ABSTRACT

Title of Document: CLIMATE ACTION PLANS – FACT OR FICTION? EVIDENCE FROM MARYLAND

Timothy F. Welch, Doctor of Philosophy, 2013

Directed By: Dr. Frederick W. Ducca
Urban and Regional Planning and Design

On a sweltering summer day in 1988, NASA scientist James Hansen sounded the alarm, in a congressional hearing, that human activity was changing our climate and without action, the world would face grave danger. Since that time, the United States government has ignored international climate policy efforts and failed multiple times to enact federal guidelines to address this serious problem. In the last decade, state governments have begun to formulate their own climate policy in an effort called Climate Action Planning. Climate action plans seek aggressive reductions and form the backbone of most statewide environmental policies but they often suffer from a lack of scientific analysis, unrealistic expectations, little funding, non-existent implementation strategies, and have no enforcement mechanisms. While plans have proliferated across the nation, little has been done to examine closely the ability of the policies to achieve climate change mitigation goals through enumerated strategies.

This thesis fills part of the research void by examining all of the built environment emissions reduction strategies specified in the Maryland CAP. The analysis proceeds by developing multiple models calibrated with local empirical data. The results of this analysis show that Maryland, even with a successful implementation of its CAP will not meet its carbon mitigation targets.

Further analysis reveals that a full state, national, and global implementation of similar carbon reduction targets would not alter the trajectory of climate change. To address climate change adequately, Maryland should take a three-prong approach. First, strengthen the mitigation strategies that show the greatest potential to reduce CO_2 while abandoning strategies that do not. Second, extend the current set of strategies to include the low hanging and quickly implementable mitigation 'fruit'. Third, in the face of serious and inevitable climate change, begin to adapt the built environment for better resiliency to more extreme conditions. The thesis concludes with a call to action for urban planners to address ambiguities that relate to the climate change and the build environment. The timing is "ripe" for planners to take the lead in what will certainly become the next great wave of planning.

CLIMATE ACTION PLANS – FACT OR FICTION? EVIDENCE FROM MARYLAND

by

Timothy F. Welch

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2013

Advisory Committee:
Dr. Frederick W. Ducca, Chair
Professor Gerrit-Jan Knaap
Professor Hiroyuki Iseki
Professor Lei Zhang
Professor Robert Nelson

Acknowledgements

I would like to acknowledge the substantial research support provided by the National Center for Smart Growth Research and Education. Many individuals, too numerous to individually list, contributed insights, thoughts and recommendations on portions of this work. I owe a sincere debt of gratitude to each one of them.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

We have, as members of an ever growing but continually better-connected global society, an imperative to preserve for future generations the finite resources, limited carrying capacity, and current climate conditions of the Earth. The imperative is not only a hallmark of a rational and conscious society, but a necessary condition of our position as temporary stewards of the planet. As a country, the notion of preserving for the future is encapsulated in the preamble of our Constitution, where it states:

"We the people of the United States, in order to form a more perfect union, establish Justice, insure domestic Tranquility, provide for the common defense, promote the general Welfare, and secure the Blessings of Liberty to ourselves and our Posterity, do ordain and establish this Constitution for the United States of America."

Posterity is a term meaning 'all future generations'. The nation's guiding document so directs us to preserve not only for the current generation but all future generations, each of the elements defined therein.

As a nation, we are failing in this duty. The massive quantities of greenhouse gas (GHG) emissions and the processes used to obtain the fuels that lead to these emissions have undoubtedly jeopardized the general welfare of future generations. As the following chapters will contend, in order to ensure the future stability of our climate, and thereby secure "domestic Tranquility, provide for the common defense, promote the general Welfare, and secure the Blessings of Liberty" we have an obligation to formulate policy that takes actions to reduce emissions that threaten our existence.

In 1988, the scientific community began to coalesce around the idea that human activity will substantially alter our climate. Since that time, the international community has worked towards developing global policies that will limit atmospheric GHG accumulation. Despite an early interest, the United States (US) has neglected to ratify an international treaty, instead deferring to domestic legislation. At the same time, the US congress has failed to pass a single federal climate change policy; leaving an unusual and significant policy gap to be formulated and implemented at a sub-national level.

This dissertation is on the efficacy of state climate change policy, both in its ability to achieve goals through enumerated strategies and in terms of the meaningfulness of such goals (as in, how closely do the policy objectives follow the known scientifically specified emission limits). An emerging trend across the US is a drive towards policies that encourage "sustainable" transportation, building, and energy sectors. Such policies invariably specify a plethora of policies familiar to most planners. While these policies, typically called "climate action plans" (CAPs) seek aggressive emission reductions and form the backbone of most statewide environmental policies, they often suffer from a lack of scientific analysis, unrealistic expectations, little funding, non-existent implementation strategies, and have no enforcement mechanisms. Many of the CAPs, in their optimistic estimations, fail to account for rebound effects including latent and induced travel demand (that tend to moderate externality reductions), limitations on technology adoption, and conflation of observed trends and self-selection bias. Plans have also been discounted for making unrealistic assumptions about travel behavior in response to transportation policies, reduction from urban density, and the ability (and demand) of alternative energy sources to supplant GHG producing fossil fuels. Moreover, while these action plans are developed at the statewide level, reduction strategies are generally left to regional, county, and local governments to implement or attempt to regulate where demand is created beyond the state regulatory jurisdiction. Such isolated policy implementation may lead to emission reductions in a single jurisdiction while simultaneously increasing emissions in other locations.

Though CAPs have become wildly popular across the US, with 39 states having completed implementation or in the process of implementing plans that are virtually identical, there has been little research on the quality, realism, or likelihood of such plans to achieve their stated goals. Further, thorough explanations have not been proffered on the meaning of emission targets established by the CAPs and little research exists relating the targets to a scientific need. That is, CAPs appear to have targets that are politically determined but not related to the current scientific evidence on needed GHG reductions.

This thesis seeks to fill part of the research gap by examining all of the built environment emission reduction strategies specified in the Maryland Climate Action Plan. The analysis will proceed by developing analytical and behavioral models at the micro, meso, and macro scale calibrated and validated with local empirical data. In doing this, all of the emission reduction strategies in the transportation, built environment (residential and commercial) and power generation sectors will be subjected to more strenuous testing than previously performed in the literature. These models consist of a nested mixed-method model based on the US Energy Information Administration's (EIA) residential energy consumption survey (RECS) to determine the likelihood that a household will produce CO2, the amount of CO2, and (electric) energy that is consumed. The EIA's commercial building energy consumption survey (CBECS) is also regressed based on building and locational characteristics; then applied to Maryland property and micro-scale employment data to derive the inventories of building level emissions and consumption. These results are then aggregated to the zonal level to measure how changes in land use and spatial patterns, specified in the Maryland CAP, affect emissions, and energy consumption. Data on power generation sources in the state of Maryland and power purchased from other states through the PJM interconnect is used to measure total power generation emissions and the amount that such emissions can be replaced by power from alternative sources and the resulting emissions from such substitutions. Finally, a calibrated and validated statewide joint travel demand and emissions model for Maryland is used to develop a mobile emissions inventory to test transportation related CAP emissions reduction strategies.

All of these models are developed and multiple strategies are tested to answer two central research questions. First, will state emission reduction strategies achieve GHG reduction policy goals? Second, how well do the policies conform to the new scientific evidence on GHG reduction needs? Answering these questions will shed light on a rapidly emerging, critically important, yet little studied area of planning and policy.

The remainder of this thesis is organized as follows. Chapter two presents a literature review of climate change policy followed by a discussion of the more technical climate change literature in chapter three. In chapter four, the methods for evaluating each of Maryland's emissions reduction policies are presented followed by a discussion of the specifics of each policy in chapter five. Chapter six presents the results of the emission reduction strategy testing. In chapter seven, a set of policy recommendations is offered followed by recommendations for where future climate action policy should move in chapter eight. The final discussion and conclusions are presented in chapter nine.

Chapter 2: Policy Background

The scientific consensus on climate change has generally been settled (DiMento & Doughman, 2007). In a 2011 poll of the scientific community, 97 percent of scientists were found to believe climate change is underway ("Climate Change: Public Skeptical, Scientists Sure : NPR", 2013). Specifically for researchers actively publishing in the field of climate science, 97 to 98 percent believe in anthropogenic (man-made) climate change (Anderegg et al., 2010). These polls show an unprecedented level of agreement despite a still low belief in anthropogenic climate change among the general population. A poll of 1,010 American adults in 2011 found that just 64 percent believe in global warming and of that group less than half (47 percent) believe it is mostly caused by human activity (Leiserowitz et al., 2011).

Public beliefs about climate change are influenced by media coverage, world events, and guidance from political leaders. However, there is a degree of circularity in these beliefs in that political motivation to formulate climate policy comes in part from the general public's viewpoint on climate change and desire to see regulation. Part of the divergence between politicians, the public, and scientists stems from sources of information, but another part may come from a lack of agreement on a formal definition of climate change. Such disagreement distracts from the issue of mitigating and adapting to climate change thereby leading to inaction.

Climate Change Policy

The year 1988 was perhaps the time of greatest hope for meaningful policy related to climate change. In that year, scientist James Hansen testified before a congressional panel arguing publicly that there was a 90 percent certainty that we face anthropogenic climate change (Hansen, 1988). At that time, the International Panel on Climate Change, arguably the most influential climate group in the world got its start, the United Nations General Assembly (UNGA) resolved to protect the climate, a new president promised serious change towards environmental policy entered office, and the first ever climate change specific policy, the National Energy Policy Act, was introduced to congress. What followed that rousing year of new possibilities was a systematic abandonment of all these climate policies in the US. In the following section, a brief description of the many international, US, regional, and state climate polices are described to provide a better context of the current need for Maryland and other state wide CAPs.

Key International and US National Policies

The International Panel on Climate Change (IPCC), likely the best known climate organization, was established in 1988 by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) to compile the latest scientific knowledge of climate change (IPCC, 2010). The establishment of the organization and sanction of the IPCC's work was further mandated by the UNGA resolution to protect the climate for future generations.

The IPCC does not conduct its own scientific research but rather it assembles teams of experts in the field to review and report on the latest scientific and technical information. The first product of the IPCC was the 1990 First Assessment Report (FAR) that outlined the historical impact of CO2 on climate, the current state of emissions, and predations of multiple climate models of the impact on climate under a BAU scenario. The report also contained recommendations for target CO2 levels and emissions (IPCC, 1990). The report outlined the need for drastic action and lead to the first international action on climate change, the United Nations Framework Convention on Climate Change (UNFCCC).

The UNFCCC was created by the UNGA in 1992 to take coordinated international action on the IPCC findings. The framework convention had the objective to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a period sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. (Oppenheimer & Petsonk, 2005)

The framework itself did not set emissions targets and was simply a non-binding agreement that established the general convention for future binding treaties or amendments that would be called protocols. The first of these protocols was formed in Kyoto; in what is commonly called the Kyoto Protocol. The Protocol was created in 1997 with 37 industrialized nations and 15 states in the European Union agreeing to binding emission reductions in a four year period between 2008 and 2012 (O'Neill & Oppenheimer, 2002; Oberthür & Ott, 1999; Grubb et al., 1999). Though most nations negotiated their targets, the estimate of combined Kyoto member reductions was about 4.7 percent below 1990 levels (EIA, 2010). The protocol had mixed success with many members missing their targets. One significant member that missed its target was Canada that was estimated to have emissions nearly 24 percent greater than the target thus leading to the nation's withdrawal from Kyoto in 2012 ("Canada, the Surprise 'Pariah' of the Kyoto Protocol", 2012).

A new round of climate negotiations to set targets for 2013 and beyond took place in Doha in 2012. The results of the conference led to minor progress with the extension of existing Kyoto targets previously set to expire in 2012 ("UN Summit Strikes Climate Deal", 2012). The negotiations and treaty suffered a major blow with the refusal of Canada, Japan, New Zealand, and Russia to renew their treaty obligations.

Throughout the international climate change talks, the US has been noticeably absent from emissions reduction commitments. Instead of binding itself to international agreements, the US decided that it would attempt to establish its own similar climate policy but autonomous from Kyoto (Harris, 1999). Table 1 shows the past efforts to establish US climate change policy. In each case, the bill either died in committee or in congressional debate. As of early 2013, the US had not bound itself to any international treaties on climate change and had no national climate change policy.

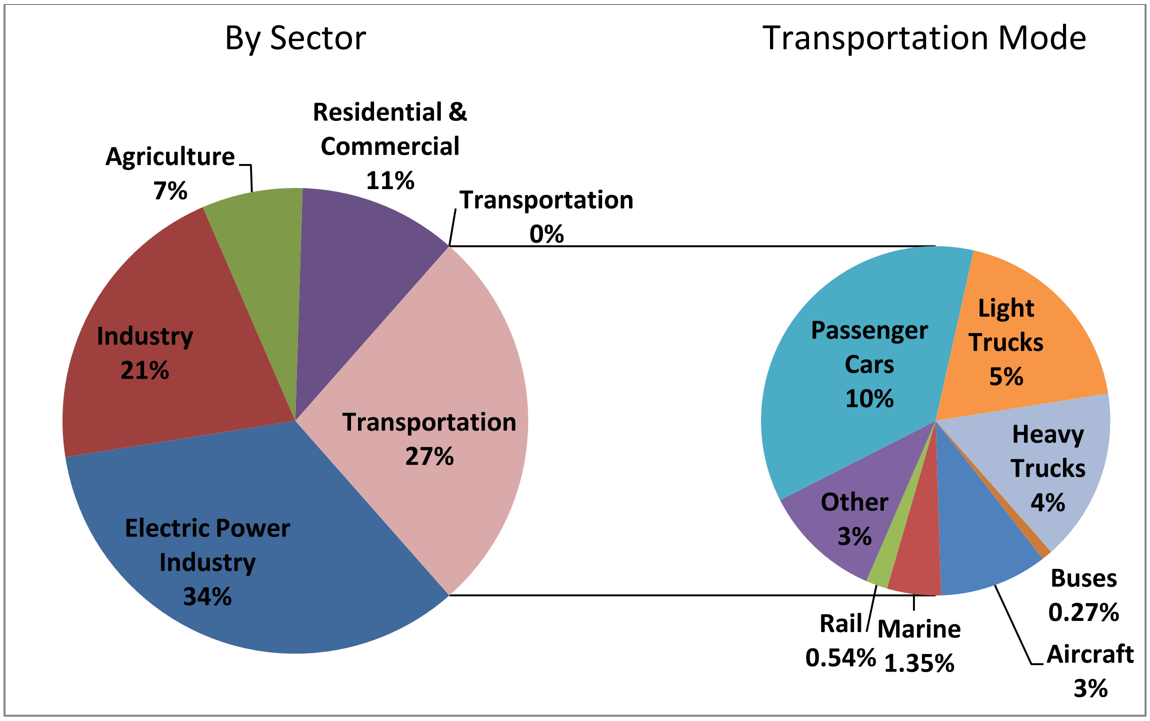
Table 1

US Climate Change Policy

ACT	TARGET
Climate Stewardship Act of 2007 (Olver-Gilchrest) H.R.620 & H.R. 4226 (Died – at Introduction and Committee, respectively)	70% below 1990 level in 2050
Global Warming Reduction Act of 2007 (Kerry-Snowe) S.485 (*Failed*)	62% below 1990 level in 2050
Climate Stewardship and Innovation Act (McCain-Lieberman) S.280 (*Failed* – 2003/5/7)	60% below 1990 level in 2050
Global Warming Pollution Reduction Act (Sanders-Boxer) S. 309 (*Proposed - 2007*)	80% below 1990 level in 2050
Lieberman-Warner Climate Security Act of 2008, S.3036 (Died in Senate)	71% below 2005 level in 2050
American Clean Energy and Security Act of 2009 (Waxman) H.R. 2454 (Died in Senate)	83% below 2005 level in 2050
Executive Branch – EPA can regulate CO_2 as a pollutant Pledge to the United Nations	17% below 2005 level in 2020
Energy Tax Prevention Act of 2011 (Upton) H.R.910 (Passed House – April 07, 2011)	Bars EPA from taking any GHG related action

Though the US congress has failed to pass any broad national climate change policy, there have been advances in specific sectors. One of the greatest contributors to GHG emissions comes from the transportation sector.

Figure ***1*** shows the percent of CO2 that results from transportation emissions and the major contributors of those emissions in the sector.



Source: EPA (2010)

Figure 1. US Emissions by sector.

Federal regulations aimed at curbing vehicle emissions were essentially non-existent until 1970 with the passage of the Clean Air Act (CAA, 1970). This act gave a federal agency, the Environmental Protection Agency (EPA), authority to regulate motor vehicle emissions for the first time in history (Bolbach, 1974). The 1970 CAA set an ambitious goal to reduce vehicle emissions by 90 percent from their pre-1968 levels in less than five years, which meant significant changes had to be made to vehicle technology before the 1974 introduction of the 1975 model year. The 1970 CAA set a policy precedent that persists to this day. The act called for a device to be attached to vehicles that would reduce its emissions and last for 50,000 miles but left the implementation and details to others. This regulation created two new markets for existing products, catalytic converters and unleaded gasoline. In addition to changes in technology, the gas crisis of 1973-4 led to reductions in vehicle travel. Limitations on the type of pollutant that fell under the 1970 CAA also made it easier to achieve emissions reductions. The law only required reductions in hydrocarbons (organic compounds) and carbon monoxide (CO). By adding oxygen to CO, the catalytic converters created in mass, another pollutant (by current EPA definition) CO_2, did little to reduce volatile organic compounds (VOC) or nitrous oxides (NOX), and created (though not substantially so) more sulfuric acid.

Fortunately for the auto industry, policy-makers, and drivers, the 1970 CAA was able to achieve reductions by relying on markets created for products first developed in the 1920s (such as the catalytic converter) and the convergence of world events to both change travel behavior and drive the market for more efficient vehicles. Even with these significant events, researchers found that emissions reductions were much more modest than the ambitious policy goals. Portney (Portney & Stavins, 2000) found that between 1970 and 1987, VOCs were reduced by 25 percent and CO by 39 percent (though most of the CO was converted to CO_2).

There is no doubt that the regulations of the 1970 CAA contributed to a reduction in emissions. Though much of the early reductions were achieved by technology, it was regulation that spurred their adoption and Kahn (1996) found that changes in regulatory stringency led to the greatest reductions in emissions. Yet federal policy has not kept pace with the need for drastic CO_2 reductions.

The shortcoming of a strong federal policy for emissions is not isolated to the transportation sector. The absence of international binding or national US climate change policy has resulted in an unusual policy vacuum where regions, states, and even municipalities have begun to formulate their own policies. Some of the major polices at this level are discussed below.

Regional Policy

In the absence of more stringent and enforceable federal regulations since 1970 and the amendments to the CAA in 1990, sub-national jurisdictions have been actively formulating policy from the bottom-up (Lutsey & Sperling, 2008). In this emerging policy environment, regions, states, and municipalities have begun to enact their own regulatory frameworks for emission reductions. At the regional level, several initiatives have been undertaken in this cross-border work (Figure 2).

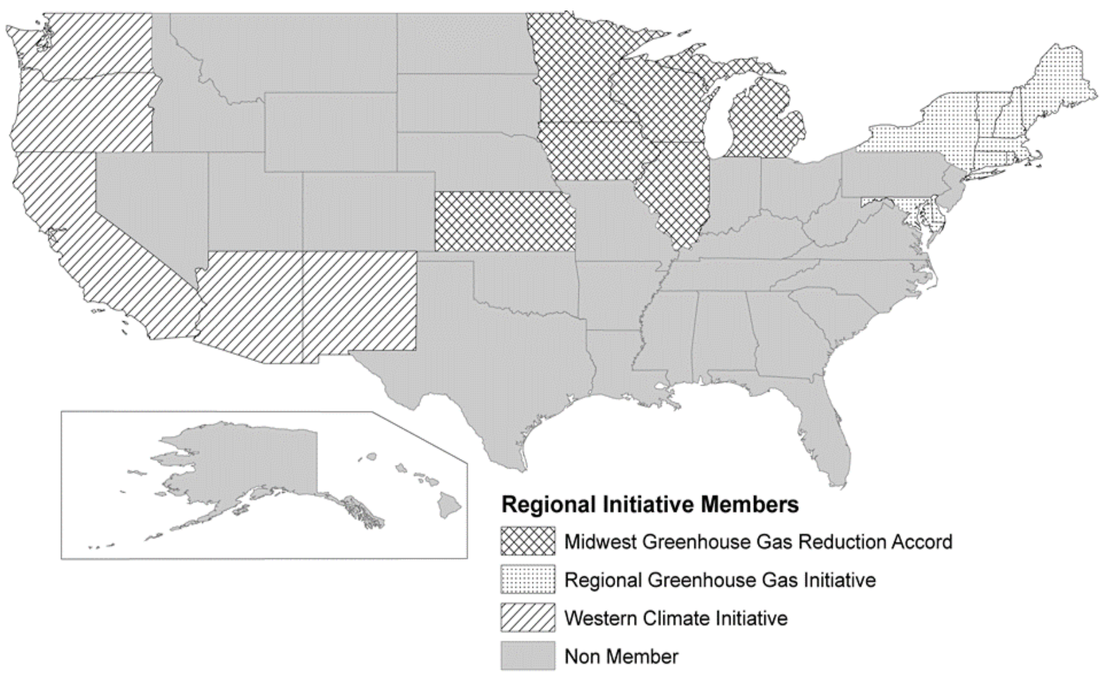


Figure 2. Regional climate plan participant states.

The largest and best-known regional climate action plan is the Regional Greenhouse Gas Initiative (RGGI, pronounced ‘Reggie”). RGGI was formed from a memorandum of understanding between the governors of seven New England states including Connecticut, Delaware, Maine, New Jersey, New York, New Hampshire, and Vermont ("Regional Greenhouse Gas Initiative (RGGI) CO2 Budget Trading Program - Memorandum of Understanding", 2013). In 2007, Rhode Island, Massachusetts, and Maryland joined RGGI and in 2011, Governor Chris Christie withdrew New Jersey from the initiative, citing the belief the RGGI would not be "effective in reducing greenhouse gases and is unlikely to be in the future" This move brought the final number of participating states to nine. These nine states agreed first to set an emission cap in two, three-year conformity periods then another period of yearly incremental conformity periods. The initial cap was set at 188 short tons for 2009-2011, then reduced to 165 short tons from 2012-2014 and finally a 2.5 percent reduction each year from 2015-2018. The total GHG reduction represents roughly a 20 percent reduction from the initial cap (RGGI, 2007).[1] All power plants that produce more than 25 megawatts of energy are subject to the RGGI cap and must purchase state created credits. The cap and trade system is administered through an auction with proceeds used by states to fund renewable energy and efficiency programs.

RGGI represents the first and best-known regional climate initiative, but since its founding, a number of other similar organizations have formed. For instance, the Midwest Greenhouse Gas Reduction Accord (MGGRA) is an agreement between six Midwestern states and the premier of Ontario formed in 2007. In 2010 the accord formed its final model rule that established a goal of reducing GHG by 20 percent below 2005 levels by the end of 2020 and 80 percent below 2005 levels by the end of 2050 (Drapalski, 2010). Another large regional initiative is the Western Climate Initiative

---

[1] As of January 2013 the RGGI had proposed new target reductions. See Chapter 5 for discussion.

(WCI) that consists of seven western states and the provinces of British Columbia, Manitoba, Ontario, and Quebec. In 2010, the initiative released it final program design document establishing a GHG reduction goal of 15 percent below 2005 levels by 2020 (“Design for the WCI Regional Program”, 2013).

As the need for climate change policy grows, more regional initiatives may start to take root. While such organizations form, many states have begun to form their own climate policy. In the following section, some of the state efforts are summarized with particular focus on climate policy leader California and action taken in the state of Maryland, the subject of analysis in this thesis.

State Policy

Like the regional initiatives, states have taken up the policy space left by the lack of federal policy. Unlike regional plans, states have considerably more authority over sectors that produce the most GHG including power generation and transportation (Rabe, 2004; PCGCC, 2011) to develop these CAP policy schemes.

California was the first state to regulate GHG in the context of climate action planning by passing Assembly Bill 32 (AB32), also known as Global Warming Solutions Act of 2006. The act set into law the specific statewide GHG reduction targets of achieving 1990 levels by 2020 (California Global Warming Solutions Act, 2006). AB32 gave the California Air Resources Board (CARB) the authority to regulate any source of emissions including power plants and vehicles (Hanemann, 2007).

In supporting legislation, Senate Bill 375 (SB375) directs the CARB to develop regional emissions targets in support of the statewide goal, which will then be left to municipalities, counties, and MPOs to achieve. The primary method of achieving local reductions is through the transportation and land use planning process.

Following California's lead, a number of other states began to formulate and enact climate action plans. Similar to the California bills, Washington State adopted RCW70.235.020, in 2008, which set state GHG targets. To supplement the bill, RCW 47.01.440 was enacted in the same year requiring per capita vehicle miles traveled (VMT) reductions of 18 percent by 2020, 30 percent by 2035, and 50 percent by the year 2050 (Howard, 2010). Policy plans are not limited to the US. Australia, and Europe, for example, are making significant efforts to shift automobile to non-automobile transportation modes that would imply a significant change in urban land-use patterns to much higher-density living and toward greater use of mass transit thereby reducing VMT (Moore, Staley, & Poole Jr., 2010). These regulations are examples of a growing number of laws that seek to mitigate congestion and climate change, encourage transit usage, and increase public health all through the mechanism of VMT and emissions reductions.

As of 2012, 38 of 50 US states have either completed or are in the process of completing CAPs (US EPA, 2012; Figure 3). These plans consist of policies designed to reduce emissions inventories substantially. Most of the plans rely on a specific set of policies that will result in the bulk of emissions reductions. These policies are based on building efficiency, reduced vehicle use and efficiency, less carbon intensive power generation, and forestry and agricultural changes (Pollak, Meyer, & Wilson, 2011; PCGCC, 2011).

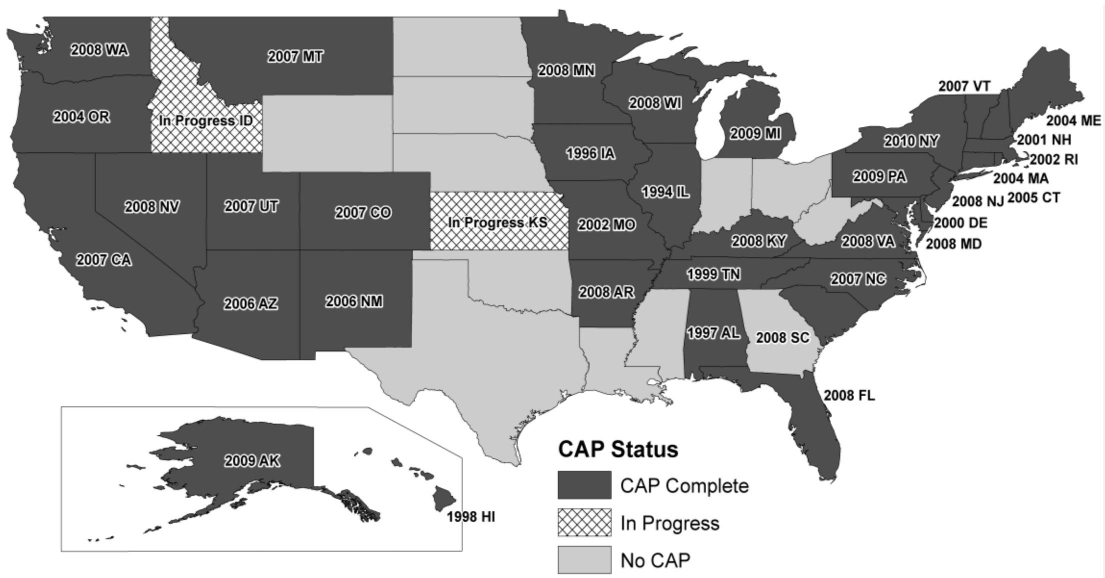


Figure 3. States with CAPs.

Among the states that have CAPs completed, 23 set specific emissions targets (Figure 4) framed in the same way as the original IPCC guidance by setting a percent of reduction from a given year to be achieved by a future year.

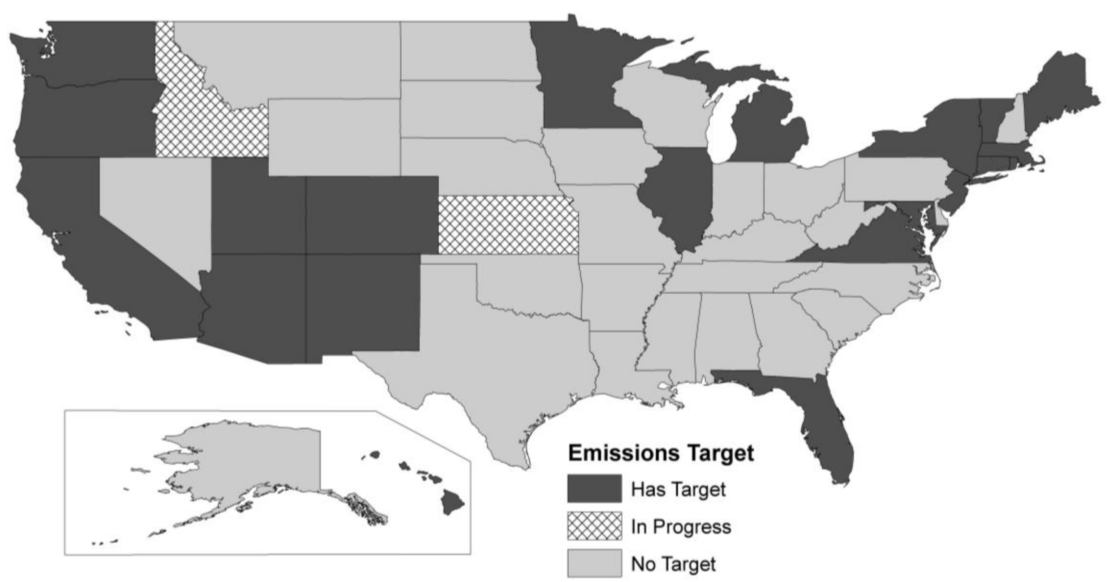
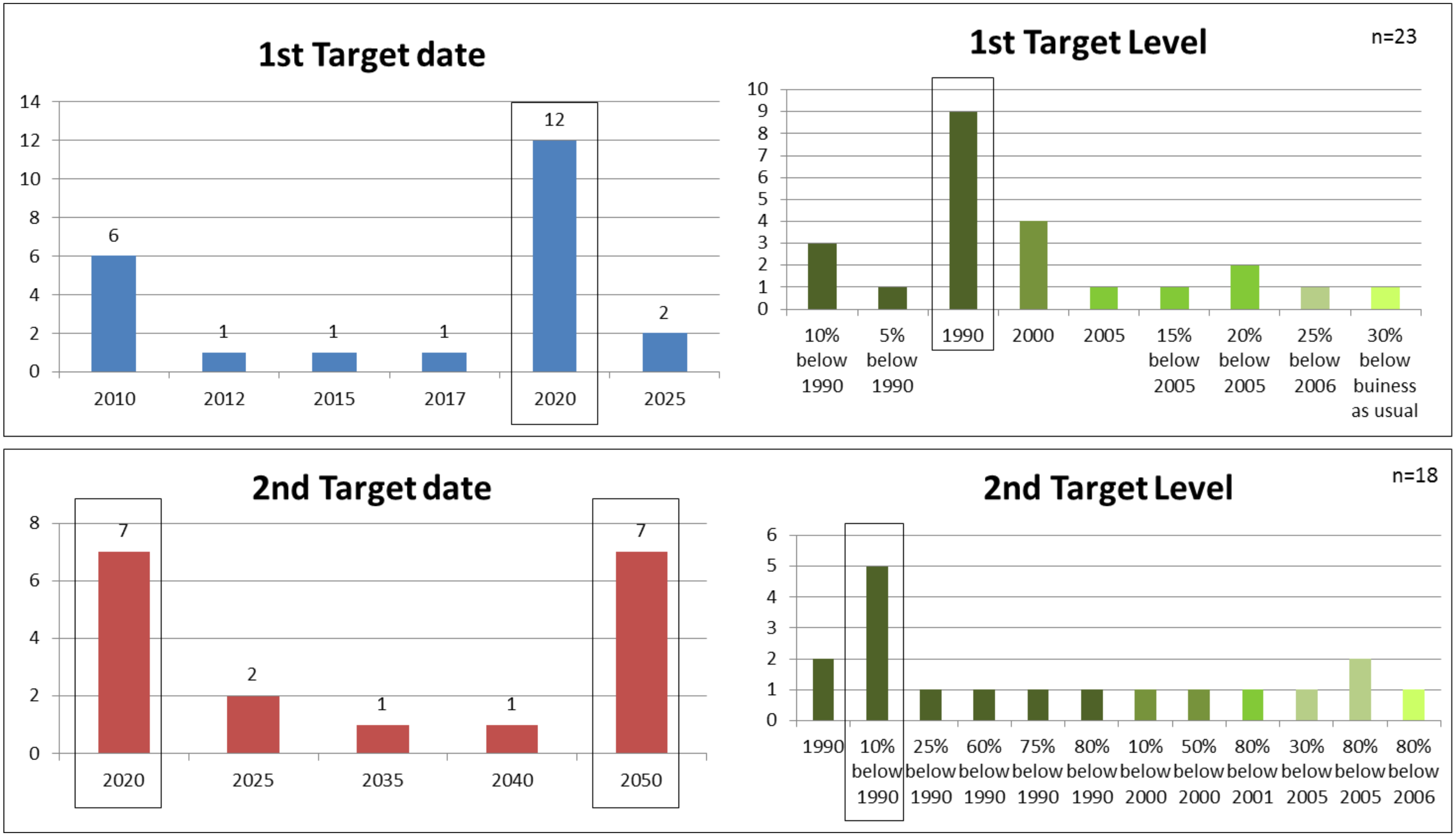


Figure 4. States with emission reduction targets.

Source: *Author's calculation from review of state CAPs*

*Figure **5*** shows the general emission targets states have set. The figure provides four quatrants of bar charts. The top two quadrants so the number of CAPs that with a given emission reduction target date and the target level of emissions; the lower graphs show the number of CAPs with a second target date and the corresponding reduction target. The majority of targets are set for 2020 with emissions to be reduced to 1990 levels. Many states also set a second target date usually for the year 2050 where emissions will be reduced a further 10 percent below 1990 levels.

Many of the CAPs are startlingly similar in process and method from the formation of the initial stakeholder panel, typically called a Climate Advisory Group (CAG) to the quantification of GHG inventories, reduction strategies, and policy analysis (Pollak et al., 2011). The reason for this similarity is the entities involved in the process. Of the 38 states with a completed CAP or one in progress, 19 (or 50%) have been facilitated by a group called the Center for Climate Strategies (CCS) ("Center for Climate Strategies", 2013). CCS follows a very specific path of CAP development (Colburn, 2009), which is then modified based on stakeholder input, but the slate of options for GHG reduction strategies are identical for all states (Pollak et al., 2011).



Source: Author's calculation from review of state CAPs

Figure 5. Synthesis of State GHG Reduction Goals.

Figure 6 shows the states where CCS had a major role in CAP development. Since many state CAPs where quantified by the same entity, using the same methodology and seeking reductions from the same set of strategies (this includes Maryland) a thorough analysis of the effectiveness of a CAP in one of these states using much more sophisticated tools will provide insight on the likely performance of many other state CAPs.

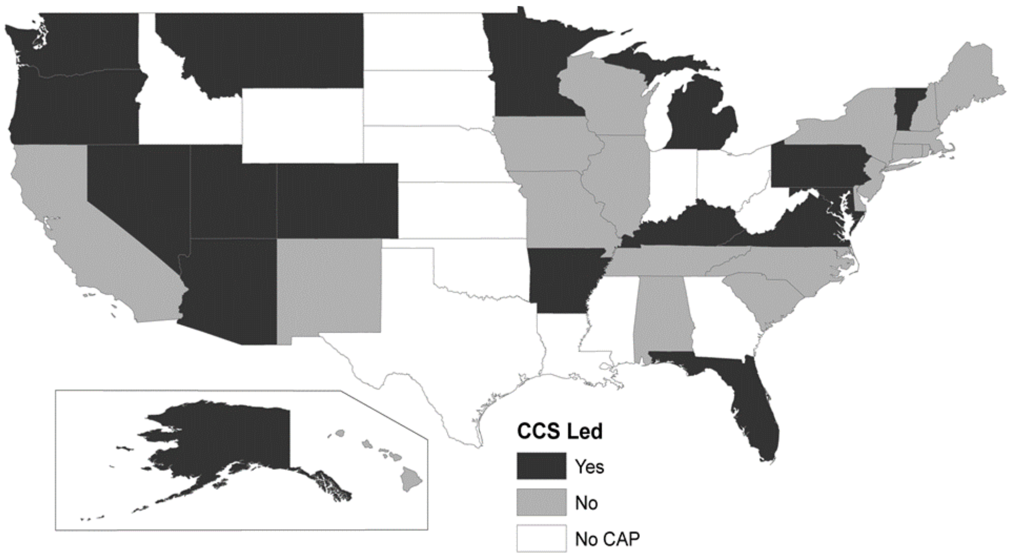
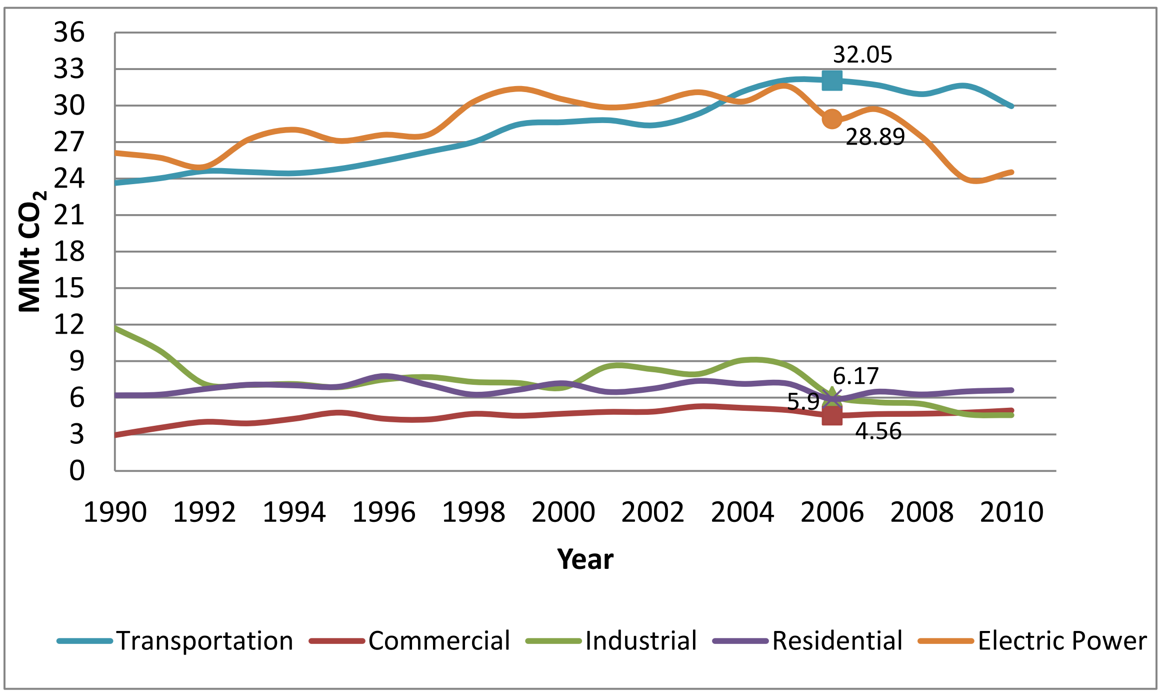


Figure 6. States with CCS involvement.

Maryland enacted its CAP called the "Maryland Greenhouse Gas Reduction Act" (GGRA) in 2009 formed largely as a clone of California's climate policy, but with stricter GHG reduction targets. The act requires the state to achieve a 25 percent reduction in statewide GHG emissions from 2006 levels by 2020 (Pinsky, 2009, sec. 2–1201). The bill also requires the Department of Environment (MDE) to develop a proposed statewide GHG reduction plan by 2011 to solicit public comment on the proposed plan from interested stakeholders and the public, and to adopt a final plan by 2012. Some caveats, limiting what can occur to reduce emissions were embedded in the legislation. For example, the GGRA requires that there be no loss of existing jobs in the

State's manufacturing sector, a net increase in State jobs, a net economic benefit to the State's economy, opportunities for new "green" jobs in the energy and low carbon technology fields, and no adverse impact on the reliability and affordability of electricity service and fuel supplies.

The GGRA requires emission reductions from seven economic sectors including electricity use and supply; residential, commercial and industrial buildings (RCI) fossil fuel combustion; transportation; industrial processes; fossil fuel industry, including fugitive emissions from GHGs released from leakage; waste management; agriculture. This thesis will focus on emissions from the first three sectors (electricity supply, RCI, and transportation), as these are the greatest contributors to statewide CO2 emissions with a combined total of nearly 78 million metric tons (MMt) (see Figure 7).



Source: EIA (2010)

Figure 7. CO_2 emissions by source.

The RCI and power supply emission estimates and reductions are developed and managed by the MDE and in some cases either the Maryland Energy Administration (MEA) or Maryland Department of Planning (MDP).

The Maryland Department of Transportation (MDOT) is tasked with developing and implementing plans to reduce emissions through many transportation and land use policies. A few of these policies focus on travel demand management, but many rely on the development and adoption of new technologies. The transportation portion of the emissions reduction plan calls for significant increases in fuel economy achieved by following the newly adopted CAFE standards (setting new light duty vehicle economy at 54.5 mpg), adopting California's more stringent air quality and economy standards, moving towards lower carbon fuels, and requiring MPOs to identify transportation emissions reduction measures (TERMs) that may be capable of achieving state goals (MDOT, 2011).

While all of the CAPs are a move in the right direction, many of these policies such as those for Maryland lack an element of reality. Like the 1970 CAA, the new state policies tend to set unrealistic goals, allocate scant resources, and lack substantial implementation tools (Wheeler, 2008). Further, very little if anything is mentioned in the policies about enforcement mechanisms. Few studies have worked to determine if the proposed emission reductions set out by these state plans can actually be achieved. Those that have, generally focus on a single sector such as transportation (Gallivan, Ang-Olson, & Turchetta, 2011) or land use (Rodier, 2009). Other studied focus on plans as a whole, but at an very aggregate national level (Drummond, 2010; Barry G. Rabe, 2007; Barry George Rabe, 2004).

By some accounts, the plans have little chance of making a change, due to the limited methods proposed to achieve goals (Tang et al., 2010). The goal of this thesis is the use of empirical data (much of which is discussed in Chapters 3 and 4) to build micro and meso-scopic models specifically for Maryland to measure how likely, the policies specified in the CAP, are to achieve emission reduction targets. This type of analysis has never been completed at the scale and level of detail as presented in this work. An analysis like this is critical to the future of climate action plans as they represent a significant opportunity cost. The resources required to develop the plans occupy a space that could be used to develop other environmental policies. If these plans have little possibility of affecting emissions reductions or climate change, then states should consider a new policy direction to address the serious effects of future climate change.

Chapter 3: Technical Background

The United Nations (UN) recently reported that nearly 400,000 people die each year as a direct result of climate change and these effects already cost the global economy 1.2 trillion dollars a year (DARA, 2012). Numerous reports suggest, without equivocation, that we are nearing the limits of the Earth to safely handle our activity (Meadows, Randers, & Meadows, 2004). The measured effects of climate change are growing and in some cases accelerating beyond initial expectation. A recent report shows sea level rise is occurring 60% faster than previously predicted (Rahmstorf, Foster, & Cazenave, 2012), while another finds polar ice melting at a much faster than expected rate (Shepherd et al., 2012). From a constant stream of emissions (Raupach et al., 2007), to widespread changes in land cover (Feddema et al., 2005), to the continuing acidification of oceans (Orr et al., 2005), there is little doubt that anthropogenic climate change is real and presents a serious threat to humanity.

The Bathtub

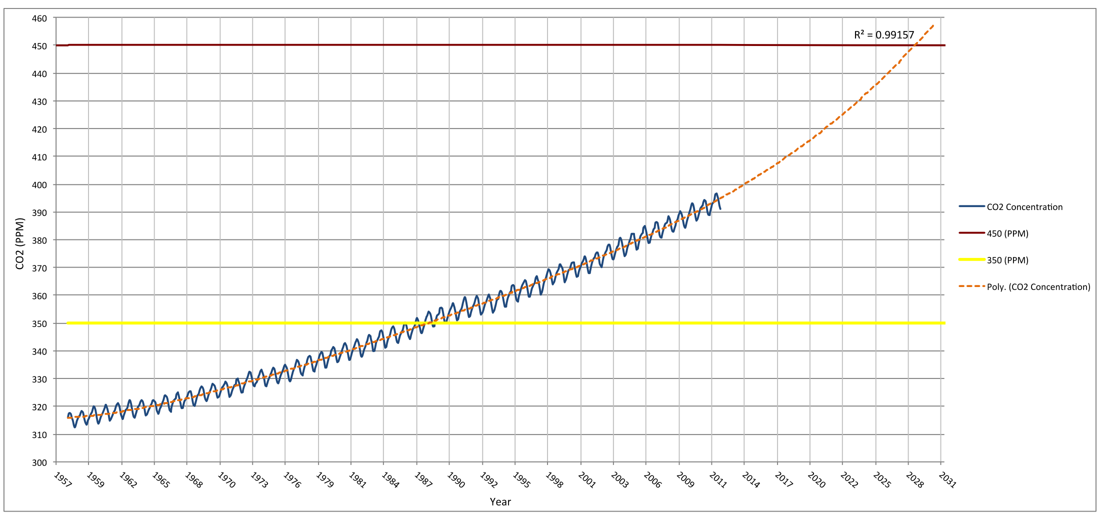
When dealing with complex, non-liner, and circular systems like the global climate (Schneider, 2004; Colman, Power, & McAvaney, 1997), it is often helpful to reduce the complexity to a simpler analogy. For example, it is easy to view the atmosphere as an enormous bathtub (Sterman, 2008). Rather than filling the tub with water, the facet is pouring carbon, which like a bathtub can be imagined to be pouring warm water on a pool of slightly cooler water. This tub has two mechanisms, the first is the faucet pouring in carbon, and the second is the drain disposing of atmospheric carbon. In this bathtub analogy we are certain of a few things. First, we know the rate at which the carbon is flowing into the tub. We also know, though with a bit less certainty, the amount of carbon the entire tub can safely handle before the bath water becomes too hot. Finally, we know generally how large the drain is.

The analogy can be used to explain the sources of the filling tub, the function of the drain, the capacity of the tub, and what we can do to stop the flow, expand the drain, and prepare for overflow. A recent data release from oil giant British Petroleum (BP) shows that we have just 54.4 years of proven oil reserves remaining (BP, 2012), yet a recent study in Nature argues that even with this limited supply, we have enough oil in proven reserves, which given its economic value, is nearly certain to be combusted to push the planet towards serious climate destabilization (Meinshausen et al., 2009). A recent report also suggests that US non-oil well reserves, the more difficult shale and tar sands fossil fuel, is equal to or greater than the current known oil-well reserves ("US Daily Oil Production To Reach 7.5 Million Barrels By 2020, EIA Says", 2013).

In the year 2011, world emissions of CO2 reached 31.6 gigatons (EIA, 2012) (or up to 34 gigatons depending on the source; Olivier, Janssens-Maenhout, & Peters, 2012), which represents a one-gigaton increase over the previous year. The change translates to a three percent increase in emissions, which are in line with long-term expected global trends (Olivier et al., 2012). The rate at which the world is burning fossil fuels, leading to emissions of CO2, is increasing the concentration of atmospheric CO2 at a rate of two parts per million (ppm) per year. This is a rate that has been increasing exponentially since measurements began at the Mauna Loa Hawaii Observatory in 1957.

The rate of increase for atmospheric CO2 concentrations is important for a few reasons. First, the concentration level has a direct impact on climate forcings; that is, the amount of heat that can escape the planet. Higher concentrations of CO2 trap a greater amount of heat, leading to runaway feedbacks and extreme climate change. Many scholars have argued that a safe concentration of CO2 is 350 ppm (Hansen, 2008; Hansen et al., 2008; McKibben, 2007), however we long ago surpassed that level (now 392.2 ppm) and are swiftly moving towards the next critical level 450-500 ppm, which scientists argue is the absolute highest concentration of CO2 the planet can withstand and still keep an 80% chance of just a 2 degree Celsius warming (Meinshausen et al., 2009). The upper limit is either 450 or 500 ppm (Pacala & Socolow, 2004).

Figure 8 shows the passing of the 350-ppm level in 1989 and the likely surpassing of the 450-ppm mark by 2028 (using a simple polynomial forecast).



Source: Atmospheric CO_2:Mauna Loa Observatory (Scripps / NOAA / ESRL), Forecast: author's projections.

Figure 8. Observed historic atmospheric CO_2 concentration.

Unless serious action is taken quickly, we will lose our small window of opportunity to hold global temperatures and potentially devastating climate change at a minimum level. Action to reduce CO2 emissions will not be easy. We have enough proven oil, natural gas, and coal reserves, which carry a very high financial incentive to be extracted and combusted, to far exceed our 549 Gt CO_2 budget and propel us towards a highly unstable 5 degree Celsius temperature increase (Taylor, 1999). In fact the largest oil companies hold in reserve nearly 750 Gt in fossil fuel carbon equivalents, 150% the total budget, which itself is dwarfed by the estimated 2,050 Gt of carbon in worldwide proven reserves, a number that has recently grown due to new technology that has helped make more types of fuel fields available. These figures also leave out non-fossil fuels the world burns such as fuel alcohol and biodiesel that are not limited by existing reserves. It is not unrealistic to draw an analogy between the reserves of fossil fuel and the stockpiles of nuclear arms, as each exists in excess to imperil civilization many times over. The analogy fails though when one considers serious limitation and deference given on exploding nuclear ordinance but the free and positively influenced acceptance of fossil fuel combustion.

As the evidence is clear about the increasing concentrations of atmospheric CO_2, so too is the evidence on the amount of temperature change that has already occurred, the level that we are already committed to, and the time the commitment will last (that is the length of the change we have already committed to). Research indicates that we have already committed ourselves to a 1.8 degree Celsius temperature increase (Lynas, 2008), so we will be fighting to maintain a final .3 degrees over the next several decades. Further, the speed at which atmospheric CO_2 decays into a non heat-trapping particle is so slow that all the climate change effects we have committed ourselves to through CO_2 emissions since the industrial revolution will remain for the next several thousand years. The change our descendants will experience operates at a geological scale, which makes the human experience of such change essentially permanent.

Scientific Need

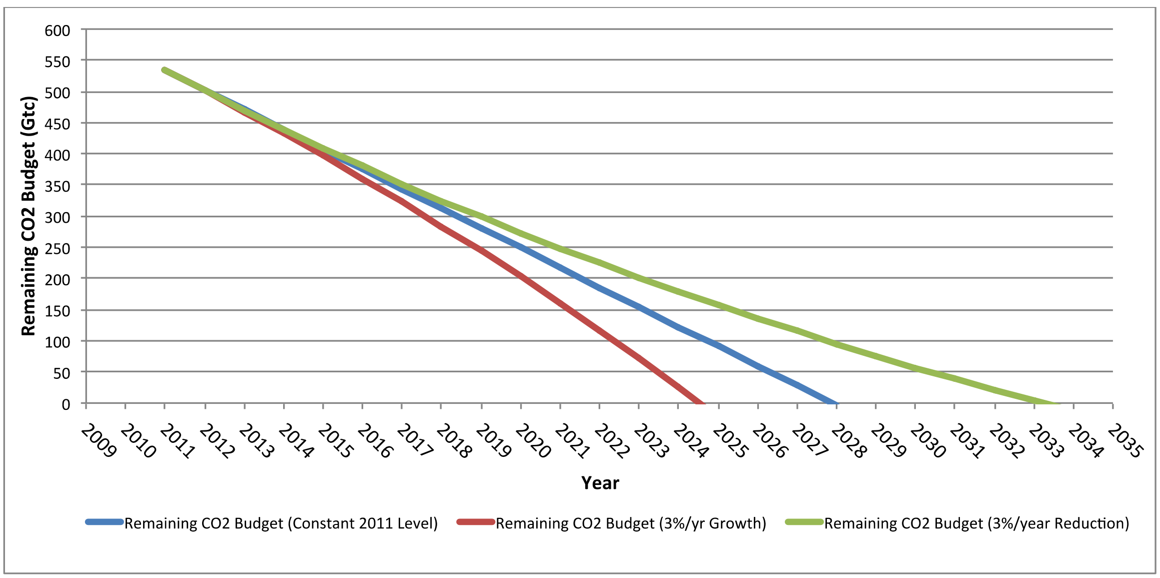
Many of the international, national, and state climate action plans set targets based either on other state's action plans, international policy, or simply through intuition. Many are modeled off the IPCC's Fourth Assessment Report's (Pachauri & Reisinger, 2007) recommendation to nations. The recommendation stated there was an urgent need for CO2 reductions with target guidance of 25-40 percent below 1990 levels by 2020 and 80-95 percent below 1990 levels by 2050.

Most CAP state reduction targets look similar to the IPCC recommendation. These goals and targets make action plans appear serious and aggressive, but tend to lack a strong relationship to current scientific need. Reports from the IPCC have shown that the world will need to maintain an atmospheric concentration of CO2 no greater than 450 ppm (+/- 50ppm) to hold the global average temperature increase at or below two degrees Celsius (Pachauri & Reisinger, 2007), yet CAPs do not relate how emission targets at the state level will further this goal.

The needed CO2 concentration limits are difficult to translate to state targets because of the complexity of multiple factors that influence concentrations. Some of these factors include the scale and intensity of carbon sinks, climate forcings, and the natural release of carbon from decaying organic matter. In recent research using 40 of the latest and most sophisticated climate models combined with multiple probabilistic models Meinshausen et al. (2009) were able to estimate the total CO2 the world can emit until 2050 and still maintain an 80 percent chance of only a 2 degree Celsius temperature increase (compared to pre-industrial temperatures). The results of the Meinshausen et al. analysis indicate that between 2000 and 2050 the global CO2 budget was 886 Gt. From

2000 to 2011, a total of 337 Gt of CO2 have been emitted, which leaves a total remaining CO2 capacity of 549 Gt for the next 39 years (EIA, 2010).

Figure 9 shows this limit graphically assuming first if worldwide emissions are held at the 2011 level (a highly unrealistic assumption given what is known about the development of coal power plants in both China and India), then with a three percent per year increase in emissions (consistent with growth between 2000-10; EIA, 2010) and with a three percent reduction in global emissions by 2013. Under all scenarios, the budget is depleted long before the common emissions reduction target date of 2050, with the allowance completely used by 2028, 2024, and 2033, respectively.



Source: Meinshausen et al. (2009), EIA world emissions, author's calculations.

Figure 9. CO_2 budget and different emissions rate scenarios.

The new analysis presents a bright-line definition of how much carbon can emit and offers new insight on how CAP targets match this budget. This thesis will address whether the Maryland CAP target of a 25 percent below 2006 GHG reduction by 2020 matches the newly understood need or if not, how far the CAP target is from this scientific evidence.

Theoretical Complexities of Carbon Mitigation

Limitations on Energy Reduction Strategies

The future environmental impact that results from human activity, is commonly assessed with reference to the IPAT identity (Ogawa 1991; Parikh & Gokarn, 1991; Nakićenović et al., 1993; Alcamo & Swart, 1998; Gaffin & O'Neill, 1997; Gürer & Ban, 1997; O'Neill, MacKellar, & Lutz, 2005; Pebley, 1998) The formula asserts that impacts (I) are caused by population (P), income per capita or affluence (A) and technology (T), in the following formula:

environmental **I**mpact = **P**opulation x **A**ffluence x **T**echnology

A derivative of IPAT is another identity specifically related to carbon emissions. Any policy with an aim to reduce carbon emissions is limited in its ability to achieve such an objective by the sources of emissions. This limitation has come to be known as the KAYA Identity (Kaya, 1990), a simple equation that reduces carbon emissions to four constituent components: population, per capita GDP, energy intensity, and carbon intensity; represented by the following equation:

$$CO_2Emission = (Pop)\left(\frac{GDP}{Pop}\right)\left(\frac{GEC}{GDP}\right)\left(\frac{CO_2}{GEC}\right)$$

Where pop is population, GDP is the gross domestic population and GEC is gross energy consumption. Though four components or policy levers exist, two levers are generally considered unacceptable options of reducing emissions. As many climate change policy scholars point out (see for example Pielke Jr., 2010; IPCC, 2007), most energy and climate policy forbids the reduction of population or GDP; only a reduction in energy intensity or carbon intensity can be used to reduce carbon emissions.

The Maryland CAP is no different than others subject to the two-lever limitation. The policy specifically requires growth in jobs (something directly associated with GDP growth) and implicitly assumes an increase in population (see Chapter 4 for Maryland population projections). As a result, the Maryland CAP, like most other climate policies, must reduce carbon emissions through the following formula.

$$CO_2 Emissions = \left(\frac{GEC}{GDP}\right)\left(\frac{CO_2}{GEC}\right)$$

Policy scenarios discussed in the Maryland CAP and variants analyzed in this thesis will reflect the limitation imposed by the IPAT and Kaya identities and address only scenarios that reduce emissions through lower energy or carbon intensity. Policies that are consistent with this limitation are those that result in fewer tons of GHG emitted per unit of energy or dollar of GDP.

Carbon Emission Sources - Maryland

CO2 emissions result primarily from activities conducted within the built environment (

Figure ***10***). CO2 emissions result from the combustion of fossil fuels, an activity that is responsible for ninety eight percent of anthropogenic CO2. Three categories of emissions are primarily responsible for CO2 production including transportation, elements of land use composing the RCI sectors, and electric power generation. The last two sectors RCI and energy generation are highly related, with RCI producing the majority of demand for power generation. Thus the discussion and analysis will be grouped into two major categories: vehicle emissions and land use emissions.

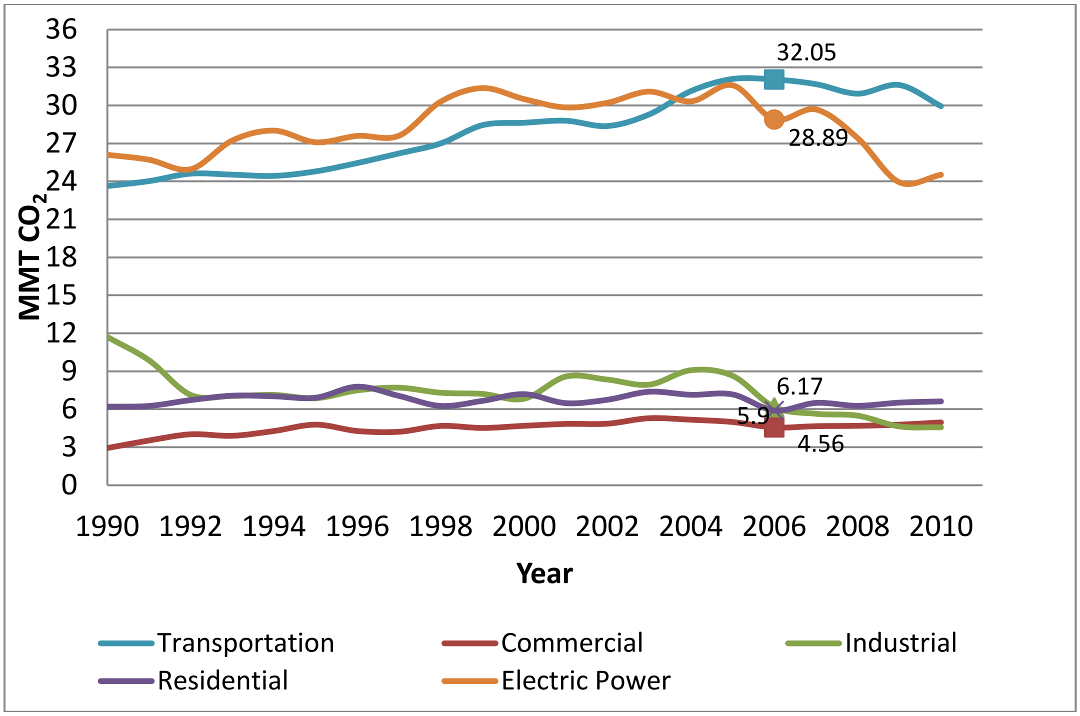


Figure 10. CO_2 Emissions from Fossil Fuel Combustion in Maryland.

<u>Building Related Energy Consumption and Emissions</u>

The primary driver of land use emissions is directly related to buildings. CO2 emissions are a result of combustion of fossil fuels at the building location and the demand for electricity for each building, or in other terms, direct and indirect emissions. Sources of building emissions are typically divided between three sectors: residential, commercial and industrial.

Combined, the three building sectors produced over 21 percent of total CO2 emissions in 2006 and nearly 23 percent in 2010 (see Figure 11). How emissions are generated directly from building will be discussed in the next section. Indirect emissions, while partly a function of demand, are substantially the result of the type of fuel used to generate electricity, thus the discussion on indirect building emissions will focus on power plants.

