Strategies for Carbon Dioxide Emissions Reductions:

Residential Natural Gas Efficiency, Economic and Ancillary Health Impacts in Maryland

A Study Commissioned by
the Maryland Department of the environment

Center for Integrative Environmental Research (CIER)
University of Maryland

In collaboration with

The Johns Hopkins University

Towson University

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October 2009

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Executive Summary

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1. Introduction

Regional efforts to curb emissions of greenhouse gases (GHG) through cap-and-trade systems are proliferating in the US and elsewhere (Ruth et al., 2007; Ruth et al., 2008). For the majority of these efforts, upper limits of GHG emissions are set for utilities and industry, and tradable permits are made available to emitters in the form of allocations on the basis of past emissions, auctions or a combination of both. One such regional cap-and-trade system is the Regional Greenhouse Gas Initiative (RGGI) in which Maryland and nine other Mid-Atlantic and Northeastern states have committed to reduce their electric power sector emissions by 10 percent by 2018 (Ruth et al, 2007; Ruth et al., 2008).

RGGI focuses on emissions from electricity generation. On a broader level, Maryland aims to reduce statewide greenhouse gas emissions 25 percent from 2006 levels by 2020, as required by the Greenhouse Gas Reduction Act of 2009 (RGGI, 2005a). To meet that goal will require strategies that extend beyond those that are part of RGGI.

The Center for Integrative Environmental Research (CIER) at the University of Maryland, in collaboration with research partners from the University of Maryland's Department of Civil and Environmental Engineering, Johns Hopkins University, the Regional Economic Studies Institute (RESI) at Towson University, and the University of California, Merced, examined the potential to achieve CO_2 reductions by improving household natural gas efficiency in Maryland. Specific attention was given to critical aspects of household natural gas efficiency improvements including: consumer energy savings; household and state-wide economic impacts; potential health effects associated with efficiency improvements; and optimal bundling of efficiency measures under alternative state budget constraints. This report, prepared to inform the Maryland Department of the Environment (MDE) about potential changes in natural gas use, changes in CO_2 emissions, economic impacts and ancillary health effects, is the result of the study undertaken by the research team.

The study addresses the following specific questions:

1. What potential CO_2 reductions could be achieved over time in Maryland through selected residential natural gas efficiency improvements?

2. What CO_2 benefits can be expected from efficiency improvements under alternative budget constraints?

3. What is the economic potential of selected residential natural gas efficiency improvements and what impact will the improvements have on ratepayers and the Maryland economy?

4. What environmental and health effects might be associated with selected residential natural gas efficiency improvements, aside from CO_2 impacts?

2. Background

Natural gas is an important energy source for the residential sector in Maryland. Statewide annual residential energy consumption from natural gas is roughly equal to residential energy consumption from electricity (EIA, 2007). The study focuses on natural gas, rather than electricity, because natural gas efficiency improvements have the potential to achieve CO_2 reductions for the State beyond those required by the RGGI cap. RGGI states use auctions to allocate emissions allowances among regulated power plants, and the states also commit to invest a portion of their auction revenues to benefit consumers. Policymakers are asking strategic questions about how Maryland might use RGGI auction revenues to reduce CO_2 emissions below the RGGI cap, and this study provides possible responses.

Currently, approximately 46 percent of households use natural gas in Maryland with 68 percent of total consumption coming from space heating, 23 percent from water heating, and 8 percent from other uses such as cooking (U.S. Census Bureau, 2000; EIA, 2005a). Maryland residential natural gas demand varies seasonally, with higher levels of demand during the winter months. Figure ES1 depicts Maryland residential energy use by fuel type.

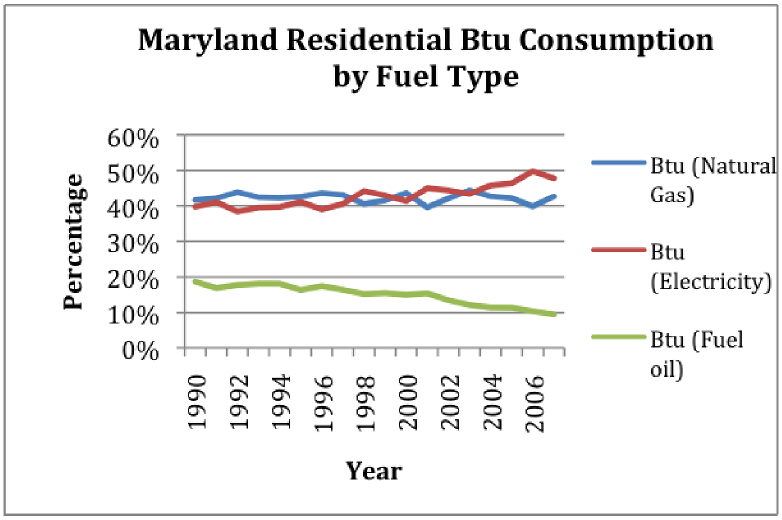

Figure ES1- Maryland Residential BTU Consumption by Fuel Type (EIA, 2007)

In 2005, natural gas use accounted for nearly 12 percent of the State's total CO_2 emissions from energy sources, excluding natural gas burned for power generation (EIA, 2005b). The residential sector – including single and multi-family households – generated nearly half of that 12 percent (EIA, 2008). In 2005, Maryland households that use natural gas generated approximately 4.8 million tons of CO_2 from natural gas consumption, or about 4.8 tons of CO_2 per household that uses natural gas [1].

In exploring the potential for residential energy efficiency improvements to reduce natural gas consumption and resulting CO_2 emissions, this study focuses on Maryland's existing single and multi-family housing stock over the period from 2010 to 2025. We separate existing construction from new construction because two policy approaches will likely be necessary for improving the overall energy efficiency of households. Existing housing will likely require policies that incentivize improvements in the energy efficiency of equipment and building shells, while new construction might be better served through changes to building code standards.

Specifically, the study examines seven energy efficiency improvements with respect to their capacity to reduce natural gas use in both space heating and water heating. The seven improvements, or measures, are[2]:

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[1] Calculated using emissions by sector and natural gas consumer data from the Energy Information Administration (EIA, 2008; EIA, 2007)

[2] See Table 2.S.11 of Chapter II for the full set of assumptions.

- Furnace replacement (increasing furnace to 92 % fuel usage efficiency)
- Improvements in ceiling insulation (improving the thermal resistance value from current level/standard to R-38[3]) and improved wall insulation (increase the thermal resistance value from current level/standard to R-13)
- Replacement of windows (single pane with Energy Star windows)
- Duct sealing (reduce the air leakage for crawl spaces and basements)
- Replacement of water heaters (improving efficiency to 67%)
- Wrapping the water heater pipes (up to 10 ft of pipe)

3. Approach

This study uses four distinct, yet interrelated approaches to explore the potentials for efficiency improvements in residential natural gas use in Maryland and the associated economic and ancillary health impacts. For the first part of our analysis, we explore potentials for efficiency improvements through ceiling and wall insulation, upgrading windows, more efficient furnaces and water heaters, water heater pipe wraps, and duct sealing. Since furnaces and water heaters naturally turn over in the existing housing stock, we develop a capital vintage model to capture aggregate fuel use efficiency changes as equipment is replaced at the end of its natural lifetime by more efficient equipment.

The second part of the analysis then explores what residential natural gas energy efficiency measures or combination of measures could achieve the greatest carbon emissions reductions for the least cost. This information would be useful if the State of Maryland were to consider funding efforts to improve residential natural gas efficiency. To find the optimal mix of measures, the study specifies the challenge as a "knapsack problem" – analogous to the challenge faced by someone who is constrained by a fixed-size knapsack and who is intent on filling it with the most useful items. In this part, we deploy a set of algorithms to optimize resource allocation for efficiency improvements under given state budgetary limits.

The third part of our analysis attends to determining the economic and fiscal impacts of the implementation of a natural gas efficiency program for households. In this part, we make use of the IMPLAN model (Minnesota IMPLAN Group, 2006) to calculate the total economic impact that comes from diversion of household expenditures from energy to other goods and services, and from purchases of efficiency improvement measures.

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[3]The R value is a measure of thermal resistance which is the ratio of temperature difference across the material to the heat flux through it. As the R value increases the resistance increases and hence less heat is lost.

The economic impacts calculated here include the multiplicative impacts that result from expenditures in the region on goods and services and as the wages of employees trickle through the local economy.

In addition to economic impacts, the study also considers the potential effects of changes in indoor and outdoor air quality that could result from decreasing the amount of natural gas burned in homes and altering the air exchange in homes due to efficiency measures. Specifically, the analysis considers reductions in outdoor nitrogen oxides (NO_x), changes in indoor concentrations of radon, and changes in indoor concentrations of second hand smoke (SHS), also known as environmental tobacco smoke (ETS).

Main features of each part of the study are described here. Technical details on the methodologies for and data used in each part of this study are provided in the following sections. The last two sections of this summary concentrate on the key findings and areas for further analysis.

3.1 Modeling Improvements in Residential Natural Gas Efficiency

Our analysis of improvements in natural gas use by households in Maryland follows three steps. First, we use information on historic and current residential natural gas consumption in Maryland to construct a pre-efficiency improvement baseline from 2010 to 2025 (See Chapter II, Section 4.1). This baseline takes into account anticipated climate variations and the current growth rate of natural gas consumption, which is a function of population growth.

Second, we examine seven potential energy efficiency improvement measures with respect to their capacity to reduce natural gas demand for both space heating and water heating. The seven measures include: ceiling and wall insulation, upgrading windows, more efficient furnaces and water-heaters, water heater pipe-wraps, and duct sealing. Data from the Residential Energy Consumption Survey (RECS) revealed the current level of energy efficiency technology saturation (EIA, 2005c).

Specific assumptions are made about how each of the seven efficiency measures might be upgraded. In all cases, we assume that 100 percent of the households eligible for a measure will adopt it. Water heaters and furnaces are retired and replaced at the end of their lifetime, which occurs throughout the period of analysis. All applicable households adopt all other efficiency measures in 2010. Ceiling insulation and duct sealing apply to only single-family homes as we assume an average multifamily unit is in a larger building and has another housing unit located above and below.

The costs reported in this study include material and installation costs. A state program might cover only part of these total costs, while homeowners or other programs cover the remainder of the costs. The costs also do not include "program costs" to manage a program or deliver services.

Third, with an established baseline projection of residential natural gas consumption in Maryland and a defined group of seven efficiency measures, we examine post-efficiency improvement energy demand reductions under four space heating scenarios and two water heating scenarios. The four space heating scenarios focus on the interactions between duct sealing and furnace efficiency, and are designed to take into account interaction effects among the space heating efficiency measures. Such interactions are present when reductions in energy demand from an individual efficiency measure are reduced when other efficiency measures have already been taken. Two of the four space heating scenarios explore impacts of a new furnace efficiency policy on average furnace efficiency in Maryland under conditions of duct sealing and no duct sealing, and the corresponding change in residential natural consumption. Two additional scenarios explore impacts on natural gas energy consumption of the natural rate of furnace turnover, also under conditions of duct sealing and no duct sealing. Finally, the two water heating scenarios explore the impacts of a new water heater policy and natural turnover. The efficiency measures that are not explicitly captured in the scenario analysis are then individually isolated and analyzed under each of the scenarios. For example, for space heating, there are four estimates of the energy reductions from wall insulation, each corresponding to a different scenario.

Each scenario is further broken down by a high and low estimate, which capture potential variation in climate over the period of analysis. The high scenario, an upper bound, determines natural gas usage and savings based upon annual heating degree day totals that are one standard deviation above the mean, while the low scenario does the same but instead uses annual heating degree day totals that are one standard deviation below the mean for Maryland. In other words, the high scenario represents a colder than average winter, requiring relatively more natural gas consumption and the low scenario represents a warmer than average winter, requiring relatively less natural gas.

From these three steps we estimate annual residential energy reductions for the time period 2010-2025 considering both the deployment of individual measures and combinations of measures (e.g., duct sealing, furnace upgrade, and wall insulation). We calculate the cost-effectiveness of individual efficiency measures, which is also referred to as the Cost of Saved Energy (CSE) using the estimated net present value of energy savings as well as installation and equipment costs, all discounted by 5 percent annually. For all measures other than furnaces and water heaters, all costs occur in 2010 since we assume that the measures are installed in all applicable households in 2010. For furnaces and water heaters, we assume that more efficient equipment is installed upon burnout of the old equipment. Therefore, costs occur over all years of the period of analysis for furnaces and water heaters. We calculate annual CO_2 reductions for the period of analysis based on the carbon content of natural gas and the predicted energy savings. Potential reductions are evaluated for both the low and high scenarios.

3.2 Scenarios

To explore the potential impacts of natural gas efficiency measures and their associated CO_2 emissions reductions and ancillary health benefits, we developed four scenarios for space heating and two scenarios for water heating. The four baseline scenarios for space heating are:

- Scenario 1 models energy consumption with natural turnover of furnace units and no duct sealing
    - 1A – Low estimate
    - 1B – High estimate
- Scenario 2 models energy consumption with natural turnover of furnace units, but with duct sealing
    - 2A – Low estimate
    - 2B – High estimate
- Scenario 3 models energy consumption with a furnace policy and no duct sealing
    - 3A – Low estimate
    - 3B – High estimate
- Scenario 4 models energy consumption with a furnace policy, but with duct sealing
    - 4A – Low estimate
    - 4B – High estimate

The two baseline scenarios for water heating are:

- Scenario 1 models energy consumption with natural turnover of water heaters
    - 1A – Low estimate
    - 1B – High estimate
- Scenario 2 models energy consumption with a water heater policy
    - 2A – Low estimate
    - 2B – High estimate

3.3 Optimal Selection of Efficiency Improvement Measures

If the State of Maryland were to consider funding efforts to improve residential natural gas efficiency, it would be useful to know what measures or combination of measures could be the most efficient in reducing CO_2 emissions taking into account the costs of these measures.

In this part of the study we explore the possible benefits that could be accrued from using RGGI allowance proceeds for the natural gas sector in Maryland, although the source would not really make a difference in the results. Typical improvements could include better home insulation and other similar measures to reduce demand for natural gas as well as the resulting drop in CO_2 that comes from more efficient home heating. Examples of specific measures that were considered include: better ceiling insulation, pipe wrap, installation of more efficient furnaces or the like.

We developed a model to explore the optimal choice of efficiency measures (See Chapter III, Section 2). In the model, we assume that the seven efficiency measures (furnaces, ceiling insulation, wall insulation, windows, duct sealing, water heaters, pipe wrap) can be chosen separately or in combination, resulting in $2^7 - 1 = 127$ different options (i.e., possible combinations of measures). The model assumes that exactly one option (one of the 127 combinations) can be picked.

To understand the tradeoff between funding levels and the possible energy efficiency benefits, a variety of scenarios were run and analyzed using the knapsack problem. Specifically, for each of the 127 options, the net present value of the total cost and the total CO_2 reductions are calculated, with the CO_2 reductions calculated for both the "low" and "high" climate scenarios (See Chapter III, Section 3). In addition, two scenarios were explored: one where measures are installed in 100% of applicable households and one where measures are installed in 50% of applicable households. Lastly, an annual budget of $5,000,000, leading to a cumulative net present value of $54,188,848 for 2010-2025 was used as a base level. Twenty different budget levels were tried starting with this base level all the way up to 20 times that base.

3.4 Economic Impacts

Three types of economic impacts from energy efficiency improvements are captured in this study (See Chapter IV, Section 2):

- ***Direct impacts:*** these impacts are generated when new businesses that deliver energy efficiency improvements (from furnaces to window replacement or duct sealing) create new jobs and hire workers to fill those jobs.
- ***Indirect impacts:*** these impacts accrue as the new firms purchase goods and services from other locally situated businesses.
- ***Induced impacts:*** both the direct and indirect impacts result in an increase in area household income. This increase allows local households to ramp up their spending at local area businesses. The increase in local spending is referred to as the induced impacts.

For the purpose of this analysis, the direct impacts are considered to be equal to the value of the energy savings as they accrue to households and the revenues as they accrue to firms installing the required energy saving devices. The indirect impacts accrue to additional supporting businesses (through purchases of goods and services by businesses and consumers that receive the direct impacts). The induced impacts result from increased household income and related spending which is driven by the direct and indirect impacts.

3.5 Non-CO_2 Environmental Impacts

Even though there are various non-energy benefits to improvements in residential natural gas use efficiencies, this part of the study concentrates mainly on a subset of the environmental benefits from the program: reductions in conventional air pollutants and changes in exposure to radon and second hand tobacco smoke (See Chapter V, Section 3). Reductions in conventional pollutant emissions arise from the reduced consumption of fossil fuels for energy, which in turn, results in fewer emissions of sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and other pollutants. These impacts could manifest themselves as both outdoor and indoor air pollutant reductions. For instance, outdoor emissions reductions can include reductions in the amounts of NO_x released to the atmosphere resulting from furnace maintenance and replacements. The effects upon indoor air pollution are, in many cases, ambiguous. Some of the proposed measures such as window replacements for space heating savings could result in a decrease in the air turnover (or exchange) rates of the homes (the rate at which air in the building is replaced by outside air). A decrease in air exchange rates can result in higher accumulations of air pollutants. This is because fresh air coming into a room dilutes pollutant concentrations, as the outdoor levels for various pollutants are usually lower than indoors. On the other hand, indoor air pollution could be decreased if emissions sources (radon leaks or gas using appliances) are reduced due to lower heating or cooling demands, basement sealing, or improved furnace and water heater efficiencies. Therefore, it is difficult to predict the change in the indoor air quality given the competing effects (decrease in emissions as well as decrease in fresh air input rate) resulting from energy efficiency programs.

We assume a set of energy efficiency measures identical to those outlined in Section 2 above. We assume that changes in NO_X emissions from furnaces and hot water heaters and changes in air exchange resulting from each efficiency measure are proportionally the same for all homes. We further assume that pollutants follow a linear dose-response relationship and that the presence of NO_X and second-hand smoking are distributed uniformly throughout the state. All homes, regardless of their relative risk to pollutants, are equally likely to have energy efficiency improvements installed.

We analyze a hypothetical case that assumes the program will be applied to all of the possible existing residential units starting in 2010, except for water heaters and furnaces that are replaced after they wear out. Again, we distinguish between energy savings for the low and high scenarios concerning the rate of appliance replacement. Consistent with the other parts of this study discussed above, we assume that ceiling insulation and duct sealing are only applied to single family residential units, and not multifamily units. Natural turnover takes the increase in efficiency of furnaces over time into account but assumes no policy or program is implemented to improve their efficiency. The furnace policy instead assumes that there exists a policy to improve all installed furnaces to the efficiency level AFUE 92 (Annual Fuel Utilization Efficiency). However, there are four possible scenarios for single residential units, depending on the assumptions about the furnace policy and whether single units have duct sealing performed on them or not.

Thus, we have the following four cases:

a) Natural turnover, no duct sealing

b) Natural turnover, duct sealing

c) Furnace policy, no duct sealing

d) Furnace policy, duct sealing

For water heating calculations, there are two scenarios, natural turnover and water heater policy. There are just two cases for both single and multifamily residential units, as duct sealing would not have any effect on water heating energy demand. These are similar to that of furnace calculations in the sense that natural turnover would involve the calculation of savings considering changes in water heaters efficiency over time but assuming no policy or program is targeted to reach a specific efficiency level. In contrast, the water heater policy would calculate savings based on a policy that all heaters would be upgraded to an efficiency of EF-67. The water heater policy also considers the effects of pipe wrappings.

From estimates of energy savings and using standard emissions factors (AQMD, 2006, DOE, 2004, Appendix K-2), we calculate reductions in outdoor NO_X emissions for the various scenarios. Forecasts of annual prices of NO_X (Evaluation markets, 2009) can then be used to infer the economic value of outdoor NO_X reductions.

Changes in the radon indoor concentrations and second hand smoke indoor concentrations that would result from the natural gas program are estimated each with a separate box model. These models, in essence, capture how concentration levels in a residential unit are affected by the source of the pollutant and removal by three mechanisms: decay, absorption, and air exchange with the outdoors.

4. Key Findings

4.1 Potential Consumer Savings Due To Household Energy Efficiency Improvements

The study results show that the average single or multi-family household in Maryland that uses natural gas would benefit by investing in energy efficiency (See Chapter II, Section 4.4). Installing energy efficiency measures such as new furnaces and duct sealing would reduce a household's natural gas consumption and cut its energy bills. The capital cost for five of the efficiency measures would be more than offset by the savings from purchasing less natural gas, which is forecasted to average around $16.70/MMBtu ($2009) for the period 2010-2025 (See Figure ES2)(EIA, 2009).

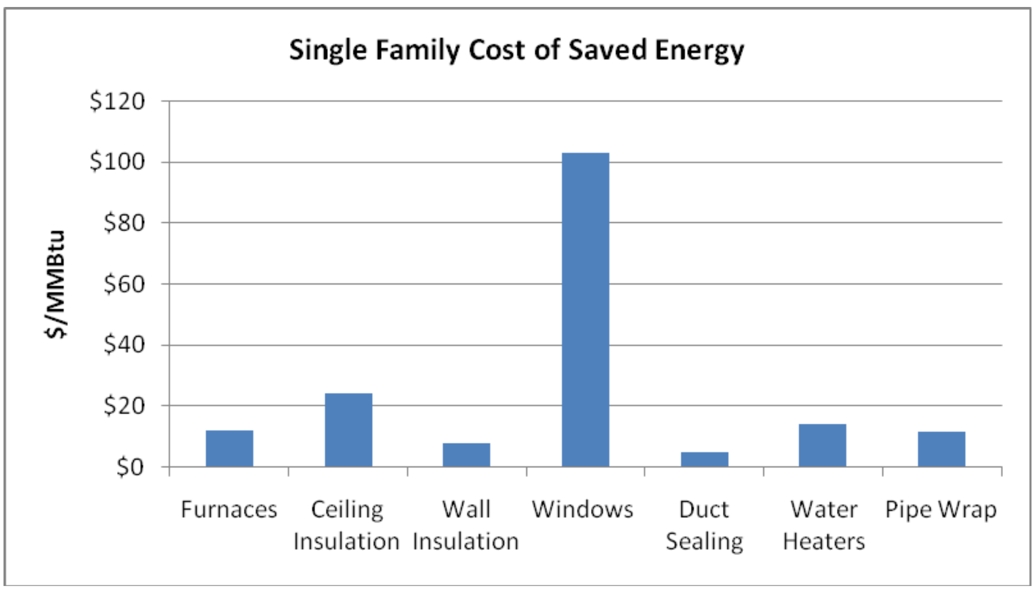


Figure ES2- Cost of Saved Energy[4] (Single-family households; average of low and high scenarios assuming all measures are installed) (See Chapter II, Section 4.4)

As Figure ES2 illustrates, for the average single-family home in Maryland, wall insulation and duct sealing would be the most cost-effective energy efficiency measures over all climate and technology scenarios. Furnaces, water heaters, and pipe wraps would also be cost-effective under all scenarios. By contrast, window upgrades and ceiling insulation would not be cost-effective.

An average single-family household could save between $400 and $500 in the first year by investing approximately $3,000 in cost-effective energy efficiency measures –

[4] Net present value of lifetime costs and savings using a 5 percent discount rate, if the CSE for an improvement is below the average fuel cost for the period (2010-2025) then the improvement is considered cost effective.

namely, wall insulation, duct sealing, furnaces, water heaters, and pipe wrap. Adding ceiling insulation, which is slightly over the cost-effectiveness threshold, could increase savings per household to $500 to $630 in the first year, with a total investment of approximately $5,200 (See Chapter II, Section 5.1).

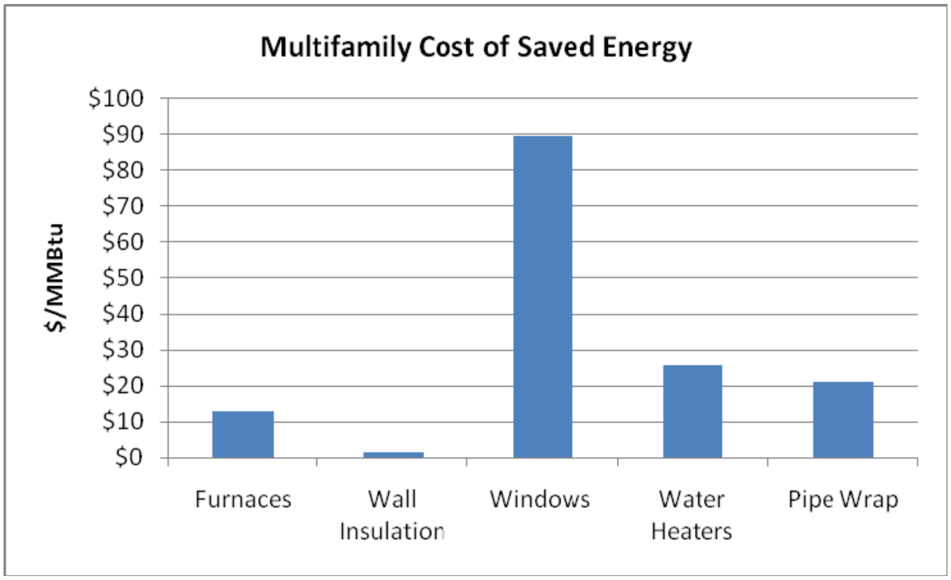


Figure ES3- Cost of Saved Energy (Multi-family households; average of low and high scenarios assuming all measures are installed) (See Chapter II, Section 4.4)

Figure ES3 shows that for the average multi-family household, wall insulation would be the most cost-effective measure and furnace improvements would be cost-effective as well (See Chapter II, Section 4.4). With some level of subsidy, pipe wraps and water heaters might be cost-effective for some households. On average, window upgrades would not be cost-effective.

4.2 Potential Reductions in Natural Gas Consumption and CO_2 Emissions

The study finds that the State of Maryland would benefit if residential households adopted energy efficiency measures (See Chapter II, Section 4.1). From 2010 to 2025, the implementation of natural gas efficiency measures in single-family households could reduce Maryland's total residential natural gas consumption by 8-18 percent, depending on the specific technologies and alternative climate scenarios. If all of the energy efficiency measures described in this study were implemented, savings of 14-18 percent could result, depending on climate, compared to forecasted consumption of natural gas in Maryland's residential sector using trends in natural gas consumption. Over the same period, the implementation of natural gas efficiency measures in multifamily households could reduce residential natural gas consumption by up to 1 percent of total residential natural gas consumption.

