projection

Population $_{2020}$ = 6,326,975 People as obtained from Maryland Department of Planning

Discard waste generation with Source Reduction $_{(Ave\ 2005-2008)}$ = 1.36 Ton/Person/Year

The quantities of waste generated were obtained from the annual Solid Waste Tonnage Report (filed by Maryland permitted solid waste acceptance facilities) and the annual MRA Tonnage Reporting Survey for the years 2005 to 2008. It is the actual amount of waste generated in Maryland as can be ascertained from required reporting. This does not include non-MRA waste, as much of that waste is from industrial and commercial entities, which are not required to report. As a result Non-MRA waste reported fluctuates from year to year, ostensibly not due to large variations in materials discarded, but rather due to reporting choices of reporting entities.

The MSW generation includes all discards *generated* in the State of Maryland. It should be noted that landfilling and incineration includes exports, but not imports.

Source Reductions

The Source Reduction Credit Reporting System provides an incentive for counties to implement and track waste prevention initiatives and report them to MDE. Through this system, Source Reduction Credits were tracked for the years 2005 to 2008 and the trend over that period was used to estimate the conservative, but steady increase of source reduction activities that will be undertaken from 2006 to 2020.

[99] http://www.epa.gov/osw/nonhaz/municipal/pubs/msw2008data.pdf
[100] Provided by MDE: WARM 2006 v 2007.xls

Waste Characterization

The data provided in EPA's Municipal Solid Waste Generation, Recycling, and Disposal in the United States 2008 was used to estimate the percentage of the waste stream for each of a number of applicable materials that can be inputted into WARM. The following table shows the estimated percentage of the total MSW discards for each material:

Recycling

Information used to develop the quantities recycled in 2006 includes:

- Beverage Container Data by County from MRA Report[101] – Use of data from counties where containers are sorted (Aluminum, Tin/Steel, Polyethylene Terephtalate (PET), High-Density Polyethylene (HDPE), #3, 4, 5 & 7)

- Annual Report Solid Waste Management in Maryland Report 2006

- The 2006 Maryland Recycling Act (MRA) Tonnage Reporting Survey:
  (1) The total amount, by weight, of solid waste collected;
  (2) The total amount, by weight, of solid waste disposed of at solid waste acceptance facilities;
  (3) The amount and types of materials recycled;
  (4) The methods of disposal of solid waste used, other than recycling; and
  (5) The percentage reduction in the amount of solid waste needing disposal that has been achieved.

End of Life Profile

The 2009 profile for the waste generated remaining after recycling and composting was obtained from the 2009 Annual Report Solid Waste Management in Maryland Report. This determined the allocation of the 2020 non-recycled, non-composted waste generation to landfill or incineration.

1.5. GHG Emission Assumptions

The following assumptions were made:

- Source Reduction: With no framework for targeting specific materials it is assumed these programs reduce the overall amount of waste that must be managed. The amount of each material that was prevented from being generated in 2020 was determined using the EPA 2008 Waste Characterization.

- Export and Import MSW rate change – it was assumed that exports and imports increased at the same rate as the MSW. As well, it was assumed that the ratio of exports to imports to discards generated remains constant.

[101] Provided by MDE: "2006 MRA totals no edit.xls"

- Of the materials remaining after recycling and composting, the percent split between landfill and incineration remained static at the percentages they were in 2009, at 61 percent and 39 percent, respectively.
- The 2006 discards (actual tonnages discarded, so this incorporates the Source Reduction into the Baseline) was allocated to the material types using the EPA 2008 MSW Waste Characterization.

The following table shows the input values calculated and input into the WARM model for the 2006 baseline.

Table AFW-9.3- Input Values for the WARM Model

	2006 Diversion	Tons Landfilled	Tons Combusted	Tons Recycled or Composted
Aluminum Cans	17%	22,478	14,311	7,678
Steel Cans	8%	43,536	27,718	6,410
Glass	16%	190,051	120,998	58,994
HDPE	57%	5,994	3,816	13,032
PET	20%	39,750	25,307	16,566
Corrugated Cardboard	42%	330,177	210,211	395,582
Magazines/Third-class Mail	0%	145,086	92,371	710
Newspaper	22%	131,948	84,006	61,277
Office Paper	58%	49,352	31,420	109,825
Phonebooks	0%	16,161	10,289	12
Food Scraps	6%	687,264	437,555	72,041
Yard Trimmings	50%	378,692	241,099	618,860
Mixed Paper (general)	62%	143,007	91,047	387,825
Mixed Metals	57%	136,221	86,727	289,934
Mixed Plastics	11%	440,582	280,502	89,660
Mixed Recyclables	66%	130,579	83,135	422,212
Mixed Organics	79%	22,647	14,419	140,261
Tires	5%	82,493	52,520	7,827
Total		**2,996,016**	**1,907,450**	**2,698,706**

1.6. GHG Emission Analysis and Recommendations

Based on the approach outlined above, the waste generation projected for 2012, 2015 and 2020 are shown in Table 4 below. Based on the trend of source reduction, the anticipated overall tons of MSW prevented is also shown.

Table AFW-9.4- Waste Generation Projections

Tons	2012	2015	2020
Waste Generated	8,486,946	8,693,182	9,010,656
MSW Source Reduced	338,179	365,291	411,272
Materials Composted	NA	NA	Varies see table below
Material Recycled	NA	NA	Varies see table below
Material Landfilled	NA	NA	Varies see table below

Rather than setting benchmark diversion goals for each material, the GHG emission reductions were analyzed based on increasing the diversion by material in 10 percent increments. This analysis provides a guideline regarding which materials to target to maximize GHG reductions, instead of summarizing the reductions for specific target reductions. While a number of the resulting diversion percentages may be extremely optimistic, as several materials reach and maintain 100 percent diversion, this more clearly highlights the materials that make an impact on the Maryland's carbon footprint. This information will be considered in conjunction with the existing diversion rates, infrastructure analysis and technological options for reducing, reusing or recycling any of these materials.

The table below shows the GHG reductions from 2006 baseline diversion per material (GHG emission reductions are shown in green font):

Table AFW-9.5-GHG Reductions from 2006 Baseline Diversion per Material

	GHG Reductions (Million Metric Tons CO_2e)									
Increment	**10%**		**20%**		**30%**		**40%**		**50%**	
Year 2020	**Diversion**	**$MMTCO_2E$**	**Diversion**	**$MMTCO_2E$**	**Diversion**	**$MMTCO_2E$**	**Diversion**	**$MMTCO_2E$**	**Diversion**	**$MMTCO_2E$**
Aluminum Cans	27%	(0.03)	37%	(0.10)	47%	(0.17)	57%	(0.24)	67%	(0.31)
Steel Cans	18%	0.01	28%	0.00	38%	(0.01)	48%	(0.02)	58%	(0.03)
Glass	26%	0.01	36%	(0.00)	46%	(0.02)	56%	(0.03)	66%	(0.04)
HDPE	67%	(0.00)	77%	(0.01)	87%	(0.01)	97%	(0.02)	100%	(0.02)
PET	30%	0.00	40%	(0.01)	50%	(0.03)	60%	(0.05)	70%	(0.07)
Corrugated Cardboard	52%	0.22	62%	(0.06)	72%	(0.33)	82%	(0.61)	92%	(0.88)
Magazines/Third-class Mail	10%	0.19	20%	0.12	30%	0.05	40%	(0.02)	50%	(0.08)
Newspaper	32%	0.07	42%	0.01	52%	(0.04)	62%	(0.10)	72%	(0.16)
Office Paper	68%	0.10	78%	0.03	88%	(0.03)	98%	(0.09)	100%	(0.10)
Phonebooks	10%	0.01	20%	0.01	30%	0.00	40%	(0.00)	50%	(0.01)
Food Scraps	16%	(0.03)	26%	(0.06)	36%	(0.09)	46%	(0.13)	56%	(0.16)
Yard Trimmings	60%	(0.02)	70%	0.00	80%	0.03	90%	0.05	100%	0.07
Mixed Paper (general)	72%	(0.40)	82%	(0.61)	92%	(0.82)	100%	(0.99)	100%	(0.99)
Mixed Metals	67%	(0.51)	77%	(0.80)	87%	(1.09)	97%	(1.38)	100%	(1.48)
Mixed Plastics	21%	(0.16)	31%	(0.34)	41%	(0.52)	51%	(0.70)	61%	(0.88)
Mixed Recyclables	76%	(0.34)	86%	(0.52)	96%	(0.69)	100%	(0.75)	100%	(0.75)
Mixed Organics	89%	(0.00)	99%	(0.00)	100%	(0.00)	100%	(0.00)	100%	(0.00)
Tires	15%	0.04	25%	0.01	35%	(0.02)	45%	(0.05)	55%	(0.08)
Total		(0.84)		(2.32)		(3.80)		(5.12)		(5.97)

In terms of the potential for refining the analysis moving forward, version 10 of the WARM model does not allow for source reduction of a number of material categories, such as mixed paper, mixed metals, mixed plastics etc. The subsequent version of the model does allow for source reduction inputs for these materials.

If adequate data is obtained regarding source reduction activities that are awarded credits, it would be more accurate to be able to allocate the source reduction to the specific materials that are prevented from being created. For example, grasscycling programs would be credited to grass (or yard trimmings as the broader category), junk mail and catalog reduction initiatives would target magazines and third class mail, and re-manufacturing programs would impact materials such as metals or plastics.

Overall, the more specific data regarding materials and categories that can be procured, the more accurate the model will be. With Maryland's E-Waste Law, tonnages of applicable electronics may be easily tallied, and split out as certified recycling efforts in WARM. As well, many of the categories requested by the MRA survey could be incorporated to further refine the data set.

2.0 AIR QUALITY CO-BENEFITS

The estimated emissions reductions from AFW-9 are shown in the following table:

Table AFW-9.6- Emissions Reductions in Maryland Associated with AFW-9 (tons/year)

	% Reductions in Combined Amount Sent to Landfill and Incineration in 2020				
Pollutant	**10%**	**20%**	**30%**	**40%**	**50%**
SO_2 (1)	24 to 61	110 to 280	190 to 500	270 to 710	350 to 890
NO_X	150	710	1300	1800	2200
CO	20	92	160	230	290
PM (2)	2.5 to 9.0	12 to 42	21 to 73	29 to 100	37 to 131

(1) The ranges of emissions for SO_2 and PM represent the different air pollution control technologies/emission levels that could be applied to those emissions. It was assumed that the emissions were controlled but not by a specific technology.

The 2020 bounding emission reductions in Table AFW-9.6 are presented as a percentage of 2018 MANE-VU inventories in Table AFW-9.7. Because all the increased values are less than two-tenths of a percent it indicates that the criteria pollutant emission increases when reductions in the amount sent to the landfill is only 10 percent would not significantly degrade air quality. Because the decreased values for CO and PM are less than one-tenth of a percent, it indicates that the criteria pollutant emissions decreases when reductions in the amount sent to the landfill is 50 percent would not significantly improve air quality. The higher impacts for SO_2 and NO_X of 1.0 percent and 2.1 percent, respectively, might result in a small improvement in air quality.

Table AFW-9.7: Percentage Reductions in State Emissions Inventory Associated with AFW-9

	Maryland (%)	
Pollutant	**Minimum Reductions (10% Reductions in Landfill Amount)**	**Maximum Reductions (50% Reductions in Landfill Amount)**
SO_2	< 0.2	1.1
NO_X	< 0.2	2.2
CO	< 0.2	< 0.1
PM	< 0.2	< 0.1

2.1. Summary of Air Quality Co-Benefits Methodology

The only significant emissions from landfills are methane and carbon dioxide. Neither of these are criteria (i.e., NAAQS) pollutants. The only affect this policy will have on air quality is if it affects the tonnage of waste that will be incinerated. The AP-42 emission factors for incineration were applied to the annual change in waste tonnage that was projected to be incinerated. The waste tonnage incinerated varied with increased recycling and composting. Calculations were made for reducing the amount of material to the landfill and incineration by 10 percent, 20 percent, 30 percent, 40 percent and 50 percent over the 2006 diversion baseline. The ratio of the amount landfilled and incinerated remained constant, at 61 percent and 39 percent respectively. Incineration tonnage decreased by 85,743 tons/year; 396,407 tons/year; 695,841tons/year; 988,105 tons/year; and 1,250,019 tons/year for increased diversion percentages 10, 20, 30, 40, and 50 percent, respectively.

2.2. Rationale for Air Quality Co-Benefits Methodology

This methodology is the only approach for estimating the change in criteria pollutant emissions. Better estimates would require site specific emission data and a determination of how the change in waste tonnage would impact specific incinerators.

2.3. Air Quality Co-Benefits Calculations

Emission factors (EF) for refuse combustion were taken from AP-42. For pollutants that are controlled, AP-42 provided emission factors for the different control techniques. It was assumed that the incinerators in Maryland were controlled. However, there was no way to determine which specific incinerators might be affected by the change in waste tonnage due to this policy. So we used the least affective and most affective air pollution controls to bind a range for the change in emissions.

The annual emissions were calculated as follows:

EF(lb/ton) x change in tonnage incinerators(ton/yr)/2000 lb/ton = emissions (tons/yr)

The changes in annual emissions are summarized in Table 1. The percentage of the statewide emission inventory represented by the emission changes in Table 1 is the potential co-benefit and is presented in Table 2.

2.4. Air Quality Co-Benefits Data and Data Sources

- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory
- **Incinerator Emission Factors. AP-42,** 2.1 Refuse Combustion, Table 2.1-2 Particulate Matter, Metals, And Acid Gas Emission Factors For Mass Burn And Modular Excess Air Combustors And Table 2.1-4 Organic, Nitrogen Oxides, Carbon Monoxide, And Carbon Dioxide Emission Factors For Mass Burn Waterwall Combustors.

2.5. Air Quality Co-Benefits Assumptions

It was assumed that any of the benefits from reducing the NAAQS pollutants emitted by landfills are insignificant compared to the benefits from reducing the incineration.

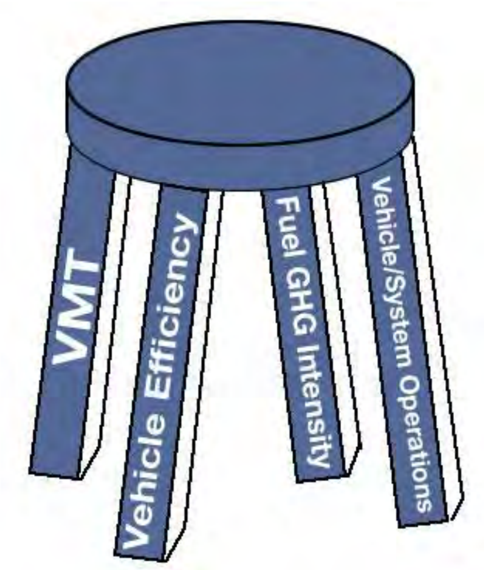
3.0 INTERACTION WITH OTHER POLICIES

The discussion of policy interactions is provided in Chapter 5.

Chapter 4: Transportation and Land Use (TLU) Policies

Transportation sector emissions are a function of many complex, often interrelated factors that include the efficiency of the overall vehicle, the carbon intensity of the fuel, the activity level of the vehicle, and the transportation system-wide operational efficiency, as illustrated in Figure 4.1. The TLU policies address each of these factors except the fuel GHG intensity factor.

Figure 4.1. Transportation GHG Emissions Mitigation Options



The following TLU Policies were analyzed:

- TLU 2: Land Use and Location Efficiency
- TLU 3: Transit
- TLU 5: Intercity Travel
- TLU 6: Pay-As-You-Drive Insurance
- TLU 8: Bike and Pedestrian Infrastructure
- TLU 9: Incentives, Pricing and Resource Measures
- TLU 10: Transportation Technologies

TLU Policy Findings

Table 4.1 presents the 2020 GHG emission reduction estimates for the above-listed seven policies. SAIC developed the reduction estimates for TLU-6 (Pay-As-You-Drive Insurance); the estimated reductions for the other six policies are from the CAP. As the table indicates, Policy TLU-9 accounts for 50 percent of the sum of the reductions across the TLU sector, while TLU-2 (Land Use and Location Efficiency) and

TLU-3 (Transit) contribute 26 percent and 12 percent, respectively, to the TLU sum. The remaining four policies combined account for 11 percent of the TLU emission reduction sum.

Table 4.1. Summary of GHG Emission Reductions from the TLU Sector in 2020

Sector/Policy	2020 GHG Emission Reductions ($MMTCO_2e$)
Transportation & Land Use (TLU)	
TLU-2: Land Use & Location Efficiency	0.96
TLU-3: Transit	0.45
TLU-5: Intercity Travel	0.02
TLU-6: Pay-As-You-Drive Insurance	0.03
TLU-8: Bike & Pedestrian Infrastructure	0.15
TLU-9: Incentives, Pricing & Resource Measures	1.84
TLU-10: Transportation Technologies	0.20
TLU Total (Unadjusted for Overlap)	**3.65**

Table 4.2 presents the projected 2020 reductions in criteria pollutant emissions for the nine AFW policies. As this table indicates, Policy TLU-9 (Incentives, Pricing and Resource Measures) accounts for the majority of the reductions for the various criteria pollutants.

Table 4.2. Summary of Criteria Pollutant Emission Reductions from the TLU Policies in 2020

		SO_2 (Tons)	NO_x (Tons)	CO (Tons)	VOC (Tons)	PM10 (Tons)	PM2.5 (Tons)
	Transportation & Land Use (TLU)						
TLU-2	TLU 2 - Land Use & Location Efficiency	15.00	620.00	14,000.00	660.00	25.00	23.00
TLU-3	TLU 3 – Transit	8.70	370.00	8,500.00	397.00	15.00	14.00
TLU-5	TLU 5 - Intercity Travel	0.60	26.00	600.00	28.00	1.00	1.00
TLU-6	TLU 6 - Pay-As-You-Drive Insurance	1.00	44.00	1,000.00	47.00	1.70	1.60
TLU-8	TLU 8 - Bike & Pedestrian Infrastructure	4.60	200.00	4,500.00	210.00	7.80	7.30
TLU-9	TLU 9 - Incentives, Pricing & Resource Measures	37.00	3,300.00	43,000.00	2,500.00	140.00	74.00
TLU-10	TLU 10 - Transportation Technologies						
	TLU Total	**66.90**	**4,560.00**	**71,600.00**	**3,842.00**	**190.50**	**120.90**

As is discussed in the individual policy sections that follow, the various TLU policies interact closely with each other, both synergistically and competitively. Due to the complexity of these interactions, a transportation and land use planning modeling effort would need to be undertaken to quantify the impact of these interactions on the GHG and criteria pollutant emission reductions projected for the different policies. Such a modeling effort was outside the scope of our analysis.

Policy No.: TLU-2

Policy Title: Land Use and Location Efficiency

SAIC was tasked with reviewingthree versions of the TLU-2 policy analysis: 1) the original TLU-2 policy analysis, which was conducted by a prior MDE contractor (henceforth referred to as CAP 2008), 2) a subsequent re-analysis of the same policy, which was conducted by Maryland Department of Transportation (MDOT) contractors,[102] and the current policy analysis conducted by the Maryland Department of Planning (MDP).[103] SAIC conducted a thorough examination of the methodologies, assumptions, source materials, and results, and documented the methodology and results, as well as provided SAIC's observations and recommendations. In addition SAIC quantified the air quality co-benefits associated with TLU-2. SAIC's findings are described below:

1. GHG EMISSION REDUCTIONS

TLU-2 is designed to implement land-use planning and development strategies that reduce the number of VMT and corresponding GHG emissions. Table TLU-2.1 presents the estimated reductions.

[102] Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report. November 4, 2009, and Appendix B of the same report.

[103] Maryland Department of Planning, 2020 CO2 Reduction Attributable to Smart Growth in Maryland, January 2011.

Table TLU-2.1- Estimated Reduction in GHG Emissions and Vehicle Miles Traveled Resulting from TLU-2

Emissions Category	Estimated Reductions		
	2012	2015	2020
Total TLU-2 GHG Reductions from Urban Transportation and Building Energy ($MMTCO_2e$)	0.16	0.43	0.96
Urban Transportation VMT-Related Reductions ($MMTCO_2e$)	0.1	0.28	0.65
Building Energy Savings from Compact Development ($MMTCO_2e$)	0.06	0.15	0.31
Statewide Transportation VMT Reductions (Million Miles)	233	645	1,502

Notes: Not all digits displayed are significant figures.

Source: Maryland Department of Planning, February 2011.

1.1. Summary of GHG Emission Methodology

MDP, for the purposes of estimating the potential climate change mitigation benefits of widespread implementation of the TLU-2 policy, includes the following four components in its desired outcomes of smart growth strategies:[104]

- Geographic and spatial relationships between origins and destinations,
- Governance of transportation, land use and development,
- Functional and social integration of transportation modes, and
- Mass transit efficiency and affordability.

MDP estimated GHG emissions from smart growth strategies using a methodology thaton the two metrics of density and relative amount of growth. MDP's methodology originated in the Urban Land Institute book *Growing Cooler*[105] and was subsequently refined and applied on behalf of the California Air Resources Board (CARB) to validate a GHG estimate for inclusion in the Draft AB 32

[104] Maryland Department of Planning, "Maryland Commission on Climate Change Report Update," TLU-2, November 2010.
[105] Reid Ewing, et al. *Growing Cooler: The Evidence on Urban Development and Climate*, Urban Land Institute, April 11, 2008.

Scoping Plan.[106] University of Maryland Professor Reid Ewing of the National Center for Smart Growth was a co-author of *Growing Cooler* and the subsequent study for CARB. MDP considers this methodology to be an interim approach, sufficiently robust to support analyses pursuant to Maryland's Greenhouse Gas Emissions Reduction Act of 2009, until Maryland transportation models are revised and updated with the capability of quantifying TLU-2 impacts.

The proposed interim methodology relates VMT and GHG reduction to smart growth based on the assumption that compact development has the potential to reduce VMT per capita by 30 percent relative to sprawl. This assumption is used in a formula that incorporates two key metrics:

- Density of Maryland's built environment – MDP plans to increase the share of Maryland's built environment that is "compact" (defined as having a minimum of 4 units per acre) to 75 percent, using strategies that influence the density of new and re-development; and

- Relative amount of growth – MDP projects that the amount of new development within the next decade will represent 10 percent of Maryland's total built environment.

In addition to VMT reductions, MDP estimates GHG reductions from building energy as a result of high-density development.

1.2. Rationale for GHG Emission Methodology

MDP chose the interim methodology for the GHG estimate based on the precedent of its application on behalf of CARB for validating GHG emission reductions attributable to smart growth in California. The methodology was applied for CARB by two of the leaders in the field of smart growth and climate change mitigation.[107] The methodology originated in the Urban Land Institute book *Growing Cooler.*[108]MDP considers the interim approach sufficiently robust to support analyses pursuant to Maryland's Greenhouse Gas Emissions Reduction Act of 2009, until Maryland transportation models are revised and updated with the capability of quantifying smart growth impacts.

1.3. Detailed Explanation of Methodology

Each of the three TLU-2 GHG reduction estimates, presented below, was based on a different methodology. MDP concluded that the reductions originally calculated in the 2008 CAP may have been overestimated. The subsequent MDOT approach considers some of the same literature as the interim MDP methodology, but adopts a different formula to compute the results.

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[106] Reid Ewing and Arthur C. Nelson, "CO_2 Reductions Attributable to Smart Growth in California," National Center for Smart Growth, University of Maryland, and Metropolitan Research, University of Utah, January 7, 2010, http://metroresearch.utah.edu/products/11-CO_2-Reductions-Attributable-to-Smart-Growth-in-California.
[107] Reid Ewing and Arthur C. Nelson, "CO_2 Reductions Attributable to Smart Growth in California," National Center for Smart Growth, University of Maryland, and Metropolitan Research, University of Utah, January 7, 2010, http://metroresearch.utah.edu/products/11-CO_2-Reductions-Attributable-to-Smart-Growth-in-California.
[108] Reid Ewing, et al. *Growing Cooler: The Evidence on Urban Development and Climate*, Urban Land Institute, April 11, 2008.

Table TLU-2.2- Comparison with Other Studies

TLU-2 Reduction Estimates Based on Different Methodologies	Reduction in 2020 ($MMTCO_2E$)
MDP 2011[109]	0.65
MDOT 2009[110]	0.18 – 0.24
CAP 2008[111]	4.6

1.4. GHG Emission Reduction Calculations

The MDP methodology is based on the following formula, which was developed for *Growing Cooler* and subsequently applied for CARB to validate its forecast of GHG reductions with compact development:

$$TER_i = MS_i * TD_{ji} * VMT * RR * BP_i$$

Where

TER_i = Total GHG emission reduction with compact development in year i for Policy

TLU-2 (million metric tons CO_2e)

MS_i = Market Share of Compact Development in year i (percent)

TD = Percent of total development built between years j and i (percent)

VMT = % VMT reduction per capita achievable by compact development relative to sprawl (percent)

RR = Ratio CO_2/VMT reduction with compact development

BP_i = Baseline projection of transportation CO_2 in year i (million metric tons CO_2e)

i = 2020

j = estimate base year of 2010[112]

MDP provided the statewide VMT reduction estimate.

[109] Maryland Department of Planning, 2020 CO2 Reduction Attributable to Smart Growth in Maryland, January 2011.

[110] Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report. November 4, 2009, Appendix B.

[111] Maryland CAP Appendix D-4, 2008.

[112] Different from CAP base year of 2006.

In addition to the transportation sector savings, compact development in Maryland is estimated to reduce building energy use and associated GHG emissions by 0.31 $MMTCO_2E$ in 2020, based on the following formula:

$TBER_i = MS_j * TD_{ji} * BECR * RCI$

Where

$TBER_i$ = Total building energy emissions reductions in year i

BECR = building energy consumption reduction (%)

RCI = Baseline estimate from Residential/Commercial/Industrial (RCI) fuel use in the CAP

1.5. GHG Emission Data and Data Sources

MDP input the following data into its estimate of emission reductions associated with compact development:

- MSi = Market Share of Compact Development – The MDP forecast of 75% compact development market share by 2020 is based on the following historic data and factors:
    - MDP reviewed 1997 to 2010 data and trend of market share of compact development in Maryland, which was obtained from the source MDPropertyView, a MDP geographic information systems (GIS) database tool that includes property map and parcel information. For 2006, the market share of compact development in Maryland was 68.5 percent. Figure TLU-2.1 presents historical data to characterize the level of compact development in the residential sector in Maryland. As the figure illustrates, high-density development generally has been increasing in Maryland since 2002.
    - MDP defined compact development as having a minimum density of 0.25 acre per housing unit, based on the transit bus service minimum density requirement of 4 housing units per acre, as established by research by the Victoria Transport Policy Institute.
- TD = Percent of total development built between years 2010 and 2020 – MDP's estimate of 10 percent, which represents the increment of new development or redevelopment in Maryland relative to the stock that will exist in the base year 2020, is based on two data sources:
    - Maryland State Data Center - housing units growth projection for 2010 to 2020 is 8.5 percent of the 2020 built environment
    - 2009 American Community Survey and the Census Bureaus' demolition rates were used to determine the housing stock replacement percentage

- VMT = Ewing and Nelson[113] and *Growing Cooler* establish the factor of 30 percent per capita VMT reduction achievable by compact development relative to sprawl. This factor applies to each increment of development or redevelopment but does not affect base development.
- RR = MDP uses a ratio CO_2e to VMT reduction of 90 percent, consistent with the conservative assumption adopted by Reid and Nelson for CARB.
- BP = Baseline projection of CO_2 in year i (million metric tons CO_2e)
- VMT = Total statewide VMT in given year. Data, in billion miles, are provided here:
    - VMT 2012 = 61.5
    - VMT 2015 = 64.8
    - VMT 2020 = 69.9

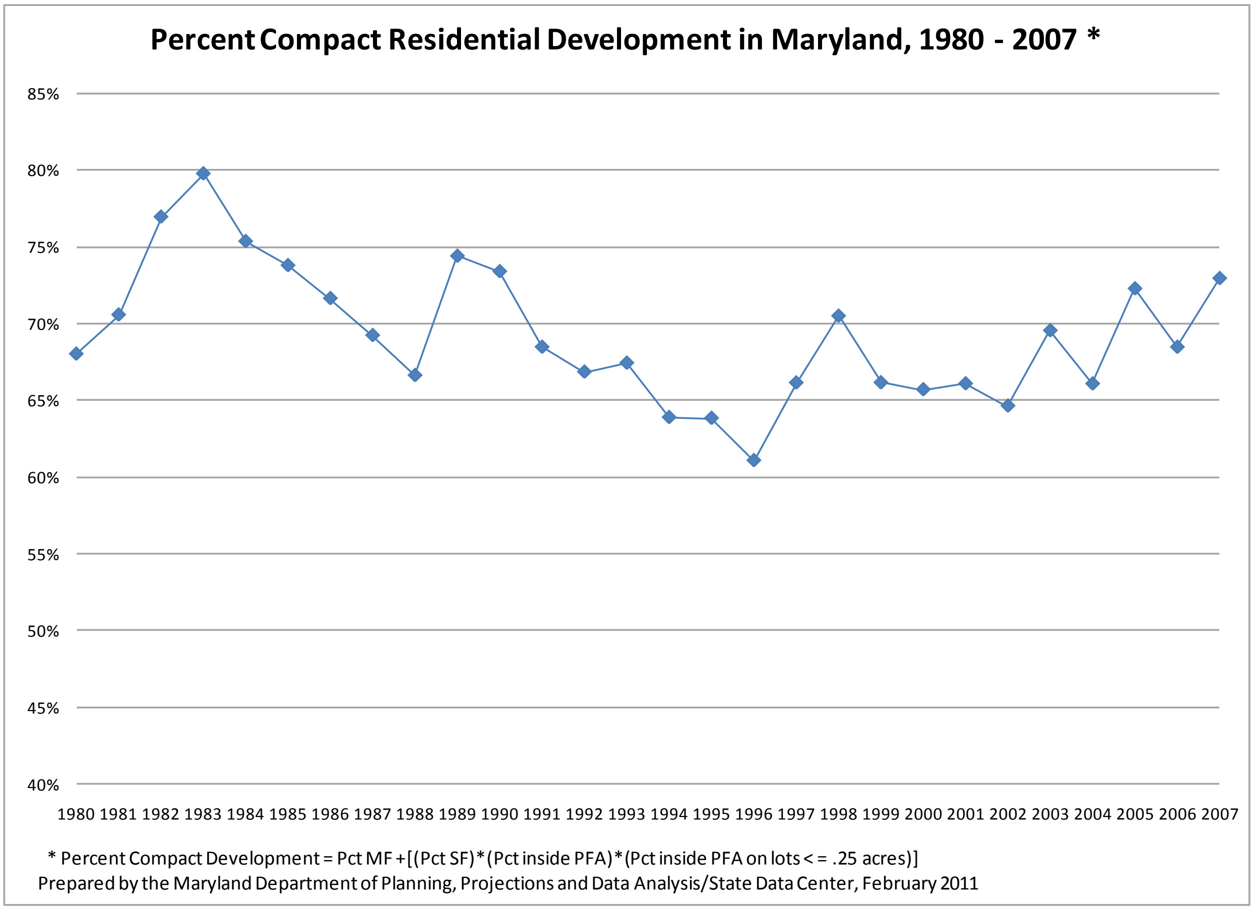
GHG emission reductions associated with building energy savings are estimated using the following data:

BECR = 20 percent

RCI = Baseline RCI = 20.7 $MMTCO_2e$

113 Reid Ewing and Arthur C. Nelson, "CO_2 Reductions Attributable to Smart Growth in California," National Center for Smart Growth, University of Maryland, and Metropolitan Research, University of Utah, January 7, 2010, http://metroresearch.utah.edu/products/11-CO_2-Reductions-Attributable-to-Smart-Growth-in-California.