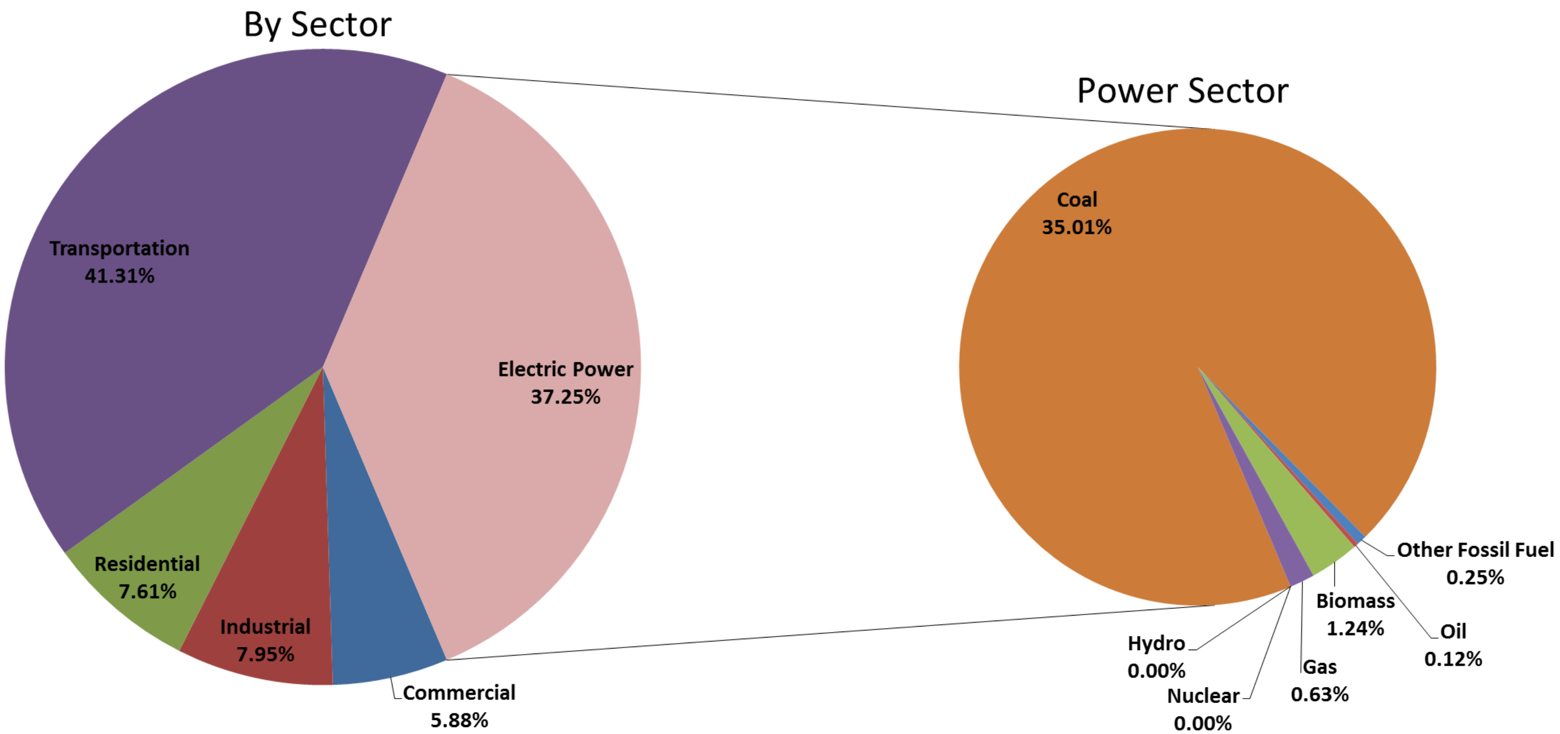
On-Site combustion

On-site combustion of fossil fuels, typically natural gas, propane fuel (diesel) oil, and even kerosene are commonly used for heating, cooking and in some cases cooling. However, the amount of CO_2 produced at the building level is rarely examined in the literature. More common is the emissions of building materials (Seo & Hwang, 2001). Part of this absence from the literature is the high resolution of data needed for such a quantification (Gurney et al.,2009). The combined CO_2 emission from on-site fossil fuel combustion is 17 percent of all CO_2 emissions in the state of Maryland.

Energy Generation – Power Plants

Power plants are a major contributor to GHG emissions producing over 37 percent of CO_2 emissions in 2007 and nearly 35 percent in 2010, and coal combusted from electric power generation accounted for over 35 percent of total CO_2 emissions in the state of Maryland in 2006 (

Figure ***11***). Among power plants, coal is responsible for more than 93 percent of total CO_2 emissions. While coal generates the most CO_2 emissions in the state, it also produces the most energy, supplying 55 percent of the state's energy capacity (Nelson, 2011). The total CO_2 produced from coal has been decreasing over the last several years as the price of lower emitting natural gas has decreased and costs for energy conversion from coal have increased (Nelson, 2011). Other sources of emissions reductions have been explored including the use of biomass to co-fire coal plants (Gustavsson et al,. 1995). Most states, including Maryland, are obligated to derive a certain percentage of their power from renewable and low or zero emission sources in an attempt to reduce emission inventories (Yi & Feiock, 2012; Lyon & Yin, 2007; Pardo & Thiel, 2012; Yi, 2010).



Source: EIA (2010)

Figure 11. Maryland CO_2 emissions by sector and energy source in 2006

Maryland derives a significant portion of its power from imported sources. This is possible due to the connection and management of several state and regional grids called the PJM interconnect. This connection coordinates the wholesale distribution of power generated by members to other locations on the interconnected grid ("PJM - About PJM", 2013).

Figure 12 shows that location and emissions from power plants in Maryland and the surrounding PJM interconnect. By using an interconnection, Maryland is able to import power and sell excess generating capacity.

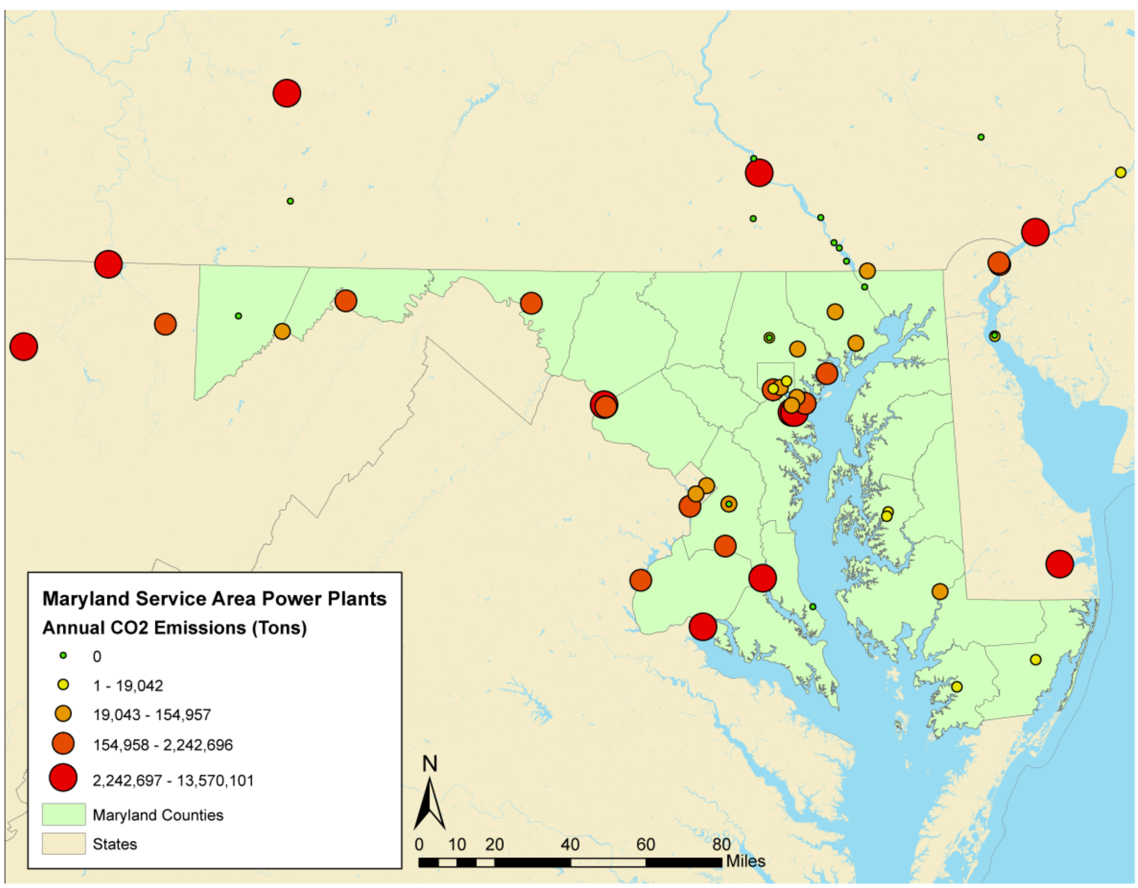


Figure 12. Maryland and PJM interconnect power plants and CO_2.

Transportation and Emissions

The literature on emissions reductions shows highly mixed results at different geographic scales. Some studies of smaller metropolitan areas conclude there could be a nearly 75 percent reduction in transportation emissions through more efficient travel patterns, when residents reside closer to their jobs (Scott, Kanaroglou, & Anderson, 1997). Beevers and Carslaw (2005) found that with the large-scale congestion cordon implemented in London, aggregate reductions in emissions were less than 11 percent. Zhou et al. (2010) found traffic system improvement strategies along with vehicle technology enhancements could reduce daily motor vehicle CO and NOx (it was mute on CO2) emissions by 44.5 percent and 49.0 percent, respectively. Loudon and Dagang (1992) found that raising the price of gasoline by $1 reduces NOx and HC by 2 percent per day, and CO by 4 percent. Daniel and Bekka (2000) modeled the impact of hypothetical congestion charging in Delaware, finding VMT and emissions decrease by about 3.4 to 10.5 percent in aggregate depending on urban density. Rodier (2009) provided a comprehensive summary of international modeling exercises that measured VMT and emission reductions. The results indicate that land use policies have little impact on VMT, in the magnitude of three percent, while pricing strategies reduce VMT by 12 percent on average over 30 years.

The following section outlines the underlying theoretical and policy-based approaches to changing travel behavior to achieve external reductions. These approaches form the framework from which the analysis of this thesis will work.

Travel Demand

Travel behavior is a complex mix of human decisions and interactions with the built environment and transport network. The need to travel is generally born out of a desire to engage in an activity aside from the act of traveling itself. This sort of demand, where the use of one activity is dependent on the demand for other activities, is called derived demand (Button, 2010). The derived nature of transport means that rational persons faced with a constrained budget (both in terms of time and money) will gain little utility from the act of driving itself. The rational person will seek to minimize the trip as much as possible (McFadden, 1974), typically in an effort to maximize the time spent at the destination. Previous research indicates that much of a travel decision hinges on the duration of the trip being considered (Levinson & Kanchi, 2002), such that demand depends largely on a calculation of the tradeoff between time spent traveling and work on home. Highway investments that expand capacity and reduce travel time, at least in the short term, cause more travel as drivers seek to use travel time savings to complete more activities (Downs, 2004; Levinson & Kanchi, 2002).

Road Pricing

The use of motor vehicles results in costs to the drivers, but also bears an unpaid cost on others in the form of pollution, noise, emissions, congestion, and many other ill effects. Externalities associated with personal and commercial vehicle use are extensive, well documented, and calculated to be in the billions of dollars (Delucchi, 1996; 1998). The full price of these unpaid social costs is a matter of debate. Some researchers argue that the costs are substantial (Litman, 1995), while others say that such costs are built into the auto operating expenses that accrue to drivers, such as the price of gas (Green, 1995) or the additional revenue generated by the gas tax. Despite the debate, there are a few certainties that remain, including: 1) the rate of motor vehicle ownership is increasing (Dargay & Gately, 1999); 2) vehicle use is generally increasing worldwide (Cameron, Lyons, & Kenworthy, 2004); 3) the consumption of fuel is growing and will likely continue to grow without economic deterrents or polices that reduce the demand for automobile use (Greening, Greene, & Difiglio, 2000); and 4) externalities from motor vehicle use will continue to grow in the absence of strict, enforceable regulations (Parry, Walls, & Harrington, 2007). The key point is that the use of autos and their resulting social costs will continue to increase without policy-based market intervention.

Pricing can have a substantial influence on travel behavior. As utility maximizing persons, road users respond to changes in the cost of travel. With the constrained budget, the more travel costs, the less likely that person is to journey. This is a very old principle, used to send signals about resource scarcity (Button & Verhoef, 1998). The idea of pricing to alter travel behavior has a long history in the literature. All travel is priced at some level, either as a user fee (toll or fare) or as a more indirect cost (gas tax, vehicle registration). Dupuit (1844) formulated one of the first road pricing problems, determining that there was a utility maximizing and revenue generating price for a bridge. More famously Pigou (1920) proposed the first road pricing to account for the marginal social cost of travel, showing a charge could be used to reduce total system travel time, enhancing welfare. Knight (1924) followed Pigou's argument, first stating that unlike in Pigou's formulation, not all facilities are public goods, and the use of pricing to achieve optimal flow enhances welfare.

The ideas of early economists on road pricing lay dormant for a number of years until Vickrey revived the topic with multiple papers arguing that the public provision of roads is inefficient, leading to travel behavior that reduced welfare (Vickrey, 1963; 1969; Vickrey & Sharp, 1968). Walters (1961) essentially argued in parallel to Vickrey, making the point that roads are underpriced and the resulting travel is inefficient. These arguments all fall under the theory of the first-best; where the marginal social cost and average cost of using a road are charged directly to the user (Rothengatter, 2003). The literature in recent history also has formulated new pricing mechanisms that fall under the category of second-best pricing. This category is generally less efficient and results in lower fees as it charges users for the average cost of using the facility, but not the marginal cost that includes the expense assigned to other users by that traveler's decision to use the road (Zhang & Ge, 2004). This occurs because there are significant technical limitations imposed by the ability to calculate the optimal marginal charge (Verhoef, Nijkamp, & Rietveld, 1995). Second best is the place for many of the common pricing models associated with transport that essentially boil down to a user fee.

Policies for Efficient Travel

Public policies aimed at improving travel efficiency can influence travel behavior to reduce transport externalities. Some researchers contend that emission and congestion problems are more a symptom of inefficient urban structure rather than market forces. This results in poor commuting patterns (or excess commuting) and altering where, when, and how commuters travel for work deals with this issue. One method, which theoretically reduces wasteful commuting (Horner, 2002; Scott, Kanaroglou, & Anderson, 1997), follows the argument that a significant amount of either travel time or distance could be saved if more commuters took jobs located within their own neighborhood. The logic is that with a better jobs-housing balance (JHB) policy could be implemented that would dramatically increase the percent of people employed in hyper-local markets relative to their place of residence (White, 1988). Most work in this area determines the number of local jobs and the number of workers, then sets-up an optimization problem to determine the minimum distance workers would have to commute if as many local jobs were filled by local residents as possible (Hamilton & Röell, 1982).

Reducing wasteful commuting or enhancing JHB can be expensive and take a significant amount of time, if even possible to implement. Transport control measures (TCM) may offer a more likely, albeit difficult to enforce, alternative to the extremes of reorganizing spatial structure. This method usually entails some sort of transportation demand management (TDM), which attempts to reduce congestion and emissions with a reduction in the demand for light-duty vehicle (LDV) transport, the most common vehicle type for commute travel. This is accomplished through a list of measures specified from the 1990 Clean Air Act (US EPA, 1990). These measures, such as encouraging ride sharing or telecommuting, are mostly policy-based options to develop programs that make more efficient use of LDVs during commute hours. Hall (1995) suggested that the implementation of such transport control measures could have the potential to jointly reduce congestion and emissions. Two studies, one by Loudon and Dagang (1992) and another by Cameron (1991) that deal with TCMs implemented in California, attempted to show emission reductions as a result of TCMs. In these cases, there were some small VMT reductions and relatively minor decreases in Hydrocarbons, Nitrogen Oxides, and Carbon Monoxides in the short term.

Chapter 4: Case Study and Methodology

Case Study

This thesis examines the potential emissions reductions expected to be achieved by 2020 from the strategies specified in the Maryland CAP. To measure the effect of these strategies several models were constructed at various base resolutions but all were aggregated and reported at a meso-scopic level. This meso level was achieved by dividing the state into 1151 modeling zones, called Statewide Modeling Zones (SMZs). Figure 13 shows the SMZ structure for the entire state.

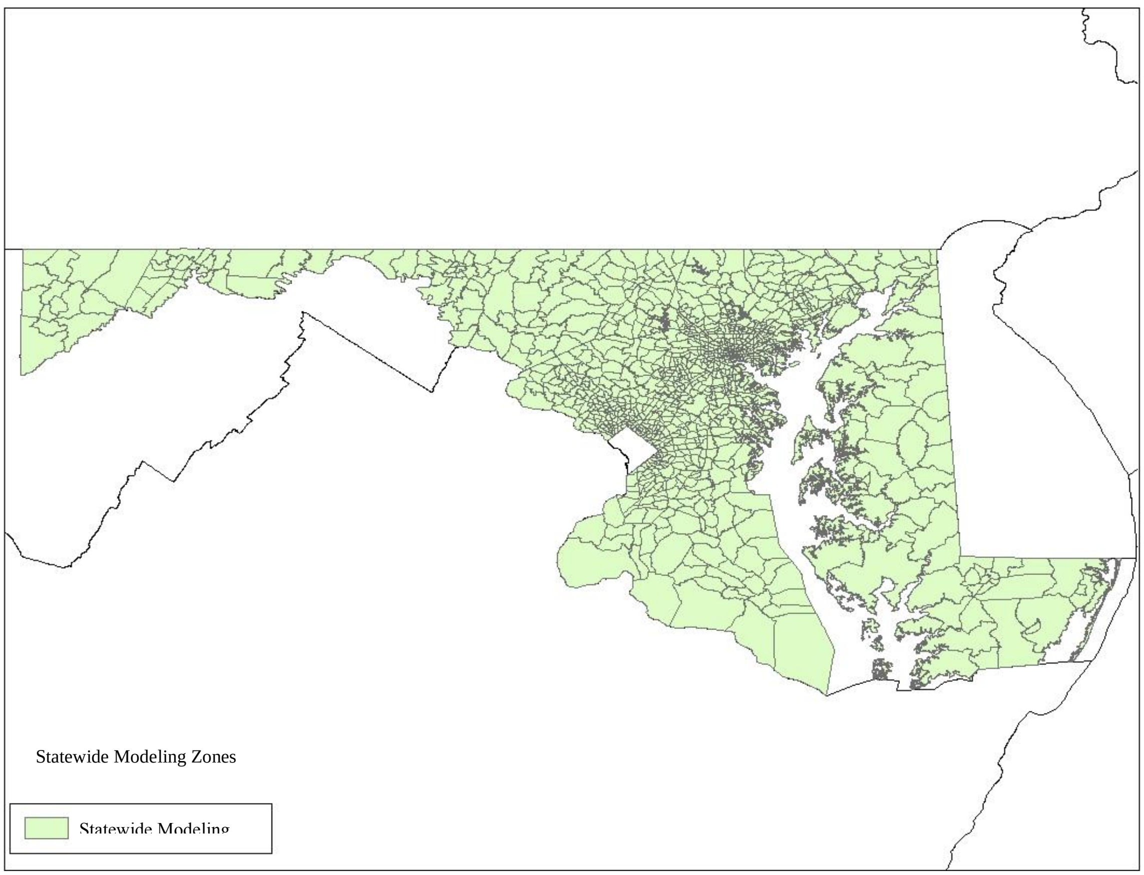


Figure 13. Maryland Modeling Zone (SMZ) structure.

Each of the SMZs was associated with a total number of households and jobs, divided into four sectors. Table 2 shows the state totals for employment and households for 2006 and 2020. These control totals were held constant for all scenarios to make the results comparable and compatible with the Maryland CAP requirements that no strategy reduce population or employment. Table 2 shows that in the 14 years between 2006 and 2020, households are projected to grow by over 17 percent and employment will increase by over 28 percent.

Table 2

Maryland household and employment

Variable	2006	2020	Per. Difference
Households	2,110,003	2,479,680	17.52%
Employment	2,716,964	3,485,948	28.30%
Sector			
Retail	483,541	526,892	8.97%
Office	1,113,217	1,547,635	39.02%
Industrial	313,279	363,971	16.18%
Other	806,927	1,047,449	29.81%

Figure 14 through Figure 17 show the spatial distribution of jobs and employment in the state modeling zones. The number of acres in each zone normalizes all the maps. The spatial distribution of jobs and households is not expected to change dramatically, as shown by the following figures.

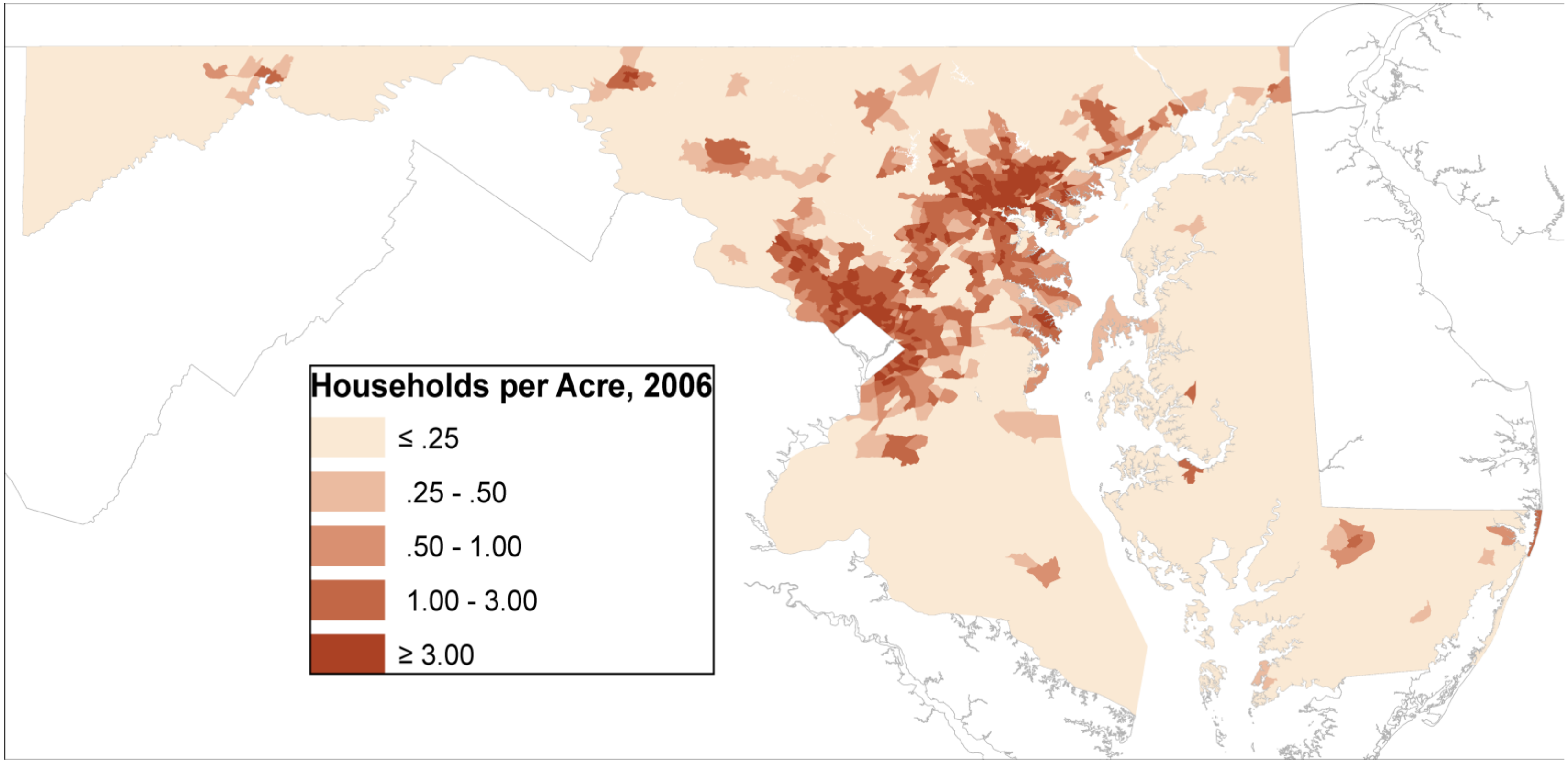


Figure 14. Households per acre, 2006.

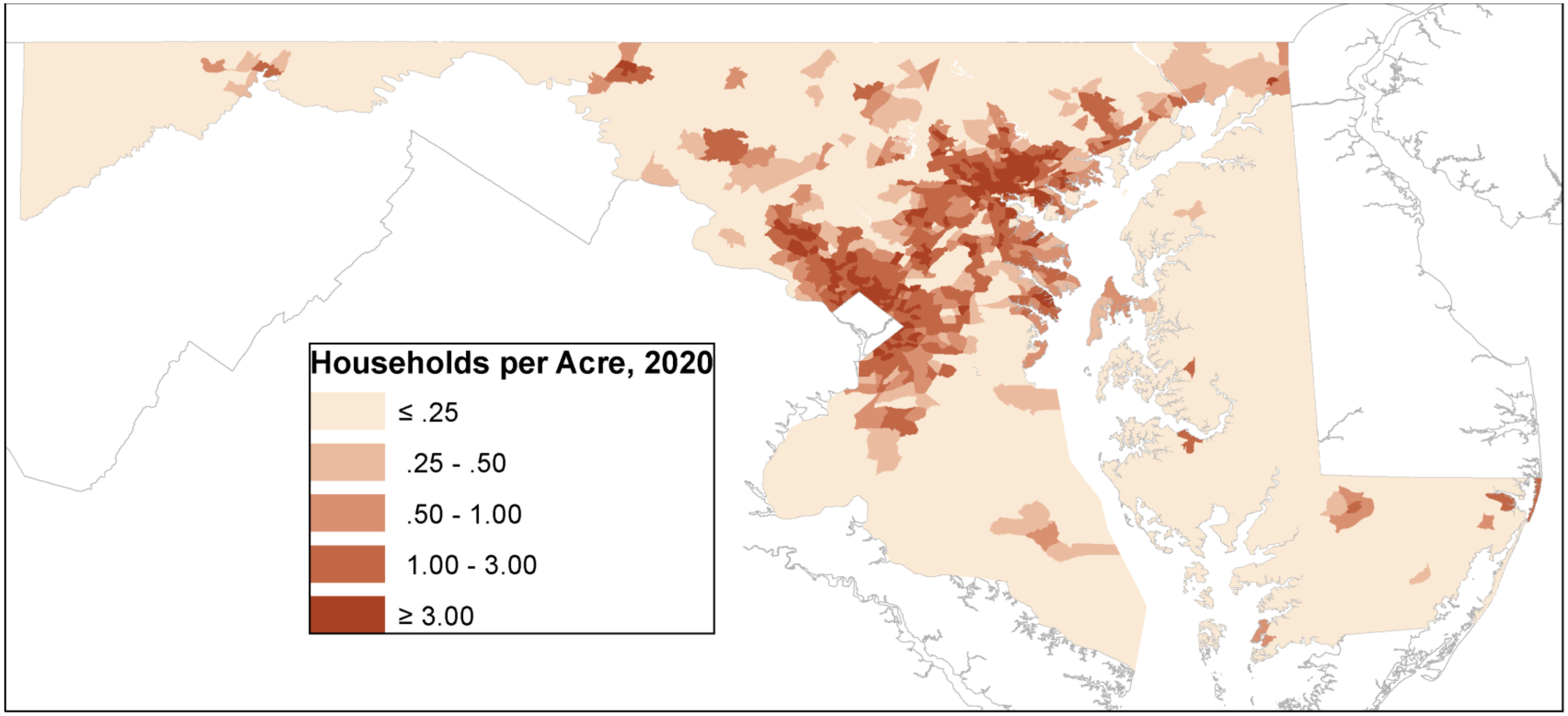


Figure 15. Households per acre, 2020.

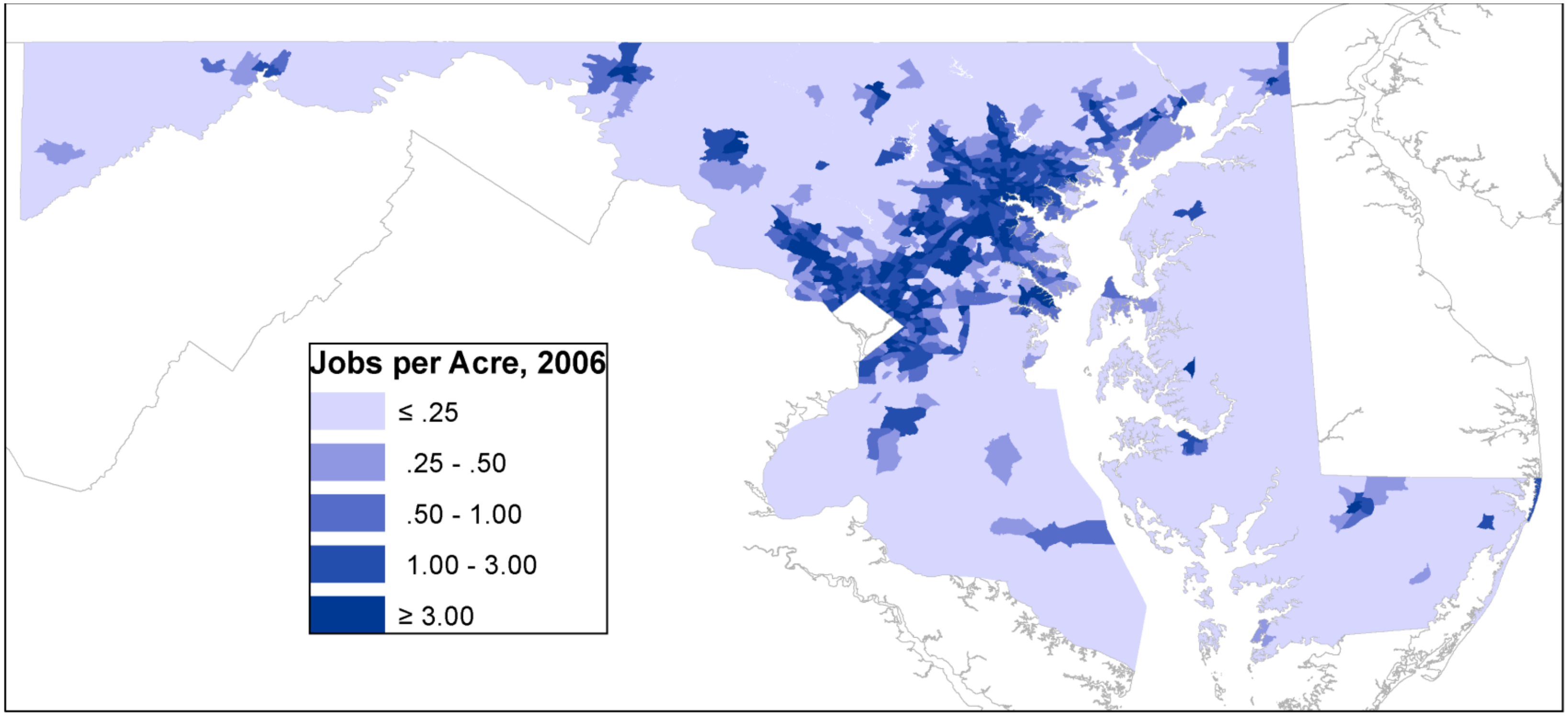


Figure 16. Jobs per acre, 2006.

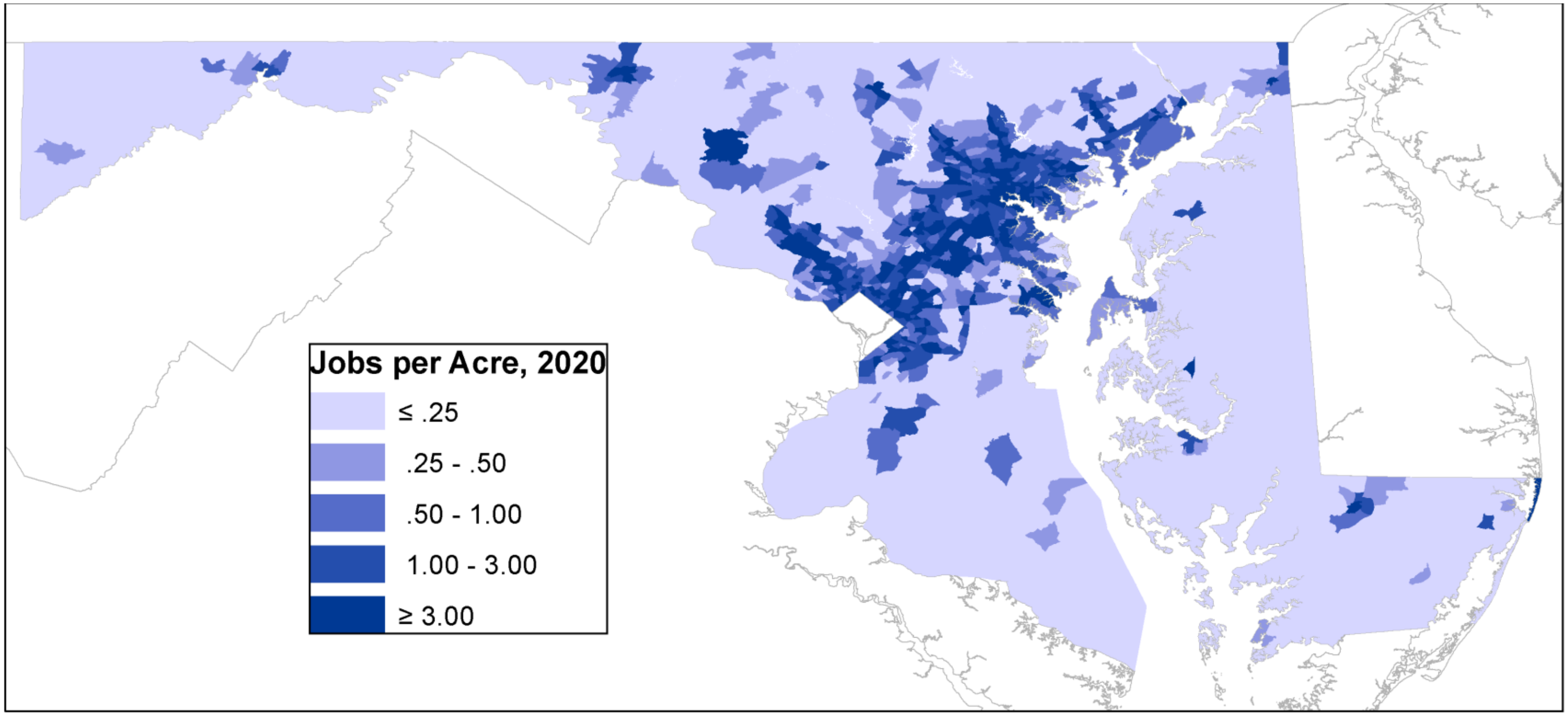


Figure 17. Jobs per acre, 2020.

Energy Consumption and Emissions Estimation Methodology

Residential, Commercial and Industrial Buildings

Building emissions and energy consumption was estimated for the residential and commercial sectors. Models for reach sector followed a specific framework for both estimating inventories and future scenarios. Figure 18 shows the conceptual framework for the building sector models.

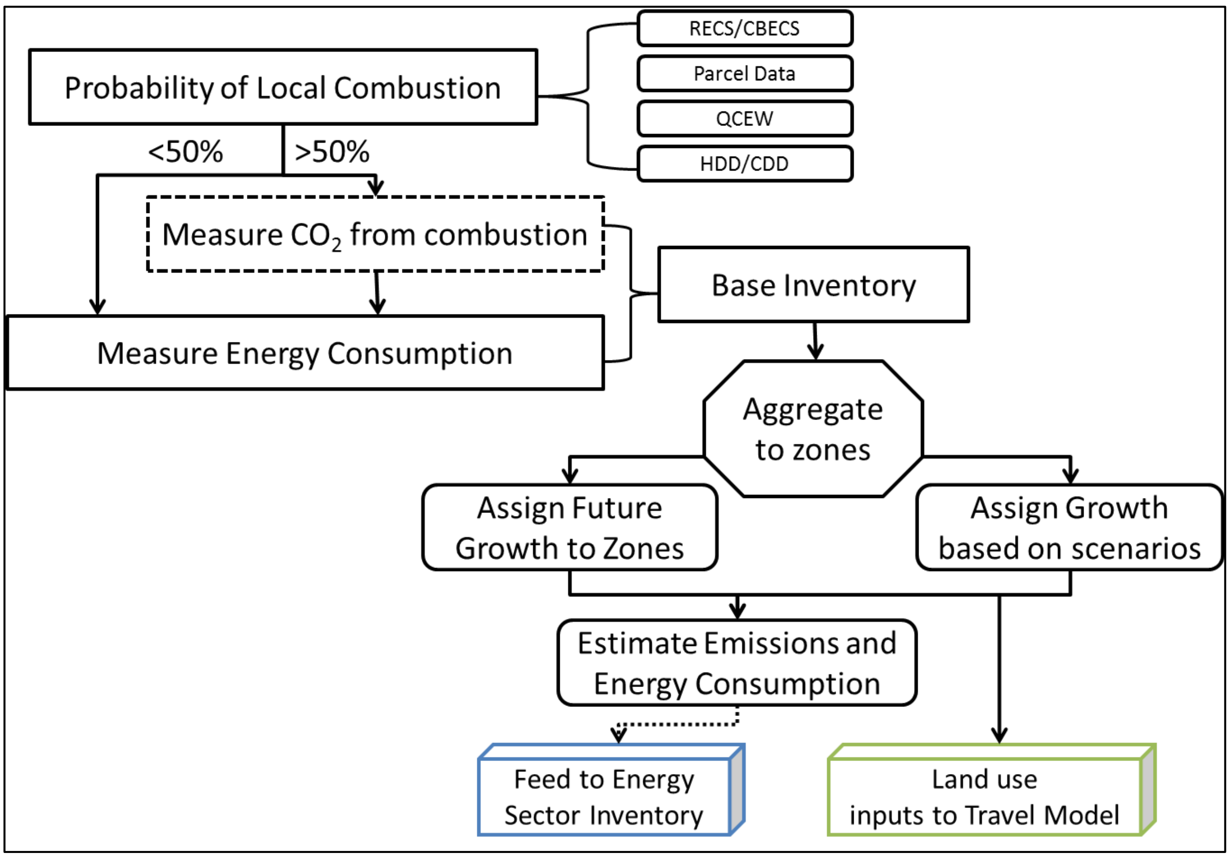


Figure 18. Building sector emissions framework.

Direct CO_2 Emissions

Not all RCI units directly produce CO2. Units that do produce CO2, do so by burning one of several fossil or wood-based fuels for heating (house, water, or laundry among others) or cooking. If some type of fuel is combusted then that source can be converted from BTUs combusted to the constituent CO2 output. The first step in the process of measuring RCI emissions is to convert BTUs of fuel consumption in EIA's micro data from the Residential Energy Consumption Survey (RECS) 2005 and Commercial Building Energy Consumption Survey (CBECS) 2003 (to match the base year as closely as possible) to tons of CO2. The dataset provides the total consumption of natural gas, fuel oil, kerosene, and wood for over 4,200 and 5,400 sampled units, respectively. The BTUs of consumption for each unit were converted to CO2 based on EPA conversion rates listed in Table 3. The initial conversion in the first column is the pounds (LBS) of CO2 that emitted from burning each fuel source to produce one million British Thermal Units (BTUs) of energy. The next columns (to the right) show the same relationship but for more aggregate units of CO_2: kilograms (KG), metric tonnes, millions of metric tonnes (MMT). The final column shows the conversion of BTUs by source to MMTs of CO2 equivalents.

Table 3

Energy Consumption to CO_2

Million	CO_2				
BTUs	LBS	KG	Metric Tonnes	MMT	To MMT CO_{2e}
Natural Gas (NG)	116.89	53.02	0.05302	5.3020E-08	1.4459E-08
Fuel Oil (FO)	163.05	73.96	0.07396	7.3960E-08	2.0169E-08
Liquid Petroleum (LP)	138.85	62.98	0.06298	6.2980E-08	1.7175E-08
Kerosene (KER)	165.79	75.20	0.0752	7.5200E-08	2.0507E-08
WOOD	206.79	93.80	0.0938	9.3800E-08	2.5579E-08

Source: EPA (2010); Author's Calculations

The next step was to regress the sampled cases in the RECS/CBECS datasets (based on variables described in Chapter 6) to isolate the building characteristics and locational variables that best predict the likelihood of a house combusting a fuel as a source of heating or cooking. Only household and location variables were selected to match the data available for residential units. Where the RECS/CBECS datasets contained more specific data on building cooking equipment and heating and cooling (HVAC) equipment age, the local data that the regression results were applied to contain a more limited set of characteristics, but did include important variables like the number of fireplaces and the type of heating and cooling unit.

A binary logistic (logit) regression equation is used in the first part of a nested mixed-model approach. The logit model predicts the probability of an individual building unit combusting fuel. The form of the model is as follows:

$$logit[\theta(CO_2)] = log\left[\frac{\theta(CO_2)}{1-\theta(CO_2)}\right] = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + +\beta_i x_i \qquad (1)$$

Where $\theta(CO_2)$ is the probability of a unit producing CO2, α is the constant, and β_i is the regression coefficient of variable x_i.

Applying the regression to the available independent variables (IVs) to maximize statistical significance yields the following model (with model fit, coefficients, and significance provided in the results section):

$$logit[\theta(CO_2)] = f(B_1, L_1, C_1) \qquad (2)$$

Where the probability of a residential unit producing CO2 is a function of a vector of building (B), location (L), and climate (C) attributes.

Measuring the total building CO2 emissions is a linear function expressed as follows:

$$Tons_{co_2} = \gamma + \delta_1 x_1 + \delta_2 x_2 + \cdots + +\delta_i x_i + \varepsilon \qquad (3)$$

Where $Tons_{co_2}$ is the total building unit CO2, γ is the constant, and δ_i is the regression coefficient of variable x_i, and ε is the error term.

The full nested model form is thus:

$$logit[\theta(CO_2)] = f(x) = \begin{cases} 1, & x < .50 \\ 0, & x \geq .50 \end{cases}$$

(4)

$$CO_2 = logit[\theta(CO_2)] \times f(B_2, L_2, C_2)$$

CO_2 Reductions – Retrofit and Weatherization

One emission reduction strategy called EmPower Maryland (see Chapter 5) seeks emissions directions at the building unit level by subsidizing the weatherization of affordable housing units. The quantification of these weatherization benefits can be full of uncertainty because of great variety in type, size, and equipment of a housing unit and the behavior of the occupants. To generalize the CO2 reductions, the National Weatherization Assistance Program's residential national energy audit tool (NEAT), version 8.9 ("Weatherization Assistant 8.9", 2013) was used to specify the savings of a typical affordable housing unit follow a methodology used in the literature (Eisenberg, 2010; Talwar, 1979; Brown, 1993; Berry & Schweitzer, 2003; Berry, 1997). Using the audit tool, the BTUs of energy saved for a single level wood construction 1,300 square foot slab foundation home with an insulated attic and medium leakage doors and windows was specified with typical equipment including a natural gas furnace with a continuously lit pilot light and non-programmable thermostat and a 15-year-old refrigerator. The savings in millions of annual BTUs were then converted to pounds of CO2 using the natural gas conversion factor from Table 3 of this chapter.

The CBECs 2003 dataset was used to quantify CO2 emission reductions from retrofitting and weatherizing commercial buildings. This dataset contains sample data of commercial buildings including variables for fossil fuel consumption (which is converted to CO2,), renovations of HVAC systems, insulation, windows, and the presence of efficiency measure such as energy management systems and HVAC turn down. OLS regression was performed on the dataset to derive the CO2 reduction factors associated with retrofits and weatherization then applied to the characteristics of the real Maryland property data.

Indirect CO_2 Emissions – Electricity Consumption

While some building units directly produce emissions by combusting fuel on-site; nearly all buildings indirectly cause CO2 emissions through electricity demand. This demand, like direct CO2 emissions, can be estimated based on a set of building characteristics.

Measuring the total BTUs of electricity consumption is similar to the CO2 analysis but since every residential unit in the sample consumes some amount of electricity, a probability model is not necessary. Instead, the regression equation is a simple linear form:

$$BTU_{EL} = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + +\beta_i x_i + \varepsilon \qquad (5)$$

where BTU_{EL} is the total BTUs of electricity consumed for the building unit, α is the constant, β_i is the regression coefficient of variable x_i, and ε is the error term.

The regression results were applied to the available independent variables (IVs) to maximize statistical significance and yield the following model (with model fit, coefficients and significance provided in Chapter 6):

$$BTU_{EL} = f(B_3, L_3, C_3) \qquad (6)$$

The building unit emissions and energy consumption models were applied to Maryland property records. Each building unit was then assigned to the location zone. Units were separated based on either 1) housing type (single or multifamily) or 2) business type (retail, service, industrial and other). Each of the building unit types were grouped together by zone to develop an average emissions profile by building type for all Maryland zones. The average emissions were then applied to the building unit, by type, and counts in each zone. This process was first completed for the year 2006 and again for 2020. The procedure allowed for testing of future land use and building efficiency standards.

Power Generation Emissions

CO_2 emissions from the power generation sector were much simpler to calculate. In this case, the available data on each powerplant serving Maryland directly or through the PJM interconnection was provided by the Emissions & Generation Resource Integrated Database (eGRID). Since all major power plants operate on a grid, they operate at a given capacity at all times, not reducing output as demand falls. Thus, the analysis requires only an inventory of base-load emissions from energy to CO_2 multipliers. Any change in emissions will generally not come from a reduction on electricity demand but from CO_2 reductions from either efficiency gains or power source (fuel) change.

Vehicle (Mobile) Emissions

For the estimation of vehicular emissions, a number of planning agencies enter pollutant specific rates and congested speeds from traffic assignment into a post processor. The traffic flow in the network was determined by solving the traffic assignment problem under the condition of user equilibrium (Sheffi, 1985). The fundamental aim of the traffic assignment process was to reproduce, in the transportation demand model, the pattern of vehicular trips/personal trips observed on the actual highway network by employing behavioral models and assigning to the network an estimated demand for travel (represented by the trip matrix, or matrices). This assignment procedure, reproducing observed network conditions, is called the Base-case in this paper. The Base-case user equilibrium formulation is provided in the Appendix, Part One. The complete model structure was implemented within the transportation planning software, Cube Voyager.

The vehicle emissions estimations, as previously mentioned, used a traditional four-step approach to replicate observed travel behavior. The following section describes the model steps generally and then describes each of the emission reduction mechanisms with an explanation of how each mechanism functions within the basic model framework.

Four-Step-Model Framework

Trip Generation

The trip generation model estimates total productions TPp(A) and attractions Tap(A) for each type represented by (purpose) p for all trips produced in a zone and all trips attracted to a zone:

$$P_i^p = T_p^p(A) \quad (7)$$

$$A_i^p = T_a^p(A) \quad (8)$$

where Pip is the total trip productions generated for trip type p for zone i, Ajp are the total trip attractions for trip type p for zone j, and A is the activity system characteristics.

Trip Distribution and Destination Choice

The utility U_{ijn} of choosing a trip attraction destination j for a trip n produced in zone i is given by:

$$U_{ijn} = S_j + \alpha L_{ij} + \sum \beta^k D_{ij}^k + \sum \beta^k D_{ij}^k N_n^k + \sum \beta^k Z_j^k + C_{jn} \quad (9)$$

where, S_j is the size (area) variable for destination zone j, L_{ij} is the mode choice logsum between zone pair ij, D_{ij}^k represents the various distance terms (linear, log, squared, cubed and square root), N_n^k represents person, household or production zone characteristics for trip n and is used for creating interaction variables with distance terms, Z_j^k represents attraction zone characteristics (other than the size term), and C_{jn} is a correction term to compensate for the sampling error in the model estimation (i.e., it represents the difference between the sampling probability and final estimated probability for each alternative). The size variable may consist of several different terms and up to four categories of employment in addition to households were used. Weights (β^k) for each term in the size variable were estimated along with all other model parameters as follows, where E_j^k is employment of type k in zone j:

$$S_j = log\left(\sum \beta^k E_j^k\right) \quad (10)$$

The destination choice model provides O-D demand for all trip purposes.

Mode Choice

A nested logit structure was formulated for mode choice, which was based on generalized utility functions for auto and transit travel. Separate utilities were developed to represent mode choice by trip purpose and time of day. The mode choice utility function is represented as follows:

The complete utility function for mode choice is as follows:

$$\begin{aligned} U_m^p = \pi_m^p + {\beta_1}_m^p IVTT_m^p + {\beta_2}_m^p TET_m^p + {\beta_3}_m^p \times AOC_m^p + {\beta_4}_m^p PC_m^p \\ + {\beta_5}_m^p \tau_m^p + {\beta_6}_m^p WT_m^p + {\beta_7}_m^p IWTa1_m^p + {\beta_7}_m^p IWTb_m^p \\ + {\beta_8}_m^p NOT_m^p + {\beta_9}_m^p TF_m^p + {\beta_{10}}_m^p DA_m^p \end{aligned} \quad (11)$$

Where π_m^p is a mode specific constant for mode m, and purpose p; β in each term is the mode and attribute specific coefficient; $IVTT$ is the in-vehicle travel time, TET is the terminal time, AOC is the auto operating cost, PC is the parking cost; τ is the toll value, WT is the waiting time, $IWTa$ is the initial waiting time less than 7.5 minutes; $IWTb$ initial waiting time greater than 7.5 minutes; NOT is the number of transfers, TF is the transit fare; and DA is the drive access time. The mode choice model results in splitting O-D trip matrices into 11 travel modes (3 auto modes and 8 transit modes). Three auto modes refer to Single Occupant Vehicles (SOV), High Occupant Vehicles with two occupants (HOV-2), and High Occupant Vehicles with three or more occupants (HOV-3+). Eight transit modes included walk and drive to bus, express bus, rail, and commuter rail.

Trip Assignment

This principle was based on the fact that individuals chose a route in order to minimize his/her travel time or travel cost and such a behavior on the individual level created equilibrium at the system (or network) level over a long period of time (Sheffi, 1984). Simply, for each origin-destination (O-D) demand pair, the travel-cost/travel-time on all used routes of the road network should be equal.

$$Minimize \sum_{a} \int_{0}^{x_a} (t_a(x_a)) \tag{12}$$

Subject to:

$$\sum_{r} f_{ij}^{r} = q_{ij} \tag{13}$$

$$x_a = \sum_{i} \sum_{j} \sum_{r} f_{ij}^{r} \, \delta_{a,ij}^{r} \tag{14}$$

$$f_{ij}^{r}, q_{ij}^{r} \geq 0 \tag{15}$$

Equation (12) represents that at equilibrium the network will satisfy User Equilibrium (UE) condition, i.e. travel time on all the used routes connecting any given i-j pair will be equal. The term, t_a, is the travel time for link a, which is a function of link flow x_a. Equation (13) is a flow conservation constraint to ensure that flow on all paths r, connecting each Origin-Destination (O-D) pair (i-j) is equal to the corresponding demand. In other words, all O-D trips must be assigned to the network. Equation (14) represents the definitional relationship of link flow from path flows. Equation (15) is a non-negativity constraint for flow and demand. The travel time function t_a is specific to a given link 'a' and the most widely used model is the Bureau of Public Roads (BPR) function given by

$$t_a(x_a) = t_o\left(1 + \alpha_a \left(\frac{x_a}{C_a}\right)\right)^{\beta_a} \quad (16)$$

where t_o is free flow time on link 'a', and α_a, and β_a are constants (and vary by facility type). C_a is the capacity for link a. In the base model, the objective is minimization of total system travel time.

Integrated Mobile Emissions

The Mobile Emissions Model (MEM) is a CUBE-based model that uses emission rates calculated by the MOVES2010a EPA model developed for conformity purposes in non-attainment areas. The MOVES model uses generalized national data such as vehicle fleet age distributions with localized county data such as average hourly temperatures and fuel mixtures to produce emission rates for every vehicle and miles traveled in Maryland. These rates are then applied to the TDM produced trip tables and loaded networks to calculate model-wide summary emissions output and link level (road segment) emissions in the network.

Mobile Emission Modeling Framework

There are two parts to the MEM modeling framework. The first model, called MOVES2010, was developed by the EPA for modeling emissions for conformity strategies in non-attainment areas. The second model is based in CUBE transportation modeling software. This model applies emission rates generated by MOVES to the TDM outputs.

General Specifications

Timeframe - Emissions are modeled for all three of the model scenario years 2000, 2007, and 2030. Each year will use a separate set of inputs to reflect changes in fleet age distribution, fuel formulation, VMT, vehicle population, and the underlying highway network.

Geographic Scale - The Mobile Emissions Model covers the entire state of Maryland with traffic sheds from Delaware and portions of southern Pennsylvania, northern Virginia, West Virginia, and southwest New Jersey. See Figure 19 for a map of the study area.

Figure 19. MEM Study Area Map.

Roads - Emissions are modeled for all roads included in the TDM network composed of major collectors, arterials, highways, and interstates. Emissions for intrazonal trips using centroid connectors (local roads not in the travel demand model network represented by a single link between the centroid of a zone and the highway network), that is, vehicle trips that do not leave a modeling zone and therefore are not calculated in the model's vehicle trip table are calculated using a special procedure (described in section 3.3) so that even emissions from local trips are included.

Vehicles - The MEM captures all vehicle trips within the region based on the vehicle trip table produced by the transportation model. Emission rates are calculated for a variety of EPA defined vehicles based fleet compositions of Maryland constituent counties for specific model years. Vehicles considered in this model are described in Table 4.

EPA MOVES Model

MOVES is the EPA's mobile emissions model designed to measure emissions inventories in areas of environmental non-attainment[2]. It is used to model pollutants from vehicle starts and from regular driving.

> MOVES (MOtor Vehicle Emissions Simulator) is a computer program designed by the US Environmental Protection Agency (EPA) to estimate air pollution emissions from mobile sources. MOVES2010 (hereafter referred to as MOVES) replaces EPA's previous emissions model for on-road mobile sources, MOBILE6.2. MOVES can be used to estimate exhaust and evaporative emissions as well as brake and tire wear emissions from all types of on-road vehicles (US EPA, 2010).

Moves offers two levels of inputs depending on the project specifications. For projects related to air quality conformity, many of the inputs must be locally generated and are quite data intensive. For all other uses related to modeling emissions, generic

[2] Areas of the state where air pollution levels persistently exceed the national ambient air quality standards may be designated "non-attainment."
http://www.epa.gov/airquality/greenbook/

inputs estimated at both the county and national level used as default data in the EPA model (developed by EPA) can be used. These inputs included information on meteorology, vehicle fleet type and age distribution, average speed distribution, road type distribution, and fuel formulation and supply.

Meteorology – Temperatures at which vehicles are started and operated are an important factor in estimating the level of emissions produced by motor vehicles. Temperature can have a substantial impact on the emission level of several important pollutants. Another factor considered in the meteorology of emissions is humidity, which has an impact on the level of nitrogen oxides (US EPA, 2010). MOVES uses meteorology data gathered by month and hour for each county in the study area. For purposes of modeling emissions in Maryland, the temperatures and humidity of July are used in MOVES to represent a worst-case scenario during the peak of the regional ozone season.

Source Type – Part of the MOVES output includes emission rates by source type (vehicle type). MOVES calculates emissions for vehicles categorized into 13 source types (Table 4), which are subsets of six HPMS[3] vehicle types in MOVES.

MOVES produces emission rates for start and non-running evaporative emissions by source type in terms of grams per vehicle. Total start and non-running evaporative emissions are then calculated outside of MOVES by multiplying the

[3] "The Highway Performance Monitoring System (HPMS) is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the Nation's highways. In general, the HPMS contains administrative and extent of system information on all public roads, while information on other characteristics is represented in HPMS as a mix of universe and sample data for arterial and collector functional systems. Limited information on travel and paved miles is included in summary form for the lowest functional systems. The HPMS was originally developed in 1978 as a continuing database to replace special biennial condition studies that had been conducted by the States since 1965. The HPMS has been modified several times since its inception, most recently in 1998; changes in coverage and detail have been made since 1978 to reflect changes in highway systems, legislation, and national priorities, to reflect new technology, and to consolidate or streamline reporting requirements." http://www.fhwa.dot.gov/policy/ohpi/hpms/abouthpms.cfm

emission rates by the vehicle populations for each source type. (US EPA, 2010)

Table 4

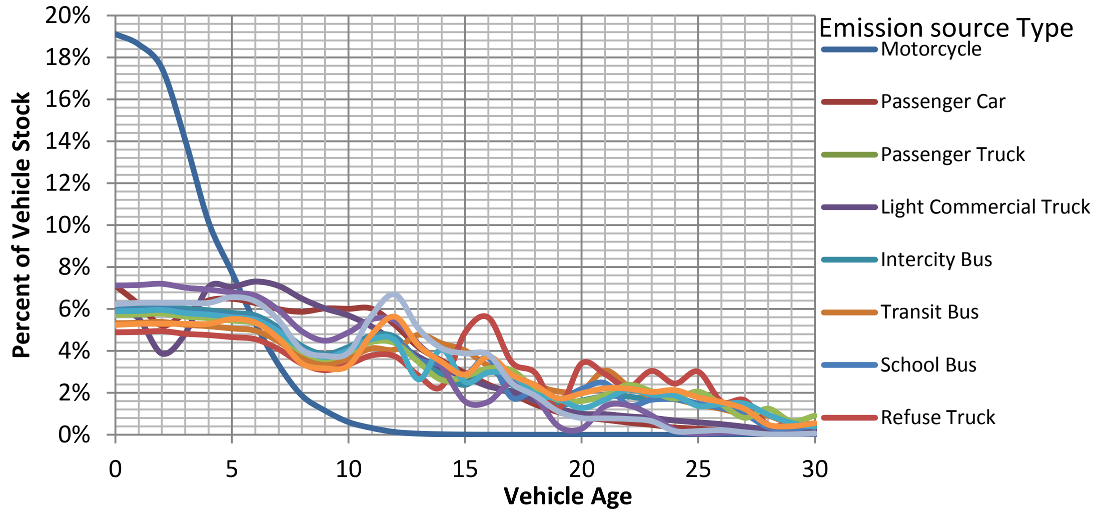
MOVES Source Types and HPMS Vehicle Types

MOVES Vehicle Specification		HPMS Vehicle Specification	
Source Type ID	Source Types	Vehicle Type ID	Vehicle Type
11	Motorcycle	10	Motorcycles
21	Passenger Car	20	Passenger Cars
31	Passenger Truck	30	Other 2 axle-4 tire vehicles
32	Light Commercial Truck	30	Other 2 axle-4 tire vehicles
41	Intercity Bus	40	Buses
42	Transit Bus	40	Buses
43	School Bus	40	Buses
51	Refuse Truck	50	Single Unit Trucks
52	Single Unit Short-haul Truck	50	Single Unit Trucks
53	Single Unit Long-haul Truck	50	Single Unit Trucks
54	Motor Home	50	Single Unit Trucks
61	Combination Short-haul Truck	60	Combination Trucks
62	Combination Long-haul Truck	60	Combination Trucks

Source: EPA Motor Vehicle Emission Simulator, 2010 (MOVES 2007)

Age distribution: The age of vehicle fleets have an impact on the level of calculated emissions in a given area. In order to accurately model emissions, a fleet with a variety of vehicle ages must be included. For each model year, MOVES covers a fleet of vehicles with a mix of ages up to 31 years, with vehicles greater than 30 year old grouped in the last category (US EPA, 2010). The EPA recommends developing local data for conformity purposes, but offers yearly default distributions for all other purposes. Due to the significant data requirements that would be needed to use local Maryland data, default age distribution is used. It is assumed that given the very large Maryland study area, vehicle age distributions trend towards the national population. “The default age distributions in MOVES are specific for each calendar year and include assumptions about changes in age distributions over time” (US EPA, 2010). A sample age distribution for the year 2011 is provided in

Figure ***20***.



Source: EPA Motor Vehicle Emission Simulator, 2010 (MOVES, 2007)

Figure 20. Sample Default MOVES Vehicle Fleet Age Distribution, 2011.

Average speed distribution: "Vehicle power, speed, and acceleration have a significant effect on vehicle emissions. MOVES models those emission effects by assigning activity to specific drive cycles or operating mode distributions" (EPA 2010). The MEM takes congested roadway speeds developed in the traffic assignment portion of the transportation model, sorts the speed for each link into EPA defined speed bins, and appends the bin to the highway link. Using these pre-defined speed bins, running emission rates were calculated for each link. Table 5 provides a listing of the EPA defined speed bins.

Table 5

MOVES Defined Speed Bins

Speed Bin ID	Average Bin Speed	Speed Bin Range
1	2.5	speed < 2.5mph
2	5	2.5mph <= speed < 7.5mph
3	10	7.5mph <= speed < 12.5mph
4	15	12.5mph <= speed < 17.5mph
5	20	17.5mph <= speed <22.5mph
6	25	22.5mph <= speed < 27.5mph
7	30	27.5mph <= speed < 32.5mph
8	35	32.5mph <= speed < 37.5mph
9	40	37.5mph <= speed < 42.5mph
10	45	42.5mph <= speed < 47.5mph
11	50	47.5mph <= speed < 52.5mph
12	55	52.5mph <= speed < 57.5mph
13	60	57.5mph <= speed < 62.5mph
14	65	62.5mph <= speed < 67.5mph
15	70	67.5mph <= speed < 72.5mph
16	75	72.5mph <= speed

Source: EPA Motor Vehicle Emission Simulator, 2010 (MOVES, 2007)

Road type distribution: The amount of VMT on varied road types can have a significant effect on overall emissions from on-road mobile emission sources. MOVES accounts for this differentiation in roads by cross-classifying emission rates by five road types:

Off-Network (roadtype 1) – all locations where the predominant activity is vehicle starts, parking, and idling (parking lots, truck stops, rest areas, freight, or bus terminals).

Rural Restricted Access (2) – rural highways that can only be accessed by an on-ramp.

Rural Unrestricted Access (3) – all other rural roads (arterials, connectors, and local streets).

Urban Restricted Access (4) – urban highways that can only be accessed by an on-ramp.

Urban Unrestricted Access (5) – all other urban roads (arterials, connectors, and local streets) (US EPA, 2010).

The MEM categorizes each of the TDM network links into these MOVES defined road types so that emission rates at the link level reflect the unique parameters of area and facility type.

Fuel formulation and supply: Fuel formulation and supply have an impact on the amount and type of pollutants produced by vehicle fleets. MOVES models these differences in fuel formulation and fuel supply at the county level for the area being modeled. The fuel formulation attributions table defines the chemical composition of local fuel (such as sulfur level, ethanol volume, etc.) while the fuel supply attribution table identifies and assigns market share for the fuel formulations used in an area. MOVES calculates fuel composition based on the attributes defined in the fuel formulation table then uses the market shares from the fuel supply attribution table to create weighted fuel adjustment factors to determine total pollutant emission rates.