If all households adopted all applicable natural gas efficiency measures Maryland could reduce its CO_2 emissions by 10.5 to 13.5 million tons between 2010 and 2025 (See Chapter II, Section 4.2). In 2005, CO_2 emissions in Maryland totaled 84.4 million tons with CO_2 emissions from the residential sector accounting for about 9 percent (EIA, 2005b).

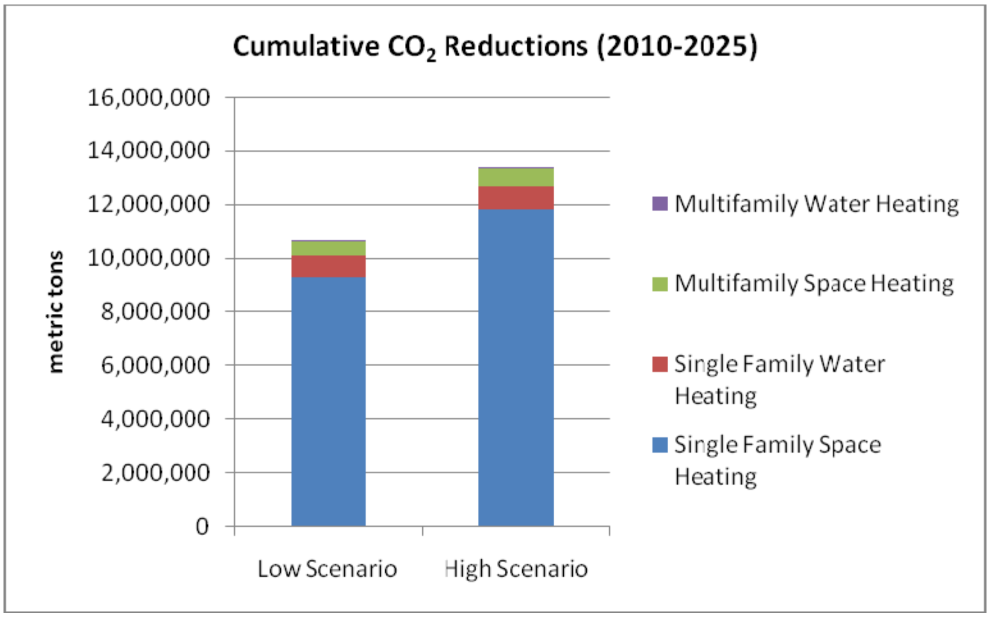


Figure ES4. Cumulative CO_2 Reductions (2010-2025) (Metric Tons)

Figure ES4 shows the cumulative CO_2 emissions reductions that natural gas efficiency improvements in single- and multi-family space heating and water heating could achieve from 2010 to 2025 (See Chapter II, Section 4.2). Most reductions come from single-family space heating with duct-sealing accounting for one-third of the total reduction in CO_2 emissions.

4.3 Optimal Combinations of Energy Efficiency Measures

The range of efficiency improvements considered in this study, if carried out together, can have interrelations that determine overall savings in natural gas use and reductions of CO_2 emissions. For example, the effect on natural gas use of replacing inefficient furnaces changes fundamentally if windows are upgraded first. In general, the marginal benefits of an additional dollar spent on efficiency for each efficiency measure depends on the expenditures already made for other measures.

To identify cost-effective combinations and properly sequence efficiency investments by households, we developed a model, which assumes that only a single combination of efficiency measure is being deployed (See Chapter III, Section 2). Next, we assumed four scenarios whereby the costs and savings of equipment and installation vary between full and discounted values, and the CO_2 reductions realized from the efficiency improvements vary between low and high estimates.

The four scenarios are as follows:

- 100% costs and CO_2 reductions, but with low CO_2 reduction estimates
- 100% costs and CO_2 reductions, but with high CO_2 reduction estimates
- 50% costs and CO_2 reductions, but with low CO_2 reduction estimates
- 50% costs and CO_2 reductions, but with high CO_2 reduction estimates

The optimization analysis found that with funding budget (limit) starting at 5 million dollars and going up to 100 million dollars, achieving a reduction goal of 1 million tons of CO_2 would take an investment with a net present value of between 157 and 283 million dollars (See table ES1) (See Chapter III, Section 3).

Table ES1 - Ranges of Required Funding ($millions) for Achieving Several Levels of CO_2 Reduction (logarithmic functions used) (See Chapter III, Section 3)

CO_2 Reductions (Millions of tons)	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	$200.20	$157.38	$283.46	$184.44
2	$608.38	$383.78	$2,185.37	$960.54
3	$1,848.79	$935.90	$16,848.66	$5,002.32

4.4 Potential Economic Effects

For the scenario of low household spending on natural gas use efficiency measures, the resulting energy savings and concomitant higher disposable income of households supports approximately 4,000 jobs in Maryland and yields nearly $400 million in economic activity as measured by gross state product (GSP) (See Chapter IV, Section 2) . While in the high household savings scenario approximately 5,000 jobs and nearly $500 million in economic activity would be supported in Maryland.

These impacts on a yearly basis would represent 0.01 percent of Maryland's current level of GSP and employment. The installation of energy-conserving devices would support more than an additional 80,000 jobs and nearly $11 billion in economic activity, representing just 0.26 percent per year and 0.21 percent per year of Maryland's current GSP and employment levels (See Table ES2)(See Chapter IV, Section 2). Because of the current state of the economy and given the general decline in construction employment in the state, much of the excess construction employment generated through the deployment of a natural gas efficiency program could be absorbed through existing jobs. As a consequence, not all of the jobs supported by the program would be net additions to the economy.

Table ES2: Total Economic and Fiscal Impacts 2010-2025 (See Chapter IV, Section 2)

Efficiency Spending Low	**Direct**	**Indirect**	**Induced**	**Total**
Employment	2,448	604	793	3,848
Wages	$82,375,470	$25,180,212	$27,729,142	$135,284,852
GDP	$231,537,753	$81,366,394	$79,674,904	$392,579,045
State and Local Taxes	$22,841,363	$4,535,034	$7,103,048	$34,479,445
Efficiency Spending High	**Direct**	**Indirect**	**Induced**	**Total**
Employment	3,076	760	997	4,835
Wages	$103,506,884	$31,639,588	$34,842,390	$169,988,872
GDP	$290,933,102	$102,238,965	$100,113,566	$493,285,610
State and Local Taxes	$28,700,757	$5,698,390	$8,925,158	$43,324,305
Installation	**Direct**	**Indirect**	**Induced**	**Total**
Employment	44,707	15,103	21,626	81,437
Wages	$2,072,969,344	$634,215,066	$754,801,791	$3,461,986,259
GDP	$6,827,419,136	$1,969,142,880	$2,168,799,092	$10,965,361,328
State and Local Taxes	$62,354,692	$165,439,696	$254,667,913	$482,462,301

4.5 Potential non-CO_2 Environmental Effects

Increased public health risk is possible whenever an energy efficiency program decreases a building's ventilation rates, allowing greater accumulations from indoor air pollutants. This is a potential problem for any energy efficiency program that addresses the building envelope, whether the purpose is to save electricity, fuel oil, propane, or natural gas. Therefore, potential risks are not specific to or greater for natural gas customers than for consumers using any other type of energy source.

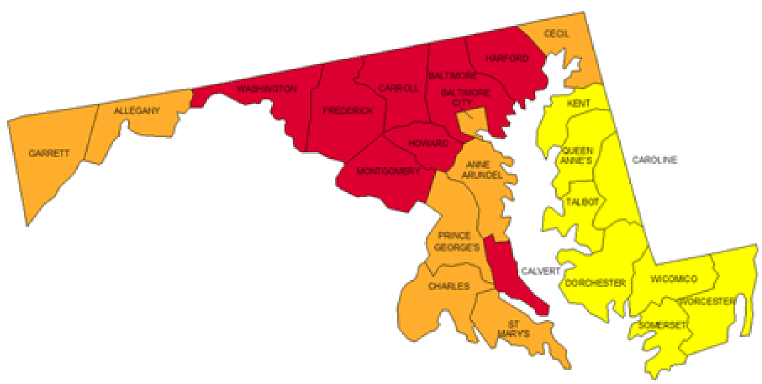
The analysis found that full implementation of a large-scale residential natural gas energy efficiency program in Maryland would reduce outdoor NO_x emissions by 300-600 tons per year. The precise value depends on the furnace and hot water heater replacement scenarios, as explained above. While NO_x reductions are a benefit, these reductions are relatively small (two orders of magnitude smaller) compared to Maryland's NO_x emissions from power plants. See table ES3 for a detailed breakdown of emissions reductions in single residential units as an example of the results of the analysis.

Table ES3.- Annual NO_x Savings from Single Residential Units' Space Heating (See Chapter V, Section 4.2)

SINGLE UNIT SPACE HEATING	**Natural Turnover, No Duct Sealing**		**Natural Turnover, Duct Sealing**	
Savings Scenario	**Low**	**High**	**Low**	**High**
Energy Saving [MMBTU] (16 years)	106,329,355	135,408,780	158,070,516	201,109,672
NO_x Reductions (16 years in tons)	4,447	5,663	6,610	8,410
Annual NO_x savings in tons	**278**	**354**	**413**	**526**
SINGLE UNIT SPACE HEATING (cont.)	**Furnace Policy, No Duct Sealing**		**Furnace Policy, Duct Sealing**	
Savings Scenario	**Low**	**High**	**Low**	**High**
Energy Saving [MMBTU] (16 years)	124,322,675	158,607,358	174,597,654	222,425,373
NO_x Reductions (16 years in tons)	5,199	6,633	7,301	9,301
Annual NO_x savings in tons	**325**	**415**	**456**	**581**

In terms of the value of equivalent emissions allowances under RGGI, the NO_X reductions associated with a large-scale residential natural gas energy efficiency program are worth approximately one half million dollars to over four million dollars per year, or about $0.5 to $7.50/yr per participating household per year. The higher value results from assuming relatively high NO_x allowance prices ($7000/ton rather than $1000/ton) as well as the high appliance replacement scenario.

With respect to the two indoor air pollutants analyzed, radon concentrations are a health concern in some regions of Maryland, while the health impacts of second hand smoke (SHS) are widely recognized. As Figure ES5 illustrates, radon is not uniformly present throughout the state, but is instead concentrated in the center of the state. The counties with the highest potential for radon exposure are Washington, Frederick, Montgomery, Carroll, Howard, Baltimore County, Harford and Calvert (See Figure ES5)



Zone 1 counties have a predicted average indoor radon screening level greater than 4 pCi/l (pico curies per liter) **(red zones) Highest Potential**

Zone 2 counties have a predicted average indoor radon screening level between 2 and 4 pCi/l **(orange zones) Moderate Potential**

Zone 3 counties have a predicted average indoor radon screening level less than 2 pCi/l **(yellow zones) Low Potential**

Figure ES5- Map of Radon Zones for Maryland (Source: EPA, 2009a)

The health effects analysis assumed that energy efficiency measures would decrease the air exchange rates of single and multi-family homes by sealing them more tightly and improving their building envelopes to lower heat loss. The analysis found that for radon, if no steps are taken to avoid installations in high radon areas and no steps are taken to mitigate radon risks in homes where radon concentrations are high to begin with, then the estimated order of magnitude for the long run increase in mortality in Maryland – the values that would be reached after several decades if decreased ventilation levels are maintained for that period of time – is in the range of 10 to 100 deaths per year. This risk would occur primarily in areas that already have high radon concentrations. Radon risks are much less in those large portions of the state where radon levels are not higher than average.

For SHS (or Environmental Tobacco Smoke), the increase in estimated mortality is approximately one-third the values for radon. There are fewer estimated total deaths due to SHS in residences, and changes in building ventilation rates do not affect SHS concentrations as much as they do radon.

Rather than pointing to possible problems, these findings point the way for more effective program design. Radon risks are highly variable across the state, and if a residential energy efficiency program were implemented in a way that avoided efficiency measures where risks are highest, the increase in public risks from radon due to energy efficiency measures would be much smaller than estimated here. Impacts can be avoided by not installing efficiency measures in the specific regions where heightened radon risks exist; by avoiding installations at homes with significant SHS exposure; by simultaneously installing energy-efficiency ventilation systems; and by simultaneously installing radon mitigation measures. Indeed, taking such steps can result in net decreases in radon- or SHS-concentrations, which would yield public health benefits.

5. Policy Considerations

The study offers important lessons for developing a possible future residential energy efficiency program focused on residential natural gas efficiency improvements. In particular:

- Single- and multi-family households would save on energy costs with the adoption of a program to encourage or require select cost-effective energy efficiency measures.
- A residential natural gas energy efficiency program would help achieve the state's ambitious economy-wide CO_2 reduction goals beyond what can be achieved by the RGGI cap alone. Such a program could be used to satisfy Maryland's obligations

under RGGI by allowing a portion of the proceeds from auctioning emissions allowances to benefit consumers.

- A residential energy efficiency program would have direct, indirect and induced economic impacts on Maryland's economy, resulting in an increase in jobs, wages, GSP, and tax revenue.
- The cost-effectiveness of several energy efficiency measures (e.g., duct sealing, wall insulation) suggests that one of the State's roles could be to promote awareness and inform homeowners that they could save money by adopting such measures.
- Interaction effects among efficiency measures must be recognized; as more energy efficiency measures are adopted in a home, energy reductions per efficiency measure will decrease, though cumulative reductions will increase.
- In the case of multi-family homes operated by landlords, misaligned incentives are a barrier to investing in energy efficiency measures. For example, tenants responsible for their own utility bills may not wish to invest in energy efficiency measures that would benefit their landlords and future tenants in the long term.
- Ancillary impacts of residential energy efficiency improvements include a decrease in the amount of natural gas burned and less air exchange between the inside and the outside of homes; the former could result in fewer NO_X emissions while the latter could result in adverse health impacts, including death, from higher home concentrations of radon (in areas of the state with radon) and second-hand smoke.
- However, mitigation of these health impacts is possible through specific technological or programmatic design; in particular, the non-uniform distribution of radon and second-hand smokers in Maryland should be a primary factor in mitigation of health impacts.

6. Future Research

The design of a residential natural gas energy efficiency program in Maryland would benefit from future research in several areas. For instance, it will be useful to incorporate additional "real world" conditions of the existing capital stock and the adoption of technologies into this analysis. This would require more county-specific data on housing stock and equipment characteristics. Additional issues to be included in future analyses may comprise "free rider" and spillover effects, the administrative costs associated with a residential natural gas energy efficiency program, and the division of program costs among households, the state, and others. In addition, future research could analyze a broader array of options for reducing CO_2 emissions, including the potential for natural gas reductions in the commercial, industrial, transportation, and agricultural sectors to enable a more comprehensive cost comparison of options.

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I. Introduction

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1. Scope

Maryland has already committed to achieving reductions in CO_2 emissions through its participation in the Regional Greenhouse Gas Initiative (RGGI), which aims to reduce CO_2 emissions from the electric power sector by 10 percent by 2018. However, the Greenhouse Gas Reduction Act of 2009 passed by the Maryland Legislature requires the State to reduce statewide greenhouse gas emissions by 25 percent by 2020 compared to 2006 levels (MDE, 2009). In order to meet this target, significant measures to reduce CO_2 emissions must be undertaken apart from the State's participation in RGGI.

Natural gas consumption in Maryland in 2005, excluding power generation, contributed almost 12 percent of total CO_2 emissions from energy sources, and almost half of this came from the residential sector (EIA, 2008). In this analysis, we estimate the technical potential for reducing natural gas consumption and CO_2 emissions through investments in natural gas end-use efficiency in the residential sector. In addition, we calculate the cost-effectiveness of the seven individual natural gas efficiency measures analyzed for both single-family and multifamily households.

In this introductory chapter we briefly describe the motivations for RGGI and examine Maryland natural gas consumption. We close with an overview of the remaining chapters of this report.

2. Regional Greenhouse Gas Initiative

In 2007, Maryland joined the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program involving 10 Northeast and Mid-Atlantic States with aims to reduce CO_2 emissions from the electric power sector by 10 percent by 2018[5]. Under the RGGI Memorandum of Understanding (MOU), each participating state must allocate at least 25 percent of its allowances and use the revenue for a "consumer benefit or

[5] The ten RGGI states are Maine, New Hampshire, Vermont, Connecticut, New York, New Jersey, Delaware, Massachusetts, Maryland, and Rhode Island.

strategic energy purpose (RGGI, 2005)." Most RGGI states have decided to auction close to 100 percent of allowances; in 2009 Maryland auctioned 85.4 percent of its allowances (Environment Northeast, 2009).

Several RGGI states have indicated that they plan to invest significant portions of the auction revenue in energy efficiency programs. Investments in electricity efficiency can offset increases in consumer electricity expenditures as a result of the cap-and-trade program by decreasing electricity demand. However, investments in electricity efficiency will not reduce total CO_2 emissions in the RGGI region by utilities subject to the RGGI rules below the established RGGI cap. In effect, reducing electricity demand allows electric power generators to delay taking other measures to reduce emissions. Therefore, in order to reduce CO_2 emissions below the cap, investments must be made outside the electric power sector.

Under the RGGI program, utilities can meet up to 3.3 percent of their compliance obligation through investments in offsets such as energy efficiency programs (RGGI, 2005). If utilities exploited all economically meaningful efficiency improvements in residential natural gas efficiency programs, a state natural gas efficiency program would likely be unnecessary. To lower emissions below the RGGI cap would then require that investments in emission reductions be made in other sectors.

In 2005, Maryland residential natural gas consumption produced roughly 4.8 million tons of CO_2, or on average about 4.8 tons of CO_2 for each household that uses natural gas [6]. If efficiency improvements were to reduce natural gas demand per household by one-third, or about 1.6 metric tons per household per year, this would amount to 16 metric tons per household for a 10-year period. RGGI offsets can be claimed for an initial ten-year allocation period. For the first five auctions through September 2009, the average clearing price for 2009 vintage allowances was $3.08 (RGGI, 2009). Based on this price, the value of emissions reductions of 1.6 metric tons for a 10-year period for each household would be about $50. Efficiency measures resulting in a one-third reduction in natural gas consumption per household would likely cost much more. Therefore, it seems unlikely that residential natural gas efficiency programs would be a cost-effective offset opportunity from the perspective of electric generators, especially as it is possible to achieve greater economies of scale on larger projects that are not possible in residential efficiency programs. This suggests that there is an appropriate role for the State in encouraging investments in residential natural gas efficiency.

[6] Calculated using emissions by sector and natural gas consumer data from the Energy Information Administration (EIA, 2008; EIA, 2007)

3. Natural Gas Consumption in Maryland

Maryland residential natural gas demand is highly seasonal, with higher levels of demand during the heating season, which then decline during the spring and summer months, as temperatures rise and space heating demand decreases. Space heating accounts for the largest portion of residential natural gas consumption at 68 percent, followed by water heating (23 percent) and other uses, such as cooking (8 percent)(EIA, 2005a).

Approximately 46 percent of Maryland households use natural gas in their homes (U.S. Census Bureau, 2000). A significant portion of all energy used in the residential sector for space conditioning, water heating, and other appliances come from natural gas. Between 1990 and 2007, natural gas in Maryland on average accounted for 42 percent of residential energy consumption (EIA, 2007b) (Figure 2.1).

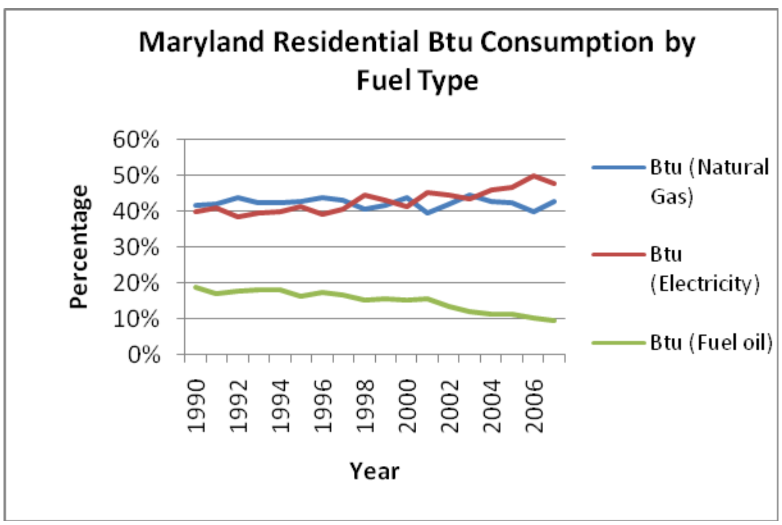

Figure 2.1-Maryland Residential BTU Consumption by Fuel Type

Maryland residential natural gas consumption has varied significantly annually but has generally ranged between 70,000 and 90,000 million cubic feet (MMcf) (See Figure 2.2)(EIA, 2008). Annual natural gas demand for the period 1990-2008 has averaged approximately 78,000 MMcf with a standard deviation of almost 7,000 MMcf. Variation in climate, number of natural gas customers, average housing size, and changes in natural gas equipment efficiency can largely explain the variation in annual natural gas demand.

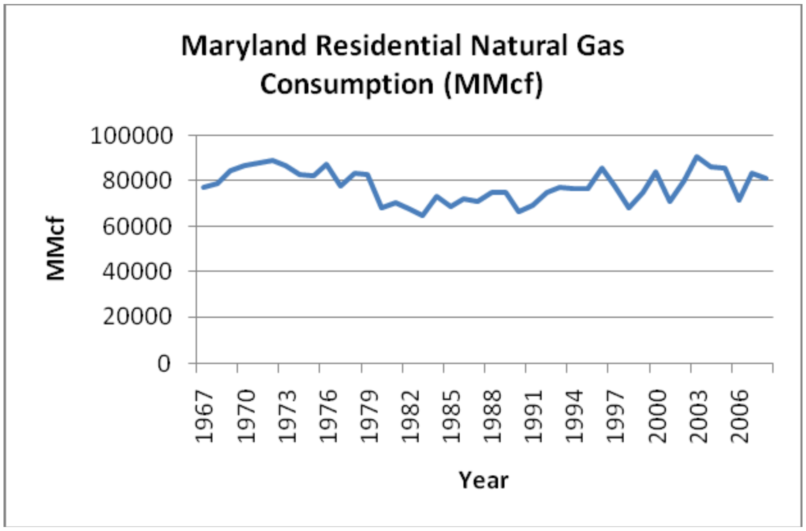

Figure 2.2- Maryland Residential Natural Gas Consumption (EIA, 2008)

The number of natural gas customers has been growing roughly 2% annually since the mid-1990s (EIA, 2007a). Currently, about 1,054,000 households use natural gas (U.S. Census Bureau, 2000). Of these households, about 84%, or 895,000, are single-family homes with an average size of 2018 sq. ft in 2005 (U.S. Census Bureau, 2000; EIA, 2005b). The remainder, approximately 169,000 households, are multi-family residences with an average size of 888 square feet (EIA, 2005b). We estimate, in 2005, the total square footage of homes using natural gas in Maryland to be 1.95 billion square feet, which we estimate to increase to approximately 2.06 billion square feet by 2010.

4. Overview of the Study

Opportunities exist for the state to lower its CO_2 emissions by stimulating efficiency improvements in residential natural gas use. The remainder of this report analyzes various issues surrounding the choice of efficiency measures. Specifically, Chapter II presents the efficiency gains and CO_2 emissions reductions that can come from seven different measures: improvements to ceiling and wall insulation; more efficient furnaces and water heaters; upgrades to windows; duct sealing; and the installation of pipe wraps. Distinctions are made between their deployment in single and multi-family homes, and particular attention is paid to the rate at which some of the measures can be implemented, which depends in part on the natural turnover of the equipment.

Since overall efficiency gains are a function of the mix of measures that are chosen, Chapter III explores, for given budgets to stimulate efficiency improvements, the optimal mix of measures. Chapter IV then presents impacts of the combination of efficiency gains, and the cost savings they may generate for households, with the stimulus that outlays of these measures cause to the state's economy. Ancillary benefits may exist in the form of improved indoor and outdoor air quality, which in turn may change health outcomes in the state. Chapter V attends to these ancillary benefits. Chapter VI concludes the report.

5. References

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II. Potential for CO_2 Reductions in Maryland through Residential Natural Gas Efficiency

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1. Introduction

To meet the goals set out in the Greenhouse Gas Reduction Act of 2009 will require the State of Maryland to identify additional reduction strategies. Energy efficiency programs aimed at reducing natural gas use in Maryland residences may provide one means to achieve further reductions, beyond caps set by RGGI. Residential natural gas efficiency measures could include replacement of old gas furnaces and water heaters, ceiling insulation, blown-in wall insulation, window replacement, duct sealing and water heating pipe wrap.

Such an energy efficiency program would target fuel savings by lowering residential energy demand for space conditioning and water heating in residences. Fuel savings for water heating and heating would be achieved by improving efficiency of water heaters and natural gas furnaces or replacing with newer equipment, respectively. Space heating savings could also be obtained by improving the thermal insulation of the building envelope.

This chapter first details the efficiency measures that are investigated here. Section three then describes our approach to measure potential efficiency improvements and CO_2 emissions reductions as these efficiency measures are adopted in the residential sector. The fourth section discusses our results and findings. We close the chapter with a summary and conclusions.

2. Efficiency Measures

Seven natural gas efficiency measures are examined in this study. These include ceiling and wall insulation, upgrading windows, more efficient furnaces and water heaters, water heater pipe wraps, and duct sealing. This list of efficiency measures should not be considered exhaustive for residences within the state. The full set of assumptions as well as data sources for each measure can be found in Table 2.S.13 of the Supplemental Data section.