Figure TLU-2.1. Percent Compact Residential Development in Maryland (1980 – 2007)



1.6. GHG Emission Assumptions

MDP relied on several assumptions to quantify smart growth impacts on GHG emissions, including the following associated with compact development market share:

- MDP assumes the compact development market share in Maryland will increase to 75 percent by 2020, from 68 percent in 2010. MDP based this assumption on discussions with a demographer and reviews of historic data and trends (described in the *Data and Data Sources* section), and feels it is achievable through the implementation of aggressive but realistic policy actions. MDP provides the following background:

> *Land use patterns that support the TLU-2 strategy include redevelopment and infill, smaller lot sizes, designated growth areas, rural conservation zoning, transit-oriented development (and other development that can make use of existing alternative transportation networks), development patterns that can support extensions of and future alternative transportation networks, mixed-use development, and building new homes (origins) near jobs and other destinations.*[114]

[114] Maryland Department of Planning, TLU-2, Maryland CAP Update Project, January 2011.

- MDP assumes that the share of new attached units to all units constructed in Maryland will continue to increase, not only in response to recent nation-wide financial sector events, but also changing demographics and housing market trends, consistent with assumptions adopted by Ewing and Nelson in the study "CO_2 Reductions Attributable to Smart Growth in California," on which the overall MDE methodology is based.
- MDP validated the feasibility of the 75 percent target by calculating possible compact development market share values from a range of potential scenarios reflecting changes in shares of single family and multi-family units within and outside Maryland's Priority Funding Areas, relative to the respective historic levels for each housing type.

Assumptions regarding the estimated increment of new development or redevelopment include:

- MDP assumes that roughly 10 percent of the total development will be built between years 2010 and 2020, which compares to Dr. Ewing's estimate for CARB of 25 percent of California's built environment in 2020 will be built between 2010 and 2020.
- MDP estimated a 10-year loss rate of approximately 1.6 percent.
- There is no demolition of homes less than ten years old; i.e., no loss rate is applied to houses built this decade.

The key assumption in the analysis is that VMT per capita will be reduced by 30 percent with compact development relative to sprawling development. This assumption is based on four different empirical literatures reviewed in *Growing Cooler*, whichindicate compact development has the potential to reduce VMT per capita by 20 to 40 percent relative to sprawl. MDP's assumed reduction percent of 30 is consistent with Ewing and Nelson for CARB.

MDP assumes a ratio CO_2e to VMT reduction of 90 percent, consistent with the conservative assumption adopted by Reid and Nelson for CARB. Reid and Nelson refer to Growing Cooler and explain that a reduction in VMT emissions would produce a slightly smaller reduction in CO_2 emissions, as a result of CO_2 penalties associated with cold starts and reduced vehicle operating speeds.

MDP estimates relevant VMT based on the share of statewide VMT that occur in urban areas, which was 74 percent as of 2009. MDP projected that the urban share will continue to increase at a rate of 6 percent through 2020, based on regression analysis of historical data from 1996 to 2009.

2.0 AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

TLU-2 is estimated to reduce emissions to the atmosphere due to reduced VMT and reduced production at EGUs. The reductions in emissions from EGUs were estimated to be less than 2 thousandths of a ton for relevant NAAQS pollutants making them insignificant. The emissions and percent reductions in the following tables represent changes due to reductions in VMT.

The estimated emissions reductions from TLU-2 are shown in the following table:

Table TLU-2.3- Emissions Reductions in Maryland Associated with TLU-2

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	2.2	6.3	15
NO_X	200	410	620
CO	2,600	6,700	14,000
VOC	150	350	660
PM10 - primary	8.6	17	25
PM2.5 - primary	4.5	11	23

These numbers were compared against the MANE-VU inventories for 2012 and 2018 in Table TLUE-2.4. Because all the values are less than eight-tenths of a percent, the table indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to significantly improve air quality.

Table TLU-2.4- Percentage Reduction in State Emissions Inventory Associated with TLU-2

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	< .80	< .80
NO_X	< .80	< .80
CO	< .80	< .80
VOC	< .80	< .80
PM10-primary	< .80	< .80
PM2.5-primary	< .80	< .80

2.2. Rationale for Air Quality Co-Benefits Methodology

Given the small role of VMT reductions due to car-based passenger-mile reductions, a simple comparison (i.e., percentage) of change in the statewide emission inventory was used as the parameter for net co-benefit. The contribution to the mobile source emission inventory of non-LDVs was not readily available and would involve significant resources for modeling that are not really justified for the minimal impact this approach estimates for those VMT reductions.

2.3. Summary of Air Quality Co-Benefits Methodology

The method used to calculate the change in emissions to the atmosphere due to reduced VMT is based upon the estimated change in statewide VMT. It was assumed that the percentage reduction in Maryland's VMT would result in an equivalent percentage reduction in the state's mobile source emission inventory.

The potential for improved air quality was estimated by comparing reductions in the mobile source inventory to estimates for the total statewide emission inventory.

The method used to calculate the change in emissions to the atmosphere due to reduced production at EGUs is based on the PROMOD model. The PROMOD model results estimate the decreased fuel consumption at various plants based on marginal reductions in electricity consumption. The marginal plant emissions reductions are calculated by multiplying each power plant's decreased fuel consumption by the plant-specific emission factors (lb pollutant/mmBtu), and domain-wide emission factors are computed from the marginal calculations. Then emissions reductions are computed by multiplying the policy's decrease in fuel consumption by the domain-wide emission factors.

2.4. Air Quality Emission Reduction Calculations

Statewide VMT estimates of 55,631 and 78,989 million VMT (mVMT) were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

As a result of Policy TLU-2, vehicle miles traveled will be reduced by 233, 645, and 1,502 mVMT in 2012, 2015 and 2020, respectively. The reductions represent 0.4, 1.0 and 2.2 percent reductions to the total statewide VMT in 2012, 2015 and 2020, respectively. When those percent reductions are applied to the total state mobile source inventory the emission reductions listed in Table TLU-2.3 are derived. The potential co-benefit of those emission reductions listed in Table TLU-2.4 is the absolute reductions in Table TLU-2.3 compared to the statewide emission inventory.

The emission reductions associated with electricity consumption reductions were calculated as follows:

- Use the marginal electricity emissions factors.
- Divide the CO_2 saved (tons CO_2) by the average CO_2 rate of change (tons CO_2/MWh) to find the energy saved (MWh).
- Multiply the calculated energy saved (MWh) by the emission factors (lb/MWh) to calculate the emission reductions.

2.5. Air Quality Emission Reduction Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, AICP, Secretary, Maryland Department of Planning, November 15, 2010

- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.6. Air Quality Emission Reduction Assumptions

- It was assumed that the reduction in VMT would result in a proportional reduction in the mobile source inventory and that emissions from light duty vehicles (LDV) are such a large fraction of the total mobile source emissions, that these calculations can be based on the total emissions of mobile sources.

- It was assumed that TLU 2 would impact all mobile sources equally. In actuality it would mostly impact the light duty vehicle (LDV) portion of mobile sources. LDVs emit less per VMT than other portions of the source category. So the impacts are probably lower than what has been estimated by this method.

3. INTERACTION WITH OTHER POLICIES

The interactions of land uses and development and transportation infrastructure and policy decisions are many in number and complex in character. Local and regional governments and organizations nationwide have begun to recognize the importance of system-wide transportation and land-use modeling and analysis. Such modeling is outside the scope of this project, but key interactions can be summarized qualitatively for TLU-2. TLU-2 strategies have significant interactions with each other, primarily synergistic, however there is the possibility of conflicting and overlapping effects.

Some TLU policies may achieve little reductions on their own, but with the implementation of TLU-2 and others, they have large impacts. For example, transit service is not feasible in low-density areas where parking is plentiful, as high density development is a prerequisite for cost-effective transit system deployment. Therefore, certain transit strategies alone would not achieve reductions without compact development in place. However, transit enhancements (TLU-3) in combination with smart growth strategies (TLU-2) and pricing incentives (TLU-9) will provide significant VMT and GHG reductions. Such interactions are the subject of an anticipated 2011 Transit Cooperative Research Program project, titled: Determining the Land Use Effect of Transit's Role in Reducing Regional Greenhouse Gas Emissions. The following is an excerpt from the project background:

Evidence also suggests that there are additional synergies for reducing GHG among transit ridership, land use, and pricing strategies for transportation, including parking. Detailed information on the character and magnitude of these synergies is not currently available. Research in this area would further help local and state governments, metropolitan planning organizations, transit agencies, and others to estimate potential GHG reduction that would result from pursuing combined strategies regarding increased transit capacity, related land use planning and development, and associated pricing policies affecting related services.

In addition to TLU-2 interactions with TLU-3 and TLU-9, TLU-2 also interacts with TLU-8, the Bike and Pedestrian strategies, and may support TLU-6 and TLU-10 as well. Further research is needed to better describe these TLU interactions. Beyond interactions among the TLU strategies, there will be interactions between select TLU policies and other sectors. Specifically, the Land Use & Location Efficiency TLU-2 policy will interact with the AFW-4 policy (Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land). This TLU-2 policy encourages high density development and discourages urban sprawl, which will protect vegetation, and land protection measures just as AFW-4 will promote high density development over sprawl. Therefore, the joint TLU-2 and AFW-4 policy implementation will have a synergistic effect, as noted in Chapter 5. However, since the emissions reductions from these two policies are calculated based on two different metrics (reduced VMT for TLU-2 and avoided carbon emissions from the clearing of forests AFW-4), the emission reductions for the two policies may be summed.

Finally, TLU2 will impact the energy sector in ways that are not captured by other policies. For example, compact and mixed use developments will reduce residential and commercial energy, since high density developments associated with TLU-2 increase multi-family housing and mixed-use buildings, and multi-family buildings have been shown to use approximately half the electricity of single family dwellings. In addition, more compact developments may be expected to decrease inefficiencies of local electricity distribution systems.

Policy No.: TLU-3

Policy Title: Transit

SAIC was tasked with reviewing 1) the original TLU-3 policy analysis, which was conducted by a prior MDE contractor (henceforth referred to as CAP 2008), and 2) the subsequent re-analysis of the same policy, which was conducted by MDOT contractors[115] (henceforth referred to as MDOT). SAIC conducted a thorough examination of the methodologies, assumptions, source materials, and results, and documented the methodology and results, as well as provided SAIC's observations and recommendations. In addition, SAIC estimated reductions for the intermediate years that MDOT did not analyze. Finally, SAIC quantified the air quality co-benefits associated with TLU-3. SAIC's findings are described below:

1. GHG EMISSION REDUCTIONS

TLU-3 is designed toshift passenger transportation mode choice to increase transit ridership and carpooling. This strategy will reduce GHG emissions by reducing VMT (fewer vehicle trips)[116]. The TLU-3 target is based on the Maryland Transit Administration (MTA) 2001 Maryland Comprehensive Transit Plan (MCTP) goal of doubling transit ridership by 2020 from a 2000 baseline.

Table TLU-3.1- Estimated GHG Emission Reductions Resulting from TLU-3

Emissions Category	GHG Emission Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
TLU-3	0.05	0.11	0.45

Note: The GHG emission reduction estimate reflects the sum of VMT-related reductions (0.31 $MMTCO_2e$) and delay-related reductions (0.14 MMT). The VMT avoided were estimated to be 414.3 million, which isattributed solely to the addition of 105.8 million unlinked transit trips in 2020. The VMT underlying the 0.31 MMT reductions includes a land use adjustment calculation, which MDOT converted to a total VMT reduction of 900 million.

1.1. Summary of GHG Emission Methodology

MDOT first quantified the baseline, and then forecasted the 2020 transit trip ridership values in the absence of TLU-3 strategies (i.e., business-as-usual). Next, MDOT subtracted the BAU 2020 ridership estimate from the 2001 MCTP 2020 goal. The resulting difference in transit trip ridership values was the basis for converting to avoided VMT and then calculating GHG reductions. Specifically, MDOTconverted these transit passenger trips to VMT using average vehicle occupancy and average trip length data. Finally, MDOT converted VMTs to GHG reductions using emission factors from EPA's MOBILE 6 model. In addition, MDOT estimated reductions associated with reduced delay, following the American Public Transportation Association (APTA) recommended guidelines for transit, which include a land-use adjustment calculation.

[115]Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report. November 4, 2009, and Appendix B of the same report.
[116] 2008 Maryland CAP

1.2. Rationale for GHG Emission Methodology

The interpolation method used by SAIC for the intermediate years of 2012 and 2015 was chosen based on expert judgment in absence of data, and to maximize transparency and flexibility to facilitate future updates or revisions.

The methodology for the 2020 GHG estimate developed by MDOT was chosen based on data availability and expert judgment to improve upon the original 2008 estimate by providing a more accurate representation of emission reductions associated with existing and planned projects and funding levels.

1.3. Detailed Explanation of GHG Emission Methodology

MDOT quantified the MCTP ridership goal as 459.0 millionunlinked passenger trips per year in 2020, equal to a doubling of 2000 ridership. To quantify the incremental increase required to meet the goal, MDOT developed an estimate of the 2020 ridership forecast based on assumed business-as-usual (BAU) transit-related programs and expansions (i.e., 353.2 million unlinked trips). MDOT defined BAU as already planned and funded. To estimate the BAU growth through 2020, MDOT uses a combination of data sources (defined below), starting from a 2007 ridership value.

MDOT subtracted the BAU unlinked passenger trips ridership forecast (i.e., passenger-trips) from the 2020 target of doubling the 2000 ridership. The difference represents 105.8 million unlinked transit trips.[117] MDOT translated these transit passenger trips to VMT by using average vehicle occupancy and average trip length data.Specifically MDOT calculated VMTs by multiplying unlinked transit passenger trips by average trip length (i.e., miles per trip), and dividing the result by average vehicle occupancy (i.e., passengers per vehicle). Finally, MDOT converted the resulting VMTs to GHG reductions using emission factors from EPA's MOBILE 6 model.

MDOT explains that the 414.3 million VMT reductions is attributed solely to the addition of 105.8 million unlinked transit trips in 2020. The VMT underlying the 0.31 $MMTCO_2e$ reductions includes a land use adjustment calculation, consistent with a 2008 report from APTA, which brings the total VMT reduction in a range from 770 to 900 million. MDOT elected to report the higher value in order to reflect the maximum benefit possible by 2020.

1.4. Difference between Original Methodology and Revised Methodology

The CAP 2008[118]projected GHG reductions of 1.1 and 2.2 $MMTCO_2e$ in 2012 and 2020, respectively,[119] which is an order of magnitude greater than the 2009 MDOT estimate.

Several factors contribute to the difference, including:

1) The CAP 2008 estimate for TLU-3 included reductions associated with TLU-3 and TLU-8 (Bike and Pedestrian Infrastructure).

[117] Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report, Appendix B. November 4, 2009.
[118] Maryland CAP Appendix D-4, 2008.
[119] Maryland Commission on Climate Change CAP documents report conflicting estimates of TLU-3 GHG reductions in 2020: 2.8 and 2.2 $MMTCO_2e$ in Chapter 4 and Appendix D-4, respectively.

2) The CAP 2008 methodology reportedly reflects the synergistic emission reductions effects of bundling TLU-3 and TLU-9 (Incentives, Pricing, and Resource Measures), although those synergies, with regard to GHGs, are not documented in the CAP. The MDOT estimate reflects each measure individually.

3) The most significant reason for the difference in estimates is the difference in methodology. The key differences are two-fold:

1) The original 2008 CAP methodology was based on the assumption that the proposed funding increase was equal to 84 percent (based on the predicted revenue from a TLU-9 strategy, rather than the 42 percent increase defined by the policy goal). The original method assumed that each percent increase in funding would result in an equal percent (84 percent) increase in transit mode share, and the resulting transit increase shifted entirely from single occupancy vehicle trips. The MDOT methodology disregarded the 2008 CAP approach as unrealistic and therefore did not attempt to directly relate transit funding levels to mode shift. The revised MDOT methodology represents a more pragmatic approach with a tangible 2020 policy goal and required costs to achieve the goal. MDOT commented that the mode share approach is arbitrary and does not reflect the realities of the current and proposed funding and operation of the transit system in Maryland.

2) The CAP 2008 methodology attributed all changes in transit and single-occupancy-vehicle mode shares after 2005 to the TLU-3 policy. In contrast, the MDOT method documented includes in the baseline any existing projects or programs planned or underway as of 2009, and excludes the resulting BAU projected growth rate in transit ridership from the TLU-3 policy.[120]

1.5. GHG Emission Reduction Calculations

MDOT did not calculate emission reductions associated with TLU policies for any baseline or intermediate years. Therefore, the TLU-3 emission reduction estimates for 2012 and 2015 are interpolated from 2010 using the following equation based on an exponential trendline that reflects 10 percent and 25 percent, respectively, of the 2020 total annual GHG reduction.

$TER_i = TER_{2020} * RUF_i$

Where

TER_i = Total GHG emission reductions in year i for Policy TLU-3 ($MMTCO_2e$)

TER_{2020} = Total GHG emission reductions in year 2020 for Policy TLU-3 ($MMTCO_2e$)

[120] MDOT comments dated January 2011 acknowledged that its goal was to measure the benefit of Maryland's existing transportation program through 2020, before estimating the potential benefits of additional funding across the TLU categories. MDOT noted that it is difficult, and ultimately not instructive to this process to extract the benefit of a single strategy (transit expansion and operations) from forecast VMT reductions from plans and programs through 2020 due to the multimodal nature of the transportation system and it's interaction with population and employment growth.

RUF_i = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved in year i

RUF_{2012} = 10%

RUF_{2015} = 25%

1.6. GHG Emission Data and Data Sources

MDOT used several data sources to estimate the existing ridership trend through 2020 and the more aggressive ridership rates associated with the TLU-3 policy goal, as documented in the 2009 MDOT Climate Action Plan Draft Implementation Status Report, Appendix B.[121]

Table TLU-3.2 presents historical statewide transit trip data.

Table TLU-3.2. Historical Statewide Transit Trip Data

Ridership	Unlinked Transit Trips (million)		
	2000	2006	2020 (goal)
Maryland total	229.515	252.8	459.0

Sources: The source of the 2020 value is Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report, 2009. MDOT determined the 2000 value based on interpolating annual statewide ridership values as reported in the Maryland Annual Attainment Report. The 2020 value is double the 2000 ridership value. The source of 2006 value is the Comprehensive Greenhouse Gas and Carbon Footprint Reduction Strategy, Report of the Maryland Commission on Climate Change Greenhouse Gas and Carbon Mitigation Working Group, Maryland CAP Appendix D-4, August 2008.

MDOT used the following data sources to develop the BAU ridership forecast:

- National Transit Database (NTD)
- Maryland Annual Attainment Report (AAR)
- Baltimore Regional Transportation Board (BRTB) and Metropolitan Washington COG Long Range Plans
- American Public Transportation Association (APTA) 2008 and 2009 ridership reports

These sources were used to come up with the following Maryland Transit Ridership Trends, which reflect all transit modes.

[121] For more details on the technical approach, assumptions, GHG emission reduction and costs analysis for each TLU policy option, refer to Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report, Appendix B. November 4, 2009.

Table TLU-3.3- Maryland Transit Ridership Trends

Scenario	Annual Growth Rate	2020 Ridership Forecast (million unlinked trips)	MCTP 2020 Goal Differential (million unlinked trips)	Equivalent mVMT Reduction
NTD (1998-2007)	1.5%	322.8	136.2	533.3
AAR (2001-2007)	1.5%	315.9	143.1	560.5
MPO Plans	1.3%	305.6	153.5	601.0
Plans & Programs (2010 – 2020)	2.4%	353.2	105.8	414.3
CAP 2020 Goal	5.3%	459.0	--	--

Source: 2009 MDOT Climate Action Plan Draft Implementation Status Report, Table B2.
Note: Red text in Plans & Programs row highlights the numbers that were used to estimate the 2020 CAP goal, which is highlighted in red in subsequent row.

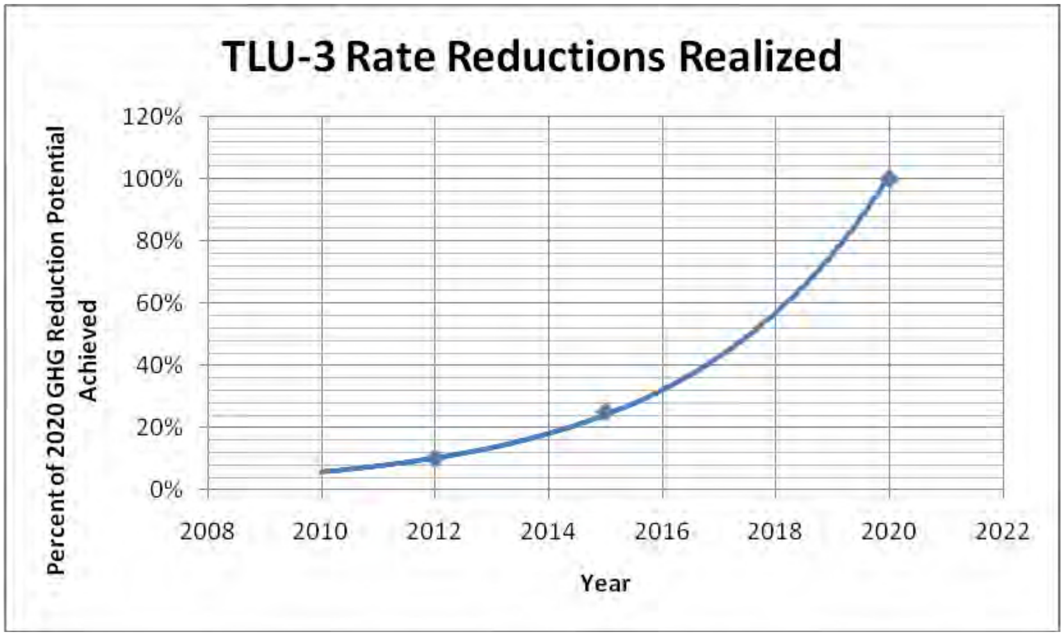
MDOT used the following data sources to relate the increase in transit trips to a reduction VMT:

- Average vehicle occupancy: 1.43 persons per vehicle from the 2001 National Household Travel Survey
    - assumes that 60 percent of new transit trips were home based work vehicle trips with an average occupancy of 1.14, and
    - 40 percent of the new transit trips were non-work vehicle trips with an average occupancy of 1.84
- Average transit trip length: 5.6 miles per trip based on the weighted average of Maryland 2007 NTD data.

1.7. GHG Emission Assumptions

The GHG reductions for intermediate years 2012 and 2015 were estimated based on an exponential trendline from zero in 2010. This pace at which we assume the reductions will be achieved is illustrated here:

Figure TLU-3.1- TLU-3 Rate Reductions Realized



For the 2020 GHG estimate, MDOT documented the assumptions it developed in a separate detailed report.[122] Among MDOTs assumptions, the most influential in the resulting GHG reduction estimate are the Maryland transit ridership rates that were selected to best represent the existing ridership trend through 2020. The existing ridership trend, which is included in the BAU baseline, assumes the implementation of all 2009-2014 Consolidated Transportation Program (CTP) transit projects and Transportation Emission Reduction Measures (TERMs), and Metropolitan Planning Organization (MPO) long range transit projects included in modeling assumptions by 2020 (e.g., Purple Line, Corridor Cities Transitway, Red Line). The benefits for CTP projects were captured in MDOTs Existing Plans and Programs Analysis.

1.8. GHG Emission Analysis and Recommendations

A recommended approach to track progress toward the defined goal of doubling ridership is to monitor annual statewide ridership levels and compare them to projected values illustrated by the trend line in Figure 1. To achieve the emission goal without drastic actions in the last five years, ridership in 2012 and 2020 should reach at least roughly 320 million and 360 million, respectively. In addition, sources of and any assumptions about ridership data should be transparent.

There are four areas that could be considered for further analysis or refinement of the MDOT methodology:

1) The methodology does not attempt to quantify the emissions effects of changes in transit operations resulting from increased ridership, such as emissions from fuel use for additional bus service, electricity for rail service, or impacts of inefficient vehicle retirements and more efficient

[122]Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B. November 4, 2009.

and advanced technology vehicle procurements. Future analyses should consider such impacts in addition to reduced VMT. [123]

2) A baseline-related issue for clarification is whether and how the strategy is quantified separately from BAU. For its TLU-3 analysis, MDOT assumed that the ridership trend associated with BAU funding and activities is not credited toward the TLU-3 policy. Future revisions to this and other policies could include a review of this assumption and whether it has been or should be consistently applied across policies. It is a useful approach for identifying the likely gap between the goal and what is likely to be achieved by implementing strategies already planned or underway, and in such it is one technique for measuring the challenge of meeting the policy goal. Further, MDOT acknowledged that it is a challenge to estimate the benefit of plans and programs by individual TLU policies, therefore a single BAU for the transportation sector was estimated representing all activities through 2020.

3) Although, for all TLU strategies, the Original Methodology documents that GHG estimates were quantified for CO_2, methane (CH_4), and black carbon, which differs from widely accepted guidance, MDOT quantified reductions for CO_2, CH_4 and N_2O, which have been recognized as more common metrics. The MDOT approach is recommended.

2. AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from TLU-3 are shown in the following table:

Table TLU-3.4- Emissions Reductions in Maryland Associated with TLU-3

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	0.86	2.2	8.7
NO_X	76	140	370
CO	1,000	2,300	8,500
VOC	59	123	397
PM10 - primary	3.3	5.9	15.0
PM2.5 - primary	1.8	3.9	14.0

These numbers were compared against the MANE-VU inventories for 2012 and 2018 in Table TLU-3.5. Because all the values are less than one-half of a percent, the table indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to significantly improve air quality.

[123] MDOT commented in January 2011 that for TLU-3, annual transit revenue miles are estimated to increase 43.4-46.1 million in 2020 to reach the ridership goal. Additional emissions from these miles could be calculated.

Table TLU-3.5- Percentage Reduction in State Emissions Inventory Associated with TLU-3

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	< .5	< .5
NO_X	< .5	< .5
CO	< .5	< .5
VOC	< .5	< .5
PM10-primary	< .5	< .5
PM2.5-primary	< .5	< .5

2.2. Summary of Air Quality Co-Benefits Methodology

The method is based upon the estimated change in statewide VMT. It was assumed that the percentage reduction in Maryland’s VMT would result in an equivalent percentage reduction in the state’s mobile source emission inventory. The potential for improved air quality was estimated by comparing reductions in the mobile source inventory to estimates for the total statewide emission inventory.

2.3. Rationale for Air Quality Co-Benefits Methodology

Given the small role of VMT reductions due to car-based passenger-mile reductions, a simple comparison (i.e., percentage) of change in the statewide emission inventory was used as the parameter for net co-benefit. The contribution to the mobile source emission inventory of non-LDVs was not readily available and would involve significant resources for modeling that are not really justified for the minimal impact this approach estimates for the associated VMT reductions.

2.4. Air Quality Co-Benefits Calculations

Statewide VMT estimates of 55,631 and 78,989 million VMT (mVMT) were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

As a result of Policy TLU-3, VMT will be reduced by 90, 225 and 900 mVMT in 2012, 2015 and 2020, respectively. The reductions represent 0.15, 0.36 and 1.3 percent reductions to the total statewide VMT in 2012, 2015 and 2020, respectively. When those percent reductions are applied to the total state mobile source inventory the emission reductions listed in Table TLU-3.4 are derived. The potential co-benefit of those emission reductions listed in Table TLU-3.5 is the absolute reductions in Table TLU-3.4 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefits Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, AICP, Secretary, Maryland Department of Planning, November 15, 2010

- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.6. Air Quality Co-Benefits Assumptions

- It was assumed that the reduction in VMT would result in a proportional reduction in the mobile source inventory and that emissions from LDV are such a large fraction of the total mobile source emissions, that these calculations can be based on the total emissions of mobile sources.

- It was assumed that TLU 3 would impact all mobile sources equally. In actuality it would mostly impact the LDV portion of mobile sources. LDVs emit less per VMT than other portions of the source category. So the impacts are probably lower than what has been estimated by this method.

3. INTERACTIONS WITH OTHER POLICIES

The interactions of land uses and development and transportation infrastructure and policy decisions are many in number and complex in character. Local and regional governments and organizations nationwide have begun to recognize the importance of system-wide transportation and land-use modeling and analysis. Such modeling is outside the scope of this project, but key interactions can be summarized qualitatively for TLU-3. TLU-3 strategies have significant interactions with other TLU policies, primarily synergistic, however there may be conflicting and overlapping effects as well.