> MOVES has default gasoline and diesel fuel formulation and supply information for every county-year-month combination that can be selected. The default fuels in each county were developed from two sources: 1) the NMIM County Database (NCD), which incorporates data from local, regional (refinery-level), and RFG fuel surveys, for years up to 2005; and 2) the Energy Information

Administration's Annual Energy Outlook 2007, which projected fuel usage for 2012 (all later years are identical to 2012). Values for some fuel properties were interpolated in the gap between 2005 and 2012 to generate a consistent trend. (US EPA, 2010)

The MEM models emissions for two fuel formulations, gasoline, and diesel. The EPA describes the chemical composition of each fuel and its impact on emission in each county as follows:

Gasoline: The Tier 2 gasoline sulfur rule established a national average of 30 ppm sulfur (S) and a cap of 80 ppm S, which was fully implemented in 2006 (except for the Geographic Phase-In Area, see 65 FR 6755, February 10, 2000). This means that some areas will have sulfur levels above 30 ppm S and users creating a new formulation should not assume 30-ppm S gasoline. Areas where the MOVES default gasoline sulfur level is above 30 should use this value unless local data on sulfur content are available. MOVES2010 does not provide additional benefits or reductions for sulfur levels below 30 ppm S.

Diesel: Between 2006 and 2010, the Ultra-Low Sulfur rule requires at least 80% of the highway diesel fuel sold to meet the 15-ppm S standard; the remaining 20% must meet the Low Sulfur Diesel standard of 500 ppm S. In the Regulatory Impact Analysis for the Non-road Diesel rule (RIA: EPA420-R-04-007, Rule: 69 FR 38957, June 29, 2004), a weighted average of the sulfur level in diesel fuel was estimated as 43 ppm S and in many areas, the MOVES default sulfur level value is 43 ppm S for these years because the singular value from the NCD was used to generate the fuel properties in

MOVES. The default-weighted value is acceptable if users do not have local data in this instance because the diesel sulfur value influences the fuel adjustment in a linear fashion for all emission calculations. However, users can also enter two diesel fuel formulations, with sulfur level of 11 and 331 and market shares of 0.9 and 0.1, respectively, which would yield an average sulfur level of 43 ppm S and be more representative of actual fuel usage. If users have volumetric data for diesel fuel sulfur levels in the area being modeled, this information can be entered in the sulfurLevel and marketShare fields of the fuelformulation and fuelsupply tables, respectively. (US EPA, 2010)

Emissions Model Software

Benefits of Modeling in CUBE: There are many benefits to modeling emissions for the travel demand model in CUBE. The process allows for streamlined emissions calculations by minimizing the number of times MOVES needs to be run. This results in shorter run times since rates are calculated faster in MOVES than calculating total emissions within the MOVES software package. Outputs for use in MEM are in summary tables in .csv and .dbf format that can be input into the CUBE based model for faster total emissions calculations.

MOVES outputs are simply exported from an SQL server where the emission rate tables were created and then placed into the input folder. This structure reduces human error by eliminating the need for interaction with the model or the need to adjust settings. The model structure is further beneficial since unlike other emissions models, emissions are calculated at the link-level and results are appended to each link on the TDM highway network.

The MEM uses the MOVES Emissions Rate (Factor) Model to measure emissions across the entire network. The emission rates (emissions per unit of distance for running emissions or per vehicle for starts, extended idle and resting evaporative emissions) are created in a look-up table format that is then applied to the appropriate figures from the uploaded TDM network. Emissions rates are output from MOVES input into MSTM as part of the emissions model. The mobile emissions model generates no emissions data so rates that come from MOVES are applicable for every run of the model. Changes in the underlying highway network, vehicle population, or VMT will not necessitate re-runs of MOVES. Only changes in model year require a new run to develop fresh emission rates.

Overview of the Emissions Model process

The MEM has four explicit steps that must be run to calculate total Maryland emissions. These steps are described in detail below and outlined in Figure 21. They include the development of emission factors, preparation of Maryland and MOVES data, calculations of intrazonal VMT, and application of emission rates by total output tables, and at the link level on a network.

Step 1: Develop emissions factors from MOVES2010. Emissions are categorized by speed bin, pollutant, and model year. Emissions are further classified by multipliers relating to Grams per mile (running emissions) and Grams per vehicle (non-running emissions). The Mobile Emissions Model reformats MOVES output emissions factors for input into MSTM model.

Step 2: Prepare TDM DATA. This step categorizes congested speeds from the assigned network into HPMS and MOVES pre-defined speed bins through a link read phase. Vehicle miles traveled within the network are calculated for application to the running emission rates. This procedure also requires calculating intrazonal VMT, which in itself takes several steps. First, intrazonal VMT is calculated by assuming an intrazonal travel distance of one-half the average distance between the nearest three zones by skimming the loaded TDM network to get the congested travel time on each link. This VMT is then appended to centroid connectors. Second, intrazonal VMT is determined by multiplying the new intrazonal time matrix by the vehicle trip matrix. With the intrazonal trips calculated in the new trip matrix, the intrazonal VMT is appended to the network. The intrazonal VMT is pro-rated by the total VMT distribution between centroid connectors within the zone. The pro-rated VMT is appended to each centroid connector in the network. Finally, emissions factors are applied to the centroid connectors by five miles per hour speed bins. A 25 mph speed is applied to all centroid connectors to reflect a likely average speed along local roads that are not represented in the TDM Network.

In the second part of step two, MOVES road types are matched and appended to the TDM network based on facility type and area type. Additionally, HPMS functional classification codes are appended to the TDM network. It is important to account for intrazonal trips, as they are not directly captured in the TDM loaded network, so emissions estimates without these trips have undercounts of total pollutants.

Step 3: This step is an intermediate process to create HPMS Adjustment Factors. Link level VMT is aggregated by HPMS functional class. HPMS adjustment factors are then calculated using the ratio of HPMS VMT to model VMT. The new HPMS adjustment factors are applied to VMT estimates at the link-level by HPMS functional class.

Step 4: The final model step is the emissions calculation. Running emissions are calculated by applying emissions factors per mile to model VMT for each link. Aggregate link-level emissions are also calculated by HPMS functional class and pollutant. Non-running emissions are calculated by applying emissions factors per vehicle to the pre-calculated vehicle population. Link level emission rates are appended to the MSTM network and running and non-running emissions by HPMS functional class by pollutant are summed.

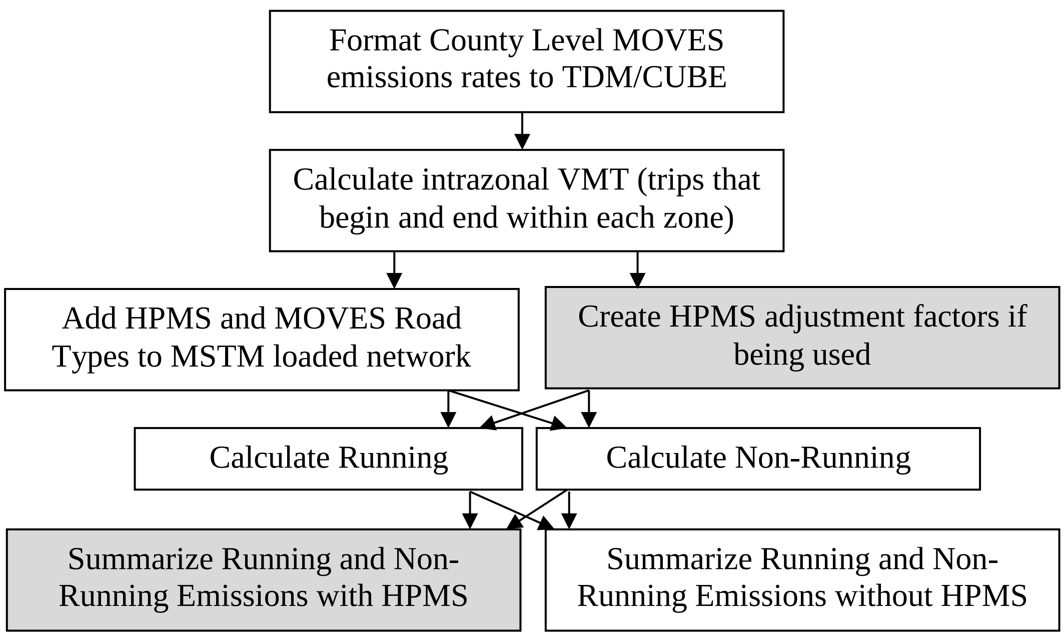


Figure 21. Mobile Emissions Model Flow Chart.

Mobile Emission Model Outputs

MOVES and MEM account for several forms of emissions. Within the two broad categories of running and non-running emissions, six sources are considered. For running (when vehicle is in motion) tailpipe exhaust, crankcase (engine), and evaporative emissions are calculated. For non-running (when vehicle is stationary) start exhaust, refueling, and evaporative emissions are calculated. A summary table of pollutant types is produced along with a new highway network with emissions calculated for every link.

Mobile Emission and Transport Model Integration

Aside from simply using the emissions model to calculate total link level emissions, it is fully integrated with the highway assignment module of the travel demand model. Figure 22 shows a flowchart of the solution algorithm for both the Base-case and the other transportation emissions reduction models. The algorithm relies first on inputs commonly found in demand models, which includes the characteristics of the transportation networks (highway and transit); socio-economic and other inputs needed for the trip generation, destination choice, mode choice, and traffic assignment programs. The traffic assignment is solved with a Frank Wolfe algorithm (Sheffi, 1985) when the model has met the convergence criteria, the next model begins by running the first group of programs in the emissions model to setup the emissions inventory derived from the Base-case.

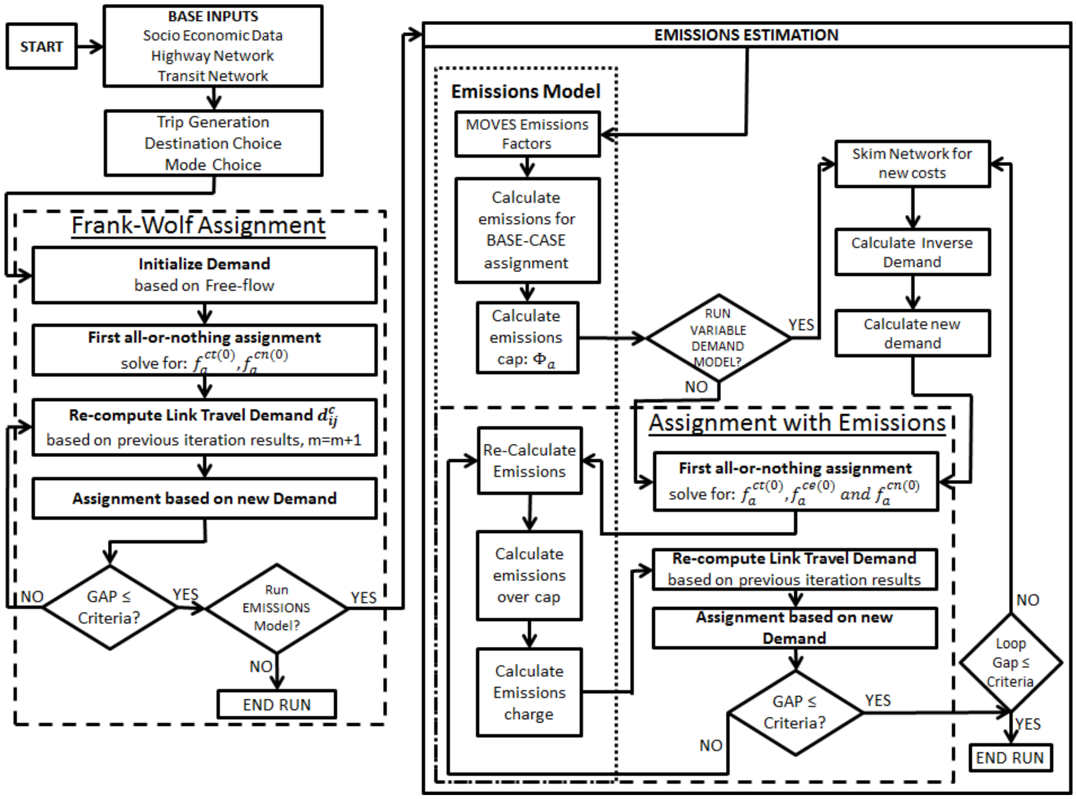


Figure 22. Mobile emissions integration solution methodology.

Variables, assumptions, and sources of data

Variables

Each of the variables used on the analysis for this paper are described in Table 6 below.

Table 6

Notations for Model Formulations

Notation		Explanation
C_1	:	The average commute cost from the commute optimization operation
C_1	:	Average commute before optimization
C_2	:	Average commute cost after optimization
C_a	:	The capacity for link a
C_{excess}	:	The excess commute derived from commute optimization
D_{ij}^k	:	Various distance terms (linear, log, squared, cubed and square root)
e_a	:	Emission price
f_{ij}^r	:	Flow on path *r*, connecting each Origin-Destination (O-D) pair (*i*-*j*)
l_a	:	Distance for link a
q_{ij}	:	Demand between each Origin-Destination (O-D) pair (*i*-*j*)
t_a	:	Travel time for link a
$t_a(x_a)$	:	Travel cost on link *a* as a function of flow
t_{ij}	:	Travel cost between origin *i* and destination *j*
$u_a^I(x_a, e_a,)$	:	Travel time function which incorporates emission pricing term e_a
$u_a^{II}(x_a, \theta_a,)$	:	Travel time function which incorporates VMT tax term θ_a
$u_a^{III}(x_a, \sigma)$	:	Travel time function which incorporates gas tax term σ
u_a	:	User cost for link a
u_{ij}^c	:	Least cost path between O-D pairs *i*-*j*
x_a	:	Flow for link a
α_a	:	Constant, varying by facility type (BPR function)
β_a	:	Constant, varying by facility type (BPR function)
β^k	:	Weights for each term in the size variable (S_j)
γ^c	:	Value of time (VOT) for user class c
$\delta_{a,ij}^r$	:	Flow on link a, a subset of path *r*, connecting each Origin-Destination (O-D) pair (*i*-*j*)
τ_a	:	Toll value for link a
Φ_a	:	Emissions cap for each link a
ϕ_a	:	Total emissions for link a
c	:	User class
d_{ij}	:	The number of commuter trips between *i* and *j*
n	:	Assignment iteration number
T	:	The total number of commuters
t_o	:	Free flow time on link a
φ	:	Emissions charge per gram of emissions, in cents
ω	:	A positive constant (exponential demand function)

Assumptions

A number of assumptions and simple extrapolations, forecasts, and calculations were made through the dissertation. Most of those assumptions and forecasts along with their rationale are described below.

Fleet Efficiency and CAFE Standards

Using current total highway miles reported through the Federal Highway Admiration's (FHWA) Highway Performance Monitoring System (HPMS) for each state and fuel consumption data for the same period from EIA, the average fleet fuel economy was estimated. Figure 23 shows the national average fuel economy for the years 1970 through 2010. The results indicate that economy increased with initial implementation of CAFE[4] standards in the 1970s but has held relatively constant (with CAFE) from 1990 to 2010. The 2006 LDV economy used on the transportation demand and emissions model was 24.45 mpg.

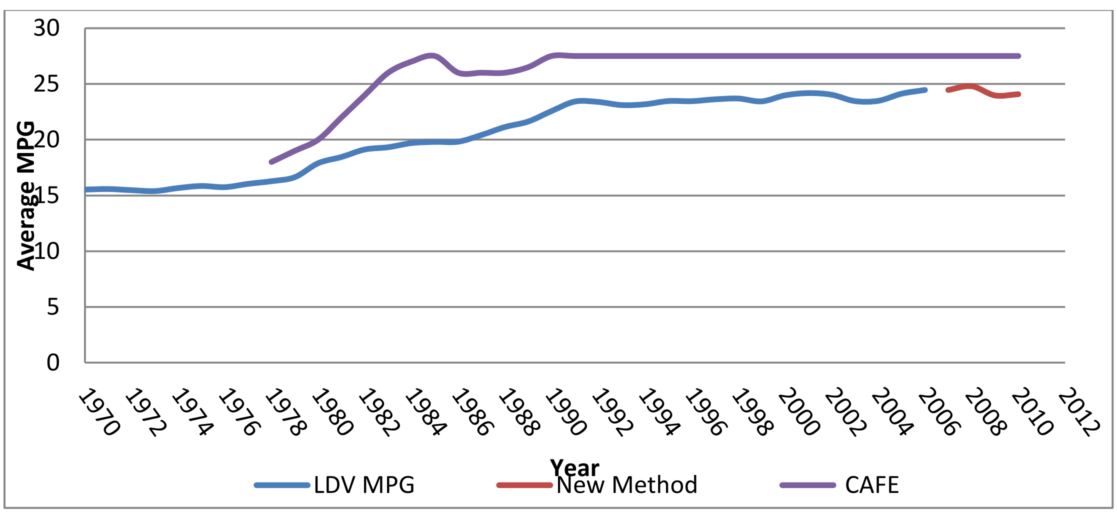


Figure 23. Historical CAFE Standards and Average US Fleet Economy.

---

[4] Corporate Average Fuel Economy (CAFE) standards are federal regulations that require auto makers to produce their fleet of passenger cars and light duty truck with a specific average fuel economy.

Emissions for the year 2020 were estimated based on historic efficiency trends and future CAFE standards using a 4th order polynomial forecasting method. In 2006, the CAFE standard was 27.5 mpg, that standard increases 34.1 mpg in 2016, and 54.5 in 2025. The resulting 2020-estimated LDV fleet average economy is 32.66, shown in Figure ***24***.

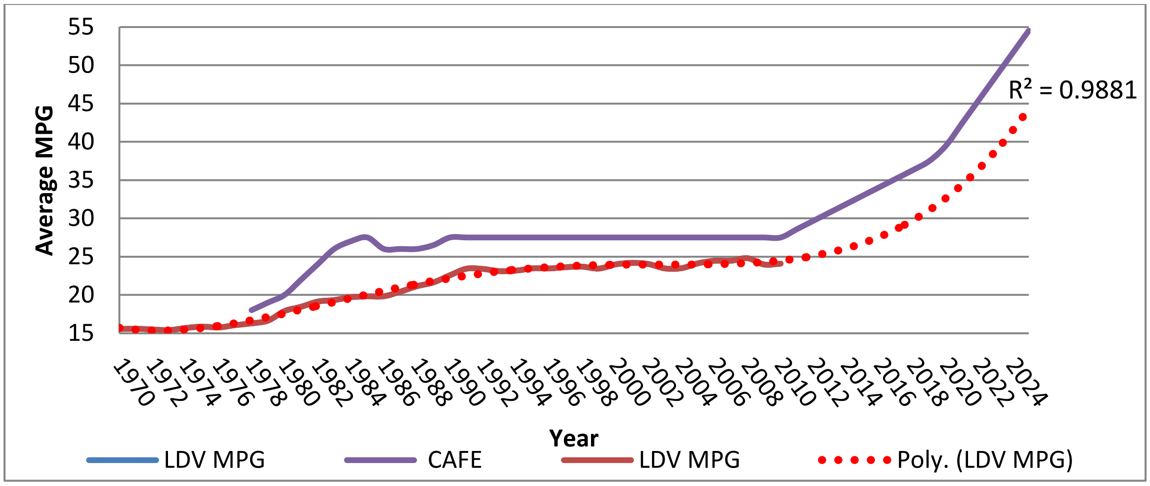


Figure 24. Historical & Projected CAFE Standards and Average US Fleet Economy.

Consumer Price Index

Vehicle fuel economy is one factor that affects the auto operating cost over time. Another important factor is the rate of inflation. This is measured by the Consumer Price Index (CPI). Using national CPI data, a linear project (which assumes no major economic anomalies) estimates the 2020 CPI. The same technique is used to estimate the nominal price of gas to the year 2020. The estimates are show in Figure 25.

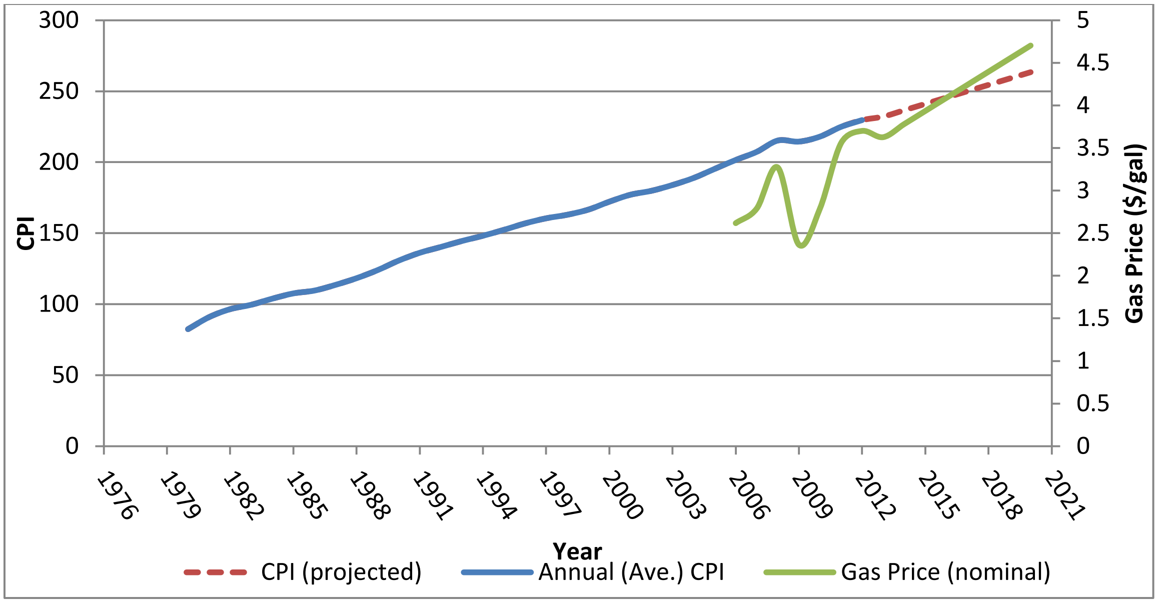


Figure 25. Historical & Projected CPI and Fuel Price.

Auto Operating Cost

Combining fuel efficiency, gas prices, inflation, and fixed auto operating cost with the pricing scenarios in the transportation demand model results in the total AOC used in each transportation scenario, shown in Figure 26.

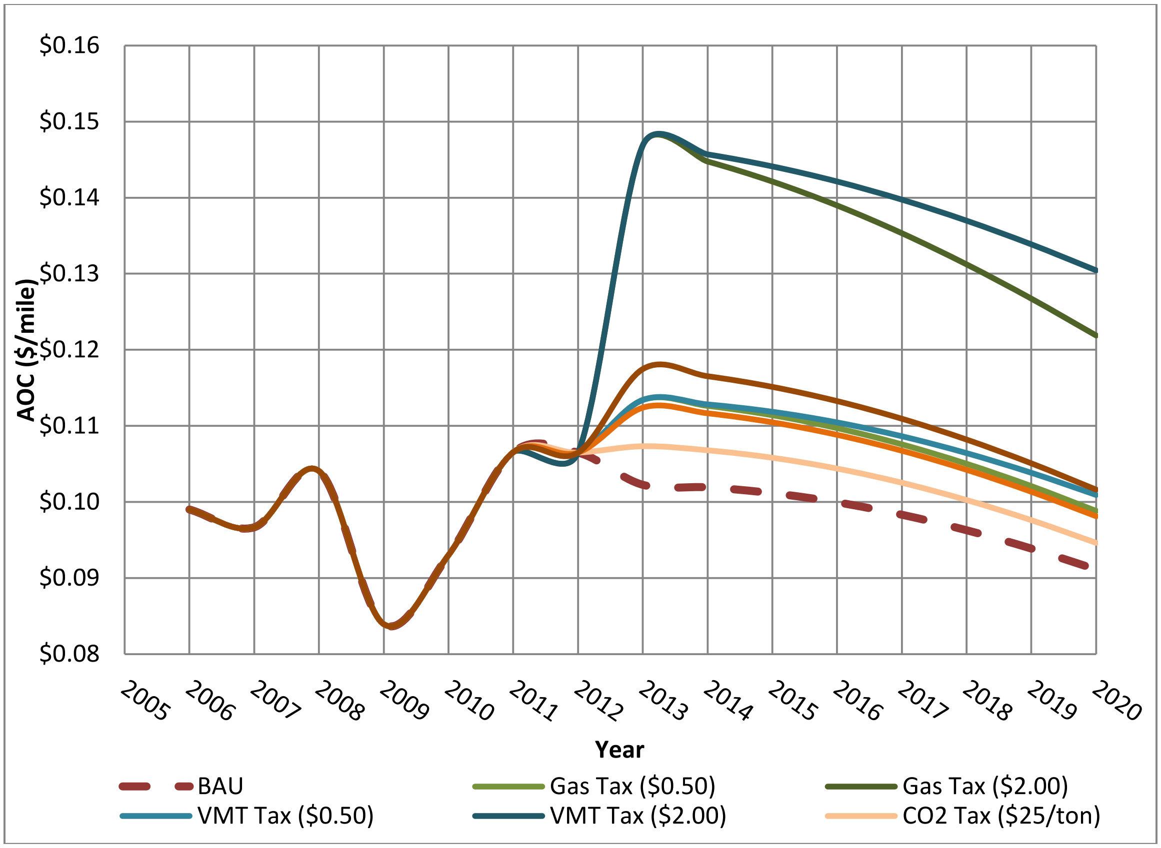


Figure 26. Scenario Auto Operating Cost ($/mi, 2000 Constant Dollars).

Data Sources

Data derived for the transportation, building emission and energy consumption models, statistical and policy analysis of energy consumption and power plant emissions is listed in Table 7, with the sources of the data.

Table 7

Sources of data sets

Data	Source
Atmospheric CO2 Concentrations	Mauna Loa Observatory (Scripps / NOAA / ESRL
Building footprints	Derived from MD county sources
Census divisions	EIA
Census regions	EIA
Commercial Energy Consumption	EIA CBECS
Consumer Price Index (Baseline Data)	U.S. Bureau of Labor Statistics
Energy consumption to CO2	EPA
Energy conversion factors	EPA
Energy Reserves	BP Statistical Review of World Energy
Feul Efficiency Standards	EPA CAFE
Heating and Cooling Degree Days	NOAA National Climatic Data Center
Historic Gas Prices	EIA
Manufacturingl Energy Consumption	EIA MECS
Maryland Emissions Data	Maryland Department of Envirment and EIA
National Motor Fuel Consumption	EIA
National Vehicle Miles Traveled	FWHA HPMS
Non-Feul Auto Operating Cost	AAA
Power Plant Data	eGrid
Residential Energy Consumption	EIA RECS
Travel Demand Model Inputs	Maryland Statewide Transportation Model (MSTM)
Vehicle Emissions Factors	EPA MOVES2010a
Vehicle Survivability	NHTSA

Chapter 5: Maryland Emission Reduction Policies

This dissertation tests multiple CO2 mitigation strategies related to the built environment specified in the Maryland CAP. The policies are grouped into three major sectors: buildings and land use, power plants and transportation. This work differs significantly from other CAP quantification exercises in its use of empirical and behavioral models developed at a micro-level and aggregated for forecasting purposed. Where many other quantification exercises borrow multipliers from other studies or states and apply them to highly simplistic general formulas; this work constructed complex but tractable models from local data on buildings, climate, individual power plants, personal travel surveys, and state vehicle inventories. The micro-level approach resulted in much greater detail and better estimates of emission sensitivity to policies.

The strategies for emissions reductions were developed directly from the Maryland CAP policy document. Initial 2006 CO2 estimates were developed from models using parcel, highway link and power plant level models then calibrated where necessary to match the EIA (EIA, 2012) reported emissions for the state. Starting at the same baseline, emissions were then estimated for 2020 using the models developed for the initial estimation with state household and employment locations first allocated to the MPO level from local plans, then disaggregated to the county based on a Lowry-type iterative fitting procedure and finally to the zone level using a gravity based allocation model. The growth totals were controlled at the state-level by INFORM ("INFORUM", 2013) projects developed through a macro economic model. The strategies were then developed and specified within the three sectorial models. It was noted where a strategy in the CAP policy document was too vague to model or required significant assumptions to produce and estimate.

A total of 42 built-environment related strategies are specified in the Maryland CAP. After careful analysis of each policy, a total of 11 distinct policies were formed for testing with the modeling framework of this thesis. The final set of tested strategies is listed in Table 8. A more in-depth discussion of the policies by sector is provided in the following sections.

Table 8

Summary of tested emission reduction strategies

Policy	Initiative	Description
1	EmPOWER MD 1	Strategies that reduce residential and commercial sector emissions by subsidizing weatherization and equipment retrofits for building units
2	EmPOWER MD 2	A suite of strategies that result in a 15% reduction of electricity demand in Maryland, power plant operators reduce future growth/expansion to accommodate
3	Bldg/LU 1	80% of residential growth to 2020 to PFAs with a 25/75 Multi-family and single family split, 84% percent in ¼ acres lots or less
4	Bldg/LU 2	80% of commercial growth to 2020 to PFAs
5	Energy 1	The Regional Greenhouse Gas Initiative (RGGI)
6	Energy 2	GHG Emission Reductions from Imported Power
7	Energy 3	The Maryland Renewable Energy Portfolio Standard Program
9	Transport 1	Suite of strategies aimed at reducing GHG through vehicle efficiency and cleaner fuel technology
10	Transport 2	Policies to reduce GHG emissions by increasing public transit ridership
11	Transport 3	Road pricing mechanisms to reduce emissions

<u>*Buildings and Land Use*</u>

Several emission reduction strategies are specified in the Maryland CAP related to buildings and land use. The majority of these policies fall under the scope of boiler efficiency or the large "EMPOWER Maryland" suite of policies. These two reduction mechanisms are discussed in detail in the energy section. Table 9 lists the CAP specified building and land use strategies and the modeled polices into which they aggregated.

Table 9

Building Sector GHG Mitigation Strategies

Policy/Sector (GGRA Name)	Title	Modeled	
		Alone	Aggregated
Energy 4	Boiler Maximum Achievable Control Technology (MACT)	N/A[a]	
Energy 6	EMPOWER: Energy Efficiency in the Residential Sector.		EmPOWER MD 1
Energy 7	EMPOWER: Energy Efficiency in the Commercial and Industrial Sectors		
Energy 8	Energy Efficiency Appliances and Other Products		
Energy 15	Main Street Initiatives		EmPOWER MD 2
Energy 16	Energy Efficiency for Affordable Housing		
Land Use 1/3/4	PlanMaryland (Smart Growth) - Residential	Bldg/LU 1	
Land Use 1/3/4	PlanMaryland (Smart Growth) - Commercial	Bldg/LU 2	
Buildings 1	Green Buildings	EmPOWER MD 1	
Buildings 2	Building Codes to include minimum efficiency		

a Does not currently apply to utilities. See below for policy details

EmPOWER MD 2 - Main Street Initiatives & Energy Efficiency for Affordable Housing

Two initiatives fall under the EmPOWER Maryland 1 scenarios both of which rely on federal funding. The first is called the Main Street Initiative. This program used $16.8 million in federal block grant funding from the American Recovery and Reinvestment Act of 2009 to subsidized commercial and downtown residential unit HVAC retrofits and weatherization to reduce unit-level combustion. The funding is divided among unit types with $6 million going to commercial property, $6 million for multifamily units, and $4.8 million for single-family homes. The second initiative used $46.7 million from the same American Recovery and Reinvestment Act of 2009 block grant to subsidize weatherization efforts for low income housing units. Electric energy consumption reductions from these upgrades and other efficiency improvements are addressed in the power plant section.

Using the National Weatherization Assistance Program's audit tool (described in Chapter 4), a set of recommended upgrades was developed for the average affordable housing unit to minimize the total cost of upgrades while maximizing the emission reduction benefit. The recommended upgrades, their cost, energy, and emissions savings are provided in Table 10. The upgrades included replacement of older thermostats with programmable units, retrofitting furnaces that use natural gas with Intermittent Ignition Devices (IID) to replace continuously burning pilot lights, electronically controlled vent covers (dampers), upgrades to existing attic insulation to increase the insulation's R-value to 38 (an extremely high efficiency level), furnace tune-ups and maintenance, the addition of storm windows, insulation for water heaters, weatherizing to reduce the infiltration of outdoor air, and upgrades to older single pane windows.

Table 10

Recommended affordable housing weatherization upgrades

Recommended Upgrade*	Cost	mmBTUs (saved)	CO_2 (lbs) (saved)
Smart Thermostat	$ 75	2.8	327
Intermittent Ignition Device (IID)	$ 225	2.1	245
Electronic Vent Damper	$ 475	2.9	339
R-38 Attic Insulation	$ 2,026	4.8	561
Furnace Tune-up	$ 125	0.5	58
Storm Windows	$ 908	0.1	12
Hot Water Heater Wrap	$ 40	0.5	58
Infiltration Reduction	$ 500	0.6	70
Window Replacement	$ 1,432	3.5	409
Total	***$ 5,806***	***18***	***2,081***
	Pre-Weatherization	***76.5***	*8,942*
	Post-Weatherization	***59***	*6,861*

*average Sqft = 1,300
Source: Author's calculations, National Weatherization Assistance Program Audit Tool

Commercial and downtown residential unit (townhouses, apartments, and condominiums) upgrade recommendations are based on data from the CBECs dataset and National Weatherization Assistance Program's audit tool. These recommendations are limited compared to the list of upgrades for affordable housing units. This is due to the limited data available on efficiency gains for these types of units and the limited amount of funding available for the upgrades. Table 11 through Table 13 list the recommended upgrades, their cost, energy, and emissions savings. These upgrades include education and promotional material to encourage reducing heating during late night hours, HVAC tune-ups and regular maintenance cycles, energy management and control systems for large multiunit buildings, and programmable thermostats for single units and HVAC equipment upgrades for all units. Emissions reductions and cost estimates were based on the average square footage of each unit type derived from the Maryland property assessor's database.

Table 11

Recommended commercial building upgrades

Recommended Upgrade*	Cost	mmBTUs (saved)	CO_2 (lbs) (saved)
Heating reduced during 24 hour period	$ -	25.1	3,672
Regular HVAC maintenance	$ 357	42.9	6,264
Energy management and control system	$ 277	38.5	5,624
HVAC equipment upgrade	$ 14,000	38.7	5,662
Total	***$ 14,634***	***145.2***	***21,222***
Pre-Weatherization		***720.3***	*105,263*
Post-Weatherization		***575.1***	*84,041*

*median Sqft = 4,796

Source: Author's calculations, National Weatherization Assistance Program Audit Tool

Table 12

Recommended multifamily building upgrades

Recommended Upgrade*	Cost	mmBTUs (saved)	CO_2 (lbs) (saved)
Heating reduced during 24 hour period	$ -	54.2	7,920
HVAC Tune-up and maintenance	$ 770	92.5	13,513
Energy management and control system	$ 597	83.0	12,132
HVAC equipment upgrade	$ 14,000	83.6	12,215
Total	***$ 15,366***	***313.2***	***45,779***
Pre-Weatherization		***1,553.7***	*227,065*
Post-Weatherization		***1,240.5***	*181,286*

*median Sqft = 10,345

Source: Author's calculations, National Weatherization Assistance Program Audit Tool

Table 13

Recommended single family building upgrades

Recommended Upgrade*	Cost	mmBTUs (saved)	CO_2 (lbs) (saved)
Heating reduced during 24 hour period	$ -	6.4	934
Regular HVAC maintenance	$ 125	10.9	1,593
Energy management and control system	$ 75	9.8	1,431
HVAC equipment upgrade	$ 2,500	9.9	1,440
Total	***$ 2,700***	***36.9***	***5,399***
Pre-Weatherization		***183.2***	*26,777*
Post-Weatherization		***146.3***	*21,378*

*median Sqft = 1,220

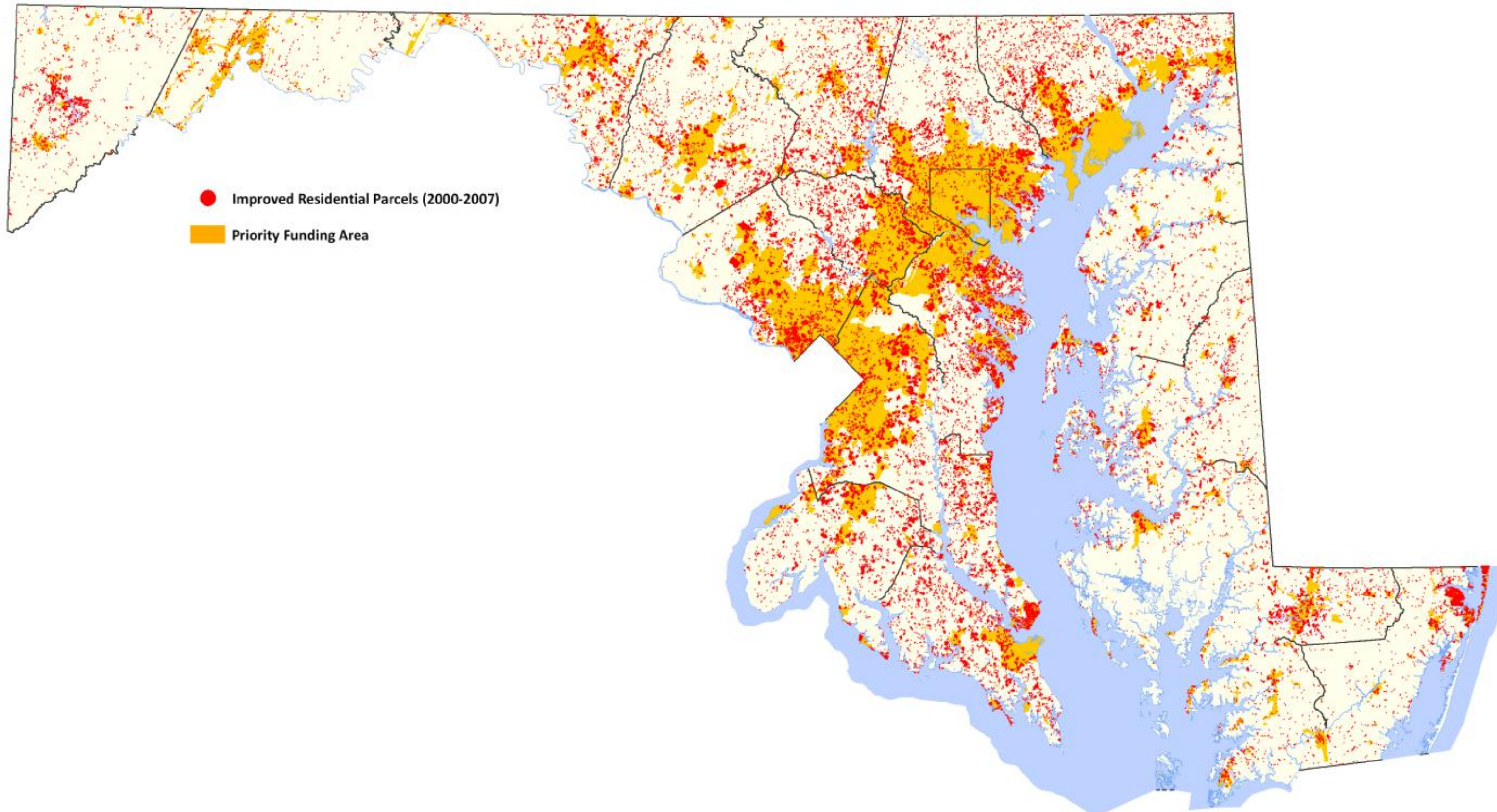
Source: Author's calculations, National Weatherization Assistance Program Audit Tool

Bldg/LU 1 – PlanMaryland (Smart Growth) - Residential

The Maryland CAP specifies that 80 percent of future residential growth will occur in state recognized special planning areas called Priority Funding Areas (PFA). PFAs are county designated areas where future state investment will be concentrated in an effort to channel growth to these locations (Lewis et al., 2008). The logic of such areas is that higher density development is more efficient and reduces the rate of externalities such as GHG emissions by reducing the need to drive as far or often as development occurring in a less concentrated pattern.

The effectiveness of these designated area's ability to influence growth patterns has been criticized with evidence indicating that more development has occurred outside the PFAs than before the zones were planned (Lewis et al., 2008). The Maryland CAP's assumption that 80 percent of future growth will occur in PFAs may be overly optimistic considering the number of parcels developed outside a PFA in 1998 (the time of the legislation) was just over 24 percent, yet just six years later the number had increased to nearly 27 percent. Figure 27 shows the location PFAs in orange and the location of improved parcels from the year 2000 to 2007.

The Maryland CAP also specifies that 25 percent of all future residential growth will be multi-family residential units with the remaining 75 percent single-family residences. This too goes beyond the historic and current development trend. The final component to the residential smart growth strategy entails 84 percent of future development occurring on 1/4 acres lots or less. The lot size within PFAs has remained nearly constant for several decades at about 3/4 of an acre (Lewis et al., 2008).



Source: Maryland Department of Planning
Figure 27. Priority Funding Areas and Developed parcels from 2000-2007.

To develop this scenario, the amount of future residential development was calculated and 80 percent of the growth was allocated to modeling zones that were more than 75 percent within a PFA. Housing unit types were converted from their historic ratios in the original allocation to modeling zones with the desired 25/75 split.

Bldg/LU 2 – PlanMaryland (Smart Growth) – Commercial

The commercial building strategy simply specifies that 80 percent of future growth in the commercial sector will occur within PFAs. To develop this scenario, the amount of future commercial development was calculated and 80 percent of the growth was allocated to modeling zones that were more than 75 percent within a PFA.

Power Plants

Carbon emissions related to power plants are a significant portion of the total Maryland GHG emissions footprint. A full 38% of emissions are produced from state power plants or accounted for from imported power (a full 30 percent of Maryland energy) on the regional PMJ grid. Power plant emissions are difficult to moderate through traditional policy instruments since the industry has been substantially deregulated since 1996. At the federal level, the EPA has the power to regulate emissions, but this power to exercise control has only recently begun to take shape in the form of policy. It is unlikely the emissions from existing power plants will be regulated to any measureable degree within the short timeframe of the Maryland CAP. At the state level, the Public Service Commission (PSC) has oversight of electric utilities, but this power only extends to cap consumer electricity rates and permit future power plants with the primary goal of moderating future energy rates, but not GHGs.

Table 14 lists the GHG mitigation strategies specified in the Maryland CAP and describes how each strategy will be modeled. A single model will be directly specified within the modeling framework while an aggregated strategy is modeled as part of a larger group presented as a single scenario.

Table 14

Energy Sector GHG Mitigation Strategies

Policy/Sector	Title	Modeled	
		Alone	Aggregated
Energy 1	The Regional Greenhouse Gas Initiative (RGGI)	Energy 1	
Energy 2	GHG Emission Reductions from Imported Power	Energy 2	
Energy 3	GHG New Source Performance Standard	N/A[b]	
Energy 4	Boiler Maximum Achievable Control Technology (MACT)	N/A[c]	
Energy 5	GHG Prevention of Significant Deterioration Permitting Program	N/A[d]	
Energy 9	Energy Efficiency in the Power Sector: General		EmPOWER MD 1
Energy 10	EMPOWER: Utility Responsibility		
Energy 11	The Maryland Renewable Energy Portfolio Standard Program	Energy 3	
Energy 12	Incentives and Grant Programs to Support Renewable Energy		EmPOWER MD 1
Energy 13	Offshore Wind Initiatives to Support Renewable Energy		
Energy 14	Combined Heat and Power		

b Applies only to new petroleum refineries or fossil fuel combusting power plants, none are planned for Maryland
c Does not currently apply to utilities. See below for policy details
d Generally, applies only to new or modified sources of GHG emitting more than 75,000 tons per year. No such projects have been planned in the state of Maryland.

Energy 1 - The Regional Greenhouse Gas Initiative (RGGI)

The RGGI is a multi-state agreement to reduce power plant GHG emissions through a regional cap and trade program (RGGI, 2007). The program will cap power plant emissions at 188 million tons in 2015 and then start reducing the allowed emissions and credits from 2015 to get to 10 percent of the cap by 2020. Plants are allowed to emit above the regional cap, but will be required to purchase credits at auction. A portion of the revenues from the carbon auction is used for energy efficiency programs and investment in renewable energy (RGGI, 2007).

Despite initial optimism, analysts have recently criticized the cap's ability to achieve reductions for several reasons (Barringer & Galbraith, 2008). Current emissions from participating state power plants are just 156 MMt, nearly 20 percent below the original 2015 cap. The level of emissions far below even the future cap had led to a devaluation of carbon credit at auction, resulting in the latest price of just $1.86 per ton of carbon (Table 15). The regional average cost of production for a MWh is $99. The cost of a carbon credit is marginal in comparison to the total cost of production and revenue per MWh. Further, the stability of the RGGI has been questioned and recently the state of New Jersey withdrew from the pact and New Hampshire seeks to vote on legislation to abandon the agreement in 2013. It is unclear what the future holds for the RGGI and its participants.

Table 15

RGGI auction results, 2009 - 20012

Number	Auction Date	2009 Allowances	2009 Proceeds	Price per Allowance	2012 Allowances	2012 Proceeds	Price per Allowance	Total Auction Proceeds
1	25-Sep-2008	5,331,781	$16,368,568	$3.07				$16,368,568
2	17-Dec-2008	5,331,781	$18,021,420	$3.38				$18,021,420
3	18-Mar-2009	5,331,783	$18,714,558	$3.51	399,884	$1,219,646	$3.05	$19,934,205
4	17-Jun-2009	5,331,782	$17,221,656	$3.23	399,884	$823,761	$2.06	$18,045,417
5	9-Sep-2009	5,331,782	$11,676,603	$2.19	399,884	$747,783	$1.87	$12,424,386
6	2-Dec-2009	5,331,782	$10,930,153	$2.05	294,317	$547,430	$1.86	$11,477,583
Cumulative Total		**31,990,691**	**$92,932,957**		**1,493,969**	**$3,338,620**		**$96,271,577**

Source: The Regional Greenhouse Gas Initiative: Auction Results. http://www.rggi.org/co2-auctions/results

The effect of RGGI on Maryland emissions is highly uncertain. While the state is a participant in the agreement, most of the states (and DC) that Maryland imports power from are not participants. Of states on the PJM interconnect from which Maryland derives power, only Delaware is a member of the RGGI. The remaining 70 percent of domestic power is significantly cleaner than out of state sources since a major portion, some 50 percent is derived from Nuclear, land fill gas, wind, and solar. This leaves a small fraction of total emissions that can be reduced from RGGI participation.

As of 2013, RGGI developed a new prospective model rule significantly reducing the 2014 cap from 188 MMt CO2 to 91 MMt CO2. The impacts of the new RGGI model rule are modeled in this work since the rule as it currently exists would not result in an emissions reduction over the BAU scenario for 2020.

Energy 2 - GHG Emission Reductions from Imported Power

Maryland imports a significant portion of its electricity from the regional PMJ interconnected grid (Nelson, 2011), totaling 30 percent of the all power consumed in the state. Much of the imported power comes from coal fire power plants that emit high levels of CO2. Maryland accounts for the CO2 emitted from power plants that generate electricity imported into the state. In order to reduce the state's CO2 levels, the CAP specifies a strategy to reduce the carbon intensity from imported power. To achieve this goal, the states through this strategy aim to enact standards on energy providers supplying electric load to produce the power at a carbon intensity of 1,125 pounds of GHG per MWh. The primary energy source that may be quickly substituted for coal energy and remain within the carbon intensity limit is natural gas. Testing of this strategies CO2 reduction potential will operate on the assumption that 100 percent of imported energy currently derived from coal plants will be converted to natural gas.

Source Performance

Greenhouse Gas New Source Performance Standard for Electric Generating Units for New Sources (NSPS) is a new policy from the EPA promulgated after the agency was sued in 2010 to enforce GHG reduction standards and later gained the power to regulate emissions related to GHG by classifying CO2 as a pollutant. Assuming the congress does not intervene to restrict the EPA's authority on GHGs, the new rules will require newly constructed and modified petroleum refineries and fossil fuel combusting power plants to reduce CO2 emissions. The EPA published the proposed rule as 40 CFR Part 60 on April 13, 2012 and received several million comments. The comment period closed June 12, 2012 and the final rule is expected in March 2013.

The published rule limits CO2 to 1,000 pounds per MWh. Most natural gas and biomass plants are within this limit according to the EPA's accounting method (though recent research indicates that biomass likely produces 3,000 pounds of CO2 per MWh)[5].

There are no planned petroleum refineries or fossil fuel combusting power plants in the state of Maryland nor are any modifications known at this time. Savings from a future EPA rule will come from imported electricity sources on the PJM interconnect grid.

The major caveat for this strategy, like many in the energy sector, is that currently no rule regulating GHG from existing power plants either exists or is currently on the EPA's agenda. Further, the NSPS is still a proposed subject to change. Therefore, a firm rule, a policy time horizon, or an inventory of affected plants and their emissions is only

[5] The carbon neutrality of biomass is only effective if 1) new trees are planted to re-capture CO_2 combusted biomass and 2) the same amount of carbon would have been released from the biomass through forest fires had the biomass not been cultivated. Otherwise the carbon in biomass decays and either produced methane or is naturally sequestered in the soil.

speculative. A total reduction in CO_2 is assumed for this strategy to present a maximum achievable reduction.

Boiler Efficiency

The EPA's Boiler Maximum Achievable Control Technology (MACT) rule originally set out to reduce emissions from the nation's 1.5 million boilers. The original text of the proposed rule would have regulated nearly all boilers combusting a variety of fuels. Under the revised Boiler MACT of December 2012[6], the rule does not apply to natural gas boilers or a variety of others so that less than one percent or 5,500 large industrial boilers would need to make adjustments based on the rule. Another 13 percent of boiler would simply be required to conduct routine maintenance, with no conformity monitoring.

The Boiler MACT rule does not apply to major utility plants of any type as it only applies to industrial, commercial, and institutional boilers as defined under 40 CFR 63.11237 to include facilities such as large manufacturing plants, universities, and hospitals. The rule only applies to boilers that produce up to but no more than 25 MW of electricity. Further, the rule only applies to hazardous, non-criteria pollutants such as mercury and dioxins, but not to CO_2. There is no evidence that equipment and maintenance used to reduce hazardous pollutants would have a measureable impact on carbon emissions. As a result, no CO_2 reductions are assumed for the implementation of Boiler MACT in Maryland.

EmPOWER MD 1

[6] http://www.epa.gov/airquality/combustion/

EmPOWER Maryland 1 is a set of policies aimed at reducing the statewide demand for electricity. It seeks these reductions by providing subsidies for investments in building envelope retrofits including better-insulated windows, improvements to HVAC systems, encouraging more efficient lighting and appliances, and education on ways to reduce consumption by 15 percent by the year 2015. According to the MDE, 30 percent of the needed energy sector emissions reductions will be accounted for through the EmPower Maryland plan[7].

While EmPOWER Maryland reportedly has been effective in reducing demand, the goals of the program do not necessarily coincide with the realities of the power generation market. For instance, utilities in Maryland are connected to the PJM network, which coordinates the distribution of power and planning for future needs on a 15-year planning horizon. Most future power plant expansions and retirements have been planned many years beyond 2015 and the GHG emission reduction goal of 2020 since conformity with Maryland energy regulations, site selection, environmental impact assessments and constriction require many years to complete. Thus, any reduction in demand in the home market likely will result not in a reduction of generation and emission but the exporting of power as demand response to other markets on the PJM interconnect. Nonetheless, this thesis will endeavor to look beyond the grid constraints and make the assumption that a 15 percent reduction in demand can be achieved and future power plant construction will be reduced in accordance with this change. While the Maryland PSC approves the construction of new power plants in the state, it does this with the aim of proving 'fair

[7] https://www.google.com/url?q=http://webapp.psc.state.md.us/Intranet/Casenum/NewIndex3_VOpenFile.cfm%3FServerFilePath%3DC:%255CCasenum%255C9100-9199%255C9157%255C%255C202.pdf&sa=U&ei=j9v6UMS-BYLm2QWwnIGwDw&ved=0CAkQFjAB&client=internal-uds-cse&usg=AFQjCNFw_mUNTdoA8t0KtUamzhVH-yyZRQ

and just' energy prices for consumers but is not primarily concerned with the emissions of GHG. Currently, there is no clear relationship either in regulatory or market based terms between reductions in state energy demand and power plant level GHG emissions. Until such a relationship is established by either bridging the power gap between MDE, the agency that is tasked with reducing emissions and the PSC the agency that regulates power plants, or by a change in exporting rights through the PJM interconnect, there will be no direct path from changes in consumption to emissions. As a result, this analysis will not attempt to measure the exact change in demand at the building level, but will as previously stated; assume a 15 percent reduction in demand affecting the construction of new energy generators.

Energy 3 - The Maryland Renewable Energy Portfolio Standard Program

Maryland enacted its state specific version of the renewable portfolio standard (RPS) in 2004 with a requirement that utilities derive 20 percent of their energy from renewable sources by 2022. In 2010, to match the GGRA's GHG reduction goals the state amended its RPS to require 2 percent of energy comes from solar sources and the remaining 18 percent from renewable. At that same time the target date was accelerated to 2020 ("DSIRE", 2013).

While the state has certified a range of renewable sources, the primary renewables that currently exist in the state as a regulated utility derived source of energy and are certified renewable by the Maryland RPS are landfill gas, municipal solid waste incineration (MSW), and hydroelectric. Among these sources the current state portfolio in terms of MWHs generated by source are 4.93 percent landfill gas, 90.36 percent municipal solid waste, and 4.70 percent hydroelectric.

Transportation

Multiple transportation-related strategies are specified in the Maryland cap. Many of the strategies use the same method but target slightly different markets. For instance, transport policies 1-3 all address different segments of the market with the goal or a more efficient fleet. Where the strategies lend themselves to aggregation they have been added together under a single modeled policy. Table 16 lists each of the transportation policies in the Maryland CAP and shows how they are handled in this modeling analysis.

Table 16

Transportation Sector GHG Mitigation Strategies

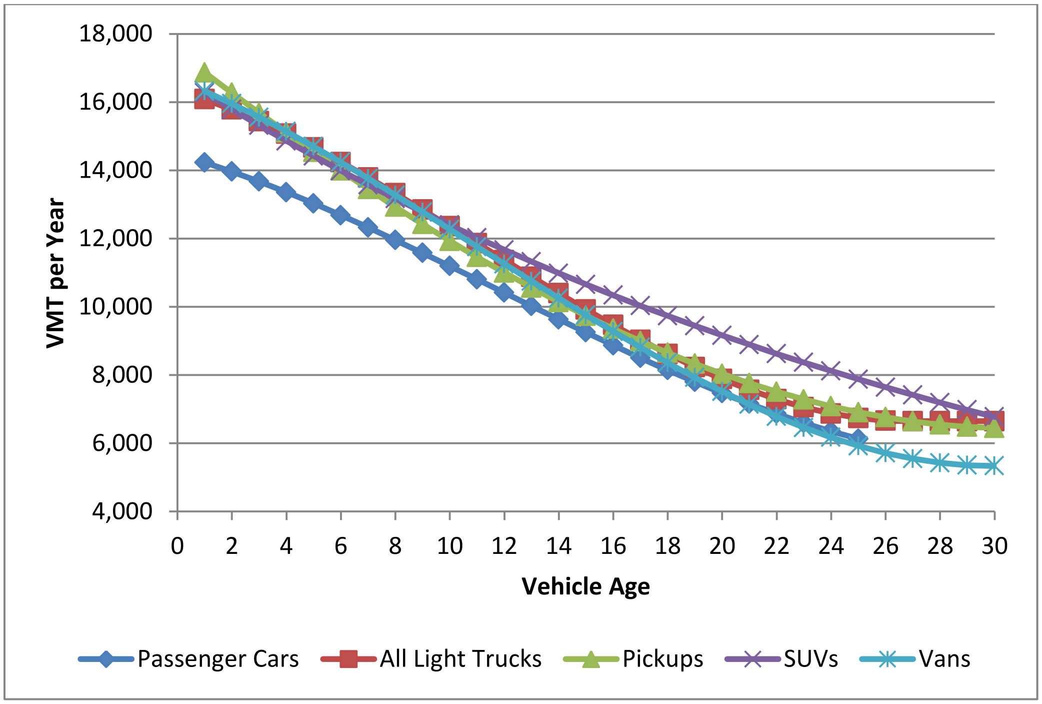
Policy/Sector	Title	Modeled	
		Alone	Aggregated
Transport 1	Maryland Clean Cars Program		Transport 1
Transport 2	National Medium- & Heavy-Duty Fuel Efficiency Standard		Transport 1
Transport 3	Clean Fuels Standard		Transport 1
Transport 4	Transportation and Climate Initiative		Transport 1
Transport 5	Public Transportation Initiatives		Transport 2
Transport 6	Double Transit Ridership by 2020		Transport 2
Transport 7	Intercity Transportation Initiatives		Transport 2
Transport 8	Bike and Pedestrian Initiatives	N/A[e]	
Transport 9	Pricing Initiatives		Transport 3
Transport 10	Transportation Technology Initiatives		Transport 1
Transport 11	Electric Vehicle Initiatives		Transport 1
Transport 12	Low Emitting Vehicle Initiatives		Transport 1
Transport 13	Evaluating GHG Emissions from Major New Projects	N/A[f]	
Transport 14	Airport Initiatives		Transport 1
Transport 15	Port Initiatives		Transport 1
Transport 16	Freight and Freight Rail Strategies		Transport 1/2
Transport 17	Renewable Fuels Standard		Transport 1
Transport 18	CAFE Standards (MY2008-2011)		Transport 1
Transport 19	Promote Hybrids and Electrics		Transport 1
Transport 20	Pay-As-You-Drive Insurance		Transport 3

e The plan encourages the development of bike/ped friendly infrastructure and bike share programs; however, a firm quantification of the GHG benefits is not attempted in this analysis
f the plan only encourages the measurement of future GHG but does not seek reductions.

Transport 1 – Efficient Vehicles

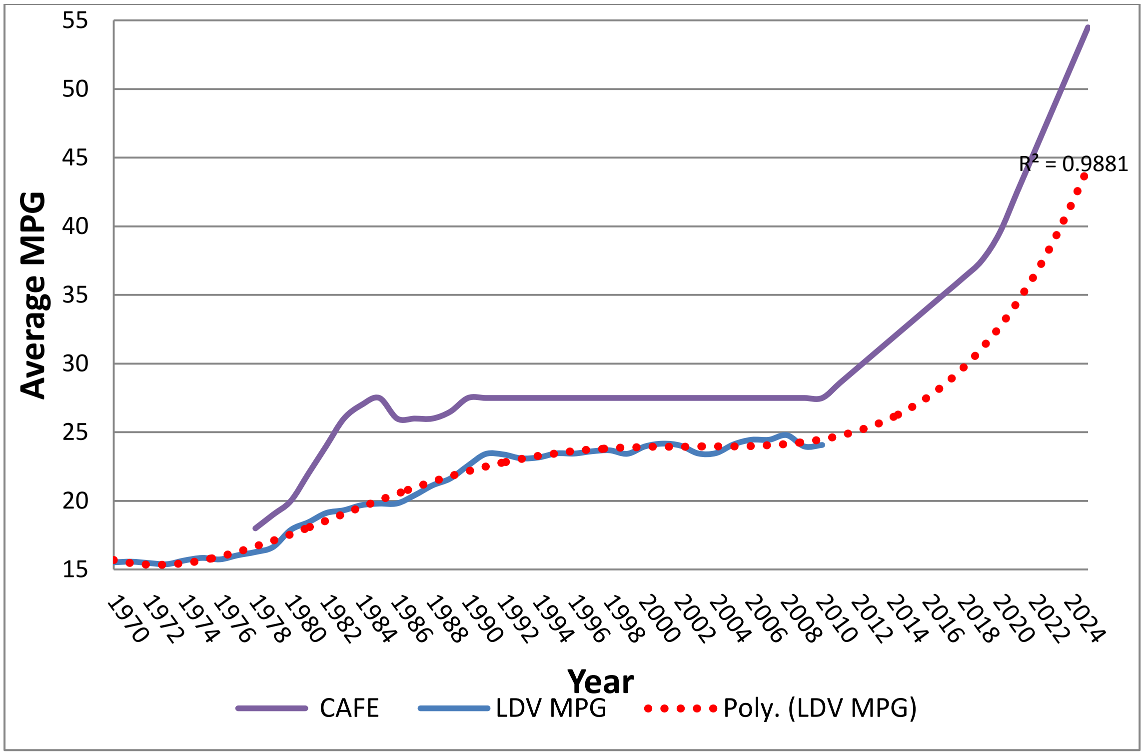
The set of strategies that the Efficient Vehicle scenario encompasses are aimed at increasing fleet-wide average fuel efficiency to achieve closer proximity to the expected CAFE standard of 36 mpg in 2020. To model this effect, all vehicles projected to be on the road with model year greater than 2012 be assumed to have higher levels of efficiency until the 32.5 mpg level is met for model year 2020. This formulation will be based on NTHSB's vehicle survivability rate (Figure 28) and a polynomial forecast based on historic fleet emissions and CAFE standards (

Figure ***29***).



Source: NTHB (2010)

Figure 28. Vehicle survival and use over time.



Source: EPA CAFE, FHWY HPMS, Author's Calculations

Figure 29. Historic fleet emissions and CAFE standards.

Transport 2 – Double Transit Ridership

Maryland has set the goal of doubling transit ridership by the year 2020 in an effort to reduce emissions from personal or light duty vehicle (LDV) travel. A package of strategies is aimed at achieving the goal. These strategies include the long planned construction of the Purple Line light rail in the DC suburbs, the Red Line light rail in Baltimore, a new commuter rail (MARC) station and system expansion, and a host of local transit system expansions. The exact dates of these planned projects are highly uncertain. Locations of stations and levels of service are unknown. Including the planned Purple and Red lines only marginally increases transit ridership in the 2020 transportation demand model. Due to the substantial policy assumptions shifting mode shares in a historically unprecedented direction and limits the transportation model to reflect past trends within a realm of observed behavior, to achieve the desired levels of transit ridership the mode choice tables used to calculate mode shares were manually manipulated to mimic a transit share doubling while removing an equal number of single occupancy vehicle trips.