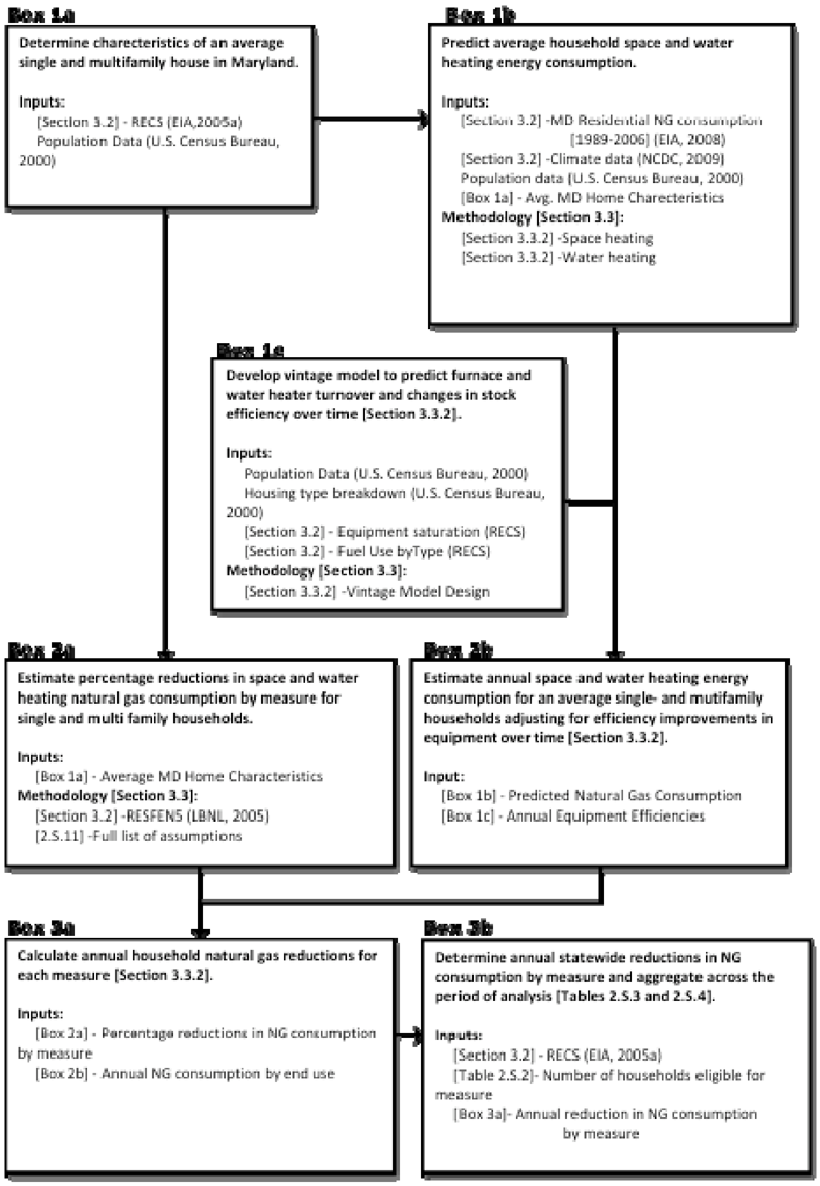
For this analysis, we consider multifamily homes to range from duplexes to large apartment buildings. Since many multifamily homes do not have a ceiling that is exposed to the exterior, we assume that the ceiling insulation measure does not apply to multifamily homes. In addition, because the available data on duct losses is related to the type of foundation, which does not apply to a large number of multifamily homes, we also assume that the duct sealing measure does not apply to multifamily households. We assume that all other measures apply to both single- and multifamily homes.

For furnaces and water heaters, we assume that equipment is retired at the end of its natural lifetime. We assume that costs and energy savings for these two measures are incremental, and we compare baseline equipment to more energy efficient models. For all other measures, we assume that they are installed in all applicable households in 2010 and that costs and energy savings are based on the total installed costs and the total energy savings compared to the baseline measures. While it is unlikely that an efficiency program would be able to reach all applicable households in the first year of a program, this approach allows for estimating total potential. In future studies, we will address questions related to adoption rates and timing, incentives, as well as the problem of free ridership, which can then be used to determine an efficiency program's emissions reduction potential.

3. Data and Methodology

3.1 Overview

The following diagram provides a general overview of the methodology, including links to sections within the document to both methods and data sources. The section numbers correspond to sections from this point forward, while box numbers correspond to boxes within the diagram itself.


Box 1a
Determine charecteristics of an average single and multifamily house in Maryland.
Inputs:
[Section 3.2] - RECS (EIA,2005a)
Population Data (U.S. Census Bureau, 2000)
Box 1b
Predict average household space and water heating energy consumption.
Inputs:
[Section 3.2] -MD Residential NG consumption [1989-2006] (EIA, 2008)
[Section 3.2] -Climate data (NCDC, 2009)
Population data (U.S. Census Bureau, 2000)
[Box 1a] - Avg. MD Home Charecteristics
Methodology [Section 3.3]:
[Section 3.3.2] -Space heating
[Section 3.3.2] -Water heating
Box 1c
Develop vintage model to predict furnace and water heater turnover and changes in stock efficiency over time [Section 3.3.2].
Inputs:
Population Data (U.S. Census Bureau, 2000)
Housing type breakdown (U.S. Census Bureau, 2000)
[Section 3.2] - Equipment saturation (RECS)
[Section 3.2] - Fuel Use byType (RECS)
Methodology [Section 3.3]:
[Section 3.3.2] -Vintage Model Design
Box 2a
Estimate percentage reductions in space and water heating natural gas consumption by measure for single and multi family households.
Inputs:
[Box 1a] - Average MD Home Characteristics
Methodology [Section 3.3]:
[Section 3.2] -RESFEN5 (LBNL, 2005)
[2.5.11] -Full list of assumptions
Box 2b
Estimate annual space and water heating energy consumption for an average single- and mutifamily households adjusting for efficiency improvements in equipment over time [Section 3.3.2].
Input:
[Box 1b] - Predicted Natural Gas Consumption
[Box 1c] - Annual Equipment Efficiencies
Box 3a
Calculate annual household natural gas reductions for each measure [Section 3.3.2].
Inputs:
[Box 2a] - Percentage reductions in NG consumption by measure
[Box 2b] - Annual NG consumption by end use
Box 3b
Determine annual statewide reductions in NG consumption by measure and aggregate across the period of analysis [Tables 2.5.3 and 2.5.4].
Inputs:
[Section 3.2] - RECS (EIA, 2005a)
[Table 2.5.2]- Number of households eligible for measure
[Box 3a]- Annual reduction in NG consumption by measure

3.2 Data

This section briefly describes the main data sources used in our analysis, and how they are used in conjunction with each other to provide a comprehensive perspective on the nature of and change in residential natural gas use efficiency in Maryland's residential sector.

DEER-Database for Energy Efficient Resources

DEER (Database for Energy Efficient Resources) is a database developed by the California Public Utilities Commission (CPUC) that contains information about a wide range of energy efficiency measures (CPUC, 2008). We use the DEER database for installation and material cost information for several of the measures analyzed, adjusting the costs for Maryland using city cost indexes (RS Means, 2009, p. 695).

RECS-Residential Energy Consumption Survey

The Residential Energy Consumption Survey (RECS) is a survey conducted every four years by the Energy Information Administration (EIA)(EIA, 2005a). The survey provides information on residential energy use in the United States including characteristics of the housing unit, fuel use, appliance and equipment use, as well as other information pertaining to household energy use. For this study we use the 2005 RECS micro dataset.

RECS data are reported for the four largest states (New York, California, Texas, and Florida) and each census division. Since there are not state-specific data for Maryland, the 19th most populous state, we instead analyze census division data.

According to the US Census Bureau and EIA, Maryland is located in the South Atlantic census division but borders the Mid-Atlantic census division. As a result, it is necessary to determine which area best describes characteristics of Maryland's housing stock and energy use. About half of all Maryland residents use natural gas in their homes. In addition, most Maryland households that use natural gas for heating use a forced warm air furnace (ACEEE, 2009b).

In the Mid-Atlantic region, a greater portion of households use natural gas than in Maryland and homes using natural gas tend to use boilers instead of furnaces, which means that the Mid-Atlantic region does not represent Maryland well for the purposes of this study (ACEEE, 2009a). If instead we examine the RECS data for the South Atlantic census division excluding

Florida, about the same percentage of homes are classified as using natural gas as in Maryland, with more homes using furnaces than boilers (EIA, 2005a). Since Florida has such a large population and a climate that is very different than that of Maryland, the South Atlantic census division data including Florida would likely be a poor estimate of Maryland's housing stock and energy use. Consequently, we use the South Atlantic census division data after removing Florida as our best approximation of characteristics for Maryland.

The RECS data are used to determine the saturation rates of existing equipment and measures such as the number of households with natural gas furnaces and the number of households with single pane windows. In combination with census data from the Maryland Department of Planning (MDP), we arrive at the estimated number of households that are applicable for each of the efficiency measures analyzed.

RESFEN-Residential Fenestration Performance Design Tool

RESFEN 5.0 (Residential Fenestration Performance Design Tool) is a computer tool developed by the Lawrence Berkeley National Laboratory (LBNL) that calculates the heating and cooling energy use of a home based on inputs such as location, square footage, type of foundation, and type of windows and insulation (LBNL, 2005). We use RESFEN 5.0 to estimate percentage savings in space heating energy use from improvements in windows, ceiling insulation, and wall insulation. While RESFEN 5.0 is designed for evaluating windows, the program allows for specifying insulation levels as well. Percentage savings are estimated by comparing space heating energy use values generated by RESFEN 5.0 for baseline insulation or window levels and improved levels.

EIA-Maryland Natural Gas Consumption

The Energy Information Administration (EIA) provides residential natural gas consumption data for the years 1989 to 2006. The data are aggregated monthly (EIA, 2008).

NCDC-National Climate Data Center

The National Climate Data Center (NCDC) is the world's largest archive of weather data. NCDC provides comprehensive weather information for locations throughout Maryland (NCDC, 2009). For this study we use maximum and minimum temperatures from weather stations located throughout each of Maryland's eight climate zones to calculate population-weighted heating and cooling degree-day totals for each zone.

3.3 Methodology

3.3.1 Engineering estimates versus pre-and post-weatherization measurements

Two methods are typically used in assessing the impact of energy saving measures on household energy consumption: engineering estimates and pre- and post-weatherization energy measurements. Only the first method is a useful tool for predicting the outcome of a weatherization program, as the second must necessarily be conducted after the program has been implemented. However, engineering estimates often exaggerate energy savings as compared to pre- and post-weatherization measurements due to behavioral factors and installation inconsistencies (Fels and Keating, 1993). Previous studies have been found to overestimate, sometimes significantly, the energy savings potential from efficiency programs. For example, Fels and Keating (1993) found that actual energy savings from residential efficiency programs ranged from 15 to 117 percent of energy savings based on engineering estimates, with most programs achieving actual savings that were less than 60 percent of engineering estimates.

As this study is focusing on emissions reduction potential from energy efficiency investments in the residential sector, we necessarily rely upon engineering estimates. In addition, since this study evaluates the potential for energy savings and CO_2 reductions of individual efficiency measures rather than savings from a more general efficiency program such as comprehensive weatherization, it would be difficult to adjust savings for individual measures based on evaluations of more general programs.

Therefore, given the wide range of estimates of actual energy savings compared to engineering estimates and our focus on individual efficiency measures rather than comprehensive weatherization or other programs, we do not adjust our savings estimates. However, we recognize that this may result in an overestimation of energy savings, perhaps to a greater extent for some measures than for others.

In this analysis, we calculate total savings (e.g. reductions in consumption of natural gas, emissions reductions, etc.) and total costs (e.g. materials and labor, ignoring administrative) assuming 100 percent participation from households to which an improvement is applicable. Further, we do not consider administrative costs or subsidy levels that would be necessary to induce consumer behavior.

3.3.2 Energy Savings

We estimate potential natural gas savings over the period 2010-2025 based on the implementation of the seven efficiency measures described in Part II. We first calculate average household space heating and water heating energy use over the period of analysis for households using natural gas. All assumptions for each efficiency measure can be found in Table 2.S.11 of the Supplemental Data section.

Space Heating Energy Use

For space heating, a time-series regression analysis is used to investigate the relationship between natural gas consumption for space heating in the residential sector and various factors including the number of customers and climate.

Heating and cooling degree-days are typically used to establish the link between climate and energy demand for space conditioning. Degree-days are calculated as the difference between some balance point and the daily maximum or minimum temperature. Based on previous research, we use a balance point temperature of 71°F and generate population-weighted degree-day totals (Amato et al., 2005).

Maryland has eight climate zones and an unevenly distributed population. Because of the uneven spread of the population, we weight climate zone degree-day totals by their respective populations. For example, while Climate Zone 8 (Western Maryland)(see Figure 2.3) is much colder than Climate Zone 4 (Prince Georges and Anne Arundel Counties), Climate Zone 4 has a much higher population and should count more towards Maryland's degree-day totals. Therefore, for each climate zone, we adjust the degree-day totals before aggregating up to the state level.

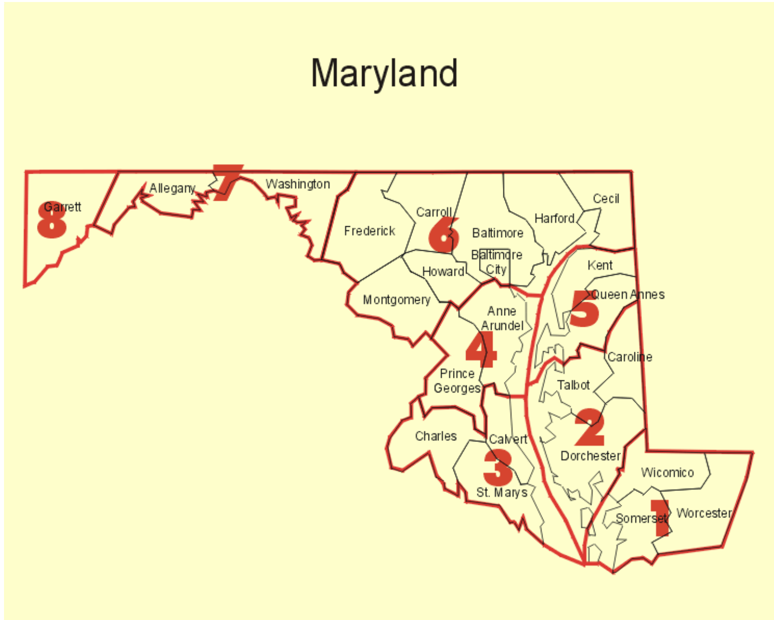


Figure 2.3- Maryland Climate Zones

Since 2000, Maryland has averaged about 6,234 heating degree-days per year with a standard deviation of 302 heating degree-days, or a range of [5631,6837] within two standard deviations of the mean. As a result of climate change, Maryland will likely see reductions in heating degree-days. By the middle of the century, under both the IPCC high and low emissions scenarios, Maryland is likely to experience increases in average winter temperatures of 2.5-3.5°F (Maryland Commission on Climate Change, 2008, p. 16). Using these estimates, we adjust the heating degree-days for the lower bound downwards, assuming a five-month heating season for the state. The lower bound from this point forward will be referred to as the low scenario, while the upper bound will be referred to as the high scenario.

For the period of analysis (2010-2025), we project Maryland residential natural gas consumption as a function of variation in climate while holding the number of households constant. As we expect, a warming climate reduces the demand for natural gas in the state. We hold households constant in order to examine the changes in energy use of the existing housing stock. Efficiency improvements in new home construction might be better served through regulatory changes in building code standards than through efficiency programs.

Using average square footage and energy intensity per square foot, which are calculated using RECS and Census data (EIA, 2005a; U.S. Census Bureau, 2000), we determine natural gas consumption for the average single and multifamily household in the state. To arrive at the energy intensity per square foot, we first sum the total square footage of all homes in the state using natural gas. We then divide the total natural gas consumption for space heating, as predicted by our econometric analysis, by the total square footage, arriving at natural gas consumption per square foot. In turn, this is then aggregated back up to the single family and multifamily household level to arrive at an estimate of natural gas consumption per household.

Water Heating Energy Use

Water heating energy use is estimated through an analysis of Maryland monthly natural gas consumption from 1989 to 2008 (EIA, 2008). We assume that natural gas consumption during summer months (i.e. June, July, and August) is primarily used for water heating and cooking/other appliances and is not used for space heating. Therefore, by averaging natural gas usage for this period, we arrive at an estimate of total monthly water heating/cooking/other appliance natural gas consumption. Then, using Energy Information Agency (EIA) national gas consumption estimates by household and end use, we divide the monthly total between water heating and cooking/other appliances (EIA, 2005b). It was assumed that natural gas consumption for water heating was the same for each housing type.

Adjusting Energy Use for Equipment Efficiency Improvements

Annual household space heating and water heating energy use are adjusted for efficiency improvements in furnaces and water heaters over time. Equipment turnover is modeled for the period of analysis using dynamic modeling software, Stella™, incorporating expected equipment lifetimes, efficiencies of equipment sold and retired, and the probability of replacement in a particular year of the lifetime of the equipment.

We develop two vintage models, one for furnaces and one for water heaters, to track these pieces of equipment as they are installed and later retired and replaced at the end of their natural lifetimes. New furnaces and water heaters are added to the respective models each year using estimates of new housing construction from the Maryland Department of Planning and the Census Bureau (MDP, 2009; U.S. Census Bureau, 2000). Households are divided into single and multifamily using percentages from the 2000 Census and then further subdivided by fuel choice for space heating and water heating using RECS data (EIA, 2005a). The total number of natural gas furnaces and natural gas water heaters installed in a given year enter into the respective models as a stock. Each stock is then assigned an efficiency value equal to EIA estimates of the average equipment efficiency of all units sold in that year.

As each stock of furnaces or water heaters progresses through time, its size decreases, following a Weibull distribution, which approximates the probability of a piece of equipment reaching the end of its natural lifetime in any given year (DOE, 2009a). Traditionally, the number of devices failing in a particular year is estimated as being equal to the total number of devices divided by the expected lifetime. However, there are drawbacks to this method, as it tends to overestimate retirement in early years while underestimating it in later years. We instead use a distribution with a zero probability of equipment failure in early years followed by a sharp increase in the probability of failure and then a rapid decline. We feel this distribution is a more realistic approximation of real world conditions.

The two vintage models track the average stock efficiency for furnaces and water heaters, respectively, in Maryland over time. The furnace and water heater models calculate a weighted average of Annual Fuel Utilization Efficiency (AFUE) and Efficiency Factor (EF), respectively, by keeping track of the number of furnaces being replaced, retired, or added due to new construction, as well as their corresponding AFUE or EF values.

In 2010, the models have built-in policy levers with potential scenarios made up of a continuous set of efficiency values between a lower bound and an upper theoretical maximum for efficiency potential. One scenario is that the model continues as is with only natural turnover. In this scenario, no changes are made to equipment efficiency standards with annual efficiency standards of installed equipment based upon EIA projections of efficiencies of equipment sold each year (Cymbalsky, 2009).

In the second case, changes are made to equipment efficiency standards for equipment installed. For these scenarios, we assume all furnaces sold have an efficiency of AFUE 92 and all water heaters have an EF of 0.67. The improved water heater efficiency standard of EF 0.67 is based on the new Energy Star standard for 2010 (Energy Star, 2009). The improved furnace efficiency value is based on the technical potential values for furnace efficiency. Due to issues with water condensation, it is not feasible to manufacture natural gas furnaces with AFUE values in the range of about 84-89. Therefore, a significant improvement over the current Federal standard of AFUE 78 requires an efficiency of at least AFUE 90. According to

ACEEE data, among high-efficiency furnace models, AFUE 92 is the most commonly sold efficiency (ACEEE, 2009b). In both the natural turnover and policy scenarios, the models generate an estimate of Maryland's stock efficiency for furnaces and water heaters.

Traditionally, equipment efficiency is treated as fixed, in that no consideration is given to natural turnover of the equipment stock. However, natural turnover reduces the savings of other efficiency improvements. For example, if the efficiency of a furnace improves, the savings due to improved windows or insulation decreases as less energy is now required to replace the heat lost through windows or insulation. Similarly, if the efficiency of a water heater improves, the savings due to a water heater pipe wrap decrease. In estimating energy savings for each efficiency improvement in this analysis, we assume either natural turnover or changes in equipment efficiency standards for furnaces and water heaters, which means that over time the returns decline from investments in other efficiency improvements.

The furnace and water heater stock efficiencies for the natural turnover and policy scenarios generated by the model were used to adjust space and water heating natural gas consumption for an average household. For each year, space heating and water heating energy use were adjusted downwards based on the percentage reduction in energy use due to the improvement in equipment efficiency for both the natural turnover and policy scenarios.

Annual and Cumulative Energy Savings

Total savings from all energy efficiency measures cannot be computed as the sum of savings from multiple devices, because of interactions among measures. For example, improvements to heating distribution systems or heating equipment itself will reduce the amount of natural gas consumed at the household level. Because the heating system has become more efficient, absolute savings from other improvements (e.g. windows or insulation) will decline. To address the interaction among the energy efficiency measures, we created four scenarios for space heating and two scenarios for water heating (see Table 2.1). We assume no interaction between space heating and water heating measures (i.e. total space heating and total water heating savings can be summed to calculate total energy savings). In addition, we assume no interaction among the ceiling insulation, wall insulation, and window measures.

The four scenarios for space heating include all paired combinations of the following: furnaces are either allowed to turnover naturally or new regulations are implemented with higher AFUE standards, and ducts are either sealed or not. Further, in analyzing reductions in natural gas consumption from water heating, two scenarios were created: water heaters are allowed to either turnover naturally or new standards are implemented. The scenarios are listed in Table 2.1 below.

Table 2.1- Furnace and Water Heater Scenarios

Space Heating Scenarios	**Water Heating Scenarios**
Natural turnover, no duct sealing	Natural turnover
Natural turnover, duct sealing	Water heater policy
Furnace policy, no duct sealing	
Furnace policy, duct sealing	

For all measures other than furnaces and water heaters, annual energy savings were calculated by multiplying household space heating or water heating savings by the number of applicable households for each individual measure.

Household space heating and water heating savings were calculated by multiplying the baseline average household space heating or water heating annual energy consumption by the estimated energy savings achieved by each measure, expressed as a percentage of total space heating or water heating energy use.

The baseline average household energy consumption depends on the scenario being analyzed. For example, the energy savings from wall insulation for the scenario where furnace efficiency improvements and duct sealing are also implemented takes into account the energy reductions due to furnaces and duct sealing. Household space heating energy consumption is adjusted downwards first for the furnace improvement and then for the duct sealing improvement. Percentage savings from wall insulation are then applied to this adjusted energy consumption value to arrive at household energy savings due to wall insulation.

We take a somewhat different approach to calculate annual energy savings from furnaces and water heaters. First, we determine the number of households in 2010 that have a natural gas furnace and the number that use a natural gas water heater. Next, we calculate total Maryland space heating and water heating energy use for the natural turnover and policy scenarios. Total annual savings are then calculated as the difference between total energy consumption under the natural turnover and the policy scenarios.

For all measures, annual energy savings from 2010-2025 are summed to determine the cumulative natural gas savings that result from each measure. It is important to note that these cumulative savings only include savings during the period of analysis, which is significant since some measures have lifetimes that are longer than 16 years.

3.3.3 Costs

Costs for each measure include both material and installation costs. For all measures other than furnaces and water heaters, all costs occur in 2010 since we assume that the measures are installed in all applicable households in that year. For furnaces and water heaters, we assume that more efficient equipment is installed upon burnout of the old equipment. Therefore, costs occur over all years of the period of analysis.

According to ACEEE data, the majority of installed furnaces either have an efficiency of about AFUE 80 or an efficiency of about AFUE 92 (ACEEE, 2009b). We assume that total costs for furnaces are based on the number of households that would purchase an AFUE 80 furnace under a business-as-usual scenario. To calculate total furnace costs, we first use our furnace model to determine the number of furnaces that are replaced each year. Then, to estimate the number of furnaces with an efficiency of AFUE 80, we use EIA projections of the average efficiency of installed furnaces in a given year to determine the number of AFUE 80 and AFUE 92 installed furnaces assuming that all furnaces fall into one of the two categories.

Unlike furnaces, where high efficiency models are widely available, the new ENERGY STAR standard for water heaters is significantly higher than almost all models currently on the market. Therefore, for water heaters, we assume that the total cost each year is based on the total number of households that are replacing a water heater.

4. Results

As a result of investments in energy efficiency, the average Maryland single- and multifamily household will accumulate benefits in terms of reduced natural gas consumption, which will lead to energy bill savings. As a result of decreasing energy consumption, the State will realize reductions in CO_2 emissions, which will help the State meet its CO_2 reduction goals.

4.1 Natural Gas Consumption

As a result of energy efficiency improvements, average household natural gas consumption should decrease. Using the Annual Energy Outlook as well as historic natural gas consumption data for Maryland and the US, we predict Maryland's residential sector natural gas consumption for 2010-2025 (without an energy efficiency program and including new construction) (EIA, 2008; AEO, 2009). Figure 2.6 shows the bounds within two standard deviations of expected natural gas consumption. In Figures 2.5 and 2.6 below we use the predictions from Figure 2.4 as the reference scenario to determine the percentage reductions in natural gas consumption from each efficiency measure.

It should be noted that it is unclear what consideration EIA has given climate change in creating US natural gas consumption forecasts. Therefore, as we use US estimates to create a forecast for Maryland, we could be over or underestimating percentage reductions because of ambiguities in the treatment of climate change in their forecast.

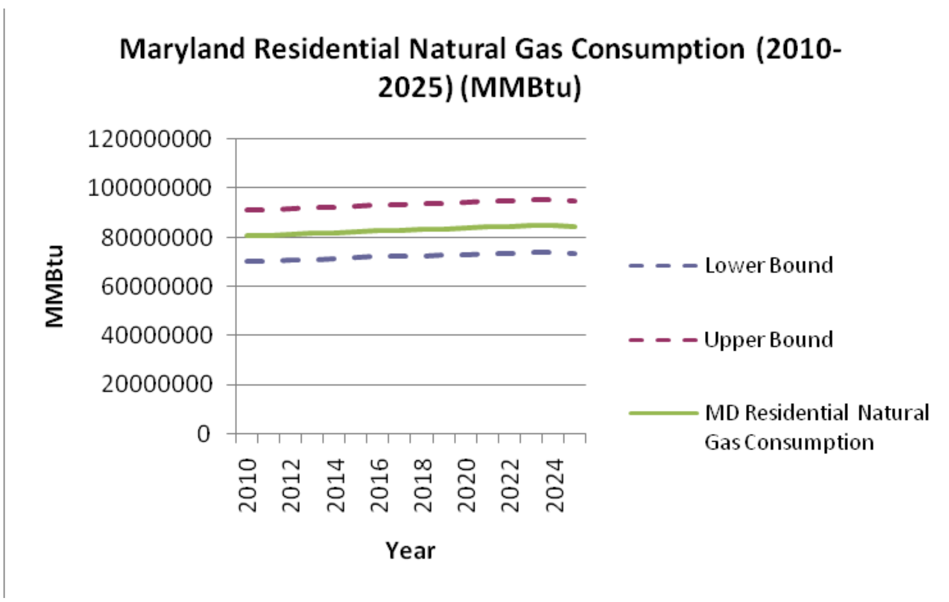


Figure 2.4- Predicted Maryland Residential Natural Gas Consumption (2010-2025) (MMBTU)

The following graphs illustrate the percentage of Maryland's natural gas usage that could be offset over the period of analysis through investments in natural gas efficiency. These percentage reductions are based on the assumptions that the efficiency measures analyzed are installed in all applicable households and that all measures other than furnaces and water heaters are installed in 2010. Figure 2.5 shows expected declines in total MMBtu of natural gas consumed in the residential sector as a result of efficiency improvements in single-family households, while Figure 2.6 does the same for multifamily households. In creating the percentages below, we use our prediction of Maryland residential natural gas demand found above (Figure 2.4) and MMBtu savings for each measure for the high and low climate scenarios found in Tables 2.S.3 and 2.S.4 of the Supplemental Data section.