Some TLU policies may achieve little reductions on their own, but with the implementation of TLU-3 with others, they have large impacts. For example, as described in the TLU-2 Interaction Section and the TLU-9 Interaction Section, transit service is not feasible in low-density areas where parking is plentiful, as high density development is a prerequisite for cost-effective transit system deployment. Therefore, certain transit strategies alone would not achieve reductions without compact development in place. However, transit enhancements (TLU-3) in combination with smart growth strategies (TLU-2) and pricing incentives (TLU-9) will provide significant VMT and GHG reductions. Such interactions is the subject of an anticipated 2011 Transit Cooperative Research Program project, titled: Determining the Land Use Effect of Transit's Role in Reducing Regional Greenhouse Gas Emissions. The following is an excerpt from the project background:

Evidence also suggests that there are additional synergies for reducing GHG among transit ridership, land use, and pricing strategies for transportation, including parking. Detailed information on the character and magnitude of these synergies is not currently available. Research in this area would further help local and state governments, metropolitan planning organizations, transit agencies, and others to estimate potential GHG reduction that would result from pursuing combined strategies regarding increased transit capacity, related land use planning and development, and associated pricing policies affecting related services.

In another example of a TLU-3 interaction, improvements to sidewalk connectivity from TLU-8 may allow a commuter to walk to a transit stop and transfer to a bus to complete a daily commute. However, in the absence of the TLU-8 policy, the transit station is inconvenient or inaccessible and therefore the entire trip is completed by car. By providing or improving alternatives to low-occupancy vehicle trips TLU-3 potentially enhances and enables all other TLU policies, including not only TLU-8 but also TLU-5 (intercity travel), TLU-6 (pay-as-you-drive insurance), TLU-9 (pricing), and TLU-10 (transportation technologies). However, it is assumed that the TLU-6 measure will have negligible interactions with other policies.

The combination of measures, in some cases, may be in conflict or produce overlapping effects. An example of competition would be if TLU-9 pricing measures effectively reduce traffic congestion enough to induce transit riders with long commutes back into their vehicle to save time, which is known as the rebound effect. In other cases, reduced congestion may draw out the latent demand from suppressed vehicular trips. In general, however, it is expected that the combination of TLU-3 and TLU-9 would have a synergistic effect, because the TLU-9 strategy is designed with pricing high enough to achieve only a freeway level of service (LOS) improvement from LOS F to LOS D, which is defined as less than free-flow levels of traffic, approaching operational capacity of the highway.

This TLU policy is not expected to significantly interact with policies in other sectors.

Policy No.: TLU-5

Policy Title: Intercity Travel

SAIC was tasked with reviewing 1) the original TLU-5 policy analysis, which was conducted by a prior MDE contractor (henceforth referred to as CAP 2008), and 2) the subsequent re-analysis of the same policy, which was conducted by MDOT contractors[124] (henceforth referred to as MDOT). SAIC conducted a thorough examination of the methodologies, assumptions, source materials, and results, and documented the methodology and results, as well as provided SAIC's observations and recommendations. In addition, SAIC estimated reductions for the intermediate years that MDOT did not analyze. Finally, SAIC quantified the air quality co-benefits associated with TLU-5. SAIC's findings are described below:

1. GHG EMISSION REDUCTIONS

TLU-5 is designed to provide transportation infrastructure between cities to create connectivity of non-auto, non-truck transportation modes. The goal of TLU-5 is to reduce transportation sector GHG emissions from intercity travel by making passenger and freight rail more accessible, efficient, and available.[125]

Table TLU-5.1- Estimated Reductions of GHG Emissions and Vehicle Miles Traveled Resulting from TLU-5

Emissions Category	Estimated Reductions		
	2012	2015	2020
GHG Reductions (Million Metric Tons CO_2e)	0	0.003	0.02
Light Duty VMT Reductions (Million Miles)	0	10	64

Note: Not all digits displayed are significant figures.

1.1. Summary of GHG Emission Methodology

The MDOT methodology for analyzing the TLU-5 strategy has two components, both associated with car-based passenger-mile reductions to be achieved by 2020. The analysis of GHG reductions is based on a total VMT reduction of 64 million, based on:

1) increasing the transit mode share for trips to/from BWI Marshall from the current public access share of 11.4 percent to a goal of 20 percent, which results in a VMT reduction of 30 million; and

[124] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report. November 4, 2009, and Appendix B of the same report.
[125] 2008 Maryland CAP

2) increasing long-distance Amtrak ridership in Maryland in the range of 5 to 10 percent, which results in a total reduction of 33 million VMT in the year 2020.[126]

1.2. Rationale for GHG Emission Methodology

The interpolation method for the intermediate years of 2012 and 2015 was chosen based on data availability, expert judgment, and to maximize transparency and flexibility to facilitate future updates or revisions.

The MDOT methodology for the 2020 GHG estimate developed by MDOT apparently was chosen based on data and resource availability and expert judgment. MDOT focused on two aspects of TLU-5 related to reducing intercity passenger car trips, for which a sound analytical method could be developed. MDOT did not attempt to quantify the other strategies identified in the 2008 CAP associated with freight transport by truck or rail, or changes in aviation.

1.3. Differences Between Original and Revised Methodologies

The CAP 2008 methodology resulted in estimated reductions of 0.2 and 0.3 $MMTCO_2e$ in 2012 and 2020, respectively, which are greater than the MDOT methodology estimates which are reported in Table.1. The MDOT methodology is unrelated to the CAP 2008, and appears to have at least partially different assumptions about the policy objectives. The MDOT methodology is based on reductions in gasoline use by passenger car-based VMTs. The CAP 2008 methodology was based on improvements only in the freight rail system that would reduce heavy-duty diesel truck VMTs.

The CAP 2008 methodology acknowledges that the "emissions reductions are for implementing only the Mid-Atlantic Rail Operations Study recommendations, and recommends broader improvement of freight and passenger infrastructure and operations in Maryland. The CAP 2008 methodology reported a low-end estimation of the possible VMT reductions that are available from improving intercity rail."[127]

The TLU-5 working group considered the freight strategies and assumed that transportation funding identified in the CTP and MPO long range plans would help improve freight movement, especially access to intermodal facilities. However, at the time of the analysis, many of the freight strategies were still unfunded and/or were unlikely to be completed before 2020. However, MDOT acknowledges that with new initiatives, there will be additional TLU-5 benefits related to freight activity that should be accounted for outside of the funded plans and programs by 2020, and will be considered in a future MDOT analysis.

1.4. GHG Reduction Calculations

For the Increased Transit Access to BWI-Marshall component of the TLU-5 strategy, the MDOT GHG estimate was developed from 2007 passenger access trip data, which was converted to passenger miles based on an average airport access trip distance. Next, the total number of passenger miles traveled to BWI Marshall in 2020 was extrapolated from the 2007 value, by applying a growth rate based on an analysis of annual enplanements[128] between 2002 and 2007. The current (11.4 percent) and target

[126] Difference between total VMT estimate and sum of estimate components due to rounding.
[127] Maryland CAP, Greenhouse Gas & Carbon Mitigation Working Group Policy Option Documents, Appendix D-4, page 34.
[128] An enplanement is defined as a revenue passenger boarding an aircraft.

(20percent) mode splits[129] for transit were applied to the 2020 passenger miles value, and the balance of miles traveled were assumed to be by passenger cars. The reduction in passenger miles by car associated with the increased transit mode share was converted to VMT reductions by dividing by the average vehicle occupancy rate. Lastly, the VMT reduction value was converted to GHG reductions by applying an aggregate emissions factor of 321 grams CO_2 per mile.

For the Increased Ridership on Amtrak component of the TLU-5 strategy, the MDOT methodology was based on multiplying the number of rail trips (221,500), which are assumed to shift to Amtrak from single occupancy vehicles, by an average trip length of 150 miles.

MDOT did not calculate emission reductions associated with TLU policies for any baseline or intermediate years. Therefore, the emission reduction estimate for 2012 and 2015 are estimated from zero in the 2006 base year using the following equation based on 0 percent and 15 percent, respectively, of the 2020 total annual GHG reduction.

$TER_i = TER_{2020} * RUF_i$

Where

TER_i = Total GHG emission reductions in year i for Policy TLU-5 (million metric tons CO_2e)

TER_{2020} = Total GHG emission reductions in year 2020 for Policy TLU-5 (million metric tons CO_2e)

RUF_i = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved in year i

RUF_{2012} = 0%

RUF_{2015} = 15%

1.5. GHG Emission Data and Data Sources

The MDOT methodology relies on the following data and sources:

- Historic data on total annual enplanements for 2002 and 2007, and mode split percentages for access trips, were used to project total passenger miles to 2020, based on data taken from Table 4 of the 2007 Washington-Baltimore Regional Air Passenger Survey by National Capital Region Transportation Planning Board, *et al*. In 2007, passenger miles totaled 377,970,000, and transit mode share was 11.4 percent.

[129] The mode split, or modal split, is defined as the percentage of trips on each of the available modes.

- An average vehicle occupancy rate of 1.4 passengers per vehicle[130] is based on the 2001 National Household Travel Survey (NHTS), which assumes that:
    - 60 percent of new transit trips were home based work vehicle trips with an average occupancy of 1.14, and
    - 40 percent of the new transit trips were non-work vehicle trips with an average occupancy of 1.84

- For the BWI Marshall analysis, the average trip distance of 21.5 passenger miles per trip was taken from data on the number of passengers arriving by ground transportation, and multiplying by 2 (based on a round trip).

- For the Amtrak analysis, MDOT considered data from the 2001 NHTS indicating the average length of a long distance rail trip is 192 miles.

- MDOT used a composite statewide average light duty GHG emission factor for the year 2020 weighted by VMT and speed of 321 grams CO_2e per mile based on Maryland data and the U.S. EPA MOBILE 6 Adjusted model. The CO_2e rate is based on the CO_2 emissions rate from the MOBILE model multiplied by 1.05 to account for the minor role of other gases in mobile source GHG emissions including CH_4, N_2O, and hydro fluorocarbons (HFCs).

1.6. GHG Emission Assumptions

The MDOT methodology used the following assumptions in its GHG estimate for 2020.

- Growth rate in BWI Marshall Access Trips from 2007 to 2020 is assumed to be 2.09 percent, based on historic growth trends in enplanements.
- All non-transit travel is assumed to be by passenger vehicle.
- Vehicle occupancy rate is assumed to be 1.4 passengers per vehicle.
- The average trip distance for airport access trips is assumed to be equal to the average of the distance from BWI Marshall to downtown Baltimore (11 miles) and to downtown Washington DC (32 miles).
- For the Amtrak analysis, MDOT assumes that the implementation of improvements to Amtrak's connectedness, accessibility, and availability of information, would "increase ridership by 5 percent to 10 percent. This translates into an increase in 2020 of 221,500 intercity rail trips."[131]
- For the Amtrak analysis, MDOT assumed the average Maryland Amtrak trip distance to be 150 miles.

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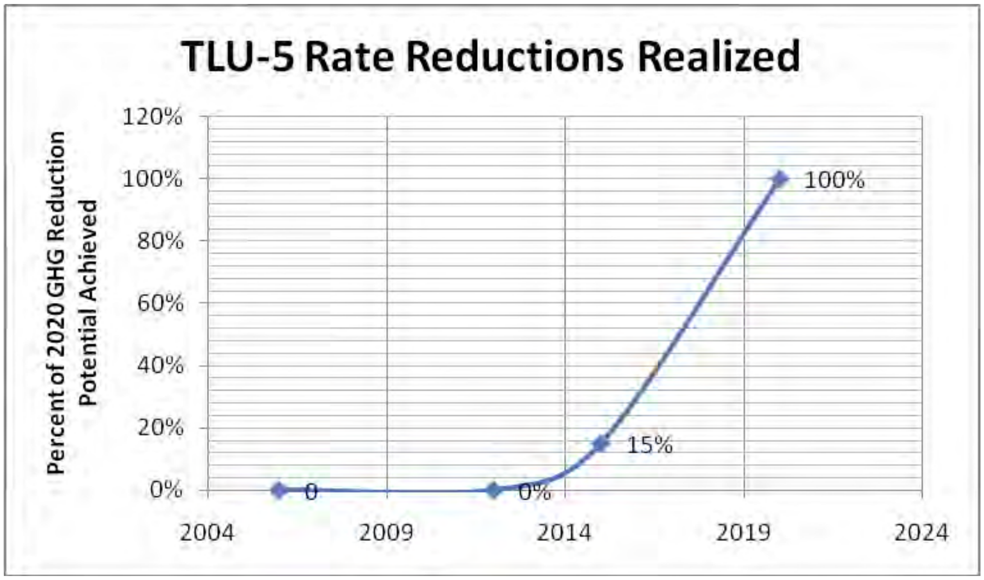
[130] MDOT does not document the source of the vehicle occupancy rate within the Draft Implementation Status Report Appendix B – Strategy Assumptions and Methodology discussion of TLU-5. However, MDOT documented its vehicle occupancy rate data source and assumptions in its explanation of TLU-3 to relate the increase in transit trips to a reduction VMT. SAIC assumes that the same NHTS data and assumptions were applied for TLU-5.
[131] Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report, Appendix B. November 4, 2009, p. B-19.

The GHG reductions for intermediate years 2012 and 2015 were estimated based on MDOT's assumption that the pace of implementation would increase over time starting from zero in 2012. This pace at which we assume the reductions will be achieved is illustrated here:

Figure TLU-5.1- TLU-5 Rate Reductions Realized



1.7. GHG Emission Analysis and Recommendations

SAIC's observations are detailed below:

- The CAP 2008 methodology included the intention of reducing air travel: "an expansion of rail is especially encouraged to shift passenger trips away from short-range air travel and to increase rail freight transportation."[132] However, the MDOT methodology does not consider changes in freight or air travel in its approach, but rather passenger VMT only. The working group, which included the Maryland Aviation Administration (MAA),did not include the reduction of air passenger travelor passenger travel growth at BWI as a recommended TLU-5 goal.[133] Therefore the focus was placed on decreasing the single occupancy vehicle (SOV) mode share of landside access to BWI.

- TLU-5 strategy results in VMT reductions, which would theoretically improve traffic flow and reduce delay, resulting in additional GHG reductions. Although reduced delay associated with VMT reductions is estimated for TLU-3 and TLU-9 and included in the overall GHG reduction estimates, reduced delay is not included in TLU-5. MDOT considered the congestion reduction impact for TLU-

[132] Comprehensive Greenhouse Gas and Carbon Footprint Reduction Strategy, August 2008, Report of the Maryland Commission on Climate Change Greenhouse Gas and Carbon Mitigation Working Group, Maryland CAP, Chapter 4, p.96.
[133] MDOT comments on SAIC draft report, January 2011.

5; however the VMT reductions are significantly lower and not necessarily tied to a peak period or time of day, and therefore assumed to have an insignificant effect on congestion.

- The MDOT methodology does not attempt to quantify the emissions effects of increases in transit or Amtrak operations resulting from increased ridership, such as emissions from fuel use for additional bus and train service, and electricity for rail service. MDOT acknowledges that future analyses should consider such net impacts in addition to reduced VMT, for both TLU-5 and TLU-3.

2. AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from TLU-5 are shown in the following table:

Table TLU-5.2- Emissions Reductions in Maryland Associated with TLU-5

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	0.0	0.1	0.6
NO_X	0.0	6.3	26
CO	0.0	100	600
VOC	0.0	5.5	28
PM10 - primary	0.0	0.26	1.0
PM2.5 - primary	0.0	0.17	1.0

These numbers were compared against the MANE-VU inventories for 2012 and 2018 in Table TLU-5.3. Because all the values are less than three-hundredths of a percent, the table indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to significantly improve air quality.

Table TLU-5.3- Percentage Reduction in State Emissions Inventory Associated with TLU-5

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	0.0	< .03
NO_X	0.0	< .03
CO	0.0	< .03
VOC	0.0	< .03
PM10-primary	0.0	< .03
PM2.5-primary	0.0	< .03

2.2. Summary of Air Quality Co-Benefits Methodology

The method is based upon the estimated change in statewide VMT. It was assumed that the percentage reduction in Maryland's VMT would result in an equivalent percentage reduction in the state's mobile source emission inventory. The potential for improved air quality was estimated by comparing reductions in the mobile source inventory to estimates for the total statewide emission inventory.

2.3. Rationale for Air Quality Co-Benefits Methodology

Given the small role of VMT reductions due to car-based passenger-mile reductions, a simple comparison (i.e., percentage) of change in the statewide emission inventory was used as the parameter for net co-benefits. The contribution to the mobile source emission inventory of non-LDVs was not readily available and would involve significant resources for modeling that are not really justified for the minimal impact this approach estimates for those VMT reductions.

2.4. Air Quality Co-Benefits Calculations

Statewide VMT estimates of 55,631 and 78,989 million VMT (mVMT) were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

As a result of Policy TLU-5, vehicle miles traveled will be reduced by 0.0, 10 and 64 mVMT in 2012, 2015 and 2020, respectively. The reductions represent 0.0, 0.02 and 0.09 percent reductions to the total statewide VMT in 2012, 2015 and 2020, respectively. When those percent reductions are applied to the total state mobile source inventory, the emission reductions listed in Table TLU-5.2 are derived. The potential co-benefit of those emission reductions listed in Table TLU-5.3 is the absolute reductions in Table TLU-5.2 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefits Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, AICP, Secretary, Maryland Department of Planning, November 15, 2010

- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.6. Air Quality Co-Benefits Assumptions

- It was assumed that the reduction in VMT would result in a proportional reduction in the mobile source inventory.
- For the co-benefits analysis, it was assumed that Policy TLU 5 would impact all mobile sources equally. In actuality it would mostly impact the LDV portion of mobile sources. LDVs emit less per VMT than other portions of the source category, and hence the air quality impacts are probably less than what has been estimated. However, given that emissions from LDVs are such a

large fraction of total mobile source emissions, the latter emissions can be used as a reasonable proxy of the former.

3. INTERACTION WITH OTHER POLICIES

The interactions of land uses and development and transportation infrastructure and policy decisions are many in number and complex in character. Local and regional governments and organizations nationwide have begun to recognize the importance of system-wide transportation and land-use modeling and analysis. Such modeling is outside the scope of this project, but examples of key interactions can be summarized qualitatively for TLU-5.

The TLU-5 strategies will interact with both TLU-3 (Transit) and TLU-8 (Bike and Pedestrian) strategies. Specifically, the maximum GHG reduction potential of TLU-5 is dependent upon the timely implementation of TLU-3 and TLU-8. TLU-3 will provide greater transit service, enabling a reduction in intercity travel by single occupancy vehicles (SOV). TLU-8 will provide enhanced connectivity and accessibility for increased bike and pedestrian travel, which would enable a reduction in intercity SOV trips. However, TLU-5 is not wholly dependent on TLU-3 and TLU-8, and a significant share of the reduction potential of TLU-5 could be achieved even if the others are not implemented. In addition, TLU-2 may provide synergistic effects for TLU-5.

This TLU policy is not expected to significantly interact with policies in other sectors.

Policy No.: TLU-6

Policy Title: Pay-As-You-Drive Insurance

SAIC was tasked with reviewing: 1) the TLU-6 policy analysis, which was conducted by a prior MDE contractor (henceforth referred to as CAP 2008), and 2) the subsequent re-analysis of the same policy, which was conducted by MDOT contractors[134] (henceforth referred to as MDOT). After conducting a thorough examination of thesemethodologies, assumptions, source materials, and results, SAIC improved the existing methodologies to create new results (SAIC Methodology) that better reflect how the policy will likely impact Maryland. SAIC documented the current methodology and provided observations and recommendations. In addition, SAIC quantified the air quality co-benefits associated with the GHG emission reductions. SAIC's findings are described in detail below:

1. GHG EMISSION REDUCTIONS

Pay-As-You-Drive (PAYD) auto insurance ties a substantial portion of consumer insurance costs to a variable cost with respect to actual motor-vehicle travel use, so premiums are more directly related to hours or miles driven, with adjustment for other rating factors, such as driving record, age, and the vehicle driven[135]. TLU-6 is designed to make PAYD insurance coverage available to all Maryland drivers by 2010, with 10 percent of Maryland drivers adopting such policies by 2012, and 100 percent adopting by 2020. The expected result of PAYD insurance is a reduction in VMT, which can then be translated to GHG emission reductions.

Table TLU-6.1. Estimated Reductions of GHG Emissions and Vehicle Miles Traveled Resulting from TLU-6

Emissions Category	Estimated Reductions		
	2012	2015	2020
TLU-6 Emission Reductions (MMTCO_2e)	0.01	0.02	0.03
VMT Reductions (Million Miles)	19	50	107

Notes: Not all digits displayed are significant figures.

1.1. Summary of GHG Emission Methodology

TLU-6 (PAYD Insurance), also known as use-based or mileage-based insurance, directly incorporates mileage as a rate factor when calculating insurance premiums. PAYD pricing would provide a financial incentive to motorists to reduce their mileage. Although there are too few actual products currently available to consumers to predict with certainty how they will be structured in the future, it is expected that the insurance premium paid will be based on the distance driven, and possibly also time spent

[134] Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report. November 4, 2009, and Appendix B of the same report.
[135] Maryland CAP, Greenhouse Gas & Carbon Mitigation Working Group Policy Option Documents, Appendix D-4

driving, time-of-day, and driving style, which would characterize safe or risky driving behavior.[136] PAYD technology that analyzes factors in addition to mileage has been successfully deployed in the commercial sector. However, the SAIC estimation methodology for TLU-6 does not consider driving style, but rather assumes that the economic price signal associated with insurance premiums would affect demand. Specifically, the opportunity to pay less for insurance would encourage consumers to drive fewer miles.

1.2. Rationale for GHG Emission Methodology

The SAIC methodology maintains a consistent approach to analyzing TLU-6 as was applied in previous analyses by the 2008 CAP and MDOT, but adjusts the assumptions as documented above, specifically:

- Relevant VMT – by excluding heavy duty VMT and uninsured motorist travel;
- Effectiveness rate – by assuming a slightly lower effectiveness than prior analyses; and
- Participation rate – by assuming only 5 percent of motorists participate by 2020.

1.3. Difference Between Original & Revised Methodologies and Results

The CAP 2008 methodology[137] considered total statewide VMT, a 100 percent statewide participation rate, and a 15 percent effectiveness rate.[138] The MDOT methodology[139] tested a range of participation from 5 to 20 percent, and analyzed a range of effectiveness rates from 5 to 10 percent.

The SAIC methodology made several changes to the data and assumptions used in the two former analyses. First, the VMT forecast to which the analysis would apply was revised. Whereas previous estimates included all statewide VMT in the analysis, the Current Methodology considered only light-duty VMT, and reduced this subtotal by 12 percent to exclude non-insured motorists. SAIC applied a 4 percent effectiveness rate and assumed a cautiously increasing participation rate that reaches only 5 percent by 2020 based on input from the Maryland Insurance Administration (MIA).

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[136] Currently in Maryland, Progressive offers a PAYD product that offers savings "for driving fewer miles, in safer ways and during safer times of the day." http://www.progressiveagent.com/auto/myrate.aspx

[137] Maryland CAP, Greenhouse Gas & Carbon Mitigation Working Group Policy Option Documents, Appendix D-4.

[138] The original MDE estimate was based on the assumption that 100% of Maryland motorists would adopt a PAYD insurance product, and it would apply not only to miles driven but also driving behavior, which would improve vehicle operational efficiency. The analysis assumed an aggressive level of implementation, and the report acknowledged that with less aggressive deployment, "expected GHG reductions would tend toward one half of the reductions shown."

[139] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B. November 4, 2009.

Table TLU-6.2. Comparison with Other Studies

TLU-6 Reduction Estimates Based on Different Methodologies and Data	Reduction in 2020 ($MMTCO_2E$)
SAIC	0.03
MDOT 2009	0.26
CAP 2008[140]	3.4

1.4. GHG Emission Reduction Calculations

The Current Methodology is based on the following formula:

$$TER_i = VMT_i * PR_i * EF * EF$$

Where

TER_i = Total GHG emission reduction from TLU-6 in year i (million metric tons CO_2e)

VMT = Relevant VMT (million)

PR_i = Participation Rate in year i

ER = Effectiveness Rate

EF = Composite CO_2e emission factor

i = given year

1.5. GHG Emission Data and Data Sources

The following data and sources were used:

- The reductions are based on light duty VMT projections from the 2006 base year to 2020, considering existing Plans and Programs.[141] MDOT [142] is the source of the following data:
  - Table 2.2 reports the 2006 baseline for statewide light duty annual VMT of 51,212 million.
  - Table 3.3 reports the 2020 statewide light duty annual VMT base forecast less Plans & Programs of 60,884 million.

[140] Comprehensive Greenhouse Gas and Carbon Footprint Reduction Strategy, Report of the Maryland Commission on Climate Change Greenhouse Gas and Carbon Mitigation Working Group, Maryland CAP Appendix D-4, August 2008.
[141] MDOT 2009 Appendix B defines Plans and Programs projections as reflective of MPO plans and HPMS data
[142] Maryland Department of Transportation, Maryland CAP – Draft Implementation Status Report. November 4, 2009.

  - The difference between these values reflects an annual growth rate of 1.24 percent. Intermediate year estimates based on these data are documented in the Assumptions section.

- Maryland has an uninsured motorist rate of 12 percent according to 2007 data reported by the Insurance Research Council, "Estimated Percentage of Uninsured Motorists by State in 2007," News Release, January 21, 2009.[143]

- This analysis adopts MDOT's composite statewide average light duty GHG emission factor for the year 2020 weighted by VMT and speed of 321 grams CO_2e per mile based on Maryland data and the U.S. EPA MOBILE 6 Adjusted model. The CO_2e rate is based on the CO_2 emissions rate from the MOBILE model multiplied by 1.05 to account for the minor role of other gases in mobile source GHG emissions including CH_4, N_2O, and HFCs. This assumption is consistent with other TLU policies quantified by MDOT.

1.6. GHG Emission Assumptions

This estimate relies on several assumptions to quantify TLU-6 impacts, including the following assumptions that were used to narrow the applicable VMT from the statewide total:

- Non-insured motorists are excluded from the relevant VMT considered in the analysis. It is assumed that the rate of non-insured motorists in Maryland would remain at 12 percent for all years.

- Heavy duty vehicles are excluded because it is assumed that a PAYD product will be offered for passenger and commercial vehicles only. Transit buses, garbage trucks, and other heavy duty truck operators typically follow assigned routes with fixed distances, so the PAYD strategy doesnot apply.

- The interim year statewide light duty annual VMT values were estimated from the MDOT 2006 and 2020 data,[144] and adjusted to exclude uninsured motorists. The resulting statewide light duty annual VMT projections used in this analysis are as follows:

Table TLU-6.3- VMT Projections

Year	2006	2012	2015	2020
Light duty, excluding uninsured (million VMT)	45,067	48,535	50,368	53,578

The participation rate was based on the following considerations and assumptions:

- The assumed rate of increase is approximately 0.5 percent per year from 2011 to 2020, resulting in 1 percent by 2012, three percent by 2015, and an adoption rate of 5 percent of policies by 2020, which is the low-end rate of participation considered in the previous MDOT analysis.

[143] http://www.ircweb.org/News/IRC_UM_012109.pdf
[144] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report. November 4, 2009, Tables 2.2 and 3.3.

- MIA has conducted research on existing programs and surveyed all in-state insurance carriers on the subject of potential PAYD products. During personal communication on February 17, 2011, MIA representatives reported that they expect a low participation rate, possibly lower than other states, which they attribute to unique circumstances in Maryland.

- Currently, only two insurer groups offer a use-based product for private passenger automobiles in Maryland[145]. Progressive Insurance Group is one group offering this product. Progressive maintains a market share of roughly six percent, based on premium volume. The other group is GMAC, which has a market share of 10%. MIA indicated that unless insurers with greater market share as measured by both premium volume and number of vehicles insured begin offering a usage-based option, the participation rate for this type of policy will remain low.[146]

- A significant change in public opinion and acceptance of new products and approaches to insurance is possible over a decade, if products and information are available. Similarly, perception of privacy issues are likely to change, and technology for tracking mileage will evolve. Therefore, even though a low participation rate may occur initially, this estimate assumes that with the marketing that is described for this policy, participation will increase each year through 2020.

The effectiveness rate was based on the following considerations and assumptions:

SAIC assumed that PAYD will have an effectiveness rate in reducing VMT of four percent per insurance participant. For a comparison, the original CAP estimate used a rate of 15 percent, and the subsequent MDOT analysis considered a range of effectiveness rates from five to ten percent.

- For perspective, gasoline prices are relatively inelastic, that is the change in price causes a relatively small change in consumption, especially in the short term, as repeatedly demonstrated by empirical data. For the TLU-5 Pricing policy analysis, the applied elasticity of travel demand relative to trip cost was -0.45 (i.e., a 10 percent increase in cost to drive will result in a 4.5 percent decrease in VMT).[147]

- Few data sets are publicly available that demonstrate PAYD effectiveness, as a result of the newness of the product and proprietary nature of competitive insurance product offerings and participation. For example, some pilot programs and studies of survey responses suggest drivers' willingness to reduce driving if offered a reduced premium and further indicate PAYD could produce up to 15 percent fewer VMT per driver. For this analysis, we assume that 10 percent or 15 percent reduction is unrealistically high for the general public's implementation, given U.S. drivers' consistently low responsiveness to changes in personal vehicle travel cost. Further, it is assumed that insurance savings aggregated for a consumer in month-or-greater installments would be less effective than daily or

[145] Two additional companies offer a commercial product (Montgomery Mutual and Ohio Casualty); however, it is unlikely that the usage will be reduced since this is a commercial product.
[146] MIA, E-mail communication to MDE, March 11, 2011.
[147] Price elasticity of demand is a metric used in economics to describe the responsiveness of the quantity demanded of a good or service to a change in its price. This metric is almost always negative, to indicate decrease in demand of the good (e.g., use of highway lanes) in response to increase in price (e.g., highway user fees).

weekly out-of-pocket expenses, such as tolls or gasoline expenditures,[148] on reducing travel demand. Recent research prepared for the Pew Center on Global Climate Change did not even include PAYD insurance in its analysis of mitigation options, stating "Another pricing idea for reducing VMT is pay-as-you-drive (PAYD) insurance, in which insurance costs rise with miles driven. A better alternative from the perspective of GHG mitigation would be Pay-At-The-Pump insurance levied via an additional surcharge on all forms of energy purchased for vehicle use."[149]

1.7. GHG Emission Analysis and Recommendations

The following items were identified during the research and analysis of TLU-6:

- The term Pay-As-You-Drive® is reportedly trademarked in several countries. Alternative terms for this policy, such as use-base, usage-based, or pay-per-mile, could be considered to avoid using the trademarked term.