Transport 3 – Pricing

Emission Pricing

First-best emission pricing comes from the idea that all users are charged for the marginal social cost of their emissions externality. For each driver that takes a particular route, his or her presence results in a reduction of traffic flow. This flow reduction costs other users time and reduces the operational efficiency of the highway, resulting in more emissions. A first-best toll sets the cost of travel on a link so that the improvement in flow (from drivers selecting other routes) and the revenue from the toll (from drivers that decide to continue on the priced link) will be sufficient to offset the marginal social cost of the trip.

This paper sets aside the political and implementation difficulties of a first-best pricing scenario to model driver response. A pre-determined cost per gram of emissions is charged to each vehicle on the network, based on the amount of emissions that particular vehicle adds to the output on the link and the additional emissions that result from other driver's reduced efficiency. We add an additional complexity by setting an emissions cap where each driver is only charged for driving on a road that exceeds a pre-determined emissions threshold and for the marginal amount of emissions, each vehicle generates. This method allows planners to set a goal for emission reduction, only instituting a charge for those links that fail to meet the target.

Based on policy criteria such as links exceeding a threshold, the value of emissions needs to be priced. The threshold value can be considered as an emission cap. The cap can be determined by calculating the link level emissions for the entire network in the base year by grams per mile for each link. The cap in this case is arbitrarily set at the average of emissions per mile. Planners can replace this cap with one of a particular meaning, such as emissions that exceed a maximum for an air quality standard or the emissions measured from a previous period in an effort to reach a specific reduction target. The cap for each link can then be determined by multiplying the average grams of emissions per mile by the distance of each link. This cap acts as a level-of-service in environmental terms. Where a first-best toll on congestion would necessarily charge anywhere that congestion occurs, the amount of emissions produced on a link does not have an analogous indicator. In response, a planner can determine for every link the maximum amount of emissions that should be allowed, anything exceeding that maximum would result in a charge to make the emission pricing equal to the marginal cost. This emissions charge is based on an extensive literature review by Nordhaus and Boyer (2003) showing a lower bound of marginal CO2 emission costs of $20 per ton and Tol (2005) provides an upper bound with a marginal cost of CO2 emissions of $50 per ton.

The emission price for each link is updated at the end of every traffic assignment iteration based on the emissions produced as a result of that traffic flow at the iteration over the predetermined cap, so that changes in the results of each assignment are reflected in the travel cost faced by each user which like travel time, will vary between iterations.

The emissions cap for each link is:

$$\Phi_a = \left[\frac{1}{N}\sum_{a=1}^{N}\left(\frac{\phi_a}{l_a}\right)\right] * l_a \qquad (1)$$

where ϕ_a is the total emissions for link a calculated for each link in the base model, and l_a is the link distance. Once the cap is determined, the emission price (e_a) can be incorporated into the travel demand model. The emission price can be converted to travel time units with appropriate factor (γ^c) representing VOT in monetary terms as cents per minute for travellers of five income categories c. The revised user cost function for link-based emission is:

$$u_a^I(x_a, e_a) = \ t_a(x_a) + \frac{\varphi e_a(x_a)}{\gamma^c} \qquad (2)$$

where $u_a^I(x_a, e_a,)$ is the travel cost function for Model-1, which incorporates emission pricing term e_a. The objective function for Model-1 is similar to base case with the exception that the third term from equation (7) ($\frac{\varphi e_a(x_a)}{\gamma^c}$) is added the generalized travel cost equation (from Chapter 4), that is, the total emissions e produced on link a, which is a function of link flow x_a multiplied by charge per gram of emissions, φ.

VMT Tax

An alternative pricing method to first-best pricing is to impose fees based on the number of miles driven on a roadway or a VMT based tax. This is considered to be a second-best solution because users will be charged a flat rate based strictly on the amount of driving they do rather than the marginal cost of their trip. A user that is the only driver on a link, causing no reduction in flow, will face the same per mile charge as a user taking a more congested route resulting in a reduced flow. This pricing method is less economically efficient as it still has the potential to result in unpaid externalities, but is more feasible in terms of calculating a price and implementing a charging system. With available technology, a VMT tax has been a genuinely considered policy option in many states, with pilot programs in Minnesota, New York, Oregon and more widely across Europe (NYSDOT Task Assignment 2012; Starr McMullen, Zhang, and Nakahara 2010; Zhang and McMullen 2008; Smalkoski and Levinson 2005; Sorensen and Taylor 2005).

While implementation is easier somewhat than first-best pricing, there are some concerns with a second-best toll. Users with a low Value of Time (VOT), typically low-income drivers, will not be able to trade-off travel time and distance for a lower toll cost. In some cases, low VOT drivers may consider using transit as an alternative mode and vice versa for high-income group travelers. Where transit is not available or not subsidized by the revenue collected from the toll, there are concerns about how equitable such a system is for the population as a whole. From an implementation viewpoint, fees could be collected annually through the vehicle registration process, as mileage calculated through odometer readings. A VMT based tax is intended as a price based dis-incentive to vehicular travel causing travelers to shift to other modes or make trips with shorter lengths resulting in lower emissions.

Analytically, the user cost function can be stated as the following to incorporate the VMT based tax.

$$u_a^{II}(x_a, \theta_a) = t_a(x_a) + \frac{\theta_a l_a}{\gamma^c} \quad (3)$$

where, θ_a is the VMT tax in $/mile for link a, $l_a$is the link length in miles, and γ^c is the VOT in $/hour. The advantage of a VMT based tax is to encourage travelers to use transit as an alternate mode if the tax appears too onerous. Equation (3) refers to a VMT based tax associated with value of time (VOT).

Gas Tax

A gas tax is another way of imposing a higher cost for highway travel, and like a VMT tax, it does not charge for the marginal cost of externalities; therefore, it operates in a second-best setting. However, the gas tax does differ from a VMT tax in three ways. First, the amount of gas consumed and thus the amount of taxes paid varies depending on the type of vehicle a road user drives. As a result, the driver has more control over total travel cost. Second, a gas tax is charged upfront (before a trip is taken) and generally hidden within the price of fuel, so users are less likely to link driving behavior to added fuel cost (Li et al., 2012). Third, while drivers do not closely link gas taxes to travel behavior like trip timing and route selection, studies have shown that drivers typically have higher consumption elasticity for gas prices than for road charges, likely because of a difference in substitution options (Parry & Small, 2005).

The effect of gas price on user behavior can be implemented as follows:

$$u_a^{III}(x_a, \sigma) = t_a(x_a) + \frac{\sigma l_a}{\gamma^c \vartheta} \tag{4}$$

where σ is the gas price in dollars per mile (as a ration of dollars per gallon and fleet-wide efficiency of 24.5 mpg), $l_a$is the link length in miles, γ^c is the VOT in $/hr, and ϑ is the automobile gasoline efficiency in miles per gallon. Auto Operating Cost (AOC) is another component that is considered in the mode choice model (please see equation 19). A higher gas price will result in a higher AOC and thus make auto travel more expensive.

The network-based pricing models' solution algorithm is outlined as follows:

Step 0: ***Initialization.***

Calculate initial demand ($q_{ij}^{c(0)}$) and feasible flow pattern ($f_{ij}^{c(0)}$), based of free-flow travel time. Set (*n)* = 0.

Step 1a: ***Update.***

$$\text{Set} \quad t_a(x_a) = t_a\left(1 + \alpha_a \left(\frac{x_a}{C_a}\right)\right)^{\beta_a} \quad \forall \quad a; \tag{A.1}$$

Step 1b: ***Update with variable demand.***

Update demand with inverse demand function

$$d_{ij}^{\varphi}(\sigma_{ij}) = d_{ij}^{\tau} \exp\left(-\omega * u_{ij}^{c(m)}\right) \quad \forall_{ij,\tau}$$

where u_{ij}^{c} is the least cost path between O-D pairs i and j and ω is a positive constant.

Step 2: ***Direction Finding.***

Find the shortest path

$$u_{ij}^{c(n)} = t_a(x_a) + \frac{\tau_a(x_a)}{\gamma^c} \tag{A.2}$$

Perform all-or-nothing assignment based on updated travel times and obtain auxiliary flows $f_{ij}^{c(m)}$.

Step 3: ***Move Size.***

Line search for optimal step size, solving for *a*:

$$Minimize \sum_a \int_0^{x_a} \left(t_a(x_a, e_a) + \frac{\tau_a(x_a)}{\gamma^c} + \frac{\varphi e_a(x_a)}{\gamma^c}\right)$$

Step 4: Flow Update with emissions charge.

Find $f_a^{ct(m)}, f_a^{ce(m)}, f_a^{cn(m)}$ *with:*

$$u_{ij}^{c(n)}(x_a, e_a,) = t_a(x_a, e_a) + \frac{\tau_a(x_a)}{\gamma^c} + \frac{\varphi e_a(x_a)}{\gamma^c} \tag{A.3}$$

Step 5: Assignment convergence criterion.

$$K \leq \frac{Abs\left[\sum_{a\in A}\left(f_a^{(n)} * t_a{}_a^{c(n)}\right) - \sum_{a\in A}\left(f_a^{(n-1)} * \delta_a^{c(n-1)}\right)\right]}{\sum_{a\in A}\left(f_a^{(n-1)} * \delta_a^{c(n-1)}\right)} \tag{A.4}$$

where K is a dimensionless convergence criterion.

For the static demand model, step 1(b) is skipped. For the variable demand, all the steps are executed. If inequality holds, terminate assignment and go to step 1a. Otherwise, set n = n + 1 and go to step 1.

Chapter 6: Results

This chapter is organized first by CO2 emission sources then by model statistics and results. The final section of the chapter will report scenario-based results; that is, the effect on CO2 emissions from implementing reduction strategies specified by the Maryland CAP. All of the results rely on models constructed from multiple sources of empirical data for the base year 2006. Table 17 reports all of the variables and data used in the models and the source for each item.

Table 17

Data Sources

Variable Name		Source
		Building Emissions and Energy
Dependent Variables		
Probability of CO2 Emissions	=	EIA: RECS, CBECS, MECS
CO2 Emissions	=	EIA: RECS, CBECS, MECS
Energy (Electric) Consumpion	=	EIA: RECS, CBECS, MECS
Independent Variables		
Building Characteristics		
Age	=	Author's Calculation using Maryland PropertyView Data
Stories	=	Maryland PropertyView Data, 2006
Exterior: Stucco	=	Maryland PropertyView Data, 2006
Single Family Unit	=	Maryland PropertyView Data, 2006
Central Warm-Air Furnace w/ Ducts	=	Maryland PropertyView Data, 2006
Radiators	=	Maryland PropertyView Data, 2006
Fireplace	=	Maryland PropertyView Data, 2006
Central A/C System	=	Maryland PropertyView Data, 2006
Full Bathrooms	=	Maryland PropertyView Data, 2006
Half Bathrooms	=	Maryland PropertyView Data, 2006
Business Type	=	QCEW micro data geocoded and spatially referenced to Maryland PropertyView Data, 2006
Employees	=	QCEW micro data geocoded and spatially referenced to Maryland PropertyView Data, 2006
Total Square Feet	=	Maryland PropertyView Data, 2006
Location Characteristics		
Heating Degree Days		NOAA National Climatic Data Center
Urban or Rural Location	=	Author's Calculation using ArcGis 10.1 Spatiail Join Tool & MSTM Activity File
Cooling Degree Days	=	NOAA National Climatic Data Center
		Energy Generation
Power Plant Data	=	eGrid
		Transportation Demand Model
Travel Demand Model Inputs	=	Maryland Statewide Transportation Model (MSTM)
		Other Data
Atmospheric CO2 Concentrations	=	Mauna Loa Observatory (Scripps / NOAA / ESRL
Building footprints	=	Derived from MD county sources
Census divisions	=	EIA
Census regions	=	EIA
Data)	=	U.S. Bureau of Labor Statistics
Energy consumption to CO2	=	EPA
Energy conversion factors	=	EPA
Energy Reserves	=	BP Statistical Review of World Energy
Feul Efficiency Standards	=	EPA CAFE
Historic Gas Prices	=	EIA
Maryland Emissions Data	=	Maryland Department of Envirment and EIA
National Motor Fuel Consumption	=	EIA
National Vehicle Miles Traveled	=	FWHA HMPS
Non-Feul Auto Operating Cost	=	AAA
Vehicle Emissions Factors	=	EPA MOVES2010a
Vehicle Survivability	=	NHTSA

Building Sector – Emission and Energy Consumption Estimation Results

Building sector emissions are divided into three sectors: residential, commercial and manufacturing. The division into these three sectors are constructed to match emissions and energy consumption statistics either estimated or reported by the EIA and to mirror the sectors specified in the Maryland CAP emission reduction strategies.

Residential

Emissions

As reported in the methodology chapter, building emissions were estimated using a mixed-nested-logit model where the first level proved an estimate of the likelihood of a unit producing emissions and the second level of the nest estimated the total emissions produced by a unit given the probability of producing emissions was greater than 50 percent. Table 18 reports the descriptive statistics for the dataset used to estimate emissions probability. The primary types of variables used for the estimation were building and location characteristics. Building characteristics include the age of the structure, a dummy variables indicating whether the building is a single family unit, has a fireplace, used central forced-air heating, has siding or has concrete walls. Two additional variables provide the number of stories and total square feet. Locational characteristics include the number of heating degree days, the area's land use density (from one: most urban to four: most rural) and the number of cooling degree days.

Table 18

Descriptive Statistics for Dependent and Independent Variables (Residential CO_2 Combustion Probability Model)

Variable Name	Minimum	Maximum	Mean	Standard Deviation
Dependent Variables				
Produces CO2 Emissions	0.00	1.00	0.89	0.32
Independent Variables				
Building Characteristics				
Age	1.00	10.00	6.05	2.85
Single Family Unit	0.00	1.00	0.89	0.32
Fireplace	0.00	1.00	0.04	0.20
Central Warm-Air Furnace w/ Ducts	0.00	1.00	0.64	0.48
Exterior: Siding (Alum, Vinyl, Steel)	0.00	1.00	0.34	0.47
Exterior: Concrete or Concrete Block	0.00	1.00	0.03	0.17
Stories	1.00	4.00	1.44	0.57
Total Square Feet	200	9,800	2,801	1,600
Location Characteristics				
Heating Degree Days	0.00	11,465.00	4,381.23	2,190.09
Urban or Rural Location	1.00	4.00	2.72	1.18
Cooling Degree Days	0.00	5,059.00	1,477.95	951.41

Table 19 provides the descriptive statistics for the variables used to estimate total emissions for the observations that met the probability threshold of producing emissions. More variables are needed to accurately estimate the amount of emissions produced by a unit than is needed to estimate the likelihood that a unit will emit CO2. The additional variables include dummies for stucco siding, steam heating and the presence of central air conditioning. In addition, a continuous variable is included for the number of bathrooms (full and half).

Table 19

Descriptive Statistics for Dependent and Independent Variables (Residential CO_2 Combustion Model)

Variable Name	Minimum	Maximum	Mean	Standard Deviation
Dependent Variables				
CO2 Emissions	46.04	16,276.40	4,777.25	2,924.69
Independent Variables				
Building Characteristics				
Age	1.00	10.00	6.25	2.83
Stories	1.00	4.00	1.46	0.57
Exterior: Stucco	0.00	1.00	0.34	0.47
Single Family Unit	0.00	1.00	0.89	0.32
Central Warm-Air Furnace w/ Ducts	0.00	1.00	0.68	0.47
Steam/Hot Water System w/	0.00	1.00	0.02	0.14
Fireplace	0.00	1.00	0.04	0.19
Central A/C System	0.00	1.00	0.81	0.39
Full Bathrooms	0.00	6.00	1.68	0.73
Half Bathrooms	0.00	4.00	0.39	0.54
Total Square Feet	200.00	9,800.00	2,856.94	1,622.02
Location Characteristics				
Heating Degree Days	0.00	11,465.00	4,588.21	2,108.17
Urban or Rural Location	1.00	4.00	2.74	1.17
Cooling Degree Days	0.00	5,059.00	1,369.15	867.41

The first stage probability results are reported in

Table 20. The results show the effect of 10 variables on the likelihood of a given residential unit to produce emissions. Extensive exploratory analysis was used in the initial model construction stage to arrive at the final ten variables based on model fit and prediction quality. All variables in the final model were significant within the 99% confidence level. The results show that the type of heating system and building materials used to construct the unit largely influences the probability of a residential unit producing CO_2 emissions. As expected, age also plays a significant role in the probability of a unit producing emissions, with the likelihood of emissions increasing with each 5-year increment of age older than the base 2005 year.

Table 20

CO_2 Emissions Probability Regression Results (Residential)

Variable Name	Coefficient	Std. Error	Wald	Prob. Value
Constant	-2.03	0.42	23.49	0.00
Dependent Variables				
Probability of CO2 Emissions	n/a	n/a	n/a	n/a
Independent Variables				
Building Characteristics				
Age	0.39	0.03	154.75	0.00
Single Family Unit	1.11	0.24	20.81	0.00
Fireplace	1.19	0.34	12.28	0.00
Central Warm-Air Furnace w/ Ducts	2.07	0.16	167.60	0.00
Exterior: Siding (Alum, Vinyl, Steel)	-0.89	0.18	24.62	0.00
Exterior: Concrete or Concrete Block	-1.85	0.32	34.09	0.00
Stories	0.84	0.18	21.71	0.00
Total Square Feet	0.00	0.00	25.16	0.00
Location Characteristics				
Heating Degree Days	0.00	0.00	35.22	0.00
Urban or Rural Location	0.15	0.06	5.48	0.02
Cooling Degree Days	0.00	0.00	18.99	0.00
Summary Statistics				
No. Observations	3,037			
-2 Log likelihood	1,335.0265			
Cox & Snell R Square	0.2395			
Nagelkerke R Square	0.4696			
Classificatoin				

		Predicted		Percentage
		0	1	Correct
Observed	0	124	225	35.53%
	1	67	2621	97.51%
		Overall Percent Correct		90.39%

In the second level of the residential building emissions model, total emissions for the units that actually produce emissions in the dataset and those that have a probability greater than 50 percent of producing emissions in the case study were estimated. Table 21 shows that emissions estimation based on 14 selected variables using ordinary least squares regression. The results show that the model is robust with an F-static over 152, indicating model significance with a confidence level of 99% and an R-square of .45, indicating the model predicts 45% of emissions variability with the specified variables.

Energy (electricity) Consumption

Building units directly produce CO2 emissions through the combustion of fossil fuels are how residential. However, units also indirectly induce the combustion of fossil fuels and the production of emissions by creating a demand for electricity. This energy is often generated by power plants that combust coal, natural gas, biomass, or some other fuel source. Energy consumption only marginally influences the production of emissions as energy sources used by power plants are typically made without the influence of consumers and even with a reduction in demand, power plants are typically committed to a certain level of output as a natural result of running the plant. When demand drops in one market, power plant operations can easily sell excess energy to other markets interconnected to the power grid. Despite this limitation, a reduction in consumer demand can reduce CO2 locally demanded for policy conformity purposes and could potentially make alternative, localized energy generation such as smaller scale solar, wind and geothermal more of a possibility for implementation in some markets. Table 22 provides the descriptive statistics for the variables used to build the residential energy consumption model.

Table 21

CO_2 Emission Regression Results (Residential)

Variable Name	Coefficient	Std. Error	t	Prob. Value
Constant	-3022.111	375.038	-8.058	0.000
Dependent Variables				
CO2 Emissions	n/a	n/a	n/a	n/a
Independent Variables				
Building Characteristics				
Age	198.48	18.11	10.96	0.00
Stories	311.81	86.09	3.62	0.00
Exterior: Stucco	610.78	147.56	4.14	0.00
Single Family Unit	867.76	142.76	6.08	0.00
Central Warm-Air Furnace w/ Ducts	1,208.96	127.43	9.49	0.00
Steam/Hot Water System w/ Radiators	2,969.45	170.12	17.46	0.00
Fireplace	2,794.47	245.11	11.40	0.00
Central A/C System	-538.45	107.10	-5.03	0.00
Full Bathrooms	527.19	74.69	7.06	0.00
Half Bathrooms	416.73	85.79	4.86	0.00
Total Square Feet	0.18	0.03	5.74	0.00
Location Characteristics				
Heating Degree Days	0.60	0.03	17.49	0.00
Urban or Rural Location	-150.99	39.36	-3.84	0.00
Cooling Degree Days	0.19	0.07583876	2.55	0.01
Summary Statistics				
No. Observations	2,628			
F Statistic (prob.)	152.9320	(.000)		
R-Squared	0.4503			
Adj. R-Squared	0.4473			
SEE	2,141.7593			

Table 22

Descriptive Statistics for Dependent and Independent Variables (Residential Energy (electric) Consumption)

Variable Name	Minimum	Maximum	Mean	Standard Deviation
Dependent Variables				
Energy (electric) Consumption	164,000.00	120,875,000.00	36,820,652.91	22,144,336.83
Independent Variables				
Building Characteristics				
Exterior: Brick	0.00	1.00	*0.27*	*0.44*
Exterior: Stucco	0.00	1.00	0.33	0.47
Single Family Unit	0.00	1.00	0.70	0.46
Central Warm-Air Furnace w/ Ducts	0.00	1.00	0.60	0.49
Steam/Hot Water System w/	0.00	1.00	0.15	0.35
Central A/C System	0.00	1.00	0.52	0.50
Full Bathrooms	0.00	6.00	1.57	0.68
Half Bathrooms	0.00	4.00	0.30	0.50
Total Square Feet	167.00	11,383.00	2,268.84	1,612.02
Location Characteristics				
Heating Degree Days	0.00	11,465.00	4,315.82	2,185.88
Urban or Rural Location	1.00	4.00	*2.85*	*1.18*
Cooling Degree Days	0.00	5,518.00	1,482.76	963.89

The residential energy consumption model implements a single state regression to measure building energy use. In the building emissions model, not all units produced energy, so a nested-logit model structure was required to first determine if a building was likely to produce emissions and if so, then it was appropriate to measure the level. In the electric energy consumption model, all buildings in the dataset consume electricity, so a model is only required to measure total consumption. Table 23 shows the regression results for the energy consumption model.

Table 23

Energy (electric) Consumption OLS Regression Results (Residential)

Variable Name	***Coefficient***	***Std. Error***	***t***	***Prob. Value***
Constant	7338622.794	1803850.908	4.068	0.000
	Dependent Variables			
Energy (electric) Consumption	n/a	n/a	n/a	n/a
	Independent Variables			
Building Characteristics				
Exterior: Brick	2,741,237.48	694,839.54	3.95	0.00
Exterior: Stucco	1,970,566.24	670,607.43	2.94	0.00
Single Family Unit	6,029,141.86	700,909.81	8.60	0.00
Central Warm-Air Furnace w/ Ducts	-5,867,164.57	676,308.64	-8.68	0.00
Steam/Hot Water System w/ Radiators	-10,769,148.71	952,179.37	-11.31	0.00
Central A/C System	5,629,285.78	814,359.23	6.91	0.00
Full Bathrooms	6,925,931.82	469,454.37	14.75	0.00
Half Bathrooms	4,213,856.33	566,394.09	7.44	0.00
Total Square Feet	1,924.43	215.25	8.94	0.00
Location Characteristics				
Heating Degree Days	465.69	196.50	2.37	0.02
Urban or Rural Location	-1,848,563.40	244,530.85	-7.56	0.00
Cooling Degree Days	5,680.47	430.08	13.21	0.00
Summary Statistics				
No. Observations	4,289			
F Statistic (prob.)	217.4487			
R-Squared	0.3980			
Adj. R-Squared	0.3962			
SEE	17,207,782			

Commercial

Emissions

Commercial building unit emissions were derived in a similar manner as residential emissions, but without a nested-logit form for the emissions model. This model form was not necessary as the number of commercial units in the dataset that do not produce emissions was so small that a binary logistic model could not be soundly specified. As a result, this section presents just the OLS based emission estimation results. Table 24 shows the descriptive statistics for the commercial building sector emissions estimation model.

Table 24

Descriptive Statistics for Dependent and Independent Variables (Commercial CO_2 Combustion Model)

Variable Name	Minimum	Maximum	Mean	Standard Deviation
		Dependent Variables		
CO2 Emissions	0.00	37,303.48	979.58	3,039.94
		Independent Variables		
Building Characteristics				
Workers	0.00	7,500.00	116.27	367.65
Number of Occupants	0.00	2,100.00	3.26	31.73
Use: Hospital	0.00	1.00	0.04	0.19
Use: Laboratory	0.00	1.00	0.01	0.09
Use: Distribution/shipping center	0	1	0.046947368	0.211548422
Use: Bank	0	1	0.106526316	0.308542544
Total Square Feet	1,001.00	1,600,000.00	80,080.67	171,911.57
Location Characteristics				
Heating Degree Days	0.00	11,059.00	4,497.07	2,275.24

Regression of the variables from Table 25 yields a set of CO2 emission parameters with a significant level of prediction. The biggest determinants of CO2 emissions in the commercial building sector was the control variable for building use. For example, hospitals produce 5,000 more tons of CO2 than most other commercial uses. The number of building occupants in a structure was negatively correlated with the amount of CO2 emissions. This was likely an indicator of building configuration and size. The more occupants in a building (which is distinct from number of workers) the more walls the building likely had. This created a better building envelope and made the entire building more efficient. The number of heating degree-days, a measure of how many days are below 65 degrees, as expected had a positive effect on CO2 use. The results of the regression were a good predictor of commercial unit CO_2, with an adjusted R-square of .80; the model variable captured 80% of the variation of CO_2 between units.

Table 25

CO_2 Emission Regression Results (Commercial)

Variable Name	***Coefficient***	***Std. Error***	***t***	***Prob. Value***
Constant	-385.148	46.604	-8.264	0.000
	Dependent Variables			
CO_2 Emissions	n/a	n/a	n/a	n/a
	Independent Variables			
Building Characteristics				
Workers	1.32	0.08	15.68	0.00
Number of Occupants	-4.84	0.65	-7.49	0.00
Use: Hospital	5,235.24	117.93	44.39	0.00
Use: Laboratory	1,959.15	219.68	8.92	0.00
Use: Distribution/shipping center	-600.64	95.79	-6.27	0.00
Use: Bank	-320.81	66.12	-4.85	0.00
Total Square Feet	0.01	0.00	54.24	0.00
Location Characteristics				
Heating Degree Days	0.06	0.01	6.25	0.00
Summary Statistics				
No. Observations	4,749			
F Statistic (prob.)	2,473.3935	(.000)		
R-Squared	0.8067			
Adj. R-Squared	0.8064			
SEE	1,380.6785			

Energy (electricity) Consumption

Table 26 provides the descriptive statistics for the commercial building sector electricity consumption estimation model. The model used fewer building use control variables to predict energy use, with just hospitals and laboratories as statistically significant uses. All other building characteristic variables were used in the analysis.

Table 26

Descriptive Statistics for Dependent and Independent Variables (Commercial Energy (electric) Consumption)

Variable Name	Minimum	Maximum	Mean	Standard Deviation
		Dependent Variables		
Energy (electric) Consumption	123.00	178,353,760.00	5,158,241.98	13,756,786.30
		Independent Variables		
Building Characteristics				
Age	3.00	235.00	37.89	30.28
Workers	0.00	7,500.00	120.59	395.70
Number of Occupants	0.00	2,100.00	3.37	32.22
Use: Hospital	0.00	1.00	0.04	0.19
Use: Laboratory	0.00	1.00	0.01	0.09
Total Square Feet	1,001.00	1,600,000.00	81,471.20	176,948.31
Location Characteristics				
Cooling Degree Days	20.00	5,904.00	1,348.38	1,025.83

Much like with CO2 emissions and somewhat intuitive, hospitals were large consumers of electricity. The number of building occupants increases the use of electricity, as does the number of workers (Table 27). The number of cooling degree-days, which is the number of days above 65 degrees, has an effect on the use of electricity likely used mostly for air conditioning. The electric consumption model had an adjusted R-square of .897, which means the model predicted nearly 90 percent deviation of electricity use between buildings in the sample. This was primarily due to the high correlation between energy use and building size and number of workers.

Table 27

Energy (electric) Consumption OLS Regression Results (Commercial)

Variable Name	***Coefficient***	***Std. Error***	***t***	***Prob. Value***
Constant	-443,926.42	146,977.48	-3.02	0.00
	Dependent Variables			
Energy (electric) Consumption	n/a	n/a	n/a	n/a
	Independent Variables			
Building Characteristics				
Age	-13,367.39	2,186.20	-6.11	0.00
Workers	10,158.90	260.94	38.93	0.00
Number of Occupants	24,546.20	2,059.86	11.92	0.00
Use: Hospital	13,437,431.25	373,498.13	35.98	0.00
Use: Laboratory	6,827,635.52	693,086.91	9.85	0.00
Total Square Feet	45.52	0.61	74.64	0.00
Location Characteristics				
Cooling Degree Days	344.27	64.60	5.33	0.00
Summary Statistics				
No. Observations	4,633			
F Statistic (prob.)	5,792.3151	(.000)		
R-Squared	0.8976			
Adj. R-Squared	0.8974			
SEE	4,405,675			

Building Sector – Inventory

The CO2 emissions and energy consumption estimation models were applied to individual buildings across the entire state of Maryland to develop a complete inventory of CO2 emissions and electricity demand. Figure 30 through Figure 33 show the results of the models applied at the individual building level. Two geographies are displayed for the example graphics. One is downtown and surrounding suburban Silver Spring, Maryland. In this area, there are many newer buildings that have been constructed in the downtown area. These buildings are less likely to produce CO2 so many show no emissions at all (Figure 30) but in all cases buildings consume electricity (Figure 32). The other geography is the city of Baltimore. Many of the Baltimore buildings are older and produce CO2 (Figure 31) but consumer less electricity (Figure 33).

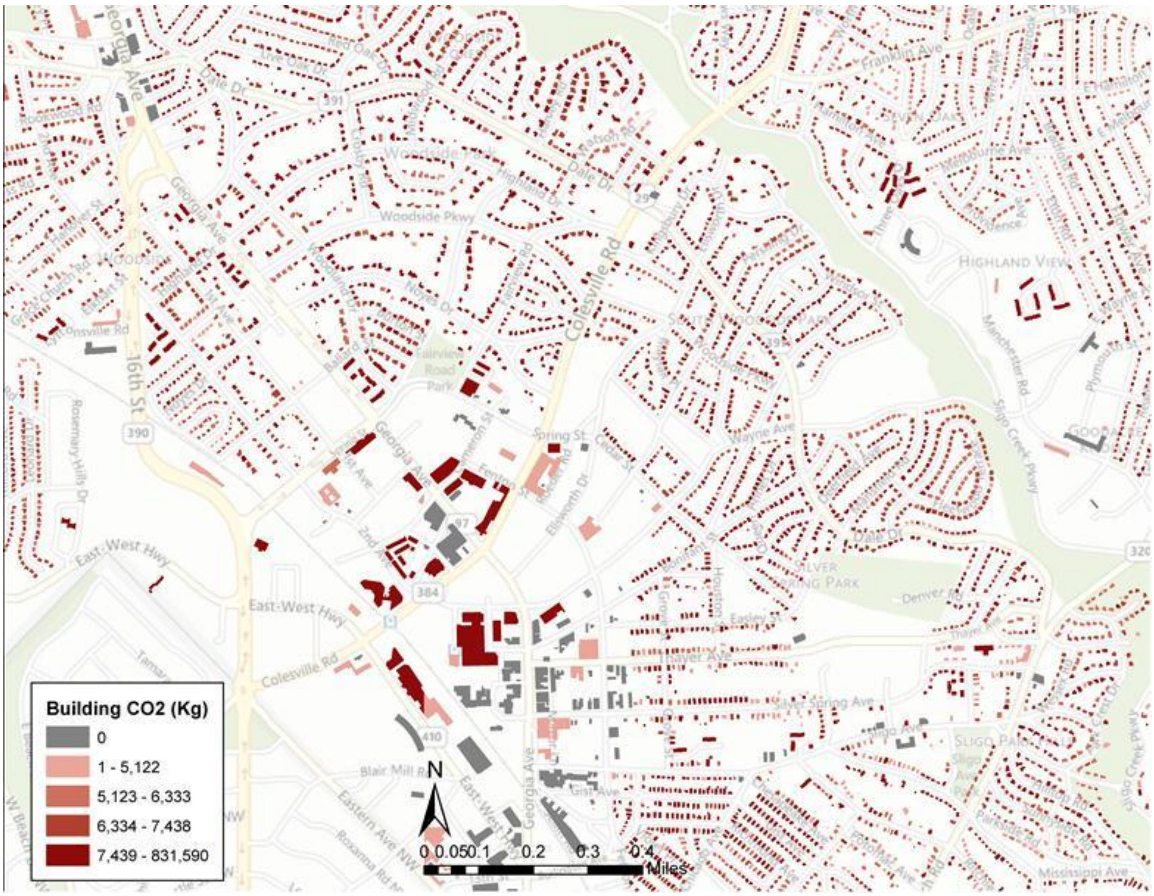


Figure 30. Building level modeled CO_2 emissions, 2006 (Silver Spring, MD).

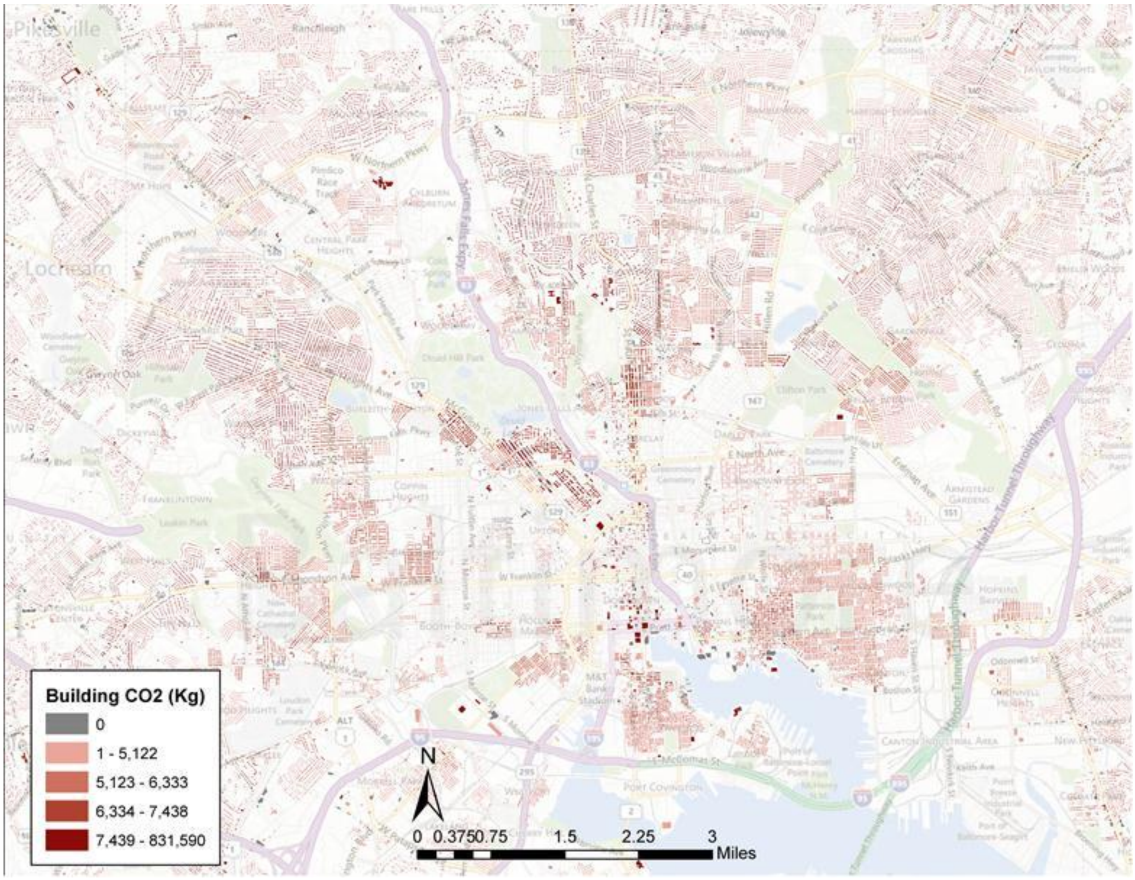


Figure 31. Building level modeled CO_2 emissions, 2006 (Baltimore, MD).

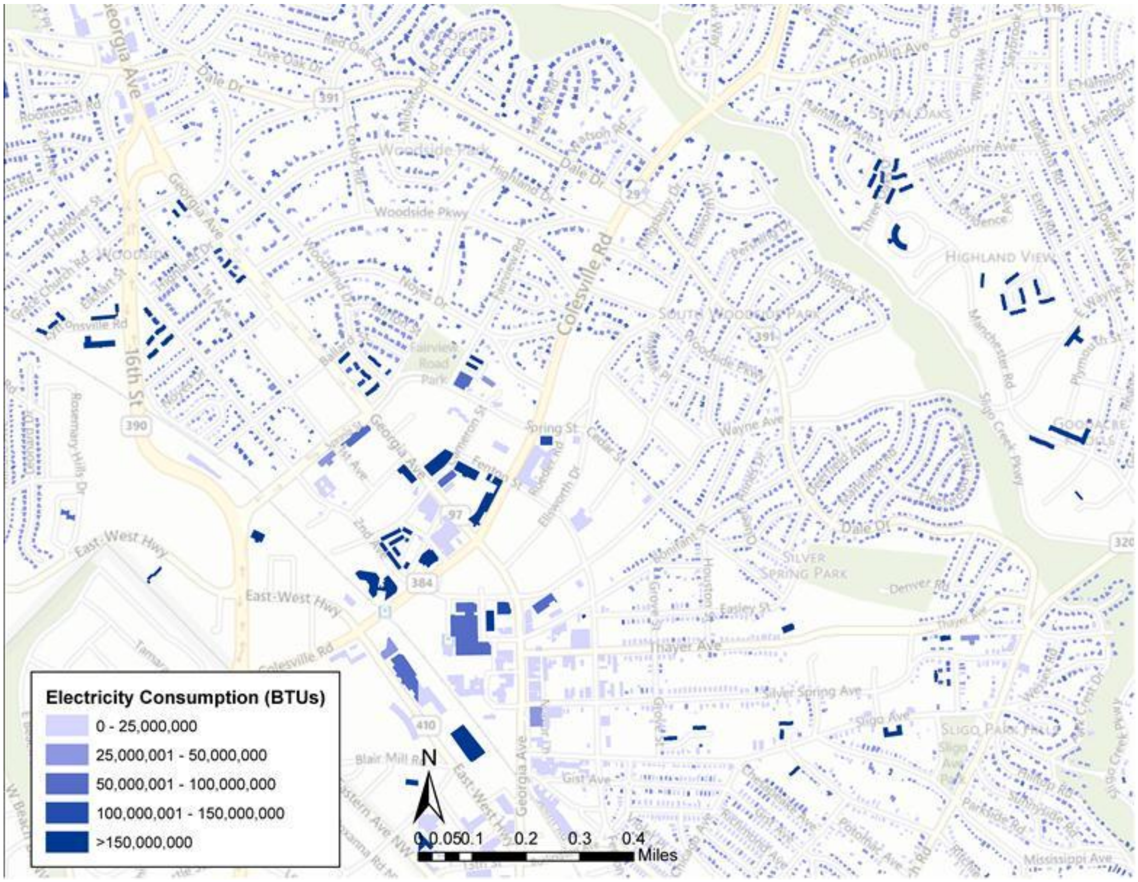


Figure 32. Building level modeled energy consumption, 2006 (Silver Spring, MD).

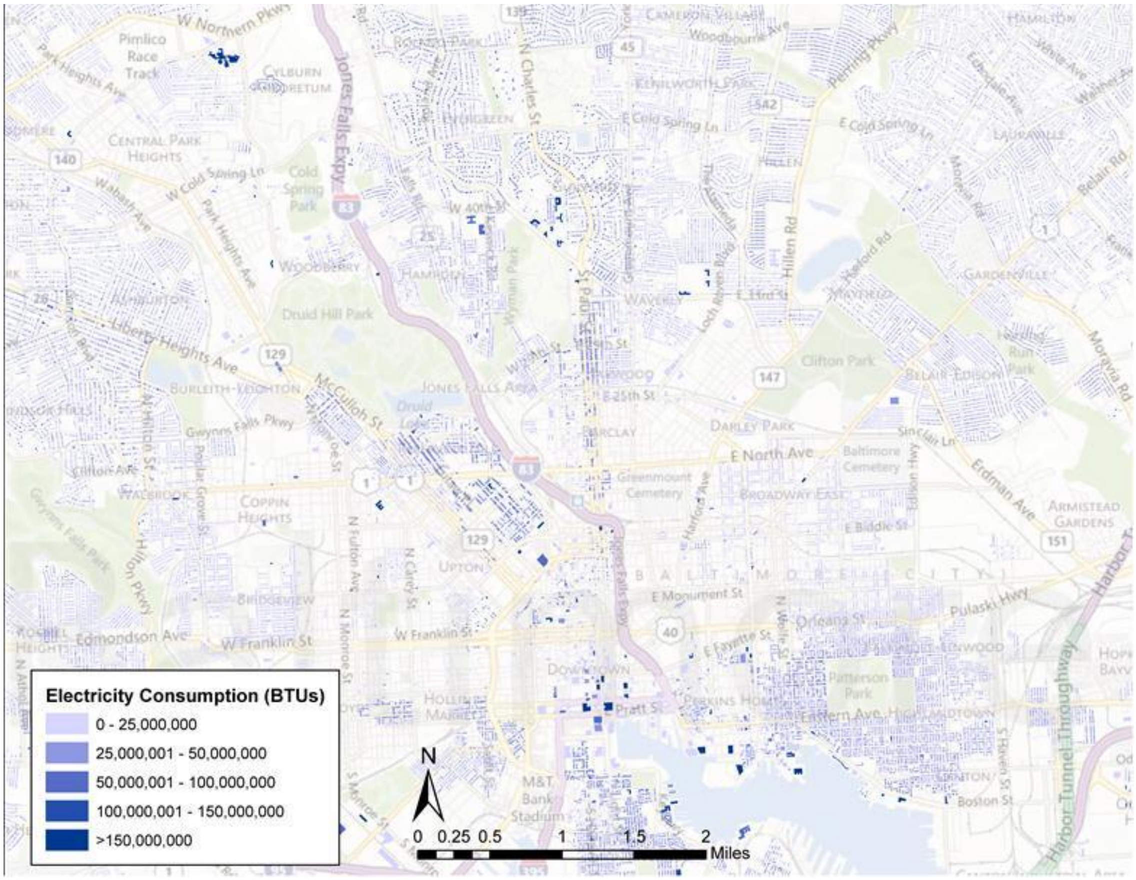


Figure 33. Building level modeled energy consumption, 2006 (Baltimore, MD).

In order to forecast future CO2 emissions and energy demand it was necessary to aggregate the building level 2006 estimated emissions (*Figure **34***) and energy consumption (*Figure **35***) to the SMZ level to put the data at the same level of aggregation as the household and employment forecasts developed for the transportation demand model.

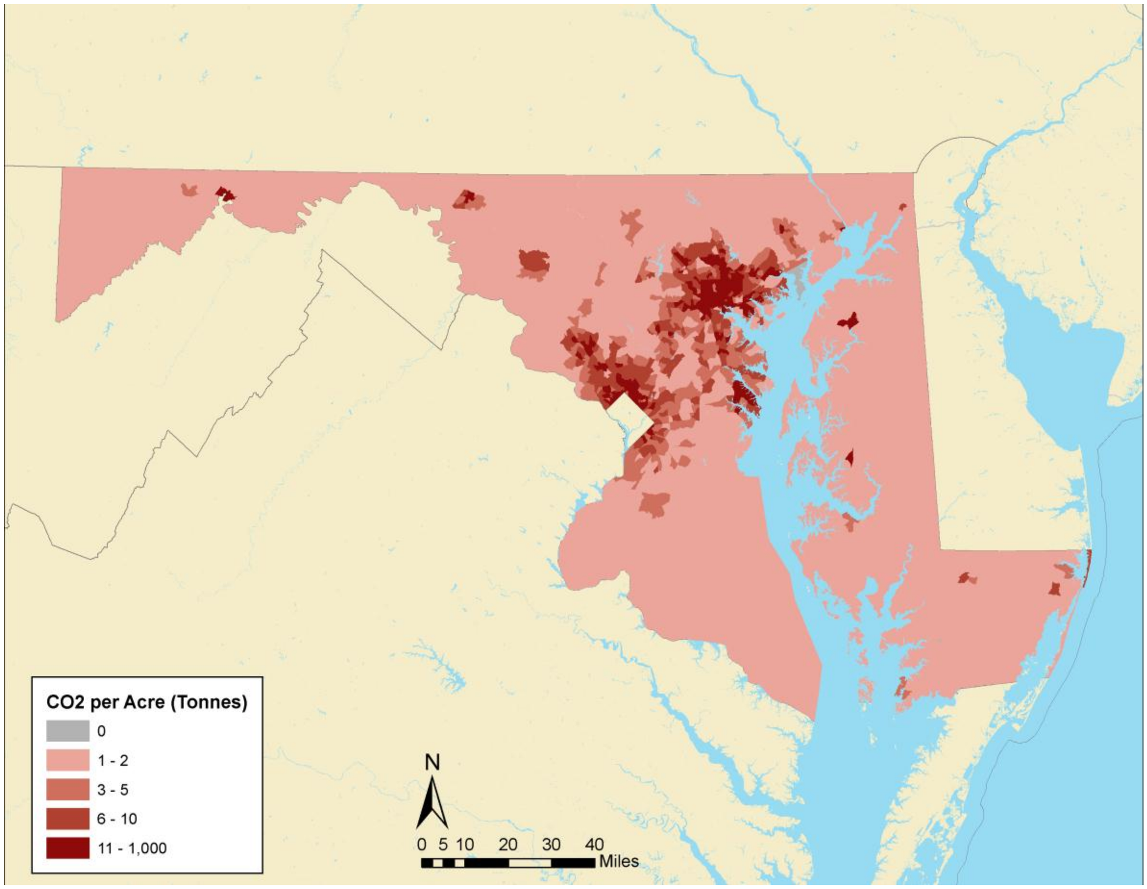


Figure 34. SMZ level modeled CO_2 emissions, 2006.

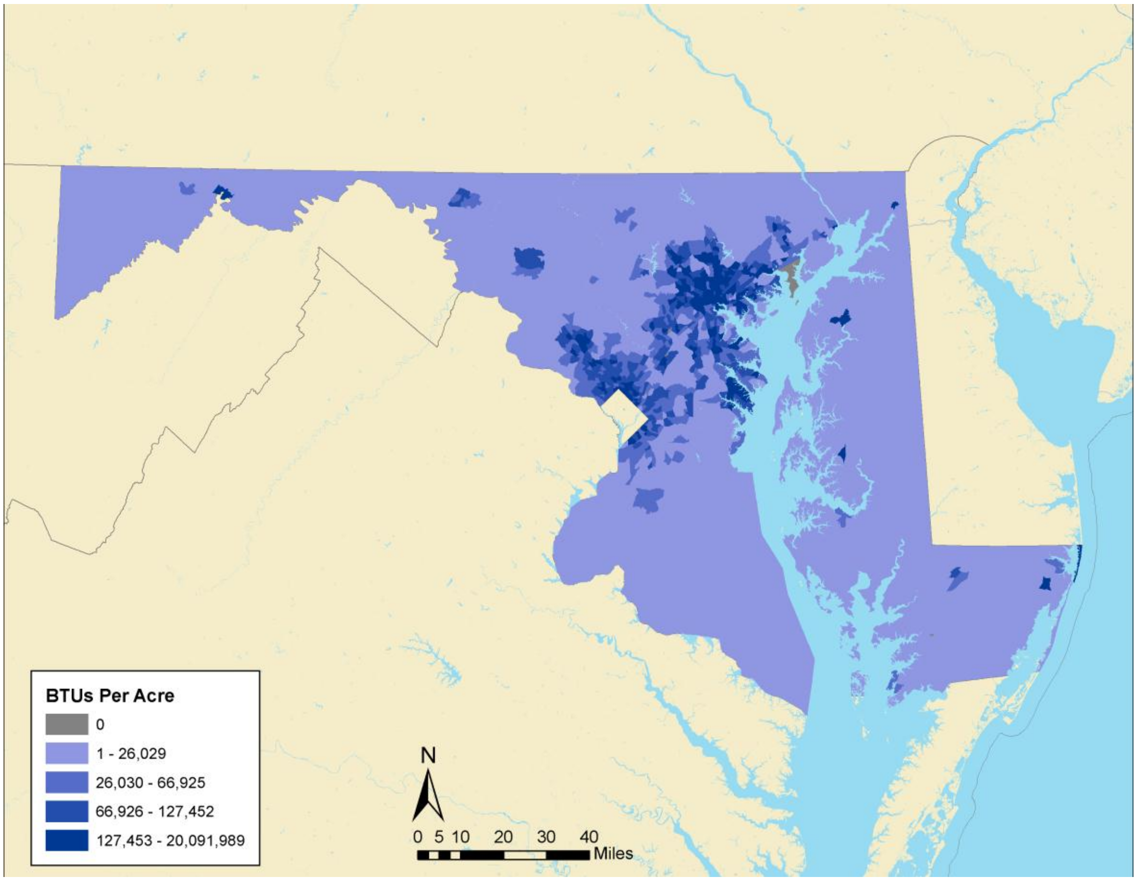


Figure 35. SMZ level modeled energy consumption, 2006.

Once the building level data was aggregated into the SMZ structure, multipliers for typical building characteristics, type of households and employment, and average CO2 emissions and energy consumption were developed. Using these multipliers and the projected spatial distribution of households and employment in 2020 forecasts of future CO2 emissions (Figure 36) and energy consumption (Figure 37) were calculated. The future growth patterns, energy consumption, and emission estimations form the Business As Usual (BAU) 2020 scenario. Both emissions and energy consumption were significantly related to future growth. The relationship was reflected in the figures where CO2 emission and energy consumption grow substantially in 2020 in more rural areas of Maryland. Older heavily urbanized areas, especially in the Washington DC metro area;

do not change significantly, as less development is likely to occur in these areas absent policies to redirect growth.

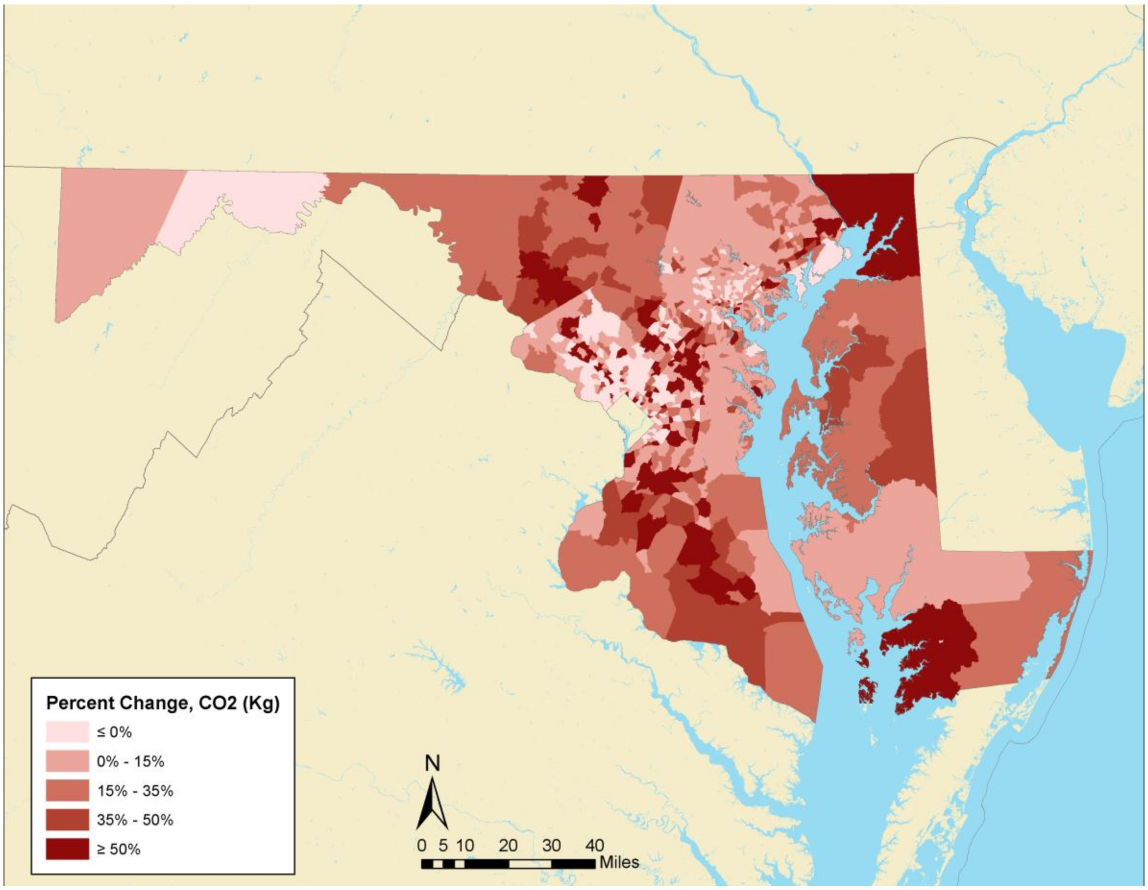


Figure 36. SMZ level percent change in modeled CO_2 emissions, 2006-2020.

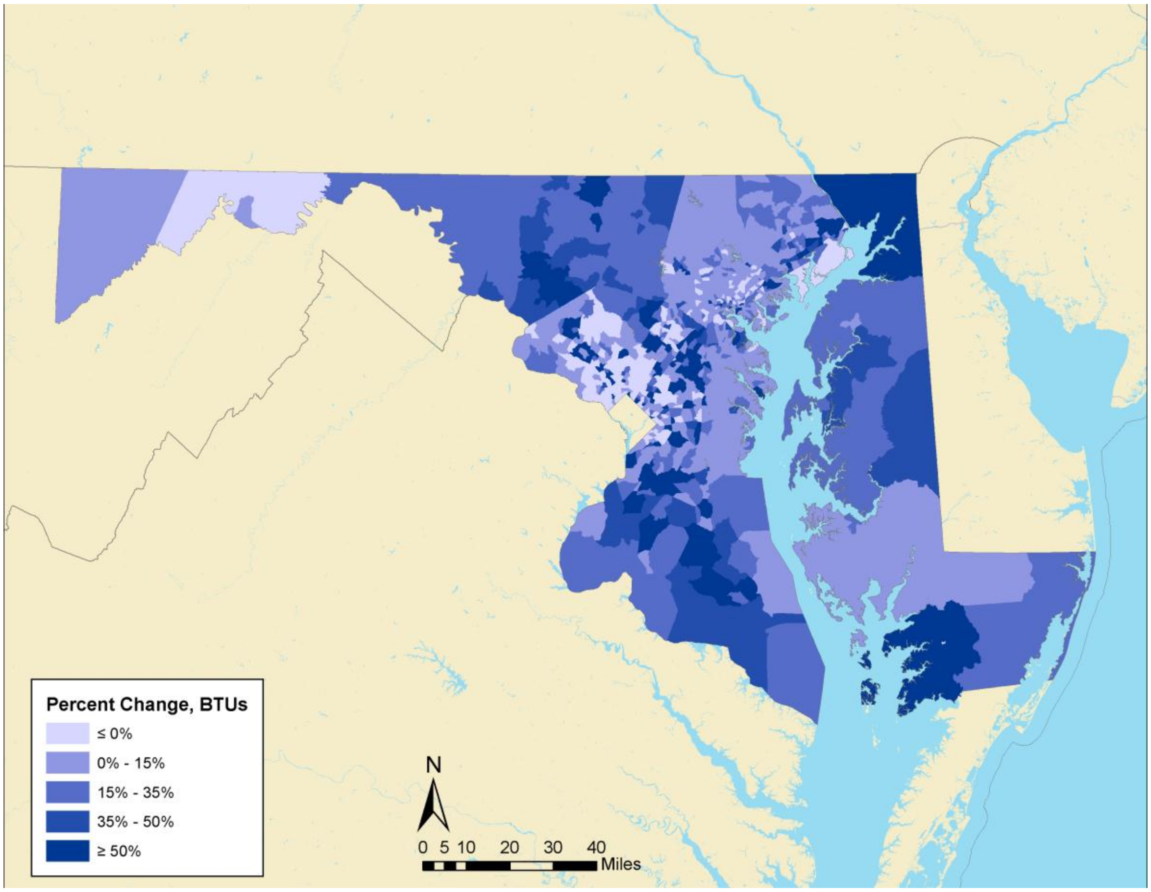


Figure 37. SMZ level percent change in modeled energy consumption, 2006-2020.

Building Sector –Strategy Results

In this section, the results from strategies to reduce emissions from residential and commercial emissions are reported. Strategies for both sectors use the same general mechanisms: directing future growth to PFAs and weatherizing/retrofitting buildings. However, the results in these sectors vary, as the method of implementation and level of funding are substantially different.

Residential

Resident CO2 emissions are projected to go up by about 15.5 percent from 2006 to 2020 or by 1.1 percent per year under the BAU scenario. Emissions in the residential sector declined between 2005 and 2006 but the long-term trend shows a slow increase in emissions since 1990 (Figure 38). This decline is explained by a number of temporary market conditions including changes in energy cost and economy. A linear extrapolation of the historical emissions resulted in a similar but slightly higher 2006 total than the BAU scenario. The BAU 2020 scenario emissions are about 54 percent higher than the required GGRA target.

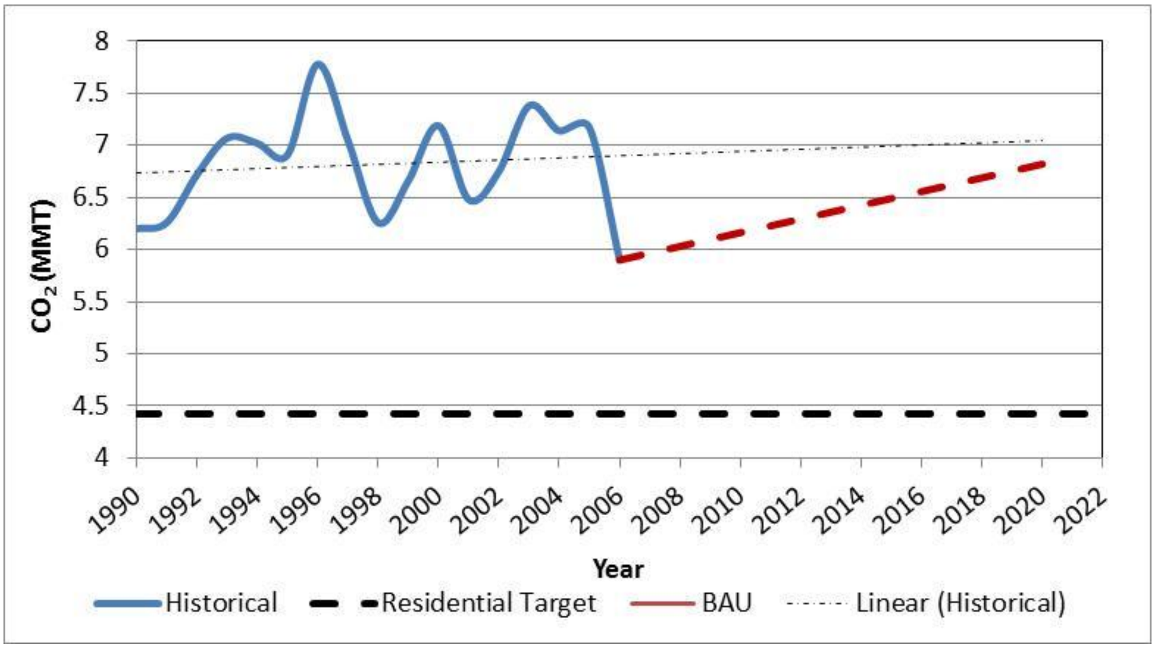


Figure 38. Residential historic and BAU (projected) Emissions.

Figure 39 provides the results of the two residential building unit emission reduction strategies. The ‘Smart Growth’ implementation directs 80 percent of future residential growth to PFAs with a 25/75 split between multifamily and single family units. As a result of this redirection in growth patterns and change in the balance of housing unit types, CO2 emissions were reduced by a little more than .26 MMt or 3.82 percent. This strategy as modeled does not assume any change from the current efficiency of housing stock. The reductions are generally the result of efficiencies gained by decreases in housing unit size both from the smaller average unit size in a PFA and the increase in the ratio of multifamily units to single-family units. An emission reduction from decreases in electrical demand and changes in travel behavior were reported in the sections for the energy and transportation sectors, respectively.

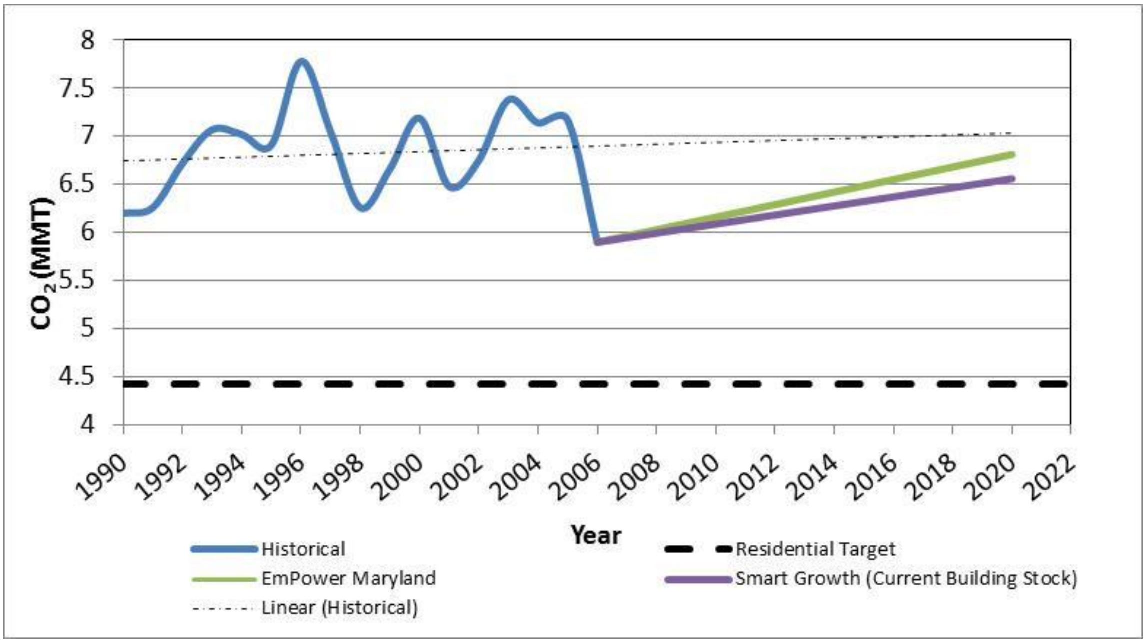


Figure 39. Residential Emissions under individual CAP strategies.