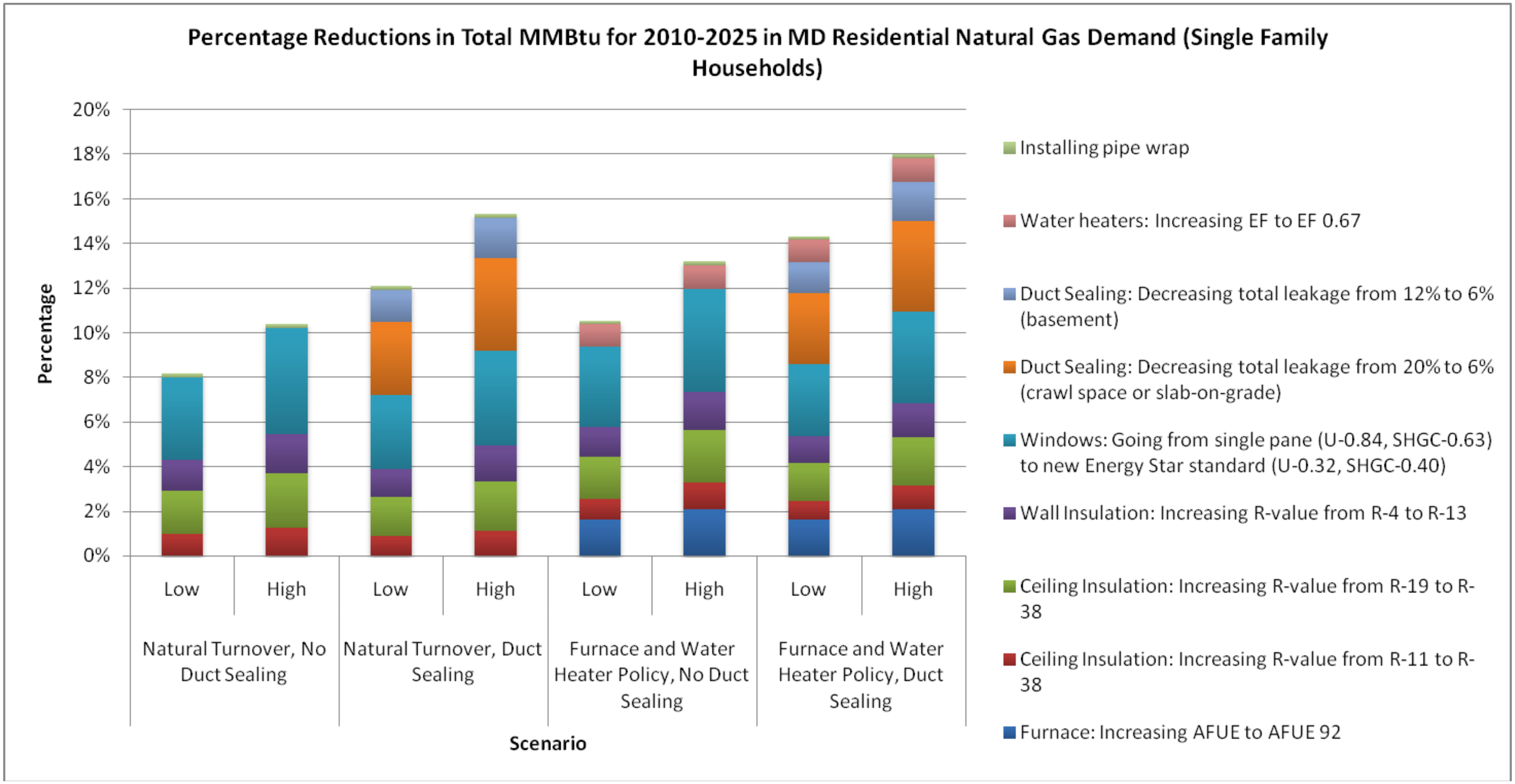


Figure 2.5- Percentage Reductions in Maryland Natural Gas Demand (Single Family Households)

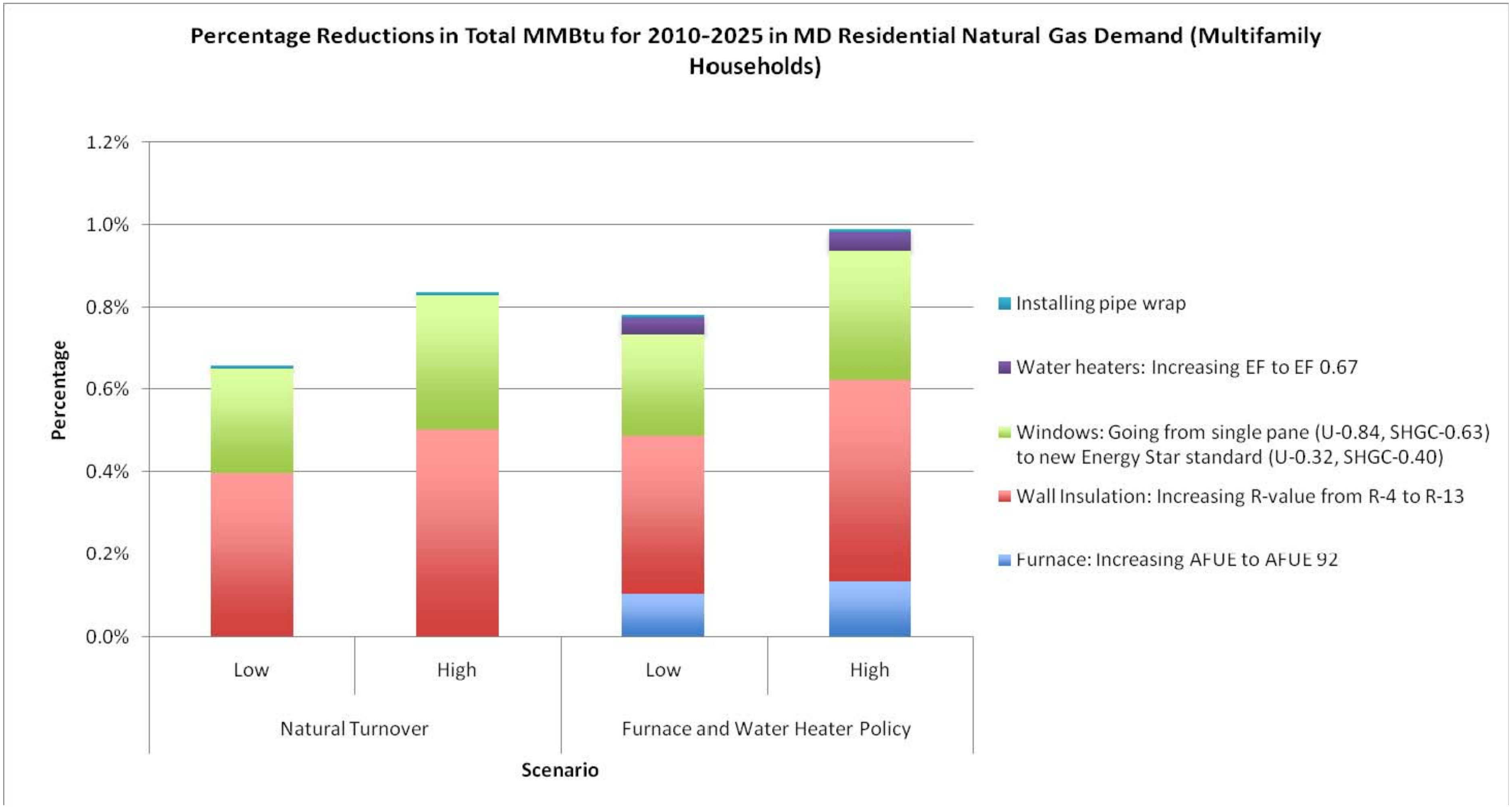


Figure 2.6- Percentage Reductions in Maryland Natural Gas Demand (Multifamily Households)

Natural gas efficiency measures implemented in single-family households could result in a reduction in total residential natural gas consumption for the period 2010-2025 of 8-18 percent, depending on the specific technology and climate scenarios. The implementation of all measures could result in savings of 14-18 percent, depending on climate, compared to the business-as-usual scenario.

The implementation of natural gas efficiency measures in multifamily households could yield reductions of up to 1 percent of total residential natural gas consumption for the period of analysis. This lower value for multifamily households is due to the following three factors: multifamily households represent only 15 percent of total households that use natural gas; average natural gas consumption of multifamily households is lower than that of single-family households, mostly due to differences in housing square footage; and we assume that ceiling insulation and duct sealing measures do not apply to multifamily households.

4.2 CO_2 Reductions

Figure 2.7 illustrates the contributions of space heating and water heating measures for both single family and multifamily homes to cumulative total potential CO_2 reductions during the period of analysis (2010-2025). Cumulative CO_2 reductions could reach 10.6-13.4 million metric tons, depending on the climate scenario, as a result of the implementation of all efficiency measures analyzed for this study. As a comparison, annual CO_2 emissions from the Maryland residential natural gas sector ranged from 3.9-5.0 million metric tons from 2000-2005 (EIA, 2005c). Therefore, the implementation of all natural gas efficiency measures could offset more than two years of residential natural gas CO_2 emissions during the period of analysis (2010-2025) based on recent emissions data.

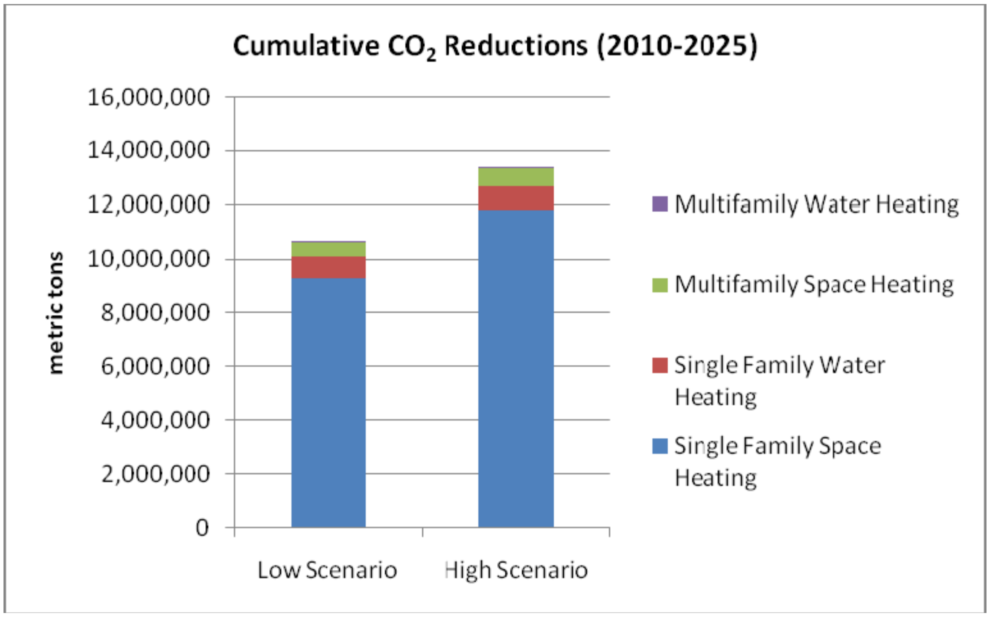


Figure 2.7- Cumulative CO_2 Reductions (2010-2025) (Metric Tons)

Single-family space heating measures make up almost 90% of the total potential CO_2 reductions in both the low and high scenarios. This result is not surprising as single-family homes make up 85% of all households in Maryland utilizing natural gas; space heating consumes about two-thirds of total natural gas use; and we assume that all building shell measures are implemented in 2010, while water heaters are replaced at the end of their natural lifetimes.

Figure 2.8 shows the contributions of each of the seven efficiency measures to single-family cumulative CO_2 reductions during the period of analysis (2010-2025). Duct sealing makes up almost one third of the cumulative CO_2 reductions followed by windows (23%), ceiling insulation (18%), and furnaces (11%). Duct sealing is therefore both the most cost-effective measure and the measure that represents the greatest potential for CO_2 reductions. Windows have significant potential yet are the most costly while the pipe wrap measure has a relatively low cost of saved energy yet represents the smallest potential for CO_2 reductions.

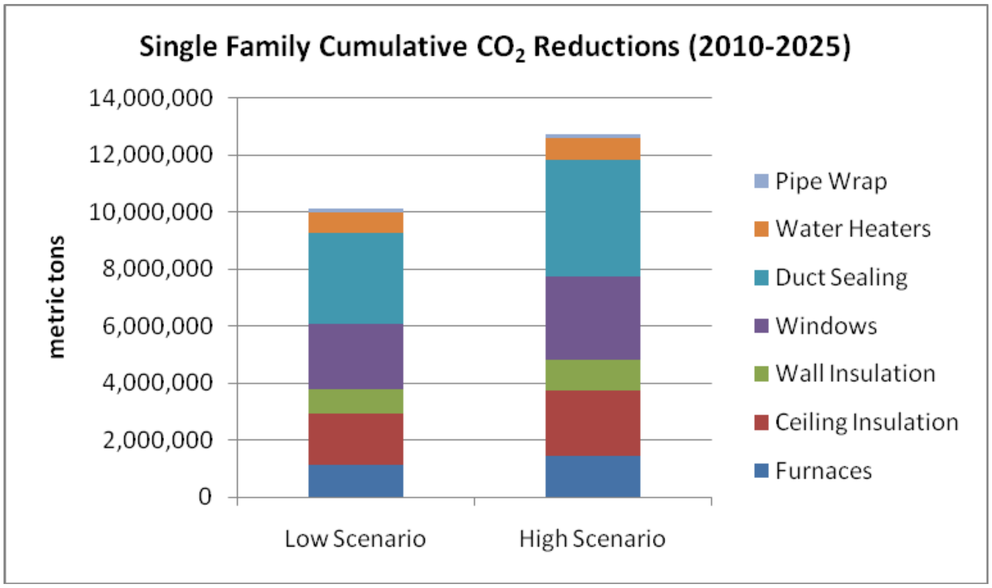


Figure 2.8- Cumulative CO_2 Reductions (Single Family Households)

It is important to note that for the purposes of this energy efficiency potential analysis, we assume that all measures other than furnaces and water heaters are installed in all applicable households in 2010. In reality, it is likely that it would take several years to implement these measures given the large number of households. Therefore, it is likely that this analysis under-represents the relative contributions of furnaces and water heaters to total potential CO_2 reductions.

Figure 2.9 shows the contributions of each of the five multifamily efficiency measures to cumulative CO_2 reductions. Wall insulation makes up almost half of the total potential CO_2 reductions followed by windows (32%), furnaces (13%), and water heaters (5%). As for single-family homes, the most cost-effective measure (wall insulation) for multifamily homes also represents the greatest potential for CO_2 reductions.

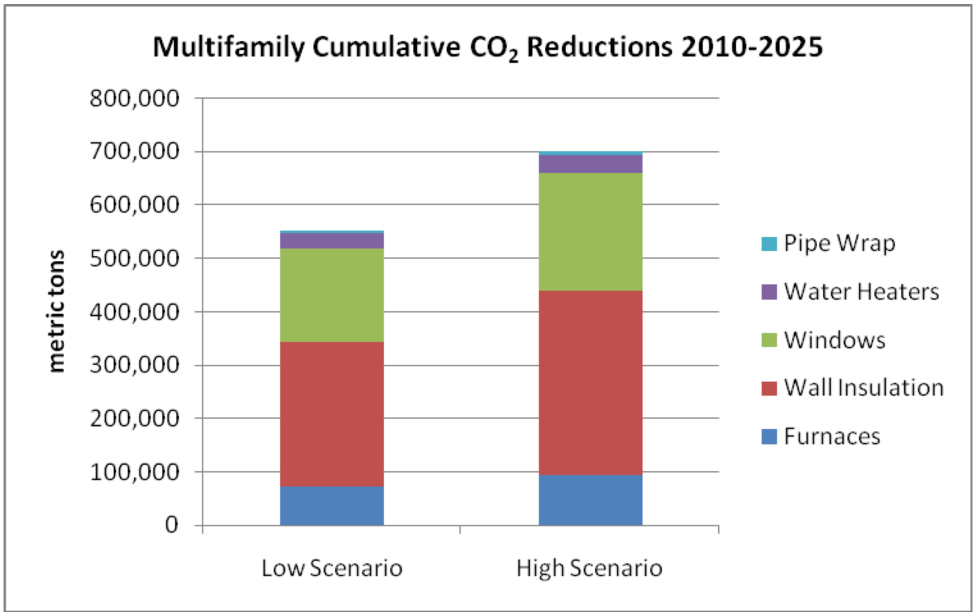


Figure 2.9- Cumulative CO_2 Reductions (Multifamily Households)

4.4 Cost of Saved Energy

A calculation of the levelized cost of saved energy (CSE), which accounts for the time value of money, can provide insight into which measures are cost-effective and would be implemented without any incentives in the absence of market barriers. The CSE in $/MMBtu for each measure was calculated by dividing the initial measure cost (both material and installation costs) by the net present value of energy savings during the measure lifetime, using a discount rate of 5%. Efficiency improvements are considered to be cost-effective for residents if the CSE is less then the average retail price of natural gas for the period of analysis (2010-2025) as forecasted by EIA. For the period of analysis, the average retail price of natural gas per MMBtu is forecast to be $16.07 in 2009 dollars (EIA, 2009).

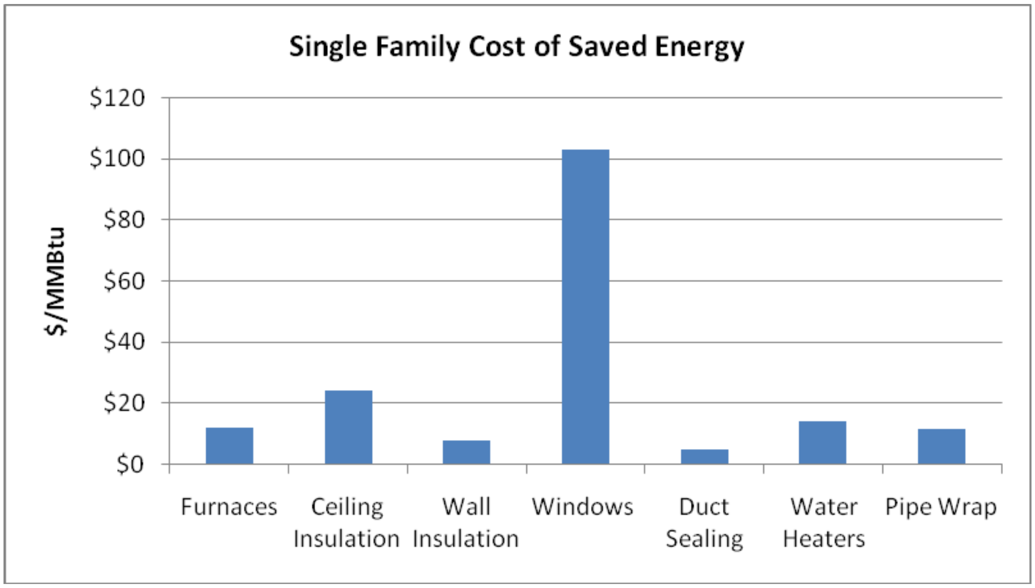


Figure 2.10- Cost of Saved Energy (Single-family households; average of low and high scenarios assuming all measures are installed)

Figure 2.10 shows the average CSE for the low and high climate scenarios for each of the efficiency measures for single-family households assuming all measures are installed. For the average single-family home in Maryland across all climate and technology scenarios, cost-effective efficiency measures include furnaces, wall insulation, duct sealing, water heaters, and pipe wraps. We find that investments in windows and ceiling insulation are not cost-effective, although in the case of ceiling insulation, the CSE in several of the scenarios is only a few dollars more than the average retail price per MMBtu (see Tables 2.S.7 and 2.S.8 of the Supplemental Data section for exact values).

The necessary incentives to encourage window upgrades may not be as high as the CSE suggests as other benefits are realized which have not been considered in this study. In terms of energy savings, windows have a very high upfront cost and a long payback period. However, window improvements offer ancillary benefits, such as improved home value due to better appearance. Therefore, homeowners might not need a large subsidy to undertake the project, which would benefit both the homeowner and the State. As both windows and ceiling insulation offer significant reductions in natural gas consumption for the State, it might be the case that Maryland would seek to incentivize these improvements even though they may have a higher CSE than other measures.

The most cost-effective measures for single-family homes are wall insulation and duct sealing. It is not surprising that duct sealing makes the list as the RESFEN model assumes that duct leakage is responsible for losses of 12-20 percent of the total energy generated by a furnace, and by sealing ducts it is possible to reduce the losses by half (LBNL, 2005).

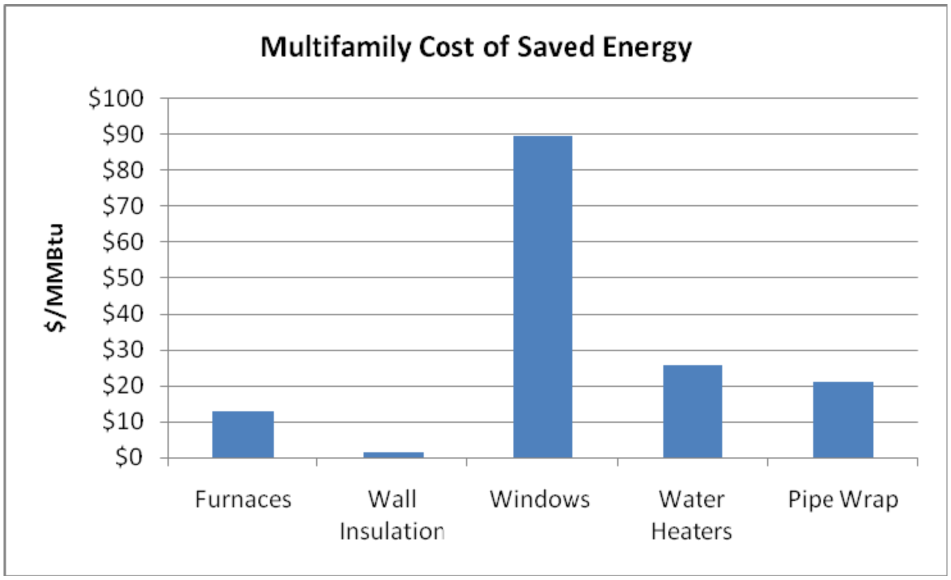


Figure 2.11- Cost of Saved Energy (Multifamily households; average of low and high scenarios assuming all measures are installed)

Cost-effective efficiency improvements in the average Maryland multifamily home include furnace improvements and wall insulation, with wall insulation by far the most cost-effective measure (see Figure 2.11). Measures which might be cost-effective for a household given some level of subsidy include pipe wraps, and to a lesser extent water heaters. As was the case in single-family homes, the CSE for window improvements for multifamily homes is significantly higher than for the other measures. (See Tables 2.S.7 and 2.S.8 of the Supplemental Data section for CSE values for an average multifamily household).

5. Summary and Conclusions

5.1 Discussion of Results

The economic potential of the natural gas efficiency measures over the period of analysis (2010-2025) could meet between 15 and 20 percent of Maryland's residential natural gas demand with the majority of savings from single-family households. For consumers, this means reductions in annual energy bills (see Table

2.S.9 of the Supplemental Data section). An average single-family household that undertook all of the energy efficiency measures investigated could save as much as $600 to $750 in 2010[7]. However, this is unlikely given that the household would need to invest approximately $16,000 in both cost effective and non-cost effective measures. If we examine only cost effective measures (wall insulation, furnaces, water heaters, duct sealing, pipe wrap), an average single-family household could save between $400 and $500 in 2010 by investing approximately $3,000 in energy efficiency measures. By including ceiling insulation, which is only slightly over the cost effective threshold, savings per household could amount to between $500 and $630 in 2010 with an investment of approximately $5,200.

As a result of reducing natural gas consumption, Maryland could reduce its CO_2 emissions by as many as 10.6 to 13.4 million tons between 2010 and 2025.

5.2 Policy Implications

A natural gas efficiency program could be considered as a potentially worthwhile undertaking for the State to further explore. However, first several factors outside the scope of this project would need to be addressed.

In this study we have assumed that 100 percent of homes eligible for a measure will adopt it, which is unlikely. In addition, a number of the measures are cost-effective investments for homeowners, suggesting that the State's role could involve removing market barriers (e.g. information campaigns identifying potential savings for homeowners).

Most of the measures analyzed for this study are cost-effective, yet market barriers prevent wide adoption. These barriers include a lack of awareness about the benefits of efficiency investments; a lack of technical knowledge and experience regarding efficiency measures on the part of homeowners and renters; the difficulty of making a large up-front investment; and split incentives in the case of landlords and renters. An efficiency program could begin to address these barriers through a combination of financial incentives, technical assistance, and education and marketing. With the limitations of the project in mind we identify the following policy implications.

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[7] Assumes an improvement in ceiling insulation from R-11 to R-38. Further, consumer savings have been calculated under the assumption that regulations concerning equipment efficiency have been strengthened and ducts have been sealed.

Improve awareness

Many households have the potential to realize significant savings through efficiency investments. Increasing awareness of the potential for efficiency improvements through education and marketing could help encourage households to make these investments.

Improve data quality

The data used to characterize the average Maryland household includes households over a broad geographic area (the entire southeastern region of the United States except Florida). As a consequence, there could be substantial error in our characterizations of an average Maryland single and multifamily household. Addressing this source of error would involve improvements to the RECS survey or an effort undertaken by the State to address the data gaps. Both of these are outside the scope of this study.

5.3 Future Research

In order to more accurately simulate real world conditions, a number of factors would need to be incorporated. In this analysis, we have only considered material and installation costs without including administrative costs. We have estimated potential energy savings based on engineering estimates while in many cases, actual energy savings are significantly less than engineering estimates would predict. In addition, we have not considered free rider or spillover effects. Finally, in this analysis we have estimated total costs of efficiency measures without regard for the division of costs between households, the State, and other parties. To better assess the necessary level of state funds to achieve the natural gas savings, it would be important to incorporate data regarding the necessary level of financial incentives to encourage the adoption of the measures analyzed.