- At a 2009 National Association of Insurance Commissioners Meeting, Ceres and a group of transportation and environmental organizations proposed a performance standard[150] analogous to the *LEED* standard for buildings and the *Energy Star* standards for appliances to rate PAYD insurance programs to reduce consumer confusion and maximize the VMT-reduction benefit. The PAYD insurance product performance standard was initially developed by the Victoria Transport Policy Institute,[151] and offers Gold, Silver, and Bronze ratings that reflect how the following four factors are incorporated into the product:

    - Mileage band size (smaller is better).
    - Minimum number of miles motorists must purchase (smaller is better).
    - Percentage reduction in total premiums provided by a 50 percent reduction in annual mileage (larger is better).
    - If unit prices vary between mileage bands, maximum difference between highest and lowest prices in a policy (smaller is better).

[148] Victoria Transport Policy Institute, Elasticities, TDM Encyclopedia, Updated 18 February 2011,http://www.vtpi.org/tdm/tdm11.htm
[149] David Greene and Steven Plotkin, "Reducing Greenhouse Gas Emissions from U.S. Transportation," Prepared for the Pew Center on Global Climate Change, January 2011. http://www.pewclimate.org/docUploads/Reducing_GHG_from_transportation.pdf
[150] CERES, Press Release, "Drive Less, Pay Less: Environmental and Transportation Groups Unveil Performance Standard for Pay-As-You-Drive Auto Insurance," December 9, 2009, http://www.ceres.org/Page.aspx?pid=1157
[151] Todd Litman, "Pay-As-You-Drive Insurance Product Rating System," Technical Report, Victoria Transport Policy Institute, December 9, 2009,

2. AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from TLU-6 are shown in the following table:

Table TLU-6.4- Emissions Reductions in Maryland Associated with TLU-6

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	0.18	0.50	1.0
NO_X	16	31	44
CO	210	520	1,000
VOC	12	27	47
PM10 - primary	0.7	1.3	1.7
PM2.5 - primary	0.37	0.9	1.6

These numbers were compared against the MANE-VU inventories for 2012 and 2018 in Table TLU-6.5. Because all the values are less than six-hundredths of a percent, the table indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to significantly improve air quality.

Table TLU-6.5- Percentage Reduction in State Emissions Inventory Associated with TLU-6

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	< .06	< .06
NO_X	< .06	< .06
CO	< .06	< .06
VOC	< .06	< .06
PM10-primary	< .06	< .06
PM2.5-primary	< .06	< .06

2.2. Summary of Air Quality Co-Benefit Methodology

The co-benefits methodology is based upon the estimated change in statewide VMT. It was assumed that the percentage reduction in Maryland's VMT would result in an equivalent percentage reduction in the state's mobile source emission inventory. The potential for improved air quality was estimated by comparing reductions in the mobile source inventory to estimates for the total statewide emission inventory.

2.3. Rationale for Air Quality Co-Benefit Methodology

Given the small role of VMT reductions due to car-based passenger-mile reductions a simple comparison (i.e., percentage) of change in the statewide emission inventory was used as the parameter for net co-benefit. The contribution to the mobile source emission inventory of non-LDVs was not readily available and would involve significant resources for modeling that are not really justified for the minimal impact this approach estimates for those VMT reductions.

2.4. Air Quality Co-Benefit Calculations

Statewide VMT estimates of 55,631 and 78,989 million VMT (mVMT) were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

As a result of TLU-6, vehicle miles traveled will be reduced by 19, 50 and 107 mVMT in 2012, 2015 and 2020, respectively. The reductions represent 0.03, 0.08 and 0.16 percent reductions to the total statewide VMT in 2012, 2015 and 2020, respectively. When those percent reductions are applied to the total state mobile source inventory, the emission reductions listed in Table TLU-6.4 are derived. The potential co-benefit of those emission reductions listed in Table TLUE-6.5 is the absolute reductions in Table TLU-6.4 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefit Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, AICP, Secretary, Maryland Department of Planning, November 15, 2010
- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.6. Air Quality Co-Benefit Assumptions

- It was assumed that the reduction in VMT would result in a proportional reduction in the mobile source inventory and that emissions from light duty vehicles (LDV) are such a large fraction of the total mobile source emissions, that these calculations can be based on the total emissions of mobile sources.

- For the co-benefits analysis, it was assumed that Policy TLU 6 would impact all mobile sources equally. In actuality it would mostly impact the light duty vehicle (LDV) portion of mobile sources. LDVs emit less per VMT than other portions of the source category. So the impacts are probably lower than what has been estimated by this method.

3.1 INTERACTION WITH OTHER POLICIES

The discussion of policy interactions is provided in Chapter 5.

Policy No.: TLU-8

Policy Title: Bicycle and Pedestrian

SAIC was tasked with reviewing 1) the TLU-8 policy analysis, which was conducted by a prior MDE contractor (henceforth referred to as CAP 2008), and 2) the subsequent re-analysis of the same policy, which was conducted by MDOT contractors[152] (henceforth referred to as MDOT). SAIC conducted a thorough examination of the methodologies, assumptions, source materials, and results, and documented the methodology and results, as well as provided SAIC's observations and recommendations. In addition, SAIC estimated reductions for the intermediate years that MDOT did not analyze. Finally, SAIC quantified the air quality co-benefits associated with TLU-8. SAIC's findings are described below:

1.0 GHG EMISSION REDUCTIONS

TLU-8 is designed to increase the bicycle- and walking-mode share of all trips in Maryland urbanized areas to 15percent by 2020 by removing obstacles to increased biking and walking, as well as improving and adding additional biking and pedestrian infrastructure. Compact communities with robust walking and biking infrastructure usually reduce VMT in those communities, which translate to GHG emission reduction benefits.

Table TLU-8.1. Estimated GHG Emission Reductions Resulting from TLU-8

Emissions Category	GHG Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
TLU-8	0.01	0.025	0.10 – 0.15

1.1. Summary of GHG Emission Methodology

To evaluate the GHG reductions potential of TLU-8 in 2020, the MDOT methodology used two unique quantification approaches, one for biking based on the Maryland Trails Plan, the other for walking based on changes in pedestrian infrastructure improvements as measured by the pedestrian environmental factor (PEF) at different population densities. MDOT estimated the amount of modal shift likely to occur as a result of the implementation of the Maryland Trails plan and the comprehensive pedestrian infrastructure improvements in targeted high-density areas. The reduction in VMTs associated with the resulting mode shift to biking and walking was quantified using GIS software. The difference in VMTs associated with the mode shift was converted to GHG reductions using emission factors from EPA's MOBILE 6 model.

1.2. Rationale for GHG Emission Methodology

The interpolation method for the intermediate years of 2012 and 2015 was chosen based on data availability, expert judgment, and to maximize transparency and flexibility to facilitate future updates or revisions.

[152] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report. November 4, 2009, and Appendix B of the same report.

To quantify 2020 GHG benefits, MDOT developed two unique approaches focused on one of the strategies for which a reasonable analytical method could be developed.

1.3. Difference Between Original & Revised Methodologies and Results

The CAP 2008 methodology did not quantify TLU-8 independently, but rather assumed that TLU-8-related reductions were included together with its TLU-3 estimate; therefore there was no original method or results to compare to the MDOT methodology.

1.4. GHG Emission Reduction Calculations

TLU-8 includes a variety of strategies such as education and marketing measures, updating land use policy guidance, and placement of bike facilities in strategic locations. MDOT's TLU-8 benefit calculations implicitly assume that the supportive programs are in place to maximize use of the bike and pedestrian facilities.[153] Mode share percentages are influenced by the presence or absence and relative "friendliness" of a transportation trail (e.g., bike trail, sidewalk), the distance between travel origins and destinations (i.e. population density and the mix of land uses), access to transit, and other factors.

To evaluate the GHG reductions potential of TLU-8 in 2020, MDOT developed two unique approaches: one for biking based on the Maryland Trails Plan, the other for walking based on changes in the PEF at different population densities. The bike approach is somewhat singularly focused on the benefit of filling in gaps in the state trails/bike network. The walking approach use of the PEF and density helps account for the benefit of multiple strategies in different urban settings.

MDOT estimated the amount of modal shift likely to occur as a result of the implementation of the Maryland Trails plan and the comprehensive pedestrian infrastructure improvements in targeted high-density areas. The reduction in VMTs associated with the resulting mode shift to biking and walking was quantified using GIS software. The difference in VMTs associated with the mode shift was converted to GHG reductions using emission factors from MDOT contractors' application of EPA's MOBILE 6 model.[154]

MDOT did not calculate emission reductions associated with TLU policies for any baseline or intermediate years. Therefore, the emission reduction estimate for 2012 and 2015 are calculated using the following equation based on 10percent and 25 percent, respectively, of the 2020 total annual GHG reduction. The lower bound of the range presented for the 2020 reductions was used where applicable for all subsequent calculations.

$TER_i = TER_{2020} * RUF_i$

Where

TER_i = Total GHG emission reductions in year i for Policy TLU-8 (million metric tons CO_2e)

[153] MDOT comments, January 2011.
[154] For more details on the technical approach, assumptions, GHG emission reduction and costs analysis for each TLU policy option, refer to Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B. November 4, 2009.

TER_{2020} = Total GHG emission reductions in year 2020 for Policy TLU-8 (million metric tons CO_2e)

RUF_i = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved in year i

RUF_{2012} = 10%

RUF_{2015} = 25%

1.5. GHG Emission Data and Data Sources.

Many sets of data from a variety of data sources were consulted to develop the method and factors for the TLU-8 analysis by MDOT, as documented in the MDOT Climate Action Plan Draft Implementation Status Report, Appendix B.[155] Key data sets and sources include:

- The 2001 Baltimore Metropolitan Commission (BMC) Household Travel Survey (HHT) was analyzed to ascertain the potential impact of trail availability on travel modes in the study area. For example, the mode shift factors, which were based on density and proximity to trails were developed in part from information from the HHT.
- A Pedestrian Environment Factor (PEF), an index reflecting qualities and deficiencies of pedestrian infrastructure, was obtained to reflect pedestrian conditions and applied to elasticities of VMT. The data source is Ewing, R. and R. Cervero (2001) Travel and the Built Environment. *Transportation Research Record 1780*, 87-114.
- Data on K-12 schools in Maryland were obtained from the National Center for Educational Statistics, 2005-06.
- Data on population and business districts were obtained from the 2000 Census.
- Factors to estimate potential increase in miles traveled by bicycle as a result of buildout of the trail plan were developed from data in Dill, J., and T. Carr (2003). "Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them – Another Look." *Transportation Research Record* No. 1828, National Academy of Sciences, Washington, D.C.

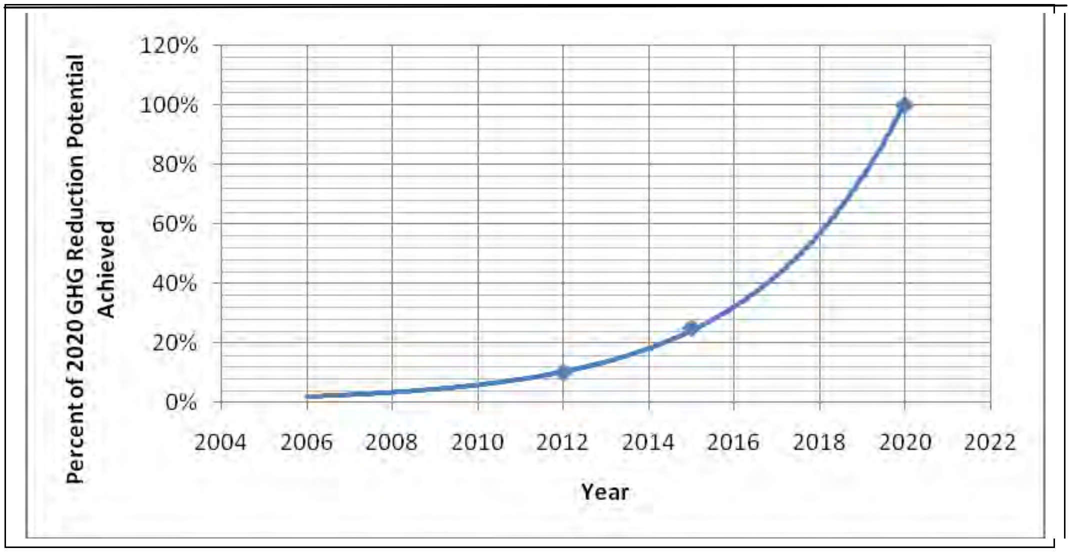
1.6. GHG Emission Assumptions

The emission reduction calculation method for 2012 and 2015 reflect the assumption that the implementation of activities on which the reductions are dependent, i.e., the completion of the Maryland Trails plan and the pedestrian infrastructure improvements, will not be completed on a linear timescale. Rather, we assume that the multiple bike and pedestrian infrastructure projects may be in various phases of planning and construction between 2010 and 2020, and the majority will not be completed very long

[155] For more details on the technical approach, assumptions, GHG emission reduction and costs analysis for each TLU policy option, refer to Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B. November 4, 2009.

before 2020. VMT reductions from mode switching to biking or walking on those trails will not begin until the completion of the trails. Further, we assume that there will be a ramp-up in use of the completed trails. As a result, the GHG reductions that are dependent upon the VMT reductions will be slow to be realized within the 2010 to 2020 timeframe. This pace at which the reductions are projected to be achieved is illustrated in Figure TLU-8.1.

Figure TLU-8.1- TLU-8 Rate Reductions Realized



MDOT documented the assumptions it developed for the 2020 GHG estimate in a separate detailed report.[156]

1.7. GHG Emission Analysis and Recommendations

Two items were identified during the analysis as potential next steps for monitoring progress or future enhancements to improve accuracy.

An additional way to monitor progress toward the TLU-8 goal is to revisit the GIS analysis of population in close proximity to the 160 trail segments of Maryland's transportation trails that are considered priority missing links, and update the analysis to reflect conditions in 2012 and 2015 based on those segments that have been connected or improved. Similarly, for the Comprehensive Pedestrian Strategy component of the methodology, progress could be monitored by updating the Pedestrian Environment Factor scores developed by MDOT. The review would be based on a review of conditions, such as changes in sidewalk availability, ease of street crossing, relative to the baseline for each interim year, 2012 and 2020.[157]

Future refinement of the TLU-8 analysis should utilize the updated Household Travel Survey Data for the Metropolitan Washington Council of Governments (MWCOG) region, which was not available at the

[156] For more details on the technical approach, assumptions, GHG emission reduction and costs analysis for each TLU policy option, refer to Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B. November 4, 2009.
[157] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B, Table B-12, November 4, 2009.

time of the original MDOT analysis in 2009, in addition to the Baltimore Metropolitan Commission data that was used.

2.0 AIR QUALITY CO-BENEFITS

2.1 Criteria Pollutant Emission Reductions

The estimated emissions reductions from TLU-8 are shown in the following table:

Table TLU-8.2: Emissions Reductions in Maryland Associated with TLU-8

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	0.45	1.2	4.6
NO_X	40	75	200
CO	530	1200	4500
VOC	31	65	210
PM10 - primary	1.8	3.1	7.8
PM2.5 - primary	0.92	2.1	7.3

These numbers were compared against the MANE-VU inventories for 2012 and 2018 in Table TLU-8.3. Because all the values are less than three-tenths of a percent, the table indicates that the criteria pollutant emissions reductions associated with this policy would be unlikely to significantly improve air quality.

Table TLU-8.3- Percentage Reduction in State Emissions Inventory Associated with TLU-8

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	< .3	< .3
NO_X	< .3	< .3
CO	< .3	< .3
VOC	< .3	< .3
PM10-primary	< .3	< .3
PM2.5-primary	< .3	< .3

2.2. Summary of the Air Quality Co-Benefits Methodology

The method is based upon the estimated change in statewide VMT. It was assumed that the percentage reduction in Maryland's VMT would result in an equivalent percentage reduction in the state's mobile source emission inventory. The potential for improved air quality was estimated by comparing reductions in the mobile source inventory to estimates for the total statewide emission inventory.

2.3. Rationale for Air Quality Co-Benefits Methodology

Given the small role of VMT reductions due to car-based passenger-mile reductions a simple comparison (i.e., percentage) of change in the statewide emission inventory was used as the parameter for net co-benefit. The uncertainty and assumptions associated with a more detailed modeling approach would not produce a better result.

2.4. Air Quality Co-Benefit Emission Calculations

Statewide VMT estimates of 55,631 and 78,989 million VMT (mVMT) were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

As a result of Policy TLU-8, vehicle miles traveled will be reduced by 47.6, 119.1 and 476.3 mVMT in 2012, 2015 and 2020, respectively. The reductions represent 0.08, 0.19 and 0.70 percent reductions to the total statewide VMT in 2012, 2015 and 2020, respectively. When those percent reductions are applied to the total state mobile source inventory, the emission reductions listed in Table TLU-8.2 are derived. The potential co-benefit of those emission reductions listed in Table TLU-8.3 is the absolute reductions in Table TLU-8.2 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefit Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, AICP, Secretary, Maryland Department of Planning, November 15, 2010
- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.6. Air Quality Co-Benefit Assumptions

- It was assumed that the reduction in VMT would result in a proportional reduction in the mobile source inventory.
- It was assumed that Policy TLU-8 would impact all mobile sources equally. In actuality it would mostly impact the light duty vehicle (LDV) portion of mobile sources. LDVs emit less per VMT than other portions of the source category. So the impacts are probably lower than what has been estimated by this method. Since the conclusion was "no significant impact" a refined method would not change the results.
- Percentage changes in VMT in metro areas where transit ridership reductions are most likely to occur will be a higher percentage changes than the statewide values but they will still be insignificant.

3.0 INTERACTION WITH OTHER POLICIES

The interactions of land uses and development and transportation infrastructure and policy decisions are many in number and complex in character. Local and regional governments and organizations nationwide have begun to recognize the importance of system-wide transportation and land-use modeling and analysis. Such modeling is outside the scope of this project, but examples of key interactions can be summarized qualitatively for TLU-8.

TLU-8 interacts slightly with all other policies, in that it improves and increases alternatives to driving, so it enhances the effectiveness of other strategies, such as TLU-2, TLU-3, and TLU-5. Additionally, the success of most other strategies will increase the effects of TLU-8. For example, the employer-based travel demand management (TDM) strategies included in TLU-9 are considered highly supportive of bike and pedestrian trips, even though the VMT reduction estimates from that strategy are assigned to TLU-9.

Using an example provided under the TLU-3 Interactions section, improvements to sidewalk connectivity from TLU-8 may allow a commuter to walk to a transit stop and transfer to a bus to complete a daily commute. However, in the absence of the TLU-8 policy, the transit station is inconvenient or inaccessible and therefore the entire trip is completed by car. By providing or improving alternatives to low-occupancy vehicle trips TLU-8 potentially enhances and enables all other TLU policies, including not only TLU-8 but also TLU-5 (intercity travel), TLU-6 (pay-as-you-drive insurance), TLU-9 (pricing), and TLU-10 (transportation technologies). However, it is assumed that the TLU-6 measure will have negligible interactions with other policies.

This TLU policy is not expected to significantly interact with policies in other sectors.

Policy No.: TLU-9

Policy Title: Pricing and Travel Demand Management

SAIC was tasked with reviewing 1) the TLU-9 policy analysis, which was conducted by a prior MDE contractor (henceforth referred to as CAP 2008), and 2) the subsequent re-analysis of the same policy, which was conducted by MDOT contractors[158] (henceforth referred to as MDOT). SAIC conducted a thorough examination of the methodologies, assumptions, source materials, and results, and documented the methodology and results, as well as provided SAIC's observations and recommendations. In addition, SAIC estimated reductions for the intermediate years that MDOT did not analyze. Finally, SAIC quantified the air quality co-benefits associated with TLU-9. SAIC's findings are described below:

1. GHG EMISSION REDUCTIONS

TLU-9 involves implementing a variety of transportation pricing and education strategies, such as VMT fees, congestion pricing and managed lanes, parking impact fees, and employer commute incentives, which will result in reduced VMT and therefore reduced GHG emissions.

Table TLU-9.1. Estimated Reductions of GHG Emissions and Vehicle Miles Traveled Resulting from TLU-9

Emissions Category	Estimated Reductions		
	2012	2015	2020
GHG Reductions (Million Metric Tons CO_2e)			
TLU-9 Total	0.02	0.04	0.41 - 1.84
*VMT Fees**	0	0	0.18 - 0.91
*Congestion Pricing and Managed Lanes**	0	0	0.13 - 0.68
Employer Commute Incentives	0.02	0.04	0.10 - 0.25
Light Duty VMT Reductions (Million Miles)			
TLU-9 Total	50	124	997 – 4,407
*VMT Fees**	0	0	439 - 2196
*Congestion Pricing and Managed Lanes**	0	0	279 - 1499
Employer Commute Incentives	50	124	279 - 712

Notes: Not all digits displayed are significant figures.

2012 and 2015 reflects a ramp-up rate applied to the average of the 2020 range.

[158] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report. November 4, 2009, and Appendix B of the same report.

*GHG reductions estimated for VMT Fees and Congestion Pricing and Managed Lanes strategies reflect not only the VMT reductions, but also GHG reductions associated with a reduction in delay as a result of reduced congestion. Reduced delay represents roughly 25 percent of the total GHG reductions for these two components of TLU-9. Overall, VMT represents approximately 77 percent and delay the remaining 23 percent of the GHG reductions attributable to TLU-9.

1.1. Summary of GHG Emission Methodology

TLU-9 focuses on the following four strategy components, in addition to an education component for state and local officials:

1. VMT fees,
2. Congestion pricing and managed lanes,
3. Parking impact fees, and
4. Employer commute incentives.

A unique method was developed to analyze strategies (1) and (2). The EPA's COMMUTER model was applied to analyze (4). MDOT did not quantify the GHG impact of component (3) or the educational component.

To analyze GHG reductions for components (1) and (2), MDOT first quantified the vehicle miles traveled (VMT) associated with all relevant private vehicle activity in Maryland in 2020 for each strategy component. Next, MDOT applied a travel demand elasticity factor to the quantified VMTs. For both components (1) and (2), the applied elasticity of travel demand relative to trip cost was -0.45 (i.e., a 10 percent increase in cost to drive will result in a 4.5 percent decrease in VMT).

For component (1), the analysis used a range of VMT fee rates from $0.01 to $0.05 per mile.

For TLU-9 component (2), a range of deployment levels were considered (e.g., from one lane in each direction to all lanes in both directions). The analysis assumes a congestion pricing fee ranging from $0.25 to $0.30, based on the Level of Service (LOS) D target[159].

For both (1) and (2), GHG reductions reflect not only the VMT reductions, but also the emissions benefits associated with the fuel reduction achieved by reducing congestion to LOS D conditions. MDOT estimated the change in hours of delay per 1,000 VMT. Reduced delay represents roughly 25 percent of the total GHG reductions for these two components of TLU-9. Overall, VMT represents approximately 77 percent, and delay accounts for the remaining 23 percent, of the GHG reductions attributable to TLU-9.

Lastly, the VMT reduction values estimated for (a) and (b) were converted to GHG reductions by applying an aggregate emissions factor of 321 grams CO_2 per mile.

1.2. Rationale for GHG Emission Methodology

[159] LOS ratings, typically A (best) through F (worst) are widely used in transportation planning as indicators of speed, convenience, comfort and security of transportation facilities and services as experienced by users.

The methodology for the 2020 GHG estimate developed by MDOT apparently was chosen based on expert judgment, data and resource availability, and to improve upon certain unrealistic assumptions applied in the 2008 CAP. MDOT did not attempt to quantify the parking impact fees strategy. Rather, the TLU-9 working group recommended that the state should encourage the local governments to test this potential policy, as its implementation would largely fall under the domain of local government.

The interpolation method for the intermediate years of 2012 and 2015 was chosen based on the status of current policy, expert judgment, and to maximize transparency and flexibility to facilitate future updates or revisions. While the method for estimating reductions in intermediate years for Employer Commute Incentives was relatively straight forward, for the VMT Fees and Congestion Pricing and Managed Lanes components of the TLU-9 strategies, the implementation dates are highly uncertain. The following issues informed the choice of methodology for estimating interim year reductions:

- Federal restrictions on tolling/pricing existing lanes on Federal facilities or facilities that were constructed with Federal funds – Federal restrictions must be eased or eliminated prior to broad implementation of congestion pricing/tolling. While it is assumed that this will occur prior to 2020, it is unlikely prior to the 2012 or 2015 intermediate years.
- Timeframe of building the required infrastructure for each potential facility is uncertain, not near-term –MTA is building, extending, planning, or considering projects on several facilities that could be included in the Congestion Pricing and Managed Lanes strategy, assuming Federal restrictions are reduced. Aside from the easing of Federal restrictions, the timeframe of completion of each facility will vary, and is uncertain, given necessary lead time for planning, environmental approvals, and establishing funding sources.
- Although a few states have begun considering a VMT tax, thus far, the addition of VMT fees, or the replacement of state motor fuel taxes collected on a per gallon basis, is an issue that has been discussed mostly at the Federal level. Prior to 2020 there will be increasing pressure on Federal and state governments to develop an alternative to the current per gallon fuel tax to counter the current decline in revenues from fuel tax receipts and decreasing balances in the highway trust fund and MD transportation trust fund. Even more so in the longer term, higher fuel economy standards and greater adoption of plug-in electric vehicles will accelerate the decline in revenue for transportation funds. Nonetheless, significant policy debate will occur prior to any change in this policy. Therefore, we assume that it will not occur prior to the 2012 or 2015 interim years, and consequently no GHG reductions will occur in 2012 or 2015.

1.3. Difference Between Original & Revised Methodologies and Results

The CAP 2008 methodology documents are inconsistent in their reporting of TLU-9 GHG reduction potential. The results from the CAP 2008 and the MDOT methodology are presented below, in MMTCO$_2$e, for 2012 and 2020, respectively:

- 2.7 and 4.7 (2008 CAP[160])
- 2.6 and 3.7 (CAP Appendix D-4[161])
- 0.02 (SAIC[162]) and a range of 0.41 - 1.84 (MDOT [163])

The CAP 2008 methodology estimates of GHG reductions are significantly greater than the MDOT methodology's results. For example, for 2020, the CAP estimate of 4.7 $MMTCO_2e$ is an order of magnitude greater than MDOT's lower bound of 0.41 $MMTCO_2e$. The CAP 2008 methodology is not fully understood, other than the assumption that a carbon fuel tax would be applied starting in 2011 at $0.15 per gallon, and would increase smoothly to the equivalent of $1.00 per gallon (real dollars) in 2020.[164]

1.4. GHG Emission Reduction Calculations

Section 1.1 describes how the 2020 GHG reduction estimates were calculated or modeled.

MDOT did not calculate emission reductions associated with TLU policies for any baseline or intermediate years. Therefore, the emission reductions for 2012 and 2015 are estimated individually for each component of TLU-9 that was quantified (i.e., a, b, and d), using the following equation:

$TER_{ij} = TER_{2020} * RUF_{ij}$

Where

TER_{ij} = Total GHG emission reductions in year i for component j of Policy TLU-9 (million metric tons CO_2e)

TER_{2020} = Total GHG emission reductions in year 2020 for each component of Policy TLU-9, which is assumed to be the average of the estimated range (million metric tons CO_2e)

RUF_{ij} = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved by component j in year i

$RUF_{2012,\ VMT\ fees} = 0\%$

$RUF_{2015,\ VMT\ fees} = 0\%$

$RUF_{2012,\ congestion\ pricing} = 0\%$

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160 Comprehensive Greenhouse Gas and Carbon Footprint Reduction Strategy, Report of the Maryland Commission on Climate Change Greenhouse Gas and Carbon Mitigation Working Group, August 2008, downloaded from: http://www.mdclimatechange.us/.

161 Maryland CAP Appendix D-4.

162 SAIC developed the 2012 estimate; MDOT did not quantify reductions for interim years

163 Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B. November 4, 2009.

164 Maryland CAP Appendix D-4.

$RUF_{2015,\ congestion\ pricing} = 0\%$

$RUF_{2012,\ employer\ commute\ incentives} = 10\%$

$RUF_{2015,\ employer\ commute\ incentives} = 25\%$

To estimate VMT reductions in intermediate years, the same percentages are applied for each given year and strategy component.

1.5. GHG Emission Data and Data Sources

VMT Fees

- To develop the VMT fee assumption, MDOT reviewed current State and Federal motor fuel taxes.
- MDOT referenced the travel demand elasticity values documented in the Federal Highway Administration (FHWA) 2006 Conditions and Performance Report to Congress. The FHWA Report documented that a short-run travel demand elasticity value of 0.4 and a long-run elasticity value of 0.8 was applied in analyses.[165] The analyses for the FHWA Conditions and Performance Reports are conducted using the Highway Economic Requirements System (HERS) model, which estimates the future investments to maintain and improve U.S. highways. The 2006 source was the basis for the travel demand elasticity value that MDOT applied in both the VMT and Congestion Pricing and Managed Lanes analysis. We reviewed the 2008 Conditions and Performance Report and confirmed that FHWA continued to apply the same short- and long-run elasticity values in HERS.[166]
- To estimate delay, MDOT used Highway Performance Monitoring System (HPMS) data from the FHWA's HERS model to develop baseline statistics for Maryland interstates.
- For the VMT Fee strategy, as well as Congestion Pricing, MDOT used a composite statewide average light duty GHG emission factor for the year 2020 weighted by VMT and speed of 321 grams CO_2e per mile based on Maryland data and the U.S. EPA MOBILE 6 Adjusted model. The CO_2e rate is based on the CO_2 emissions rate from the MOBILE model multiplied by 1.05 to account for the minor role of other gases in mobile source GHG emissions including CH_4, N_2O, and HFCs.

Congestion Pricing and Managed Lanes

- There are a total of 3,140 interstate and expressway (i.e., freeway) lane miles in Maryland.
- To quantify the total potential relevant VMT to which this strategy applies, MDOT reviewed the 2008 Annual Attainment Report, which reported the share of those freeway lane miles in Marylandthat are congested daily in 2006 to be 30.4 percent.