The EmPower Maryland scenario uses $46.7 million in block grant funding to weatherize low-income housing units. An estimated total of 8,044 homes can be weatherized at the cost of $5,806 per house. Table 28 shows the total reduction in CO2 emissions expected from the weatherization assistance program. The total reduction amounts to approximately 0.11 percent of total residential sector emissions. The cost per ton of emission reduction is equivalent to $6,152.

Table 28

Costs and benefits from low-income weatherization

Empower Maryland: Low-income Housing Weatherization	
Total Funding	$46,702,271
Cost per retrofit/weatherization	$5,806
Total properties retrofitted/weatherized	8,044
CO_2 savings per unit (lbs)	2,081
Total CO_2 savings (lbs)	16,736,257
Total CO_2 savings (MMt)	0.0076

The combined results of both residential building emission reduction strategies are shown in Figure 40. The total effect of both strategies is a .2678 MMt CO2 or 3.93 percent reduction in emissions from the BAU scenario. These strategies fall short of the needed 25 percent reduction from 2006 levels. The total shortfall is 4.69 MMt CO2 or 59.8 percent.

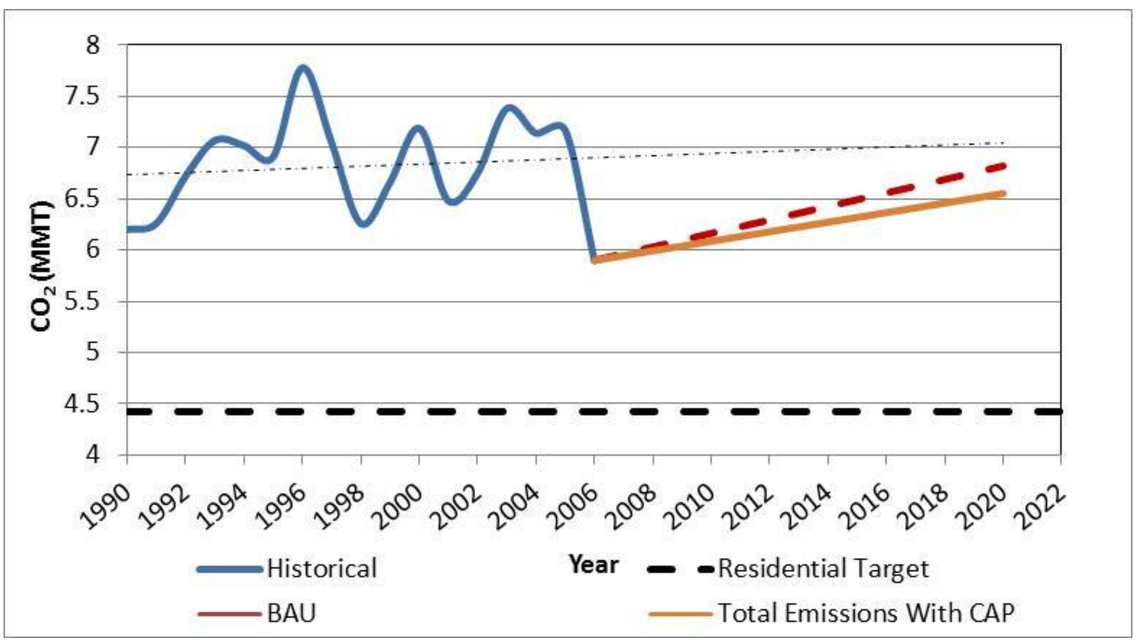


Figure 40. Residential emissions with all CAP strategies implemented.

Commercial

Figure 41 provides the historical (until 2006) and projected (2006-2020) emissions under a BAU scenario. Emissions for the commercial sector are projected to grow by 17.3 percent or 1.24 percent per year. The rate of change is slower than the historic average but reflects the move towards more efficient commercial buildings away from older urbanized areas in new suburban office parks.

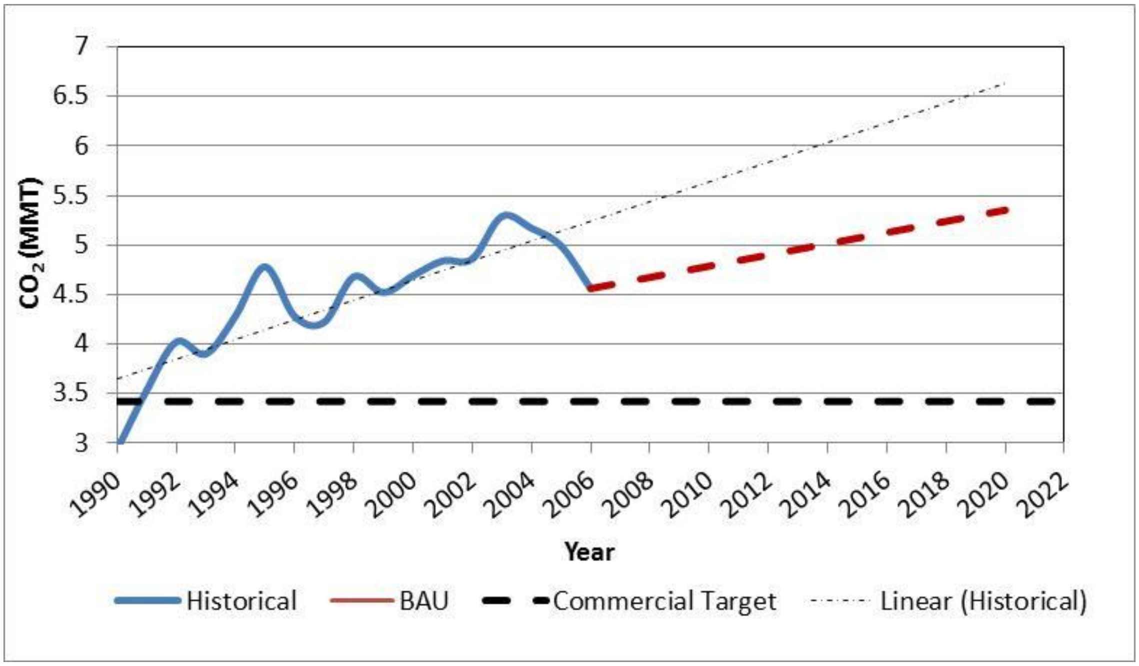


Figure 41. Commercial historic and BAU (projected) Emissions.

Figure 42 shows the results of the two commercial sector emission reduction strategies. The smart growth strategy, which directs 80 percent of future commercial job growth into PFAs, results in an increase in emissions over the BAU scenario. This result reflects a limitation in both the projection methodology and the policy itself. The parameters for building efficiency at the SMZ level were left at the 2006 constant so no changes in building stock were assumed for the period between 2006 and 2020. Most of the area covered by PFAs was already heavily urbanized areas so the likelihood of enough infill and redevelopment taking place between the implementation of the GGRA policy in 2014 and the date of the emissions target 2020 was sufficiently low that assuming a constant efficiency for these locations was a reasonable choice.

If this assumption is correct, emissions for the commercial sector under the smart growth scenario will increase in 2020 by 12 percent over the BAU set-up. However, this change represents only one part of the smart growth policy effect. When jobs are moved closer to households under the smart growth scenario there should be a measurable decline in vehicle travel. This effect is further discussed in the transportation section.

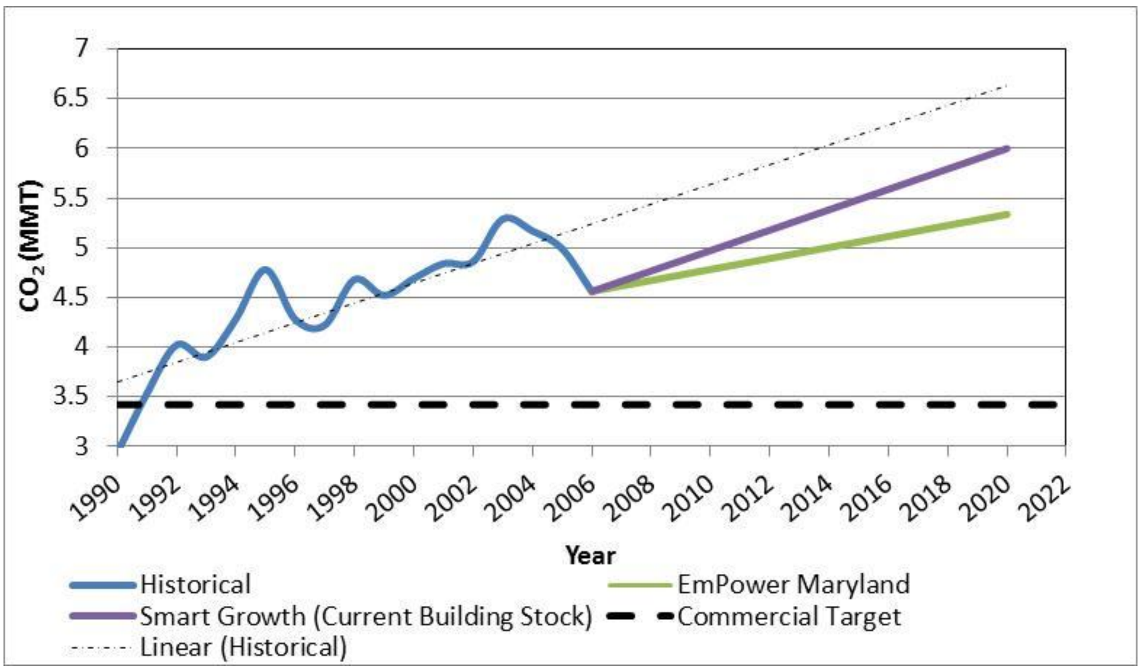


Figure 42. Commercial Emissions under individual CAP strategies.

The EmPower Maryland scenario for the commercial sector does produce an overall emissions reduction from the BAU set-up. The total expected emission reduction from this strategy is 0.19 percent. Table 29 through Table 31 provide a detailed description of the funding, number of units affected, and resulting CO2 emission reductions for each of the unit types selected for retrofitting and weatherization.

Table 29

Costs and benefits from commercial building retrofit

Commercial Retrofit	
Total Funding	$6,000,000
Cost per retrofit/weatherization	$14,634
Total properties retrofitted/weatherized	410
CO_2 savings per unit (lbs)	21,222
Total CO_2 savings (lbs)	8,701,590
Total CO_2 savings (MMt)	0.0039

Table 30

Costs and benefits from multifamily building retrofit

Multifamily Retrofit	
Total Funding	$6,000,000
Cost per retrofit/weatherization	$15,366
Total properties retrofitted/weatherized	390
CO_2 savings per unit (lbs)	45,779
Total CO_2 savings (lbs)	17,874,947
Total CO_2 savings (MMt)	0.0081

Table 31

Costs and benefits from single-family building retrofit

Single Family Retrofit	
Total Funding	$4,800,000
Cost per retrofit/weatherization	$2,700
Total properties retrofitted/weatherized	1,778
CO_2 savings per unit (lbs)	5,399
Total CO_2 savings (lbs)	9,597,412
Total CO_2 savings (MMt)	0.0044

Figure 43 shows the total effect of both commercial sector emission reduction strategies. In this case, the estimated emissions increase from the smart growth strategy is greater than the retrofit and weatherization strategy. If both policies are implemented, commercial sector emissions are expected to increase by 11.7 percent over the BAU scenario and miss the GGRA reduction target by about 56 percent.

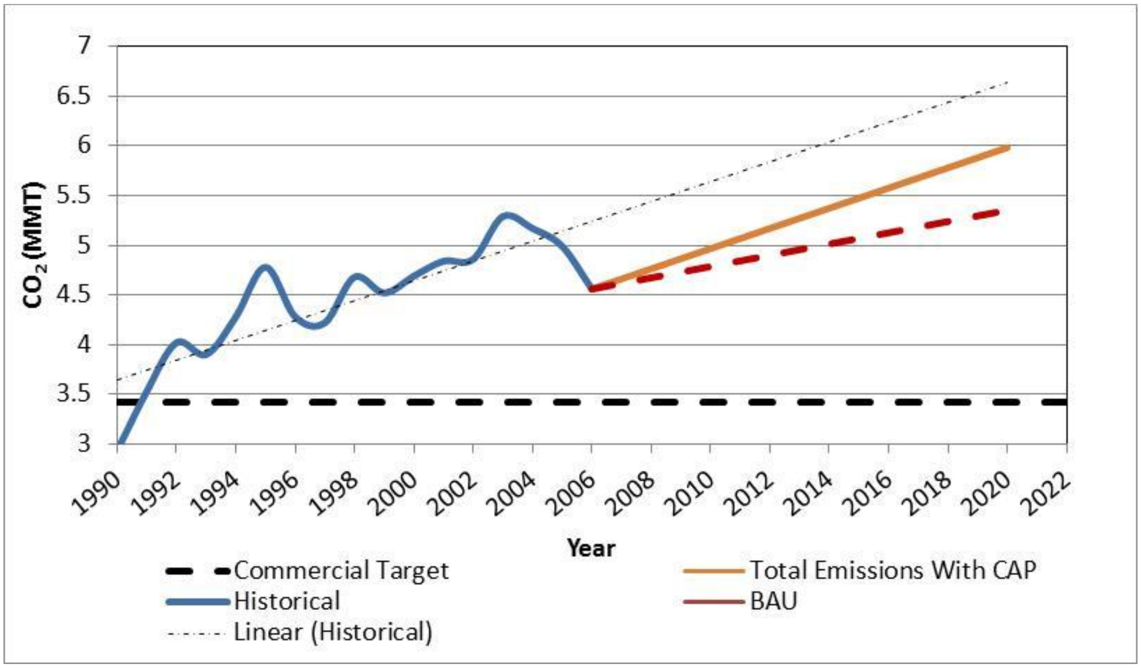


Figure 43. Commercial emissions with all CAP strategies implemented.

Energy Sector

Several policies for reducing emissions from the energy generation sector were tested and the results are summarized in

Table **32**.

Table 32

Summary of energy sector reduction strategies

Baselines			
Total Inventory	**Annual CO_2 (MMT)**	**%Change (From 2020 BAU)**	
Maryland BAU 2020	77.58		
Energy Sector 2006	28.89		
2020 CAP Target	21.67	-36.62%	
Strategy Results			
Future Inventory	**Annual CO_2 (MMT)**	**%Change (From 2006)**	**%DIFF (From Target)**
Energy Sector BAU 2020	34.19	N/A	57.77%
RGGI (Energy 1)	24.88	-27.22%	14.83%
Reduced Import CO2 (Energy 2)	31.64	-7.43%	46.04%
Renewable Portfolio Standard (Energy 3)	35.63	4.22%	64.43%
Coal to Biomass: Emissions (EmPOWER	34.63	1.31%	59.83%

MD 1)			
Empower Maryland 2	28.32	-17.17%	30.68%
Total Emissions With CAP	***18.36***	***-46.30%***	***-15.27%***
Total Emissions With CAP (No RGGI)	***27.66***	***-19.08%***	***27.67%***

Figure 44 shows the projected 2020 BAU emissions for the energy sector. Emissions are estimated to grow at a slower pace than the historical average. The total BAU growth is expected to grow by 18.3 percent or about 1.3 percent per year. Projects are based on the current distribution of energy sources in the state. The BAU scenario is nearly 58 percent over the 2020 GGRA target emissions level.

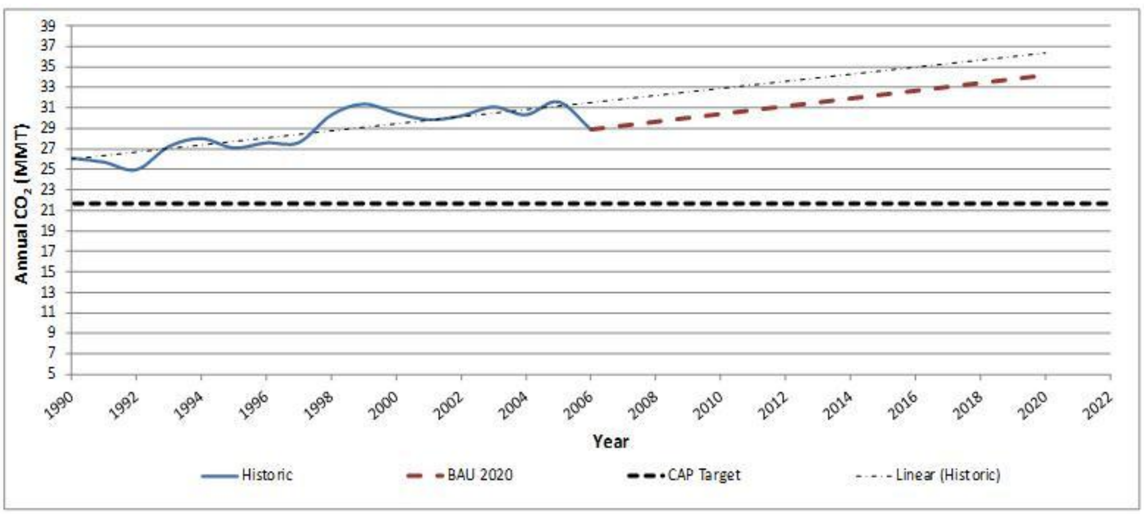


Figure 44. Energy sector historic and BAU (projected) emissions.

Figure 45 shows the emission reduction results from the five strategies. The strategy with the greatest impact on emissions is the RGGI program. In this case, the RGGI reductions are based on the newly announced model emissions cap and reduction. These larger reductions will only be realized in Maryland if the new model rule is approved by the member states and Maryland revises its state regulations to reflect the change (see chapter 5). The emission reductions in the energy sector that may be possible by adopting the new RGGI proposed cap is shown in the second to last row of Table 32. By contrast, the reductions without adopting the new cap is shown in the last row of the table.

Strategies that involve ‘renewable energy’ or biomass result in higher emissions than would occur under a BAU scenario. This is particularly noticeable for the RPS (Energy 3). In this case, Maryland classifies municipal solid waste (MSW) incineration as a renewable energy source. Among other tier 1 renewables (landfill gas, hydroelectric, etc.) Maryland derives 90 percent of its renewable energy from MSW for a total of 1.3 percent of its total energy generation. This energy source produces an average of three times the CO2 emissions compared to coal, according to the EPA. If the RPS strategy is implemented in Maryland following the current portfolio mix of renewables, emissions of CO2 will increase substantially. The state will need to replace approximately 18.6 percent of its total energy generating capacity with renewables to meet the RPS requirements. Two percent will come from zero emission solar with the remaining 16.6 percent coming from 90 percent MSW.

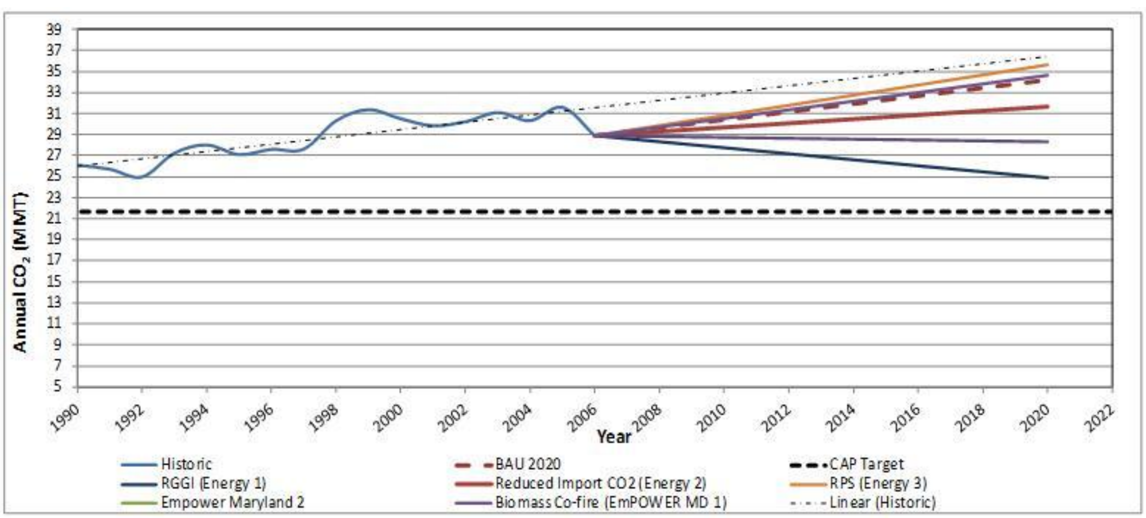


Figure 45. Energy sector emissions under individual CAP strategies.

If all of the emission reduction strategies were implemented including the RPS and the new model RGGI rules, Maryland would reduce energy sector emissions below the 2020 GGRA target (Figure 46). This package of strategies could reduce emissions over 15 percent below the target, aiding in achieving the overall state target. If Maryland does not adopt the stricter RGGI standards or cannot meet the initiative's goals, emissions will reduce but miss the GGRA target by over 27 percent.

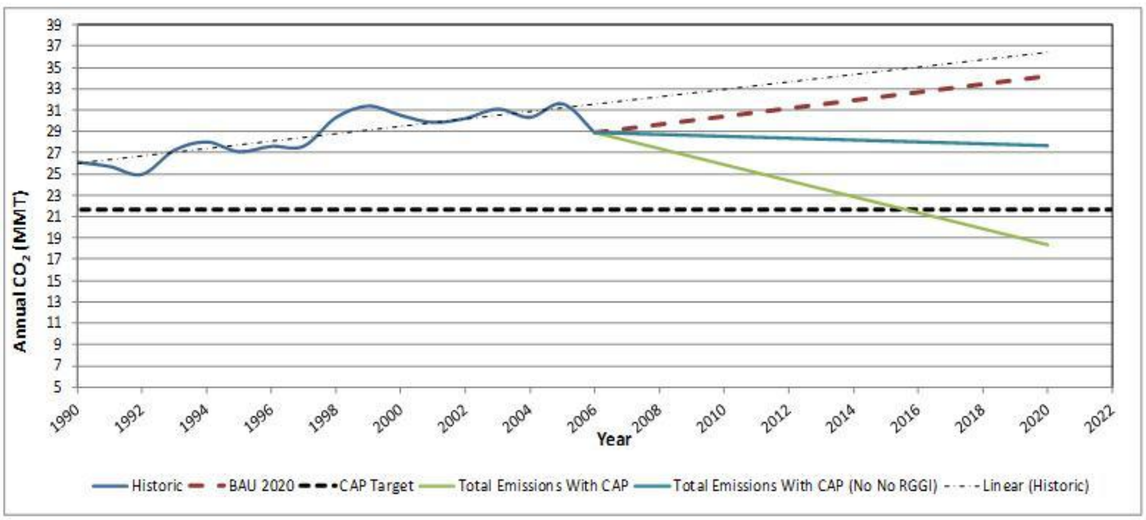


Figure 46. Energy sector emissions with all CAP strategies implemented.

Transportation Sector

Table 33 provides a summary of the various transportation emission reduction strategies tested from the Maryland CAP. The emission reduction strategies reported below fall into two categories: pricing and non-pricing.

Table 33

Summary of transportation sector emission reduction strategies

Baselines				
Total Inventory	**Annual CO_2 (MMT)**	**Avg. Daily CO_2 (Grams)**	**%Change (From 2020 BAU)**	
Maryland BAU 2020	77.58	212,547,945,205		
Transportation 2006	32.05	87,808,219,178		
2020 CAP Target	24.04	65,856,164,384	-38.44%	
Strategy Results				
Future Inventory	**Annual CO_2 (MMT)**	**Avg. Daily CO_2 (Grams)**	**%Change (From 2006)**	**%DIFF (From Target)**
Transportation BAU 2020	39.05	106,979,444,445	N/A	62.44%
Gas Tax ($0.50)	38.64	105,851,291,575	-1.05%	60.73%
Gas Tax ($2.00)	37.24	102,014,794,076	-4.64%	54.91%
VMT Tax ($0.50)	37.55	102,872,402,106	-3.84%	56.21%
VMT Tax ($2.00)	33.87	92,791,155,090	-13.26%	40.90%
CO2 Tax ($25/ton)	37.34	102,290,000,000	-4.38%	55.32%
CO2 Tax ($50/ton)	36.65	100,402,956,665	-6.15%	52.46%
CO2 Tax ($75/ton)	35.98	98,578,688,439	-7.85%	49.69%
Efficiency (CAFE)	35.12	96,208,303,882	-10.07%	46.09%
2x Ridership	37.02	101,415,107,786	-5.20%	53.99%
Smart Growth	34.10	93,412,821,307	-12.68%	41.84%
Total CAP Emissions	***28.72***	***78,697,069,868***	***-26.44%***	***19.50%***

Transportation sector emissions in Maryland have grown at a near constant linear rate since 1990. A comparison of the linear extrapolation of historical emissions and the modeled change in emissions in 2020 (Figure 47) show the two figures are nearly identical. Emissions are projected to grow by about 22 percent or approximately 1.5 percent per year.

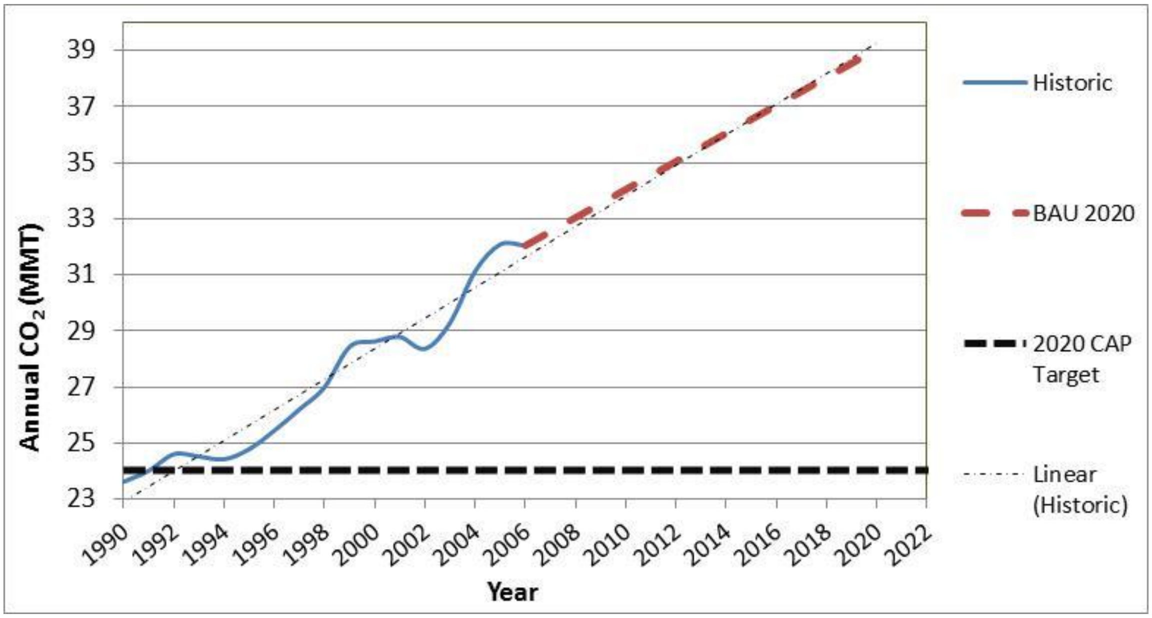


Figure 47. Transportation historic and BAU (projected) emissions.

Figure 48 shows the modeled transportation network in Maryland with the estimated 2006 link level CO2 emissions, normalized by emissions per mile. The red lines on the map, showing links with heavy emission, generally follow the interstate system and other major road facilities. Figure 49 shows the projected relative change in transportation network CO2 emissions between 2006 and 2020. The areas of significant change, highlighted in red, generally follow the location of future household and employment growth. Much of the future emissions will likely occur in the suburban areas, surrounding the major urbanized and metropolitan locals.

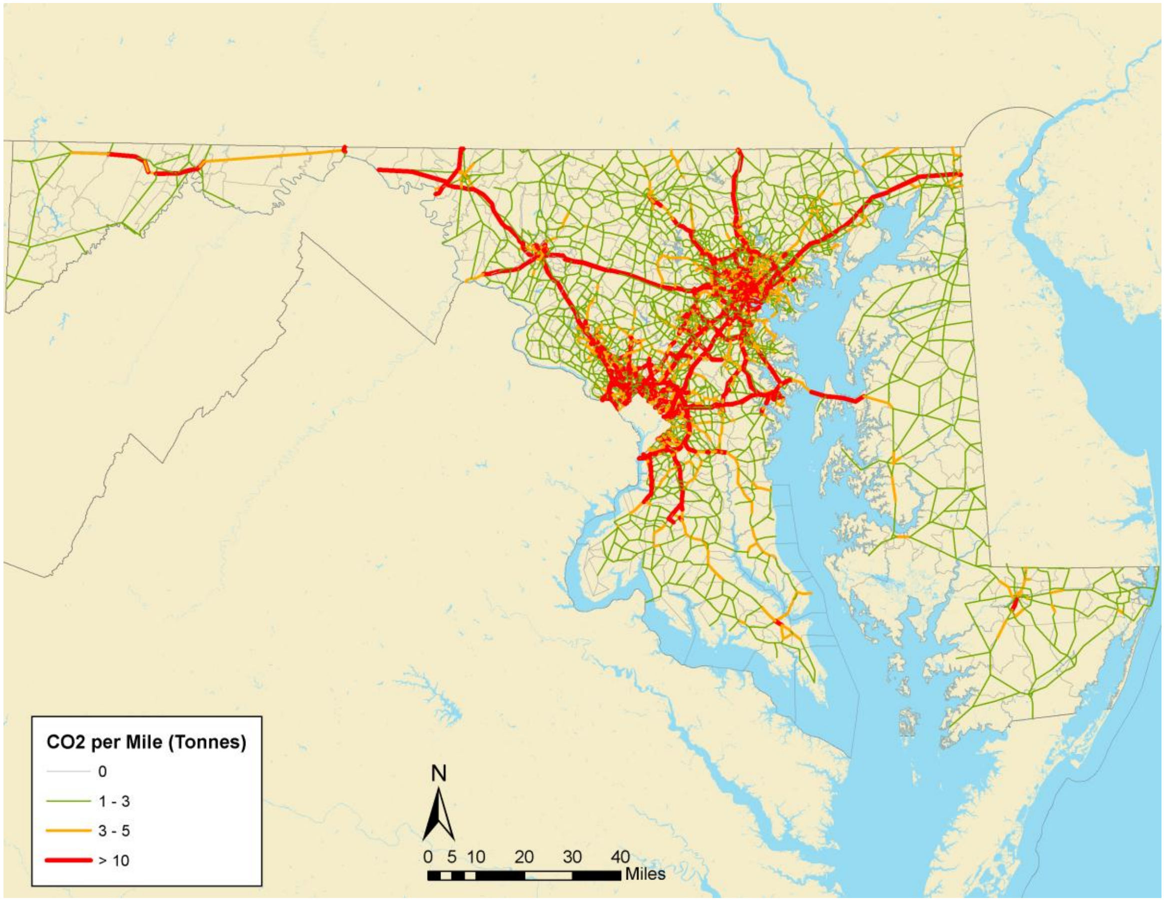


Figure 48. Transportation 2006 network emissions.

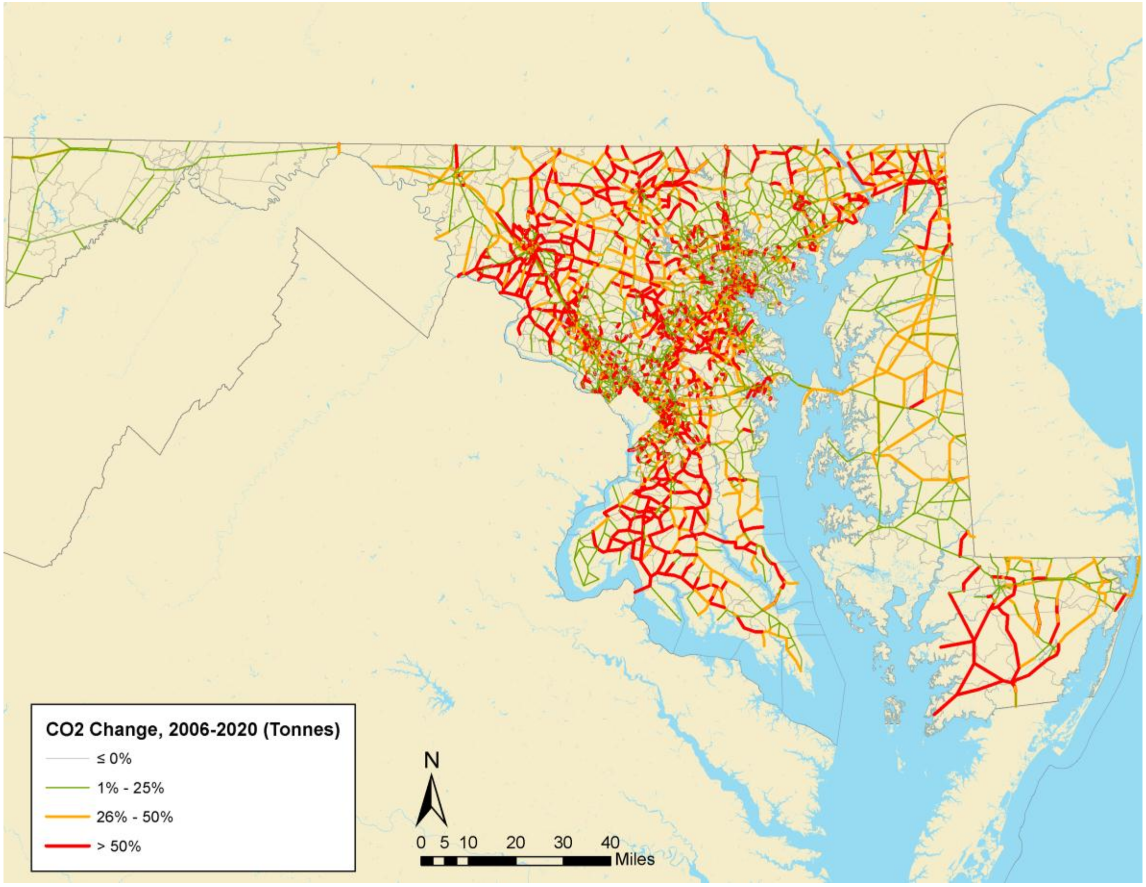


Figure 49. Change in transportation network CO_2 emissions, 2006-2020.

Pricing Strategies

Pricing strategies are suggested when Maryland CAP and GHG reductions are quantified, but specifics on mechanisms and the level of price change are not articulated. Moreover, the Maryland CAP's GHG quantification method did not use any behavior, economic, or transportation models to arrive at GHG reductions. In order to better quantify possible CO2 emission reductions from pricing, three common scenarios were developed with different gradations of price. Each of these methods is discussed in this section.

Figure 50 shows the quantification of emission reductions from a hypothetical gas tax of either $0.50 or $2.00 per gallon. The model assumes an average fuel economy in

2013 of 25.55 mpg. Drivers travel an average of 12,000 miles per year consuming roughly 470 gallons of gas. A $0.50 per gallon gas tax would add $234.83 to the cost of driving while a $2.00 per gallon tax would add $939 to the cost of driving. The current (2013) Maryland gas tax is $0.235 per gallon. Thus, an additional $0.50 tax would increase the total fuel tax by 212% and reduce total CO2 emissions by 1.05 percent and an additional $2.00 per gallon would increase the price by 904 percent and decrease emissions by 4.64 percent.

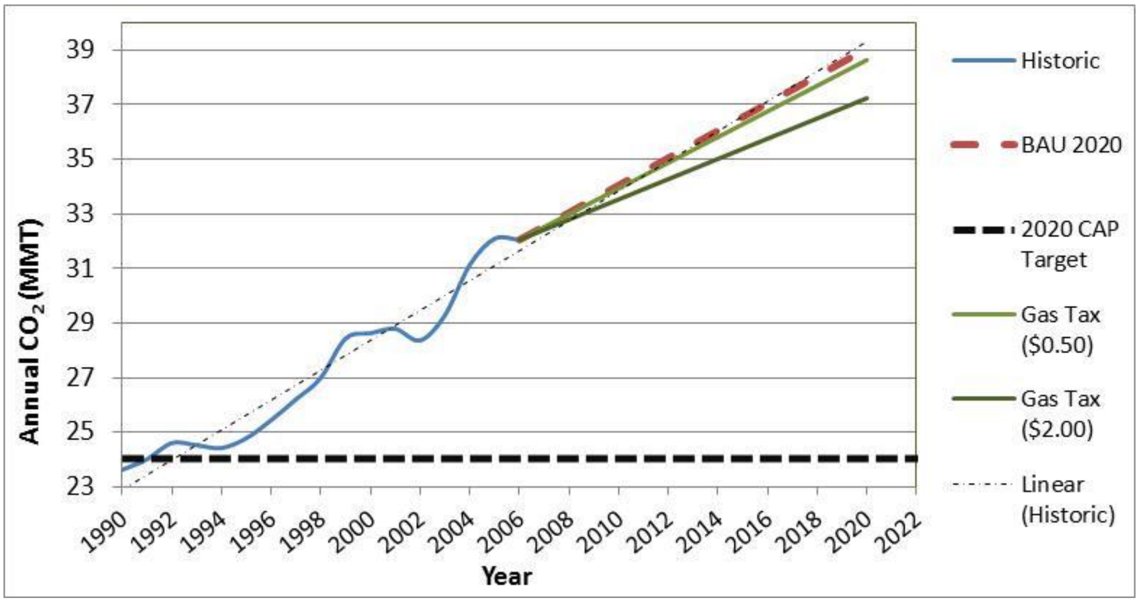


Figure 50. Transportation emissions under gas tax strategy.

Figure 51 shows the results of a hypothetical VMT tax of $0.50 or $2.00; indexed to the price of gas. This means the actual VMT price is equivalent to the cost to travel a mile with an average vehicle with a $0.50 or $2.00 gas tax. The realized price per mile, assuming an average fuel economy in 2013 (the year the policy would be implemented) of 25.54 mpg, is $0.0127 per mile and $0.0512 respectively, in 2020 but index to inflation to year 2000 dollars. Implementing a $0.50 (gas tax equivalent) VMT tax reduces transportation sector CO2 emission by 3.84 percent. A $2.00 (gas tax equivalent)

VMT tax achieves a 13.26 percent emissions reduction over the BAU 2020 scenario. The $2.00 VMT tax is the most effective of the pricing strategies in reducing CO2 emissions but most expensive for drivers. The cost of an average eight-mile trip would cost drivers today (2013) roughly 63 cents. While this may not seem like much, if the cost is carried out over the average yearly personal VMT of 12,000 miles the added cost to travel for drivers would be $940 that is equal to about 3/4 the annual cost of gasoline twice the non-gas auto operating cost.

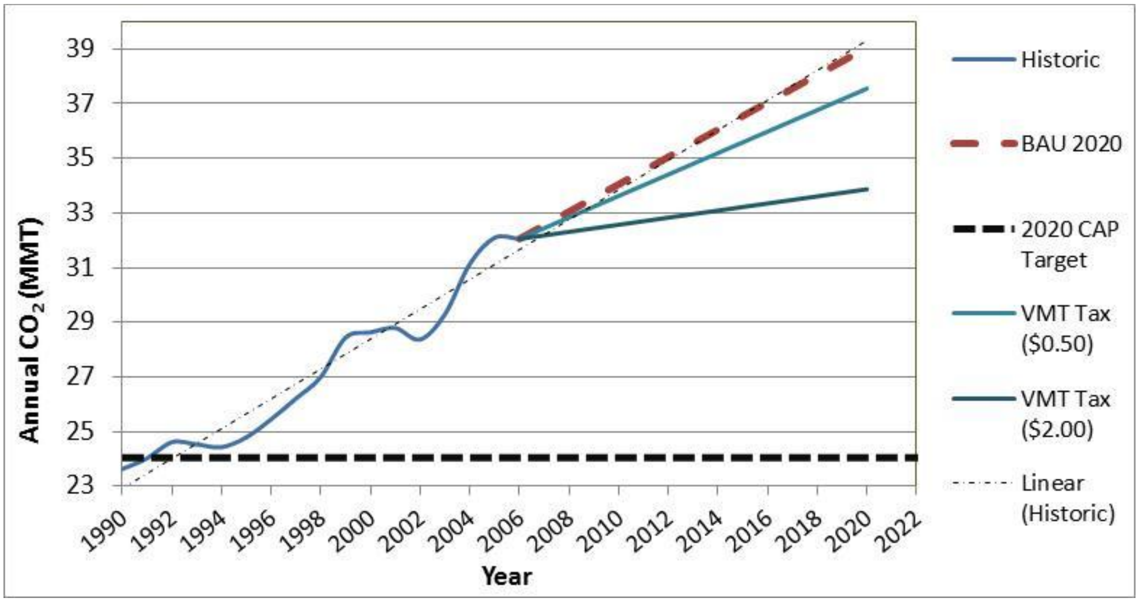


Figure 51. Transportation emissions under VMT tax strategy.

The final pricing scenario charges users for the amount of CO2 they produce by traveling based on three levels of pricing aggressiveness (Figure 52). When drivers face an emissions tax of $25 per ton, emissions are reduced by 4.38 percent. Doubling the price to $50 per ton reduces emissions by 6.15 over the 2020 BAU scenario. Tripling the initial price to $75 per ton reduces emission by 7.85 percent.

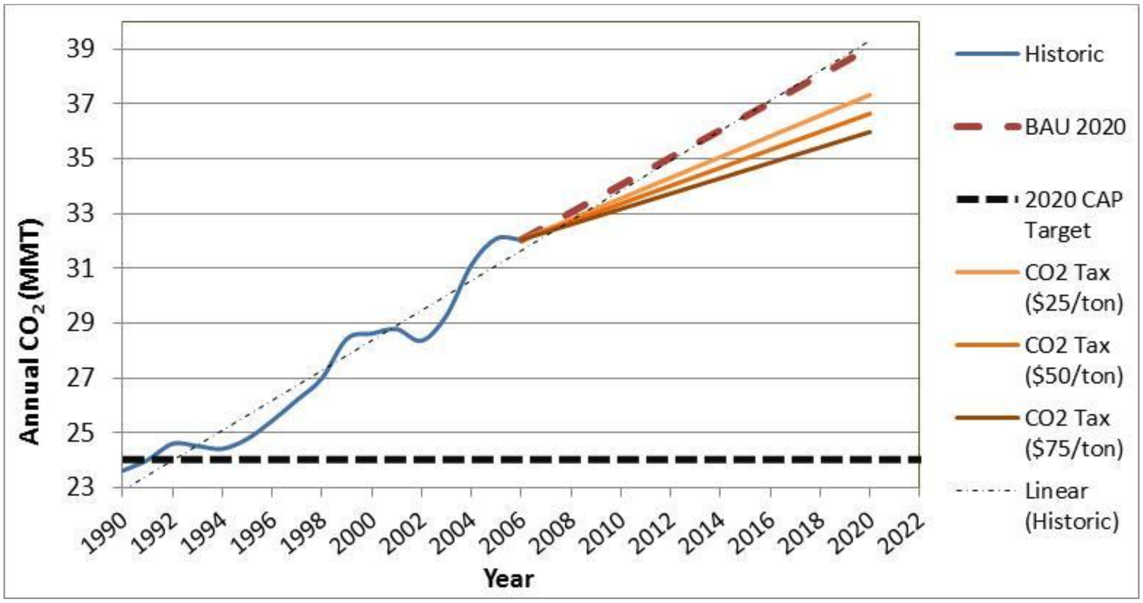


Figure 52. Transportation emissions under CO_2 tax strategy.

Non-Pricing Strategies

Several non-pricing related strategies are specified in the Maryland CAP. Each of these policies was modeled independently and the results reported in Figure 53. Among these scenarios, 'Smart Growth" which re-directs growth and creates significantly higher urban densities, produces the greatest CO2 reductions. This scenario reduces CO2 by 12.68 percent from the BAU scenario. Following this scenario, higher efficiency for vehicles produces a significant CO2 reduction. Increasing fleet efficiency to the CAFE standards results in a 10.07 reduction from BAU. Finally, doubling transit ridership with an equal reduction in single occupancy vehicle trips results in the smallest CO2 reduction; just 5.20 percent from BAU.

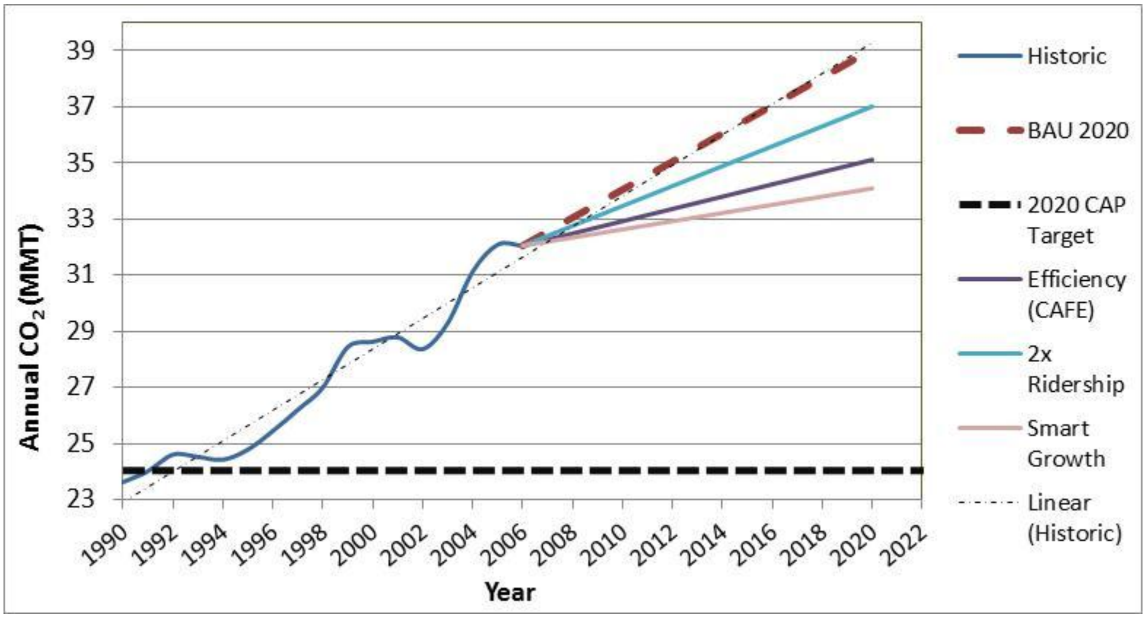


Figure 53. Transportation emissions under non-pricing strategies.

Combined Transportation Result

Modeling a package of transportation emission reduction strategies is conceptually different than modeling reductions in other sectors. Transportation emissions are highly related to travel behavior while emissions in other sectors are much less dependent on individual behavior. To capture the effect of several policies implemented at once it is inappropriate simply to add-up the cumulative effects of each policy. For example, doubling transit ridership and dramatically increasing the efficiency of cars will reduce emissions individually, but will work against each other to some degrees when implemented together. This is because travelers are attracted to transit when the cost of driving increases. However, if a vehicle is significantly more efficient, the relative cost of the trip is reduced and this will pull some drivers from transit. Added to the cost of travel through road pricing will moderate this effect, so when all three strategies are combined the resulting emissions reduction will be less than the cumulative effect of the individual policies.

Figure 54 shows the results of modeling the 50-cent gas tax strategies with all three non-pricing strategies.[8] The effect is a 26 percent reduction in transportation emissions from the BAU scenario in 2020. While this is a significant reduction in transportation emissions, the total reduction is 19.5 percent over the 2020 GGRA emissions target.

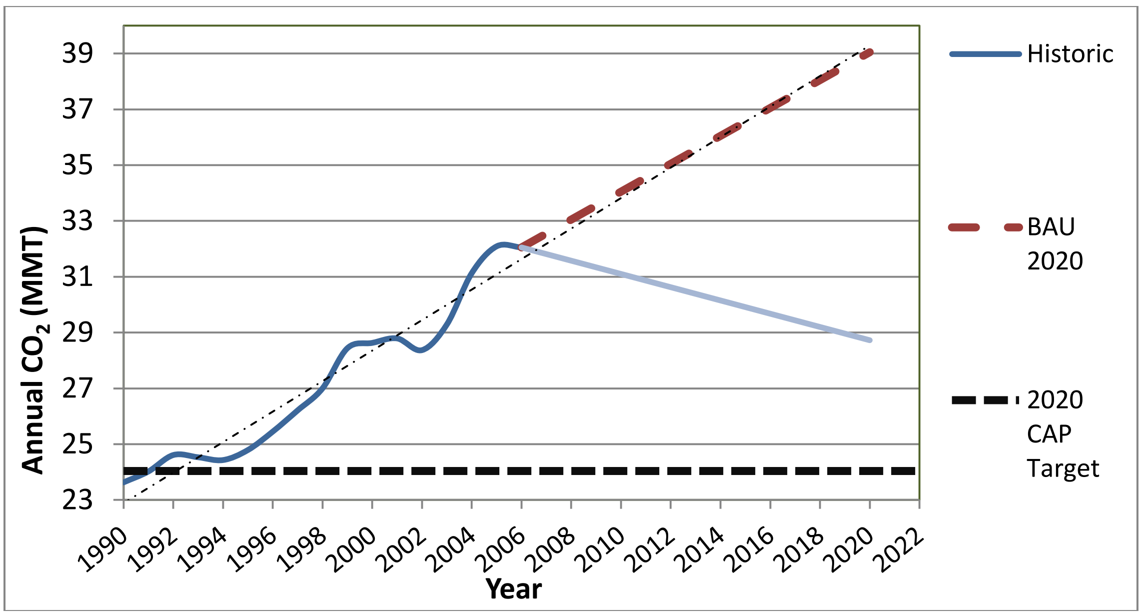


Figure 54. Transportation emissions with all CAP strategies implemented (lowest price).

Total Combined Results

*Figure **55*** shows combined effect on emissions of the residential, commercial energy, and transportation sector strategies. Two combinations are shown in the graphic. The first shows the results of the strategies if the new aggressive RGGI model rule is not

---

[8] The $0.50 gas tax was selected over the more aggressive pricing scenarios because it was the least onerous for travelers, the most likely to be implemented (assuming a pricing strategy were to be implemented at all) and testing showed that the target transportation emissions reduction was not met with all other pricing options in combination with the non-pricing strategies. Thus the final result is not altered by the selection of a pricing strategy or level of aggressiveness.

adopted by Maryland. In that case, total emissions are reduced by about 19 percent from 2020 BAU (see Table **33**), and emissions remain nearly 29 percent above the 2020 GGRA target. If Maryland does enact the new RGGI model rule emissions will be reduced by over 30 percent and the state will come within 11 percent of the goal to reduce emissions 25 percent below 2006 levels by 2020.

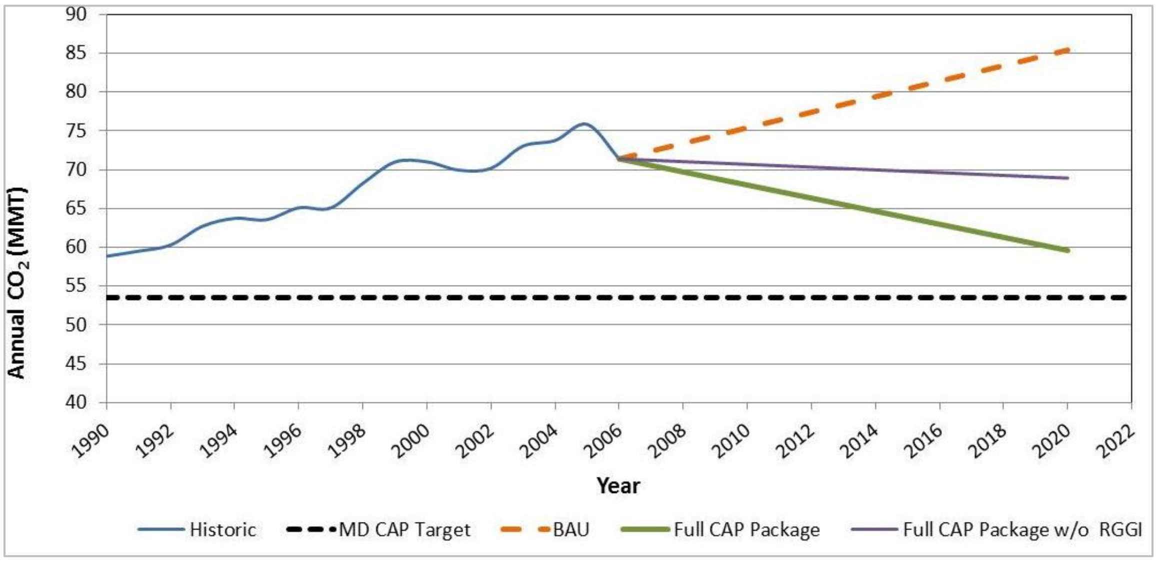


Figure 55. Transportation emissions with all CAP strategies implemented.

In Chapter 3, a distinction was made between the typical policy recommendation related to CO2 reductions and the true scientific need as articulated by Meinshausen et al. (2009). Using the total budget of 549 Gt CO2 until 2050, we assigned mission budgets with all counties and US states based on their 2010 share of global emissions. Assuming a constant growth of global emissions of three percent and that Maryland is able to enact all of this CAP strategies, the scientific evidence indicates that for Maryland to do its part in aiding the world staying within its 80 percent probability of a 2oC temperature increase over pre-industrial temperatures, its emissions target should be a 68.7 percent reduction from 2006 levels by 2020. The combined results of the most aggressive

Maryland CAP strategies are 167 percent above the needed target (*Figure **56*** and Table **35**).

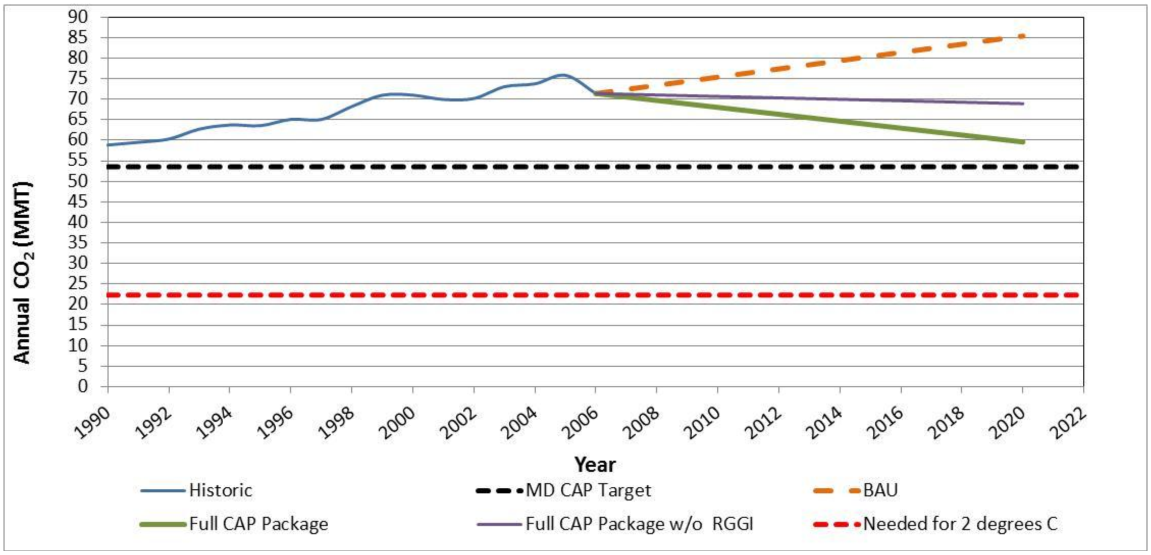


Figure 56. Emission with CAP strategies compared to scientific need.

Taking the rationality of the emissions targets a step further; it was shown in Figure ***9*** (Chapter 3) that if world emissions continue at their current pace global emissions will exceed the emissions budget (with its 80% probability of retaining a 2^{o}C temperature increase) by 2028. The timing of this budget can be affected by swift implementation of the CAP for meeting GHGs target goals, but not by much.

Table **34** shows by date that the state, national, and global CO2 budget would be exceeded if all the state national and global emissions targets were to be met. For Maryland, a successful implementation of the CAP would only add two years to the time it would take to exceed its CO2 budget. The more aggressive national and world targets would extend the timeline by three and seven years, respectively. However, in all cases, the budget is for 2050, thus with the most optimistic scenario the world runs out of 'safe' CO2 emissions 17 years to early.

Table 34

Effect of CO_2 targets on CO_2 budget

Jurisdiction	Planned Target Year	Year CO2 Budget Exceeded (w/o Target)	Year CO2 Budget Exceeded (w/ Target)
Maryland	**2020**	2027	2029
US	**2050**	2028	2031
World	**2050**	2026	2033

Table 35

Summary of emissions, targets, and strategy results

Baselines			
Total Inventory	**Annual CO_2 (MMT)**	**%Change (From 2020 BAU)**	
Maryland Total Emissions 2006 (w/o industrial)	71.40	-16.40%	
2006 Emissions by sector			
Residential	5.90	-13.49%	
Commercial	4.56	-14.77%	
Energy Sector	28.89	-15.49%	
Transportation	32.05	-17.92%	
2020 Emissions targets by sector (GGRA)			
Residential	4.43	-35.12%	
Commercial	3.42	-36.07%	
Energy Sector	21.67	-36.61%	
Transportation 2006	24.04	-38.44%	
2020 Emissions targets by sector (scientific need)			
Residential	1.77	-74.05%	
Commercial	1.37	-74.43%	
Energy Sector	8.67	-74.65%	
Transportation 2006	10.52	-73.06%	
Strategy Results			
Future Inventory	**Annual CO_2 (MMT)**	**%Change (From 2020 BAU)**	**%DIFF (From Target)**
BAU 2020	85.40	N/A	59.48%
Target 2020 (GGRA)	53.55	-37.30%	N/A
Target 2020 (scientific need)	22.33	-73.86%	
Total Emissions with CAP (w/ New RGGI)	***59.61***	***-30.20%***	***11.32%***
Total Emissions with CAP (w/o New RGGI)	***68.92***	***-19.30%***	***28.70%***
Building Sector			
Residential			
BAU 2020	6.82	N/A	54.12%
Empower Maryland 2	6.81	-0.15%	53.90%

Smart Growth: Current Building Stock (Bldg/LU 1)	6.56	-3.81%	48.25%
Total Residential Sector Emissions with CAP	6.55	-3.96%	48.02%
Commercial			
BAU 2020	5.35	N/A	56.43%
Empower Maryland 2	5.34	-0.19%	56.14%
Smart Growth: Current Building Stock (Bldg/LU 2)	6.00	12.15%	75.44%
Total Commercial Sector Emissions with CAP	5.98	11.78%	74.85%
Energy Sector			
BAU 2020	34.19	N/A	57.77%
RGGI (Energy 1)	24.88	-27.22%	14.83%
Reduced Import CO2 (Energy 2)	31.64	-7.43%	46.04%
Renewable Portfolio Standard (Energy 3)	35.63	4.22%	64.43%
Coal to Biomass: Emissions (EmPOWER MD 1)	34.63	1.31%	59.83%
Empower Maryland 2	28.32	-17.17%	30.68%
Total Emissions With CAP	***18.36***	***-46.30%***	***-15.27%***
Total Emissions With CAP (No RGGI)	***27.66***	***-19.08%***	***27.67%***
Transport			
BAU 2020	39.05	N/A	62.44%
Gas Tax: $0.50 (Transport 3)	38.64	-1.05%	60.73%
Gas Tax: $2.00 (Transport 3)	37.24	-4.64%	54.91%
VMT Tax:$0.50 (Transport 3)	37.55	-3.84%	56.21%
VMT Tax:$2.00 (Transport 3)	33.87	-13.26%	40.90%
CO2 Tax:$25/ton (Transport 3)	37.34	-4.38%	55.32%
CO2 Tax:$50/ton (Transport 3)	36.65	-6.15%	52.46%
CO2 Tax:$75/ton (Transport 3)	35.98	-7.85%	49.69%
Efficiency:CAFE (Transport 1)	35.12	-10.07%	46.09%
2x Ridership (Transport 1)	37.02	-5.20%	53.99%
Smart Growth (Bldg/LU 1/2)	34.10	-12.68%	41.84%
Total Transport Emissions with CAP	***28.72***	***-26.44%***	***19.50%***

Chapter 7: Policy Recommendations

In the previous chapters, hosts of climate change mitigation strategies were tested first against the stated policy goals then against the actual need as determined by the current climate science. From these results, it is possible to make recommendations on what policies are likely to be most effective in reducing emissions. Table **36** provides a list of the policies tested in this analysis and a recommendation on how the policy might better be treated within the policy frameworks, moving forward. For each of these recommendations, it should be noted that a change in the analytical method used to quantify the effectiveness of each policy could potentially lead to a different conclusion. Thus, these recommendations may warrant further investigation prior to adoption.

Policies that are marked 'abandon' should be dropped from the Maryland CAP, for reasons explained below, while those marked strengthen should develop stronger targets, more thorough implementation, should receive more funding, and should carry an enforcement mechanism. An additional column provides recommendations for new policies that will likely reduce emissions at a very cost effective rate but are not in the current Maryland CAP, so they should be investigated by the state and considered for inclusion into the plan in order to expand the policy instrument to a more comprehensive scope.