Future research could involve a broader analysis of potential options for reducing CO_2 emissions. This could include estimates of potential natural gas reductions in the commercial/industrial sector as well as potential CO_2 reductions in the transportation and agriculture sectors. This would allow for a comparison of potential costs and benefits of various options.

6. Supplemental Data

Table 2.S.2-[8]

Measure	End Use	Specific Measure	Measure Lifetime	Single Family			Multifamily		
				Natural Gas Savings (% of Space Heating or Water Heating)	Cost per Household	Number of Households Measure Applies To	Natural Gas Savings (% of Space Heating or Water Heating)	Cost per Household	Number of Households Measure Applies To
Furnaces	Space Heating	Increasing AFUE to AFUE 92	20	--	$1,500	--	--	$700	--
Ceiling Insulation	Space Heating	Increasing R-value from R-11 to R-38	25	11.7%	$1,998	122,843	--	--	--
		Increasing R-value from R-19 to R-38	25	7.1%	$1,383	401,090	--	--	--
Wall Insulation	Space Heating	Increasing R-value from R-4 to R-13	25	16.7%	$1,025	122,843	31.4%	$153	42,397
Windows	Space Heating	Going from single pane (U-0.84, SHGC-0.63) to new Energy Star standard (U-0.32, SHGC-0.40)	25	13.5%	$10,641	407,190	13.9%	$4,662	61,657
Duct Sealing	Space Heating	Decreasing total leakage from 20% to 6% (crawl space or slab-on-grade)	15	14.0%	$334	370,071	--	--	--
		Decreasing total leakage from 12% to 6% (basement)	15	6.0%	$334	368,846	--	--	--
Water Heaters	Water Heating	Increasing EF to EF 0.67	13	--	$400	--	--	$400	--
Water Heater Pipe Wrap	Water Heating	Installing a pipe wrap to 10 ft of pipe	10	1.5%	$29	726,763	1.5%	$29	54,206

[8] Data Sources and Assumptions can be found in Table 2.S.11

Table 2.S.3-

Measure	Specific Measure	Space Heating Cumulative Natural Gas Savings 2010-2025 (MMBtus)											
		Single Family								Multifamily			
		Natural Turnover, No Duct Sealing		Natural Turnover, Duct Sealing		Furnace Policy, No Duct Sealing		Furnace Policy, Duct Sealing		Natural Turnover		Furnace Policy	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Furnaces	Increasing AFUE to AFUE 92	--	--	--	--	21,230,618	27,372,388	21,230,618	27,372,388	--	--	1,376,783	1,775,070
Ceiling Insulation	Increasing R-value from R-11 to R-38	12,911,386	16,442,449	11,620,248	14,798,205	12,518,287	15,935,631	11,266,458	14,342,068	--	--	--	--
	Increasing R-value from R-19 to R-38	25,704,786	32,734,645	23,134,307	29,461,181	24,922,179	31,725,640	22,429,962	28,553,076	--	--	--	--
Wall Insulation	Increasing R-value from R-4 to R-13	18,405,092	23,438,599	16,564,583	21,094,739	17,844,732	22,716,133	16,060,259	20,444,520	5,249,800	6,685,539	5,089,965	6,479,465
Windows	Going from single pane (U-0.84, SHGC-0.63) to new Energy Star standard (U-0.32, SHGC-0.40)	49,308,091	62,793,087	44,377,282	56,513,778	47,806,859	60,857,566	43,026,173	54,771,810	3,382,600	4,307,688	3,279,613	4,174,909
Duct Sealing	Decreasing total leakage from 20% to 6% (crawl space or slab-on-grade)	--	--	43,705,269	55,524,378	--	--	42,451,086	53,912,597	--	--	--	--
	Decreasing total leakage from 12% to 6% (basement)	--	--	18,668,827	23,717,392	--	--	18,133,099	23,028,916	--	--	--	--
Total		**106,329,355**	**135,408,780**	**158,070,516**	**201,109,672**	**124,322,675**	**158,607,358**	**174,597,654**	**222,425,373**	**8,632,400**	**10,993,227**	**9,746,361**	**12,429,445**

Table 2.S.4-

Measure	Specific Measure	Water Heating Cumulative Natural Gas Savings 2010-2025 (MMBtus)							
		Single Family				Multifamily			
		Natural Turnover		Water Heater Policy		Natural Turnover		Water Heater Policy	
		Low	High	Low	High	Low	High	Low	High
Water Heaters	Increasing EF to EF 0.67	--	--	13,410,942	14,258,603	--	--	540,300	627,759
Pipe Wrap	Installing pipe wrap	2,364,117	2,513,545	2,260,631	2,403,518	95,245	110,662	91,076	105,818
Total		**2,364,117**	**2,513,545**	**15,671,573**	**16,662,122**	**95,245**	**110,662**	**631,376**	**733,577**

Table 2.S.5-

Measure	Specific Measure	Space Heating Cumulative CO_2 Reductions 2010-2025 (metric tons)											
		Single Family								Multifamily			
		Natural Turnover, No Duct Sealing		Natural Turnover, Duct Sealing		Furnace Policy, No Duct Sealing		Furnace Policy, Duct Sealing		Natural Turnover		Furnace Policy	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Furnaces	Increasing AFUE to AFUE 92	--	--	--	--	1,126,497	1,452,379	1,126,497	1,452,379	--	--	73,052	94,185
Ceiling Insulation	Increasing R-value from R-11 to R-38	685,078	872,436	616,570	785,193	664,220	845,545	597,798	760,990	--	--	--	--
	Increasing R-value from R-19 to R-38	1,363,896	1,736,900	1,227,506	1,563,210	1,322,371	1,683,362	1,190,134	1,515,026	--	--	--	--
Wall Insulation	Increasing R-value from R-4 to R-13	976,574	1,243,652	878,917	1,119,287	946,841	1,205,318	852,157	1,084,786	278,554	354,735	270,074	343,800
Windows	Going from single pane (U-0.84, SHGC-0.63) to new Energy Star standard (U-0.32, SHGC-	2,616,287	3,331,801	2,354,659	2,998,621	2,536,632	3,229,102	2,282,969	2,906,192	179,481	228,566	174,016	221,521
Duct Sealing	Decreasing total leakage from 20% to 6% (crawl space or slab-on-grade)	--	--	2,319,002	2,946,123	--	--	2,252,455	2,860,602	--	--	--	--
	Decreasing total leakage from 12% to 6% (basement)	--	--	990,568	1,258,445	--	--	962,142	1,221,914	--	--	--	--
Total		**5,641,836**	**7,184,790**	**8,387,222**	**10,670,879**	**6,596,561**	**8,415,706**	**9,264,152**	**11,801,890**	**458,035**	**583,301**	**517,142**	**659,506**

Table 2.S.6-

Measure	Specific Measure	Water Heating Cumulative CO_2 Reductions 2010-2025 (metric tons)							
		Single Family				Multifamily			
		Natural Turnover		Water Heater Policy		Natural Turnover		Water Heater Policy	
		Low	High	Low	High	Low	High	Low	High
Water Heaters	Increasing EF to EF 0.67	--	--	711,585	756,562	--	--	28,668	33,309
Pipe Wrap	Installing pipe wrap	125,440	133,369	119,949	127,531	5,054	5,872	4,832	5,615
Total		**125,440**	**133,369**	**831,534**	**884,092**	**5,054**	**5,872**	**33,501**	**38,924**

Table 2.S.7-

Measure	Specific Measure	Space Heating Cost of Saved Energy ($/MMBtu)											
		Single Family								Multifamily			
		Natural Turnover, No Duct Sealing		Natural Turnover, Duct Sealing		Furnace Policy, No Duct Sealing		Furnace Policy, Duct Sealing		Natural Turnover		Furnace Policy	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Furnaces	Increasing AFUE to AFUE 92	--	--	--	--	$13.51	$10.60	$13.51	$10.60	--	--	$14.44	$11.33
Ceiling Insulation	Increasing R-value from R-11 to R-38	$21.71	$16.97	$24.12	$18.85	$22.46	$17.57	$24.96	$19.52	--	--	--	--
	Increasing R-value from R-19 to R-38	$24.64	$19.26	$27.38	$21.40	$25.50	$19.94	$28.33	$22.16	--	--	--	--
Wall Insulation	Increasing R-value from R-4 to R-13	$7.81	$6.11	$8.68	$6.78	$8.08	$6.32	$8.98	$7.02	$1.41	$1.10	$1.46	$1.14
Windows	Going from single pane (U-0.84, SHGC-0.63) to new Energy Star standard (U-0.32, SHGC-0.40)	$100.33	$78.42	$111.47	$87.14	$103.82	$81.20	$115.35	$90.22	$97.02	$75.84	$100.40	$78.52
Duct Sealing	Decreasing total leakage from 20% to 6% (crawl space or slab-on-grade)	--	--	$4.06	$3.21	--	--	$4.17	$3.30	--	--	--	--
	Decreasing total leakage from 12% to 6% (basement)	--	--	$9.48	$7.49	--	--	$9.72	$7.69	--	--	--	--

Table 2.S.8-

Measure	Specific Measure	Water Heating Cost of Saved Energy ($/MMBtu)							
		Single Family				Multifamily			
		Natural Turnover		Water Heater Policy		Natural Turnover		Water Heater Policy	
		Low	High	Low	High	Low	High	Low	High
Water Heaters	Increasing EF to EF 0.67	--	--	$14.79	$13.91	--	--	$27.38	$23.56
Pipe Wrap	Installing pipe wrap	$11.67	$10.98	$12.17	$11.45	$21.61	$18.60	$22.54	$19.40

Table 2.S.9- Average Annual Single-Family Household Savings (using nominal $'s) (see Table 2.S.10 for natural gas price assumptions)[9]

	Single Family																	
Year	Furnaces		Ceiling Insulation R-11 to R-38		Ceiling Insulation R-19 to R-38		Wall Insulation		Windows		Duct Sealing 20% to 6%		Duct Sealing 12% to 6%		Water Heaters		Pipe Wrap	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
2010	$133.19	$163.70	$89.53	$110.04	$54.59	$67.10	$127.63	$156.86	$103.15	$126.78	$118.85	$146.08	$50.94	$62.60	$41.51	$44.13	$4.75	$5.05
2011	$136.51	$168.57	$90.31	$111.52	$55.07	$68.00	$128.73	$158.97	$104.05	$128.48	$119.88	$148.03	$51.38	$63.44	$37.16	$39.51	$4.77	$5.07
2012	$137.84	$171.01	$92.07	$114.23	$56.14	$69.65	$131.25	$162.84	$106.08	$131.61	$122.23	$151.64	$52.38	$64.99	$35.90	$38.16	$4.84	$5.15
2013	$135.99	$169.51	$92.90	$115.81	$56.65	$70.61	$132.43	$165.08	$107.03	$133.42	$123.32	$153.73	$52.85	$65.88	$34.26	$36.43	$4.87	$5.18
2014	$139.03	$174.13	$94.02	$117.76	$57.33	$71.80	$134.03	$167.87	$108.32	$135.68	$124.81	$156.33	$53.49	$67.00	$32.63	$34.69	$4.92	$5.23
2015	$141.44	$178.00	$95.66	$120.39	$58.33	$73.41	$136.36	$171.61	$110.21	$138.70	$126.99	$159.81	$54.42	$68.49	$31.65	$33.65	$5.00	$5.31
2016	$135.62	$171.50	$97.58	$123.39	$59.50	$75.24	$139.10	$175.90	$112.42	$142.17	$129.53	$163.80	$55.51	$70.20	$30.60	$32.54	$5.09	$5.41
2017	$140.49	$178.52	$99.97	$127.03	$60.96	$77.45	$142.50	$181.08	$115.18	$146.35	$132.70	$168.62	$56.87	$72.27	$29.98	$31.87	$5.23	$5.56
2018	$149.42	$190.78	$102.29	$130.60	$62.37	$79.63	$145.81	$186.17	$117.84	$150.47	$135.78	$173.37	$58.19	$74.30	$29.73	$31.61	$5.42	$5.76
2019	$153.91	$197.48	$104.74	$134.39	$63.86	$81.94	$149.30	$191.57	$120.67	$154.83	$139.04	$178.39	$59.59	$76.45	$29.37	$31.22	$5.57	$5.92
2020	$156.38	$201.63	$105.94	$136.60	$64.60	$83.29	$151.02	$194.72	$122.06	$157.38	$140.64	$181.33	$60.27	$77.71	$28.89	$30.72	$0.00	$0.00
2021	$157.57	$204.17	$106.37	$137.82	$64.86	$84.04	$151.63	$196.47	$122.55	$158.79	$141.20	$182.96	$60.51	$78.41	$28.28	$30.07	$0.00	$0.00
2022	$158.91	$206.93	$107.12	$139.48	$65.31	$85.05	$152.70	$198.83	$123.41	$160.70	$142.20	$185.16	$60.94	$79.35	$27.87	$29.63	$0.00	$0.00
2023	$159.71	$209.01	$107.82	$141.09	$65.74	$86.03	$153.69	$201.13	$124.22	$162.56	$143.12	$187.30	$61.34	$80.27	$27.54	$29.28	$0.00	$0.00
2024	$166.30	$218.71	$112.14	$147.48	$68.38	$89.93	$159.85	$210.24	$129.20	$169.92	$148.86	$195.78	$63.80	$83.91	$28.19	$29.97	$0.00	$0.00
2025	$171.42	$226.58	$115.61	$152.82	$70.49	$93.18	$164.80	$217.84	$133.20	$176.06	$0.00	$0.00	$0.00	$0.00	$28.62	$30.43	$0.00	$0.00

[9] Savings are based on the scenario where all measures are implemented (e.g. furnace policy, duct sealing). Savings were calculated using nominal natural gas prices from AEO 2009 for the South Atlantic region (see Table 2.S.10).

Table 2.S.10- Nominal natural gas prices from Annual Energy Outlook (AEO) 2009 for the South Atlantic region

Year	$2007/MMBtu	$Nominal/MMBtu
2010	13.69	14.41
2011	13.78	14.71
2012	13.97	15.17
2013	13.95	15.47
2014	13.99	15.83
2015	14.07	16.28
2016	14.15	16.75
2017	14.33	17.34
2018	14.56	18.01
2019	14.73	18.63
2020	14.74	19.04
2021	14.69	19.31
2022	14.72	19.64
2023	14.77	19.96
2024	15.34	20.96
2025	15.81	21.81

Table 2.S.11-

Measure	Baseline Assumption	New Measure Assumption	Measure notes
Natural Gas Furnace	Baseline varies by year as predicted by furnace vintage model	1. No policy: Natural turnover 2. Institute policy: AFUE 92 (replaced upon burnout)	Number of homes using natural gas from DOE (EIA, 2007). Percentage of homes with own furnace from RECS (EIA, 2005a). Percentage of homes utilizing natural gas (U.S. Census Bureau, 2000; EIA, 2005a). Percentage of homes using a furnace RECS (EIA, 2005a). Lifetime estimates (DOE, 2009a). Costs from Maryland contractors (Maryland Contractors, 2009). Savings calculated from increase in AFUE.
Seal Ductwork	20% duct leakage for homes with slab-on-grade/crawl-space (LBNL, 2005)	Reduces leakage to 6% (LBNL, 2005)	Baseline consumption is average MD space heating for homes with furnaces using natural gas. Measure life from Efficiency Vermont (Efficiency Vermont, 2006). Number of homes by foundation type from RECS (EIA, 2005a). Savings estimates from RESFEN 5.0 (LBNL, 2005). Costs from DEER (CPUC, 2008).
Seal Ductwork	12% duct leakage for homes with a basement (LBNL, 2005)	Reduces leakage to 6% (LBNL, 2005)	Baseline consumption is average MD space heating for homes with furnaces using natural gas. Measure life from Efficiency Vermont (Efficiency Vermont, 2006). Number of homes by foundation type from RECS (EIA, 2005a). Savings estimates from RESFEN 5.0 (LBNL, 2005). Costs from DEER (CPUC, 2008).
Ceiling Insulation	Households that currently have R-11 (ACEEE, 2008)	R-38 (ACEEE, 2008)	Baseline consumption is average MD space heating for homes with furnaces using natural gas. Measure lifetime from Efficiency Vermont (Efficiency Vermont, 2006). Costs from (RSMeans, 2009). Percentage applicable, "stock poorly insulated and stock with no insulation" from RECS (EIA, 2005a). Assumption is based upon previous research (ACEEE, 2008). Savings from RESFEN 5.0 simulations (LBNL, 2005); using weighted average of results for average MD 1 and 2 story home, assuming single pane windows. Percentage of homes by stories from RECS (EIA, 2005a).
Ceiling Insulation	Households that currently have R-19 (ACEEE, 2008)	R-38 (ACEEE, 2008)	Baseline consumption is average MD space heating for homes with furnaces using natural gas. Measure lifetime from Efficiency Vermont (Efficiency Vermont, 2006). Costs from (RSMeans, 2009). Percentage applicable, "stock adequately insulated" from RECS (EIA, 2005a). Assumption is based upon previous research (ACEEE, 2008). Savings from RESFEN 5.0 simulations (LBNL, 2005) using weighted average of results for average MD 1- and 2-story homes, assuming single pane windows. Percentage of homes by stories from RECS (EIA, 2005a).
Wall Insulation	Households that currently have an un-insulated wall (R-4) (ACEEE, 2008)	R-13; blow in wall insulation (ACEEE, 2008)	Baseline consumption is average MD space heating for homes with furnaces using natural gas. Savings from RESFEN 5.0 simulations (ACEEE, 2008) using weighted average of 1-story and 2-story homes assuming R-7 wall and single-pane windows, increased by multiplier (2.625) to incorporate savings from R-4 to R-7. Percentage applicable, homes, which responded "poorly insulated" RECS (EIA, 2005a). Cost from DEER (CPUC, 2008) adjusted for MD using city cost indexes (RS Means, 2009). Wall area calculated based on average square footage of 1-and2-story homes RECS (EIA, 2005a) assuming a square floor plan. Multi-family units are assumed to have 1.5 exterior walls. Measure lifetime from Efficiency Vermont (Efficiency Vermont, 2006).
Windows	Households that currently have single pane windows (U-0.84, SHGC-0.63) (ACEEE, 2008)	Energy Star windows (U-0.32, SHGC-0.40) (ACEEE, 2008)	Baseline consumption is average MD space heating for homes with furnaces using natural gas. Savings from RESFEN 5.0 simulations (LBNL, 2005) using weighted average of 1-and 2-story homes. Costs from contractors (Personal Communication with Maryland Contractors, 2009). Average window area based upon home square footage RESFEN 5.0 (LBNL, 2005). Heated square footage from RECS (EIA, 2005a). Lifetime from Efficiency Vermont (Efficiency Vermont, 2006).

Pipe wrap	Assume no pipe wrap (ACEEE, 2008)	Installing pipe wrap to 10 ft. of pipe leaving water heater. (ACEEE, 2008)	Baseline consumption is average MD single-family water heating natural gas use. Savings based on electric savings assuming 3/4" pipe (CL&P, 2008) and average electric water heater energy use (U.S. DOE, 2009b). Cost from DEER (CPUC, 2008) adjusted for MD using city cost indexes (RS Means, 2009). Lifetime from Efficiency Vermont (Efficiency Vermont, 2006). Applicable houses include all natural gas homes with natural gas water heaters.
Water heater	Baseline varies by year as predicted by water heater vintage model	1. No policy: Natural Turnover 2. Institute policy: EF 0.67 (replaced upon burnout)	Baseline consumption is average MD single-family water heating natural gas use; savings based on EF increase. Incremental cost from Energy Star (Energy Star, 2008). Lifetime from Efficiency Vermont (Efficiency Vermont, 2006). Houses applicable are number of households installing water heaters each year (replacement and new construction) that would purchase EF 0.59 under business as usual scenario (based on water heater lifetime, new construction estimates, and NEMS input data for AEO 2009).

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III. Knapsack Problem Formulation for Carbon Reduction Benefits in Natural Gas: Identifying Optimal Spending

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1. Introduction

If the State of Maryland were to consider funding efforts to improve residential natural gas efficiency, it would be useful to know what measures or combination of measures could be the most efficient in reducing carbon dioxide emissions taking into account the costs of these measures. Finding such an optimal mixture of measures can be approached as a classical "knapsack problem" from Operations Research. In this setting, one attempts to maximize the benefits (i.e., reductions in carbon dioxide emissions) by picking the best set of home improvement or other measures to stay within a given financial budget. This class of problems derives its name from the challenge faced by someone who is constrained by a fixed-size knapsack and must fill it with the most beneficial items.

While the funds might come from a variety of sources, policy makers are asking strategic questions about how the auction revenues from RGGI might be utilized to leverage greater reductions in CO_2 emissions beyond that cap. Each state that has signed up for RGGI can allocate a certain portion of the resulting CO_2 allowance proceeds for public benefit such as energy efficiency or other programs. The fifth CO_2 Allowance Auction was held on September 9, 2009 marking the first year of the program. By then, more than $432.7 million in allowance proceeds were raised.[10]

This study explores the possible benefits that could be accrued from using allowance proceeds for investments in residential natural gas efficiency in Maryland, although the source of funding would not really make a difference in the results.

2. Mathematical Formulation of Knapsack Problem and Data

The Knapsack Problem (KP) is a classical formulation in Operations Research relating to selecting a subset of n items so as to maximize the total value of the subset while

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[10] (http://www.rggi.org/docs/Auction_5_News_Release_MM_Report.pdf).

maintaining a budget-like constraint. In the current context, the items to select relate to seven measures to improve energy efficiency in the residential natural gas sector.

These measures are:

- Furnace replacement (increasing furnace to 92 % fuel usage efficiency)
- Improvements in ceiling insulation (improving the thermal resistance value from current level/standard to R-38[11]) and improved wall insulation (increase the thermal resistance value from current level/standard to R-13)
- Replacement of windows (single pane with Energy Star windows)
- Duct sealing (reduce the air leakage for crawl spaces and basements)
- Replacement of water heaters (improving efficiency to 67%)
- Wrapping the water heater pipes (up to 10 ft of pipe)

Each of these measures can be chosen separately or in combination, resulting in $2^7 - 1 = 127$ different options (i.e., possible combinations of measures). [12] It is not necessarily the case that the benefit of adopting measures k and j, $B(k \cap j)$ is equal to the sum of their separate benefits (i.e., $B(k) + B(j)$).

Thus, if x_i is the binary variable representing if option i is chosen ($x_i = 1$) or not ($x_i = 0$), then the following represents the total benefit:

(1) $$\sum_{i=1}^{127} B(i)x_i$$

This sum takes into account all of the 127 possible options. In the present context, the benefit of option i represents the net present value of tons of CO_2 that can be reduced by selecting the particular combination of efficiency measures. In what follows, we present a model to maximize the benefit of CO_2 reduction while taking into account a budget constraint

(2) $$\sum_{i=1}^{127} c_i x_i \leq Budget$$

where c_i is the cost of option i and *Budget* is the net present value of the total amount of funding available.

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[11] The R value is a measure of thermal resistance which is the ratio of temperature difference across the material to the heat flux through it. As the R value increases the resistance increases and hence less heat is lost.

[12] If all of the 2^7 combinations were allowed, this would include the empty set, which is not relevant here.

It is important to note that the costs considered in this analysis represent the total measure and installation costs, not necessarily the total costs that the State would accrue since households and possibly other entities would likely contribute a significant portion. Therefore, budget levels do not necessarily refer to State budget levels, but rather the total amount of funding contributed by all parties.

3. Model

The model assumes one of the 127 combinations can be selected. The full knapsack problem for this model is

$$(3)\qquad \begin{aligned} &\max \sum_{i=1}^{127} B(i)x_i \\ &\sum_{i=1}^{127} c_i x_i \le Budget \\ &\sum_{i=1}^{127} x_i = 1 \\ &x_i \in \{0,1\}, i = 1,\ldots,127 \end{aligned}.$$

Here, the benefit of options i and *j* being picked would be $B(i \text{ and } j)$.

4. Analysis

4.1 Overview

To understand the tradeoff between funding levels and the possible energy efficiency benefits, a variety of scenarios were run and analyzed using the knapsack problem (3) shown above. Specifically, for each of the 127 options, the net present value of the total cost and the total CO_2 reductions are calculated. The CO_2 reductions are calculated for both the "low" and "high" climate scenarios described in Chapters I and II. While the analysis in Chapter II assumes that all measures other than furnaces and water heaters are installed in 2010, this analysis instead assumes that the measures other than furnaces and water heaters are installed in equal increments over the period of analysis (2010-2025). In addition, two scenarios were run for each of the two climate scenarios: the first assumes that all measures are implemented in all applicable households and thus 100% of costs and CO_2 reductions are used; the second assumes that all measures are implemented in 50% of all applicable households and thus 50% of costs and CO_2 reductions are used. The 50% scenario attempts to take into account budget and program implementation constraints that could prevent measures being implemented in all applicable households. Lastly, an annual budget of $5,000,000, leading to a cumulative net present value of $54,188,848 for

2010-2025 was used as a base level. Twenty different budget levels were tried starting with this base level all the way up to 20 times it.

Thus, there were four scenarios used:

- 100% costs and CO_2 reductions, but with low CO_2 reduction estimates
- 100% costs and CO_2 reductions, but with high CO_2 reduction estimates
- 50% costs and CO_2 reductions, but with low CO_2 reduction estimates
- 50% costs and CO_2 reductions, but with high CO_2 reduction estimates

For each of these scenarios, twenty budget levels were used and the knapsack problem was repeatedly solved.

4.2 Regression Results on Solutions to Knapsack Problem

The results were somewhat similar for each of these four scenarios. Namely, there was a strongly diminishing effect of using more dollars to fund CO_2 reductions. If we consider the first scenario, from figures 3.1, 3.2 and 3.3, we see that a logarithmic equation best describes the relationship between funding and ultimate CO_2 reduction. This equation for all four scenarios takes on the form:

(4) $y = \alpha \ln(x) - \beta$

where

α, β are positive values

y is the net present value of millions of tons of CO_2 reduced from the specific energy efficiency options selected

x is the net present value of budget in millions of dollars that is devoted to these natural gas efficiency options.