[165] Although it is common practice for analysts to ignore the negative sign, as FHWA in this case, elasticities are almost always negative.
[166] FHWA, 2008 Conditions and Performance: Chapter 10 Sensitivity Analysis, http://www.fhwa.dot.gov/policy/2008cpr/chap10 htm

- To estimate the miles of freeway that will be congested in 2020, MDOT used BMC and MWCOG travel demand model forecasts of 40 percent of freeway miles.
- Delay was estimated using the same data and approach as applied in the VMT fees analysis.

Employer Commute Incentives

- Data from national studies were reviewed to develop estimates for future participation in all employer based commute strategies.
- We approximate the composite emission factor used by the EPA COMMUTER model for this TLU-9 component to be roughly 355 grams CO_2e per mile, by dividing the model results for GHG reductions by model results for VMT reductions.

1.6. GHG Emission Assumptions

MDOT documented the following assumptions in the Climate Action Plan Draft Implementation Status Report, Appendix B:

VMT Fees

- MDOT assumed Maryland would apply alternative VMT fees ranging from $0.01 per mile to a high of $0.05 per mile for the year 2020, which equates to equivalent gas tax increase of $0.27 to $1.37 per gallon.
- MDOT assumed an average on-road fuel economy in 2020 of 27 mpg.
- For both the VMT Fee and Congestion Pricing analysis, the applied travel demand elasticity value was a combined short- and long-run elasticity estimate of -0.45.

Congestion Pricing and Managed Lanes

- The analysis considers two scenarios: a moderate and a high projection of growth in congested lane miles by 2020.
- This table presents the assumed range of deployment of congestion pricing in 2020.

Table TLU-9.2: Assumed Range of Deployment of Congestion Pricing in 2020

Lane Miles to Apply Congestion Pricing, Assumed Target in 2020	Share of Total Freeway Miles In Maryland
1. Half of congested areas, 1 lane each direction	7.5%
2. All congested areas, 1 lane each direction	15.0%
3. Half of congested areas, all lanes in both directions	20.0%
4. All congested areas, all lanes in both directions	40.0%

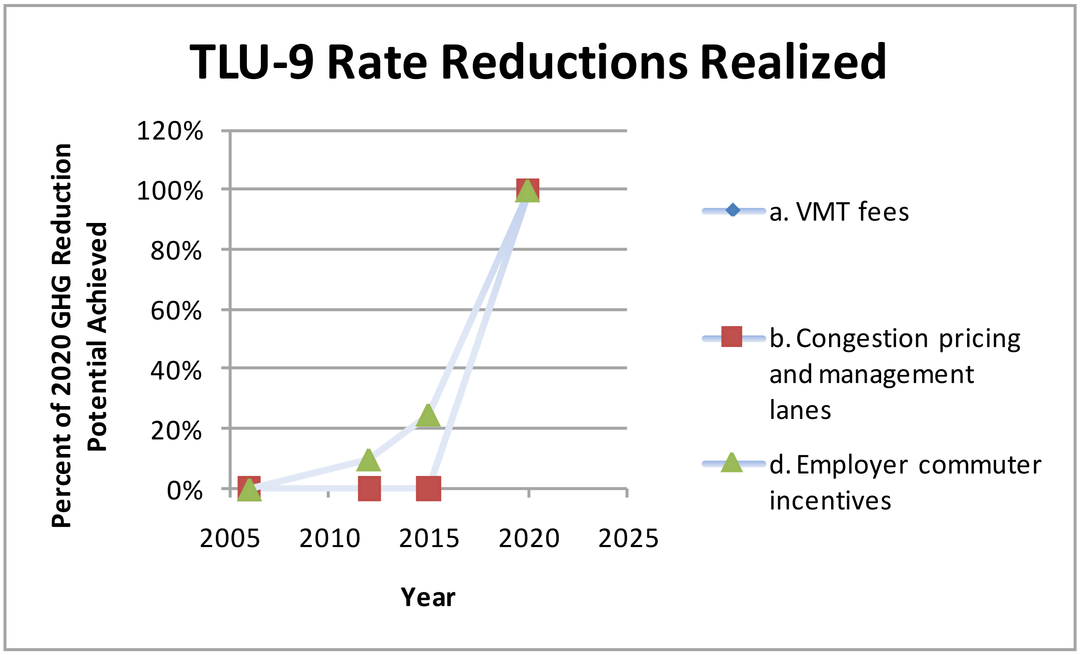
Employee Commute Incentives

- Based on national data, the analysis assumes that approximately 25 percent of Maryland's workforce would take advantage of some type of a commute program, if offered.
- The assumed medium and high participation rates in 2020 represent a program participation increase of 50 and 100 percent respectively.
- Specific inputs to the EPA COMMUTER model regarding the assumed baseline, medium, and high participation rates for 2020 are documented in the MDOT Climate Action Plan Draft Implementation Status Report Appendix B.
- The EPA COMMUTER model estimated reductions are in addition to benefits associated with the TERM strategy analysis in 2020.

Intermediate Year Reduction Estimates

The GHG reductions for intermediate years 2012 and 2015 were estimated individually for each of the three components that MDOT quantified for the TLU-9 policy. For the VMT Fees and Congestion Pricing and Managed Lane components, we assume that the strategies are not implemented prior to 2015, and therefore we assume no GHG benefits are realized in 2012 or 2015. For the Employer Commute Incentives component, we assume that the subcomponents of the strategy are implemented over time, as will the accrual of GHG benefits. For example, all state agencies may offer transit benefits and cash-in-lieu parking benefits to their employees sooner than lessors are encouraged to restructure lease contracts to unbundle residential parking costs, which may occur sooner than on-street parking spots are reduced and sidewalks expanded. Therefore, we applied an exponential growth rate from the base year until 2020. This pace at which we assume the reductions will be achieved is illustrated here:

Figure TLU-9.1- TLU-9 Rate Reductions Realized



1.7. GHG Emission Analysis and Recommendations

SAIC's observations include:

- Reductions associated with reduced delay – We recommend that MDOT describe the estimation method in more detail for readers not familiar with the LOS metrics and the peak traffic volumes and capacity data that may have been applied.

- VMT fees – the original CAP estimate was based in part on the assumption that a new fuel tax could be applied beginning in 2011. We anticipate that the implementation of any new VMT fee is unlikely to occur sooner than 2016, which is reflected in the Rate Reductions Realized chart.

- The combined short- and long-run elasticity estimate of -0.45 applied in both the VMT fee and Congestion Pricing analyses is conservative. The referenced FHWA 2006 Report that MDOT used to develop its combined elasticity estimate discusses its choice of lower elasticities than comparable parameter values used in the preceding 2004 Conditions and Performance Report. We agree that the conservative weighting toward the less elastic short-term elasticity is appropriate given the short timeframe of implementation assumed in the analyses. As noted, we assume the two relevant TLU-9 components will begin to demonstrate emissions reductions in 2016. Travel demand has been shown to be more inelastic in the short-term. Many drivers have no reasonably available alternatives to the status quo in the short term, and it often takes time to identify new travel options, and develop new patterns that reduce VMT. In the longer-term, drivers may make more drastic lifestyle choices, such as relocating to new homes and work locations, to reduce VMT and avoid costs.

2.0 AIR QUALITY CO-BENEFITS

2.1. Criteria Pollutant Emission Reductions

The estimated emissions reductions from TLU-9 are shown in the following table:

Table TLU-9.3: Emissions Reductions in Maryland Associated with TLU-9

	Statewide (tons/year)		
Pollutant	**2012**	**2015**	**2020**
SO_2	0.48	1.2	9.6 – 37
NO_X	42	78	410 – 3,300
CO	560	1300	9,400 -43,000
VOC	33	68	440 – 2,500
PM10 – primary	1.9	3.3	16 – 140
PM2.5 - primary	0.97	2.2	15 – 74

These numbers were compared against the MANE-VU inventories for 2012 and 2018 in Table TLU-9.4. Because the values for NO_X, CO, and VOC are 3.3, 2.9 and 1.4 percent, respectively, the criteria pollutant emissions reductions associated with this policy may result in a measurable improvement in air quality.

Table TLU-9.4: Percentage Reduction in State Emissions Inventory Associated with TLU-9

Reductions	Maryland (%)	
Pollutant	**2012**	**2018**
SO_2	< .001	< .2
NO_X	< .001	3.3
CO	< .001	2.9
VOC	< .001	1.4
PM10-primary	< .001	< .2
PM2.5-primary	< .001	< .2

2.2. Summary of Air Quality Co-Benefits Methodology

The method is based upon the estimated change in statewide VMT. It was assumed that the percentage reduction in Maryland's VMT would result in an equivalent percentage reduction in the state's mobile source emission inventory. The potential for improved air quality was estimated by comparing reductions in the mobile source inventory to estimates for the total statewide emission inventory.

2.3. Rationale for Air Quality Co-Benefits Methodology

This policy may result in significant reductions in the range of 1 to 3 percent for NO_X, CO, and VOC compounds. This method assumes that the emissions per VMT are the same for all categories of mobile sources. This policy is most likely going to reduce VMTs for the LDV mobile sources, which have lower emissions per VMT than most of the other mobile source categories. Therefore the actual co-benefit is likely lower than the 1 to 3 percent that is estimated. The data needed to refine this estimate was not readily available. Creating it would involve modeling well beyond the resources available for this portion of the analysis. This method produces a reasonable result with the information that was readily available.

2.4. Air Quality Co-Benefits Calculations

Statewide VMT estimates of 55,631 and 78,989 million VMT (mVMT) were estimated for 2009 and 2030, respectively. An estimate of 59,000, 62,000 and 68,000 mVMT in 2012, 2015 and 2020, respectively were determined by linear interpolation.

As a result of Policy TLU-9, vehicle miles traveled will be reduced by 50,124 and a range 997 – 4,407 mVMT in 2012, 2015 and 2020, respectively. The reductions represent 0.08, 0.2 and a range of 1.47 – 6.49 percent reductions to the total statewide VMT in 2012, 2015 and 2020, respectively. When those percent reductions are applied to the total state mobile source inventory the emission reductions listed in Table TLU-9.3 are derived. The potential co-benefit of those emission reductions listed in Table TLU-9.4 is the absolute reductions in Table TLU-9.3 compared to the statewide emission inventory.

2.5. Air Quality Co-Benefits Data and Data Sources

- **Statewide VMT estimates.** A Presentation Smart Growth & Transportation, Funding/Investment, Blue Ribbon Commission on Transportation Funding, Richard E. Hall, AICP, Secretary, Maryland Department of Planning, November 15, 2010

- **Statewide emission inventory.** MARAMA, MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

2.6. Air Quality Co-Benefits Assumptions

The following assumptions were made:

- The reduction in VMT would result in a proportional reduction in the mobile source inventory.
- TLU-9 would impact all mobile sources equally. In actuality it would mostly impact the light duty vehicle (LDV) portion of mobile sources. LDVs emit less per VMT than other portions of the source category. So the impacts are probably lower than what has been estimated by this method. Since the conclusion was "no significant impact" a refined method would not change the results.

3.0 INTERACTION WITH OTHER POLICIES

The interactions of land uses and development and transportation infrastructure and policy decisions are many in number and complex in character. Local and regional governments and organizations nationwide have begun to recognize the importance of system-wide transportation and land-use modeling and analysis. Such modeling is outside the scope of this project, but examples of key interactions can be summarized qualitatively for TLU-5.

Some TLU policies may achieve little reductions on their own, but with the implementation of TLU-9 with others, they have large impacts. For example, which is also provided in the TLU-2 Interaction Section and the TLU-3 Interaction Section, transit service is not feasible in low-density areas where parking is plentiful, as high density development is a prerequisite for cost-effective transit system deployment. Therefore, certain transit strategies alone would not achieve reductions without compact development in place. However, transit enhancements (TLU-3) in combination with smart growth strategies (TLU-2) and pricing incentives (TLU-9) will provide significant VMT and GHG reductions. Such interactions is the subject of an anticipated 2011 Transit Cooperative Research Program project, titled: Determining the Land Use Effect of Transit's Role in Reducing Regional Greenhouse Gas Emissions. The following is an excerpt from the project background:

Evidence also suggests that there are additional synergies for reducing GHG among transit ridership, land use, and pricing strategies for transportation, including parking. Detailed information on the character and magnitude of these synergies is not currently available. Research in this area would further help local and state governments, metropolitan planning organizations, transit agencies, and others to estimate potential GHG reduction that would result from pursuing combined strategies regarding increased transit capacity, related land use planning and development, and associated pricing policies affecting related services.

Outside the TLU sector, this TLU policy could enhance the effectiveness of AFW-4, by reducing demand for sprawling development patterns, similar to TLU-2 smart growth strategies, although a detailed analysis of such interactions is beyond the scope of this project. This TLU policy is not expected to significantly interact with any other policies in other sectors.

Policy No.: TLU-10

Policy Title: Transportation Technologies

SAIC was tasked with reviewing 1) the TLU-10 policy analysis, which was conducted by a prior MDE contractor (henceforth referred to as CAP 2008), and 2) the subsequent re-analysis of the same policy, which was conducted by MDOT contractors[167] (henceforth referred to as MDOT). SAIC conducted a thorough examination of the methodologies, assumptions, source materials, and results, and documented the methodology and results, as well as provided SAIC's observations and recommendations. In addition, SAIC estimated reductions for the intermediate years that MDOT did not analyze. Finally, SAIC quantified the air quality co-benefits associated with TLU-10. SAIC's findings are described below:

3.0 GHG EMISSION REDUCTIONS

TLU-10 is designed to promote transportation technologies to reduce GHG emissions from on-road engines/vehicles by an additional 7.5 percent by 2020 from current adopted baseline policies (the Maryland Clean CarsProgram) through more efficient technologies and operations. In addition, TLU-10 seeks to reduce emissions from off-road transportation sources through use of more efficient technologies and operations by 15 percent by 2020.[168] TLU-10 contains a number of specific types of transportation technologies, as described in Table TLU-10.1 below:

[167] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report. November 4, 2009, and Appendix B of the same report.
[168] 2008 Maryland CAP Appendix D-4.

Table TLU-10.1- Estimated Reductions of GHG Emissions and Fuel Use from TLU-10

Emissions Category	Units of Reductions	2012	2015	2020
TLU-10 Total	$MMTCO_2e$	**0.16**	**0.19**	**0.20**
TLU-10.2 – Active traffic management and traffic management centers	$MMTCO_2e$	0.06	0.05	0.05
	Mgal Gasoline	*5.9*	*5.6*	*5.2*
	Mgal Diesel	*0.5*	*0.4*	*0.4*
TLU-10.3 – Traffic signal synchronization/optimization	$MMTCO_2e$	0.01	0.01	0.01
	Mgal Gasoline	*0.24*	*0.23*	*0.21*
	Mgal Diesel	*0.56*	*0.53*	*0.49*
TLU-10.7 – Reduce idle time in light duty vehicles, commercial vehicles, buses, locomotives, and construction equipment	$MMTCO_2e$	0.05	0.07	0.07
TLU-10.9 – Promote and incentivize fuel efficiency technologies for medium and heavy duty trucks	$MMTCO_2e$	0.04	0.05	0.05
TLU-10.12 – Encourage retrofit and/or replacement of non-highway diesel engines	$MMTCO_2e$	0.01	0.01	0.02
	Mgal Diesel	*0.6*	*1.2*	*2.13*

Notes: Gasoline and diesel fuel reductions listed above represent the basis of estimate for GHG reductions

Not all digits displayed are significant figures.

1.1. Summary of GHG Emission Methodology

The MDOT quantification effort for the TLU-10 policy included the following five strategy components:

- TLU-10.2 – Active traffic management and traffic management centers,
- TLU-10.3 – Traffic signal synchronization/optimization,
- TLU-10.7 – Reduce idle times in tractor trailer trucks, transit buses, and school buses,
- TLU-10.9 – Promote and incentivize fuel efficiency technologies for medium and heavy duty trucks, and
- TLU-10.12 – Encourage retrofit and/or replacement of non-highway diesel engines.

The revised methodologies used to estimate GHG emission reductions from each of these five strategies are summarized below. MDOT explains the reasons why the other sub-strategies of TLU-10 were not quantified (e.g., lack of data).

- TLU-10.2 – Currently, the State of Maryland operates the Coordinated Highways Active Response Team (CHART) program, an active traffic management (ATM) system that encompasses a range of intelligent transportation system (ITS) technologies. MDOT estimated GHG reductions associated with TLU-10.2 by projecting the delay reduction impacts of the CHART system into the future, and converting those delays from units of time to fuel, and then to emissions.

- TLU-10.3 – Traffic signal synchronization/optimization data on 2008 fuel savings associated with specific corridors, which were provided directly from the Maryland State Highway Administration (SHA), were projected to 2020 and converted to emissions. The analysis assumes no new corridor or intersection updates.

- TLU-10.7 – Idle time reduction potential for each vehicle class was estimated based on factors found in literature, applied to 2006 vehicle and inventory data and converted to fuel units, forecast from 2006 to 2020 using assumptions, and converted to emissions using MOBILE emission rates.

- TLU-10.9 – Reductions associated with technologies for medium and heavy duty trucks were estimated using the U.S. EPA SmartWay calculator.

- TLU-10.12 – The reduction potential of retrofits and/or replacement of non-highway diesel engines was estimated using a general assumption of five percent reduction in fuel use applied to the relevant quantity of off-road diesel fuel.

1.2. Rationale for GHG Emission Methodologies

The MDOT methodology for the 2020 GHG estimates was chosen based on data availability. The interpolation method for the intermediate years of 2012 and 2015 was chosen based on expert judgment and to maximize transparency and flexibility to facilitate future updates or revisions.

Difference Between Original & Revised Methodologies and Results

The following results were reported, in $MMTCO_2e$, for 2020 (the 2008 CAP documents are inconsistent in their reporting of TLU-10 GHG reduction potential):

- 0.44 (2008 CAP[169])

- 2.83 (CAP Appendix D-4[170])

- 0.20 (MDOT[171])

[169] Comprehensive Greenhouse Gas and Carbon Footprint Reduction Strategy, Report of the Maryland Commission on Climate Change Greenhouse Gas and Carbon Mitigation Working Group, August 2008, downloaded from: http://www.mdclimatechange.us/.
[170] Maryland CAP Appendix D-4.
[171] Maryland Department of Transportation, Maryland Climate Action Plan – Draft Implementation Status Report, Appendix B. November 4, 2009.

The CAP 2008 estimates of GHG reductions are significantly greater than the MDOT methodology. For example, for 2020, the CAP 2008 methodology estimate of 2.83 $MMTCO_2e$ is an order of magnitude greater than the MDOT methodology estimate of 0.20 $MMTCO_2e$.

1.3. GHG Emission Calculations

The specific algorithms used to project the emission reductions of TLU-10 in 2020 were not reported by MDOT, however the details of the data sources and assumptions are described in MDOT's documentation,[172] and reported below.

MDOT did not calculate emission reductions associated with TLU policies for any baseline or intermediate years. Therefore, the emission reductions for 2012 and 2015 are estimated individually for each component of TLU-10 that was quantified by calculating the trend between the base year for the given strategy and 2020, either individually in gasoline and diesel fuel, if given, or in emissions. Some assumptions were developed, and are included under the *GHG EmissionAssumptions* Section below. For 10.2 and 10.3, the interim year fuel reduction estimates were converted to emissions using the implied average emission factor calculated from MDOT's reported results –tons CO_2e per gallons fuel. For 10.2 and 10.3, the gasoline to diesel fuel ratio in 2020 was assumed constant for the intermediate years.

1.4. GHG Emission Data and Data Sources

TLU-10.2

The GHG emission benefits associated with this strategy were calculated based on 2008 delay data provided directly by the Maryland State Highway Administration (SHA) for the CHART program, and projected to 2020 using assumptions.

TLU-10.3

Emissions are based on 2008 fuel data, specifically 856,266 total gallons of fuel, which represent the difference in 2008 vehicle fuel consumption between the before and after conditions of the specific regional corridors for which the traffic signals were synchronized or optimized. These data were provided directly by the SHA. These fuel savings were projected to 2020 using assumptions.

TLU-10.7

The source of the total CO_2e emissions data for each of the vehicle categories that are examined in this strategy is the MDOT contractor modeling for State transportation inventories, based on traffic volume data in the HPMS database, and emissions rates from the MOBILE model. The emissions data reflect the 2006 network, and were projected using assumptions.

[172] Ibid.

TLU-10.12

- The source of the 5 percent reduction in fuel use estimate is an MDOT analyst estimate in absence of available data set.
- Off-road diesel fuel consumption source is the EIA Annual Energy Outlook.

1.5. GHG Emission Assumptions

MDOT documented its assumptions in the Climate Action Plan Draft Implementation Status Report, Appendix B. These and additional assumptions used are as follows:

TLU-10.2

The GHG emission benefits associated with this strategy were calculated based on 2008 data obtained from the CHART program, which were projected to 2020 utilizing the following assumptions:

- An average annual VMT growth rate of 1.11 percent, obtained from the Baltimore Regional Transportation Board (BRTB) 2035 Long Range Plan (LRP) and 2010-2013 Transportation Improvement Program (TIP) dated May 2009.
- A 2020 fleet mix of 90 percent light duty vehicles (LDV), 3 percent heavy duty gasoline vehicles (HDGV), and 7 percent heavy duty diesel vehicles (HDDV).
- A 2008 average fuel economy (mpg) of 21.4 for LDVs, 8.0 for light duty gasoline vehicles (LDGVs), 8.3 for HDDVs, and 20.1 fleet-wide.
- A 2020 average fuel economy (mpg) of 29.4 for LDVs, 8.0 for LDGVs, 8.3 for HDDVs, and 27.3 fleet-wide.
- A 2008 annual fuel savings of 6.7 million gallons.
- A delay reduction of 2.66 M vehicle-hour (veh-h) for trucks and 33.32 M veh-hr for cars.
- A fuel economy adjustment factor of 0.74.
- It is assumed that the chart system continues to operate in the same manner each year between 2008 and 2020.

TLU-10.3

Traffic Signal Synchronization / Optimization – The GHG emission benefits resulting from the implementation of this strategy were calculated using several of the same assumptions as TLU-10.2, including: average annual VMT growth rate in the BMC region, fleet mix, fuel economy adjustment factor, and 2008 and 2020 fuel economy.

The specific signals and corridors for which projects were completed prior to 2008 are not specified. It is assumed that no additional traffic signal synchronization /optimization occurred between 2008 and 2020.

Traffic signal synchronization /optimization provides fewer gallons in annual fuel savings in 2020 than in the base year because the assumed fuel economy gains, both in terms of average fleet MPG and operational efficiency in the traffic network, do not make up for increases in overall VMT.

TLU-10.7

Reducing Idling Times – The GHG emission benefits calculated from this strategy represent the sum of a reduction in 1) long term truck idling (overnight and loading), 2) transit bus idling, and 3) school bus operations.

- Long Term Tractor Trailer Truck Idling – 3.4 percent of all class 8 truck CO_2 emissions were assumed attributable to long term idling. It was assumed that a 40 percent reduction in long-term truck idling could be achieved by 2020. The source of these assumptions on long term idling- overnight and loading in the base year is a Pennsylvania study on truck idling[173] . Applying these assumptions results in a 1.36 percent reduction in class 8 truck GHG emissions in 2020 relative to 2006 class 8 truck emissions.

- Transit Bus Idling – Based on a California Air Resources Board (ARB) study,[174] it was assumed that 7 percent of transit operating time is attributable to idling in excess of 1 minute. The average emission rate at the average operating speed of 15 mph is equivalent to 3,070 grams per mile, while the CO_2 idling emission rate equals 5,337 gallons per hour, based on the MOBILE model. Assuming an 80 percent reduction by 2020, also based on the ARB study, results in a 0.86 percent reduction in transit bus emissions.

- School Bus Idling – Based on the same ARB study, 14 percent of school bus operating time is attributable to idling in excess of 1 minute. The average emission rate at the average speed of 15 mph equals 4.02 gallons per hour. The average idling emission rate is equal to 0.5 gallons per hour. Assuming a reduction in idling of 80 percent by 2020 results in a 1.98 percent reduction in all school bus emissions statewide.

TLU-10.9

Technology Improvements for On-highway Vehicles – EPA's SmartWay calculator was utilized to calculate the emission benefits from this strategy utilizing the following options: aluminum wheel sets for singlewide tires and automatic tire inflation. Bunker heaters and auxiliary power units (APUs) were not included as they are included in TLU-10.7. Based on these assumptions, the SmartWay calculator estimates a reduction in fuel burn of 4.6 percent. A 25 percent participation rate was anticipated, resulting in a 1.125 percent reduction in class 8 truck GHG emissions. MDOT assumed participation rate of 6,705 trucks in 2020. The participation rate is based on 2006 HDDV trucks registered in Maryland (43.18 percent of which are class 8 trucks) and a growth factor of 1.1897 based on regional travel demand models and 1990-2008 HPMS.

TLU-10.12

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173 Specific study is unknown. MDOT contractor was not able to identify the report
174 IBID

Technology Advances for Non-highway Vehicles:

- MDOT assumed this strategy will result in a 5 percent reduction in fuel use in 2020 relative to 2020 off-road highway diesel fuel use in the absence of the strategy. The resulting total fuel use reduction in 2020 is assumed to be 2,133,866 gallons per year.
- MDOT assumed an average annual off-road diesel fuel usage of 40,780,000 gallons based on 2002-2006 EIA data.
- The projected annual growth rate in fuel use across all sectors, which is assumed to be conservative for off-highway diesel, is assumed to be 1.05
- MDOT acknowledged that it expects the impact of this strategy to be relatively small based on two reasons: 1) retrofitting off-road equipment with after treatment technologies does not increase fuel efficiency, and 2) engine replacements are already reflected in the inventory. We agree on these two points. We assume then that the fuel reduction estimate is based on the difference in fuel used in applicable off-road vehicles under the assumed replacement schedule, which we assume would be through attrition, and fuel used in the same categories of vehicles if they were subject to an accelerated replacement schedule.
- For the interim year estimate, we assume the strategy implementation begins in 2010 because an accelerated schedule would take time to approve and fund.

1.6. GHG Emission Analysis and Recommendations

TLU-10.3

The resulting reduction in diesel fuel consumption is roughly double the gasoline savings in 2020. This should reflect the vehicle mix on the specific corridors, although these details currently not available.

To the extent that local jurisdictions consider, plan and implement additional traffic signal timing optimization and corridor synchronization projects, the potential emission benefits would be estimated using the same tools that would be used to calculate the delay reduction benefits, e.g., traffic flow models or signal timing software tools such as TRANSYT-7F or Synchro.

Traffic signal priority is the process of proving special treatment to transit vehicles at signalized intersections. Since transit vehicles can hold many people, giving priority to transit can potentially increase the person throughput of an intersection and reduce emissions. There are many ways signal priority can be implemented. No details are available regarding whether transit vehicle prioritization at intersections was incorporated into the signal timing updates that are the basis of this TLU-10.3 strategy. To the extent that it was, this TLU-10.3 strategy would also contribute to TLU-3 transit-related reductions.

TLU-10.12

We suggest that MDOT documents additional detail on the estimation methodology when they update their TLU estimates including the baseline fuel use projection, assumed timing of replacements under each schedule and the approximate number of locomotives (and/or other vehicles) to which it is assumed that this strategy applies.

2.0 AIR QUALITY CO-BENEFITS

This policy has no measurable NAAQS co-benefits. The estimated reductions in gasoline and diesel fuel consumption are less than 0.01 hundredths and 0.03 hundredths of a percent, respectively of the statewide consumption (2008) of those fuels for transportation.

2.1. Air Quality Co-Benefits Data and Data Sources

- **Statewide Fuel Consumption**. U.S. Energy Information Administration, Independent Statistics & Analysis, Consumption, Physical Units, 1960-2008. http://www.eia.doe.gov/states/_seds.html

3.0 INTERACTION WITH OTHER POLICIES

The interactions of land uses and development and transportation infrastructure and policy decisions are many in number and complex in character. Local and regional governments and organizations nationwide have begun to recognize the importance of system-wide transportation and land-use modeling and analysis. Such modeling is outside the scope of this project, but examples of key interactions can be summarized qualitatively for TLU-10.

TLU-10 and TLU-3 are mutually supportive of one another, although the impact of either one on the other is not expected to be large. For example, the real-time information provided by the CHART system included in TLU-10, in combination with TLU-3 strategies that provide greater transit service and awareness, may influence some single occupancy drivers to choose transit as an alternative to a trip by car, under certain circumstances highlighted by the CHART system. In a similar relationship, TLU-10 is expected to interact with TLU-8 bike and pedestrian strategies. TLU-10 is not expected to interact with policies other than TLU-3 and TLU-8.

This TLU policy is not expected to significantly interact with policies in other sectors.

Chapter 5: Policy Overlap Analysis

5.1. Introduction: The Sources of Policy Overlap

The preceding chapters present and document SAIC's estimates of the GHG and criteria pollutant emission reductions that can be expected to be generated by eight of the policies included in Maryland's 2008 CAP. Some of these policies have been revised since the 2008 Climate Action Plan; all (including the revised policies will be included in the draft 2012 Greenhouse Gas Emissions Reduction Act (GGRA) plan. Table E.2 in the Executive Summary presents the GHG emission reductions SAIC re-estimated for each of these eight of policies. In developing these emission reduction estimates, each policy was treated as independent of all other policies. The purpose of this chapter is to analyze and quantify the *interactions* between these policies. These interactions take the form of overlaps between the emission reduction estimates for the policies. As a result of these overlaps the emission reduction estimates shown in Table E.2 are not additive; rather, the total emission reductions that will be generated by the eight policies will be *less* than the sum of the reductions estimated for each individual policy. In this chapter the magnitude of the overlaps is estimated, and the methodology used to quantify the overlaps is documented.

In general, overlaps between different GHG emission reduction policies may arise from three main sources:

- **Similar Methods.** Two or more policies may be targeted towards achieving similar goals using similar, explicitly-defined methods, leading to redundancy in the policies. As a hypothetical example, a policy designed to increase biomass co-firing at coal-fired power plants and an RPS policy may both tend to increase renewable usage at the expense of fossil fuels. To the extent that biomass co-firing helps to meet the RPS policy's goals for the use of biomass the two policies are duplicative and overlap.