Table 36

Summary of tested emission reduction strategies

Policy	Initiative	Description	Recommendation		
			Abandon	Strengthen	Investigate
1	Boiler Efficiency	A measure to reduce 2020 CO_2 from commercial, industrial and institutional boilers	X		
2	EmPOWER MD 2	A suite of strategies that result in a 15% reduction of electricity demand in Maryland, power plant operators reduce future growth/expansion to accommodate		X	
3	Bldg/LU 1	80% of residential growth to 2020 to PFAs with a 25/75 Multi-family and single family split, 84% percent in ¼ acres lots or less	X		
4	Bldg/LU 2	80% of commercial growth to 2020 to PFAs	X		
5	Energy 1	The Regional Greenhouse Gas Initiative (RGGI)		X	X
6	Energy 2	GHG Emission Reductions from Imported Power	X		
7	Energy 3	The Maryland Renewable Energy Portfolio Standard Program		X	
8	Energy 4	GHG New Source Performance Standard		X	
9	Transport 1	Suite of strategies aimed at reducing GHG through vehicle efficiency and cleaner fuel technology		X	
10	Transport 2	Policies to reduce GHG emissions by increasing public transit ridership	X		
11	Transport 3	Road pricing mechanisms to reduce emissions		X	
12	Transport 4	Eco-diving Education			X
13	Transport 5	Urban Parking Limits			X
14	Transport 6	Speed Limit reduction and harmonization			X

Of the 11 primary built environment strategies specified in the Maryland CAP, just six should be pursued by the state; the remaining five should be abandoned.

Policies to Abandon

The following section describes the policies that should not be pursued by the state of Maryland for CO2 mitigations. The term abandon is meant to reflect the need to drop these polices only from the climate action plan. Many of these policies serve other important purposes but tend to obscure the CAP from the clear objective of CO2 mitigation.

Boiler Efficiency

As discussed in chapter 5, EPA's Boiler MACT rule pertains to an extremely small number of boilers and does not explicitly include reductions in CO2 emissions. The goals of this policy are aimed at reducing hazardous pollutants, not climate change related compounds. This policy should not be used as a substitute for building-level emissions reductions. For this policy to be effective in reducing GHGs in the state of Maryland it would first need to be copied at the state level for better control of the policy mechanisms. A state level policy would need to be expanded to include: 1) utility and residential boilers, 2) boilers that use all types of fuel, 3) boilers of all sizes (not limited to 25MW or less), 4) reduction of criteria pollutants, and 5) a monitoring and enforcement mechanism. The EPA, in setting out its most recent (December, 2012) revisions to the Boiler MACT policy faced considerable opposition in earlier versions of the policy. The state of Maryland, as a smaller governmental entity, would also face substantial impediments to implementing the stringent policy objective set out by these recommendations. For these reasons, the state should pursue other policy options to reduce GHG from combusted fuels.

Bldg/LU 1 – Smart Growth – Residential

The building and land use policy that relies on 80% of residential growth between 2012 and 2020 to occur within PFAs and for that growth to be a 25/75 Multi-family and single family split and requiring much denser development with 84% percent in ¼ acres lots or less would require a substantial reversal of long term growth trends in the state. The current trends show more development is occurring outside of PFAs than the state currently assumes and the trend is towards more growth external to PFAs. The same trends also indicate that lot sizes have held constant within PFAs at about 3/4 acres, a substantial increase from the desired lot size.

The amount of funding and direct policy intervention that would be required to redirect growth, building mix, and lot size would be substantial. There is also little evidence to indicate that there are direct GHG benefits to developing inside a PFA as opposed to outside PFAs. The major GHG benefit occurs with the development of multifamily housing as opposed to single-family units. However, there is no evidence that the desired mix could be achieved within a PFA as opposed outside a PFA. Since infrastructure and planning funding is the primary method of incentivizing growth within a PFA (Dawkins, Sartori, & Knaap, 2012), there are very few private market incentives to develop smaller lots and more multifamily units within than on a green-field outside the PFA.

Bldg/LU 2 – Smart Growth – Commercial

There are a number of reasons why commercial property is developed outside a PFA. Through this analysis, it was found that commercial units located with PFAs typically produce a higher level of carbon emissions than those outside a PFA. There are several reasons for this. Many commercial units within a PFA are older and rely on larger, less efficient HVAC systems to heat the building and older boilers to heat water. This means that reducing emissions by directing commercial growth to PFAs would require either 1) significant retrofitting or reconstruction of older buildings or 2) construction of new buildings either by replacing older units or building on unimproved lots. Both options face substantial time constraints. A considerable portion of buildings within PFAs would need to be completely retrofitted or renovated to accommodate 80 percent of future growth as the availability of unimproved lots in these areas is likely not great enough to accommodate such growth. This large rebuilding effort would have to take place in just seven years, to transform the commercial building landscape of PFAs substantially. Further, there are few market incentives to develop commercial property within a PFA. Land is typically higher cost, infrastructure is older (especially for IT needs), and property taxes can be substantially higher. There is no evidence that the state can channel such a high percentage of future commercial growth into PFAs and achieve GHG reductions. For this reason, the smart growth option should be abandoned.

Bldg/LU 1& 2 – Smart Growth – Generally

The policy recommendations with regard to the effects of smart growth oriented development on GHG emissions are in-line with a growing body of research that indicates these policy instruments do not achieve emission reductions as effectively as other policies, especially when working with a very short time frame. Rodier (2009) examined the results of dozens of international modeling exercises addressing VMT and GHG reductions; the results of the analysis found vey small, in the order of .1-2 percent changes in VMT resulting from changes in land use. VMT and GHG are highly correlated (Greene, 2011) such that a reduction in VMT almost invariably results in a very similar reduction in GHG.

A multitude of recent studies are confirming the weak link between smart growth (or compact development) and GHG reductions. A recent modeling exercise of land use change in California found the a 10 percent adjustment in density produces a mere 1.9 percent reduction in VMT, thus an elasticity of .19 (Heres-Del-Valle & Niemeier, 2011).

Studying households in California, Brownstone and Golob (2009) found that a 40 percent change in density could bring about a 4.8 percent reduction in VMT, which equates to an elasticity of .12.

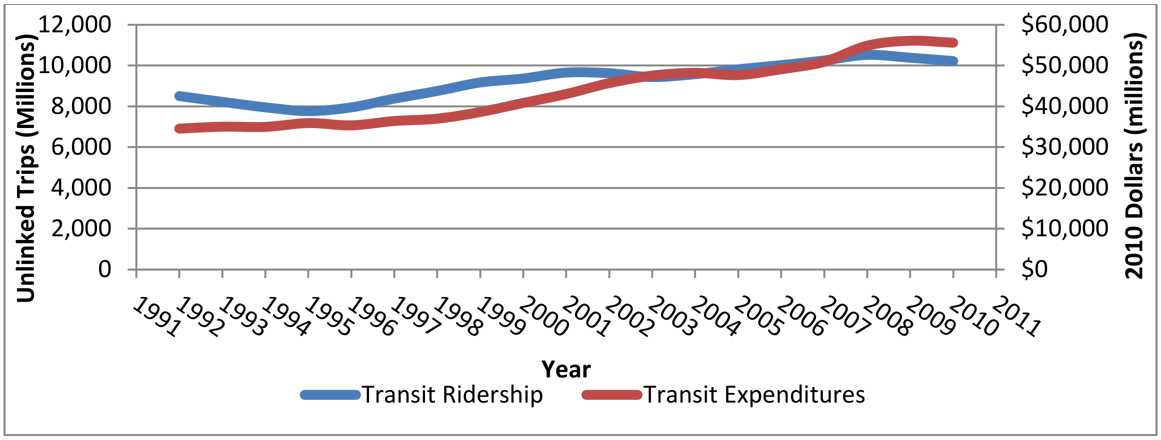
The effect of density or smart growth on travel behavior is anything but a settled matter. For all the studies that find a weak or non-existent relationship between density and VMT, there are nearly as many that arrive at an opposite conclusion. For instance, Newman and Kenworthy (1989), in one of the most commonly cited texts on the subject, examined the correlation between residential density and VMT with a data set of 32 cities across the globe and found a strong negative relationship between the two phenomena. However, Mindali, Raveh, and Salomon (2004) examined the relationship several years later using the same data set but a different method and found no statistically significant relationship between density and VMT. One of the most comprehensive studies of density and VMT, a meta-analysis of multiple studies, found a weak relationship with regard to density and VMT (Ewing & Cervero, 2010). The authors found an elasticity of demand between residential density and VMT of -0.04 and a job density of 0.00. Despite many contradictory studies, one seemingly evident trend emerges: if density does reduce VMT and subsequently GHG, the required level of change in density to produce a level of GHG reduction needed for the Maryland CAP would be enormous. Such a change would not likely occur in the seven (or fewer) years between the time such policies become effective and reduction targets must be met. From these we can conclude that smart growth policies, while potentially supportive of a sustained long-term GHG reduction should not be used as a GHG reduction policy.

Energy 2 - GHG Emission Reductions from Imported Power

Maryland imports 30 percent of its electricity. A substantial portion of that imported energy is derived from fossil fuel combustion, particularly coal. The state desires a reduction of emissions from imported electricity by importing only cleaner natural gas and fossil fuels. However, coal power plants produce more power per generator than any other combustion-based power plant. To convert imported power entirely to natural gas, the second highest power generating fuel, a full 200 new natural gas plants would need to be constructed by 2020 at the rate of 38 power plants per year. There is little Maryland can do to influence the multiple state partners on the PJM interconnect to endeavor to make such a substantial investment in natural gas plants. While the objective of reducing CO2 from imported power is important, a better policy option is to address demand for consumption and domestic production.

Transport 2 - Policies to reduce GHG emissions by increasing public transit ridership

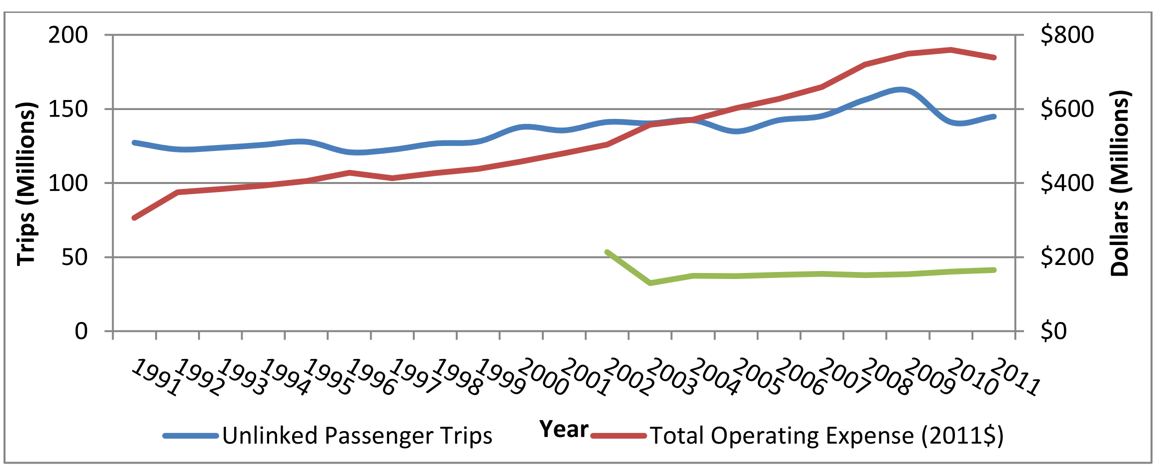
The cost of doubling transit ridership in an effort to reduce emissions could potentially be enormous. Evidence on transit ridership trends in the last two decades shows that the number of transit trips nationally has increased just 20 percent, while expenditures for the transit system has increased nearly 34 percent (in 2010 dollars) during the same period (Figure 57). The average cost per unlinked trip has increased (in 2010 dollars) from$4.06 to $5.44. Figure 58 shows the change in the number of unlinked transit trips and total transit expenditures from 1992 to 2010.



Source: APTA, Factbook 2012 Appendix A

Figure 57. Unlinked transit trips and total transit expenditures, 1992 - 2010.

In Maryland the transit ridership and expense trends is even less optimistic. Since 1992, the number of unlinked passenger trips has increased less than 14 percent while transit system expenditures increased by nearly 142. At the same time, revenue from passenger fares decreased over 22 percent and the cost per unlinked trip of the transit service increased from $2.40 to $5.10. Fare box recovery (the ratio of fare revenue to total expenses) has been cut in half from 42 to 22 percent. Figure 58 shows this trend from 1992 to 2011.



Source: NTD, TS2 - Operating Expenses, Service Supplied and Consumed Dataset

Figure 58. Unlinked transit trips, fare revenues, and total transit expenditures, 1991 - 2011.

Doubling transit ridership as an emission reduction strategy suggests that the marginal rate of emissions production per trip is lower than that of the personal vehicle. However, research indicates that for many modes of transit, the marginal or per capita emissions rate can be substantially higher than for personal vehicle travel when the transit vehicle is traveling at off-peak and even some peak routes.

The cost of reducing emissions through transit is substantially higher than the valuation of CO2 mitigation to avoid climate change costs or of market value of recent cap and trade auctions. The recent McKinsey study (McKinsey, 2008) placed an average value of $50 per ton to offset the societal impacts of climate change. An extensive literature review by Nordhaus and Boyer (2003) showed a lower bound of marginal CO2 emission costs of $20 per ton and Tol (2005) provided an upper bound of $50 per ton. California recently conducted its first round of auctions of CO2 credits for an average rate of $10 per ton (Lopez, 2012). The RGGI had several rounds of CO2 auctions with the lowest price per ton set at just under $2 per ton ("Regional Greenhouse Gas Initiative (RGGI) CO2 Budget Trading Program - Auction Results", 2013).

Reducing carbon emissions with transit is considerably more expensive then the societal cost or market value of emission reductions. A scenario exercise for national transportation GHG mitigation strategies conducted by Cambridge Systematics called Moving Cooler (Cambridge Systematics, 2009) provided a host of transit based strategies, at a cost much higher than those discussed in the previous paragraph.

Table 37 shows the estimated cost of GHG reductions for several public transit strategies, the GHG reductions, and expected cost per tonne for the reduction. The costs are shows for three levels of aggressiveness for which a strategy may be implemented. The lowest cost measure calls for a reduction of transit fares in large urban areas by 25% in the first gradation and up to a 50% reduction by 2050. The reported implementation cost is misleading in that the authors do not include lost revenue, which would range from $3 to $6.6 billion for the most aggressive scenario. The cost of reducing emissions through public transit ranges from roughly $419 to $2,082 per tonne. The cost estimate is much worse if one digs into the numbers to measure change by 2020, Maryland's target. The reported rate and annual reduction is about one MMt of GHG per year for most strategies under the least aggressive scenarios and 2 MMt for the most aggressive, with urban transit (the most costly) ranging from 2 to 8 MMt. Moreover, Maryland does not consider cumulative emissions reductions, but rather the final reduction in 2020 over the 2006 baseline. As a result, the cost of even the most aggressive reduction strategy would be staggeringly high compared to the minor reduction achieved.

Table 37

Public Transit GHG reduction strategies and estimated costs

	Expanded Current Pracitce Deployment (2010 -2050)			Aggressive Deployment (2010 -2050)			Maximum Deployment (2010 -2050)		
Public Transit	**GHG Reduction (mmt)**	**Implementation Cost ($ B 2008)**	**Reduction Cost ($/tonne)**	**GHG Reduction (mmt)**	**Implementation Cost ($ B 2008)**	**Reduction Cost ($/tonne)**	**GHG Reduction (mmt)**	**Implementation Cost ($ B 2008)**	**Reduction Cost ($/tonne)**
Transit Fare Measures	19	$0.05	$2.63	34	$0.05	$1.47	78	$0.05	$0.64
Transit Frequency/LOS/Extent	45	$52.50	$1,166.67	72	$102.60	$1,425.00	168	$243.80	$1,451.19
Urban Transit Expansion	144	$255.00	$1,770.83	281	$503.00	$1,790.04	575	$1,197.30	$2,082.26
Intercity Passenger Rail	46	$19.30	$419.57	47	$35.60	$757.45	50	$76.10	$1,522.00
High-Speed Passenger Rail	73	$99.60	$1,364.38	97	$108.20	$1,115.46	142	$144.20	$1,015.49

Source: Moving Cooler table 4.1 for GHG reduction and implementation cost, Author's calculations for cost per tonne.

The recent Transit Investment for Greenhouse Gas and Energy Reduction (TIGGER) program, sponsored by the Federal Transit Administration (FTA) is a good example. TIGGER works with state and local agencies to enhance efficiency in their transit systems. Of the programs funded many involve enhancements to bus and rail efficiency including 19 projects that introduce hybrid-electric vehicles, retrofitting buses with electric cooling systems for five systems, 16 projects deploying zero-emission buses, and 10 projects implementing rail technology (including locomotive upgrades, onboard energy storage systems, wayside energy storage systems, and efficient controls for track subsystems). Other projects include upgrades to facilities including 38 projects that implement some mix of efficient lighting and control, building envelope upgrades, and renewable energy technologies. The last group of projects is aimed at energy sources that include 15 projects that fit facilities with solar photovoltaic (PV) cells or solar heating systems, two that use windmills to capture energy, five that use geothermal heating, and three that will use fuel cells for energy.

The initiative spent, or is in the process of spending $255 million on 88 projects for an estimated lifetime GHG reduction of 411,000 tons of carbon dioxide equivalent. While these reductions are touted as significant and compared to powering 397,000 homes for a year or removing 72,000 cars from the road for a single year, a back-of-the-envelope calculation shows the inefficiency of the program.

At the rate of 5.71 tons of CO2e per year, rather than funding transit improvements ,5,625 electric vehicles (at the cost of $40,000) could have been used to replace current cars for a reduction of 513,900 tons CO2e, assuming a 16 year vehicle lifetime at the same program cost. While such a scenario is absurd, the cost of these reductions is much higher than the current cost of carbon. The first official 'Cap and Trade' program in the US was established by California's AB32. When the program goes into effect in 2013, the value the carbon credits were expected to get at auction was $40 per ton (Greenwire, 2011; Citizens Climate Lobby and Our Children's Earth Foundation V. California Air Resources Board, 2012). However, when the action took place, there was a much lower demand for the credits, which sold for a final price of $10.09 per ton, just nine cents above the minimum reserve price (California Environmental Protection

Agency, 2012) Estimates of cost per ton if federal legislation is enacted range from a low of $15/ton in 2020 to a high of $30/ton, even at the high range project to the year 2040 (this assumes very aggressive GHG targets creating high demand for trade), the cost of CO2e only rises to $90/ton. With the FTA's TIGGER program, the cost of the CO2e reduction is approximately $547/ton or 1,268 times the value of carbon. The TIGGER program is a demonstration of the important need for rational and coordinated GHG reduction strategies.

The TIGGER estimates provide an important link to the cost and expected reduction of transit related efficiency projects. The FTA's first assessment report (FAR) on the program's effectiveness estimates the cost of various projects per unit of CO2e reduced. The estimate indicates that efficiency upgrades for bus, rail, and facilities are approximately $262/ton, $1,084/ton, and $6,790/ton, respectively. Each of these figures compare quite dis-favorably to the average $2 to $50 per ton that cap and trade systems have valued carbon emissions or the calculated societal value.

Proving transit options has important policy implications of its own; abandoning the emission reductions strategy of doubling ridership is important because the cost of each reduced ton of carbon and the likely increase in GHG with increases in service will likely far outweigh the GHG benefits. We do not recommend abandoning transit-based mobility goals, but they should not be used to reduce emissions.

<u>Policies to Strengthen</u>

Energy 1 - Regional Greenhouse Gas Initiative (RGGI)

The RGGI was initially an important step towards reducing emissions from a significant contributing sector. However, as the program has evolved, member states have left or contemplated leaving the initiative, the cap on emissions was set too high and the price of carbon credits, valued through auction is far too low to seriously influence production and emissions decisions and the power of the initiative to contribute to the meaningful reduction of GHG from power plants has waned. As discussed in previous chapters, the emissions cap for the region was set to 188 MM (short) tons; based on the 2003-4 period and will reduce to 169 MMt by 2018 to achieve a 10 percent reduction. Current estimates indicate that member states produce 137 MMt of carbon dioxide (in 2010), even with an estimated 18 percent growth in emissions, assuming no more power plants will co-fire with natural gas for higher efficiency the total emissions will only reach 162 MMt. Power plants can further reduce this obligation but substituting reductions with up to 3.3 percent carbon offsets, so that the total emissions after offsets are just 156 tons. Power plants will not be required to make any adjustments beyond the current trend. In 2010, Maryland's total limit under RGGI for energy generation emissions was 37.5 MMt, yet the state only produces 28.9 MMt of emissions.

The market for natural gas has caused a reduction in emissions from the energy sector greater than the RGGI limits. This change in market structure will result in the undermining of any future RGGI initiatives as the program becomes more underfunded and has difficulty auctioning future credits. This difficulty had become more significant with the withdrawal of New Jersey from the agreement in 2013 and the passing of recent legislation in New Hampshire that bars the expiration of carbon credits that were not sold in the first 14 auctions, adding more credits to the market, and also allowing the state to withdraw from RGGI if two other states opt out or one other state (with 10 percent of the total RGGI emissions) leaves (“Hb 1490”, 2013).

However, as discussed in chapter 5, in February 2013 RGGI proposed a new model rule that would reduce the emissions cap by nearly 52 percent from 188 MM (short) tons to just 91 MM (short) tons in 2014. In addition, each state would be required to further reduce their emissions by 2.5 percent per year from 2015 to 2020 (“Regional Greenhouse Gas Initiative (RGGI) CO2 Budget Trading Program - Program Review”, 2013). Maryland should adopt the new stricter RGGI model rules by amending the state’s implementing regulations. Moving to the new rule could dramatically reduce that state’s power plant emissions, increase the auction value of carbon credits, and significantly boost funding from RGGI participation. However the potential for RGGI to be less effective still remains; there continues to be an excess of existing carbon credits which can be used in the future the mitigate a utilities obligation to reduce emissions. The results provided in this analysis and subsequent recommendations are based on a best-case scenario, but actual reductions may very well fall short.

EmPOWER Maryland

EmPOWER Maryland seeks to achieve a 15% reduction in consumer demand for electricity through a suite of efficiency programs. However, the program itself will not achieve emissions reductions without stronger enforcement mechanisms that tie demand reductions to permitting of future power plants, limitations of exporting, and efficiency requirements. Demand management for residential and commercial use is further complicated by a lack of alternatives. Unlike transportation where higher price serves as a signal to some users to change modes or enhance efficiency, when electric power prices increase, many consumers have no alternatives. This complication requires direct efficiency investments from utilities and governments. To ensure the long-term effectiveness of this EmPower Maryland, the program should use funds from RGGI (energy 1) to subsidize building envelope upgrades and HVAC replacement and maintenance.

Energy 4 - Renewable Energy Portfolio Standard Program

The Maryland Renewable Energy Portfolio Standard Program has a strong potential to affect emissions reductions. The policy bypasses many of the messy behavior obstacles that challenge the effectiveness of transportation and land use strategies by directly regulating the source of emissions. This policy strategy, while potentially effective, will need strong backing regulation and continual monitoring to achieve reduction goals fully. The policy could be further strengthened by using funds generated from the RGGI auctions to subsidize the development of zero emissions energy sources for adoption under this strategy. In Maryland, there are some exemptions to the load considered under the RPS. While 98 percent of the total load is subject to RPS, the existing exemptions for co-ops and large industrial consumers still limit the effectiveness of the RPS. Such loopholes should be closed to ensure long terms goals could be met.

Maryland utilities will need to generate nearly 2,000 megawatts of renewable energy by 2020 to comply with the RPS. To make the rule truly effective for GHG reduction, biomass, natural gas, and municipal waste to energy plants should not be considered renewable under the RPS definition. The state should further eliminate the use of renewable energy certificates (RECS) as a substitute for in-state renewable energy generation since the definition of renewable energy can vary widely across jurisdictional boundaries.

Energy 3 – GHG new source performance standards

Greenhouse Gas New Source Performance Standard for Electric Generating Units for New Sources (NSPS) has little potential for reduce GHG emissions in Maryland as the policy exists currently. However, modifying the language of the policy to incorporate stricter standards for existing power plants offers a potentially significant opportunity for GHG reduction.

Transport 1 - Vehicle efficiency and cleaner fuel technology

Historically, an increase in fleet efficiency has substantial emission reduction potential. A strong policy that incentivizes increased efficiency (such as the California cars regulation) has the added benefit of reducing the reliance on unpredictable changes in travel behavior by directly addressing the source of emissions. The strategy also provides two points of market regulation: vehicle manufacturers and consumers. Federal policy already exists raising the long stagnant CAFE standards substantially by 2025. No state other than California is allowed to mandate clean car standards stricter than the national CAFE standards. The state should seek to amend this rule to allow it to apply higher efficiency standards not only to LDVs but also to commercial vehicles.

Transport 3 - Road pricing mechanisms to reduce emissions

Road pricing mechanisms to reduce emissions are generally effective in bringing about desired change. Studies cited earlier in this thesis explain the relationship between pricing and travel behavior. The major sticking point is getting the right pricing mechanism at the exact price for the correct travelers. This can be an extremely difficult process, but the results in terms of emission reduction can be substantial. The Maryland CAP offers only vague reference to the possibility of pricing as a strategy. This option should be strengthened with a more thorough treatment of the potential for pricing in

Maryland, a clear delineation of the proposed pricing strategy, and specific timeline for implementation.

Policies to Investigate

Several policies there are cost effective and very fast to implement are completely absent from the Maryland CAP. In the following section, a number of polices are recommended for investigation and possible adoption to reduce emissions.

Transport 4 - Eco-diving Education

In mid-2009, a study commissioned by the Urban Land Institute (ULI) that examined the potential for transportation related strategies to reduce emissions was released. While many have said Moving Cooler and similar documents are valuable, it is in the numbers that have not made headlines. By far, the most cost effective and generally substantial emissions come from very simple programs that can be implemented immediately for very fast results. Table 38 shows an estimate of the cost per ton to reduce GHG with eco-driving education to be just .03 cents with the most aggressive course of action. The effectiveness of this strategy compares favorably with many other more costly strategies. The emissions reduction mechanism can be bolstered by a host of existing technologies that re-enforce learned eco-driving strategies.

Table 38

Public Transit GHG reduction strategies and estimated costs

	Expanded Current Pracitce Deployment (2010 -2050)			Aggressive Deployment (2010 -2050)			Maximum Deployment (2010 -2050)		
Most Cost Effective Strategies	GHG Reduction (mmt)	Implementation Cost ($ B 2008)	Reduction Cost ($/tonne)	GHG Reduction (mmt)	Implementation Cost ($ B 2008)	Reduction Cost ($/tonne)	GHG Reduction (mmt)	Implementation Cost ($ B 2008)	Reduction Cost ($/tonne)
Carbon Pricing	1431	$0.10	$0.07	4410	$0.10	$0.02	15186	$0.10	$0.01
Speed Limit Restrictions	1236	$4.10	$3.32	2320	$6.50	$2.80	2428	$7.50	$3.09
Eco-driving	727	$0.05	$0.07	1170	$0.05	$0.04	1815	$0.05	$0.03
Urban Parking Restrictions	80	$0.05	$0.63	189	$0.05	$0.26	359	$0.05	$0.14

Source: Moving Cooler table 4.1 for GHG reduction and implementation cost, Author's calculations for cost per tonne.

While the literature on the effectiveness of eco-driving with respect to GHG reductions is limited and just beginning to emerge, early results are promising. A study of past programs recently found that even modest efforts are able to rapidly produce a 10 percent reduction in CO2 (Barkenbus, 2010). Programs aimed at other transportation sectors such as urban bus drivers have found similar results (Zarkadoula, Zoidis, & Tritopoulou, 2007). Such reductions could be made even greater with larger or mandatory education and technology aides.

Transport 5 - Urban Parking Limits

Un-priced parking may produce emission reductions at a very low marginal cost. Studies have found parking policies may be effective in reducing emissions by up to 2 percent simply through better parking control (Marsden, 2006; Vaca & Kuzmyak, 2005). These policies are likely most effective in urbanized areas where alternative modes are readily available or where a number of activities are clustered so that multiple purposes can be accomplished with a single trip. The cost of implementing parking limits and pricing is low in comparison to many other GHG reduction strategies. The most aggressive strategy from the text Moving Cooler suggest that CO2 can be reduced at a cost of just 14 cents per tonne. The Maryland CAP should incorporate new parking standards as a part of its transportation emission reduction strategies.

Transport 6 - Speed Limit reduction and harmonization

Speed harmonization produces a benefit similar to eco-driving in that it seeks to smooth out heavy fuel consuming acceleration. Acceleration has been cited as one of the biggest contributors to fuel consumption and emissions (Hansen, Winther, & Sorenson, 1995). Maintaining a more harmonious speed throughout a journey has the potential to significantly reduce vehicle emissions (Trozzi, Vaccaro, & Crocetti, 1996). Acceleration is just one factor that influences emissions; another is the top speed of a given facility. The relationship between speed and CO_2 emissions resembles a convex curve with the highest emissions resulting from the low and high ends of the curve, roughly less than 25 mph and greater than 65 mpg. The lowest point in the curve typically falls around the 55 mph range (Barth & Boriboonsomsin, 2010). Highways that limit speed to 55 mph and work towards harmonizing that speed across all links will produce significant emissions reductions. The cost of implementing such a program can range from a high estimate (from Moving Cooler) of about three dollars per ton to much less (Table 35). This all depends on the amount of enforcement and the level of technology used in the implementation process.

Chapter 8: Adaptation

The following emission-related strategies revolve around adaptation policies the state of Maryland should adopt to protect human welfare and infrastructure. A major conclusion of the work is that the combination of existing and potential emission mitigation strategies implemented in Maryland will not alter the trajectory of climate change significantly. Facing a nearly certain impact from climate change, the state should adopt a more comprehensive set of adaptation strategies to better prepare for the uncertain, but potentially significant, impacts of climate destabilization and sea level rise.

Most state climate action plans do not address adaptation at all. In a review of 29 CAPs, Wheeler (2008) found only two states (Maryland and Illinois) that have adaptation measures in their action plan. Both states only have specific strategies related to floods and storm surge. Maryland mentions very few traditional built environment related adaptation measures in its CAP. The CAPs implementing legislation, the GGRA of 2009 makes no mention of adaptation, thus under state policy any implementation of these type strategies would be purely voluntary.

The adaptation portion of the plan was primarily developed and coordinated by the Maryland Department of Natural Resources (DNR) so its primary focus is on the natural environment. There are two documents that address issues of climate instability and opportunities for adaptation. This first is the Comprehensive Strategy For Reducing Maryland's Vulnerability To Climate Change where the first “phase” addresses sea level rise and coastal storms and the second addresses resiliency issues for society, ecology, and economy. In each of these documents, the potential problems related to climate change are assessed and extremely vague recommendations are made, typically encouraging future work to develop strategies and strengthen existing policies with no additional funding. For proper protection of human life and the build environment, specific strategies must be developed. In the following each of the recommend adaptation strategies are discussed.

Adapt 1 – Heat Island/Pavement Cooling and cooling centers

As climate change leads to more extreme heat events, urban centers are likely to experience exponentially greater temperatures than rural areas (Stone & Norman, 2006). The increased urban heat, often termed the heat island effect can significantly and negatively impact human health especially for vulnerable populations (Schuman, 1972; Tan et al., 2010; Semenza et al., 1996; Luber & McGeehin, 2008). Adaptation strategies to mitigate the potential of increased heat in urban areas are simple and easy to implement. Studies have shown that planting more trees in an urbanized area can reduce heat (Akbari, Pomerantz, & Taha, 2001). Another alternative is to use more reflective building materials or retrofit existing infrastructure with reflective surfaces (Bretz, Akbari, & Rosenfeld, 1998). Heat island and pavement cooling have an added CO2 co-benefit by reducing the demand of energy during extreme heat events and for most cooling days (Akbari, 2002; 2005). To the extent that heat island mitigation efforts fail to reduce top end heat from extreme climate events, Maryland will need a larger network of public cooling centers to accommodate those unable to cool their own homes. Such accommodation may need to be able to accept longer-term residents as heat events are extended in duration.

Adapt 2 - Bridge Scour

Bridge scour occurs when swiftly moving water erodes the dirt/mud, sand, pebble, and stone base that bridge piers and abutments rest on, a phenomena typically associated with flooding (Melville & Coleman, 2000). Scour reduces the stability of bridges and can lead to a compromise of structural integrity. Climate change may have an impact on both the frequency and severity of that flooding, leading to an increased risk of scour (Molnar, 2001; Kinsella & McGuire, 2005). In Maryland, the risk of dangerous bridge scour is particularly acute as that state has over 5,000 bridges (Bridgereport, 2013). Of these bridges nearly 400 are considered structurally deficient already (Bridgereport, 2013). The number of deficient and at risk bridges will increase significantly if preventative and adaptive measures are not taken. Adaptation strategies addressing this climate change risk are categorized by either armoring the infrastructure or altering of water around a bridge (Deng & Cai, 2010). The benefit of implementing bridge scour mitigation as climate adaptation strategies is several-fold. Deficient bridges can be shored up, erosion can be reduced, infrastructure can be renewed, and jobs created.

Adapt 3 - Land Loss

Sea level rise is now expected to increase at a more rapid pace than previously expected and to a higher level than once thought (Gillis, 2013); with levels rising beyond a meter (3.28) or up to 5 feet by the end the this century (Bamber & Aspinall, 2013). The rapid rise of water is especially problematic for Maryland. One major problem will be a significant loss of costal land and to some degree, inland wetlands. The loss of land will force human settlements to develop land that was previously preserved and could threaten space used for animal migration (Moore et al., 1995; Burkett & Kusler, 2007). The built environment, especially future developments and road infrastructure, will need to accommodate changes in migration patterns for Maryland and some national wildlife movements.

Adapt 4 - Air Quality

Changes in atmospheric composition and surface ambient heat are likely to increase the duration and intensity of air pollution episodes significantly (Jacob & Winner, 2009; Mickley et al., 2004). This reduction in air quality has the potential to cause harm to human health (Tagaris et al., 2009; D'amato et al., 2010) through inflicting respiratory distress resulting in hospitalization, prolonged illness, and in some cases death. The Maryland CAP should plan for changes in air quality by building up existing health care infrastructure and reaching out to potentially vulnerable groups with education and preventative care.

Adapt 5 - 100-year flood plain map update

Climate change will result in higher sea levels and greater river and tributary discharge (Booij, 2005). This change in hydrology will lead to larger and more frequent flooding events (Schreider, Smith, & Jakeman, 2000). Recent evidence and simulations show that the frequency of large-scale flood events has and will continue to increase over time (Milly et al., 2002; Cameron, Beven, & Naden, 2000). Maryland can adapt to these change by updating 100-year flood plain maps and change land use and zoning accordingly.

Adapt 6 - Public transit resiliency and interruption contingency plans

Rising water tables and sea levels combined with stronger storms have the potential to influence public transit infrastructure severely. The recent storm event called hurricane Sandy impacted much of the New York public transportation infrastructure, severely flooding many subway tunnels (Flegenheimer, 2012). Maryland was lucky that the main part of the storm missed its major urban areas; however, with an increase in storm frequency, there is a greater likelihood of future storms influencing the transportation network. The state will need to explore the possibility of developing floodgates for subway infrastructure and develop plans for when major parts of light rail and bus routes become inaccessible.

Adapt 7 - Convert non-productive farmland to forest

Mitigation and adaptation, which work well together in certain land use applications, should be considered together in climate action plans. Farmland that is not productive should be converted to forestland. This has a mitigation benefit as forests typically remove more CO2 and sinks more carbon than agricultural lands and the root systems of forests provide greater erosion, dust control, and hold grown moisture better than agricultural land. Moreover, lower productivity land typically is applied with greater amounts of fertilizer that affects the nutrient load of waterways along the ground shed.

Adapt 8 - Building resiliency

Climate change tends to be synonymous with extreme temperatures (Luber & McGeehin, 2008) and higher intensity storms (Yin, 2005; Knutson & Tuleya, 2004; Webster et al., 2005; Emanuel, 2005). In order to address these issues, building infrastructure should be adapted. Building codes need to be enhanced and existing buildings need to be retrofitted with better weatherization to use less energy in extreme temperatures and with stronger materials that make them more resilient to higher intensity storms.

Chapter 9: Conclusions

The failure of the US government to adopt international treaties addressing the issue of climate change and the lack of a domestic federal policy has left the critical task of reducing dangerous GHG emissions to sub-national entities. A recent but widely adopted method of addressing this need is through the formation of state-level policies called CAPs. These plans seek aggressive emissions reductions by developing strategies to reduce CO_2 from a wide variety of economic sectors. However, even as these CAPs have proliferated across the nation, little analysis has been conducted on the likelihood of the strategies specified within the CAPs of achieving emission reduction goals and whether such goals are relevant to the currently known scientific need for reductions. This thesis is an effort to fill that critical research gap. By thoroughly examining the emissions reduction strategies developed for a single state, but that largely mirror the larger US policy trend, the quality and efficacy of these plans is examined.

To carry out this mission, the Maryland CAP is used as a case study. Models were constructed to estimate emission reductions for all built environment sectors including residential and commercial buildings, energy supply, and transportation. By directly modeling the strategies for these sectors, a firm conclusion is derived, finding that the Maryland emission reduction strategies will not be sufficient to meet a CO_2 reduction target of 25 percent below 2006 levels by 2020. Not only will the strategies be ineffective at achieving stated targets but many of the strategies are so extremely draconian and costly in their underlying assumptions that they have no possibility of being implemented. For those strategies that are not so draconian as to be outside the realm of implementation, they rely on legislation that does not affect the state of Maryland (e.g.

the new source performance standards and boiler MACT rule) or cannot be easily influenced by the state (e.g. CAFE standards and CO2 imported power).

Even if Maryland could fully implement all of its emission reduction strategies and achieve its emission target, the levels proposed by the CAP are not aligned with the latest scientific evidence on the need for CO2 reductions. Given the modeled results of the Maryland CAP and the latest scientific evidence, Maryland emissions with CAP implementation will exceed the needed levels of reduction by over 58 percent. Further, a full state, national, and global implementation would only extended the time the world exceeds its emissions budget by two years in Maryland, three years in the US and six years for the world. There appears to be one common thread among the outcomes of CAPs, whether implemented at the sub-national level or globally; no set of existing policies will alter the trajectory of climate change.

With this simple but important conclusion in mind, Maryland must take a three-prong approach to address the realities of climate change. In the first part, the state must strengthen the mitigation strategies that show the greatest potential to reduce CO2 and abandon strategies that sound good politically but do little to mitigate carbon emissions. Specifically, Maryland should put more resources behind encouraging residential, commercial, and power supply sector efficiency to reduce the demand for energy generation. The state should also approve the new RGGI model rules and amend state regulations to enforce the lower emissions cap. Maryland, where possible, ought to go beyond federal policy pertaining to renewable energy and sources of pollution in the energy sector to enforce cleaner standards. In the transportation sector, the state should more aggressively encourage the adoption of higher efficiency vehicle technology and implement road or vehicle usage pricing to subsidize technology that is more efficient and reduce single occupancy travel. The state must abandon draconian and highly uncertain policies related to PlanMaryland, a plan to double transit ridership and policies to reduce CO_2 from imported energy sources.

Second, the state should extend the current set of strategies to include low-hanging and quickly implementable mitigation CO_2 'fruit'. Such polices include the implementation of eco-driving education, urban parking limits and speed reduction, and harmonization. Such policies are low cost options that can be rapidly deployed, require little to no new legislation or technology, and are certain to result in measurable CO_2 reductions.

Third, in the face of serious and inevitable climate change, Maryland must begin to adapt the built environment for better resiliency to more extreme conditions. Though the current Maryland CAP is one of just two state CAPs that develop adaptation strategies; the strategies relate to coastal land conditions and not to the built environment. To address the risk climate change poses to urbanized areas, Maryland should adopt strategies to adapt to the heat island effect by cooling pavement and providing cooling centers, assess and remediate bridges in danger of significant scour, update 100-year flood plains, develop public transit interruption contingency plans, and work towards enhancing building resiliency.

The coming era of climate uncertainty must be met with a new wave of the urban planning movement. The needs presented by the city and society from a changing environment are a call to action for planners. No other group of professionals is better equipped to lead a large-scale effort to re-envision our built environment. With perseverance and careful planning, the built environment will weather the next climate change, but it will require a generation of planners implementing realistic and tested strategies.

Appendix

The MSTM Model Overview

The transportation demand model used for this research is called the Maryland Statewide Transportation Model (MSTM). The evolution of the MSTM is a result of several years of continued research at the National Center for Smart Growth Research and Education, at the University of Maryland. The model was developed with the support of the Maryland State Highway Administration (SHA). The following describes the basic details of the model. What follows is adapted from the MSTM User's Guide.

The Maryland Statewide Travel Model (MSTM) is by design a multi-layer model working at a Regional, Statewide and Urban level (Figure A1). The Regional Model covers North America, the Statewide Model includes Maryland, Washington DC, Delaware and selected areas in Pennsylvania, Virginia and West Virginia, and the Urban Model which serves to link for comparison purposes only, the urban travel models where they exist within the statewide model study area, for instance by connecting MSTM with the Baltimore Metropolitan Council (BMC) Model or the Metro Washington Council of Governments (MWCOG) Model.

This documentation is a User's Guide focusing on the implementation of the Regional and the Statewide Model components. Past and future efforts strive to compare MSTM model results to MPO models and data at the Urban level. Every level is simulated to study travel behavior at an appropriate level of detail. The interaction of the three levels potentially improves every level by providing simulation results between upper and lower levels. All MSTM assignment of the travel demand occurs at the Statewide level.

At the Statewide Level, there are The 1588 Statewide Model level Zones (SMZs) that cover Maryland, Delaware, Washington DC, and parts of New Jersey, Pennsylvania, Virginia and West Virginia (Figure A2). The 151 Regional Model Zones (RMZs) cover the full US, Canada, and Mexico. RMZs are used for the multi-state commodity flow model and the long distance passenger model only and are eventually translated into flows assigned to networks and zones at the Maryland-focused (SMZ) level.

Figure A3 summarizes the MSTM model components within the Statewide and Regional levels. Economic and Land Use assumptions drive the model. On the person travel side, the Regional model includes a person long-distance travel model for all resident and visitor trips over 50 miles, reflecting only travel between their local trip end and their point of entry/exit (highway, airport, train station or bus terminal). These trips are combined with Statewide level short-distance person trips by study area residents, produced using a trip generation, trip distribution, and mode choice components. On the freight side, the Regional model includes a long-distance commodity-flow based freight model of truck trips into/out of and through the study area (EI/IE/EE trips). These flows are originally estimated for the entire US and disaggregated to the study area zonal system. These trips are combined with short distance truck trips (II trips) generated at the Statewide level using a trip generation and trip distribution method. The passenger and truck trips from both the Regional (long-distance) and Statewide (short-distance) model components provide traffic flows allocated to a time period (AM peak, PM peak or off-peak) are input to a single Multiclass Assignment.

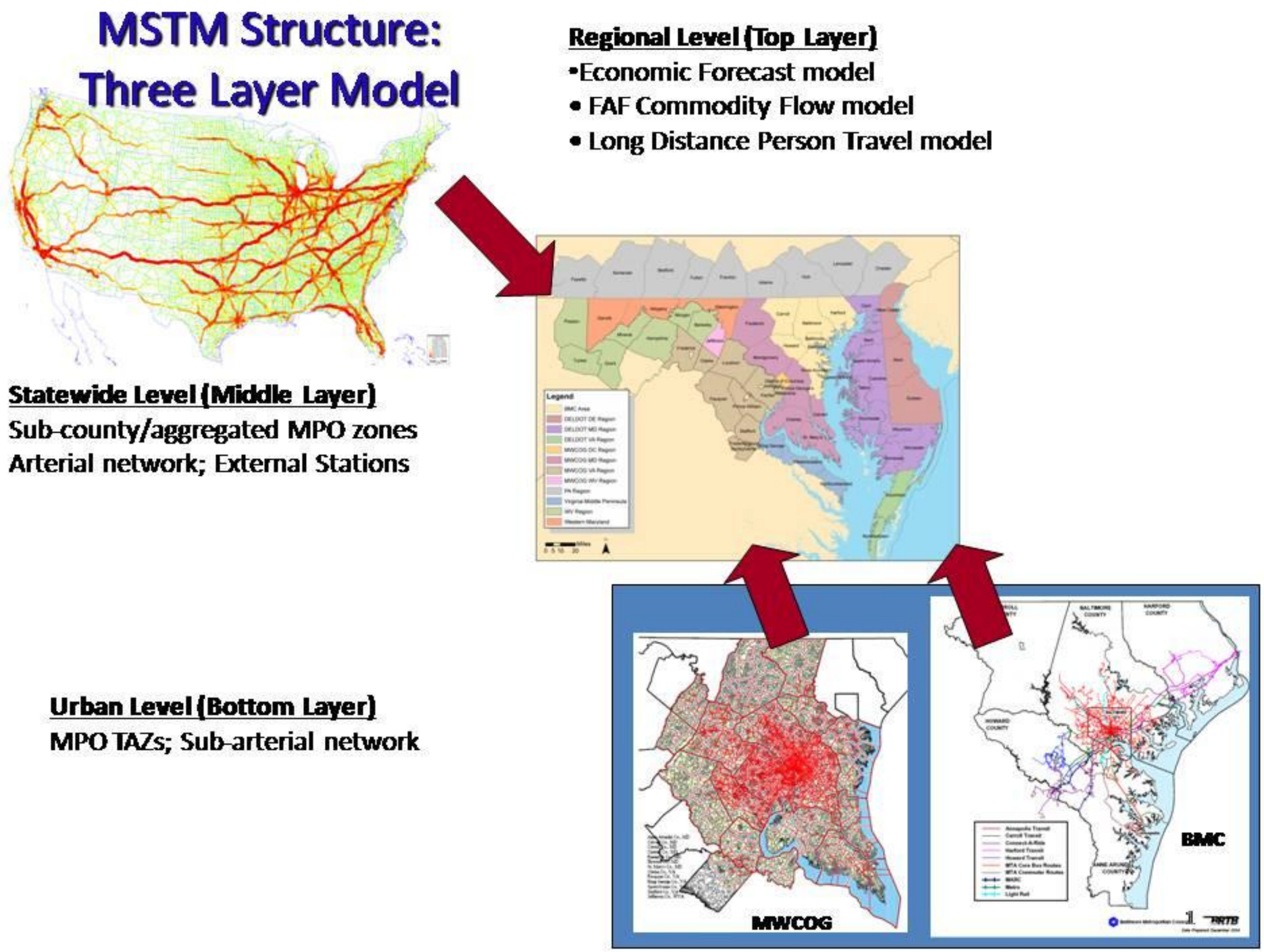


Figure A1. MSTM Three Level Model

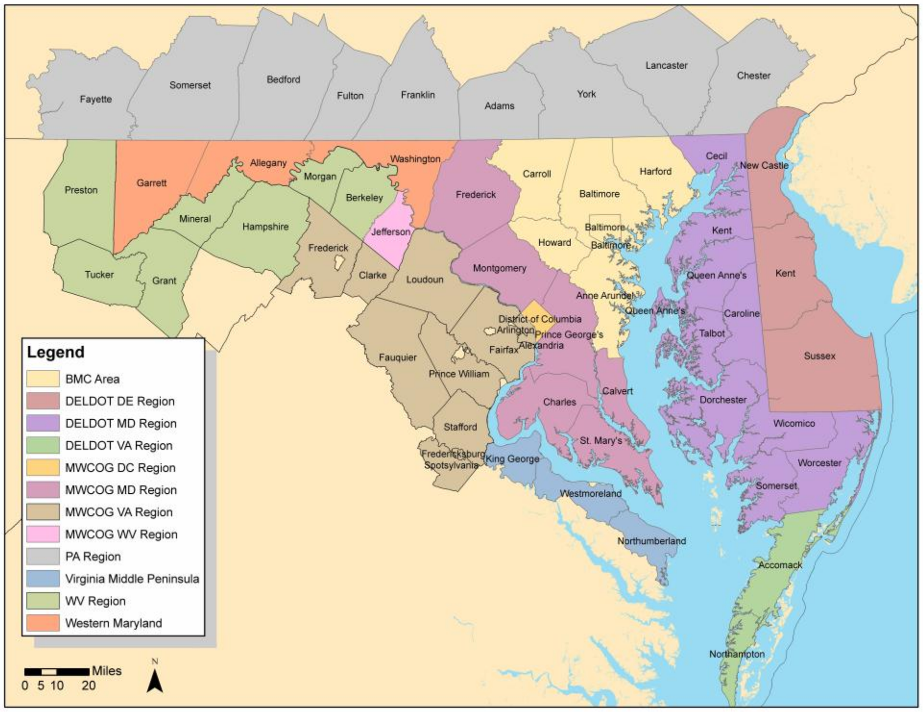


Figure A2. MSTM Statewide Level Coverage Map

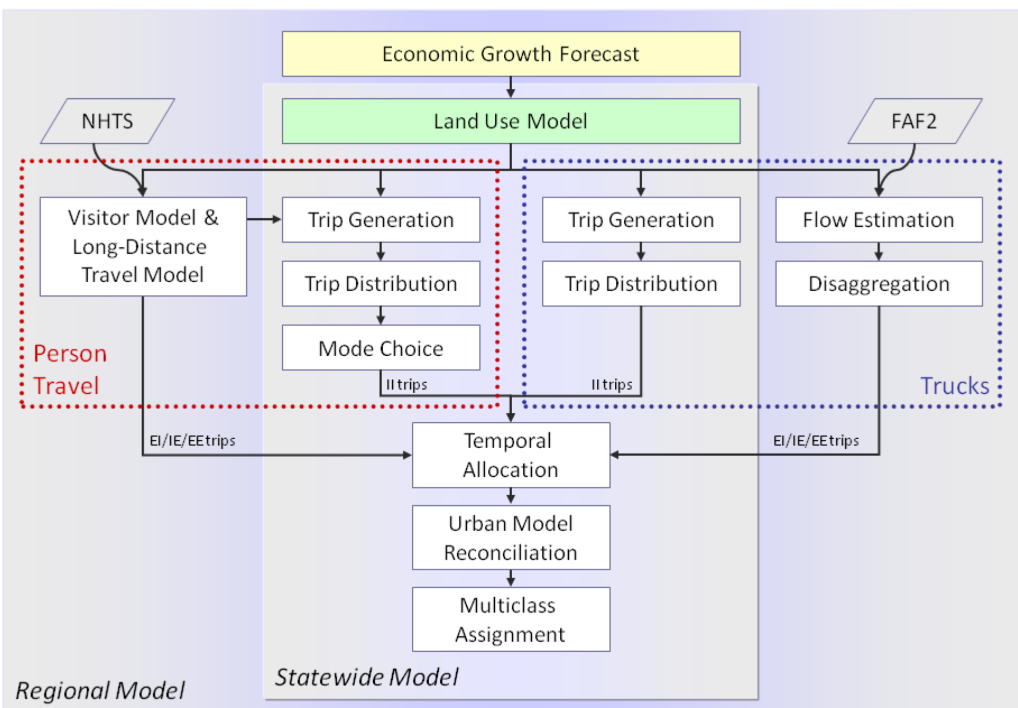


Figure A3. Overview of the MSTM model components

Model Inputs

Zone System

This section summarizes the zone systems used in the three-layers of the MSTM [5].

Regional Level:151 Regional Model Zones (RMZs) in the MSTMRegional model cover the entire US, Canada, and Mexico. These zones are used for the Regional long distance models only. Flows from these model zones are eventually translated into flows assigned to networks and zones at the Statewide Model Zone (SMZ) level, discussed below.

Statewide Level:1588 Statewide Model Zones (SMZs) in the MSTMStatewide level cover all of Maryland and selected counties in adjacent states. SMZs are the basis for MSTM transportation assignment and input land use assumptions. They nest within counties and are aggregations of MPO TAZs where they exist.

Urban Level: 3,056 Urban Model Zones (UMZs) in the MSTM urban level are taken directly from the Traffic Analysis Zones (TAZs) in the Baltimore Metropolitan Council (BMC) and Metro Washington Council of Governments (MWCOG) MPO models.

Statewide Model Zones (SMZs)

The MSTM SMZs were developed through an iterative process. The outer study area was identified from analysis of 2000 Census Transportation Package (CTPP) data to encompass the bulk of labor flows in/out of Maryland. Within this larger boundary, six regions were identified for SMZ formation, treating each region as a separate entity with its own datasets and issues. These regions are shown in Figure A4.

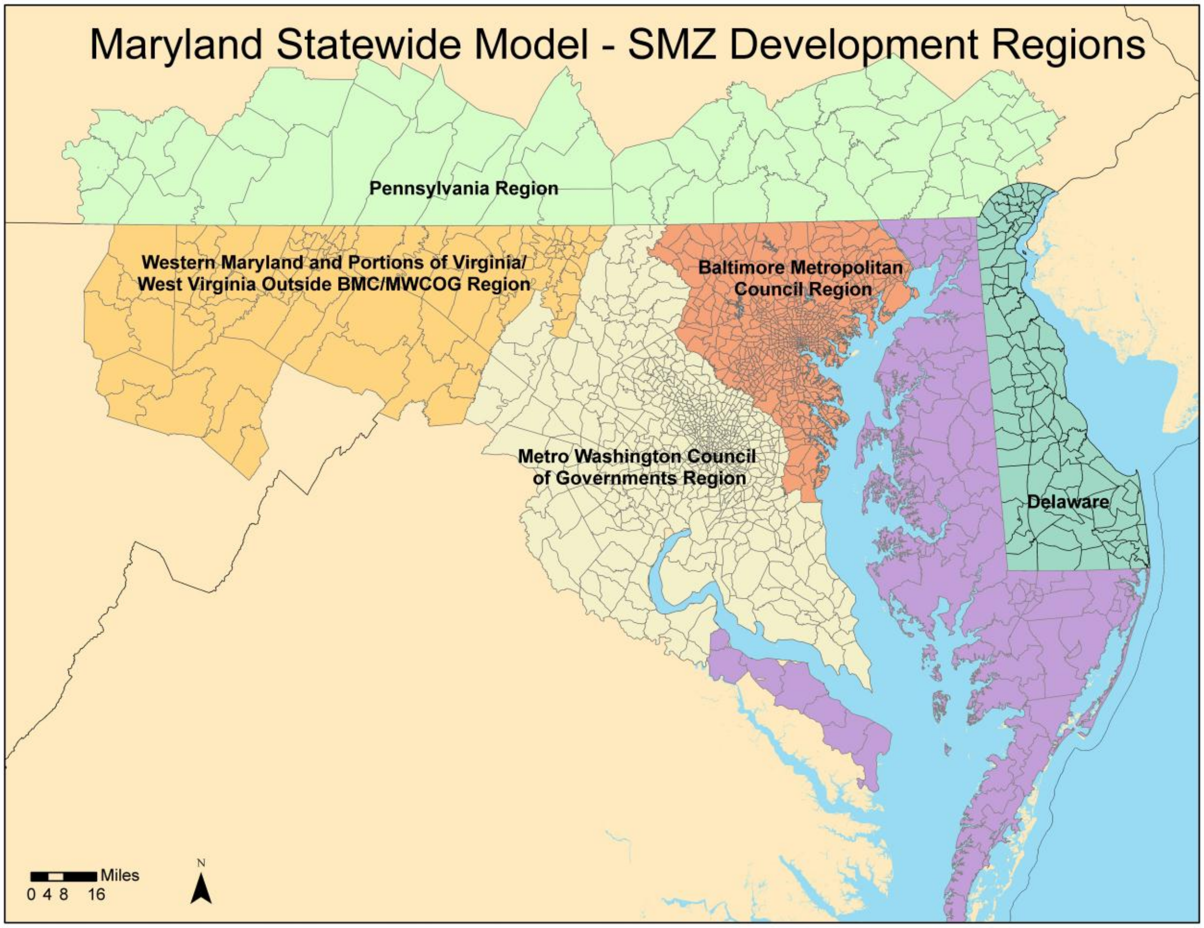


Figure A4. Regions used to develop SMZs

The remainder of this section discusses the process and assumptions made in developing SMZs for each of these sub-regions and overall. The goal was to adhere to the following major factors in the development of the SMZs.

- To the extent possible, SMZs conform to census geography to best utilize census data products in model development/updates and model calibration/validation. However, MWCOG MPO TAZs[9] are retained, and do not follow census geography.
- SMZs must nest within Counties and conform to County boundaries.

[9] From Ver 2-2 Model

- Aggregations of MPO zones, to facilitate linkages between MPO and statewide models.
    - Within Washington and Baltimore MPO areas, SMZs should be equal to or aggregations of MPO TAZs and nest within the MPO's TADs/RPDs.
    - SMZs should be more uniform in size than TAZs. In general, SMZ should be greater than 0.25 and less than 10 square miles. There should be greater aggregation in central areas where MPO TAZs are smaller (often individual street blocks) and little to no aggregation of larger MPO TAZs.
- SMZs should not straddle freeways, major rivers or other natural barriers.
- SMZs should separate the traffic sheds of major roads. MPO TAZs on opposite sides of a major road can be combined to define a traffic shed or corridor.
- SMZs should separate activity centers from surrounding areas and, where the activity center has been subdivided into multiple MPO TAZs, group adjacent TAZs into a single SMZ.

In each region, SMZs were developed with reference to various GIS overlays.

- MPO or other TAZ GIS shape file (where available) with activity density (ActDen) symbology (where TAZ data available) and Labels = TAZ number.
- Activity Density maps, calculated from historic/forecast demographic and acreage in areas of Maryland where TAZ demographic data is not available;
- Where TAZ shape files and related data are not available, use statewide land use or zoning coverage instead of Activity Density.

- Major roads coverage, from MPO networks where available, with Freeways and Major Arterials highlighted.
- MPO analysis districts (i.e., TAD or RPD) boundaries, where relevant.
- County boundaries.

The process for developing the zones consisted of a first cut based on the criteria above followed by review by SHA and other team members. Comments were addressed and conflicting comments resolved. During a final review the following additional changes were made:

- Isolate protected or restricted development lands for the land use model.
- Baltimore and District central business district aggregation to provide somewhat more uniform SMZ size and accentuate downtown activity levels on par with suburban centers.
- Distinctions were made to delineate areas with good accessibility to Metrorail stations.
- To the extent possible, the SMZ boundaries outside the MPOs and Eastern Maryland were made to distinguish rural from urban/suburban development zoning boundaries, with zones centered upon activity/town centers and major crossroads.

Regional Model Zones (RMZs)

The MSTM Regional model, primarily used in multi-state freight modeling, has its own zone system of RMZs. In Maryland and adjacent areas where MSTM RMZs and SMZs overlap, SMZs nest within RMZs, i.e., RMZs are aggregations of smaller SMZs. The following approach was followed.

- In Maryland, District of Columbia, and Delaware, counties were used to form RMZs.

- In four adjacent states, counties were used near the Maryland border with aggregations of counties in outer areas. Aggregation were based on the following sources:
    - Pennsylvania commodity flow districts per Pennsylvania DOT Statewide Freight Model User's Guide v2.1 (August 2006).
    - West Virginia Department of Motor Vehicles (DMV) Districts.
    - Virginia DOT Construction districts, with some adjustments.
- In the remainder of the US, states were used, including Alaska and Hawaii.
- In the remainder of North America, three zones were as follows:
    - Canada East: Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland and Labrador.
    - Canada West: Manitoba, Saskatchewan, Alberta, British Columbia, Yukon, Northwest Territories, and Nunavut.
    - Mexico.

The resulting RMZs are shown graphically in Figure A5.

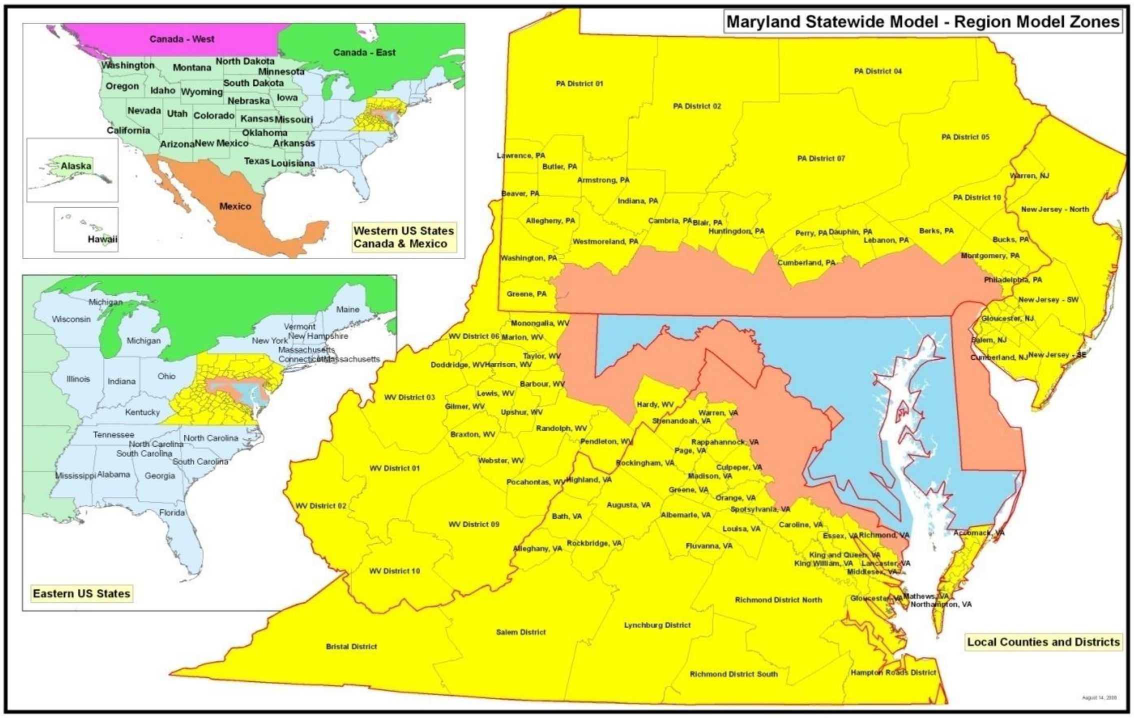


Figure A5. Map of RMZ zones

Network and Skim Development

MSTM uses a multi-modal network at the Statewide level, including highway and transit networks and associated assumptions on link attributes and model-wide intercity and urban transit service. The networks were compiled from various existing models, including MPO, DOT, and other sources, and standardized. Extensive efforts were made to map the highway network to the SHA CenterLine network to enable sharing of data.

MSTM Network Attributes

Tables A1 and A2 provide a summary of the attributes that have been developed for the MSTM. Other attributes from the various networks may be adopted in the future if deemed necessary. Since several of the coding conventions used in the various networks are not the same, a hybrid set of codes had to be developed for the MSTM.