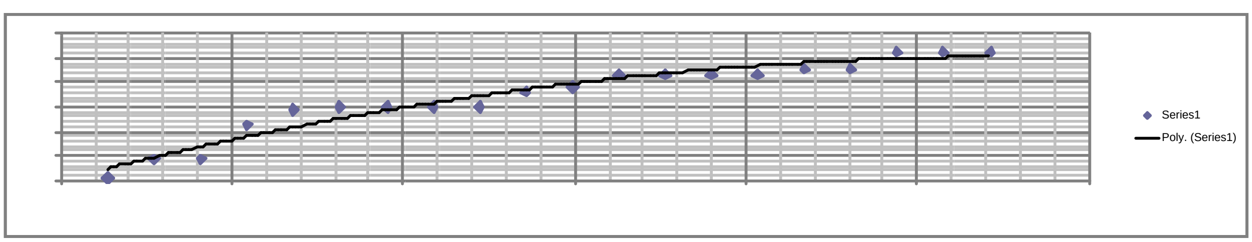

Figure 3.1 - Quadratic Fit, 100%C0₂Low Scenario

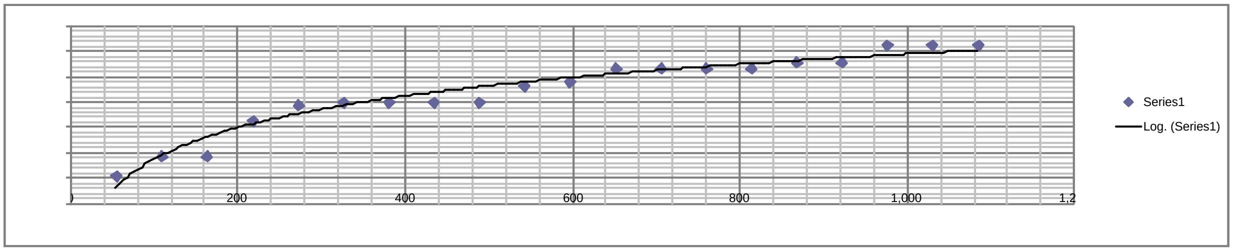

Figure 3.2 - Logarithmic Fit, 100%CO2Low Scenario

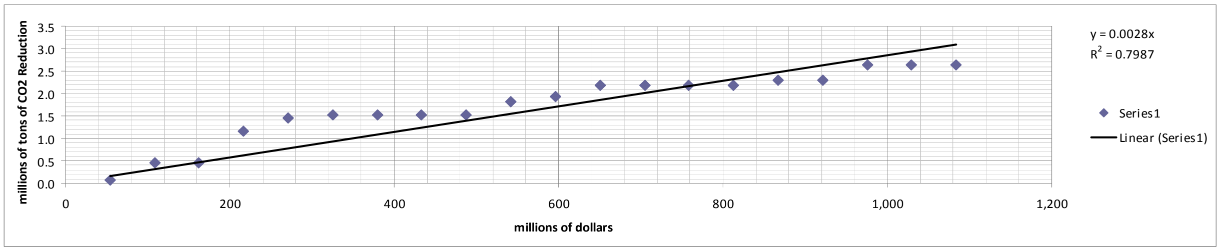

Figure 3.2 - Linear Fit, 100%CO2Low Scenario

The following table summarizes the results for the four scenarios.

Table 3.1 - Regression Results for Knapsack Problem

Scenario	Equations	R^2 value
100% costs and CO_2 reductions, but with low CO_2 reduction estimates	**$y = 0.8997\ln(x) - 3.7678$** $y = -2E-06x^2 + 0.0045x$ $y = 0.0028x$	**$R^2 = 0.9549$** $R^2 = 0.9473$ $R^2 = 0.7987$
100% costs and CO_2 reductions, but with high CO_2 reduction estimates	**$y = 1.1218\ln(x) - 4.6748$** $y = -3E-06x^2 + 0.0058x$ $y = 0.0036x$	**$R^2 = 0.9555$** $R^2 = 0.9431$ $R^2 = 0.7697$
50% costs and CO_2 reductions, but with low CO_2 reduction estimates	**$y = 0.4896\ln(x) - 1.7648$** $y = -2E-06x^2 + 0.0037x$ $y = 0.0019x$	**$R^2 = 0.9802$** $R^2 = 0.9462$ $R^2 = 0.3927$
50% costs and CO_2 reductions, but with high CO_2 reduction estimates	**$y = 0.606\ln(x) - 2.1617$** $y = -3E-06x^2 + 0.0046x$ $y = 0.0024x$	**$R^2 = 0.9811$** $R^2 = 0.9402$ $R^2 = 0.348$

4.3 How to Use the Regression Results

The importance of the results shown above are in planning how best to use funds for an efficiency program, such as funds from RGGI auction revenue or other sources. For example, if we believed that Scenario 1 (100% costs and CO_2 reductions, but with low CO_2 reduction estimates), was the most accurate, then from Table 3.1, we see that the following equation is relevant

(5) $$y = 0.8997\ln(x) - 3.7678$$

Thus, if a CO_2 reduction of 2 million tons were desired [13], then we would solve (5) for a value of $y = 2$. This would mean for

(6) $$\begin{aligned} & 2 = 0.8997\ln(x) - 3.7678 \\ \Leftrightarrow & \frac{5.7678}{0.8997} = \ln(x) \\ \Leftrightarrow & \exp\left(\frac{5.7678}{0.8997}\right) = x \\ \Leftrightarrow & x = 608.3824 \end{aligned}$$

Given these findings, a net present value of about 608 million dollars of funding from RGGI would be needed to achieve a net present value of 2 million tons of CO_2 emissions from residential natural gas use in Maryland.

In contrast, if we believed that Scenario 4 (50% costs and CO_2 reductions, but with high CO_2 reduction estimates), was the most accurate, then a similar line of reasoning would give a necessary funding level of 960 million dollars. The ranges for three selected levels of CO_2 reductions are given below in Table 3.2. Note that all reductions and funding levels are net present values.

[13] Strictly speaking, (5) and other regression equations should only be used for the ranges of values for which they were estimated.

Table 3.2 - Ranges of Required Funding ($millions) for Achieving Several Levels of CO_2 Reduction (logarithmic functions used)

CO_2 Reductions (Millions of tons)	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	$200.20	$157.38	$283.46	$184.44
2	$608.38	$383.78	$2,185.37	$960.54
3	$1,848.79	$935.90	$16,848.66	$5,002.32

Thus, we see that to achieve a net present value CO_2 reduction of 1 million tons of CO_2, it would take a net present value investment of between 157 and 283 million dollars. This range widens as the desired CO_2 reduction levels increase due to the differences in the logarithmic functions used. However, one can say that Scenario 2 provides the minimum funding levels and Scenario 3 provides the high-end estimates.

IV. Economic and Fiscal Impacts of Residential Natural Gas Efficiency Improvements in Maryland

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1. Introduction

RESI was tasked with determining the economic and fiscal impact of the implementation of an energy saving program for households. Specifically, the adopted energy efficiency measures are outlined in the table below.

Table 4.1 – Energy Efficiency Measures Adopted by Maryland Households

Measure	End Use	Specific Measure
Furnaces	Space Heating	Increasing AFUE to AFUE 92
Ceiling Insulation	Space Heating	Increasing R-value from R-11 to R-38
		Increasing R-value from R-19 to R-38
Wall Insulation	Space Heating	Increasing R-value from R-4 to R-13
Windows	Space Heating	Going from single pane (U-0.84, SHGC-0.63) to new Energy Star standard (U-0.32, SHGC-0.40)
Duct Sealing	Space Heating	Decreasing total leakage from 20% to 6% (crawl space or slab-on-grade)
		Decreasing total leakage from 12% to 6% (basement)
Water Heaters	Water Heating	Increasing EF to EF 0.67
Water Heater Pipe Wrap	Water Heating	Installing a pipe wrap to 10 ft of pipe

For each of the energy savings programs implemented, there are two direct economic and fiscal impacts. First, the installation of new water heaters, windows, etc. will generate new economic activity in the construction sector of the economy. Second, as households realize savings from these measures, they will likely increase their expenditures on goods and services.

The program is scheduled to be implemented over the time period 2010 through 2025 with the bulk of the installation taking place in the first five years of the program. Using data on the number of households (both single and multifamily), estimates of the installation costs, and the estimates of household savings, all of which were provided by CIER, RESI estimated the total costs of installation and the total realized savings attributable to these programs for each year, from 2010 through 2025. To distribute the energy savings across households, RESI used Maryland's income distribution. For household savings, there are two scenarios, a high savings and low savings.

To undertake the analysis, RESI used IMPLAN and input-output model. Input-output models are the primary tool used by economists to measure the total economic impact of a policy, business or event. For example, input-output models are used to measure the total economic impacts associated with the relocation of a firm to an area. For more information on the IMPLAN model, please see the Supplemental Information section below.

The theory behind economic impact analysis is that the total economic impact of a new firm entering a region is not merely limited to the number of employees the firm hires or to the payroll associated with these employees. Rather, the total economic impact includes these impacts as well as additional, multiplicative impacts. Multiplicative impacts occur as the new firm spends money in the region on goods and services and as the wages of employees trickle through the local economy.

Specifically, there are three types of impacts captured by input-output models:

- ***Direct impacts:*** these impacts are generated when the new business creates new jobs and hires workers to fill those jobs.
- ***Indirect impacts:*** these impacts accrue as the new firm purchases goods and services from other locally situated businesses.
- ***Induced impacts:*** both the direct and indirect impacts result in an increase in area household income. This increase allows local households to ramp up their spending at local area businesses. The increase in local spending is referred to as the induced impacts.

For the purpose of this analysis, the direct impacts are considered to be equal to the value of the energy savings as they accrue to households and the revenues as they accrue to firms installing the required energy saving devices. The indirect impacts accrue to additional supporting businesses (through purchases of goods and services by businesses and consumers that receive the direct impacts). The induced impacts result from increased household income and related spending which is driven by the direct and indirect impacts.

2. Results

The table below provides the total economic and fiscal impacts attributable to the household spending and the economic and fiscal impact of the installation of the devices over the period 2010 through 2025.

Table 4.2 - Total Economic and Fiscal Impacts 2010-2025

Efficiency Spending Low	**Direct**	**Indirect**	**Induced**	**Total**
Employment	2,448	604	793	3,848
Wages	$82,375,470	$25,180,212	$27,729,142	$135,284,852
GDP	$231,537,753	$81,366,394	$79,674,904	$392,579,045
State and Local Taxes	$22,841,363	$4,535,034	$7,103,048	$34,479,445
Efficiency Spending High	**Direct**	**Indirect**	**Induced**	**Total**
Employment	3,076	760	997	4,835
Wages	$103,506,884	$31,639,588	$34,842,390	$169,988,872
GDP	$290,933,102	$102,238,965	$100,113,566	$493,285,610
State and Local Taxes	$28,700,757	$5,698,390	$8,925,158	$43,324,305
Installation	**Direct**	**Indirect**	**Induced**	**Total**
Employment	44,707	15,103	21,626	81,437
Wages	$2,072,969,344	$634,215,066	$754,801,791	$3,461,986,259
GDP	$6,827,419,136	$1,969,142,880	$2,168,799,092	$10,965,361,328
State and Local Taxes	$62,354,692	$165,439,696	$254,667,913	$482,462,301

From table 4.2, the total direct employment form household spending in the low scenario is nearly 2,500 and then due to spillover effects (indirect and induced), it rises to nearly 4,000 jobs paying on average $35,000. Moreover, the direct increase in economic activity, as measured by Gross Domestic Product (GDP), is approximately $231 million and due to the multiplicative effect, the total economic activity attributable to household spending in the low scenario is nearly $400 million. Finally, the state and local taxes that are likely to be generated is just under $35 million.

Using the latest data from the Bureau of Economic Analysis, Maryland's Gross Domestic Product (GDP) was approximately $273 Billion in 2008 and employment was 2.6 million in 2008. So to put the findings for household spending into context, the annual GDP and employment that is generated through these programs would amount to less than 0.01 percent per year of Maryland's current GDP level and employment levels.

The installation of these energy saving devices will support approximately 44,000 jobs in the trades sector of the economy and will likely generate over 80,000 jobs over the entire period, paying on average $41,000. Because of the current state of the economy and given the general decline in construction employment in the state, much of the excess construction employment generated through the deployment of a natural gas efficiency program could be absorbed through existing jobs. As a consequence, not all of the jobs supported by the program would be net additions to the economy. The economic activity (GDP) directly generated by the installation exceeds six billion dollars and will rise to over ten billion dollars when all the multiplicative impacts are accounted for in the analysis. Finally, the state and local tax revenues will rise to nearly $500 million over the lifetime of the project.

Again to put the findings into context, the annual GDP and employment that is generated would only constitute 0.26% per year of Maryland's current GDP levels and 0.21 percent per year of Maryland's current employment levels. For more detailed, year-by-year findings, please see the Supplemental Information section below.

3. Supplemental Information

Detailed Tables

In the following tables, the annual economic and fiscal impacts are reported.

Table 4.3A - Efficiency Spending Low Scenario, Employment

	Employment			
	Direct	**Indirect**	**Induced**	**Total**
2010	141	35	46	221
2011	142	35	46	224
2012	143	35	46	225
2013	144	35	47	226
2014	145	36	47	228
2015	147	36	48	230
2016	148	37	48	233
2017	152	38	49	239
2018	157	39	51	246
2019	161	40	52	252
2020	161	40	52	253
2021	162	40	53	255
2022	164	40	53	257
2023	165	41	53	259
2024	172	42	56	270
2025	145	36	47	227
Total	**2,448**	**604**	**793**	**3,845**

Table 4.3B- Efficiency Spending Low Scenario, Wages

	Wages			
	Direct	**Indirect**	**Induced**	**Total**
2010	$4,742,599	$1,449,699	$1,596,449	$7,788,747
2011	$4,791,150	$1,464,540	$1,612,792	$7,868,482
2012	$4,821,794	$1,473,907	$1,623,107	$7,918,809
2013	$4,832,467	$1,477,170	$1,626,700	$7,936,337
2014	$4,883,819	$1,492,867	$1,643,986	$8,020,671
2015	$4,937,853	$1,509,384	$1,662,175	$8,109,411
2016	$4,994,584	$1,526,725	$1,681,271	$8,202,580
2017	$5,125,480	$1,566,737	$1,725,334	$8,417,550
2018	$5,267,418	$1,610,124	$1,773,113	$8,650,655
2019	$5,406,455	$1,652,624	$1,819,915	$8,878,995
2020	$5,418,017	$1,656,158	$1,823,807	$8,897,983
2021	$5,457,884	$1,668,345	$1,837,227	$8,963,456
2022	$5,504,351	$1,682,549	$1,852,869	$9,039,768
2023	$5,544,813	$1,694,917	$1,866,489	$9,106,218
2024	$5,774,737	$1,765,199	$1,943,886	$9,483,822
2025	$4,872,048	$1,489,269	$1,640,024	$8,001,340
Total	**$82,375,470**	**$25,180,212**	**$27,729,142**	**$135,284,824**

Table 4.3C- Efficiency Spending Low Scenario, GDP

	GDP			
	Direct	**Indirect**	**Induced**	**Total**
2010	$13,330,312	$4,684,503	$4,587,119	$22,601,935
2011	$13,466,778	$4,732,460	$4,634,079	$22,833,318
2012	$13,552,911	$4,762,729	$4,663,718	$22,979,358
2013	$13,582,911	$4,773,271	$4,674,042	$23,030,224
2014	$13,727,247	$4,823,994	$4,723,710	$23,274,951
2015	$13,879,124	$4,877,366	$4,775,972	$23,532,462
2016	$14,038,581	$4,933,402	$4,830,843	$23,802,826
2017	$14,406,499	$5,062,694	$4,957,448	$24,426,641
2018	$14,805,453	$5,202,894	$5,094,733	$25,103,081
2019	$15,196,254	$5,340,228	$5,229,212	$25,765,694
2020	$15,228,751	$5,351,648	$5,240,395	$25,820,795
2021	$15,340,807	$5,391,026	$5,278,955	$26,010,788
2022	$15,471,415	$5,436,924	$5,323,898	$26,232,238
2023	$15,585,143	$5,476,890	$5,363,034	$26,425,067
2024	$16,231,405	$5,703,998	$5,585,420	$27,520,823
2025	$13,694,162	$4,812,367	$4,712,325	$23,218,853
Total	**$231,537,753**	**$81,366,394**	**$79,674,904**	**$392,579,051**

Table 4.3D- Efficiency Spending Low Scenario, State and Local Taxes

	State and Local Taxes			
	Direct	**Indirect**	**Induced**	**Total**
2010	$1,315,045	$261,095	$408,943	$1,985,083
2011	$1,328,507	$263,768	$413,130	$2,005,405
2012	$1,337,004	$265,455	$415,772	$2,018,232
2013	$1,339,964	$266,043	$416,693	$2,022,699
2014	$1,354,203	$268,870	$421,121	$2,044,193
2015	$1,369,185	$271,845	$425,780	$2,066,810
2016	$1,384,916	$274,968	$430,672	$2,090,555
2017	$1,421,211	$282,174	$441,958	$2,145,344
2018	$1,460,568	$289,988	$454,197	$2,204,754
2019	$1,499,121	$297,643	$466,186	$2,262,950
2020	$1,502,327	$298,279	$467,183	$2,267,790
2021	$1,513,381	$300,474	$470,621	$2,284,476
2022	$1,526,266	$303,032	$474,628	$2,303,926
2023	$1,537,485	$305,260	$478,116	$2,320,862
2024	$1,601,240	$317,918	$497,942	$2,417,100
2025	$1,350,939	$268,222	$420,106	$2,039,266
Total	**$22,841,363**	**$4,535,034**	**$7,103,048**	**$34,479,445**

Table 4.4A - Efficiency Spending High Scenario, Employment

	Employment			
	Direct	**Indirect**	**Induced**	**Total**
2010	171	42	55	268
2011	173	43	56	272
2012	175	43	57	275
2013	176	44	57	277
2014	179	44	58	281
2015	182	45	59	286
2016	185	46	60	291
2017	191	47	62	300
2018	197	49	64	309
2019	203	50	66	319
2020	205	51	66	322
2021	207	51	67	325
2022	210	52	68	330
2023	212	52	69	334
2024	222	55	72	349
2025	188	46	61	295
Total	3,076	760	997	4,833

Table 4.4B - Efficiency Spending High Scenario, Wages

	Wages			
	Direct	**Indirect**	**Induced**	**Total**
2010	$5,737,648	$1,753,862	$1,931,402	$9,422,912
2011	$5,820,386	$1,779,153	$1,959,253	$9,558,792
2012	$5,891,658	$1,800,940	$1,983,244	$9,675,842
2013	$5,933,287	$1,813,664	$1,997,257	$9,744,208
2014	$6,024,723	$1,841,614	$2,028,036	$9,894,373
2015	$6,124,110	$1,871,994	$2,061,492	$10,057,596
2016	$6,223,063	$1,902,242	$2,094,802	$10,220,107
2017	$6,417,745	$1,961,752	$2,160,335	$10,539,832
2018	$6,627,254	$2,025,794	$2,230,860	$10,883,908
2019	$6,833,083	$2,088,711	$2,300,146	$11,221,940
2020	$6,888,359	$2,105,607	$2,318,753	$11,312,720
2021	$6,970,452	$2,130,701	$2,346,387	$11,447,540
2022	$7,063,557	$2,159,161	$2,377,728	$11,600,446
2023	$7,149,476	$2,185,424	$2,406,650	$11,741,550
2024	$7,481,548	$2,286,931	$2,518,432	$12,286,910
2025	$6,320,535	$1,932,037	$2,127,613	$10,380,185
Total	$103,506,884	$31,639,588	$34,842,390	$169,988,862

Table 4.4C - Efficiency Spending High Scenario, GDP

	GDP			
	Direct	**Indirect**	**Induced**	**Total**
2010	$16,127,157	$5,667,364	$5,549,548	$27,344,069
2011	$16,359,714	$5,749,089	$5,629,574	$27,738,376
2012	$16,560,043	$5,819,488	$5,698,509	$28,078,040
2013	$16,677,050	$5,860,606	$5,738,773	$28,276,429
2014	$16,934,055	$5,950,922	$5,827,211	$28,712,188
2015	$17,213,408	$6,049,092	$5,923,340	$29,185,839
2016	$17,491,543	$6,146,833	$6,019,049	$29,657,425
2017	$18,038,746	$6,339,130	$6,207,349	$30,585,225
2018	$18,627,627	$6,546,073	$6,409,990	$31,583,690
2019	$19,206,163	$6,749,381	$6,609,071	$32,564,615
2020	$19,361,531	$6,803,980	$6,662,535	$32,828,045
2021	$19,592,273	$6,885,066	$6,741,936	$33,219,276
2022	$19,853,970	$6,977,031	$6,831,989	$33,662,990
2023	$20,095,468	$7,061,898	$6,915,091	$34,072,457
2024	$21,028,842	$7,389,902	$7,236,276	$35,655,020
2025	$17,765,513	$6,243,111	$6,113,326	$30,121,949
Total	$290,933,102	$102,238,965	$100,113,566	$493,285,633

Table 4.4D - Efficiency Spending High Scenario, State and Local Taxes

	State and Local Taxes			
	Direct	**Indirect**	**Induced**	**Total**
2010	$1,590,955	$315,876	$494,744	$2,401,576
2011	$1,613,897	$320,431	$501,878	$2,436,207
2012	$1,633,660	$324,355	$508,024	$2,466,039
2013	$1,645,203	$326,647	$511,614	$2,483,463
2014	$1,670,557	$331,681	$519,498	$2,521,735
2015	$1,698,115	$337,152	$528,068	$2,563,335
2016	$1,725,553	$342,600	$536,600	$2,604,753
2017	$1,779,535	$353,318	$553,387	$2,686,240
2018	$1,837,629	$364,852	$571,453	$2,773,933
2019	$1,894,702	$376,183	$589,201	$2,860,086
2020	$1,910,029	$379,227	$593,967	$2,883,223
2021	$1,932,792	$383,746	$601,046	$2,917,584
2022	$1,958,608	$388,872	$609,074	$2,956,554
2023	$1,982,432	$393,602	$616,483	$2,992,517
2024	$2,074,510	$411,883	$645,116	$3,131,510
2025	$1,752,580	$347,966	$545,005	$2,645,551
Total	$28,700,757	$5,698,390	$8,925,158	$43,324,305

Table 4.5A - Installation, Employment

	Employment			
	Direct	**Indirect**	**Induced**	**Total**
2010	7,874	2,660	3,809	14,343
2011	7,874	2,660	3,809	14,343
2012	7,874	2,660	3,809	14,343
2013	7,874	2,660	3,809	14,343
2014	7,874	2,660	3,809	14,343
2015	485	164	235	884
2016	485	164	235	884
2017	485	164	235	884
2018	485	164	235	884
2019	485	164	235	884
2020	485	164	235	884
2021	485	164	235	884
2022	485	164	235	884
2023	485	164	235	884
2024	485	164	235	884
2025	485	164	235	884
Total	44,707	15,103	21,626	81,436

Table 4.5B - Installation, Wages

	Wages			
	Direct	**Indirect**	**Induced**	**Total**
2010	$365,102,278	$111,701,298	$132,939,667	$609,743,243
2011	$365,102,278	$111,701,298	$132,939,667	$609,743,243
2012	$365,102,278	$111,701,298	$132,939,667	$609,743,243
2013	$365,102,278	$111,701,298	$132,939,667	$609,743,243
2014	$365,102,278	$111,701,298	$132,939,667	$609,743,243
2015	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2016	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2017	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2018	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2019	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2020	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2021	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2022	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2023	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2024	$22,496,177	$6,882,598	$8,191,223	$37,569,999
2025	$22,496,177	$6,882,598	$8,191,223	$37,569,999
Total	$2,072,969,344	$634,215,066	$754,801,791	$3,461,986,201

Table 4.5C - Installation, GDP

	GDP			
	Direct	**Indirect**	**Induced**	**Total**
2010	$1,202,481,016	$346,815,815	$381,980,318	$1,931,277,149
2011	$1,202,481,016	$346,815,815	$381,980,318	$1,931,277,149
2012	$1,202,481,016	$346,815,815	$381,980,318	$1,931,277,149
2013	$1,202,481,016	$346,815,815	$381,980,318	$1,931,277,149
2014	$1,202,481,016	$346,815,815	$381,980,318	$1,931,277,149
2015	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2016	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2017	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2018	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2019	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2020	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2021	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2022	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2023	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2024	$74,092,187	$21,369,437	$23,536,136	$118,997,760
2025	$74,092,187	$21,369,437	$23,536,136	$118,997,760
Total	$6,827,419,136	$1,969,142,880	$2,168,799,092	$10,965,361,108

Table 4.5D - Installation, State and Local Taxes

	State and Local Taxes			
	Direct	**Indirect**	**Induced**	**Total**
2010	$10,982,237	$29,138,111	$14,116,886	$54,237,233
2011	$10,982,237	$29,138,111	$14,320,454	$54,440,802
2012	$10,982,237	$29,138,111	$14,495,812	$54,616,159
2013	$10,982,237	$29,138,111	$14,598,234	$54,718,581
2014	$10,982,237	$29,138,111	$14,823,203	$54,943,550
2015	$676,683	$1,795,377	$15,067,734	$17,539,793
2016	$676,683	$1,795,377	$15,311,199	$17,783,259
2017	$676,683	$1,795,377	$15,790,193	$18,262,252
2018	$676,683	$1,795,377	$16,305,669	$18,777,729
2019	$676,683	$1,795,377	$16,812,090	$19,284,149
2020	$676,683	$1,795,377	$16,948,091	$19,420,150
2021	$676,683	$1,795,377	$17,150,071	$19,622,130
2022	$676,683	$1,795,377	$17,379,147	$19,851,206
2023	$676,683	$1,795,377	$17,590,542	$20,062,601
2024	$676,683	$1,795,377	$18,407,569	$20,879,629
2025	$676,683	$1,795,377	$15,551,019	$18,023,078
Total	$62,354,692	$165,439,696	$254,667,913	$482,462,301

Detailed Explanation of the IMPLAN Model

IMPLAN is an economic impact assessment software system. The system was originally developed and is now maintained by the Minnesota IMPLAN Group (MIG). It combines a set of extensive databases concerning economic factors, multipliers and demographic statistics with a highly refined and detailed system of modeling software. IMPLAN allows the user to develop local-level input-output models that can estimate the economic impact of new firms moving into an area as well as the impacts of professional sports teams, recreation and tourism, and residential development. The model accomplishes this by identifying direct impacts by sector, then developing a set of indirect and induced impacts by sector through the use of industry-specific multipliers, local purchase coefficients, income-to-output ratios, and other factors and relationships.

There are two major components to IMPLAN: data files and software. An impact analysis using IMPLAN starts by identifying expenditures in terms of the sectoring scheme for the model. Each spending category becomes a "group" of "events" in IMPLAN, where each event specifies the portion of price allocated to a specific IMPLAN sector. Groups of events can then be used to run impact analysis individually or can be combined into a project consisting of several groups.