- **Integrated Systems.** Two or more policies may seek to achieve different goals using different methods, but by targeting highly integrated systems, such as the electric power grid, consisting of components that interact closely with one another. For example, when demand for electricity from end-use devices declines, there is an immediate, commensurate decline in the amount of electricity generated by power plants serving these loads. Even when two policies target different aspects of the electricity system they may often interact in complex ways, due to the highly integrated nature of the electricity grid. Consider, for example, two different polices, one of which is designed to reduce electricity *demand* while the other affects electricity *supply* by incentivizing increased use of natural gas in place of coal. Even though the former policy is targeted towards electricity users and the latter towards electricity suppliers, the potential for overlap between the two policies is high. As emissions from the generation of electricity declines in response to the increased use of natural gas, the emission *reductions* achievable by reducing end use electricity consumption will also decline. Specifically, the natural gas policy will cause MD's electricity emissions factor to decrease, and the emission reductions generated by the parallel reduction in electricity use will decline in direct proportion to the decline in the emissions factor. Suppose, as a hypothetical example that the electricity consumption policy results in a 1 million MWh decline in the consumption of electricity generated within MD. Suppose, further, that the in-state electricity emissions factor for MD is projected to be 0.7 metric tons CO_2e/MWh under a BAU scenario. In this case, absent the effect of the natural gas policy, emission reductions would be estimated as (1,000,000 MWh x 0.7 tons CO_2e/MWh =) 700,000 metric tons CO_2e. Now, suppose that the fuel switching incentivized by the natural gas policy causes the emissions factor to decline from 0.7 to 0.6 metric tons CO_2e/MWh. With the natural gas policy included, in-state electricity emission reductions from the electricity consumption policy would now be estimated as (1,000,000 MWh x 0.6 tons CO_2e/MWh =) 600,000 metric tons CO_2e. The overlap between the two policies would thus be (700,000 – 600,000 =) 100,000 metric tons CO_2e.[175] We emphasize that this is a purely hypothetical example solely intended to illustrate the nature of the overlap between policies targeted to the electric power system.

- **Unspecified Methods.** Policies that specify emission reduction goals *without* specifying the methods used to achieve those goals may overlap with policies that define specific methods for meeting goals. The former policies in many cases may be intended to allow market forces to determine the specific methods that will be used to meet the goals. But to the extent that more narrowly-specified policies may help meet the numeric goals of the former market-based policies their impact on emissions may in effect be subsumed under these market-based policies. Consider, for example, a cap-and-trade policy that sets a quantitative limit on emissions but without specifying how the market must meet that limit. If such a policy is combined with an RPS that specifies explicit targets for the market penetration of renewables, then meeting the explicit RPS targets will also help the market to meet the emissions cap. Since there are no constraints specifying how the cap is to be met, the emission reductions caused by the RPS will count towards meeting the cap and will hence reduce the *further* emission reductions needed to meet the cap. In such a situation, the GHG impacts of the RPS are effectively subsumed under the cap-and-trade policy.

In section 5.2 we will address each set of interacting policies, and develop and apply methodologies for estimating the overlap between the policies. As shall be seen, each of the above three sources of overlap comes into play for different combinations of the policies.

5.2. Greenhouse Gas Overlap Analysis by Policy Category

Sub-sections 5.2.1 through 5.2.4 provide greater detail on the analyses of interactions within the individual policies. Each sub-section represents a different policy category. A summary is provided in sub-section 5.2.5.

5.2.1. Transportation and Land-Use (TLU) Policy

SAIC was tasked with addressing only one of the various TLU policies—namely TLU-6, Pay-As-You-Drive Insurance. This policy is designed to provide incentives for motorists to reduce their vehicle miles

[175] Another way to compute the overlap in this example would be to approach the overlap from the viewpoint of the natural gas policy rather than the electricity consumption policy. From this viewpoint, the magnitude of the emission reductions achieved will be reduced because the total quantity of electricity generated will decline as a result of the drop in electricity consumption. Since the switch to natural gas is estimated to cause a decline in emissions equal to 0.1 metric tons CO_2e/MWh (0.7 minus 0.6), and total electricity generation is expected to decline by 1million MWh as a result of the electricity consumption policy, the reduced effectiveness of the natural gas policy would be estimated as (1,000,000 MWh)(0.1 metric tons CO_2e/MWh), or 100,000 metric tons CO_2e/MWh. This result is the same as the overlap estimated above from the viewpoint of the electricity consumption policy.

travelled (VMT) by incorporating VMT as one of the factors used to determine automobile insurance premiums.

In part because it is the only policy re-estimated by SAIC that directly targets the transportation sector, there is little potential for overlap between TLU-6 and any of the other policies. One other policy—AFW-9 (Waste Management through Source Reduction and Advanced Recycling)—may have an indirect effect on transportation through its impact on the tonnage of waste that must be hauled to landfills and incinerators. However, TLU-6, as re-estimated by SAIC, explicitly excludes the heavy-duty vehicles (i.e., garbage trucks) whose VMT would be impacted by AFW-9. Therefore there should be no overlap between these two policies.

The only other potential overlap between TLU-6 and any of the other policies might result from the impact of TLU-6 on electricity consumption. As discussed in section 5.1, policies that impact the electricity sector tend to overlap in their effect on emissions, due to the highly integrated nature of the electricity grid. However, while TLU-6 can be expected to result in a reduction in the VMT of plug-in hybrid electric vehicles (PHEVs) along with conventional vehicles, the contribution of PHEVs to Maryland's total VMT—and therefore to the reduction in VMT resulting from TLU-6—is expected to be insignificant. Even in 2020, we project PHEV VMT to be a very small fraction—much less than 1 percent—of total light-duty vehicle VMT. For example, the U.S. Energy Information Administration (EIA), in its 2011 Annual Energy Outlook, projects U.S. electricity consumption by light duty vehicles to represent only 0.04 percent of the total energy consumed by these vehicles in 2020.[176] The emission reductions associated with such a small percentage falls well below the *de minimis* levels we have used in determining significant digits for our TLU-6 emission reduction estimates. Therefore, the potential overlap between TLU-6 and the other policies affecting the electricity sector has been judged to be insignificant.

5.2.2. Agriculture, Forestry and Waste (AFW) Policies

SAIC re-estimated emission reductions for two AFW policies: AFW-2 and AFW-9. Each of these two policies is addressed separately below:.

Managing Urban Trees and Forests for Greenhouse Gas (GHG) Benefits (AFW-2). The purpose of AFW-2 is to reduce GHG emissions and increase carbon sequestration through urban forestry. As AFW-2 is the only policy that seeks to affect carbon sequestration through urban trees, there is no overlap between the carbon sequestration benefits of AFW-2 and the other AFW policies. Furthermore, because the GHG emission reductions resulting from energy savings due to reduced cooling demand were determined to be *de minimis*, it necessarily follows that any overlap between AFW-2's emission reductions and those of the other policies is also *de minimis*. In short, there are no overlaps between either the carbon sequestration or emission reduction components of AFW-2.

Waste Management through Source Reduction and Advanced Recycling (AFW-9). Within the AFW policies, there is a very small possibility of interaction between AFW-9 and AFW-6 (Expanded Use of Forest and Farm Feedstocks and By-Products for Energy Production). AFW-9 seeks to reduce municipal solid waste (MSW) which is a non-preferred feedstock for biomass energy production. However, as

[176] http://www.eia.gov/forecasts/aeo/tables_ref.cfm, Table 47.

mentioned above in the AFW-6 policy discussion, MSW would only become limiting after much larger preferred sources, from agriculture and forestry, became unavailable, so even a large impact of AFW-9 upon MSW availability is judged to be inconsequential for AFW-6.

More generally, AFW-9 reduces GHG emissions through a combination of waste reduction and recycling measures. These measures may have a broad impact on a variety of GHG emission sources, including landfills, incinerators, factories that produce the goods that eventually become waste, and the various energy sources used to extract, process, transport, use or dispose of materials. However, AFW-9 is the only policy re-estimated by SAIC that affects most of these sources. The sole possible exception is electric generating stations, which may be impacted indirectly via the effect of AFW-9 on electricity consumed to produce, process, and dispose of materials. However, it is assumed that the net indirect impact of AFW-9 on electricity use is insignificant relative to its direct impact on landfills and incinerators. Therefore, the overlap between AFW-9 and other policies affecting the electricity sector is judged to be insignificant.

5.2.3. Residential, Commercial and Industrial (RCI) Policies

SAIC re-estimated all three of the remaining RCI policies: RCI-1, RCI-4, and RCI-10. Significant overlap exists both between these three policies, as well as across the RCI policies and the Energy Supply (ES) policies. This sub-section focuses on the overlap across the three RCI policies; with one exception, the interactions between the RCI and ES policies will be addressed in sub-section 5.2.4.

Government Lead-By-Example (RCI-4). Policy RCI-4 consists of two components. First, the policy includes a set of Energy Performance Contracts (EPCs) entered into by the State government. Second, the policy includes the Generating Clean Horizons program (GCH).. Overlap between the EPC component of RCI-4 and RCI-10 (EmPOWER Maryland) is addressed below in the discussion of EmPOWER Maryland (RCI-10) below. Here, we limit our analysis to the GCH component of RCI-4. As addressed below by SAIC, the GCH component will entirely be represented in the annual Renewable Portfolio Standard (RPS) compliance demonstration.

Although the GCH program is essentially voluntary participation of State government with Maryland's RPS, it is important to recognize that under the GCH program the government will *not* take title to the Renewable Energy Credits (RECs) generated via the GCH program. Instead, the generated RECs will remain within the private sector. This in effect means that all of the credits earned through the GCH program will be applicable to the RPS goals specified in ES-7 (Renewable Portfolio Standard, RPS). For this reason, *all* of the emission reductions generated via the GCH program overlap with the emission reductions from Policy ES-7. The GCH program and ES-7 are essentially examples of two polices with similar (in fact the same) quantitative goals and similar methods (increase renewable usage). Although the two policies are targeted to different sectors (the public sector in the case of GCH and the private sector in the case of ES-7), the ability of the private sector to take credit for the benefits of GCH effectively reduces the size of the emission reductions that the private sector must achieve under ES-7. As a result, GCH's emission reductions are offset 100 percent by a corresponding reduction in the emission reductions achieved under ES-7 (RPS).

EmPOWER Maryland (RCI-10). Policy RCI-10 (which incorporates and subsumes old policies RCI-2, RCI-3, RCI-7, and RCI-11 in addition to RCI-10) represents the EmPOWER Maryland Act. EmPOWER

Maryland, enacted in 2007, requires utilities and the MEA to reduce the state's per capita electricity consumption by 15 percent by 2015. The 15 percent reduction is to be achieved against a 2007 baseline.

RCI-10 is an example of a policy that specifies energy savings goals *without* specifying the methods used to achieve those goals. Therefore any other policy that reduces electricity consumption, regardless of the methods used, will help to meet the numeric goal specified under RCI-10. Specifically, those components of RCI-1 (Improved Building and Trade Codes and Beyond-Code Building Design and Construction in the Private Sector) and RCI-4 (Government Lead-By-Example) that lead to reductions in electricity consumption will help the State to meet the 15 percent consumption goal specified in RCI-10 (both RCI-1 and RCI-4 achieve their emission reductions through energy savings, although it should be stressed that only a portion of the energy savings takes the form of electricity savings). Assuming, as we have in our analysis of RCI-10 as an independent policy, that the 15 percent goal specified under EmPOWER Maryland will be met but not exceeded, it follows that the entire reduction in electricity consumption provided by RCI-1 and RCI-4 will be applied towards the RCI-10 goal. Therefore, RCI-10 will entirely subsume the RCI-1 and RCI-4 (Government Lead-By-Example) emission reductions resulting from reduced electricity use *unless* the sum of those reductions exceeds the emission reductions projected to be achieved through the implementation of RCI-10. As we shall see this is not the case.

Table 5.1 below compares the reduction in GHG emissions for the three RCI policies. This table separates out the emissions savings due to reduced electricity consumption from the savings resulting from reductions in the direct combustion of fossil fuels (e.g., in home furnaces, water heaters), etc. There are no interactions between the policies in their effect on direct combustion emissions, as the two policies that impact these emissions (RCI-1 and RCI-4) use different methods (building codes vs. Energy Performance Contracts). Therefore the overlap between the three policies is limited to the emission reductions caused by reduced electricity demand.

Table 5.1. Estimated Emission Reductions Including and Excluding Overlap for the RCI Policies

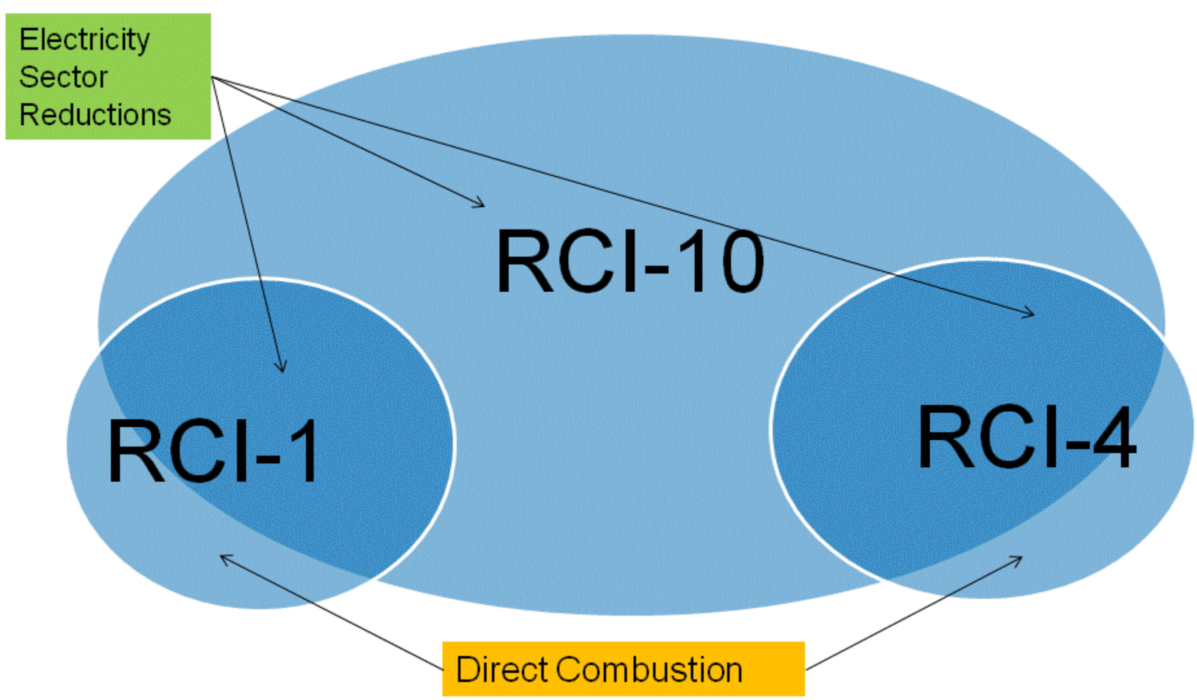
Sector/Policy	Emission Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
In-State Electricity Sector Reductions			
Including Overlap			
1. RCI-1	0.34	1.04	2.63
2. RCI-4*	0.03	0.04	0.03
3. RCI-1 & 4 Total (Sum of Rows 1 and 2)	**0.37**	**1.08**	**2.66**
4. RCI-10	2.16	4.39	3.49
5. All RCI Total (Sum of Rows 3 and 4)	**2.53**	**5.47**	**6.15**
6. All RCI Total Excluding Overlap (Equals Row 4, RCI-10)	**2.16**	**4.39**	**3.49**
Out-of-State Electricity Sector Reductions			
Including Overlap			
7. RCI-1	0.16	0.47	1.43
8. RCI-4*	0.01	0.02	0.02
9. RCI-1 & 4 Total (Sum of Rows 7 and 8)	**0.17**	**0.49**	**1.45**
10. RCI-10	0.98	2.00	1.89
11. All RCI Total (Sum of Rows 9 and 10)	**1.15**	**2.49**	**3.34**
12. All RCI Total Excluding Overlap (Equals Row 10, RCI-10)	**0.98**	**2.00**	**1.89**
Direct Combustion Reductions			
Including Overlap			
13. RCI-1	0.13	0.43	1.37
14. RCI-4*	0.02	0.03	0.03
15. RCI-10	0.00	0.00	0.00
16. All RCI Total (Sum of Rows 13, 14 and 15)	**0.15**	**0.46**	**1.40**
17. All RCI Total Excluding Overlap (Equals Row 16)	**0.15**	**0.46**	**1.40**
18. Grand Total (Sum of Rows 5, 11, and 16)	**3.83**	**8.42**	**10.89**
19. Grand Total Excluding Overlap (Sum of Rows 6, 12, and 17)	**3.29**	**6.85**	**6.78**

*This table includes only the ECP component of RCI-4. As discussed in the analysis of Government Lead-By-Example (RCI-4) above, the emission reductions generated via the GCH program component of RCI-4 overlap in their entirety with the emission reductions achieved via Policy ES-7, and hence these reductions are excluded from the table.

As the first three columns of Table 5.1 show, in each of the three forecast years the projected emission reductions from both the in-state and out-of-state electricity sectors are larger for RCI-10 than for RCI-1 and RCI-4 (Government Lead-By-Example) combined. For example, in 2012 the In-State electricity sector reductions for RCI-1 (0.35 million metric tons CO_2e) and RCI-4 (0.03 million metric tons CO_2e) total 0.38 million metric tons CO_2e; this total is less than In-State electricity reductions projected for RCI-10 (2.54 million metric tons CO_2e). Therefore in each year the electricity sector emission reductions from RCI-10 can be expected to fully subsume the electricity sector emission reductions for both other policies. This is shown in the last three columns of Table 5.1. In these three columns, electricity sector emission reductions *excluding* the overlap will be found to equate with the emission reductions for RCI-10 shown in the first three columns of the table.

Figure 5.1 is a Venn diagram illustrating the overlap between RCI-10, RCI-1, and RCI-4. Again, the building code improvements implemented under RCI-1, and the energy performance contracts signed by the government under RCI-4, will contribute directly to the EmPOWER Maryland goal of a 15 percent reduction in per capita electricity use, thereby reducing the amount of additional electricity savings that must be achieved over and above the RCI-1 and RCI-4 savings to reach the EmPOWER goal. The overlap in this case arises from the fact that EmPOWER Maryland specifies a numeric electricity savings goal without specifying the method(s) that must be used to meet the goal, thereby enabling electricity savings arising from other policies—namely RCI-1 and RCI-4—to count towards the goal.

Figure 5.1. Venn Diagram Illustrating the Overlap Between Policies RCI-1, RCI-4, and RCI-10



5.2.4. Energy Supply (ES) Policies

SAIC re-estimated emission reductions for two ES policies: ES-3(Cap-and-Trade) and ES-7 (RPS). As we have already seen, Policy ES-7, comprising Maryland's Renewable Portfolio Standard (RPS), overlaps with the GCH component of Policy RCI-4 (Government Lead-By-Example). However, we have already taken this overlap into account by excluding the GCH emission reductions from the total (overlap excluded) reductions calculated for the combined RCI policies in Table 5.1. This said, because Policy ES-7's goal is to ensure that a set *percentage* (20 percent by 2022) of Maryland's electricity generation is provided by renewable sources, any policies that reduce In-State electricity generation will also reduce the *absolute* quantity of fossil-fuel generated electricity that will be replaced by clean renewables under the ES-7 RPS. As discussed in sub-section 5.2.3, the RCI policies will have the combined effect of reducing per capita electricity consumption by 15 percent by 2015; the resulting "saved" electricity generation will not be an additional source of emission reductions from the RPS. The ES-7/RCI overlap is an example of double counting arising from the highly integrated nature of the electricity grid. Although ES-7 targets electricity supply while the RCI policies target electricity demand, changes in the latter impact the former due to the close interactions between supply and demand when it comes to the electric grid.

While some overlap exists between ES-7 (RPS) and the combined RCI policies, by far the main source of overlap arises from Policy ES-3 (Cap-and-Trade). Like Policy RCI-10 (see sub-section 5.2.3); ES-3 specifies a numeric target without specifying the method(s) to be used to meet the target. In the case of ES-3, the target is specified as a cap on total GHG emissions from Maryland's electricity sector. This cap is specified as part of an emissions allowance trading regime designed to enable the market to determine the least-cost methods of meeting the cap. However, because the only requirement is that the cap be met regardless of how this is accomplished, any and all emission reduction policies that have the effect of reducing GHG emissions from the State's electricity sector will count towards meeting the goals of ES-3. Thus, for example, emission reductions resulting from the RPS implemented under ES-7 will count towards meeting the ES-3 cap. Similarly, the reductions in electricity consumption resulting from the combined impact of the RCI policies will likewise reduce electricity sector emissions and thereby count towards meeting the cap. Like RCI-10 (EmPOWER Maryland), ES-3 (Cap-and-Trade) is an example of a policy with specific emission reduction goals but that allows the application of a wide variety of the methods to achieve those goals. In fact, ES-3 encompasses an even wider variety of methods than RCI-10. The latter policy specifies its target as a numeric reduction in electricity *consumption*, thereby limiting the methods that can be used to meet the goal to *demand-side* measures. In contrast, the cap specified in ES-3 can be met using either supply side (such as an RPS) or demand side measures (such as those specified in the RCI policies). For this reason ES-3 (Cap-and-Trade) has the potential to subsume not only ES-7 (RPS) but also the combined emission reductions from the RCI policies. Specifically, if the projected emission reductions from ES-3 exceed the sum of the reductions from ES-7 and the combined RCI policies, then ES-7 and the RCI policies will serve to help Maryland meet its emission cap under RGGI but will not provide additional GHG reductions beyond those needed to meet the cap.

Table 5.2 was developed to determine whether or not the sum of the emission reductions from ES-7 (RPS) and the combined RCI policies exceed the reductions from ES-3. This table shows the projected emission reductions from each policy/set of policies. Note that for the combined RCI policies the reductions shown in Table 5.2 are the reductions *excluding* overlap, as previously calculated in Table 5.1.

Also, in the case of ES-7 (Cap-and-Trade) we are using the *original* reduction estimates although, as discussed above, there is in fact some overlap between ES-7 and the RCI policies. In light of this overlap we present the ES-7 estimates as maximums; actual reductions for ES-7 excluding the overlap will be less than the quantities shown in Table 5.2. Finally, note that in Table 5.2 all of the emission reductions generated by the ES policies occur within the in-state electricity sector. Therefore there is no overlap between ES-3, ES-7 and the combined RCI policies for either out-of-state electricity generation sources or direct fuel combustion sources in the buildings sector. In Table 5.2 emission reductions for these two sources are simply equal to those calculated for the combined RCI policies (from Table 5.1 above).

Table 5.2. Estimated Emission Reductions Including and Excluding Overlap for the ES and Combined RCI Policies

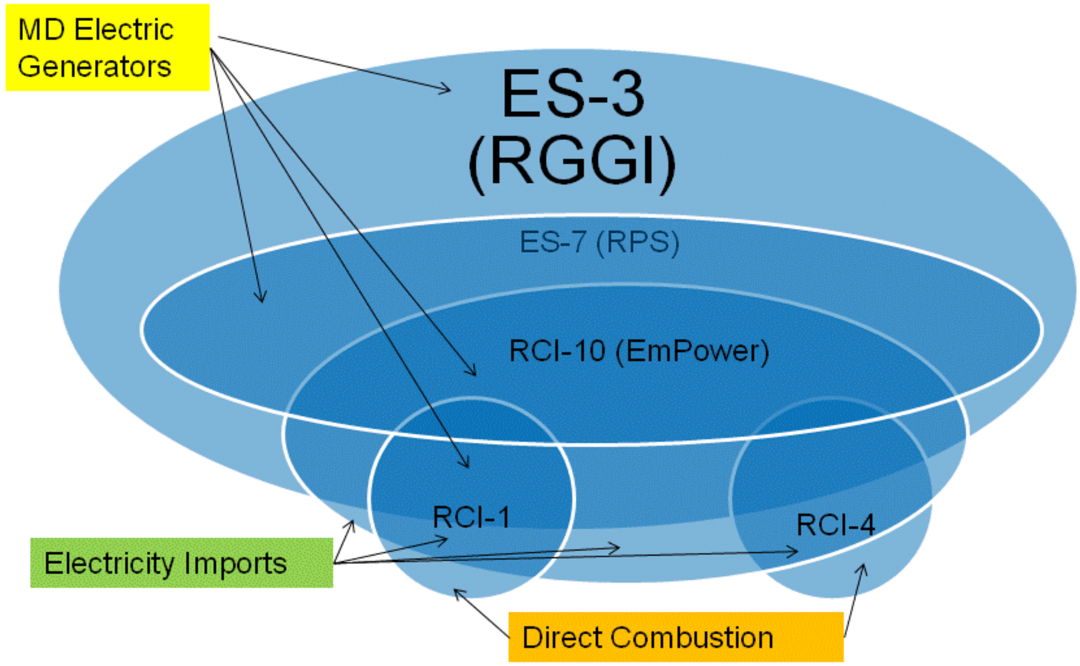
Sector/Policy	Emission Reductions (Million Metric Tons CO_2e)		
	2012	2015	2020
In-State Electricity Sector Reductions			
Including Overlap			
1. ES-7	<1.19	<2.04	<3.04
2. RCI	2.16	4.39	3.49*
3. ES-7 & RCI Total (Sum of Rows 1 and 2)	**<3.35**	**<6.43**	**<6.53**
4. ES-3	7.81	9.29	12.26
5. ES & RCI Total (Sum of Rows 3 and 4)	**<11.16**	**<15.72**	**<18.79**
6. ES & RCI Total Excluding Overlap (equals Row 4, ES-3)	**7.81**	**9.29**	**12.26**
Out-of-State Electricity Sector Reductions			
Including Overlap			
7. ES-7	0.00	0.00	0.00
8. RCI	0.98	2.00	1.89*
9. ES-7 & RCI Total (Sum of Rows 7 and 8)	**0.98**	**2.00**	**1.89**
10. ES-3	0.00	0.00	0.00
11. ES & RCI Total (Sum of Rows 9 and 10)	**0.98**	**2.00**	**1.89**
12. ES & RCI Total Excluding Overlap (Equals Row 11)	**0.98**	**2.00**	**1.89**
Direct Combustion Reductions			
Including Overlap			
13. ES-7	0.00	0.00	0.00
14. RCI	0.15	0.46	1.40
15. ES-3	0.00	0.00	0.00
16. ES & RCI Total (Sum of Rows 13, 14 and 15)	**0.15**	**0.46**	**1.40**
17. ES & RCI Total ExcludingOverlap (Equals Row 16)	**0.15**	**0.46**	**1.40**
18. Grand Total (Sum of Rows 5, 11, and 16)	**<12.29**	**<18.18**	**<22.08**
19. Grand Total Excluding Overlap (Sum of Rows 6, 12, and 17)	**8.94**	**11.75**	**15.55**

*The reader may note that electricity-related emission reductions for the RCI sector decline between 2015 and 2020. As is discussed in Chapter 1, RCI-10 (which subsumes all of the RCI sector emission reductions) reaches its final goal of a 15 percent reduction in per capita electricity demand by 2015. From 2015 to 2020, although per capita electricity demand remains constant at a level 15 percent below 2007 levels, the reduction in total electricity demand increases slightly because the population of Maryland is projected to increase. However, despite this slight increase in electricity savings, GHG emission reductions decline between 2015 and 2020. This decline in emission reductions occurs because the current trend towards lower-emitting sources of electricity (such as natural gas) is projected to continue after 2015. Thus the emission factor used to convert the electricity savings resulting from RCI-10 declines between 2015 and 2020, resulting in an erosion in the emission reductions generated by this policy, and therefore by the RCI sector as a whole.

As the first three columns of Table 5.2 indicate, the sum of In-State electricity sector emission reductions for ES-7 (RPS) and the combined RCI policies is less than the ES-3 (Cap-and-Trade) reductions in all forecast years. This is the case even though we have not eliminated the double counting described above from ES-7; without the double counting ES-3's emission reductions would exceed the sum of the ES-7 and RCI reductions by an even larger amount. Hence for the In-State electricity sector the emission reductions projected for Policy ES-3 entirely subsume the emission reductions from both ES-7 and the combined RCI policies. Total In-State electricity sector emission reductions across all policies are therefore equal to the emission reductions projected for ES-3 (as indicated in the last three columns of Table 5.2). Other policies will contribute towards meeting the emission cap set under ES-3, but they will not generate emission reductions beyond, or in addition to, the reductions necessary to meet the cap.

Figure 5.2 is a Venn diagram illustrating the overlaps between the ES and RCI policies. The overlap between ES-3 and the other policies affecting In-State electricity generation arises from the fact that ES-3 specifies a numeric emissions goal without specifying or limiting the method(s) that must be used to meet the goal, thereby enabling emission reductions arising from other policies to count towards the goal. These other policies have the effect of shifting the State's electricity emissions trend downward towards the RGGI emission cap; thereby reducing the additional emission reductions that must be achieved by ES-3 to meet the cap.

Figure 5.1. Venn Diagram Illustrating the Overlap Between the ES and RCI Policies



5.2.5. Summary of GHG Overlap Analysis Results

Table 5.3 summarizes the results of our GHG quantitative overlap analysis for 2020. In addition to presenting our overlap estimates (in the third column) for the four key sectors (RCI, RCI combined with ES, AFW, and TLU), this table also presents the sums of the GHG reductions in each sector, both unadjusted for the overlap (in the second column) and adjusted for the overlap (in the fourth column). Finally, in the bottom row the table presents the total unadjusted and adjusted GHG reductions across all four sectors, along with the total overlap.

As Table 5.3 indicates, there are no GHG overlaps for the AFW and TLU policies. However, double counting across the RCI and ES policies is significant. Of the 26.3 million metric tons CO_2e of unadjusted total reductions for these two sectors, 10.75 million metric tons (41 percent of the unadjusted total) is double counted across two or more policies. Across all four sectors, the 10.75 million metric ton CO_2e overlap represents 32 percent of the unadjusted sum of the reductions.

Table 5.3. Summary of Overlap Estimates, and Unadjusted and Adjusted GHG Emission Reductions, Across All Sectors in 2020

Sector	Unadjusted Total Reductions in 2020 ($MMTCO_2e$)	2020 Overlap Estimate ($MMTCO_2e$)	Adjusted Total Reductions in 2020 ($MMtCO_2e$)
RCI	11.00	4.11	6.89
RCI & ES	26.30	10.75	15.55
AFW	7.29*	0.00	7.29*
TLU	0.03	0.00	0.03
Grand Total	**33.62**	**10.75**	**22.87**

*Includes 1.32 $MMTCO_2e$ of carbon sequestration.