Table A1

MSTM Network Metadata – Links

Field	Description
A	A node
B	B node
AMLIMIT	AM peak link usage restriction code
PMLIMIT	PM peak link usage restriction code
OFFLIMIT	Off-peak link usage restriction code
FT	Facility type
DISTANCE	Distance in miles
SPDP	Posted speed limit, mph
CAPCLASS	Maximum daily lane capacity divided by 50 (Service level 'E')
CNTID	Regional count database identification
CNT00	Year 2000 daily count
CNTWKD00	Year 2000 weekday count
HTCNT00	Year 2000 heavy truck count
MTCNT00	Year 2000 medium truck count
COMCNT00	Year 2000 commercial vehicle count (not presently coded)
AMLANE	AM peak number of lanes
PMLANE	PM peak number of lanes
OFFLANE	Off-peak number of lanes
FFSPEED	Free-flow speed, mph
CONGSPD	Initial congested speed, mph
CAPE	Maximum daily lane capacity (Service level 'E')
TOLLCOSTOF	Off-peak toll, cents (year 2000 $)
TOLLCOSTPK	Peak toll, cents (year 2000 $)
FROM_TO_ID	Local network link identifier
MODEL	Local model identifier
PB_DIST	PB calculated distance in feet
RECID	Temporary ID number for links used to stitch networks
FROM_X	From Node X Coordinate
FROM_Y	From Node Y Coordinate
TO_X	To Node X Coordinate
TO_Y	To Node Y Coordinate
SWFT	Statewide Model facility type
DIR	One-way directional code
RMZ_NAME	RMZ name
JUR_NAME	Jurisdiction Name
JUR_FIPS	Jurisdiction FIPS Code
SMZRMZ	SMZ or RMZ number
RT_ID	Route ID number
RT_NAME	Route Name
ACRES	Acres
PBAREATYPE	PB defined area type
AREATYPE	Local network defined area type
FT_ORIG	Original FT

Table A2

MSTM Limits Codes

Code	Description
0	No restriction/GeneralUse
1	General Use
2	HOV2+ only
3	HOV3+ only
4	no Medium or Heavy Trucks allowed
5	Non-Airport Vehicles Prohibited
6	Transit Only
9	no vehicles (used in order to allow a link to physically remain in the network, but be closed to all traffic during certain periods; certain HOV lanes operate in this manner)

The various roadway functional classifications used in the MSTM are shown in Table A3. As discussed previously, the original MPO functional class is used to determine statewide functional class, link speeds, capacities, and VDFs.

Table A3

MSTM Functional Type

Functional Type Code	Description
1	Interstate
2	Freeway
3	Expressway
4	Major Arterial
5	Minor Arterial
6	Collector
7	Not Used
8	Medium Speed Ramps
9	High Speed Ramps
10	Local Roads
11	Centroid connector
13	Drive Access Link (Hwy - PNR)
15	Rail Links
19	Drive Access Links to IntercityBus
20	Drive Access links to IntercityRail
21	PNR - Hwy walk link
22	Not Used
23	PNR - rail walk link
24	Rail - Hwy walk link Hwy – Rail walk link
26	Amtrak

Other look-up tables from the BMC and MWCOG model documentation were used to help complete the initial set of MSTM attributes. The codes used as variables for these look-up tables will be maintained in the MSTM attribute table. A more generic set of look-up tables may be created at a later stage in the model development. For now, the values from the individual model look-up tables will be used.

Within Maryland roadway tolls are configured as link attributes and peak and off-peak tolls have been added (in 2000$). Tolls on a link basis apply to all vehicle types. Tolls on the Delaware Memorial Bridge have also been included. Other toll roads outside Maryland have also been identified but the tolls have not been included in the MSTM.

Area Type Attribute Update

MSTM calculates its own area type, consistent across the model area. The area type attribute indices are used in the mode choice models and to assist in estimating capacity on certain highway links. When a new network is created or the SMZ data updated, the area type attribute must also be updated. It then serves as a lookup table for additional attributes on the network. The MPO models use measures of zonal activity, combined with area size, to develop indices of area type. In the MSTM and BMC model the households and employment are used to measure activity whereas in the MWCOG model population and employment are used. For the MSTM, area types are classified into nine categories.

The identification of an area type in the MSTM consists of four steps:

1. A measure of activity is calculated for each SMZ equal to households plus retail employment plus total employment.
2. The activity measure is then divided by SMZ total area in acres to obtain activity density.

3. Third, SMZ's are then sorted by activity density
4. SMZ's are then assigned an area type code from 9 to 1 according to the following:
    a. Using the measure of density and the total activity, starting from the most dense SMZ, the SMZs which include one ninth of the total activity have area type 9 assigned.
    b. Area type 8 is then assigned to the next group of SMZs which also contains one ninth of total activity.
    c. This process is repeated until each SMZ has been assigned an area type (9 to 1).
5. These initial area type breaks listed below are then held fixed in all other model years and alternate scenarios:
    a. 1 – Less than 0.3914 activity density measure (step 1)
    b. 2- 0. 3915 to 0.9446 activity density
    c. 3- 0.9447 to 2.7507 activity density
    d. 4- 2.7508 to 3.6032 activity density
    e. 5- 3.6033 to 5.3648 activity density
    f. 6- 5.3649 to 7.7239 activity density
    g. 7- 7.7240 to 12.0503 activity density
    h. 8- 12.0504 to 31.2705 activity density
    i. 9- Higher than 31.2705 activity density

The results of the area type classification are shown in Figure A6.

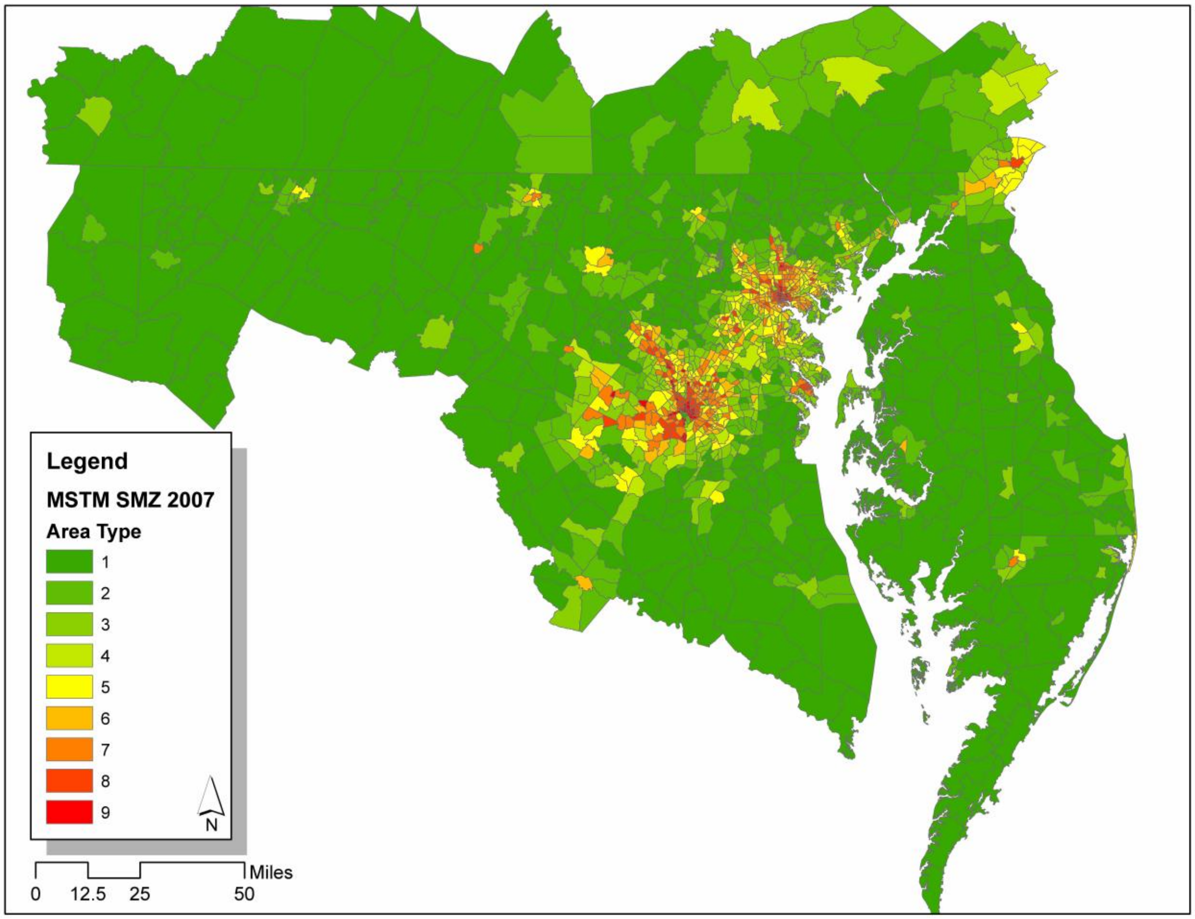


Figure A6. Area Types for MSTM SMZs (RMZ's not presented in this figure)

Node Numbering

Since several sources were used to develop the MSTM network, the node numbering sequence had to be revised to eliminate duplications. The revised numbering sequence for the MSTM network was designed so that the values could be cross-referenced to the original network node numbers. This will allow for updates to the MSTM network based on changes to the original networks used and facilitate in the creation of a future year 2030 network. Table A4 summarizes the numbering sequence developed for the MSTM network.

Table A4

MPO Node Numbers

Model System	Original Node Numbers	New Node Numbers	Comments
BMC	3002 to 39283	Unchanged	Unchanged
MWCOG	2358 to 19064	42358 to 59064	60000
DE	331 to 242037	80001 to 83165	Re-numbered 80K +
EastC	Null	83166 to 108772	Continued from DE
US	Null	108773 to 130952	Continued from EastC
SMZs	None	1 to 1588	Gaps (1607 total)
RMZs	None	1701 to 1873	Gaps (151RMZs)
Rail Nodes	None	4000 series	

Consolidated Transit Network

The MSTM network includes both MPO and intercity transit systems in Maryland and selected counties of adjacent states. As the transit focus of alternative scenarios will be on intercity transit facilities, ways to simplify local bus services in the transit networks were explored to expedite network coding. This includes the following transit systems and their system miles (2-way distance).

Transit Network Development

The objective of transit coding is to provide service to the zones that have service in the real world, not to serve as an exact representation of the route system. For example, streets that are too insignificant to be in the highway network are not added to the transit route. This would not result in a detailed description of transit service but would provide connectivity to the respective zones.

Unlike the MPO models where the non-transit links are added during the model run, in MSTM these have to be a part of the Transportation Network which is input to the model. Hence, the Park-N-Ride (PnR) node information was extracted from the MPO model files, and then those nodes were re-numbered and added to the MSTM network. PnR lots serve some specific stations which have to be coded along with the PnR information during the model run to facilitate the generation of Zonal Drive access legs described in the last section. These legs allow people to park their vehicle at the PnR lots and board the services at the stations being served.

Transit route files from the respective BMC and MWCOG models were combined and mode numbers were edited appropriately to reflect the new system. The node numbers that each route serves had to be re-numbered if they lie in MWCOG model area or if they were modified during the creation of MSTM roadway network so that they can fit on the new roadway network. This was a time consuming task as there is no automated procedure for such a conversion. It has been verified that all the transit stop nodes are highway nodes that are well connected to the network. Segments of the transit network had to be re-done to make them use the new more detailed network that came from the other MPO model. Some of the links in the present transit network may have only one link connecting two nodes while underlying highway network may have two links to establish the same connectivity, these do not cause a significant change in the results hence they were corrected to the extent possible given the scope of the project. A default speed called XYSPEED has been coded for each route to be used to calculate the time required to traverse such links using the XY distance.

The transit line descriptions follow the standard CUBE coding convention. The time periods are the same as the highway network assignment. Coded headways reflect the headway that is generally implied by the published timetable and are coded to the nearest whole minute. If the timetable suggests "clock" headways, that is what is coded (rather than the more intricate calculation used in some models, dividing the number of trips into the minutes in each time period).

Urban Transit

MSTM contains Baltimore and Metro Washington urban transit networks. These networks are taken directly from the BMC and MWCOG MPO model network files. There are two separate files, one for the Peak and one for the Off-Peak periods. These files consist of the route information for the Urban Transit Service. Bus Lines and Rail Lines are also present in separate files. The route files have been modified to reflect the re-numbered nodes in the MWCOG area. Since MSTM network derives parts of its network from different MPO networks, the transit lines had to be modified to fit the new network that came in from other MPO model. For example, parts of transit lines from BMC MPO area lying in the MWCOG's network had to be altered to fit the new network.

Modes from BMC and MWCOG models have been reorganized to form the MSTM mode system. Mode numbers 9 and 10 are not used. All modes are accessible via walk and Park-n-Ride (PnR). Below is a brief summary of the urban transit modes used in MSTM:

MODE 1. Local Bus- includes the following Bus Systems:

- BMC Buses: MTA Local Bus, MTA Premium Bus, Harford County Bus, HATS/Howard Transit/Connect-a-Ride (Howard County Bus), Carroll County Bus, Annapolis Transit Bus.
- MWCOG Buses: Local Metrobus, Other Primary - Local Bus, Other Secondary - Local Bus.

MODE 2. Express Bus- includes the following Bus Systems:

- BMC Buses: MTA Express Bus, MTA Premium Bus

- MWCOG Buses: Express Metrobus, Other Primary - Express Bus, Other Secondary - Express Bus.

MODE 3. Premium Bus: Includes BMC's MTA premium bus.

MODE 4. Light Rail: includes Baltimore light rail, Georgetown Branch, Anacostia and Montgomery Co. Corridor Cities Light Rail Lines.

MODE 5. Metro Rail: includes Baltimore Metro rail and DC Metro Subway.

MODE 6. Commuter Rail: includes MARC and Virginia Rail Express' Frederick and Manassas Lines.

Urban Transit Fares, Routes, and Schedules

Fare matrices were imported from the BMC (Version 3.3) and MWCOG (Version 2.2) models and combined to obtain the Fare matrix for the MSTM model (in 2000$). The weighted average of the trip matrix and fare matrix were used to convert the matrix from the earlier format to the newer one. Some other additional parameters like the HEADWAY for the lines is imported from the MPO models. HEADWAY 1 is for Peak period and HEADWAY 2 is for the Off-Peak Period.

Intercity Transit

Intercity transit includes Greyhound Bus and Amtrak Rail Lines in the model area, which covers six states. It may be noted that some of the routes described in the Urban Transit section also serve multiple MPOs within the State. These may also be used to commute between DC and Baltimore. Below are brief summaries of the Intercity Transit modes.

MODE 7.Amtrak Rail: Includes those routes that run regularly between DC and Baltimore. Only parts of the routes lying inside or close to the model area are coded and headways are also based on the coded segments of these routes. The following Amtrak stations are included:

- Wilmington, DE (WIL)
- Baltimore - Penn Station, MD (BAL)
- BWI Airport - Thurgood Marshall Airport, MD (BWI)
- Washington - Union Station, DC (WAS)
- Rockville, MD (RKV)
- Alexandria, VA (ALX)
- Newark, DE (NRK)
- Aberdeen, MD (ABE)
- New Carrollton, MD (NCR)

MODE 8.Greyhound Buses: Some of these routes are coded in the same way as Amtrak lines. Intercity Bus includes the following major stations:

- Annapolis
- Baltimore Downtown
- Baltimore Travel Plaza
- Easton
- Frederick
- Hagerstown
- New Carrollton

- Ocean City
- Salisbury
- Silver Spring
- Univ Of Md Eastern Shore
- Washington DC
- Wilmington DE

Intercity Transit Fares, Routes, and Schedules

Fare and scheduling data was collected for intercity transit including Greyhound Bus and Amtrak Rail line systems (in 2000$). The Amtrak data and some Greyhound data were collected using online resources from the transit providers in 2008. Web pages were used to find the data for city pairs that are included in the model area, and one stop into the halo. This allowed the modeling team to approximate the frequency of service for the transit modes. Greyhound does not have an online schedule information so a Greyhound schedule book was obtained for the route and headway information.

Non-Transit Modes

Some of the mode numbers are reserved for Non-transit modes that connect Transit services to the Highway links. A Non-transit leg is an imaginary entity representing a series of links required to establish the connection between transit and highway. The costs, such as distance and time, needed to traverse the leg are derived from the sum of the links traversed. In the following diagrams, roadway and non-transit links are combined to form the following links for three non-transit modes:

W2R = C1 + L1 + W1

W2B = C1 + L1 + L2

D2R = C1 + L1 + D1 (drive segment) and W3 (walk segment)

D2B = C1 + L1 + D1 (drive segment) and W2 + L2 (walk segment)

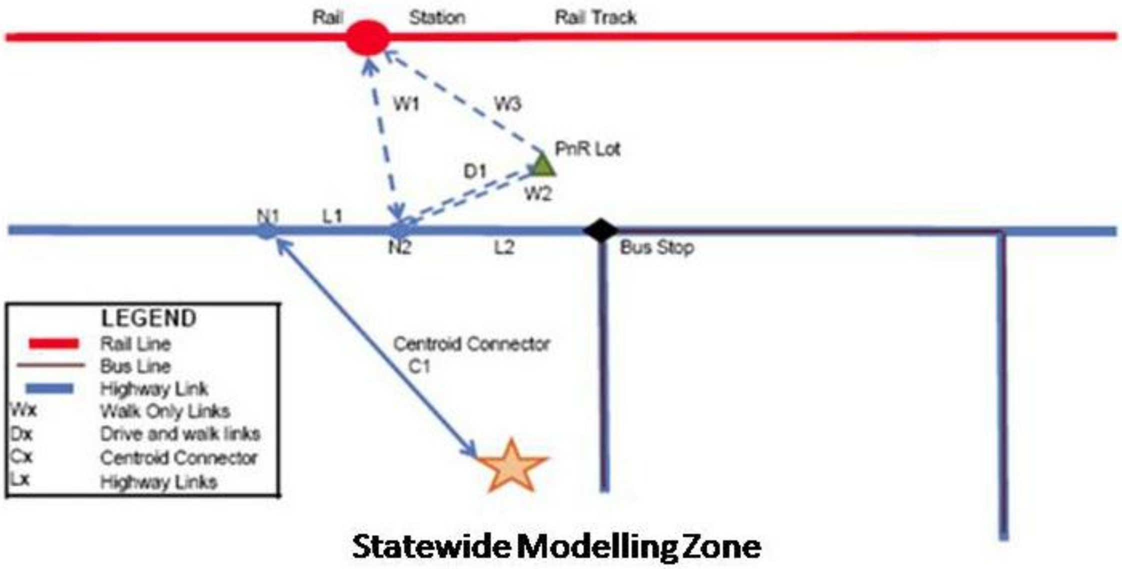


Figure A7. Transit Coding Diagram, Transit and Non-transit Links

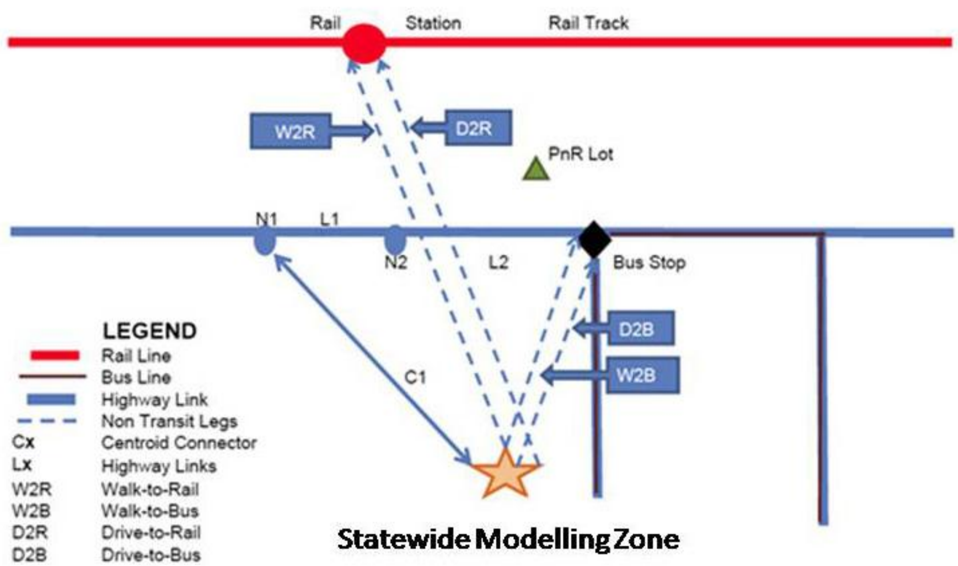


Figure A8. Transit Coding Diagram, Transit and Non-transit Legs

The Non-transit modes are summarized below.

MODE 11.Zonal Drive Access Legs: Connect the Zone Centroids with the nearby Park-n-Ride Lots. Unlike the Drive access Links whose purpose is to allow traffic to get on/off the roadway; legs connect a zone centroid to all the Park-n-Ride Lots within 10 mile distance. These PnR lots are then connected to the nearby stations/highway nodes via walk links.

MODE 12: Walk Transfer Legs: Hypothetical links that connect each line with nearby lines so that passengers can make transfers. These links derive their attribute values from the physical links that need to be traversed to establish connectivity.

MODE 13: Zonal Walk Access Legs: Similar to zonal drive access except they allow people to walk from the Zone Centroids to any of the nearby transit stop (within a mile of walking distance). These also derive their attribute values from the underlying network links.

Trip Generation (TG)

Statewide Layer

Person trip generation follows the same basic approach as the BMC model and encompasses the same trip purposes. The trip production component was updated to use household characteristics and trip rates derived from 2007-2008 HTS data and more recent Census data. The trip attraction component is based on linear regression equations derived from the same household survey data. Development of the independent household and employment variables required for each SMZ was described previously in Section 4.

Iterative Proportional Fitting:

MSTM person trip generation model uses trip production and attraction rates by household size (SIZ) by income (INC) and households workers (WRK) by income (INC). Since the SMZ data only provides households by income (see Section 4), a pre-generation step is applied to generate these joint distributions for the scenario year. An iterative proportional fitting (IPF) process combines the SMZ household data for the scenario year as marginals with joint-distribution seeds (from 2000 Census PUMS) to create households by SIZ and INC and households by WRK and INC at the SMZ level for a specified scenario year.

Trip Productions

The trip generation model produces trip productions by trip purpose for each SMZ based on joint distributions of households and trip production rates cross-classified by household category.

The following trip purposes were identified:

- HBW = Home Based Work
- HBS=Home Based Shop
- HBO=Home Based Other
- HBSCH = Home Based School
- NHBW = Non Home Based Work
- NHBO = Non Home Based Other

Trip productions for work-related purposes are based on trip rates cross-classified by income and number of workers. The work related trips rates are slightly adjusted (reduced) to reflect the trips attracted to cities outside the MSTM region such as Philadelphia. Trip productions for non-work-related purposes are based on trip rates cross-classified by income and number of persons. Differences from the BMC approach are related to the income classification of households and the way motorized shares are derived and trip rates represent only trips within 50 miles. The long distance trips greater than 50 miles are modeled with the long distance travel model. Trip generation rates by household category and region are taken directly from the 2007-2008 HTS survey data. Rates are adjusted to the MSTM income categories (quintiles). The HTS regional rates used for the various MSTM regions are show in Table A5.

Table A5

Trip production rates by region and trip purpose

	HBW1				HBS1					HBO1				
	Wrks0	Wrks1	Wrks2	Wrks3	Size1	Size2	Size3	Size4	Size5	Size1	Size2	Size3	Size4	Size5
Urban	0.03194	1.11594	2.21429	2.7381	0.6754	0.9286	1.2676	1.1212	1.8913	0.984	1.7296	2.1831	3.3636	4.0435
Suburban	0.02715	1.12707	2.7381	2.7381	0.625	1.0874	1.8	1.3902	1.8913	0.965	2.1093	2.5867	4.1707	4.0435
Rural	0.02674	1.08602	2.7381	2.7381	0.6467	1.2737	1.8	1.3902	1.8913	0.8922	1.4526	2.5867	4.1707	4.0435
	HBW2				**HBS2**					**HBO2**				
	Wrks0	Wrks1	Wrks2	Wrks3	Size1	Size2	Size3	Size4	Size5	Size1	Size2	Size3	Size4	Size5
Urban	0.10963	1.23205	2.6	4.08696	0.6212	0.9676	1.3333	1.098	1.8354	1.0291	1.8866	2.6061	2.9608	5.5063
Suburban	0.05584	1.27261	2.35433	4.08696	0.6969	1.2694	1.3864	1.6444	1.8354	1.0857	2.0531	3.0568	3.4667	5.5063
Rural	0.13793	1.22697	2.5	4.08696	0.6293	1.2034	1.2063	1.3158	2.1316	0.9768	1.9186	3.2381	3.3158	5.2895
	HBW3				**HBS3**					**HBO3**				
	Wrks0	Wrks1	Wrks2	Wrks3	Size1	Size2	Size3	Size4	Size5	Size1	Size2	Size3	Size4	Size5
Urban	0.0719	1.30427	2.47699	3.98701	0.6472	1.0985	1.5	1.9756	1.902	0.8629	2.0925	3.7308	7.8293	7.1078
Suburban	0.05706	1.24526	2.41887	3.98701	0.6492	1.2407	1.5649	1.9949	1.902	0.959	2.0725	3.3789	5.1173	7.1078
Rural	0.11392	1.12834	2.28571	3.71642	0.5614	1.5013	1.7421	1.8027	2.1667	0.7602	1.9215	3.1006	4.3673	7.4881
	HBW4				**HBS4**					**HBO4**				
	Wrks0	Wrks1	Wrks2	Wrks3	Size1	Size2	Size3	Size4	Size5	Size1	Size2	Size3	Size4	Size5
Urban	0.03797	1.31975	2.43103	3.5974	0.627	1.2314	1.9	1.6111	2.472	0.9016	1.6829	3.11	7	7.4161
Suburban	0.09406	1.23503	2.36114	3.5974	0.657	1.2935	1.552	1.9966	2.472	0.9126	2.0064	3.2514	4.8537	7.4161
Rural	0.2	1.06993	2.12554	3.35443	0.6061	1.1296	1.3967	1.8358	3.0374	0.6212	1.6698	2.7554	4.3781	6.3645
	HBW5				**HBS5**					**HBO5**				
	Wrks0	Wrks1	Wrks2	Wrks3	Size1	Size2	Size3	Size4	Size5	Size1	Size2	Size3	Size4	Size5
Urban	0.1	1.24832	2.41411	3.92727	0.5889	1.259	1.7215	1.6232	2.1695	0.8333	1.8237	3.8101	6.0145	7.0678
Suburban	0.07692	1.27925	2.34343	3.92727	0.6782	1.165	1.3969	1.7742	2.1695	0.7931	1.8595	3.0825	5.2043	7.0678
Rural	0.07692	0.91667	2.30348	3.92857	0.6782	1.0063	1.4531	1.5625	2.1695	0.7931	1.4125	2.5625	4.6562	7.0678
	NHBW				**NHBO**					**HBSCH**				
	Wrks0	Wrks1	Wrks2	Wrks3	Size1	Size2	Size3	Size4	Size5	Size1	Size2	Size3	Size4	Size5
Urban	0.02716	0.81807	1.57447	1.29056	0.6667	1.1323	1.6267	1.6703	2.7386	0.0326	0.139486	0.71297	1.756256	2.690329
Suburban	0.02586	0.73898	1.23537	1.62068	0.7607	1.2917	1.56	1.9418	2.4039	0.016762	0.095771	0.787744	1.683333	2.890661
Rural	0.05386	0.69022	1.20296	1.71001	0.8789	1.4065	1.791	2.1243	2.7306	0.003852	0.048097	0.653769	1.647994	2.560217

Trip Attractions

Trip attractions by SMZ are calculated based on regression-type equations applied to SMZ socioeconomic variables for the non-home end of trips.

The attraction rates were derived from the combined HTS survey data. The rates were calculated for the entire survey area, not distinguishing urban, suburban and rural regions. For production rates, the objects that generate trips are households. The survey is large enough to calculate region-specific production rates by households. For attraction rates, however, the objects that attract trips are zones with their employment and household numbers. As few trips in the survey had the same zone as destination, it was impossible to create region-specific attractions that were statistically significant. Therefore, the entire survey area was treated as one region to increase the number of records used to estimate attraction rates for each trip purpose.

Table A6

Trip Attraction Rates

	Purpose					
Independent variable	**HBWork**	**HBShop**	**HBOther**	**HBSchool**	**NHBWork**	**NHBOther**
Households			3.158			0.82
Total employment	1.0286					
Retail employment		6.667				
Office employment					0.79	
Other employment			0.785		0.57	0.85
School enrollment				1.902		

HBW adjustment

An analysis was done to identify the number of residents who worked outside the model area. This was of particular concern in the Philadelphia area, where MSTM contains suburbs, but not the city. An analysis of 2000 Census CTPP data was done to identify by county, the number of worker flows that originated within the model area and destined outside the worker area. These county-level adjustment factors were applied to the HBW trip table.

Motorized share

Separate relationships were derived to estimate motorized trip shares as a function of activity density and applied after total person trips were generated. The following equations and factors were applied to the activity density for each SMZ area in order to generate the motorized shares.

$$Harris: \frac{1}{a + b * ActivityDensity^{c}}$$

$$Weibull: a - b^{c * Activity\ Density^{d}}$$

$$Exponetial: a * (b^{-(c * Activity\ Density)})$$

Table A7

Parameters and functions used to estimate motorized share of productions

	Productions					
	HBW	HBSCH	HBS	HBO	NHBW	NHBO
	Weibull	Harris	Exponential	Harris	Harris	Harris
a =	0.993	0.996	-0.348	1.09	1.003	1.044
b =	0.297	0.049	-1.887	0.024	0.0077	0.0033
c =	-7.8	0.808	-0.0658	0.824	0.7276	1.092
d =	-0.755					

Parameters and functions used to estimate motorized share of attractions

	Attractions					
	HBW	HBSCH	HBS	HBO	NHBW	NHBO
	Harris	Harris	Harris	Harris	Harris	Harris
a =	0.9373	1.038	1.026	1.0663	1.009	1.0059
b =	0.0837	0.0233	0.0118	0.0848	0.003	0.0039
c =	0.1356	0.967	0.8633	0.268	1.576	1.498

Model Implementation

Trip generation for both productions and attractions are implemented in two Cube scripts.

The Cube Script (IPF.S) reads the census 2000 household by size and income groups "Cen2000Seed_HH_By_SIZ_INC.csv", households by workers and income groups "Cen2000Seed_HH_By_WRK_INC.csv", and target data"Target_Size_Wrk_Inc.csv", which contains households by SMZ, and "Target_HH_Size_Wrks.dat", which contains total households by size and income and total workers by income. The census 2000 distribution is expanded to match the target households by SMZ (rows) and total households by size and income or workers and income (columns). The Cube script (TripGeneration.S) has four steps.

Step 1: Activity Density. Read in user-created Activities.csv file, which has the number of households and employment by employment categories. The script then calculates a density for each zone and outputs a file with that data: ActivityDensity.csv.

Step 2: Motorized Shares. Reads in the ActivityDensity.csv file created in Step 1. This step also reads in the purpose-specific .txt files that have the motorized shares by productions and attractions. Then, for each purpose and zone, the motorized shares are calculated based on the density of activities. The output of this step is called PAMotorizedShares.dbf, and has the production and activity rates for each zone by purpose. This step needs to be re-run every time the input population data changes, in order recreate the rate parameter files.

Step 3: Income Shares. Reads in the HBWAttrShares.csv file, which is a user created file with the HBW purpose attraction shares by income class. This step also reads in the purpose-specific rates files used by the step 2, which also have the production shares by income group. This step calculates the production shares by purposes and by income classes. The output file of this step is called INCQShares.dbf.

Step 4: Productions and Attractions. Trip Productions reads in the motorized share file created in Step 2, as well as user-created files: HH_By_WRKS_INC and HH_By_SIZ_INC, which have the number of households by income and size classifications. Trip Attractions reads in the motorized shares, and income shares output created by Step 3, as well as the Activity Density created in Step1 and the user-created Activities file. The final output is a file called "MSTM_Ps.csv" which has the Production rates and a file called "MSTM_As.csv" which has the Attraction rates for each purpose and zone. The user has control over all of the input files to this module and can make adjustments and edits directly in those files. A list of the input files and the Steps that use them are shown in Table A8.

Table A8

Trip Generation Input Files

File Name	Steps Using File	Description
Cen2000Seed_HH_By_SIZ_INC.csv	Step 1	Census 2000 Households distribution by size and income groups
Cen2000Seed_HH_By_WRK_INC.csv	Step 1	Census 2000 Households distribution by worker and income groups
Target_Size_Wrk_Inc.csv	Step 1	Scenario year hosueholds by SMZ
Target_HH_Size_Wrks.dat	Step 1	Aggregate Scenario year households by income, size and worker groups
Activities.csv	Step 1 and Step 4	Total number of MSTM HH and Employment by SMZ.
*_rates.txt	Step 2, Step 3	* = hbw, hbsc, hbs, hbo, nhbw, or obo. Contains the production rates by region, motorized share by production and attraction by region, the income shares by productions and the attraction coefficients
HBWAttrShares.csv	Step 3	Attraction rates for the HBW purpose by zone and income group, as well as the total HBS and HBO rate for each zone
ZonestoRegions.csv	Step 2, Step 3, Step 4	Maps each zone number to a region*
HH_By_WRKS_INC.csv	Step 4	Number of households in each zone by worker and income categories, 2000 census derived pattern to disaggregate employment totals.
HH_By_SIZ_INC.csv	Step 4	Number of households in each zone by size and income categories, 2000 census derived pattern to disaggregate household totals.

Non-Motorized Share

The Maryland Statewide Transportation Model (MSTM) generates motorized trips only. Walk and bike trips are generated by trip generation, but shall not be included in trip tables for subsequent modules. A certain share of trips is dropped before trip productions and attractions are fed into the destination choice model. Previously, the MSTM model applied Weibull functions to estimate the non-motorized shares by area type and purpose. Plotting these shares showed unexpected patterns, which affect trip origins, mode choice and the assignment results. To mitigate the impact, non-motorized shares were averaged across counties. This resulted into reasonable patterns non-motorized shares, however, the was a steep border effect were two neighboring zones in different counties may have very different non-motorized shares, while all zones within one counties were treated as being equal in terms of non-motorized shares. Figure A9 shows the motorized share, which is the inverse of the non-motorized share, used in MSTM for Home-based Work trips up to phase 3.

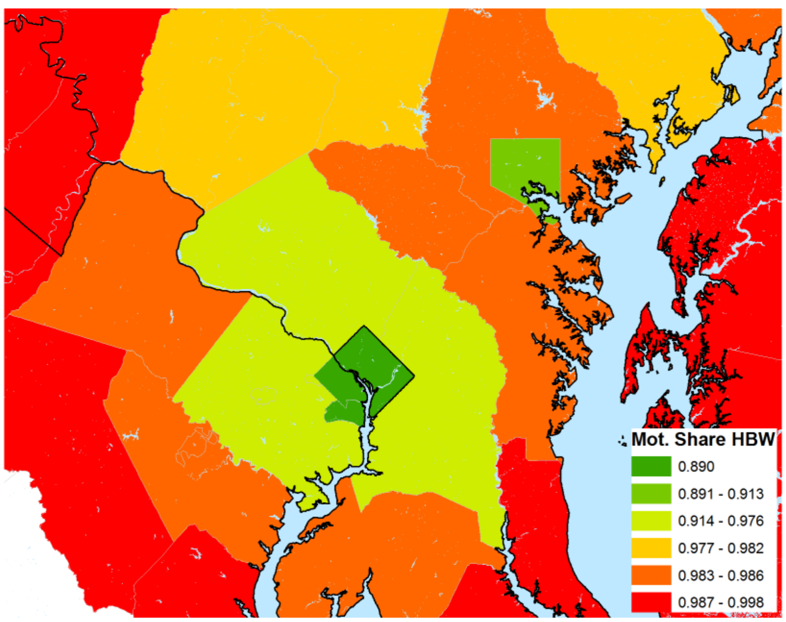


Figure A9. Previously assumed motorized share for HBW

In this phase, the 2007 Household Travel Survey was used to estimate the non-motorized share by zone. A multiple regression was set up to analyze the impact of various measures of densities and accessibilities on non-motorized shares at the zonal level.

Observed Data

The 2007 household travel survey was used to calculate the observed non-motorized shares. The primary travel modes designated in the survey are shown in Table . Each mode has been categorized as motorized or non-motorized. The survey trips data was aggregated by SMZ, purpose, and travel mode. The non-motorized shares are then calculated by SMZ for each of the 18 purposes using equation 1.

Table A9

Primary Travel Modes in the Household Travel Survey

Travel Mode	Motorized	Non-Motorized
Transit	√	
Auto D	√	
Auto P	√	
Walk		√
Bike		√
Other	√	

$$Non - Motorized\ Share\ per\ SMZ = \frac{Non-Motorized\ Trips}{(Motorized\ Trips + Non-Motorized\ Trips)} \quad (1)$$

The socioeconomic data (Activities.csv) is used to calculate the SMZ density per acre for three different densities: household, employment, and activity density. These densities were used as independent variables in the stepwise multiple regression. Table A10 shows how each of the densities were calculated.

Table A10:

Density Equations

Density	Equation
Household	HH/Acres
Employment	TotalEmp/Acres
Activity	(HH + TotalEmp + RetailEmp)/Acres

Accessibility

Besides various measures of density, accessibility was tested as an additional independent variable. Accessibility is a relative measure describing for a given zone how easily all other zones can be reached.

A large number of accessibilities have been defined over the last five decades (compare Schürmann et al. 1997[10]). The Hansen accessibility, also called potential accessibility, is probably the version that is used most commonly in transportation and land-use analyses, because it takes both the size of potential destinations as well as their distance into account. A larger size of a destination zones (measured in, for example, population or employment) increases the accessibility, while the distance to destination zones is inversely proportional accessibility:

$$acc_i = \sum_j s_j^{\alpha} \cdot \exp\left(\beta \cdot d_{i,j}\right) \tag{2}$$

acc_i Accessibility of zone *i*
s_j Size term of zone *j* (for example, population or employment)
$d_{i,j}$ Distance from zone *i* to zone *j* (measured in travel time)
α, β Parameters

[10] Schürmann, C., K. Spiekermann, M. Wegener (1997) Accessibility Indicators. Report 39. Institute of Spatial Planning, University of Dortmund.

The parameter α serves to increase or decrease the relative importance of particularly large centers accounting for agglomeration effects. The parameter β is a negative value increasing the disutility with larger distances. The exponential function makes the effect of distance non-linear, i.e. the difference between 1 mile and 2 miles is perceived to be larger than between 11 miles and 12 miles. After a few iterations of testing the impact of different parameters, α was set to 1.0 and β was set to -0.3.

Twelve different accessibility measures were calculated and tested as independent variables in the stepwise multiple regression (Table A11).

Table A11

Tested Accessibility Measures

	Accessibility by auto	Accessibility by transit
Accessibility to households	1	7
Accessibility to university enrollment	2	8
Accessibility to retail employment	3	9
Accessibility to office employment	4	10
Accessibility to other employment	5	11
Accessibility to total employment	6	12

To calculate transit accessibilities, only walk access (and not drive access) to transit was considered, as the goal of this task was to explain non-motorized trip shares. Accessibility to transit with walk access was expected to work as a proxy for walkability. All four transit modes (bus, express bus, rail and commuter rail) were taken into account, using the output files of the skimming process WBusPK.skm, WCRailPK.skm, WExpBusPK.skm and WRailPK.skm. Of the 22 tables given in every skim file, the table 11_BestJrnyTime was used. This table provides a combined travel time including initial wait time, transfer time, walk time and a penalty for every transfer. Out of the four transit modes, the one mode with the shortest travel time for a given origin-destination pair was used when calculating the accessibility, as travelers are assumed to select the fastest transit mode. Zones with no walk-access to transit received a transit accessibility value of 0.

As accessibilities are dimensionless, calculated values were normalized to values between 0 and 100.

$$acc_i' = \frac{acc_i \cdot sc}{\max(acc)} \qquad (3)$$

acc_i' Scaled accessibility of zone i
acc_i Accessibility of zone i
sc Scaler, set to 100

This ensures that the impact of accessibility remains unchanged across different scenarios and model years. As accessibility is a relative measure (zone A is more accessible than zone B), the absolute growth in accessibility between two years is irrelevant. For example, if the population grows by ten percent, and the accessibilities across the region grow accordingly, the share of non-motorized trips is not expected to be affected. Accessibility is only used to spatially distinguish non-motorized shares.

Trip Distribution

Statewide Layer

The destination choice model predicts the probability of choosing any given zone as the trip attraction end. The model was estimated in a multinomial logit form using the ALOGIT software. These models are preceded by the trip production models, which forecast the number of productions by zone for different trip markets, chiefly identified by purpose and household income level. The destination choice models include mode choice logsums, distance terms, zonal employment, household characteristics and region geographic characteristics. The destination choice formulation is used for all purposes except for Home Based School (HBSCH), which uses a gravity formulation.

Estimation Dataset

The combined household travel surveys (HTS) in the MWCOG and BMC regions constitute the backbone of the estimation dataset. No travel behavior data is available for people residing outside of these two metropolitan areas. Information about trip characteristics obtained from the household survey includes trip production and attraction location, purpose, household income and auto ownership and departure time. While the surveys provide considerably more detail about trip-makers and their households, the models are limited to the attributes forecasted by the trip production models. Mode choice logsums and distance skims from the current version of the statewide model provide the trip impedance information. In addition, various terms identifying the region where the trip starts or ends were developed. These terms identify the metropolitan area (Washington DC or Baltimore) and the area type (CBD, Urban, Suburban, Other), as well as whether a bridge crossing is required.

Since there are a large number of destination alternatives, it is not possible to include all alternatives in the estimation dataset. A sampling-by-importance approach was used to choose alternatives sets for each trip. Each trip record was duplicated 10 times and different choice sets with 30 alternatives each were selected based on the size term and distance. This approach is nearly statistically equivalent to selecting 300 alternatives as the choice set of each trip, once a sampling correction term is applied in estimation.

Main Explanatory Variables

The following variables were examined and proved to be significant on many different purposes. By allowing for the inclusion of multi-modal accessibilities and several other region and trip market terms, the destination choice framework helps explain variation in travel across the state that was difficult to explain with a single gravity model impedance function (adopted in MSTM Phase II effort):

- Mode Choice Logsum
- Distance between the home and potential work destinations
    - Linear distance
    - Distance square root
    - Distance squared
    - Distance cubed
- Household income group interacted with distance terms:
    - Low income (less than $30,000)
    - Medium-Low income ($30,000-$60,000)
    - Medium income ($60,000-$90,000)
    - Medium-High income ($90,000-$150,000)
    - High income ($150,000 and more)
- Zero-car household interacted with distance terms (not found to be significant so not used)
- Production region interacted with distance terms:
    - Washington DC CBD

- Washington semi-urban
- Washington suburban
- Baltimore CBD
- Baltimore semi-urban
- Baltimore suburban

- Intra-zonal indicator
- Attraction zone indicators:
  - Washington DC CBD
  - Baltimore CBD
- Employment:
  - Total employment
  - Office employment
  - Retail employment
  - Industrial employment
  - Other employment

Utility Structure

The utility (U_{ijn}) of choosing a trip attraction destination (j) for a trip (n) produced in zone (i) is given by:

$$U_{ijn} = S_j + \alpha \times L_{ij} + \sum \beta^k \times D_{ij}^k + \sum \beta^k \times D_{ij}^k N_n^k + \sum \beta^k \times Z_j^k + C_{jn}$$

Where, S_j is the size variable for destination zone j, L_{ij} is the mode choice logsum between zone pair ij, D_{ij}^k represents the various distance terms (linear, log, squared, cubed and square root), N_n^k represent person, household or production zone characteristics for trip n and is used for creating interaction variables with distance terms, Z_j^k represents attraction zone characteristics (other than the size term), and C_{jn} is a correction term to compensate for the sampling error in the model estimation (i.e., it represents the difference between the sampling probability and final estimated probability for each alternative). Appendix D explains how this correction factor is calculated.

The size variable may consist of several different terms; up to four categories of employment in addition to households. Weights (β^k) for each term in the size variable were estimated along with all other model parameters as follows, where E_j^k is employment of type k in zone j:

$$S_j = log(\sum \beta^k \times E_j^k)$$

Since the scale of the size term is arbitrary, one of the β^k coefficients is always set to 1.0. An alternative and equivalent specification of the size variable, implemented in ALOGIT is

$$S_j = log(\sum exp(\lambda^k) \times E_j^k)$$

ALOGIT reports the value of λ^k, instead of reporting directly the value of β^k. For this reason, the estimated size term coefficients may be negative; the actual coefficients are of course always positive, consistent with theory.

A combination of distance terms is used in the utility such that the composite distance utility function is monotonically decreasing. These distance terms are used to closely approximate the shape of the trip length frequency distribution. The distance-related disutility may be capped at a chosen maximum value, to maintain a reasonable probability of selecting far away destinations. The distance cap was established during model estimation at 30 miles, and may be adjusted during model calibration to ensure that the model reproduces the tail of the trip length frequency distributions. Note that even with a distance cap, the utility of a more distant zone decreases, all else equal, because of the mode choice logsum term.

Table A12 shows the trip length frequency for each purpose in the dataset. Figure A10 shows the trip length frequency in a graphical form.

Table A12

Observed Frequency of Distance to Chosen Attraction Zone

Miles	HBWork	HBShop	HBSchool	HBOther	NHBWork	NHBOther	Total
0 to 5	1,385,636	2,688,283	1,505,727	5,054,414	1,466,157	2,852,756	14,952,973
5 to 10	1,035,131	652,603	288,498	1,402,598	409,427	619,060	4,407,317
10 to 15	728,215	237,769	98,815	540,246	222,782	262,061	2,089,888
15 to 20	495,038	103,085	38,729	303,962	137,517	137,774	1,216,105
20 to 25	338,011	47,322	12,759	135,930	83,299	70,021	687,342
25 to 30	223,495	30,885	6,226	87,834	56,244	39,579	444,263
30 to 35	148,581	15,915	7,939	48,830	38,341	26,291	285,897
35 to 40	103,875	8,916	3,500	33,577	27,250	12,742	189,860
40 to 45	74,319	9,774	2,891	28,855	23,595	13,027	152,461
45 and up	127,528	18,223	5,491	48,048	30,788	21,358	251,436
Total	4,659,829	3,812,775	1,970,575	7,684,294	2,495,400	4,054,669	24,677,542

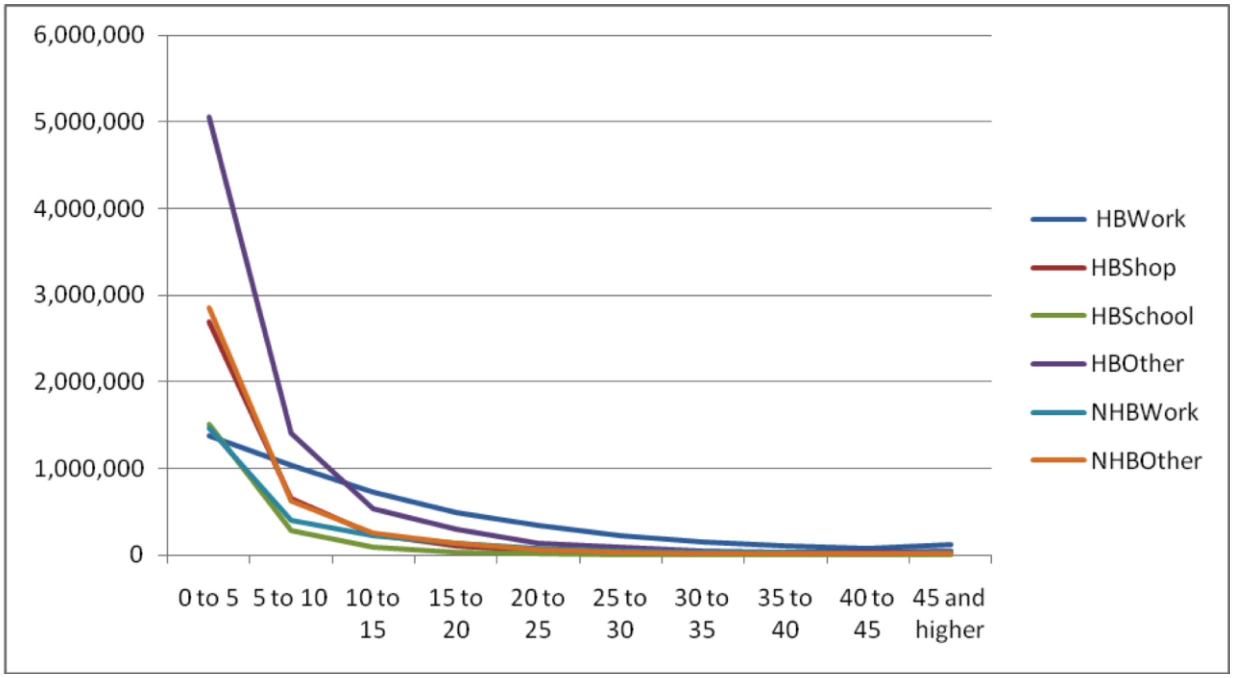


Figure A10. Observed Trip Length Frequency

Mode Choice Model

Statewide Layer

Person trip mode choice is an adaptation of the most recent BMC nested logit mode choice model, shown in Figure A11. The modes defined in Section 4.2, Consolidated Network Development, were aggregated into these nests. The figure indicates the modes and sub-modes that are incorporated in the model. Rail includes LRT and Metro and the Commuter Rail (CR) includes AMTRAK services as well as MARC commuter rail. All local bus services are included under the Bus and express bus and commuter bus services are included in the ExpBus modes.

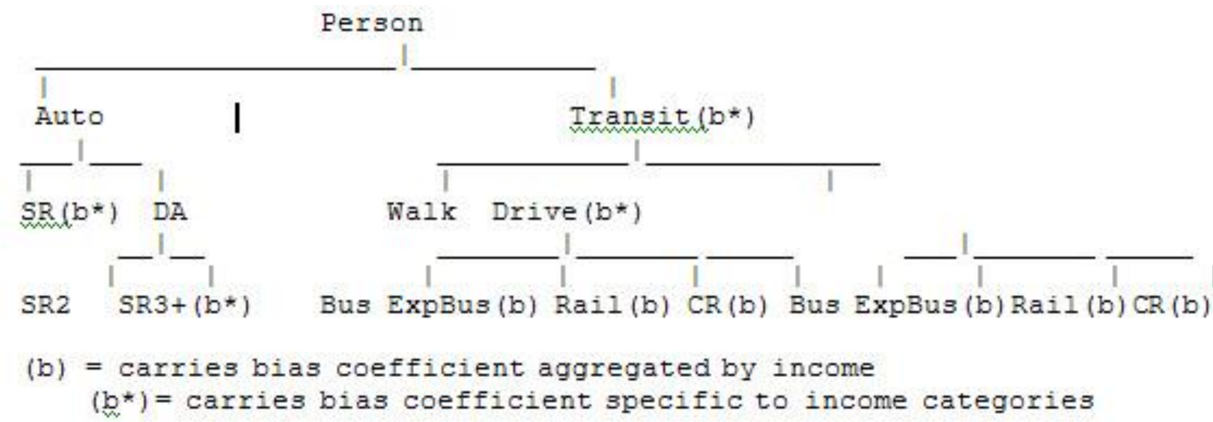


Figure A11. Structure of MSTM Mode Choice Model

Mode choice is based on generalized utility functions for auto and transit travel. Separate utilities were developed to represent peak and off-peak conditions. Home-based work trips and Non-home based work trips are based on peak period travel characteristics while other purposes are based on off-peak characteristics. Auto utilities for each auto mode include driving time and cost, terminal time and parking costs at the attraction end, and tolls. Transit utilities for each transit mode include walk and drive-access times, initial wait time, in-vehicle time, and transfer time. Bias constants or mode specific constants are included as indicated in Table A13 and Table A14 below which list all the variables included in the utility expression for each mode and sub-mode.

These variables are described in the BMC Calibration Report as follows. All monetary units were based on year 2000 dollars:

- **In-Vehicle Time** (IVT) (minutes): Run time from the network. This is Single Occupancy Vehicle (SOV) path time for Drive Alone (DA), High Occupancy Vehicle (HOV) path time plus carpool access time for Shared Ride 2 and 3 (SR2 and SR3) (which accounts for additional circulation and pick-up time for carpools). For SR2, access time is defined as the minimum of either 10 minutes or 12% of the in-vehicle time (MIN(0.120*IVT,10)); for SR3, it is the minimum of 15 minutes or 19.9% of the in-vehicle time (MIN(0.199*IVT,15)). Those functions were adopted from the old BMC model. For Transit, if the run time for each submode does not use that submode, the path is considered invalid and the submode is considered unavailable. Commuter rail run time is factored by 0.75, to reflect the fact that such trips tend to be longer and the riding experience is generally more pleasant than on other types of transit (more seating room, more amenities on-board, etc.).

- **Terminal Time** (minutes): Sum of the times for the production and attraction zones. Computed from a look-up table based on the zonal area types (see section1.4). For SR2, add 1.1 minutes to reflect additional waiting time; for SR3, add 2.5 min.

- **Auto Operating Cost** (cents): Incremental cost of driving (i.e., excludes all fixed costs of vehicle ownership). Computed as distance from the network times: 9.9 cents/mile in year 2000 dollars. About 58% of that cost (5.76 cents/mi) is fuel; the rest (4.14 cents/mi) is maintenance, tires, and oil. The fuel component was calculated using a cost of $1.314/gallon (year 2000 dollars) and an average on-road fuel efficiency of 22.8 mpg. For SR2, divide by 2. For SR3, divide by the average 3+ occupancy by purpose (derived from the Baltimore home interview survey).

- **Auto Tolls** (cents): Toll cost from the network. For SR2, divide by 2. For SR3, divide by the average 3+ occupancy by purpose.

- **Auto Parking Cost** (cents): Computed by the parking cost model for the attraction zone. For SR2, divide by 2. For SR3, divide by the average 3+ occupancy by purpose.

- **Transit Walk Time** (minutes): Sum of transit transfer walk time, from the network, plus computed production zone access to transit time, plus computed attraction zone egress from transit time. Access and egress times are multiplied by adjustment factors to reflect the difficulty or ease of walking.

- **Initial Wait Time** (7.5 min or less, in minutes): Initial wait time is the time spent waiting for the first transit vehicle, from the network. This is the amount of the initial wait time that is equal to or less than 7.5 minutes. Several urban areas have found that the first increment of wait time is more important to mode choice than the second increment. This also helps the modeling of routes with very long headways (e.g., 60+ minutes). TP+, as with most such software packages, computes the wait time as half the headway, but that does not reflect the fact that people tend to schedule their arrivals for long-headway routes, leading to shorter actual wait times than half the headway.

- **Initial Wait Time** (over 7.5 minutes, in minutes): This is the increment of initial wait time that exceeds 7.5 minutes, if any.

- **Transfer Time** (minutes): This is the time spent waiting for the second (and any subsequent) transit vehicles, from the network.

- **Number of Transfers**: In TP+, this is computed from the network as the total number of transit routes boarded, minus one.

- **Transit Fare** (cents): Computed from the network as the sum of the boarding fare and any transfer fares. For drive-access, it also includes the cost of driving to the Park and Ride (PnR) lot, computed as the drive-access distance times: 9.9 cents/mile.

- **Drive-Access Time** (minutes): The time spent driving to a transit PnR lot or station, computed from the network using over-the-road distance and speed.

Table A13

Variables Included in Utility Expressions

	Mode								
Variable	**DA/SR**	**Wbus**	**WEBus**	**WRail**	**WCRail**	**Dbus**	**Debus**	**DRail**	**DCRail**
In Vehicle Time	X	X	X	X	X	X	X	X	X
Terminal Time	X								
Auto Operating Cost	X								
Auto Tolls	X								
Auto Parking Cost	X								
Walk Time		X	X	X	X	X	X	X	X
Initial Wait Time (under 7.5 min.)		X	X	X	X	X	X	X	X
Initial Wait Time (over 7.5 min.)		X	X	X	X	X	X	X	X
Transfer Time		X	X	X	X	X	X	X	X
Number of Transfers		X	X	X	X	X	X	X	X
Transit Fare		X	X	X	X	X	X	X	X
Drive Access Time						X	X	X	X

Table A14

Nesting Coefficients

Nest	Value
Walk Transit Route (Bus, Rail, MARC)	0.30
Drive Transit Route (Bus, Rail, MARC)	0.30
Transit Access (Walk vs. Drive)	0.65
Shared Ride Occupancy (2 vs. 3+)	0.30
Auto Mode (Drive Alone vs. Shared Ride)	0.65

Mode choice coefficients are listed in Table A15. Mode specific constants and other bias coefficients, shown in Table A16 and Table A17, have been calibrated to match the Baltimore and Washington area trips by mode. The income specific bias constants have been added for Transit, Shared Ride, Share Ride3+ and Drive to Transit Nests. Bias constants have been added for express bus, rail and commuter rail modes in both, drive and walk to transit nests. These are meant for each purpose, aggregated by income. The bias constants were calibrated with the 2007 household travel survey, 2007 MTA onboard survey and 2008 WAMTA onboard survey data.

Table A15

Mode Choice Coefficients

Attribute	HBW, NHBW	HBO, HBS, SCH	OBO
In Vehicle Time	-0.025	-0.008	-0.02
Terminal Time	-0.05	-0.02	-0.05
Auto Operating Cost	-0.0042	-0.0018	-0.0044
Auto Parking Cost and Tolls	-0.0084	-0.0036	-0.0088
Walk Time	-0.05	-0.02	-0.05
Initial Wait Time (under 7.5 min.)	-0.05	-0.02	-0.05
Initial Wait Time (over 7.5 min.)	-0.025	-0.01	-0.025
Transfer Time	-0.05	-0.02	-0.05
Number of Transfers	-0.125	-0.06	-0.15
Transit Fare	-0.0042	-0.0018	-0.0044
Drive Access Time	-0.05	-0.02	-0.05

Table A16

Mode Specific Constants and Bias Coefficients at 2nd level

Purpose	DA	SR	SR2	SR3	Drive to Transit	Walk to Transit
HBW1	0	0	-0.329	-1.285	-0.856	3.996
HBW2	0	0	-0.351	-1.266	-0.539	2.464
HBW3	0	0	-0.409	-1.586	-1.072	0.771
HBW4	0	0	-0.447	-1.664	-2.503	-1.947
HBW5	0	0	-0.463	-1.695	-3.166	-3.231
HBS1	0	0	-0.094	0.035	-3.127	-1.631
HBS2	0	0	-0.194	0.104	-3.176	-2.417
HBS3	0	0	-0.116	0.09	-4.688	-3.552
HBS4	0	0	-0.043	-0.022	-5.072	-3.585
HBS5	0	0	-0.04	-0.04	-5.428	-3.806
HBO1	0	0	-0.014	0.17	-0.848	0.666
HBO2	0	0	-0.095	0.152	-2.665	-0.616
HBO3	0	0	-0.029	0.19	-3.218	-2.041
HBO4	0	0	0.008	0.197	-4.084	-2.961
HBO5	0	0	-0.001	0.18	-4.188	-3.536
HBSc	0	-0.838	0	-0.132	-0.516	-1.229
NHBW	0	-1.098	0	-0.305	-3.076	-2.419
OBO	0	0.351	0	-0.073	-2.712	-1.784

Table A17

Mode Specific Constants and Bias Coefficients at 3rd level

Purpose	Drive to Bus	Walk to Bus	Drive to Express Bus	Walk to Express Bus	Drive to Rail	Walk to Rail	Drive to Commuter Rail	Walk to Commuter Rail
HBW	0	0	-0.437	-5.442	0.378	-0.436	1.107	-3.516
HBS	0	0	0	0	-0.444	1.31	-5.717	0.877
HBO	0	0	0	0	1.398	2.028	3.018	0.272
HBSc	0	0	0	0	-0.126	9.085	41.63	37.091
NHBW	0	0	0	0	-0.33	1.154	2.887	0.792
OBO	0	0	0	0	0.799	2.393	4.36	4.892

Highway and transit networks were developed to be generally consistent with the procedures used in the BMC model although some simplifications were made in recognition of the broader purposes of MSTM and the larger area covered.

GIS techniques were used to define the portion of each zone within walking distance of transit stops and stations and related average walk times. Parking costs by SMZ were calculated as a weighted average of TAZ parking costs from the MPO TAZ data (weighted by employment density). Comparable values were developed for other areas based on employment density.

Trip Assignment

Model Integration and Time-of-Day Processing

Temporal allocation of the person, commercial and truck vehicle trips was accomplished by applying factors to the respective daily trip matrices to derive peak (AM and PM) and off-peak (MD and NT) trip matrices for network assignment. The process was taken from the BMC models. Factors for person trips are derived from household survey data on a production-to-attraction (PA) basis for home-based travel for application to person trip matrices in PA format. These factors produce directional flow matrices replicating observed average peaking characteristics. Factors for non-home-based person trips are derived on an OD basis and applied to the corresponding OD trip matrices. Vehicle trips are assigned by time of day period. Separate assignments were done for the AM and PM peak periods and for the rest of the day combined. Transit trips were assigned on a daily basis with work trip assignment based on peak service characteristics and assignment of all other trip based on off-peak service characteristics. BMC factors for auto person trips and the drive access component of transit drive-access trips are given in Table A18. They sum to 100% by purpose for the P-A and A-P directions individually.