The hallmark of IMPLAN is the specificity of its economic datasets. The database includes information for five-hundred-and-twenty-eight different industries (generally at the three or four digit Standard Industrial Classification level), and twenty-one different economic variables. Along with these data files, national input-output structural matrices detail the interrelationships between and among these sectors. The database also contains a full schedule of Social Accounting Matrix (SAM) data. All of this data is available at the national, state, and county level.

Another strength of the IMPLAN system is its flexibility. It allows the user to augment any of the data or algorithmic relationships within each model in order to more precisely account for regional relationships. This includes inputting different output-to-income ratios for a given industry, different wage rates, and different multipliers where appropriate. IMPLAN also provides the user with a choice of trade-flow assumptions, including the modification of regional purchase coefficients, which determine the mix of goods and services purchased locally with each dollar in each sector. Moreover, the system also allows the user to create custom impact analyses by entering changes in final demand. This flexibility is a critically important feature in terms of the RESI proposed approach. RESI is uniquely qualified to develop data and factors tailored to this project, and, where appropriate, overwrite the default data contained in the IMPLAN database.

IMPLAN is highly credible and widely accepted within the field. There are over five hundred active users of IMPLAN databases and software within the federal and state governments, universities, and among private sector consultants. A sample list of IMPLAN users includes:

Academic Institutions	**Federal Government**
Alabama A&M University	Argonne National Lab
Albany State University	Federal Emergency Management Agency
Auburn University	U.S. Dep't of Agriculture, Forest Research
Cornell University	U.S. Dep't of Agriculture, Econ Research Service
Duke University	U.S. Dep't of Interior, Bureau of Land Management
Iowa State University	U.S. Dep't of Interior, Fish and Wildlife Service
Michigan State University	U.S. Dep't of Interior, National Park Service
Ohio State	U.S. Army Corp of Engineers
Penn State University	
Portland State University	**Private Consulting Firms**
Purdue University	Cooper & Lybrand
Stanford University	Batelle Pacific NW Laboratories
Texas A&M University	Boise Cascade Corporation
University of CA - Berkeley	Charles River Associates
University of Wisconsin	CIC Research
University of Minnesota	BTG/Delta Research Division
Virginia Tech	Crestar Bank

West Virginia University	Deloitte & Touche
Marshal University College of Business	Ernst & Young
	Jack Faucett Associates
State Governments	American Economics Group Inc.
Maryland Department of Natural Resources	L.E. Peabody Associates
Missouri Department of Economic Development	The Kalorama Consulting Group
California Energy Commission	West Virginia Research League
Florida Division of Forestry	
Illinois Department of Natural Resources	
New Mexico Department of Tourism	
South Carolina Employment Security	
Utah Department of Natural Resources	
Wisconsin Department of Transportation	

V. Potential Air Pollution Impacts of Residential Gas Efficiency Programs in Maryland

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Summary

The purpose of this study is to quantify potential non-carbon dioxide (CO_2) environmental benefits and costs of a hypothetical large-scale natural gas efficiency program for Maryland residential consumers. We consider three issues. They are reductions in outdoor NO_X, possible increased indoor concentrations of radon in areas of the state where radon is a problem, and possible increased indoor concentrations of Second Hand Smoke (SHS), also known as Environmental Tobacco Smoke (ETS).

NO_X emissions reductions of 300-600 tons/yr could be achieved by full implementation of the efficiency program. This is two orders of magnitude smaller than Maryland's power plant NO_X emissions. In terms of the value of equivalent emissions allowances, the NO_X reductions are worth approximately one half million dollars to over four million dollars per annum, or about \$0.5 to \$7.50/yr per participating household per year. The higher value results from assuming relatively high NO_X allowance prices (\$7000/ton rather than \$1000/ton) and the version of the efficiency programs with the highest savings. We calculated avoided NO_X emissions by assuming constant NO_X, emission rates from furnaces and water heating appliances and then considering reductions in their utilization resulting from the efficiency program.

In some regions of Maryland, radon concentrations are a health concern. In addition, the health impacts of SHS are widely recognized. Increased public health risk from the accumulation of indoor air pollutants is possible if an energy efficiency program decreases ventilation rates. This is a potential problem for any energy efficiency program that addresses the building envelope, whether the purpose is to save electricity or heating fuel. The potential risks are the same regardless of fuel type and are not peculiar to or greater for natural gas customers.

The risk calculations for radon and SHS are based on the assumption that measures to improve the building envelope to lower heat loss will simultaneously result in a decrease in the building air exchange rates. Rough estimates of the long-run impact of heightened indoor pollution levels on mortality are based on published relationships between concentrations and health impacts, as well as estimates of present mortality in Maryland

due to radon and SHS, assuming that the program is implemented to the same extent in all parts of the state. However, radon risks are highly variable across the state. Thus program implementation that avoids installations in areas where risks are highest will result in substantially lower public risks from radon due to reduced air exchange rate.

In the case of radon, if no steps are taken to avoid installations in high radon areas and no steps are taken to mitigate radon risks in homes where radon concentrations are currently high, then the estimated order of magnitude for the long run increase in mortality in Maryland is in the range of 10 to 100 deaths per year. By 'long run', we mean that these are the values that would be reached after several decades if decreased ventilation levels are maintained for that period of time. This risk would occur primarily in areas that already have high radon concentrations. Radon risks are negligible in those large portions of the state where radon levels are not higher than average.

For SHS (or Environmental Tobacco Smoke), the increase in estimated mortality is approximately one-third that for radon. SHS impacts are anticipated to be less for two reasons. First, there are fewer estimated total deaths due to SHS in residences. Second, changes in ventilation rates do not affect SHS concentrations as much as they do radon, because, unlike radon, SHS is removed by both ventilation and deposition/absorption processes.

The health impact estimates presented here are very approximate because of the assumptions that are made. These assumptions include linear dose-response relationships, continued relevance of radon concentration estimates from the 1980s, decreases in ventilation rates, absorption rates for SHS, absence of radon mitigation measures, and that all households are equally likely to have efficiency measures installed. However, estimated health impacts can be avoided by not installing efficiency measures in the specific regions where heightened radon risks exist; by avoiding installations at homes with significant SHS exposure; by simultaneously installing energy-efficiency ventilation systems; and by simultaneously installing radon mitigation measures. Indeed, taking such steps can result in net decreases in radon- or SHS-mortality. As a result of such steps, MDE and Maryland residents can be assured that the natural gas efficiency programs will yield not only economic and CO_2 benefits, but public health benefits for Marylanders as well.

1. Introduction

The Johns Hopkins University along with University of California, Merced has examined the ancillary environmental and health effects that could result from potential natural gas efficiency programs. This document reports the methods and results of that ancillary benefits study.

Many states, including Wisconsin, New York, Washington, and Oregon, have implemented residential weatherization assistance programs. Some of these programs assist low-income families to reduce their financial burden on energy-related expenses by making their homes more energy efficient. Apart from energy savings that these programs were designed for, they are reported to result in a variety of non-energy benefits (Figure 5.1.1). These include ratepayer benefits (reduction in gas emergency service calls, fewer shut-offs, lower insurance rates, etc.), household benefits (e.g., increased comfort levels, sewage and water savings, property value benefits and reduction in illnesses) and societal benefits (e.g., environmental savings, economic opportunities). It is estimated that the net present value (NPV) of non-energy benefits ($3346) are of the same order of magnitude as the NPV of energy benefits ($3174) per household using natural gas for heating (Schweitzer, 2003).[14] Hence the evaluation of non-energy benefits is an important step to obtain an accurate picture of the benefits of the proposed programs.

Even though there are various non-energy benefits, we concentrate mainly on a subset of the environmental benefits from the program: reductions in conventional air pollutants and changes in exposure to radon and second hand tobacco smoke. Reductions in conventional pollutant emissions arise from the reduced consumption of fossil fuels for energy, which in turn, results in fewer emissions of sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and other pollutants. These impacts could be both outdoor and indoor air pollutant reductions. For instance, outdoor emissions reductions can include reductions in the amounts of NO_x released to the atmosphere resulting from furnace maintenance and replacements. The estimated savings for outdoor NO_x will be presented later in the report (Sections 5.3.1 and 5.3.2). Schweitzer and Tonn (2003) consider benefits from NO_x, SO_x, CO, particulates, methane, heavy metals and sewage. However, they do not address indoor air pollution issues.

[14] The study was based on various national weatherization evaluation studies since 1993. Studies from states of Ohio, Vermont and data from utility company programs provided the data for the analysis. Estimates were based upon based on a 20 year lifetime at a discount rate of 3.2%.

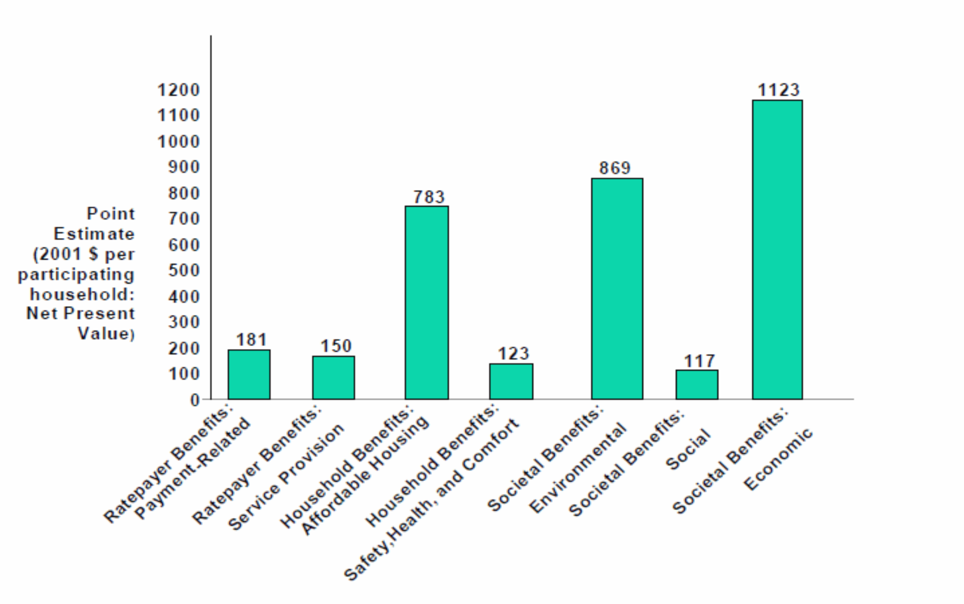


Figure 5.1.1 - Summary of Non Energy Benefits by category and subcategory (Reproduced from Schweitzer and Tonn, 2003)

Reduced fuel use and updating of furnaces can lower conventional air pollutant emissions to the outdoor environment. However, the effects upon indoor air pollution are ambiguous. Some of the proposed measures such as window replacements for space heating savings could result in a decrease in the air turnover (or exchange) rates of the homes (the rate at which air in the building is replaced by outside air). On the one hand, a decrease in air exchange rates can result in higher accumulations of air pollutants. This is because fresh air coming into a room dilutes pollutant concentrations as the outdoor levels for various pollutants are usually lower than indoors. On the other hand, indoor air pollution could be decreased if emissions sources (radon leaks or gas using appliances) are reduced due to lower heating or cooling demands, basement sealing, or improved furnace and water heater efficiencies. Therefore, it is difficult to predict the change in the indoor air quality given the competing effects (decrease in emissions as well as decrease in fresh air input rate) resulting from energy efficiency programs.

In this part of the report, we first identify the most important indoor air pollutants in Maryland that would be affected by natural gas-oriented energy efficiency programs in Section 5.2. In Section 5.3, we outline the proposed efficiency program for Maryland and summarize some non-energy benefits that are derived from existing studies related to efficiency programs. Thus, Sections 5.2 and 5.3 serve as the literature review for the study. In Section 5.4, we estimate NO_x emission reductions from an assumed large-scale natural gas efficiency programs for Maryland residential consumers, and value them based on the market price of emissions allowances. In Sections 5.5 (Radon) and 5.6 (Second Hand

Smoke), we model the changes in indoor air quality resulting from the energy efficiency program as well as the associated benefits or costs in the form of order-of-magnitude changes in health effects.

2. Review of Indoor Air Pollutants and Health Impacts

This section reviews relevant literature related to energy efficiency programs and indoor air quality. Section 5.2.1 presents a Californian indoor air quality report that summarizes various health costs associated with various indoor air pollutants. This information is used to prioritize pollutants based on the costs associated with each pollutant. Section 5.2.2 presents the major pollutants and sources of indoor air pollution in Maryland. In summary, the literature identifies that outdoor NO_x, radon and Environmental Tobacco smoke pollutants are the most important conventional pollutants that could be affected by a natural gas efficiency program. The benefits or costs of these programs might have a significant impact on how to design the efficiency program.

2.1 Health Costs of Indoor Air Pollution

In the absence of quantitative health estimates for various indoor air pollutants in Maryland, we rely on a California study (CA IAQ, 2005) to identify which pollutants have the highest impact and thus should be the focus of our analysis. That study gives an estimate of the number of deaths per year in that state from exposure to each of several indoor pollutants.

That report ranks ETS and radon as the top two causes of heart diseases, lung cancer, SIDS and various other respiratory outcomes. In contrast, it is surprising that radon was not described in detail in the Maryland IAQ report (Maryland IAQ, 2002) even though the average levels of radon in Maryland are as high as California if not more (EPA, 2009a). ETS and radon are followed by VOCs, CO poisoning, and combustion products-related illness. However, the health costs of VOCs and CO are one to two orders of magnitude less than ETS and radon (Table 5.2.1). Therefore, in our indoor air pollution analyses, we focus our attention on the potential impact of natural gas efficiency programs upon ETS and radon.

Some of the important assumptions on which the Californian report is based are: The value of one statistical life is $6.3 million, estimates are based on mid-point of incidence rates of mortality and morbidity values, and dollars used are year 2000 dollars. Sick building syndrome is not addressed in the report as the factors causing it are often building specific.

2.2 Review of Indoor Air Pollutants

In 2002, a task force was set up by the State of Maryland to address the problems associated with indoor air quality and possible regulatory responses (Maryland IAQ, 2002).

In particular, the task force report identifies indoor pollutants that are of major concern, their sources and their corresponding health effects qualitatively. The report identifies that Heating, Ventilation and Air Conditioning (HVAC) equipment and other combustion sources (furnaces, ovens and stoves) are major sources of gaseous indoor pollutants. Others pollutants of concern include biological agents, particulates, volatile organic compounds, fibers and pesticides. However, little information (death rates or health costs) is presented regarding two key pollutants: Environmental Tobacco Smoke (ETS) and radon.

In this section, we review each of the major categories of indoor air pollutants.

Table 5.2.1 - Summary of estimated annual costs of indoor air pollutants in California (Reproduced from CA IAQ, July 2005, Table 3.6)

Health End Point	Health Valuation: Premature Death ($ Billions/yr)	Medical Cost ($ Billions/yr)	Lost Productivity Cost ($ Billions/yr)	Total Cost ($ Billions/yr)
CO: poisoning	0.15	<0.001	NA	0.15
VOCs: cancer	0.73	0.011	NA	0.74
ETS: lung cancer	2.4	0.025	NA	2.4
ETS: heart disease	23	0.055	NA	23
ETS: asthma episodes	NA	0.020	NA	0.020
ETS: low birth weight	NA	0.19	NA	0.19
ETS: otitis media	NA	0.019	NA	0.019
Radon: lung cancer	9.5	0.097	NA	9.6
Mold and moisture: asthma and allergies	0.031	0.19	NA	0.22
Sick building syndrome	NA	NA	8.5	8.5
TOTAL	**36**	**0.6**	**8.5**	**45**

2.2.1 Biological Agents

Biological agents include mold, fungi, and bacteria. They have mainly been a concern in office buildings due to poor HVAC systems (sick building syndromes); they are not directly related to residential efficiency programs. These are much less of a concern compared to environmental tobacco smoke, radon and combustion products. The reason is that mold induces allergic reactions and increases the risk of asthma, but there have been no reports of deaths directly linked to molds and there is no scientific agreement about the levels of toxicity of this pollutant (Maryland IAQ, 2002). With some exceptions, outdoor levels of fungi and mold are higher than indoors (Maryland IAQ, 2002). Hence, energy efficiency programs that reduce air exchange could actually improve air quality with respect to biological agents. Since the magnitude of health effects is three orders less than ETS in Table 5.2.1, we do not address biological pollutants further in this report.

2.2.2 Volatile Organic Compounds

Volatile organic compounds (VOCs) include various organic compounds typically released from plastics, solvents, dyes, adhesives, paints, and other synthetic materials. Many of these sources are indoors; some may be brought in from outside, although outdoor concentrations are typically much lower than indoor concentrations (Maryland IAQ, 2002). There is no clear dose-response relationship, partly because there are many different types of VOCs. However, if they are present indoors in high concentrations, decreasing air exchange rates might result in health problems. On the other hand, one might over predict the effect of reduced ventilation because the source intensity of VOCs is influenced by ventilation. This is because higher air circulation often leads to higher production of VOC's from paints and wall hangings (Cox et al., 2001).

The acute health effects of VOC's include eye irritation, neuropsychological effects, and lower respiratory effects. In extreme cases, it might increase cancer risks (Vermont Department of Health, 2005). From Table 5.2.1, we find that the cost from cancers due to VOCs to be one order of magnitude lesser than that of radon or ETS. Hence like biological agents, the VOC issue is relatively a lesser problem compared to radon or ETS, and will not be considered further in this report.

2.2.3 Combustion Products

Burning of fuels often result in formation of oxides of sulfur, nitrogen oxides (NO_x), particulates, and carbon monoxide (CO). NO_x concentrations are small enough not to cause any concern as an indoor air pollutant. Observed indoor NO_x concentrations are very low and well below acute toxic levels (Burr, 2004). The National Institute for Occupational Safety and Health (NIOSH) has established a recommended exposure limit (REL) for nitrous oxide of 25 parts per million (ppm) parts of air (NIOSH, 1992). However, various studies (e.g., Lebret, 1989) have shown the average indoor concentration of NO_x to be generally much less than 1 ppm. The low values are based on the fact that furnaces are vented. Hence we do not address indoor NO_x in this report. However, malfunctioning of combustion appliances and improper vents might result in occasionally high values of NO_x concentrations. We note that NO_x does not feature in the priority indoor pollutant list in

Table 5.2.1. However, NO_x as an outdoor pollutant is a bigger concern and we will address the issue in detail in Section 4.

Particulates from combustion (other than tobacco smoke) are not a concern, as often the levels are lower than outside levels if there are no smokers in the house (EPA, 2008). Hence we do not address this issue, as the program would have minor benefits but no adverse impacts, with the exception of SHS.

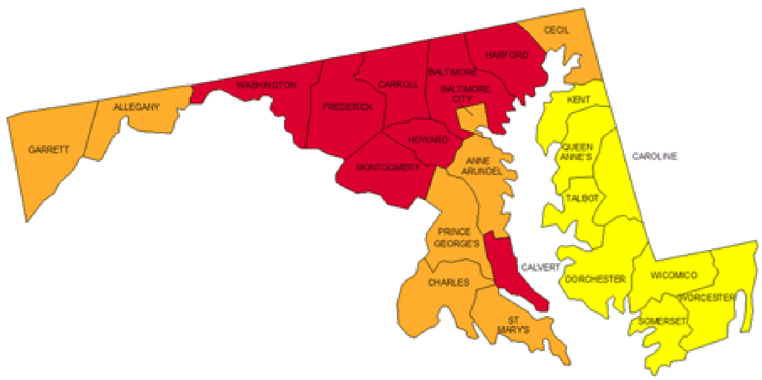
A more important indoor air pollutant resulting from combustion is CO. The formation of CO is due to incomplete combustion of fuel. CO is a poisonous odorless gas and when humans are exposed to it at higher levels it can be fatal to them. Physiologically, CO combines with hemoglobin and reduces blood's capacity to transport oxygen, thereby reducing oxygen concentrations in the blood. The EPA suggests that average levels in homes without gas stoves vary from 0.5 to 5 parts per million (ppm), whereas CO levels near properly adjusted gas stoves are often 5 to 15 ppm and those near poorly adjusted stoves could be 30 ppm or higher (EPA, 2009b). The Maryland natural gas efficiency program proposes furnace replacements as one of the strategies. This is expected to reduce CO emissions. However, the concentration of CO in a typical residential unit also depends on the number of smokers in the house. When a single smoker is present in the house, average concentration of CO is reported to be 9 ppm with peaks of 12 ppm (Ott et al., 2002). Hence, the programs benefits of CO reductions may not be as high as might be anticipated, given that there are smokers and that building envelope improvements will usually reduce air exchange rates.

According to Center for Disease Control (CDC), there were 2,631 deaths in the US during the period 1999-2004 due to unintentional CO exposure, with an average of 439 deaths per year. The report also presents a state-wide data in which Maryland had 46 CO-related deaths during this period, or 8 deaths per year. Many of these deaths are due to old equipment (vehicle motors, generators) in garages (CDC, 2007). Compared to ETS and radon in Table 5.2.1 we can see that CO is relatively a lesser problem; hence we do not address this pollutant further.

2.2.4 Radon

Radon is an invisible, cancer-causing radioactive gas formed from fission of uranium in rocks and soils. It enters homes through foundations and water supplies, and damages lung tissue when inhaled. Smokers are at a higher risk since radon decay products attach themselves to smoke particles and become trapped in the lungs; non-smokers much more readily exhale the radon particles (EPA, 2009a). Radon might also enter a body through water by ingestion. However, this pathway is shown to be negligible compared to others (Montgomery DEP, 2007). Every year there are estimated to be 15,000 to 22,000 lung cancer deaths nationally due to radon (ALA, 2008). In addition, EPA estimates about 168 deaths occur annually in the US due to radon in drinking water (Montgomery DEP, 2007). However, drinking water-based radon risks are not addressed in the report as the proposed efficiency program does not affect drinking water consumption.

Figure 5.2.1 shows potential indoor levels of radon by US counties by 3 zones. Maryland falls mainly in Zone 1 (> 4 picoCurie/liter [pCi/l]) and Zone 2 (2-4 pCi/l) (EPA Radon, 2009a). These maps show general trends; of course, concentrations in houses vary greatly depending on construction, local soils, and air exchange rates.



Zone 1 counties have a predicted average indoor radon screening level greater than 4 pCi/l (pico curies per liter) **(red zones) Highest Potential**

Zone 2 counties have a predicted average indoor radon screening level between 2 and 4 pCi/l **(orange zones) Moderate Potential**

Zone 3 counties have a predicted average indoor radon screening level less than 2 pCi/l **(yellow zones) Low Potential**

Figure 5.2.1 - Map of Radon Zones for Maryland (Source: EPA, 2009a)

EPA also provides information relating indoor radon concentration levels to additional lung cancers for life-time exposure to radon for both smokers and non-smokers (Table 5.2.2). We use Table 5.2.1 to calculate relative lung cancer risk per unit change in concentrations in our analysis later in this report (EPA, 2009c). We fit the data in Table 5.2.2 with two linear lines to represent radon dose-response relationships for smokers and non-smokers, respectively. The slope of the line divided by a thousand (the table is listed in deaths per thousand people) gives the approximate risk of lung cancer per person for a life-time exposure to radon per unit change in the concentration levels.

Based on Table 5.2.2, the lung cancer risk is 0.01325 per pCi/l/person for a smoker and 0.0018 per pCi/l/person for a non-smoker. The statistical fits are nearly perfect ($R^2 > 0.999$), indicating that a linear model was used to EPA to obtain the individual values in the table. One source reports that average 40 % of the smokers and 25 % of the non smokers affected with radon related lung cancers die (Montgomery DEP, 2007). Multiplying the above lung cancer risk rates by those ratios results in 0.4×0.01325 deaths per pCi/l/person for a smoker and 0.25×0.0018 deaths per pCi/l/person. To translate this into average death rates per year, under steady state assumptions and an average lifetime of 70 years, this would be in X = 0.000076 = 0.4×0.01325/70 deaths per pCi/l/person per year for a smoker and Y = 0.0000064 = 0.25×0.0018/70 deaths per pCi/l/person per year for nonsmokers.

However, these rates are not entirely inconsistent with the reported total number of radon related deaths in the US of around 22,000 per year (ALA, 2008). If Z = 15.3% of the 300 million US residents are smokers (CDC State, 2008[15]) and the average concentration in US homes is 1.3 pCi/l (EPA, 2009c), then the above risk rates would instead yield an estimate of 300,000,000×(X×Z + Y(1-Z))×1.3, or about 6600 deaths per year, rather than 22,000 deaths/year. Therefore, we consider both the original risk rates, and an adjusted risk rate that would result in 22,000 deaths/yr (= 22,000/6600 times the original rates). We will use these risk estimates to calculate radon health risk implications of the natural gas efficiency program in Section 5.5

Table 5.2.2 - Radon Risks (Source: EPA, 2009c)

Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime*...	If 1,000 people who never smoked were exposed to this level over a lifetime*...
20 pCi/l	About 260 people could get lung cancer	About 36 people could get lung cancer
10 pCi/l	About 150 people could get lung cancer	About 18 people could get lung cancer
8 pCi/l	About 120 people could get lung cancer	About 15 people could get lung cancer
4 pCi/l	About 62 people could get lung cancer	About 7 people could get lung cancer
2 pCi/l	About 32 people could get lung cancer	About 4 person could get lung cancer
1.3 pCi/l	About 20 people could get lung cancer	About 2 people could get lung cancer
0.4 pCi/l	About 3 people could get lung cancer	

[15] State Tobacco Activities Tracking and Evaluation

2.2.5 Environmental Tobacco Smoke/ Second Hand Smoke

> "ETS is a complex mixture of gases and particles from that includes smoke from the burning cigarette, cigar, or pipe tip (side stream smoke) and exhaled mainstream smoke. Second-hand smoke contains at least 250 chemicals known to be toxic, including more than 50 that can cause cancer" (NCI, 2007).

Among the various health issues resulting from second-hand smoke, heart disease and lung cancer are the most important among adults. Children face additional problems such as lung development impairment, ear problems, asthma, and sudden infant death syndrome (SIDS). There appear to be no risk free levels for second-hand smoke. The CDC estimates that every year there are about 22,700 to 69,600 premature deaths from heart disease and 3000 deaths from lung cancer among non-smokers due to second hand smoke in the US (CDCP, 2006). Hence, its health risk implications should be properly addressed as its concentration levels are likely to be altered if Maryland's natural gas efficiency programs affect air turnover rates.