Finally, Table 5.4 presents unadjusted and adjusted total reductions for all three forecast years: 2012, 2015, and 2020.

Table 5.4. Summary of Unadjusted and Adjusted GHG Emission Reductions for 2012, 2015 and 2020

Sector	Emission Reductions Including Overlap (Million Metric Tons CO_2e)			Emission Reductions Excluding Overlap (Million Metric Tons CO_2e)		
	2012	2015	2020	2012	2015	2020
RCI	3.88	8.50	11.00	3.34	6.93	6.89
RCI & ES	12.88	19.83	26.30	8.94	11.75	15.55
AFW*	0.16	0.45	7.29	0.16	0.45	7.29
TLU	0.01	0.02	0.03	0.01	0.02	0.03
Grand Total	**13.05**	**20.3**	**33.62**	**9.11**	**12.22**	**22.87**

*Includes CO_2 sequestered as well as CO_2e reductions.

5.3. Air Quality Co-benefits Overlap

The estimated air quality co-benefits cover eighteen different policies. To understand how the policies might affect air quality within Maryland, the policies were classified based on the affected sectors:

- Emissions from Maryland Utilities
- Emissions from Maryland Transportation Mitigation Measures
- Removal of Atmospheric Pollutants by Forests, Wetlands, and Agricultural Lands
- Emissions from Area/Off-road Sources
- Emissions from Institutional Sources

Each of the sectors (and its treatment for overlap purposes) is discussed below, and the ranges in pollutant emissions reductions follow this discussion. Because policies and regulations in other states will have a significant impact on criteria pollutant emissions in those states,[177] the overlap of Maryland's policies on emissions from electricity generation that is imported into Maryland was not included in the analysis.

5.3.1. Emissions from Maryland Utilities: The RCI and ES policies cover reductions in electricity demand, the switch to cleaner fuels for electricity generation, increased energy efficiency, and compliance with energy compact goals. Similar to the discussion in sub-section 5.2.3 on GHGs, the ES-3 policy (Cap-and-Trade) will cover the components of other electricity GHG reduction policies. In other words, the adoption of the other policies (reductions in electricity demands, the switch to cleaner fuels for electricity generation, and increased efficiency) will only help Maryland reach its ES-3 goals. Because these policies do not deal directly with criteria pollutant reductions, the benefits from their implementation are straightforward and can generally be assumed to match those emission reductions that result from the implementation of ES-3.

The specific exceptions are the two cases where implementation of a GHG policy might be expected to result in increased criteria pollutant emissions. First, the ES-7 policy (RPS) introduces uncontrolled landfill gas boilers that may replace existing boilers with more controls on them (resulting in net increases in NO_X, CO, and PM emissions). Secondly, one part of the ES-8 policy (Efficiency Improvements & Repowering Existing Plants) would encourage existing coal-fired units with significant new post-combustion control technologies to be replaced by natural gas-fired units (possibly without post-combustion controls). The increases in expected criteria pollutant emissions might be prevented in both cases through Maryland regulations or if the units were large enough to trigger New Source Review offset requirements.

Table 5.5 presents the expected emissions reductions for criteria pollutants from Maryland utilities. The high range for each of the years is presented as the reduction from the ES-3 policy. The low range subtracts the emission increases from policies ES-7 and ES-8 from the reductions in the ES-3 policy. Readers should note that a narrow range or a single number does not imply confidence in the possible emission reduction but only that negative numbers were relatively small for the ES-7 and ES-8 policies.

[177] Analysis of Emissions Trends, Air Quality Trends, and Regulations in Maryland and Nearby States in the Ozone Transport Region, SAIC Report to Maryland Department of the Environment Air Quality Planning Program, September 2010.

Table 5.5. Possible Criteria Pollutant Emissions Reductions from Maryland Utilities

Pollutant	Emissions Reductions (tons per year)		
	2012	**2015**	**2020**
SO_2	14,000	12,000	17,000
NO_X	6,300-6,800	8,000-9,000	3,200-5,700
CO	(50)-200	(370)-230	(1,000)-220
VOC	30-40	20-50	(20)-50
PM10	2,000	2,300	2,100
PM2.5	1,800	2,100	1,900

5.3.2. Emissions from Maryland Transportation Mitigation Measures: Criteria pollutant emissions reductions were calculated for the TLU-2, TLU-3, TLU-5, TLU-6, TLU-8, and TLU-9 policies, all measures designed to alter the vehicle miles traveled (VMT) for light duty vehicles by offering alternative travel modes, setting up incentives and disincentives to various commuting options, and introducing VMT fees. Because these proposed VMT reduction measures are all aimed at the same broad community (Maryland's citizens), their interactions are considerable. Some policies work synergistically (e.g., TLU-2 increases high density development while TLU-8 increases the connectivity of bike paths that can replace automobile use in high density developments), but others may compete (e.g., increasing carpooling options under TLU-3 may decrease the effectiveness of bike paths in TLU-8). A thorough overlap analysis requires an understanding of which small communities are impacted by each of the policies and how the VMT will be adjusted in each community.

Because the overlap is geographically specific for the TLU policies, direct comparisons cannot be drawn from overlap analyses in other parts of the United States and applied to Maryland communities. Detailed transportation planning modeling in consultation with the Maryland DOT would be necessary to quantify the complex interrelationships between the policies. Such modeling is outside the scope of this project.

Because some policies would have synergistic effects while others would compete, the assumption was made that the overlap for the TLU-2, TLU-3, TLU-5, TLU-6, TLU-8, and TLU-9 policies could be approximated by the sum of the emissions for these measures, in the absence of detailed transportation modeling. Table 5.6 presents the total emissions reduction estimates of criteria pollutants from these measures. Note that the presentation of a single number does not imply lack of uncertainty surrounding the value but that the input data did not present a range of VMT estimates.

Table 5.6. Possible Criteria Pollutant Emissions Reductions from Maryland Transportation Mitigation Measures

Pollutant	Emissions Reductions (tons per year)		
	2012	2015	2020
SO_2	4	12	40-70
NO_X	370	740	1,700-4,600
CO	4,900	12,000	38,000-72,000
VOC	290	640	1,800-3,800
PM10	10	10	40-200
PM2.5	4	9	39-100

The AFW-4 policy (Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land) is expected to overlap with TLU-2 (Land Use & Location Efficiency). The TLU-2 policy that encourages high density development for commuting purposes will discourage urban sprawl and protect vegetation, and land protection measures such as AFW-4 will promote high density development over sprawl. Therefore, the joint TLU-2 and AFW-4 policy implementation will have a synergistic effect. Because the criteria pollutant emissions reductions from these two policies are calculated based on two different metrics (reduced VMT for TLU-2 and avoided carbon emissions from the conversion of forests to settlements for AFW-4), the emission reductions for the two policies may be summed as co-benefits.

5.3.3. Removal of Atmospheric Pollutants by Forests, Wetlands, and Agricultural Lands: The AFW-2, AFW-3, and AFW-4 policy measures all promote vegetation growth in different parts of the state. The AFW-2 policy (Managing Urban Trees & Forests) considers land in developed areas, AFW-3 (Afforestation, Reforestation, and Restoration of Forests & Wetlands) considers acreage that is being restored to a natural state, and AFW-4 (Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land) protects lands that are currently in a natural or agricultural state. Because they protect different geographic areas, these three policies do not have significant overlap.

Because the policies did not overlap, the emissions reductions achieved by the vegetative removal of pollutants across Maryland were calculated as the sum of the emissions reductions from the three policies. Table 5.7 presents the totals.

Table 5.7. Possible Removal of Atmospheric Criteria Pollutants by Forests, Wetlands, and Agricultural Lands

Pollutant	Emissions Reductions (tons per year)		
	2012	**2015**	**2020**
SO_2	410	670	1,100
NO_X	620	1,000	1,600
CO	not estimated		
VOC	not estimated		
PM10	3,300	5,400	9,000
PM2.5	not estimated		

Emissions Reductions from Area/Offroad Sources: This category covers policies that are not necessarily associated with emissions from stationary point sources or onroad emissions:

- Part of RCI-1 Improved Building & Trade Codes (the direct combustion in residential and commercial space)
- AFW-5 "Buy Local" Programs
- AFW-7b In-State Liquid Biodiesel Production
- AFW-9 Waste Management & Advanced Recycling

Because some of these policies would take place at smaller facility operations that are likely below the Title V permit levels, they are generally modeled as area source emissions for air quality modeling exercises.

These four policies do not appear to have significant overlap with one another or with other policies evaluated in this study. Therefore, the expected emissions reductions were summed together to calculate the impact of all four policies on emissions reductions (Table 5.8). Policy AFW-7b did not contain emissions reduction estimates for 2012, and AFW-9 did not include estimates for 2012 or 2015. The ranges in 2020 emissions reduction estimates have large spans because the tonnage estimates for AFW-9 ranged from 10 percent reductions in the amounts sent to landfills and incineration to 50 percent reductions in the amounts.

Table 5.8. Possible Criteria Pollutant Emissions Reductions from Area/Offroad Sources

Pollutant	Emissions Reductions (tons per year)		
	2012	2015	2020
SO_2	290	950	2,600-3,400
NO_X	110	370	1,400-3,400
CO	190	1,300	2,400-2,700
VOC	170	640	2,000
PM10	160	510	1,800-1,900
PM2.5	120	360	1,200-1,300

5.3.4. Emissions Reductions from Institutional Sources: Only one evaluated policy (RCI-4 Government Lead-By-Example) dealt with emissions reductions that were likely to occur at government complexes. The emissions reductions from government complex direct combustion processes result from the development of Energy Performance Contracts by the State. The reduced natural gas usage rates at the government complexes do not overlap with emissions reductions from other policies and appear in Table 5.9.[178]

[178]The only other RCI policy that affects direct combustion in buildings is RCI-1. Policy RCI-1 reduces direct combustion of fossil fuels through the adoption of building codes governing the construction of new buildings, as well as major renovations to existing buildings. Since the EPCs affect existing buildings only there would be no overlap between emission reductions achieved at new government buildings under RCI-1 and reductions achieved at existing buildings under RCI-4. It is possible, however, that there might be overlap between RCI-1 and RCI-4 if, for example, a government building included in one of the EPCs were to undergo a major renovation at some future point in time. In such a situation, the improvement in the building's energy efficiency resulting from implementation of the EPC might reduce opportunities for further efficiency improvements under future building codes when the renovation is undertaken. However, it is not necessarily the case that implementation of the EPC would reduce efficiency improvement opportunities under future building codes; nor is it necessarily the case that any of the buildings covered under the existing EPCs will be subject to major renovations governed by the future building codes to be adopted under RCI-1. The existence of any overlap between RCI-1 and RCI-4 is thus highly speculative and, to the extent that such overlap does exist, is likely to be limited in magnitude in SAIC's judgment.

Table 5.9. Possible Criteria Pollutant Emissions Reductions from Institutional Sources

Pollutant	Emissions Reductions (tons per year)		
	2012	2015	2020
SO_2	--	--	--
NO_X	20	25	23
CO	18	23	23
VOC	1	2	2
PM10	2	2	2
PM2.5	2	2	2

Table 5.10 presents the totals from the five independent sectors (Tables 5.4 through 5.8) and might be considered the approximate emissions reductions if all eighteen policies were implemented. The highest uncertainties in Table 5.10 from an overlap perspective are likely in the CO and VOC emissions reductions because the overlapping transportation planning policies dominate those reductions.

Table 5.10. Possible Criteria Pollutant Emissions Reductions from All Sectors

Pollutant	Emissions Reductions (tons per year)		
	2012	2015	2020
SO_2	15,000	14,000	21,000-22,000
NO_X	7,400-7,900	10,000-11,000	7,900-15,000
CO	5,100-5,300	13,000-14,000	39,000-75,000
VOC	490-500	1,300	3,800-5,900
PM10	5,500	8,000	13,000
PM2.5	1,900	2,500	3,100-3,300

5.4. Conclusion

This chapter presented a general discussion of policy overlap, and a more detailed discussion of the interactions between the various greenhouse gas mitigation policies re-analyzed by SAIC. This overlap discussion of the policies included both the greenhouse gas mitigation and air quality benefits of the policies. The majority of the interactions occur within each of the policy categories (AFW, TLU, RCI, ES), but there are significant inter-category interactions between the RCI and ES policies. Among the RCI and ES categories, policies that specify broad policy goals without specifying implementation steps tend, by definition, to subsume other more specifically delineated policies, which contribute to the broad policy goals.

In addition to the co-benefit to air quality, many of the GHG mitigation policies also impact positively upon the Chesapeake Bay by reducing air pollution that is deposited directly or indirectly into the bay. A detailed discussion of this co-benefit is provided in Chapter 6.

Chapter 6: Water Quality Co-benefits Analysis

6.1. Introduction

A co-benefit of implementing measures that reduce GHG and criteria pollutant emissions is an improvement in the Chesapeake Bay's water quality. Approximately one-third of the nitrogen that reaches the Bay comes from emissions released into the air from vehicles, industries, power plants, dry cleaners, gas-powered lawn tools and other emission sources.[179] The nitrogen from these airborne emissions is delivered to the Bay directly by deposition onto that water body and indirectly by deposition onto land and tributaries within the watershed. The nitrogen on land migrates to the Bay through a series of complex physical, biological, and chemical processes. Runoff from the stream system eventually delivers a portion of the nitrogen to the Bay. Since a direct correlation between atmospheric concentrations of nitrogen and subsequent nitrogen loading to the Bay does not exist, models are used to estimate the local loading of nitrogen and are summed at the Bay level.

The purpose of this chapter is to analyze and quantify the co-benefits of Maryland's climate change strategies on improving the Chesapeake Bay's water quality. An atmospheric and hydrologic transport modeling analysis is used for this purpose. This chapter presents an estimate of the nitrogen load reduction to the Bay from select climate policies for years 2012, 2015, and 2020 and documents the methodology used to quantify it.

6.2. Methodology

This section presents the modeling approach, as well as both an overview and detailed discussion of the inputs to the models used.

6.2.1. Modeling Approach

Two types of models are required to estimate the quantity of atmospheric nitrogen that is transported to the Chesapeake Bay. One model is required to estimate the atmospheric transport, dispersion, transformation, and deposition of nitrogen species, and a second is required to estimate the delivery of deposited nitrogen to the Bay. The CALPUFF and SPARROW models were selected for this analysis because they have been used by the Maryland Department of Natural Resources and other agencies to analyze nitrogen load reductions, and have provided results that are consistent with other established modeling approaches, such as the Chesapeake Bay Program HSPF (Hydrologic Simulation Program - Fortran) watershed model. A brief description of the two models used in this analysis is as follows:

<u>CALPUFF</u> This is a multi-layer, multi-species, non-steady state Gaussian puff dispersion model which simulates the effects of time- and space-varying meteorological conditions and pollutant transport, transformation, and removal.[180] It was developed by the Sigma Research Corporation in the late 1980s under contract with the**Cal**ifornia Air Resources Board, and is designed to simulate the dispersion of buoyant, **puff** or continuous point and area pollution sources as well as the dispersion of buoyant,

[179] Chesapeake Bay Program, Air Deposition http://www.chesapeakebay net/airdeposition.aspx?menuitem=14746
[180]Yegnan, Garrison, Joshi, and Sherwell, 2009.*Estimation and Analysis of Long-Term Trends in Nitrogen Deposition Using CALPUFF,* The Air & Waste Management Association's 96th Annual Conference & Exhibition

continuous line sources. It is currently being distributed by the Atmospheric Studies Group at the TRC Environmental Corporation. It uses surface, upper air, and precipitation observations as recorded at National Weather Service stations, and NO_X emissions obtained from the U.S. Environmental Protection Agency's (EPA) National Emissions Trends inventory (NEI). CALPUFF predicts monthly average deposition flux rates (wet and dry).

SPARROW (**SPA**tially **R**eferenced **R**egressions on **W**atershed) This hydrologic flow and nutrient transport model is used to estimate the nitrogen delivery to the Bay by simulating the migration of nitrogen over the land surface and within the stream system. It was developed by the U.S. Geological Survey to provide information that is consistent with and supplemental to the Chesapeake Bay Program HSPF watershed model. For this reason, the same input data sets for the nutrient and land-characteristic parameters are used in both the SPARROW and HSPF models; however, a separate nitrogen load data base is used in SPARROW because its statistical nature allows calibration using loading information from more locations. A limitation of the SPARROW model is a lack of temporal variability, which means that it only provides predictions for one time period, typically a year. Thus, the SPARROW model provides detailed spatial information that represents a "snapshot" in time, but does not represent cumulative deposition over longer periods.

A spreadsheet version of the SPARROW model is used in this analysis. As designed by the Maryland Department of Natural Resources,[181] the spreadsheet tool expedites the process of determining nitrogen load reductions to the Chesapeake Bay based on changes in atmospheric nitrogen levels. The SPARROW spreadsheet tool uses CALPUFF and SPARROW modeling runs that simulate the nitrogen load to the Bay during the year 2002.

6.2.2. Modeling InputOverview

In order to compare the nitrogen deposition to the Chesapeake Bay with and without Maryland's climate change policies in place, it is necessary to create separate SPARROW spreadsheets that represent base NO_X emission scenarios for 2012, 2015, and 2020. Because SPARROW spreadsheets are based on 2002 emission estimates (2002 National Emission Inventory [NEI]), the base spreadsheets for 2012, 2015, and 2020 adjust the emissions to represent activities that have taken place since 2002 and were expected to take place regardless of climate change policies (when the regional MANE-VU inventories[182]were constructed).

Base SPARROW spreadsheets for 2012, 2015, and 2020 use the NO_X emissions levels in the absence of any Maryland climate change policies (including ES-3 [Regional Greenhouse Gas Initiative (RGGI)]). The base SPARROW spreadsheets for 2012, 2015, and 2020 predict deposition to the watershed as if no climate change policies had been implemented. However, other programs (e.g., Maryland's Healthy Air Act) continued to reduce the nitrogen deposition to the watershed.

[181]John Sherwell, Power Plant Research Program, Department of Natural Resources, Annapolis, MD, jsherwell@dnr.state.md.us
[182]MANE-VU Future Year Emissions Inventory, http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory

The climate change overlap analysis (Chapter 5) presents ranges (low to high) for the expected NO_X emission reductions. These reductions are added to the base spreadsheets to determine the range of climate change nitrogen deposition rates in 2012, 2015, and 2020. The differences between nitrogen deposition in the policy cases and those in the base cases are reported.

6.2.3. Modeling InputDetails

The total NO_X emission reductions for all policies re-estimated and re-documented by SAIC, following adjustment for overlap, are entered into the SPARROW spreadsheet tool by sector. Therefore, the modeling analysis and results represent the benefits to the Chesapeake Bay of all of the policies combined. The SPARROW spreadsheet tool divides the emissions into four sectors: utility, mobile, industry, and area. The area sector represents anthropogenic activities that do not fall into the utility, mobile, and industry categories, including off-road emissions, commercial and residential emissions, and small source emissions. A description of how the Maryland policies fall into these sectors is included in Chapter 5, and the range of expected emission reductions are summarized in Table 6.1.

Table 6.1. Summary of NO_X Emission Reduction Ranges by Sector Following Overlap Analysis

Within Maryland		NO_XEmission Reductions (tons per year)					
Sector	**Policies**	**2012 Low**	**2012 High**	**2015 Low**	**2015 High**	**2020 Low**	**2020 High**
Utility	RCI electricity generation and ES	6,300	6,800	8,000	9,000	3,200	5,700
Mobile	TLU 2,3,5,6,8,9	370	370	740	740	1,700	4,600
Area	RCI-1 direct combustion, AFW-5,7b,9	110	110	370	370	1,400	3,400
Industrial	RCI-4 direct combustion	20	20	25	25	23	23
Total		**7,400**	**7,900**	**10,000**	**11,000**	**7,900**	**15,000**

The NO_X emission reductions are presented as ranges (low and high) for years 2012, 2015, and 2020. All NO_X emission reductions described in Chapter 5 are included in the analysis, except for the removal of atmospheric pollutants by forests, wetlands, and agricultural lands. Those NO_X reductions are not included in this analysis because land use changes are not represented with the SPARROW spreadsheet, which only assigns specific deposition ratios to the individual sources. To account for changes in land use, a mechanistic model such as the Chesapeake Bay HSFP model is necessary.

The SPARROW spreadsheet tool estimates how deposition to the watershed would have changed in 2002 if various emission reductions were implemented. Through CALPUFF model runs, the spreadsheet relates the 2002 National Emissions Inventory estimates to deposition within the watershed. The spreadsheet tool assumes that the projections of nitrogen deposition to water bodies and land are linear with respect to the NO_X emissions levels at each source. However, utility emissions have dropped substantially since 2002 based on the state and federal air quality programs as shown in Table 6.2. For example, Maryland's NO_X emissions have dropped 74 percent from 2002 to 2010. To account for this drop in NO_X emissions, the SPARROW spreadsheet tool has been adjusted.

Table 6.2. Summary of Actual NO_X Emission Reductions by State from EPA's Clean Air Market Division (CAMD)[183]

NO_X reductions from 2002 to 2010 at CAMD Facilities							
State	Percent Reduction	State	Percent Reduction	State	Percent Reduction	State	Percent Reduction
Alabama	61%	Iowa	44%	Nevada	76%	South Dakota	17%
Arizona	29%	Kansas	49%	New Hampshire	30%	Tennessee	80%
Arkansas	10%	Kentucky	54%	New Jersey	77%	Texas	43%
California	58%	Louisiana	42%	New Mexico	23%	Utah	15%
Colorado	24%	Maine	38%	New York	66%	Vermont	38%
Connecticut	60%	Maryland	74%	North Carolina	66%	Virginia	58%
Delaware	53%	Massachusetts	73%	North Dakota	28%	Washington	23%
District of Columbia	9%	Michigan	43%	Ohio	72%	West Virginia	77%
Florida	72%	Minnesota	64%	Oklahoma	17%	Wisconsin	63%
Georgia	59%	Mississippi	33%	Oregon	-10%	Wyoming	27%
Idaho	-24%	Missouri	58%	Pennsylvania	38%		
Illinois	56%	Montana	38%	Rhode Island	-63%		
Indiana	57%	Nebraska	21%	South Carolina	68%		

The SPARROW spreadsheet tool adjustment accounts for the statewide NO_X emission reductions that took place from 2002 to 2010 to create a new base case. The 2002 to 2010 statewide NO_X emission reductions are treated as controls on the utility sector in each state in order to estimate the 2012 emissions baselines. Because these NO_X reductions have occurred while the RGGI program has been in place, it is assumed that NO_X emissions reductions within states falling mostly within the PJM regional transmission organization have already been affected by RGGI. Those NO_X reductions and eliminations may have included fuel switching (coal-fired plant conversions to gas-fired), the development of power generation without the use of fossil fuels (e.g. increased nuclear or renewable power), or energy conservation efforts.

[183] EPA's Clean Air Market – Data and Maps. http://camddataandmaps.epa.gov/gdm/. 5/27/2011

Therefore, the base case subtracts out the control reductions that have been attributed to RGGI (see previous discussions of ES-3 policy).

The 2002 NEI for mobile source NO_X emissions also differs significantly from the 2012 MANE-VU forecast. For example, Maryland's mobile source emissions in the 2012 MANE-VU inventory are 56 percent lower than those in the 2002 NEI. Differences between the two might be attributable to control programs, new emissions models, or changes in activity levels (e.g., miles driven) implemented since development of the 2002 NEI inventory. To create the base 2012 SPARROW spreadsheet (from the 2002 NEI SPARROW spreadsheet), NO_X controls are assumed to be implemented on the mobile source sector in the MANE-VU states (ranging from 42 percent in Pennsylvania to 64 percent in New Jersey) for the baseline condition before any climate change policies are adopted.

Because the climate change policies in this study have little effect on NO_X emissions from the industry and area source sectors, the inputs for these sectors for the base 2012 SPARROW spreadsheet have not been adjusted from the original values in the 2002 NEI SPARROW spreadsheet. However, the base 2015 and 2020 SPARROW spreadsheets required additional processing, using the MANE-VU inventories for 2012 and 2018 as the benchmarks. Thus, the statewide NO_X emissions reductions from 2012 to 2018 are totaled from the area and industrial sources and converted into percentage changes over that time period, as shown in **Table 6.3**.

Table 6.3. Differences Between the 2012 and 2018 MANE-VU Inventories

State	Area	Industrial	Mobile	Utility
Connecticut	-11%	6%	-47%	-5%
Delaware	-15%	3%	-47%	-2%
District of Columbia	-14%	9%	-50%	-1400%
Maine	-10%	7%	-42%	-3%
Maryland	-11%	12%	-44%	-8%
Massachusetts	-8%	8%	-50%	4%
New Hampshire	-5%	3%	-47%	-4%
New Jersey	-13%	10%	-47%	0%
New York	-8%	7%	-44%	26%
Pennsylvania	-13%	10%	-44%	13%
Rhode Island	-9%	-1%	-36%	12%
Vermont	-12%	1%	-41%	-48%
Total	**-10%**	**9%**	**-45%**	**10%**

Just as the EPA's Clean Air Markets Division (CAMD) changes in Table 6.2 are applied to the 2002 SPARROW spreadsheet to construct the base 2012 SPARROW spreadsheet, the inventory changes in Table 6.3 are applied to convert the base 2012 SPARROW spreadsheet into the base 2015 and 2020 SPARROW spreadsheets. For the conversion of the base 2012 SPARROW spreadsheet to the base 2015 SPARROW spreadsheet, the percent inventory changes are assumed to be half what would occur from

2012 to 2018. In the absence of forecasting information, the percent inventory changes for the base 2020 SPARROW spreadsheet are assumed to match those for the 2012 to 2018 inventory changes. For states outside of MANE-VU, the percentages listed as "Total" in Table 6.3 are used.

The NO_X emission reductions are entered into the spreadsheet tool as percentage reductions. To calculate the percentages, the NO_X emission reductions[184] are divided by the total NO_X emissions[185]. These NO_X emission values are shown in Table 6.4 along with the resulting percent reductions. The out-of-state NO_Xemission reduction percentages are shown in Table 6.5.

[184]As reported by sector in the overlap analysis section of this report (Tables 5.5, 5.6, 5.8, and 5.9 of Chapter 5)

[185]As reported by sector in the MANE-VU inventory (http://www.marama.org/technical-center/emissions-inventory/2002-inventory-and-projections/mane-vu-future-year-emissions-inventory) withsector categories = MD utility, mobile, area, non-road (added to area sector) and MD nonEGU point (industrial) in years 2012 and 2018.

Table 6.4. Maryland NO_X Emission Inventory and Reduction Values by Sector and Reduction Percentages Used in the Analysis

Sector	Reductions/Inventory	NO_X Emission Reductions					
		2012 Low*	2012 High	2015 Low	2015 High	2020 Low	2020 High
Utility	Reduction (tons per year)	6,300	6,800	8,000	9,000	3,200	5,700
	Inventory with RGGI (tons per year)[186]	14,000	14,000	14,000	14,000	15,000	15,000
	Reduction (%)	**46**	**50**	**56**	**64**	**22**	**39**
Mobile	Reduction (tons per year)	370	370	740	740	1,700	4,600
	Inventory (tons per year)	50,000	50,000	39,000	39,000	28,000	28,000
	Reduction (%)	**1**	**1**	**2**	**2**	**6**	**16**
Area	Reduction (tons per year)	110	110	370	370	1,400	3,400
	Inventory (tons per year)	38,000	38,000	36,000	36,000	34,000	34,000
	Reduction (%)	**0.3**	**0.3**	**1**	**1**	**4**	**10**
Industrial	Reduction (tons per year)	20	20	25	25	23	23
	Inventory (tons per year)	20,000	20,000	22,000	22,000	23,000	23,000
	Reduction (%)	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**

*The "low" and "high" estimates are based upon the overlap analysis in Chapter 5, and are similarly presented in Table 6.1.

[186] Note that the RGGI program is a climate change program that has been included in the MANE-VU inventory estimates.

Table 6.5. NO_X Emission Reduction Percentages Used in the Analysis

Outside Maryland		NO_X Emission Reductions (%)					
Sector	Policies	2012 Low	2012 High	2015 Low	2015 High	2020 Low	2020 High
Utility	ES and RCI	42	42	49	49	56	56

6.3. Modeling Predictions

Table 6.6 shows the nitrogen load reduction estimates for years 2012, 2015, and 2020 as predicted by the SPARROW spreadsheet tool. The nitrogen load reductions that result from reduced levels of NO_X emissions being deposited on the land surface are reported by state. The nitrogen load reductions that result from reduced levels of NO_X emissions being deposited directly into the tidal Bay are reported in the row labeled "Tidal Bay". The sum of the nitrogen load reductions transported from land and deposited directly to the tidal Bay are reported in the "Total" rows.

Table 6.6 also shows the out-of-state nitrogen load reduction estimates for years 2012, 2015, and 2020 as predicted by the SPARROW spreadsheet tool. These values represent the total benefit from utility NO_X reductions in states from where Maryland imports electricity. In other words, the values represent the sum of estimated reductions in nitrogen load to the Bay due to NO_X reductions at the out-of-state utilities.

Table 6.6. Modeling Results - Nitrogen Load Reductions to the Bay from Maryland NO_X Reductions

Co-benefits (lbs)	Nitrogen Load Reductions (lbs)					
	2012 Low	2012 High	2015 Low	2015 High	2020 Low	2020 High
Maryland	113,700	116,000	145,000	148,000	184,000	290,000
New York	23,000	23,000	27,000	27,000	30,000	31,000
Pennsylvania	290,000	291,000	341,000	343,000	380,000	399,000
West Virginia	32,000	32,000	38,000	38,000	43,000	46,000
Delaware	4,000	4,000	5,000	5,000	5,000	6,000
Virginia	202,000	204,000	238,000	242,000	256,000	280,000
District of Columbia	2,000	2,000	2,400	2,500	3,000	5,000
Tidal Bay	273,000	277,000	329,000	337,000	356,000	448,000
Total	939,000	948,000	1,125,000	1,143,000	1,257,000	1,504,000

The SPARROW spreadsheet tool predictions for nitrogen load reductions transported from land to the Chesapeake Bay, as well as direct to the tidal bay, from each jurisdiction in 2012 and 2020 are also shown on **Figures 6.2 and 6.3**, respectively. The benefits within the state of Pennsylvania and Virginia are quite large relevant to other states (including Maryland) due to the contributions from the Susquehanna and Potomac basins, respectively.