Table A18

Person Trip Time of Day Factors

Purpose	PA_AM	AP_AM	PA_MD	AP_MD	PA_PM	AP_PM	PA_NT	AP_NT
HBW1	55.27%	3.61%	18.96%	27.45%	5.57%	45.00%	20.20%	23.95%
HBW2	60.72%	2.30%	14.26%	20.22%	4.44%	53.03%	20.57%	24.45%
HBW3	63.56%	1.34%	11.57%	19.98%	3.32%	60.17%	21.54%	18.51%
HBW4	68.04%	1.50%	9.45%	18.62%	2.42%	61.94%	20.09%	17.94%
HBW5	71.47%	0.69%	9.10%	15.98%	1.91%	64.32%	17.52%	19.01%
HBS1	18.44%	3.27%	50.53%	43.71%	19.04%	29.45%	11.99%	23.58%
HBS2	17.31%	2.80%	42.50%	38.25%	21.43%	28.27%	18.76%	30.68%
HBS3	16.04%	2.53%	39.67%	37.77%	26.57%	27.63%	17.72%	32.07%
HBS4	15.55%	2.00%	36.14%	33.34%	26.83%	28.48%	21.48%	36.18%
HBS5	17.91%	2.23%	32.72%	33.73%	24.68%	26.43%	24.69%	37.61%
HBO1	38.17%	9.31%	38.69%	39.86%	13.02%	28.33%	10.12%	22.50%
HBO2	32.41%	8.72%	35.66%	32.05%	17.06%	27.42%	14.87%	31.81%
HBO3	31.51%	10.08%	33.74%	31.98%	20.40%	27.24%	14.34%	30.70%
HBO4	31.49%	9.15%	30.86%	27.91%	22.04%	30.56%	15.61%	32.38%
HBO5	31.69%	9.72%	28.98%	27.47%	22.71%	31.08%	16.62%	31.73%
HBSc	89.92%	0.21%	4.11%	62.86%	2.79%	29.16%	3.19%	7.77%
NHBW	4.62%	29.34%	50.44%	58.38%	38.88%	5.89%	6.07%	6.39%
OBO	7.46%	9.08%	57.40%	55.57%	21.16%	22.55%	13.97%	12.80%

Time of Day (TOD) factors for regional and statewide trucks are shown in Table A18. These are derived from auto and truck vehicle counts for Maryland and the adjacent states where available, and TOD factors reported for the BMC commercial and truck model. SHA classification counts were analyzed to determine the extent to which TOD patterns vary by vehicle type.

Table A19

Regional and Statewide Truck Time of Day Factors

Assignment Period (P->A Only)	Com. Veh.	MHDT	HHDT	Regional Trucks	Regional Autos	EE autos
AM 6:30-9:30	16.982	16.982	16.982	12.5	Defined explicitly by the NELDT model	16.05%
Midday 9:30a-3:30p	42.845	42.845	42.845	25		37.07%
PM 3:30-6:30	15.426	15.426	15.426	12.5		25.19%
Night 6:30p-6:30a	24.747	24.747	24.747	50		21.69%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Highway Assignment (Autos and Trucks)

Bridge crossings are a particular challenge to calibrate. On the one hand, bridges are a bottlenecks for many trips, and on the other hand research in travel demand shows that rivers form a mental barrier. To the model, a bridge crossing simply represents a link on the network as any other road, and a trip across the river is as likely in the model as a trip on the same side of the river. In reality, however, bridge crossings tend to form a mental barrier. Many trips tend to have their origin and destination on the same side of the bridge, as a river forms a natural border that tends to limit travel across. This is particular true for the Potomac River, as for large parts this river also forms the border between Maryland and Virginia. To account for this psychological barrier, the destination choice model included a factor that impacted travel from one river zone to another. No further adjustment or factoring has been applied.

Figure A12 shows which bridges were analyzed. These bridges were chosen as count data were available and as they serve major traffic flows in the region.

Figure A12. Bridge Crossings Analyzed in MSTM

In Figure A13, green bars show the count data, and the colored bars show simulated volumes of different vehicle classes. The Woodrow Wilson Bridge has less traffic in the simulation than suggested by count data, while the American Legion Bridge has more traffic than observed. It is possible that too many trips are taking the western part of the beltway for driving around Washington, while some of them should be using the eastern part of the beltway. Given the high levels of congestion in the Washington DC area and an almost identical travel time when using the eastern or the western part of the beltway for many origin-destination pairs, this deviation appears to be acceptable.

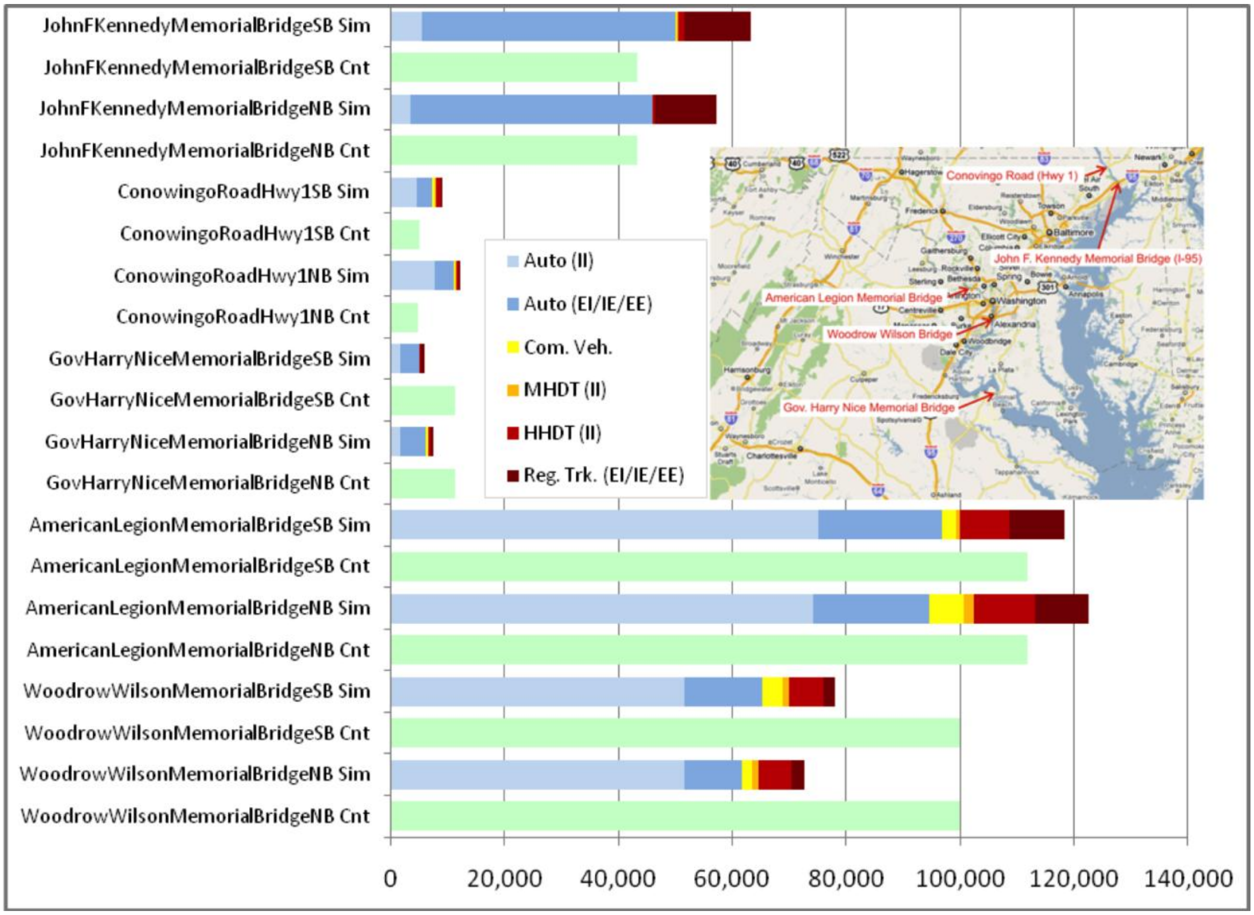


Figure A13. Validation of Traffic Volumes on Selected Bridge Crossings

Figure A14 compares the MSTM model results with results from other statewide models for which detailed validation data were available to the authors. Percent Root Mean Square Error (Percent RMSE) of different volume ranges was used as the validation criteria.

The plot shows the Maryland model results in blue. There are two models, Ohio and Oregon, for which a lot of count data were available, and therefore, a very detailed analysis was feasible. In general, these two models have performed better than the MSTM model, which is mainly due to two reasons. For one, these two models were developed over more than a decade, and thus had more iterations to evolve than MSTM, which was developed over the course of approximately two years. Secondly, the geographies of Ohio and Oregon are easier to model than

Maryland. Ohio and Oregon have a limited number of metropolitan areas, and density declines rapidly at the border of the study area. Much of Maryland, on the other hand, is covered by a huge Mega-Region that extends all the way from Boston, MA to Richmond, VA. Therefore, a statewide model for Maryland has to deal with a lot of through traffic, and there are a lot of local trips crossing the northern and southern border of the MSTM study area.

Task 91 in Figure A14 is a mix of several statewide models across the U.S. for which these validation data were available. Some of these models have performed better, while others performed worse. Overall, the validation of MSTM is within the range of many other statewide models.

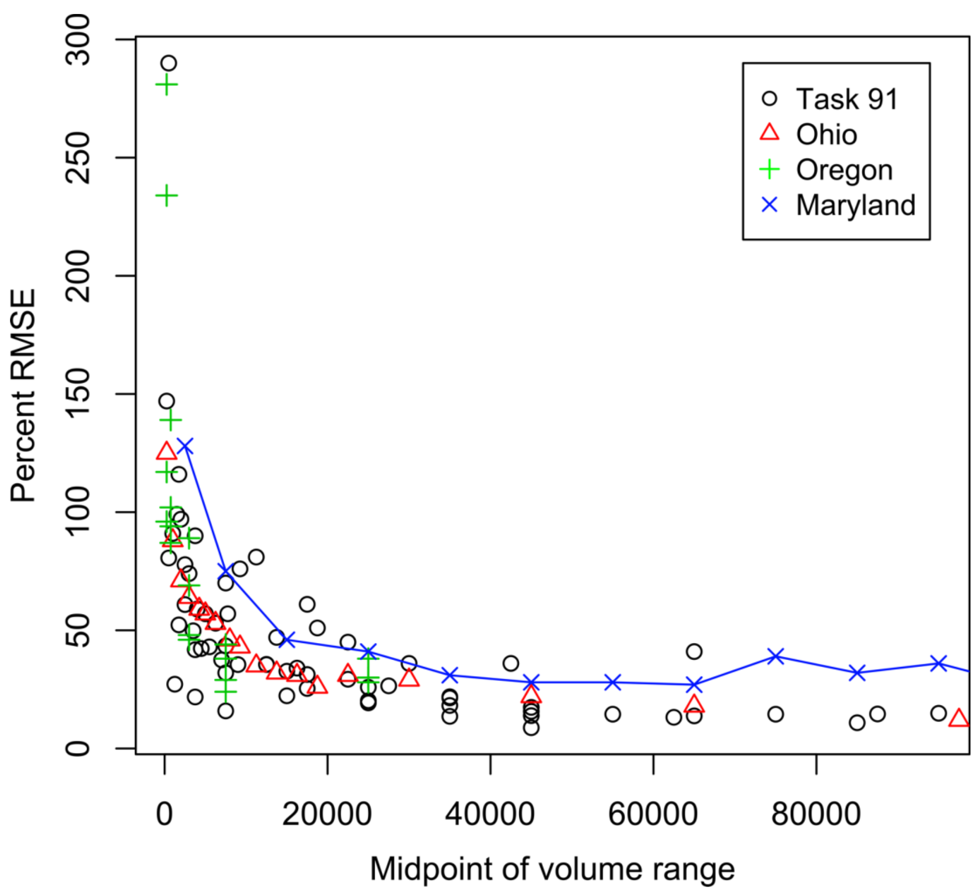


Figure 14. ***Comparison of MSTM with Other Statewide Models***

Miscellaneous Auto-related Forecasts

The following set of tables provides the forecasts and calculations for the auto operating costs used in each of the transportation scenarios.

Table A20

Auto operating cost calculation - BAU

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	Non-Gas Operating Cost	Total Auto Operating Cost - BAU
					Cost (¢/mi) in 2000 Constant Dollars		
2006	$2.62	0.8542	$2.24	24.45	$0.0914	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	$0.0280	$0.1386
2013	$3.63	0.7418	$2.69	25.55	$0.1053	$0.0277	$0.1331
2014	$3.78	0.7278	$2.75	26.10	$0.1054	$0.0272	$0.1326
2015	$3.93	0.7143	$2.81	26.79	$0.1049	$0.0267	$0.1316
2016	$4.09	0.7013	$2.87	27.61	$0.1039	$0.0262	$0.1301
2017	$4.24	0.6887	$2.92	28.59	$0.1022	$0.0258	$0.1280
2018	$4.40	0.6766	$2.97	29.75	$0.1000	$0.0253	$0.1253
2019	$4.55	0.6650	$3.03	31.10	$0.0973	$0.0249	$0.1222
2020	$4.70	0.6537	$3.07	32.66	$0.0941	$0.0244	$0.1186

Table A21

Auto operating cost calculation – Gas Tax ($0.50)

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	Non-Gas Operating Cost	Total Auto Operating Cost - Gas Tax ($0.50)
					Cost (¢/mi) in 2000 Constant Dollars		
2006	$2.62	0.8542	$2.24	24.45	$0.0914	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	$0.0280	$0.1386
2013	$4.13	0.7418	$3.06	25.55	$0.1199	$0.0277	$0.1476
2014	$4.28	0.7278	$3.12	26.10	$0.1194	$0.0272	$0.1466
2015	$4.43	0.7143	$3.17	26.79	$0.1183	$0.0267	$0.1450
2016	$4.59	0.7013	$3.22	27.61	$0.1166	$0.0262	$0.1428
2017	$4.74	0.6887	$3.27	28.59	$0.1142	$0.0258	$0.1400
2018	$4.90	0.6766	$3.31	29.75	$0.1114	$0.0253	$0.1367
2019	$5.05	0.6650	$3.36	31.10	$0.1080	$0.0249	$0.1329
2020	$5.20	0.6537	$3.40	32.66	$0.1042	$0.0244	$0.1286

Table A22

Auto operating cost calculation – Gas Tax ($2.00)

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	Non-Gas Operating Cost	Total Auto Operating Cost - Gas Tax ($2.00)
					Cost (¢/mi) in 2000 Constant Dollars		
2006	$2.62	0.8542	$2.24	24.45	$0.0914	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	$0.0280	$0.1386
2013	$5.63	0.7418	$4.17	25.55	$0.1634	$0.0277	$0.1911
2014	$5.78	0.7278	$4.21	26.10	$0.1612	$0.0272	$0.1884
2015	$5.93	0.7143	$4.24	26.79	$0.1583	$0.0267	$0.1850
2016	$6.09	0.7013	$4.27	27.61	$0.1547	$0.0262	$0.1809
2017	$6.24	0.6887	$4.30	28.59	$0.1504	$0.0258	$0.1761
2018	$6.40	0.6766	$4.33	29.75	$0.1455	$0.0253	$0.1708
2019	$6.55	0.6650	$4.36	31.10	$0.1401	$0.0249	$0.1649
2020	$6.70	0.6537	$4.38	32.66	$0.1342	$0.0244	$0.1586

Table A23

Auto operating cost calculation – VMT Tax ($.50)

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	VMT Tax	VMT Tax	Non-Gas Operating Cost	Total Auto Operating Cost - VMT Tax ($0.50)
					Cost (¢/mi) in 2000 Constant Dollars				
2006	$2.62	0.8542	$2.24	24.45	$0.0914	$0.0000	$0.0000	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	$0.0000	$0.0000	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	$0.0000	$0.0000	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	$0.0000	$0.0000	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	$0.0000	$0.0000	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	$0.0000	$0.0000	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	$0.0000	$0.0000	$0.0280	$0.1386
2013	$3.63	0.7418	$2.69	25.55	$0.1053	$0.0196	$0.0145	$0.0277	$0.1476
2014	$3.78	0.7278	$2.75	26.10	$0.1054	$0.0195	$0.0142	$0.0272	$0.1468
2015	$3.93	0.7143	$2.81	26.79	$0.1049	$0.0195	$0.0139	$0.0267	$0.1456
2016	$4.09	0.7013	$2.87	27.61	$0.1039	$0.0195	$0.0137	$0.0262	$0.1438
2017	$4.24	0.6887	$2.92	28.59	$0.1022	$0.0195	$0.0134	$0.0258	$0.1414
2018	$4.40	0.6766	$2.97	29.75	$0.1000	$0.0195	$0.0132	$0.0253	$0.1385
2019	$4.55	0.6650	$3.03	31.10	$0.0973	$0.0195	$0.0130	$0.0249	$0.1351
2020	$4.70	0.6537	$3.07	32.66	$0.0941	$0.0195	$0.0127	$0.0244	$0.1313

Table A24

Auto operating cost calculation – VMT Tax ($2.00)

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	VMT Tax	VMT Tax	Non-Gas Operating Cost	Total Auto Operating Cost - VMT Tax ($2.00)
					Cost (¢/mi) in 2000 Constant Dollars				
2006	$2.62	0.8542	$2.24	24.45	$0.0914	$0.0000	$0.0000	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	$0.0000	$0.0000	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	$0.0000	$0.0000	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	$0.0000	$0.0000	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	$0.0000	$0.0000	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	$0.0000	$0.0000	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	$0.0000	$0.0000	$0.0280	$0.1386
2013	$3.63	0.7418	$2.69	25.55	$0.1053	$0.0783	$0.0581	$0.0277	$0.1911
2014	$3.78	0.7278	$2.75	26.10	$0.1054	$0.0783	$0.0570	$0.0272	$0.1896
2015	$3.93	0.7143	$2.81	26.79	$0.1049	$0.0783	$0.0559	$0.0267	$0.1876
2016	$4.09	0.7013	$2.87	27.61	$0.1039	$0.0783	$0.0549	$0.0262	$0.1850
2017	$4.24	0.6887	$2.92	28.59	$0.1022	$0.0783	$0.0539	$0.0258	$0.1819
2018	$4.40	0.6766	$2.97	29.75	$0.1000	$0.0783	$0.0530	$0.0253	$0.1783
2019	$4.55	0.6650	$3.03	31.10	$0.0973	$0.0783	$0.0521	$0.0249	$0.1742
2020	$4.70	0.6537	$3.07	32.66	$0.0941	$0.0783	$0.0512	$0.0244	$0.1698

Table A25

Auto operating cost calculation – Emissions Tax ($25)

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	CO2/Mile	CO2 Tax	CO2 Tax	Non-Gas Operating Cost	Total Auto Operating Cost - CO2 Tax ($25/ton)
						Cost (¢/mi) in 2000 Constant Dollars				
2006	$2.62	0.8542	$2.24	24.45	$0.0914	371.8830	$0.0000	$0.0000	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	371.8362	$0.0000	$0.0000	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	366.8029	$0.0000	$0.0000	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	379.4670	$0.0000	$0.0000	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	377.6993	$0.0000	$0.0000	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	367.4163	$0.0000	$0.0000	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	362.3008	$0.0000	$0.0000	$0.0280	$0.1386
2013	$3.63	0.7418	$2.69	25.55	$0.1053	355.9758	$0.0089	$0.0066	$0.0277	$0.1397
2014	$3.78	0.7278	$2.75	26.10	$0.1054	348.3836	$0.0087	$0.0063	$0.0272	$0.1390
2015	$3.93	0.7143	$2.81	26.79	$0.1049	339.5080	$0.0085	$0.0061	$0.0267	$0.1377
2016	$4.09	0.7013	$2.87	27.61	$0.1039	329.3787	$0.0082	$0.0058	$0.0262	$0.1359
2017	$4.24	0.6887	$2.92	28.59	$0.1022	318.0722	$0.0080	$0.0055	$0.0258	$0.1334
2018	$4.40	0.6766	$2.97	29.75	$0.1000	305.7092	$0.0076	$0.0052	$0.0253	$0.1305
2019	$4.55	0.6650	$3.03	31.10	$0.0973	292.4485	$0.0073	$0.0049	$0.0249	$0.1270
2020	$4.70	0.6537	$3.07	32.66	$0.0941	278.4782	$0.0070	$0.0046	$0.0244	$0.1231

Table A26

Auto operating cost calculation – Emissions Tax ($50)

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	CO2/Mile	CO2 Tax	CO2 Tax	Non-Gas Operating Cost	Total Auto Operating Cost - CO2 Tax ($50/ton)
							Cost (¢/mi) in 2000 Constant Dollars			
2006	$2.62	0.8542	$2.24	24.45	$0.0914	371.8830	$0.0000	$0.0000	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	371.8362	$0.0000	$0.0000	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	366.8029	$0.0000	$0.0000	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	379.4670	$0.0000	$0.0000	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	377.6993	$0.0000	$0.0000	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	367.4163	$0.0000	$0.0000	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	362.3008	$0.0000	$0.0000	$0.0280	$0.1386
2013	$3.63	0.7418	$2.69	25.55	$0.1053	355.9758	$0.0178	$0.0132	$0.0277	$0.1463
2014	$3.78	0.7278	$2.75	26.10	$0.1054	348.3836	$0.0174	$0.0127	$0.0272	$0.1453
2015	$3.93	0.7143	$2.81	26.79	$0.1049	339.5080	$0.0170	$0.0121	$0.0267	$0.1438
2016	$4.09	0.7013	$2.87	27.61	$0.1039	329.3787	$0.0165	$0.0115	$0.0262	$0.1416
2017	$4.24	0.6887	$2.92	28.59	$0.1022	318.0722	$0.0159	$0.0110	$0.0258	$0.1389
2018	$4.40	0.6766	$2.97	29.75	$0.1000	305.7092	$0.0153	$0.0103	$0.0253	$0.1356
2019	$4.55	0.6650	$3.03	31.10	$0.0973	292.4485	$0.0146	$0.0097	$0.0249	$0.1319
2020	$4.70	0.6537	$3.07	32.66	$0.0941	278.4782	$0.0139	$0.0091	$0.0244	$0.1277

Table A27

Auto operating cost calculation – Emissions Tax ($75)

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	CO2/Mile	CO2 Tax	CO2 Tax	Non-Gas Operating Cost	Total Auto Operating Cost - CO2 Tax ($75/ton)
							Cost (¢/mi) in 2000 Constant Dollars			
2006	$2.62	0.8542	$2.24	24.45	$0.0914	371.8830	$0.0000	$0.0000	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	371.8362	$0.0000	$0.0000	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	366.8029	$0.0000	$0.0000	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	379.4670	$0.0000	$0.0000	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	377.6993	$0.0000	$0.0000	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	367.4163	$0.0000	$0.0000	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	362.3008	$0.0000	$0.0000	$0.0280	$0.1386
2013	$3.63	0.7418	$2.69	25.55	$0.1053	355.9758	$0.0890	$0.0660	$0.0277	$0.1991
2014	$3.78	0.7278	$2.75	26.10	$0.1054	348.3836	$0.0871	$0.0634	$0.0272	$0.1960
2015	$3.93	0.7143	$2.81	26.79	$0.1049	339.5080	$0.0849	$0.0606	$0.0267	$0.1923
2016	$4.09	0.7013	$2.87	27.61	$0.1039	329.3787	$0.0823	$0.0577	$0.0262	$0.1878
2017	$4.24	0.6887	$2.92	28.59	$0.1022	318.0722	$0.0795	$0.0548	$0.0258	$0.1827
2018	$4.40	0.6766	$2.97	29.75	$0.1000	305.7092	$0.0764	$0.0517	$0.0253	$0.1770
2019	$4.55	0.6650	$3.03	31.10	$0.0973	292.4485	$0.0731	$0.0486	$0.0249	$0.1708
2020	$4.70	0.6537	$3.07	32.66	$0.0941	278.4782	$0.0696	$0.0455	$0.0244	$0.1641

Table A28

Auto operating cost calculation – CAFE

Year	Retail Gas Price (Current $)	CPI	Gas Price (2000 $)	Fuel Economy (MPG)	Gasoline Operating Cost	Non-Gas Operating Cost	Total Auto Operating Cost - CAFE
					Cost (¢/mi) in 2000 Constant Dollars		
2006	$2.62	0.8542	$2.24	24.45	$0.0914	$0.0374	$0.1288
2007	$2.79	0.8305	$2.32	24.46	$0.0947	$0.0311	$0.1258
2008	$3.27	0.7998	$2.62	24.79	$0.1055	$0.0299	$0.1354
2009	$2.37	0.8027	$1.90	23.96	$0.0792	$0.0300	$0.1092
2010	$2.79	0.7897	$2.20	24.08	$0.0915	$0.0295	$0.1210
2011	$3.56	0.7655	$2.72	24.75	$0.1100	$0.0286	$0.1386
2012	$3.70	0.7497	$2.77	25.10	$0.1105	$0.0280	$0.1386
2013	$4.13	0.7418	$3.06	30.80	$0.0994	$0.0277	$0.1271
2014	$4.28	0.7278	$3.12	31.90	$0.0977	$0.0272	$0.1249
2015	$4.43	0.7143	$3.17	33.00	$0.0960	$0.0267	$0.1227
2016	$4.59	0.7013	$3.22	34.10	$0.0944	$0.0262	$0.1206
2017	$4.74	0.6887	$3.27	35.20	$0.0928	$0.0258	$0.1185
2018	$4.90	0.6766	$3.31	36.30	$0.0913	$0.0253	$0.1166
2019	$5.05	0.6650	$3.36	37.50	$0.0895	$0.0249	$0.1144
2020	$5.20	0.6537	$3.40	39.50	$0.0861	$0.0244	$0.1106

References

Akbari, H. (2002). "Shade Trees Reduce Building Energy Use and CO< Sub> 2</sub> Emissions from Power Plants." *Environmental Pollution, 116,* S119–S126.

———. (2005). "Energy Saving Potentials and Air Quality Benefits of Urban Heat IslandMitigation." Retrieved from http://escholarship.org/uc/item/4qs5f42s.pdf

Akbari, H., Pomerantz, M., & Taha, H. 2001. "Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas." *Solar Energy, 70(3),* 295–310.

Alcamo, J., & Swart, R. (1998). "Future Trends of Land-use Emissions of Major Greenhouse Gases." *Mitigation and Adaptation Strategies for Global Change, 3 (2),* 343–381.

Anderegg, W. R. L., Prall J. W., Harold, J., & Schneider, S. H. (2010). "Expert Credibility in Climate Change." *Proceedings of the National Academy of Sciences* (June 21). doi:10.1073/pnas.1003187107. Retrieved from http://www.pnas.org/content/early/2010/06/04/1003187107

Bamber, J. L., & Aspinall, W. P. (2013). "An Expert Judgement Assessment of Future Sea Level Rise from the Ice Sheets." *Nature Climate Change*. doi:10.1038/nclimate1778. Retrieved from http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate1778.html?WT.mc_id=FBK_NatureClima

Barkenbus, J. N. (2010). "Eco-driving: An Overlooked Climate Change Initiative." *Energy Policy 38(2),* 762–769. doi:10.1016/j.enpol.2009.10.021.

Barringer, F., & Galbraith, K. (2008). "States Aim to Cut Gases by Making Polluters Pay." *New York Times*. Retrieved from http://www.e2.org/ext/doc/20080916NYT-StatesToMakePollutersPay.pdf

Barth, M., & Boriboonsomsin, K. (2010). "Traffic Congestion and Greenhouse Gases." *TR News* 268. Retrieved from http://www.uctc.net/access/35/access35_Traffic_Congestion_and_Grenhouse_Gases.pdf

Beevers, S. D., & Carslaw, D. C. (2005). "The Impact of Congestion Charging on Vehicle Emissions in London." *Atmospheric Environment, 39(1),* 1–5.

Berry, L. (1997). "State-level Evaluations of the Weatherization Assistance Program in 1990-1996: A Metaevaluation That Estimates National Savings". Oak Ridge National Lab., TN (United States). Retrieved from http://www.osti.gov/bridge/product.biblio.jsp?osti_id=560715

Berry, L, & Schweitzer, M. (2003). “Metaevaluation of National Weatherization Assistance Program Based on State Studies.” *ORNL/CON-488 Oak Ridge National Laboratory, Oak Ridge, Tennessee*. Retrieved from http://weatherization.ornl.gov/pdfs/ORNL_CON-488.pdf

Bolbach, C.J. (1974). “Land Use Controls Under the Clean Air Act.” *Seton Hall L. Rev. 6*, 413.

Booij, M. J. (2005). “Impact of Climate Change on River Flooding Assessed with Different Spatial Model Resolutions.” *Journal of Hydrology, 303(1),* 176–198.

BP. (2012). “BP Statistical Review of World Energy.” Retrieved from http://www.bp.com/sectiongenericarticle800.do?categoryId=9037130&contentId=7068669

Bretz, S., Akbari, H., & Rosenfeld, A. (1998). “Practical Issues for Using Solar-reflective Materials to Mitigate Urban Heat Islands.” *Atmospheric Environment, 32(1),* 95–101.

“Bridgereport-md.pdf.” (2013). Accessed February 5. Retrieved from http://t4america.org/docs/bridgereport/states/bridgereport-md.pdf

Brown, M. A. (1993). *National Impacts of the Weatherization Assistance Program in Single-Family and Small Multifamily Dwellings*. Oak Ridge National Laboratory.

Brownstone, D., & Golob, T. F. (2009). “The Impact of Residential Density on Vehicle Usage and Energy Consumption.” *Journal of Urban Economics, 65(1),* 91–98. doi:10.1016/j.jue.2008.09.002.

Burkett, V., & Kusler, J. (2007). “CLIMATE CHANGE: POTENTIAL IMPACTS AND INTERACTIONS IN WETLANDS OF THE UNTTED STATES1.” *JAWRA Journal of the American Water Resources Association, 36(2),* 313–320.

Button, K. J, & Verhoef, E. T. (1998). *Road Pricing, Traffic Congestion and the Environment: Issues of Efficiency and Social Feasibility*. Edward Elgar Publishing. Cheltenham, England.

Button, K. (2010). *Transport Economics*. Edward Elgar Publishing. Heinemann, London.

California Environmental Protection Agency. (2012). “California Air Resources Board Quarterly Auction 1.” Retrieved from http://www.arb.ca.gov/cc/capandtrade/auction/november_2012/auction1_results_2012q4nov.pdf

California Global Warming Solutions Act. (2006). *Assembly Bill No. 32*.

Cambridge Systematics. (2009). *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions*. Urban Land Institute. Washington, D.C.

Cameron, D., Beven, K., & Naden, P. (2000). "Flood Frequency Estimation by Continuous Simulation Under Climate Change (with Uncertainty)." *Hydrology and Earth System Sciences Discussions, 4(3),* 393–405.

Cameron, I., Lyons, T. J., & Kenworthy, J. R. (2004). "Trends in Vehicle Kilometres of Travel in World Cities, 1960–1990: Underlying Drivers and Policy Responses." *Transport Policy, 11(3),* 287–298. doi:10.1016/j.tranpol.2004.01.002.

Cameron, M. (1991). "Transportation Efficiency: Tackling Southern California's Air Pollution and Congestion." Environmental Defense Fund. Oakland, California.

"Canada, the Surprise 'Pariah' of the Kyoto Protocol." (2012). *The Guardian*. November 26. Retrieved from http://www.guardian.co.uk/world/2012/nov/26/canada-kyoto

"Center for Climate Strategies." (2013). Accessed February 14. Retrieved from http://www.climatestrategies.us/

Citizens Climate Lobby and Our Children's Earth Foundation V. California Air Resources Board. (2012). San Francisco Sup. Ct.

"Climate Change: Public Skeptical, Scientists Sure : NPR." (2013). *NPR.org*. Accessed February 20. Retrieved from http://www.npr.org/2011/06/21/137309964/climate-change-public-skeptical-scientists-sure

Colburn, K. (2009). "Climate Action Planningin the States: Structured Stakeholder Processes Show Atimulating Results." *EM,* Air & Waste Management Association edition. Retrieved from http://pubs.awma.org/gsearch/em/2009/4/colburn.pdf

Colman, R. A., Power, S. B., & McAvaney, B. J. (1997). "Non-linear Climate Feedback Analysis in an Atmospheric General Circulation Model." *Climate Dynamics, 13(10),* 717–731. doi:10.1007/s003820050193.

D'amato, G., Cecchi, L., D'amato, M., & Liccardi, G. (2010). "Urban Air Pollution and Climate Change as Environmental Risk Factors of Respiratory Allergy: An Update." *Journal of Investigational Allergology and Clinical Immunology, 20(2),* 95–102.

Daniel, J.I., & Bekka, K. (2000). "The Environmental Impact of Highway Congestion Pricing." *Journal of Urban Economics, 47(2),* 180–215.

DARA. (2012). "Climate Vulnerability Monitor, A Guide to the Cold Calculus for a Hot Planet."

Dargay, J., & Gately, D. (1999). "Income's Effect on Car and Vehicle Ownership, Worldwide: 1960–2015." *Transportation Research Part A: Policy and Practice, 33(2),* 101–138. doi:10.1016/S0965-8564(98)00026-3.

Dawkins, C., Sartori, J., & Knaap, G-J. (2012). "Barriers to Development Inside Maryland's PFAs: Perspectives of Planners, Developers, and Advocates". HOUSING STRATEGIES GROUP AT THE NATIONAL CENTER FOR SMART GROWTH RESEARCH AND EDUCATION. Retrieved from http://smartgrowth.umd.edu/assets/documents/research/dawkinssartoriknaap_pfabarriers_2012.pdf

Delucchi, M. A. (1996). "Total Cost of Motor-vehicle Use." *Access, 8,* 7–13.

Delucchi, M. A. (1998). "SUMMARY OF THE NONMONETARY EXTERNALITIES OF MOTOR-VEHICLE USE." Retrieved from http://trid.trb.org/view.aspx?id=579438

Deng, L., & Cai, C. (2010). "Bridge Scour: Prediction, Modeling, Monitoring, and Countermeasures—Review." *Practice Periodical on Structural Design and Construction, 15(2),* 125–134. doi:10.1061/(ASCE)SC.1943-5576.0000041.

"Design for the WCI Regional Program." (2013). Accessed February 20. http://www.westernclimateinitiative.org/the-wci-cap-and-trade-program/program-design

DiMento, J. F. C., & Doughman, P. M. (2007). *Climate Change: What It Means for Us, Our Children, and Our Grandchildren*. Boston, MA: MIT Press.

Downs, A. (2004). *Still Stuck in Traffic: Coping with Peak-hour Traffic Congestion*. Brookings Inst Press. Washington, D.C.

Drapalski, H. J. (2010). "Viability of Interstate Collaboration in the Absence of Federal Climate Change Legislation, The." *Duke Environmental Law & Policy Forum, 21,* 469.

Drummond, W. J. (2010). Statehouse Versus Greenhouse. Journal of the American Planning Association, 76(4), 413–433. doi:10.1080/01944363.2010.499537

"DSIRE." (2013). *DSIRE USA*. Accessed February 19. http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=MD05R.

Dupuit, J. (1844). "On the Measurement of the Utility of Public Works." *International Economic Papers, 2(1952),* 83–110.

EIA. (2012). “IEA - May:- Global Carbon-dioxide Emissions Increase by 1.0 Gt in 2011 to Record High.” Retrieved from http://www.iea.org/newsroomandevents/news/2012/may/name,27216,en.html

EIA, U.S. Energy Information Administration. (2010). “Annual Energy Review.” Government Printing Office. Washington, D.C.

Eisenberg, J. F. (2010). “Weatherization Assistance Program Technical Memorandum Background Data and Statistics.” *ORNL/TM-2010/66, Oak Ridge National Laboratory, Oak Ridge, TN*. Retrieved from http://psb.vermont.gov/sites/psb/files/orders/2012/2012-3/Illuzzi.Exhibit2.pdf

Emanuel, K. (2005). “Increasing Destructiveness of Tropical Cyclones over the Past 30 Years.” *Nature, 436(7051),* 686–688.

Ewing, R., & Cervero, R. (2010). “Travel and the Built Environment.” *Journal of the American Planning Association, 76(3),* 265–294.

Feddema, J. J., Oleson, K. W., Bonan, G. B., Mearns, L. O., Buja, L. E., Meehl, G. A., & Washington, W. M. (2005). “The Importance of Land-Cover Change in Simulating Future Climates.” *Science, 310(5754),* 1674–1678. doi:10.1126/science.1118160.

Flegenheimer, M. (2012). “Subways May Be Shut for Several Days After Hurricane Sandy.” *The New York Times*, October 30, sec. N.Y. / Region. Retrieved from http://www.nytimes.com/2012/10/31/nyregion/subways-may-be-shut-for-several-days-after-hurricane-sandy.html

Gaffin, S. R., & O’Neill, B. C. (1997). “Population and Global Warming with and Without CO_2 Targets.” *Population & Environment, 18(4),* 389–413.

Gallivan, F., Ang-Olson, J., & Turchetta, D. (2011). Toward a Better State Climate Action Plan. Transportation Research Record: Journal of the Transportation Research Board, 2244(1), 1–8.

Gillis, J. (2013). “Seeking Clues About Sea Level From Fossil Beaches.” *The New York Times*, January 21, sec. Science / Environment. Retrieved from http://www.nytimes.com/2013/01/22/science/earth/seeking-clues-about-sea-level-from-fossil-beaches.html

Green, K. (1995). *Defending Automobility: a Critical Examination of the Environmental and Social Costs of Auto Use*. Reason Foundation. Washington, D.C.

Greene, D. L. (2011). "What Is Greener Than a VMT Tax? The Case for an Indexed Energy User Fee to Finance Us Surface Transportation." *Transportation Research Part D: Transport and Environment, 16(6), 451-458.*

Greening, L. A., Greene, D. L., & Difiglio, C. (2000). "Energy Efficiency and Consumption — the Rebound Effect — a Survey." *Energy Policy, 28(6–7),* 389–401. doi:10.1016/S0301-4215(00)00021-5.

Greenwire, A. C. M. (2011). "Offsets Could Make Up 85% of Calif.'s Cap-And-Trade Program." *The New York Times*, August 8, sec. Business Day / Energy & Environment. Retrieved from http://www.nytimes.com/gwire/2011/08/08/08greenwire-offsets-could-make-up-85-of-califs-cap-and-tra-29081.html

Grubb, M., Vrolijk, C., Brack, D., & Forsyth, T. (1999). *The Kyoto Protocol: a Guide and Assessment*. Royal Institute of International Affairs London. Retrieved from http://www.lavoisier.fr/livre/notice.asp?id=RSAW2SA2ASROWQ.

Gürer, N., & Ban, J. (1997). "Factors Affecting Energy-related CO2 Emissions: Past Levels and Present Trends." *OPEC Review, 21(4),* 309–350.

Gurney, K. R., Mendoza, D. L., Zhou, Y., Fischer, M. L., Miller, C. C., Geethakumar, S., & de la Rue du Can, S. (2009). "High Resolution Fossil Fuel Combustion CO2 Emission Fluxes for the United States." *Environmental Science & Technology, 43(14),* 5535–5541. doi:10.1021/es900806c.

Gustavsson, L., Börjesson, P., Johansson, B., & Svenningsson, P. (1995). "Reducing CO2 Emissions by Substituting Biomass for Fossil Fuels." *Energy, 20(11),* 1097–1113. doi:10.1016/0360-5442(95)00065-O.

Hall, J. V. (1995). "The Role of Transport Control Measures in Jointly Reducing Congestion and Air Pollution." *Journal of Transport Economics and Policy, 36(1),* 93–103.

Hamilton, B. W., & Röell, A.. (1982). "Wasteful Commuting." *The Journal of Political Economy, 97,* 1035–1053.

Hansen, J. (2008). "Global Warming Twenty Years Later: Tipping Points Near." *Briefing to the House Select Committee on Energy Independence and Global Warming*. Retrieved from http://consin.org/view/CHansencongress.pdf

Hansen, J. E. (1988). "Testimony Before US Senate Committee on Energy and Natural Resources." *June 23.*

Hansen, J., Sato, M., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., ... & Zachos, J. C. (2008). "Target Atmospheric CO2: Where Should Humanity Aim?" *arXiv Preprint arXiv:0804.1126*. Retrieved from http://arxiv.org/abs/0804.1126

Hansen, J. Q., Winther, M., & Sorenson, S. C. (1995). "The Influence of Driving Patterns on Petrol Passenger Car Emissions." *Science of The Total Environment*, *169(1–3),* 129–139. doi:10.1016/0048-9697(95)04641-D.

Harris, P. G. (1999). "Common But Differentiated Responsibility: The Kyoto Protocol and United States Policy." *New York University Environmental Law Journal*, *7,* 27.

"Hb 1490." (2013). Accessed February 19. http://www.gencourt.state.nh.us/legislation/2012/HB1490.html

Heres-Del-Valle, D., & Niemeier, D. (2011). "CO2 Emissions: Are Land-use Changes Enough for California to Reduce VMT? Specification of a Two-part Model with Instrumental Variables." *Transportation Research Part B: Methodological*, *45(1),* 150–161. doi:10.1016/j.trb.2010.04.001.

Horner, M. W. (2002). "Extensions to the Concept of Excess Commuting." *Environment and Planning A, 34(3),* 543–566.

"Inforum." (2013). Accessed February 20. http://www.inforum.umd.edu/

IPCC. (1990). "Summary for Policy Makers, in Scientific Assessment of Climate Change: Report of Working Group I". Geneva: IPCC, Secretariat.

———. (2010). "Understanding Climate Change: 22 Years of IPCC Assessment." Retrieved from http://www.ipcc.ch/pdf/press/ipcc_leaflets_2010/ipcc-brochure_understanding.pdf

Jacob, D. J., & Winner, D. A. (2009). "Effect of Climate Change on Air Quality." *Atmospheric Environment*, *43(1),* 51–63. doi:10.1016/j.atmosenv.2008.09.051.

Kahn, M. E. (1996). "New Evidence on Trends in Vehicle Emissions." *The RAND Journal of Economics, 27(1),* 183–196. doi:10.2307/2555798.

Kinsella, Y., & McGuire, F. (2005). "Climate Change Uncertainty and the State Highway Network: A Moving Target." *Transit New Zealand*. Retrieved from http://sh20mountroskill.co.nz/content_files/news/ConferencePaper36_PDFFile.pdf

Knight, F. H. (1924). "Some Fallacies in the Interpretation of Social Cost." *The Quarterly Journal of Economics*, *38(4),* 582.

Knutson, T. R., & Tuleya, R. E. (2004). "Impact of CO2-induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Parameterization." *Journal of Climate*, *17(18),* 3477–3495.

Leiserowitz, A., Maibach, E., Roser-Renouf, C., & Smith, N. (2011). "Climate Change in the American Mind: Americans' Global Warming Beliefs and Attitudes in May 2011." *Yale Project on Climate Change Communication*. *May 2011*.

Levinson, D., & Kanchi, S. (2002). "Road Capacity and the Allocation of Time." *Journal of Transportation and Statistics, 5(1),* 25–46.

Litman, T. 1995. "Evaluating Transportation Land Use Impacts." *World Transport Policy & Practice*, *1(4),* 9–16.

Lopez, R. (2012). "California's First Carbon-credit Auction Raises $290 Million." *Los Angeles Times*, November 20. Retrieved from http://articles.latimes.com/2012/nov/20/business/la-fi-pollution-credits-20121120

Loudon, W. R., & Dagang, D. A. (1992). "Predicting the Impact of Transportation Control Measures on Travel Behavior and Pollutant Emissions." In *JHK and Associates*, *Paper Presented to the 1992 Meeting of the Transportation Research Board*.

Luber, G., & McGeehin, M.. (2008). "Climate Change and Extreme Heat Events." *American Journal of Preventive Medicine*, *35(5),* 429–435.

Lutsey, N., & Sperling, D. (2008). "America's Bottom-up Climate Change Mitigation Policy." *Energy Policy, 36(2)*, 673–685. doi:10.1016/j.enpol.2007.10.018.

Lynas, M. (2008). *Six Degrees: Our Future on a Hotter Planet*. Harpercollins Pub Limited. London, England.

Lyon, T. P., & Yin, H. (2007). "Why Do States Adopt Renewable Portfolio Standards? An Empirical Investigation". SSRN Scholarly Paper ID 1025513. Rochester, NY: Social Science Research Network. Retrieved from http://papers.ssrn.com/abstract=1025513

Marsden, G. (2006). "The Evidence Base for Parking Policies—a Review." *Transport Policy*, *13(6),* 447–457.

McFadden, D. (1974). "The Measurement of Urban Travel Demand." *Journal of Public Economics*, *3(4)*, 303–328.

McKibben, B. (2007). "Remember This: 350 Parts Per Million." *Washington Post* 28. Retrieved from http://www.natcapsolutions.org/Presidio/Articles/Climate/RememberThis_MCKIBBEN_25xii07.pdf

McKinsey, R. U. S. (2008). *Greenhouse Gas Emissions: How Much at What Cost*.

MDOT. (2011). “2011 Draft GGRA Plan Appendices.” Retrieved from http://www.mde.state.md.us/programs/Air/ClimateChange/Pages/2011draftGGRAPlanAppendices.aspx

Meadows, D. H., Randers, J., & Meadows, D. (2004). *Limits to Growth: Limits to Growth*. Chelsea Green. Retrieved from http://books.google.com/books?hl=en&lr=&id=QRyQiINGW6oC&oi=fnd&pg=PR9&dq=limits+to+growth&ots=Go9P8K65l1&sig=VzTQLkhTAhOr5-ADXlwKOAfLOiw

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., Frame, D. J., & Allen, M. R. (2009). “Greenhouse-gas Emission Targets for Limiting Global Warming to 2 °C.” *Nature, 458(7242),* 1158–1162. doi:10.1038/nature08017.

Melville, B. W., & Coleman, S. E. (2000). *Bridge Scour*. Water Resources Publication. Retrieved from http://books.google.com/books?hl=en&lr=&id=SoIA3P1zLAEC&oi=fnd&pg=PR11&dq=bridge+scour&ots=SJp6PtX_sD&sig=eo8cxRdRXyukpwaa47Qu5PmjI_U.

Mickley, L. J., Jacob, D. J., Field, B. D., & Rind, D. (2004). “Effects of Future Climate Change on Regional Air Pollution Episodes in the United States.” *Geophysical Research Letters, 31 (24):* n/a–n/a. doi:10.1029/2004GL021216. L24103.

Milly, P. C. D., Wetherald, R. T., Dunne, K. A., & Delworth, T. L. (2002). “Increasing Risk of Great Floods in a Changing Climate.” *Nature, 415(6871),* 514–517.

Mindali, O., Raveh, A., & Salomon, I. (2004). “Urban Density and Energy Consumption: a New Look at Old Statistics.” *Transportation Research Part A: Policy and Practice, 38(2),* 143–162. doi:10.1016/j.tra.2003.10.004.

Molnar, P. (2001). “Climate Change, Flooding in Arid Environments, and Erosion Rates.” *Geology, 29(12),* 1071–1074.

Moore, A. T., Staley, S. R., & Poole Jr, R. W. (2010). “The Role of VMT Reduction in Meeting Climate Change Policy Goals.” *Transportation Research Part A: Policy and Practice, 44(8),* 565–574. doi:10.1016/j.tra.2010.03.012.

Moore, F. R., Gauthreaux Jr, S. A., Kerlinger, P., &Simons, T. R. (1995). “Habitat Requirements During Migration: Important Link in Conservation.” *Ecology and Management of Neotropical Migratory Birds,* 121–144.

Nakićenović, N., Grübler, A., Inaba, A., Messner, S., Nilsson, S., Nishimura, Y., Rogner, H-H, Schäfer, A., Schrattenholzer, L., & Strubegger, M. 1993. “Long-term Strategies for Mitigating Global Warming.” *Energy,18(5),* 401.

Nelson, R. (2011). “Energy Smoke and Mirrors in Maryland: Problems of Existing Policies and the Need to Rethink Maryland’s Electric Power Future.” Report of the Environmental Policy Workshop.

Newman, P. G., & Kenworthy, J. R. (1989). *Cities and Automobile Dependence: An International Sourcebook*. Retrieved from http://trid.trb.org/view.aspx?id=351194

Nordhaus, W. D., & Boyer, J. (2003). *Warming the World: Economic Models of Global Warming*. Boston:MA, MIT Press.

NYSDOT Task Assignment, C. 2012. “Mileage-Based User Fees: Prospects and Challenges.”http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.258.8533&rep=rep1&type=pdf.

O’Neill, B. C., & Oppenheimer, M. (2002). “Dangerous Climate Impacts and the Kyoto Protocol.” *Science 296(5575)*, 1971–1972.

O’Neill, B. C., MacKellar, F. L., & Lutz, W. (2005). *Population and Climate Change*. Cambridge University Press. http://books.google.com/books?hl=en&lr=&id=jYZr59nCMuMC&oi=fnd&pg=PP1&dq=+Population+and+Climate+Change.&ots=RaVdbFNkS0&sig=dZd1t-W254cf7kXY0LwPjkQkDMs

Oberthür, S., & Ott, H. E. (1999). *The Kyoto Protocol: International Climate Policy for the 21st Century*. Springer. Retrieved from http://books.google.com/books?hl=en&lr=&id=-qp7Wt9GvccC&oi=fnd&pg=PA1&dq=kyoto+protocol&ots=ZFIFns6JPL&sig=eGS5faFoMJz_NYLODQR5y3Hsd2o

Ogawa, Y. (1991). “Economic Activity and the Greenhouse Effect.” *The Energy Journal*, 23–35.

Olivier, J. G. J., Janssens-Maenhout, G., & Peters, J. A. H. W. (2012). “Trends in Global CO2 Emissions: 2012 Report.” *Wyd.: Wspólne Centrum Badawcze Komisji Europejskiej (JRC), Environmental Assessment Agency (www. Pbl. Nl/en/)*.

Oppenheimer, M., & Petsonk, A. (2005). “Article 2 of the UNFCCC: Historical Origins, Recent Interpretations.” *Climatic Change, 73(3)*, 195–226. doi:10.1007/s10584-005-0434-8.

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., Gnanadesikan, A. (2005). “Anthropogenic Ocean Acidification over the Twenty-first Century and Its Impact on Calcifying Organisms.” *Nature, 437(7059)*, 681–686. doi:10.1038/nature04095.

Pacala, S., & Socolow, R. (2004). "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science, 305(5686),* 968–972.

Pachauri, R. K., & Reisinger, A. (2007). "IPCC Fourth Assessment Report." *IPCC Fourth Assessment Report*. Retrieved from http://www.construible.es/construible%5Cbiblioteca%5Cpresentacion_informe_ipcc.pdf

Pardo, N., & Thiel, C. (2012). "Evaluation of Several Measures to Improve the Energy Efficiency and CO2 Emission in the European Single-family Houses." *Energy and Buildings, 49(June),* 619–630. doi:10.1016/j.enbuild.2012.03.006.

Parikh, J., & Gokarn, S. (1991). "Consumption Patterns: The Driving Force of Environmental Stress". Indira Gandhi Institute of Development Research-. Retrieved from http://econpapers.repec.org/RePEc:fth:indgan:59

Parry, I. W. H., Walls, M., & Harrington, W. (2007). "Automobile Externalities and Policies." *SSRN eLibrary* (January 1). Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=927794

PCGCC. (2011). "Climate Change 101: Understanding and Responding to Global Climate Change." Pew Center on Global Climate Change.

Pebley, A. R. (1998). "Demography and the Environment." *Demography, 35(4),* 377–389.

Pigou, A. C. (1920). *The Economics of Welfare*. Transaction Publishers. London, England.

Pinsky, P. (2009). *Greenhouse Gas Emissions Reduction Act of 2009*. *Annotated Code of Maryland*. Retrieved from http://mlis.state.md.us/2009rs/billfile/sb0278.htm

"PJM - About PJM." (2013). Accessed February 15. http://www.pjm.com/about-pjm.aspx

Pollak, M., Meyer, B., & Wilson, E. (2011). "Reducing Greenhouse Gas Emissions: Lessons from State Climate Action Plans." *Energy Policy, 39(9),* 5429–5439. doi:10.1016/j.enpol.2011.05.020.

Portney, P. R., & Stavins, R. N. (2000). *Public Policies for Environmental Protection*. Resources for the Future. Washington, D.C.

Rabe, B. G. (2004). *Statehouse and Greenhouse: The Emerging Politics of American Climate Change Policy*. Brookings Inst Press. Retrieved from http://books.google.com/books?hl=en&lr=&id=DB7LNVlcTS0C&oi=fnd&pg=PR9&dq=statehouse+and+greenhouse&ots=qXCuJOVar9&sig=BNPB0pFlnYT2q3soXUYPUa66M1o

———. (2007). Beyond Kyoto: Climate Change Policy in Multilevel Governance Systems. Governance, 20(3), 423–444. doi:10.1111/j.1468-0491.2007.00365.x

Rahmstorf, S., Foster, G., & Cazenave, A. (2012). "Comparing Climate Projections to Observations up to 2011." *Environmental Research Letters, 7(4),* 044035. doi:10.1088/1748-9326/7/4/044035.

Raupach, M. R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J. G., Klepper, G., & Field, C. B. (2007). "Global and Regional Drivers of Accelerating CO2 Emissions." *Proceedings of the National Academy of Sciences, 104(24),* 10288–10293. doi:10.1073/pnas.0700609104.

"Regional Greenhouse Gas Initiative (RGGI) CO2 Budget Trading Program - Auction Results." (2013). Accessed February 4. http://www.rggi.org/market/co2_auctions/results.

"Regional Greenhouse Gas Initiative (RGGI) CO_2 Budget Trading Program - Memorandum of Understanding." (2013). Accessed February 20. http://www.rggi.org/design/history/mou.

"Regional Greenhouse Gas Initiative (RGGI) CO_2 Budget Trading Program - Program Review." (2013). Accessed February 19. http://www.rggi.org/design/program_review.

RGGI. (2007). "About RGGI." *RGGI Website, Retrieved from http://www. Rggi. Org/home.*

Rodier, C. (2009). "Review of International Modeling Literature: Transit, Land Use, and Automobile Pricing Strategies to Reduce Vehicle Miles Traveled and Greenhouse Gas Emissions." Retrieved from http://trid.trb.org/view.aspx?id=882281

Rothengatter, W. (2003). "How Good Is First Best? Marginal Cost and Other Pricing Principles for User Charging in Transport." *Transport Policy, 10(2),* 121–130.

Schneider, S. H. (2004). "Abrupt Non-linear Climate Change, Irreversibility and Surprise." *Global Environmental Change, 14(3),* 245–258. doi:10.1016/j.gloenvcha.2004.04.008.

Schreider, S. Y., Smith, D. I., & Jakeman, A. J. (2000). "Climate Change Impacts on Urban Flooding." *Climatic Change, 47(1),* 91–115.

Schuman, S. H. (1972). "Patterns of Urban Heat-wave Deaths and Implications for Prevention: Data from New York and St. Louis During July, 1966." *Environmental Research, 5(1),* 59–75.

Scott, D.M., Kanaroglou, P. S., & Anderson, W. P. (1997). "Impacts of Commuting Efficiency on Congestion and Emissions: Case of the Hamilton CMA, Canada." *Transportation Research Part D: Transport and Environment*, *2(4)*, 245–257.

Semenza, J. C., Rubin, C. H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L., & Wilhelm, J. L. (1996). "Heat-related Deaths During the July 1995 Heat Wave in Chicago." *New England Journal of Medicine, 335(2),* 84–90.

Seo, S., & Hwang, Y. (2001). "Estimation of CO_2 Emissions in Life Cycle of Residential Buildings." *Journal of Construction Engineering and Management*, *127(5),* 414–418. doi:10.1061/(ASCE)0733-9364(2001)127:5(414).

Sheffi, Y. (1985). *Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods*. New Jersey: NJ, Prentice-Hall Englewood Cliffs.

Shepherd, A., Ivins, E. R., Geruo A., Barletta, V. R., Bentley, M. J., Bettadpur, S., Briggs, K. H. (2012). "A Reconciled Estimate of Ice-Sheet Mass Balance." *Science, 338(6111),* 1183–1189. doi:10.1126/science.1228102.

Smalkoski, B., and D. Levinson. 2005. "Value of Time for Commercial Vehicle Operators in Minnesota." In *Journal of the Transportation Research Forum,* 44:89–102.

Sorensen, Paul A., and Brian D. Taylor. 2005. "Review and Synthesis of Road-use Metering and Charging Systems." *Transportation Research Board*. http://its.ucla.edu/research/rpubs/Sorensen_Taylor_v8.pdf.

Starr McMullen, B., Lei Zhang, and Kyle Nakahara. 2010. "Distributional Impacts of Changing from a Gasoline Tax to a Vehicle-mile Tax for Light Vehicles: A Case Study of Oregon." *Transport Policy* 17 (6) (November): 359–366. doi:10.1016/j.tranpol.2010.04.002.

Sterman, J. D. (2008). "Risk Communication on Climate: Mental Models and Mass Balance." *Science, 322(5901),* 532–533.

Stone, B., & Norman, J. M. (2006). "Land Use Planning and Surface Heat Island Formation: A Parcel-based Radiation Flux Approach." *Atmospheric Environment, 40(19),* 3561–3573.

Tagaris, E., Liao, K. J., DeLucia, A. J., Deck, L., Amar, P., & Russell, A. G. (2009). "Potential Impact of Climate Change on Air Pollution-related Human Health Effects." *Environmental Science & Technology, 43(13),* 4979–4988.

Talwar, R. (1979). "Evaluation of the Federal Weatherization-Assistance Program in Minnesota". Mid-American Solar Energy Center, Minneapolis, MN (USA).

Retrieved from http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5327116

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A. J., & Li, F. (2010). "The Urban Heat Island and Its Impact on Heat Waves and Human Health in Shanghai." *International Journal of Biometeorology, 54(1),* 75–84.

Tang, Z., Brody, S. D., Quinn, C., Chang, L., & Wei, T. (2010). "Moving from Agenda to Action: Evaluating Local Climate Change Action Plans." *Journal of Environmental Planning and Management, 53(1),* 41–62. doi:10.1080/09640560903399772.

Taylor, K. (1999). "Rapid Climate Change: New Evidence Shows That Earth's Climate Can Change Dramatically in Only a Decade. Could Greenhouse Gases Flip That Switch?" *American Scientist, 87,* 320–327.

Tol, R. S.J. (2005). "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." *Energy Policy, 33(16),* 2064–2074. doi:10.1016/j.enpol.2004.04.002.

Trozzi, C., Vaccaro, R., & Crocetti, S. (1996). "Speed Frequency Distribution in Air Pollutants' Emissions Estimate from Road Traffic." *Science of The Total Environment, 189–190,* 181–185. doi:10.1016/0048-9697(96)05208-4.

"UN Summit Strikes Climate Deal." (2012). *BBC,* December 8, sec. Science & Environment. Retrieved from http://www.bbc.co.uk/news/science-environment-20653018

"US Daily Oil Production To Reach 7.5 Million Barrels By 2020, EIA Says." (2013). *NASDAQ.com*. Accessed February 19. http://www.nasdaq.com/article/us-daily-oil-production-to-reach-75-million-barrels-by-2020-eia-says-20121205-00930.

US EPA, Office. (2012). "State Climate and Energy Program | State and Local | US EPA". Choose from the 8 types, choose only 1. Accessed September 5. http://epa.gov/statelocalclimate/state/index.html

US EPA, Office of Air and Radiation. (1990). "Clean Air Act." Retrieved from http://www.epa.gov/air/caa/

Vaca, E., & Kuzmyak, J. R. (2005). *TRAVELER RESPONSE TO TRANSPORTATION SYSTEM CHANGES. CHAPTER 13-PARKING PRICING AND FEES*. Project B-12A FY'99. Retrieved from http://trid.trb.org/view.aspx?id=753961

Verhoef, E., Nijkamp, P., & Rietveld, P. (1995). “Second-best Regulation of Road Transport Externalities.” *Journal of Transport Economics and Policy, 29 (2),* 147–167.

Vickrey, W. S. (1963). “Pricing in Urban and Suburban Transport.” *The American Economic Review, 53(2),* 452–465.

———. (1969). “Congestion Theory and Transport Investment.” *The American Economic Review, 59(2),* 251–260.

Vickrey, W., & Sharp, C. H. (1968). “Congestion Charges and Welfare.” *Journal of Transport Economics and Policy, January,* 107–125.

Walters, A. A. (1961). “The Theory and Measurement of Private and Social Cost of Highway Congestion.” *Econometrica: Journal of the Econometric Society, October 1961,* 676–699.

“Weatherization Assistant 8.9.” (2013). Accessed February 19. Retrieved from http://waptac.org/Weatherization-Assistant/Weatherization-Assistant-8002E9.aspx

Webster, P. J., Holland, G. J., Curry, J. A., & Chang, H. R. (2005). “Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment.” *Science, 309(5742):* 1844–1846.

Wheeler, S. M. (2008). “State and Municipal Climate Change Plans: The First Generation.” *Journal of the American Planning Association, 74(4),* 481–496. doi:10.1080/01944360802377973.

White, M. J. (1988). “Urban Commuting Journeys Are Not‘ Wasteful’.” *The Journal of Political Economy, 96(5),* 1097–1110.

Yi, H. (2010). “The Politics of Renewable Portfolio Standards and Clean Energy Production in the States”. SSRN Scholarly Paper ID 1643785. Rochester, NY: Social Science Research Network. Retrieved from http://papers.ssrn.com/abstract=1643785

Yi, H., & Feiock, R. C. (2012). “Policy Tool Interactions and the Adoption of State Renewable Portfolio Standards.” *Review of Policy Research, 29(2),* 193–206. doi:10.1111/j.1541-1338.2012.00548.x.

Yin, J. H. (2005). “A Consistent Poleward Shift of the Storm Tracks in Simulations of 21st Century Climate.” *Geophys. Res. Lett, 32(18),* L18.

Zarkadoula, M, Zoidis, G., & Tritopoulou, E. (2007). “Training Urban Bus Drivers to Promote Smart Driving: A Note on a Greek Eco-driving Pilot Program.”

Transportation Research Part D: Transport and Environment, 12(6), 449–451. doi:10.1016/j.trd.2007.05.002.

Zhang, H. M., & Ge, Y. E. (2004). "Modeling Variable Demand Equilibrium Under Second-best Road Pricing." *Transportation Research Part B: Methodological, 38(8),* 733–749.

Zhang, Lei, and B. Starr McMullen. 2008. "Statewide Distance-based User Charge: Case of Oregon." In *Transportation Research Board 87th Annual Meeting*. http://trid.trb.org/view.aspx?id=848406.

Zhou, Y., Wu, Y., Yang, L., Fu, L., He, K., Wang, S., Hao, J., Chen, J., & Li, C. (2010). "The Impact of Transportation Control Measures on Emission Reductions During the 2008 Olympic Games in Beijing, China." *Atmospheric Environment, 44(3),* 285–293.