Figure 6.2. Modeling Results - Nitrogen Load Reductions to the Bay by Jurisdiction in 2012

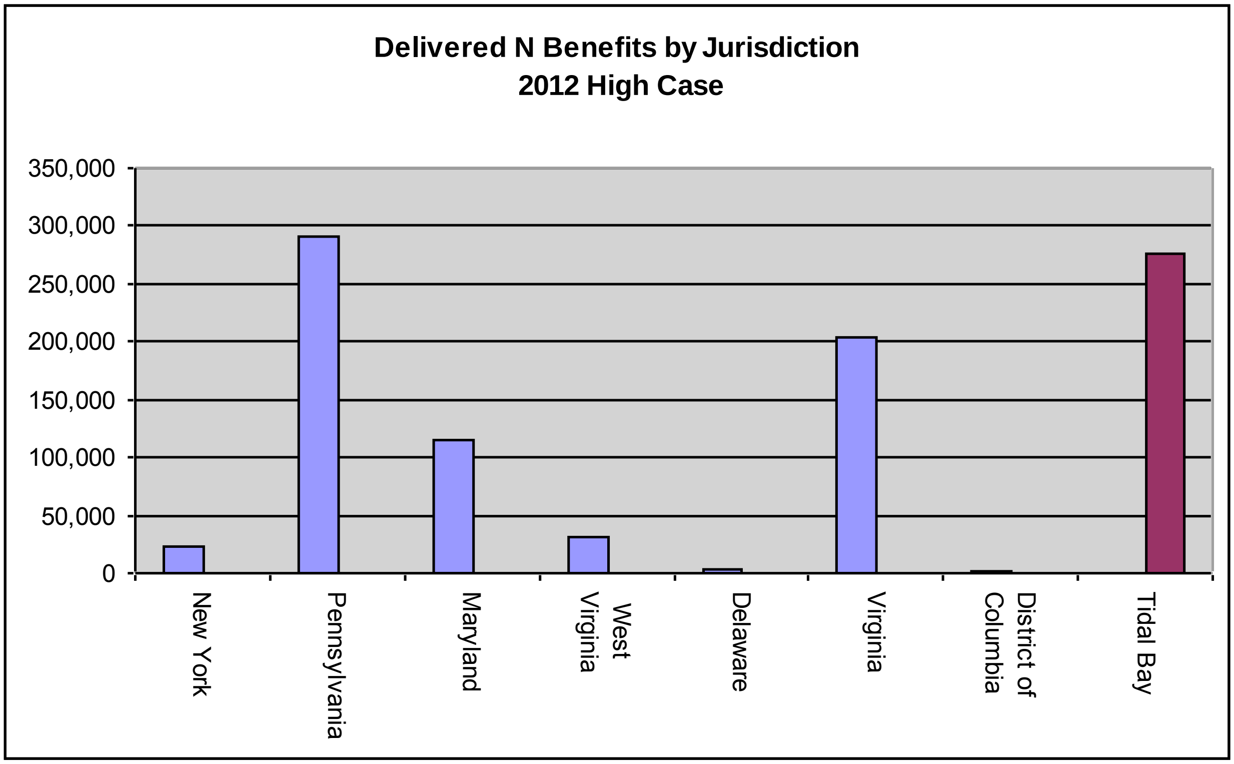
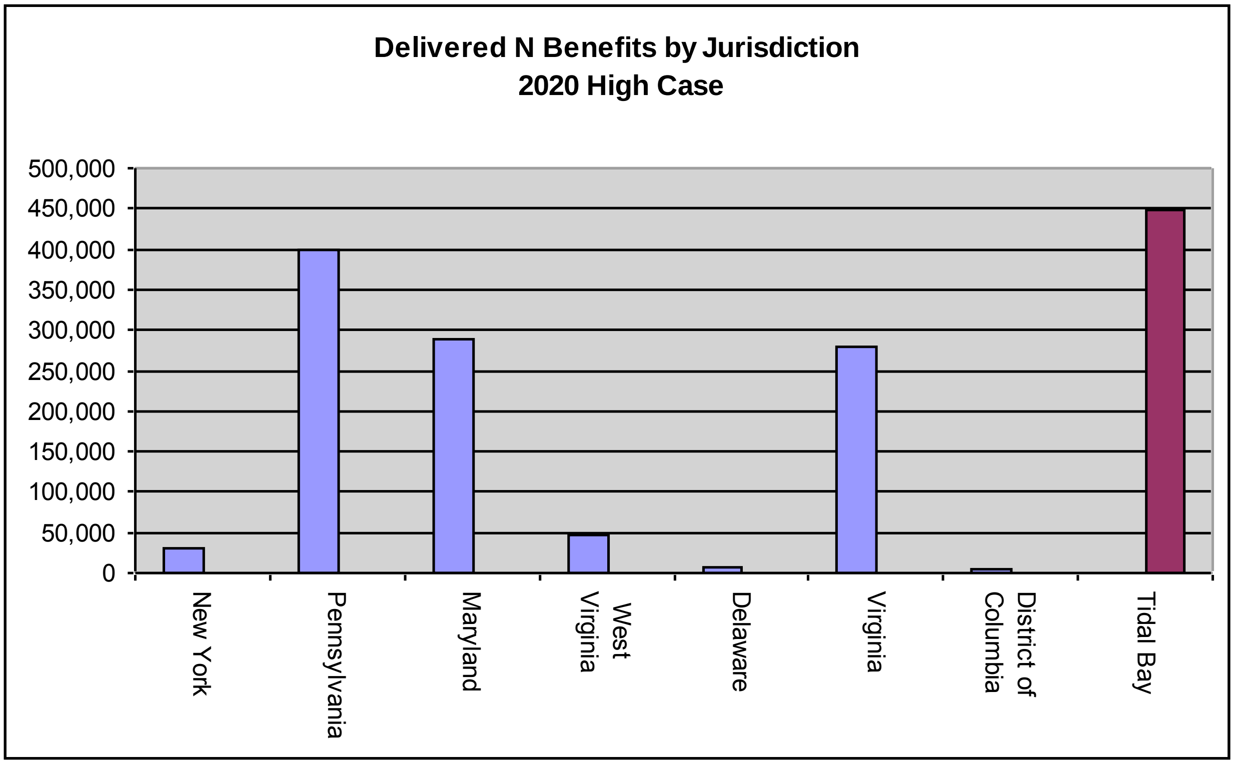


Figure 6.3. Modeling Results - Nitrogen Load Reductions to the Bay by Jurisdiction in 2020



6.4. Conclusion

This chapter estimates the nitrogen load reduction to the Chesapeake Bay from select climate policies for years 2012, 2015, and 2020. The SPARROW spreadsheet tool was used to make the predictions. The total NO_X emission reductions for policies re-estimated and re-documented by SAIC, following adjustment for overlap, were entered into the SPARROW spreadsheet tool (i.e., RCI, ES, TLU 2, 3, 5, 6, 8, 9, and AFW 5, 7b, 9 policies). The SPARROW modeling results represent the benefits to the Chesapeake Bay from all of the policies combined.

The SPARROW modeling analysis predicts that the total nitrogen load reductions to the Chesapeake Bay will be in the range of 0.94 to 0.95 million pounds in 2012. The total nitrogen load reductions will increase to the range of 1.13 to 1.14 million pounds in 2015, and increase again to the range of 1.26 to 1.5 million pounds in 2020. In Maryland, the range of nitrogen load reductions in 2012 is predicted to be between 114 to 116 thousand pounds. In 2015, the range of load reductions is predicted to increase to between 145 to 148 thousand pounds, and increase again to the range of 184 to 290 thousand pounds in 2020.

Appendix – Equations Used to Estimate GHG Reductions and Air Quality Co-benefits

This appendix lists the equations used to estimate GHG reductions and air quality co-benefits, per policy. **For detailed information on the calculations, please refer to the individual policy discussions in the body of this report.**

Chapter 1: Residential, Commercial, and Industrial (RCI) Policies

RCI-1. Improved Building and Trade Codes

$$NBA_{i,t} = (NBB_{i,t})(LGAR_i)$$

$$EBA_{i,t} = (R_t)(NBA_{i,t})$$

Where

$NBA_{i,t}$ = Number of new housing units, or million square feet of commercial space, of type t (residential or commercial) built to code in year i

$NBB_{i,t}$ = Total number of new housing units, or million square feet of commercial space, of type t (residential or commercial) built in year i

$LGAR_i$ = Fraction of MD localities adopting new code in year i

$EBA_{i,t}$ = Number of existing housing units, or million square feet of commercial space, of type t (residential or commercial) undergoing major renovations according to code in year i

R_t = Ratio of renovated to new buildings, of type t (residential or commercial)

$$ES_{i,t} = [(ESG_{i,t})(NBA_{i,t}) + (RESEN)(ESG_{i,t})(EBA_{i,t})](AEU_t)$$

Where

$ES_{i,t}$ = Energy saved by new and renovated buildings of type t (residential or commercial) built to code in year i (mmBtus)

$ESG_{i,t}$ = Energy saved via adoption of new code by buildings of type t (residential or commercial) in year i (fraction)

RESEN = Energy saved through renovation of existing buildings, as a fraction of energy saved by new buildings

AEU_t = Average current energy use of buildings of type t (residential or commercial) (mmBtus/square foot or unit/year)

The specific algorithms used to complete Step 3 were as follows:

$$E_i = (ES_{i,r})(1+TD)(RE_i) + (ES_{i,c})(1+TD)(CE_i) \quad (4)$$

$$FS_{i,t} = (ES_{i,r})(RFF_{i,t}) + (ES_{i,c})(CFF_{i,t}) \quad (5)$$

Where

E_i = Total electricity saved by buildings built/renovated to code in year i (mmBtus)

$FS_{i,t}$ = Total direct fuel saved by buildings built/renovated to code in year i (mmBtus), by fuel type t (e.g., natural gas, distillate oil, etc.)

$ES_{i,r}$ = Energy saved by new and renovated residential buildings built/renovated to code in year i (from Equation 3, in mmBtus)

$ES_{i,c}$ = Energy saved by new and renovated commercial buildings built/renovated to code in year i (from Equation 3, in mmBtus)

TD = Electricity losses due to transmission and distribution (fraction)

$RFF_{i,t}$ = Fraction of total energy savings by residential buildings of fuel type t (natural gas, distillate oil, etc.), in year i

$CFF_{i,t}$ = Fraction of total energy savings by commercial buildings of fuel type t (natural gas, distillate oil, etc.), in year i

RE_i = Fraction of total energy savings by residential buildings in the form of electricity

CE_i = Fraction of total energy savings by commercial buildings in the form of electricity

The specific algorithm used to complete Step 4 was as follows:

$$ER_i = (EEFIS_i) [\sum_{y=2009 \text{ to } i} (E_y)(FIS_y)] + (EEFOS_i) [\sum_{y=2009 \text{ to } i} (E_y)(1-FIS_y)] +$$

$$\sum_{2009 \text{ to } i,\, t} (FS_{y,t})(FEF_t)$$

Where

ER_i = Total emission reductions from buildings built/renovated to code in year i (metric tons CO_2e)

FEF_t = Emission factor for fuel type t (metric tons/mmBtu)

FIS_y = Fraction of total electricity from in-state generators in year y (where y is a year between 2009 and i)

$EEFIS_i$ = Electricity emissions factor for in-state generators in year i (metric tons CO_2e/mmBtu)

$EEFOS_i$ = Electricity emissions factor for out-of-state generators in year i (metric tons CO_2e/mmBtu)

RCI-4. Government Lead-By-Example

$KWH\$ = KWH_{15} / Cost_{15}$

And

$mmBTU\$ = mmBTU_{15} / Cost_{15}$

Where

$KWH\$$= average kilowatt hours saved per program dollar cost, for all fifteen EPC projects for which data was provided (KWh/$)

$mmBTU\$$ = average mmBTU saved per program dollar cost, for all fifteen EPC projects for which data was provided (mmBTU/$)

$Cost_{15}$ = total approximate cost of all fifteen EPC projects for which data was provided ($)

KWH_{15} = total electricity saved for all fifteen EPC projects for which data was provided (KWh)

$mmBTU_{15}$ = total thermal energy saved for all fifteen EPC projects for which data was provided (mmBTU)

$KWH_y = [KWH_{15} + (KWH\$ \text{ x } \sum_i NEW\$_{i,y})] \text{ x } (1+TL)$

And

$mmBTU_y = mmBTU_{15} + (mmBTU\$ \text{ x } \sum_i NEW\$_{i,y})$

Where

KWH_y = total electricity saved for all EPC projects in year *y* (KWh)

$mmBTU_y$ = total thermal energy saved for all EPC projects in year *y* (mmBTU)

$NEW\$_i$ = forecast cost of each new project ($s)

TL = transmission losses (8%)

$ERNG_y = mmBTU \text{ x } (53.08/1000)$

Where

$ERNG_y$ = total annual emissions reductions from natural gas savings per year *y* (tCO_2e)

53.08 = emissions factor for natural gas ($kgCO_2e/mmBTU$)

1000 = conversion factor from kilograms to metric tons

$ERIE_y$ = (KWH/1000) x $EFIE_y$ x 0.71

Where

$ERIE_y$ = total annual emissions reductions from in-state produced electricity per year *y* (tCO_2e)

$EFIE_y$ = emissions factor for in-state electricity production in year *y* (tCO_2e/MWh)

1000 = conversion factor from kilowatts to megawatts

0.71 = proportion of electricity produced in-state

$EROE_y$ = (KWH/1000) x $EFOE_y$ x (1 – 0.71)

Where

$EROE_y$ = total annual emissions reductions from out-of-state produced electricity per year *y* (tCO_2e)

$EFOE_y$ = emissions factor for out-of-state electricity production in year *y* (t CO_2e/ MWh)

MD_y = [MD_{2009} x (MAC_y / MAC_{2009})] x (1 + TL)

Where

MD_y = projected electricity consumption, including losses for the State of Maryland's government in year *y* (KWh)

MD_{2009} = reported electricity consumption for the State of Maryland's government in 2009 (KWh)

MAC_y = EIA projection of mid-Atlantic electricity consumption for the commercial sector in year *y* (quadrillion BTU)

MAC_{2009} = EIA reported mid-Atlantic electricity consumption for the commercial sector in 2009 (quadrillion BTU)

TL = transmission losses (8%)

SE_y = SS_{2011} + [(SS_{2020} – SS_{2011}) / 9] (y – 2011)

Where

SE_y = percent of total State electricity from solar sources in year *y* (%)

SS_y = solar electricity standard in year *y*

9 = yearly increments between 2011 and 2020

y = year being modeled

And

$NSE_y = NSS_{2011} + [(NSS_{2020} – NSE_{2011}) / 9] (y – 2011) – BNS$

Where

NSE_y = percent of total State electricity from non-solar Tier 1 sources in year *y*

NSS_y = non-solar Tier 1 standard in year *y*

9 = yearly increments between 2011 and 2020

BNS = baseline non-solar Tier 1 renewable electricity produced in 2008

$$AMER_i = \sum_{m=1}^{12} \sum_{j=1}^{4} PR_j * MEF_{m,j} * MER_m$$

Where

$AMER_i$ = Adjusted Marginal GHG Emissions Rate for Year i (million metric tons CO_2e per MWh)

m = month

j = Resource

PRj = Percentage of Resource j (wind, biomass, landfill gas, or hydro; solar is calculated separately)

MEF_{mj} = Monthly Energy Factor for month m for resource j (% of annual energy produced in month m)

MER_m = Marginal GHG Emissions Rate for month m (million metric tons CO_2e per MWh)

$ERSE_y = SE_y \times MDy \times AMER_{y,s}$

And

$ERNS_y = (NSE_y \times MDy \times AMER_{y,ns}) – \sum_i(NSE_{y,i} \times EF_i)$

Where

ERSE = total annual emissions reductions in year *y* from the use of solar electricity (tCO_2e)

$AMER_{y,s}$ = annual marginal emissions factor for avoided emissions from use of solar electricity in year *y* (tCO_2e/MWh)

ERNE = total annual emissions reductions in year *y* from the use of non-solar Tier 1 electricity (tCO_2e)

$AMER_{y,ns}$ = annual marginal emissions factor for avoided emissions from use of non-solar Tier 1 electricity in year *y* (tCO_2e/MWh)

$NSE_{y,i}$ = percent of non-solar Tier 1 electricity from renewable source *i* in year *y* (%)

EF_i = emissions factor for renewable source *i*

RCI-10. EmPOWER Maryland

$ES_{i,s} = (P_i)(EC_{2007}/P_{2007})(SG_i)(SF_s)$

Where

$ES_{i,s}$ = Total reduction in electricity consumption (in MWh) in year i, for sector s (where s is residential, commercial, or industrial)

EC_{2007} = Total MD electricity consumption in 2007, including losses (in MWh)

P_{2007} = MD population in 2007 (in MWh)

P_i = MD projected population in year i

SG_i = RCI-10 electricity saving’s goal for year i (fraction)

SF_s = Fraction of total saving’s goal to be met by each sector s (where s is residential, commercial, or industrial)

$ERIS_{i,s} = (ES_{i,s})(FIS_i)(EEFIS_i)$

$EROS_{i,s} = (ES_{i,s})(1\text{-}FIS_i)(EEFOS_i)$

Where

$ERIS_{i,s}$ = In-State emission reductions in year i (in metric tons CO_2e) for sector s (where s is residential, commercial, or industrial)

$EROS_{i,s}$ = Emission reductions from imported electricity in year i (in metric tons CO_2e) for sector s (where s is residential, commercial, or industrial)

FIS_i = Fraction of total electricity from in-state generators in year i

$EEFIS_i$ = Electricity emissions factor for in-state generators in year i (metric tons CO_2e/MWh)

$EEFOS_i$ = Electricity emissions factor for out-of-state generators in year i (metric tons CO_2e/MWh)

Chapter 2: Energy Supply (ES) Policies

ES-3. GHG Cap and Trade

$$TER_i = PE_i - RC_i$$

Where

TER_i = Total GHG emission reductions in year i for ES-3 (million metric tons CO_2e)

PE_i = Projected Emissions without RGGI for year i, (million metric tons CO_2e)

RC_i = RGGI Cap for year i, (million metric tons CO_2e)

ES-7. Renewable Portfolio Standard

$CGR_i = CG_i * PR_i$

Where

CGR_i = Coal Generation Replaced for year i (GWh)

CG_i = Coal Generation for year i (GWh)

PR_i = Percentage of coal generation Replaced for year i (%)

$CER_i = CGR_i * CER_i$

Where

CER_i = Coal Emissions Reduction for year i ($MMTCO_2e$)

CGR_i = Coal Generation Replaced for year i (GWh)

CER_i = Coal Emissions Rate ($MMTCO_2e$ per GWh)

$NGE_i = CGR_i * NGER_i$

Where

NGE_i = Natural Gas Emissions for year i ($MMTCO_2e$)

CGR_i = Coal Generation Replaced for year i (GWh)

$NGER_i$ = Natural Gas Emissions Rate ($MMTCO_2e$ per GWh)

Coal Plant Repowering Option: $NER_i = CER_i - NGE_i$
or

Biomass Cofiring Option: $NER_i = CER_i$

Where

NER_i = Net Emissions Reduction for year i ($MMTCO_2e$)

CER_i = Coal Emissions Reduction for year i ($MMTCO_2e$)

NGE_i = Natural Gas Emissions for year i ($MMTCO_2e$)

ES-8. Efficiency Improvements & Repowering Existing Plants

$CGR_i = CG_i * PR_i$

Where

CGR_i = Coal Generation Replaced for year i (GWh)

CG_i = Coal Generation for year i (GWh)

PR_i = Percentage of coal generation Replaced for year i (%)

$CER_i = CGR_i * CER_i$

Where

CER_i = Coal Emissions Reduction for year i ($MMTCO_2e$)

CGR_i = Coal Generation Replaced for year i (GWh)

CER_i = Coal Emissions Rate ($MMTCO_2e$ per GWh)

$NGE_i = CGR_i * NGER_i$

Where

NGE_i = Natural Gas Emissions for year i ($MMTCO_2e$)

CGR_i = Coal Generation Replaced for year i (GWh)

$NGER_i$ = Natural Gas Emissions Rate ($MMTCO_2e$ per GWh)

Coal Plant Repowering Option: $NER_i = CER_i - NGE_i$
or

Biomass Cofiring Option: $NER_i = CER_i$

Where

NER_i = Net Emissions Reduction for year i ($MMTCO_2e$)

CER_i = Coal Emissions Reduction for year i ($MMTCO_2e$)

NGE_i = Natural Gas Emissions for year i ($MMTCO_2e$)

Chapter 3: Agriculture, Forestry, and Waste (AFW) Policies

Please refer to the policy discussions for the AFW policies. The nature of the methodologies is generally such that it is important to view the equations in context with the accompanying tabular data and detailed methodological descriptions. The equations below only partially capture the quantification process.

AFW-1. Forest Management for Enhanced Carbon Sequestration

Average Annual Sequestration = 1/90 (Sequestration at year 90 - Sequestration at Year 0)

Difference = Average Annual Sequestration in Intensive Stands - Average Annual Sequestration in "Average" Stands (Expressed as a percentage difference = 5%)

Enhanced Average Annual Sequestration per Forest Type = Carbon Storage of Forest Type * Percentage Increase (e.g., 0.8 * 1.05 for oak-hickory)

Weighted Annual Sequestration per Forest Type = Fraction of Forest Type * Enhanced Average Annual Sequestration per Forest Type (e.g., 0.63 * 0.8 * 1.05 for oak-hickory)

Average Annual Sequestration Across Forest Types = Sum of Annual Sequestration per Forest Type (for oak-hickory, oak-pine, and loblolly-shortleaf pine)

Overall Average Annual Sequestration = 0.63 * 0.8 * 1.05 + 0.1 * .604 * 1.05 + 0.11 * 0.662 * 1.05 = 0.669 tons C/acre/year.

AFW-2. Managing Urban Trees & Forests

Please see the discussion of this policy. Methodology is too complex and reliant on accompanying tabular data to be represented as simple equations here.

AFW-3. Afforestation, Reforestation & Restoration of Forests & Wetlands

Average Annual Sequestration = 1/45 (Sequestration at year 45 - Sequestration at Year 0)

Weighted Annual Sequestration per Forest Type = Fraction of Forest Type * Average Annual Sequestration per Forest Type (e.g., for oak-hickory = 0.7 * 1.2 = 0.84 tons/acre/year)

Average Annual Sequestration Across Forest Types = Sum of Weighted Annual Sequestration per Forest Type = 0.7 * 1.2 + 0.15 * 1 + 0.15 * 0.9 = 1.155 tons/acre/year

Total Annual Sequestration (in a given year) = Average Annual Sequestration * CO2/C mass ratio * Annual Acreage * 1 * 10^-6 MMt/Mt (e.g., for 2008 = 1.155 * 44/12 * 6,300 * 10^-6 = 0.027 MMTCO2e)

Total Policy Acreage = 900 miles * 50 feet * 1.894*10^-4 miles/foot * 640 acres/square mile * 0.4 = 2,182 acres.

Annual Acreage = 2,182 acres / 13 years = 168 acres / year

AFW-4. Protection & Conservation of Agricultural Land, Coastal Wetlands & Forested Land

Protecting Agricultural Lands

Loss of Soil Carbon Per Acre (as CO_2) = Soil Carbon Content * Fraction of Land Cleared * Fraction of Carbon Lost * CO_2/C mass ratio

Loss of Soil Carbon Per Acre (as CO_2) = 1.7*10^-5 MMTC * 0.5 * 0.75 * 44/12 = 2.3375 * 10^-5 $MMTCO_2$/acre.

Avoided Emissions = Annual Target for Avoided Land Conversion * Loss of Soil Carbon per acre

(For example for the first year, 909 acres of agricultural land not lost to development = 909 acres * 2.3375*10^-5 $MMTCO_2$/acre = 0.021 $MMTCO_2$)

Avoided Deforestation

Non-soil forest carbon = Total Forest Carbon – Soil Carbon

Non-soil forest carbon = 73.9 - 25.5 = 48.4 metric tons carbon per acre

Carbon lost from Forest to Development Conversion = Fraction of Land Cleared * Fraction of Carbon Lost * Non-soil Forest Carbon

Carbon lost from Forest to Development Conversion = 0.67 * 1 * 48.4 = 32.43 tons carbon per acre.

CO_2 lost from Forest to Development Conversion = Carbon lost from Forest to Development Conversion * CO_2/C mass ratio = 27.9 metric tons C * 44/12 metric ton CO_2/metric ton C = 102.3 metric tons CO_2 per acre.

Avoided Emissions = Acreage * CO_2 "Lost" from Forest to Development Conversion (e.g., for 2008 = 19,200 acres * 102.3 metric tons CO_2 per acre = 1,964,160 tons CO_2 or 1.96 $MMTCO_2$)

Sequestration in Protected Forests

Average Annual Sequestration = 1/50 (Sequestration at year 75 - Sequestration at Year 25)

Weighted Annual Sequestration per Forest Type = Fraction of Forest Type * Average Annual Sequestration per Forest Type (e.g., for oak-hickory = 0.75 * 0.8 = 0.6 tons/acre/year)

Average Annual Sequestration Across Forest Types = Sum of Weighted Annual Sequestration per Forest Type = 0.75 * 0.8 + 0.15 * 0.7 + 0.15 * 0.5) = 0.78 metric tons C/acre/year. In CO_2 terms = 0.78 * 44/12 = 2.86 tons CO_2 / acre / year

Annual Sequestration = Acreage * Average Annual Sequestration Across Forest Types (e.g., for 2008 = 19,200 * 2.86 * 1* 10^-6 $MMTCO_2$= 0.055 $MMTCO_2$)

AFW-5. "Buy Local" Programs

Please see detailed policy discussion.

AFW-6. Expanded Use of Forest & Farm Feedstocks & By-Products for Energy Production

Please see detailed policy discussion.

AFW-7b. In-State Liquid Biodiesel Production

Emission reduction benefit formula: soybean lifecycle EF – (miles*fossil diesel EF)/ gallons of bio-diesel per short ton of soybeans*ton-miles per gallon of diesel = emission reduction benefit, or, 7,207 tCO_2e per million gallon = 7,261$mtCO_2e$ per million gallon – (100*(.01006 $mtCO_2e$)*10^6)/44.632 gal per ton*423 ton-miles

AFW-8. Nutrient Trading with Carbon Benefits

Please see detailed policy discussion.

AFW-9. Waste Management & Advanced Recycling

Please see detailed policy discussion.

Chapter 4: Transportation and Land Use (TLU) Policies

TLU-2. Land Use & Location Efficiency

$TER_i = MS_i * TD_{ji} * VMT * RR * BP_i$

Where

TER_i = Total GHG emission reduction with compact development in year i for Policy TLU-2 (million metric tons CO_2e)

MS_i = Market Share of Compact Development in year i (percent)

TD = Percent of total development built between years j and i (percent)

VMT = % VMT reduction per capita achievable by compact development relative to sprawl (percent)

RR = Ratio CO_2/VMT reduction with compact development

BP_i = Baseline projection of transportation CO_2 in year i (million metric tons CO_2e)

i = 2020

j = estimate base year of 2010[187]

$TBER_i = MS_j * TD_{ji} * BECR * RCI$

Where

$TBER_i$ = Total building energy emissions reductions in year i

BECR = building energy consumption reduction (%)

RCI = Baseline estimate from Residential/Commercial/Industrial (RCI) fuel use in the CAP

187 Different from CAP base year of 2006.

TLU-3. Transit

$TER_i = TER_{2020} * RUF_i$

Where

TER_i = Total GHG emission reductions in year i for Policy TLU-3 ($MMTCO_2e$)

TER_{2020} = Total GHG emission reductions in year 2020 for Policy TLU-3 ($MMTCO_2e$)

RUF_i = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved in year i

RUF_{2012} = 10%

RUF_{2015} = 25%

TLU-5. Intercity Travel

$TER_i = TER_{2020} * RUF_i$

Where

TER_i = Total GHG emission reductions in year i for Policy TLU-5 (million metric tons CO_2e)

TER_{2020} = Total GHG emission reductions in year 2020 for Policy TLU-5 (million metric tons CO_2e)

RUF_i = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved in year i

$RUF_{2012} = 0\%$

$RUF_{2015} = 15\%$

TLU-6. Pay-As-You-Drive Insurance

$TER_i = VMT_i * PR_i * EF * EF$

Where

TER_i = Total GHG emission reduction from TLU-6 in year i (million metric tons CO_2e)

VMT = Relevant VMT (million)

PR_i = Participation Rate in year i

ER = Effectiveness Rate

EF = Composite CO_2e emission factor

i = given year

TLU-8. Bike & Pedestrian Infrastructure

$TER_i = TER_{2020} * RUF_i$

Where

TER_i = Total GHG emission reductions in year i for Policy TLU-8 (million metric tons CO_2e)

TER_{2020} = Total GHG emission reductions in year 2020 for Policy TLU-8 (million metric tons CO_2e)

RUF_i = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved in year i

RUF_{2012} = 10%

RUF_{2015} = 25%

TLU-9. Incentives, Pricing & Resource Measures

$$TER_{ij} = TER_{2020} * RUF_{ij}$$

Where

TER_{ij} = Total GHG emission reductions in year i for component j of Policy TLU-9 (million metric tons CO_2e)

TER_{2020} = Total GHG emission reductions in year 2020 for each component of Policy TLU-9, which is assumed to be the average of the estimated range (million metric tons CO_2e)

RUF_{ij} = Ramp-Up Factor for year i, which reflects how much of the annual GHG reduction in 2020 can be expected to be achieved by component j in year i

$RUF_{2012,\ VMT\ fees} = 0\%$

$RUF_{2015,\ VMT\ fees} = 0\%$

$RUF_{2012,\ congestion\ pricing} = 0\%$

$RUF_{2015,\ congestion\ pricing} = 0\%$

$RUF_{2012,\ employer\ commute\ incentives} = 10\%$

$RUF_{2015,\ employer\ commute\ incentives} = 25\%$

TLU-10. Transportation Technologies

Please see detailed policy discussion.