Major constituents of tobacco smoke include CO, nicotine, and volatile organic compounds (NRC, 1986, Table 2-10). Levels of CO associated with ETS are often are not directly harmful as the concentration levels are low. The peak indoor concentrations of CO from ETS are modeled to be in the range of 12 ppm in one study (Ott, 2002). The EPA standard for 1 hour exposure of CO is 35 ppm. Hence we do not address this issue from ETS. Even though there are other sources such as combustion sources for CO, the combined peak levels have been observed to be no more than 27 ppm under controlled conditions in one study (12 ppm for ETS and 15 ppm for combustion) (EPA, 2009b). The report dedicates Section 6, below, to a quantitative analysis of the increase in ETS-based risks resulting due to installation of energy efficiency measures.

3. Proposed Maryland Natural Gas Efficiency Program for the Residential Sector

In Section 3.1, we describe the energy efficiency measures proposed in the hypothetical natural gas efficiency program for Maryland, as well as some related assumptions. This information is used in Sections 5 and 6 to calculate changes in air exchange rates and population at risk to air pollution. Section 3.2 presents the amount of possible energy units that are saved (in Million British Thermal Units (MMBTU)) for each measure. The energy savings is used to calculate the outdoor NO_x reductions in Section 4.

3.1 Measures Proposed In Natural Gas Efficiency Program

The Center for Integrated Environmental Research (CIER) at the University of Maryland provided us with the set of possible measures that are considered for the hypothetical statewide natural gas efficiency program aimed at residential consumers. These are in large part explained in Chapters I and II of this report and include:

- Furnace replacement (increasing furnace to 92 % fuel usage)
- Improvements in ceiling insulation (improving the thermal resistance value from current level/standard to R-38[16]) and improved wall insulation (increase the thermal resistance value from current level/standard to R-13)
- Replacement of windows (single pane with Energy Star windows)
- Duct sealing (reduce the air leakage for crawl spaces and basements)
- Replacement of water heaters (improving efficiency to 67%)
- Wrapping the water heater pipes (up to 10 ft of pipe)

The numbers of households that are assumed to receive these programs are presented in Table 5.3.1. These numbers are based on an assumption of full implementation in all homes that could benefit; of course, an actual program would actually be much smaller.

Table 5.3.1 - Proposed Measures and Number of households taking up efficiency measures (Source: See Chapter II)

Measure	End Use	Maximum Number of Single Family Households	No. of Multi-family Households
Furnaces	Space Heating	--	--
Ceiling Insulation	Space Heating	122,843	--
		401,090	--
Wall Insulation	Space Heating	122,843	42,397
Windows	Space Heating	407,190	61,657
Duct Sealing	Space Heating	370,071	--
		368,846	--
Water Heaters	Water Heating	--	--
Water Heater Pipe Wrap	Water Heating	726,763	54,206

[16]The R value is a measure of thermal resistance which is the ratio of temperature difference across the material to the heat flux through it. As the R value increases the resistance increases and hence less heat is lost.

The number of replacements of furnaces and water heaters is not presented in the table as there are two different options for implementation. We discuss the possible savings scenario for space heating (with Natural turnover and Furnace Policy) later in this section.

The study analyzes a hypothetical case that assumes the program will be applied to all of the possible existing residential units starting in 2010, except for water heaters and furnaces that are replaced after they wear out. The study analyzes energy savings at two possible levels: low and high. The low scenario refers to the lower estimate of the possible average household energy savings while high scenario refers to the high end of the range of average household savings. It is assumed that ceiling insulation and duct sealing are only applied to single family residential units, and not multifamily units (See Chapter II). "Natural turnover" and "Furnace policy" are the two possible scenarios for multi-family residential units. Natural turnover takes the increase in efficiency of furnaces over time into account but assumes no policy or program is implemented to improve their efficiency. The furnace policy instead assumes that there exists a policy to improve all installed furnaces to the efficiency level AFUE 92 (Annual Fuel Utilization Efficiency). However there are four possible scenarios for single residential units, depending on the assumptions about the furnace policy and whether single units have duct sealing performed on them or not. Thus, we have following four cases:

a) Natural turnover, no duct sealing

b) Natural turnover, duct sealing

c) Furnace policy, no duct sealing

d) Furnace policy, duct sealing

For water heating calculations, there are two scenarios, natural turnover and water heater policy. There are just two cases for both single and multifamily residential units, as duct sealing would not have any effect on water heating energy demand. These are similar to that of furnace calculations in the sense that natural turnover would involve the calculation of savings considering changes in water heaters efficiency over time but assuming no policy or program is targeted to reach a specific efficiency level. In contrast, the water heater policy would calculate savings based on a policy that all heaters would be upgraded to an efficiency of EF-67. The water heater policy also considers the effects of pipe wrappings (See Chapter II).

3.2 Estimated Energy Savings from the Program

The next step is to calculate the energy savings associated with natural gas consumption (MMBTU) due to each individual measure. This information is important for calculating NO_x reductions. We make an assumption that appliances have a constant emission rate for a particular pollutant, in terms of mass per unit of energy consumed. However, emission rates could differ, depending on the type of the appliance, maintenance levels; heat input rate and fuel types (EPA, 1989, Tables 3.7- 3.10). Unfortunately, we could not find data or projections that would allow us to disaggregate the population in the study by these criteria. There are various papers that give emission rates for different heat input rates and fuel compositions and type of appliances, but we could not find data and literature sources that considered all the above mentioned factors in the same experimental study. Because we do not consider the possible of reduced emission rates over time, we may be underestimating the outdoor NO_x emissions reductions that result from the efficiency program.

Different measures have different lifetimes, and the same measures might have different savings depending upon the types of buildings to which the measures have applied (e.g., single or multi unit). In Chapter II, there is a table consisting of savings for the period 2010-2025, differentiating by types of buildings. For example, maximum cumulative energy savings due to window replacements for a single unit would be either 134 MMBTU or 56 MMBTU depending on whether duct sealing is performed on the unit or not. This value is different from the 68 MMBTU savings value for a multifamily residential unit if windows are replaced. These calculations do not include savings after 2025 for measures with lifetimes longer than 15 years (i.e., furnace replacement and ceiling insulation). The following Tables 3.2 and 3.3 present the estimated amounts of energy saved in million British thermal units of fuel input for the years 2010 to 2025 for space heating (See Chapter II).

Table 5.3.2 - Space Heating Energy Savings (2010 to 2025) for Multifamily Residences (Source: See Chapter II)

	Cumulative Space Heating Multifamily (2010- 2025) in MMBTU			
Measures	**Natural Turnover**		**Furnace Policy**	
	Low	High	Low	High
Furnaces	--	--	1,376,783	1,775,070
Ceiling Insulation	--	--	--	--
	--	--	--	--
Wall Insulation	5,249,800	6,685,539	5,089,965	6,479,465
Windows	3,382,600	4,307,688	3,279,613	4,174,909
Duct Sealing	--	--	--	--
	--	--	--	--
Total	**8,632,400**	**10,993,227**	**9,746,361**	**12,429,445**

Table 5.3.3 and 5.3.4 present the energy saved for various scenarios resulting from different measures targeting water heating energy savings for single and multifamily units.

Table 5.3.3 - Space Heating Energy Savings (2010 to 2025) for Single Family Residential Units (Source: See Chapter II)

	Cumulative Space Heating Single Family Savings (2010- 2025) in MMBTU							
Measures	**Natural Turnover, No Duct Sealing**		**Natural Turnover, Duct Sealing**		**Furnace Policy, No Duct Sealing**		**Furnace Policy, Duct Sealing**	
	Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Furnaces	--	--	--	--	21,230,618	27,372,388	21,230,618	27,372,388
Ceiling Insulation	12,911,386	16,442,449	11,620,248	14,798,205	12,518,287	15,935,631	11,266,458	14,342,068
	25,704,786	32,734,645	23,134,307	29,461,181	24,922,179	31,725,640	22,429,962	28,553,076
Wall Insulation	18,405,092	23,438,599	16,564,583	21,094,739	17,844,732	22,716,133	16,060,259	20,444,520
Windows	49,308,091	62,793,087	44,377,282	56,513,778	47,806,859	60,857,566	43,026,173	54,771,810
Duct Sealing	--	--	43,705,269	55,524,378	--	--	42,451,086	53,912,597
	--	--	18,668,827	23,717,392	--	--	18,133,099	23,028,916
Total	**106,329,355**	**135,408,780**	**158,070,516**	**201,109,672**	**124,322,675**	**158,607,358**	**174,597,654**	**222,425,373**

Table 5.3.4 - Water Heating Energy Savings (2010 to 2025) for Single and Multifamily Residential Units (Source: See Chapter II)

Measure	**Water Heating Cumulative Natural Gas Savings 2010-2025 (MMBTU)**							
	Single Family				**Multifamily**			
	Natural Turnover		**Water Heater Policy**		**Natural Turnover**		**Water Heater Policy**	
	Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Water Heaters	--	--	13,410,942	14,258,603	--	--	540,300	627,759
Pipe Wrap	2,364,117	2,513,545	2,260,631	2,403,518	95,245	110,662	91,076	105,818
Total	**2,364,117**	**2,513,545**	**15,671,573**	**16,662,122**	**95,245**	**110,662**	**631,376**	**733,577**

4. Reductions in Outdoor Emissions by Natural Gas Using Appliances

This section calculates reductions in nitrogen oxides that are released into the atmosphere by residential furnaces using venting systems. These reductions are potentially important because NO_x is a tightly regulated pollutant. The section compares these calculated reductions to the total state emissions and estimates the economic value of the savings using recent prices of NO_x allowances. In Section 4.1 we present the background and methodology of NO_x reductions. In Section 4.2, we present the reductions from space heating and water heating and finally conclude by comparing those emissions to the total emissions from Maryland power plants and by finding the monetary value of the reductions in Section 4.3.

4.1 Background and Methodology

Natural gas-fired residential water heaters and furnaces release NO_x and CO into the atmosphere through their venting systems. In this section, we estimate the tonnage of reductions of NO_x. The focus is on NO_x because it causes a variety of problems (such as acid rain and smog) when present at elevated levels in atmosphere. NO_x above a certain concentration level can also cause asthma problems when inhaled directly. The USEPA NAAQS (National Ambient Air Quality Standards) is 0.053 ppm as the average 24-hour limit for NO_2 in outdoor air. Indoor levels are often less than outdoor levels and there are no separate standards for indoor levels.

After combining with ammonia and moisture, NO_x forms nitric acid and cause lung diseases that might lead to premature deaths or aggravate heart problems. Through a complicated series of reactions, NO_x can contribute to troposheric ozone which is harmful to children and susceptible populations. An observational study based on 95 cities in the US concludes that a 10 ppb increase in the daily 8-hour max in the ozone concentration would result in 3767 premature deaths (Bell et al., 2004). The results are robust to various specifications. In the eastern United States, the Clean Air Interstate Rule caps the total amount of SO_x and NO_x that can be released by electric utilities and sets up a cap and trade system for those pollutants. Emissions from residential consumption of natural gas are not subject to that cap. However, we can use the price of NO_x per ton to approximate the monetary value of the reductions in NO_x due to the program, as it is an indicator of the cost elsewhere in the economy of reducing such emissions. Nitrous oxide is also considered as one of the primary greenhouse gases. Hence NO_x is studied. CO is an issue only in urban atmospheres; it is a short lived pollutant that generally causes outdoor problems only in crowded city centers. Hence we do not consider outdoor CO further.

The tonnage of NO_x reductions depend on the amount of energy saved and the NO_x emission rates of the appliances per unit of energy consumed. This calculation is applied separately for space heating and for water heaters, since each has a different NO_x emission rate. We present the calculation in tons as follows:

Change (NO_x) = (1/1000) × emission rate of the appliance× total energy units saved… (4.1)

(tons/yr) (ton/kg) (kg/MMBTU) (MMBTU/yr)

The above equation is used to obtain the results reported in next section.

4.2 Reduction in Outdoor NO_x Emissions

4.2.1 Space Heating

We rely on the USEPA AP-42 manual for residential gas furnaces, which provides a NO_x emission rate 0.092 lbs/ MMBTU heat input (EPA, 1998 AP-42). Meanwhile, as a comparison, the State of California requires that all boilers with heat input less than 400,000 BTU per hour input to emit less than 93 lbs per billion BTU or 0.093 lbs/MMBTU (AQMD, 2006). Hence, given the consistency in the value of emission factors across EPA documents and California standards, we can safely use the value of 0.092 lbs/ MMBTU as an input parameter for our analysis.

From Table 5.3.2 we have energy savings in MMBTU for various scenarios of multifamily residential unit space heating policy. We can now obtain the amount of total NO_x savings by multiplying these savings by 0.093 lbs/MMBTU. We then divide them by a factor of 2.2 to covert pounds to kilograms, and further divide by 1000 to convert the estimate into ton. For example, the lower estimate of NO_x savings for all multifamily units in natural turnover policy over 16 years(2010-2025) would be equal to (8,632,400)×[MMBTU]×(0.093[lbs/MMBTU])/ 2.2[lbs/kg]/1000[kg/ton] = 361 tons.

The annual NO_x savings would therefore be 361 [tons]/16 [years] = 23 tons/year. We applied this approach to the other scenarios from Table 5.3.2 and summarize the results in Table 5.4.1. Similarly using Table 5.3.3, we can obtain Table 5.4.2.

Table 5.4.1 Annual NO_x Emission Reductions from Multifamily Residential Units' Space Heating

Multi Family Space heating	Natural Turn over		Furnace Policy	
	Low	High	Low	High
Total MMBTU savings (16 years)	8,632,400	10,993,227	9,746,361	12,429,445
NO_x Reductions [pounds]	794,181	1,011,377	896,665	1,143,509
Total annual NO_x [tons]	**23**	**29**	**25**	**32**

In summary, depending on the scenarios chosen, the assumed space heating programs would result in total reductions from single- and multifamily homes of 301 (= 23+278) to 603 (=32+571) tons NO_x/year.

4.2.2 Water Heating

According to DOE EERE (DOE, 2004, Appendix K-2), which lists emission factors for water heaters, gas-fired residential water heaters have a NO_x emission rate of 42 [g/GJ] of heat input. California has a stricter standard of around 35 [g/GJ] while New Jersey has a standard of 86 [g/GJ]. We will use the value from DOE EERE (DOE, 2004, Appendix K-2). (An emission rate of 42[g/GJ] is equivalent to 0.097 lbs/MMBTU.)

From Table 5.3.4, we have energy savings for single and multifamily residential units' water heating demands. We convert the MMBTU to GJ using the conversion rate 1 MMBTU = 1.055 GJ (Energy Source Canada, 2009). After converting to GJ of savings, we multiply the values by 42 g/GJ and divide by 1000 g/kg to obtain the NO_x savings in kilograms over 16 years. Finally, we calculate the annual tonnage of NO_x reductions by dividing by a factor of 1000 g/kg.

Table 5.4.2 Annual NO_x Savings from Single Residential Units' Space Heating

SINGLE UNIT SPACE HEATING	Natural Turnover, No Duct Sealing		Natural Turnover, Duct Sealing		Furnace Policy, No Duct Sealing		Furnace Policy, Duct Sealing	
Savings Scenario	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Energy Saving [MMBTU] (16 years)	106,329,355	135,408,780	158,070,516	201,109,672	124,322,675	158,607,358	174,597,654	222,425,373
NO_x Reductions (16 years in tons)	4,447	5,663	6,610	8,410	5,199	6,633	7,301	9,301
Annual NO_x savings in tons	**278**	**354**	**413**	**526**	**325**	**415**	**456**	**581**

Table 5.4.3 Annual NO_X Savings from Single Residential and Multifamily Residential Units' Water Heating

WATER HEATING	**Single Family**				**Multifamily**			
	Natural Turnover		**Water Heater Policy**		**Natural Turnover**		**Water Heater Policy**	
MMBTU Saved (16 years)	2,364,117	2,513,545	15,671,573	16,662,122	95,245	110,662	631,376	733,577
GJ energy (16 years)	2,494,144	2,651,790	16,533,509	17,578,538	100,483	116,749	666,102	773,924
NO_x in tons (16 years)	105	111	694	738	4	5	28	33
Annual NO_x savings in tons	**7**	**7**	**43**	**46**	**0**	**0**	**2**	**2**

The result of that calculation is the NO_x savings in kilograms over 16 years. Finally, we calculate the annual tonnage of NO_x reductions by dividing by a factor of 1000 (kg/ton) and by 16 years. As a result, we obtain Table 5.4.3 for annual NO_x savings from water heating savings. The totals are much less than for space heating, being between 7 (=7+0) and 48 (=46+2) tons/year.

4.3 Calculation of Economic Value of Outdoor NO_x Reductions

We can obtain a lower bound of the total NO_x emission reductions by adding the lowest possible space and water heating NO_x reductions for both single and multifamily residential units. This would be 308 (=23+278+7+0) tons of avoided NO_x emission per year. Similarly the higher end of the NO_x emission reductions estimate would be 661 (=32+581+46+2) tons per year. As a comparison, the annual NO_x emitted by Maryland power sector would be 60,000 tons in 2010 (EPA, 2002), which is two orders of magnitude higher. A trading firm "Evolution Markets" forecasts an annual price of $1000 per ton of NO_x for the year 2010. The summertime ozone season price was $225 per ton NO_x (Evaluation markets, 2009).

Using just the annual value (since most emissions from furnaces will be in the winter and not the summer), the estimated annual value of the NO_x reductions will range from about $310,000 to $660,000. However this price was estimated for year 2010. The prices have been as high as $7000 per ton of NO_x in earlier years, including $1500 in winter of 2008 (FERC, 2008). Hence, the value might vary over the lifetime of the program. If the $7000/ton value is an upper bound, then these emission reductions could range from about $2,100,000 to $4,600,000/year. The number of households considered in the program is around 600,000. Hence on average the value of these reductions per participating household would be between $0.50 and $7.50/year.

5. Radon Impacts

This section of the report addresses the indoor air pollutant radon and estimates how the proposed energy efficiency program might affect its health impacts in Maryland. In Section 5.1, we present the background and nature of radon, while in Section 5.2 we set up a box model to predict the changes in concentration or radon given a change in air exchange rate or source strength. We discuss the methodology in Section 5.3, list results in Section 5.4 and conclude by presenting recommendations concerning how the potential negative radon effects of the efficiency program can be converted into a positive impact on radon risks.

5.1 Radon and its Occurrence

Radon has been established as a carcinogen by the EPA. Even though radon does not directly cause cancer, its fission products are responsible for irradiation of lung tissue. The synergetic nature of radon and smoking amplifies the lung cancer risks significantly for smokers as well as non-smokers exposed to environmental tobacco smoke (EPA, 2009c).

Maryland mainly falls in Zone 1 (high) and Zone 2 (moderate) in the EPA radon maps (Figure 5.2.2). Table 5.5.1 gives a county-wise distribution of indoor radon levels based on thousands of radon tests conducted since the 1980's in Maryland (Air Chek, 1982). One can notice from Table 5.5.1 that several counties such as Carroll, Fredrick and Washington have very high values of average indoor concentrations. However, a number of counties including Somerset, Kent and Dorchester had relatively few samples, which might lead to sample error when using their average concentrations for our analysis.

Clearly, with such variability in radon concentrations across the state, if enhanced radon concentrations from energy efficiency programs are a possibility, then programs can be designed to avoid homes with the highest risk. Alternatively, radon mitigation measures or additional energy-efficient ventilation measures could be taken in such homes. However, in our analysis below we assume that the program is applied to all homes without radon mitigation measures; thus the analysis likely overstates radon risks.

5.2 Box Model

5.2.1 Model Set Up

This section describes how we model the changes in the radon indoor concentrations that would result from the natural gas program. There are three main terms that affect the concentration levels of a pollutant in a residential unit: the source of the pollutant [Source]; removal by decay [r] and absorption [AB]; and removal by air exchange with the outdoors.

Using conservation of mass, we can write (Chao, 1997):

(Change in concentration over time) =

- (Decay+ Absorption) + (Change due to air exchange with outside) + Source… (5.1)

Or:

$$dC/dt = -(r + AB) \times C + AE \times (C_o - C) + Source \quad .... (5.2)$$

Where	C	=Indoor radon concentration [mass/volume]
	t	=time [time]
	r	=decay constant [1/time]
	AB	=absorption or reactivity [1/time]
	AE	=Air Exchange rate [1/hr]
	C_o	=Outdoor radon concentration [mass/volume]

Table 5.5.1 County wise Indoor Radon Concentration levels for Maryland (Source: Air Chek, 1982)

County	TOTAL TESTS	AVG pCi/L	MAX pCi/L	EPA RISK	0–3.9 pCi/L	4–10 pCi/L	10–20 pCi/L	20–50 pCi/L	50–100 pCi/L	100+ pCi/L
	225	4.7	45.5	UNKNOWN	151	49	17	8	0	0
Allegany	419	5.7	62.8	MODERATE	261	99	34	23	2	0
Anne Arundel	2777	4.1	313.0	MODERATE	2001	527	175	65	7	2
Baltimore	2538	4.9	193.0	HIGH	1725	533	175	81	22	2
Baltimore City	709	2.1	74.4	MODERATE	611	79	12	5	2	0
Calvert	841	7.1	105.0	HIGH	443	233	107	50	6	2
Caroline	21	1.0	5.8	LOW	20	1	0	0	0	0
Carroll	1473	12.1	355.4	HIGH	726	331	182	159	49	26
Cecil	438	3.8	49.4	MODERATE	319	91	18	10	0	0
Charles	1276	2.4	76.2	MODERATE	1129	98	32	16	1	0
Dorchester	16	1.2	5.0	LOW	14	2	0	0	0	0
Frederick	3195	13.9	1800.4	HIGH	1237	902	505	399	108	44
Garrett	583	5.5	463.1	MODERATE	410	107	37	23	5	1
Harford	1119	5.3	122.3	HIGH	730	241	101	39	6	2
Howard	3863	7.1	365.0	HIGH	1911	1195	528	192	26	11
Kent	18	4.9	43.8	LOW	14	2	1	1	0	0
Montgomery	23122	4.9	1244.0	HIGH	14984	5752	1646	615	104	21
Prince Georges	8711	2.8	302.0	MODERATE	7306	1037	269	81	13	5
Queen Annes	79	2.3	57.8	LOW	68	9	1	0	1	0
Saint Marys	513	2.4	39.6	MODERATE	441	59	9	4	0	0
Somerset	7	1.1	6.7	LOW	6	1	0	0	0	0
Talbot	69	1.0	5.6	LOW	68	1	0	0	0	0
Washington	580	11.6	122.6	HIGH	175	176	136	82	10	1
Wicomico	24	0.8	3.3	LOW	24	0	0	0	0	0
Worcester	23	0.8	6.4	LOW	21	2	0	0	0	0
Grand Totals	52639	5.4	1800.4		34795 66.1%	11527 21.9%	3985 7.6%	1853 3.5%	362 0.7%	117 0.2%

Air Chek, Inc. 1936 Butler Bridge Rd, Mills River, NC 28759–3892 Phone: (828) 684–0893 Fax: (828) 684–8498

In steady state, by definition $dC/dt = 0$ and thereby we can solve for concentration C as follows:

$$C = (Source + AE \times C_o)/ (r + AB + AE) \qquad .....(5.3)$$

We assume a decay constant for radon of r = 0.00755 per hour and an average air exchange rate of AE = 0.59 per hour for Maryland (EPA, 1997, Table 17-9). Since the decay rate is two orders less than the air exchange rates, r can be disregarded. Also, since radon does not react with any other substance as it is a noble gas, we can disregard AB also. (This is not the case with SHS in Section 6, however.) Hence, we can simplify the equation (4.3) to:

$$C = C_o + (Source/AE) \qquad .... (5.4)$$

If the home is weatherized, resulting in a new source term that is X times the old source term, and a new AE that is Y times the old value, then the new concentration C' can be calculated as:

$$C' = C_o + Source'/ AE' = C_o + [(X \times Source)/(Y \times AE)] \qquad ..... (5.5)$$

Equivalently, the change in the concentration is:

$$\Delta C = (C' - C)$$

$$= (Source/ AE) \times [(X/Y) - 1]$$

$$= (C - C_o) \times [(X/Y) - 1] \qquad .... (5.6)$$

5.2.2 Structural and Parameter Assumptions Used in the Box Model

We make the following assumption about the parameters and the data set.

1) A steady state condition is rapidly achieved before and after the weatherization measures.
2) Uniform mixing of radon is achieved within the house.
3) The number of houses receiving weatherization measures in a county is proportional to the population of the county. This assumption is important because counties differ in radon concentrations, and other distributions among the counties could affect the estimated impact of the program on lung cancer cases.
4) The radon concentration dataset is still valid. This is the only county-level data available in Maryland to the best of our knowledge. However, often during changes in house ownership, houses are checked for radon and are remediated for higher sale value (EPA, 2007). There is no data set which kept track of radon mitigation at change of ownership. Industry says there has not been much change in the average concentrations as for every remediated unit, there are new radon problematic buildings being built.
5) Each household has, on average, 2.57 people per household, of which 0.66 is youth (US Census, 2003).
6) The average national outdoor radon concentration is 0.4 pCi/l. This is used as Maryland's value since no other information is available.

The percentage of smokers among Maryland adults and youth is assumed to be 14.8%, and 16.8%, respectively, according to 2007 data (CDC State, 2008). Since we have considered the population of adults to youth ratio as 1.91 to 0.66 based on US census data, we then calculate the percentage smokers as 15.31 % of the total population.

5.2.3 Changes in Air Exchange Rates

The effect on weatherization on air exchange rates depends on many factors: for instance, the present level of insulation and condition of the home, the existing type of windows, mechanical ventilation before and after weatherization. Results from two studies in Idaho and Washington indicate that implementation of the standard Bonneville Power Administration's weatherization package brought 12.5 % of reduction in specific leakage area. This included wall insulation attic insulation, floor insulation and window replacement (Grimsrud, 1988). Additional house doctoring (consisting of caulking and weatherization) brought a 26% of reduction in air change rate (Grimsrud, 1988).[17] However the proposed Maryland study does not include house doctoring, hence we use a reduction of 12.5 % as the decrease in air exchange, which we assume applies to all houses

[17] There are other studies that have estimated effects upon ventilation rates of weatherization measures, but they have generally included house doctoring as well.

weatherized. We use this number along with the smoker to nonsmoker ratio of the state to calculate the additional lung cancers that might result from the efficiency program.

In this analysis, we make two additional important assumptions. One is that no additional measures are taken to mechanically ventilate the house after weatherization. Such additional ventilation is often advised if a house is tightened significantly, and indoor air pollution (due to smoking, radon, or other causes) is a concern. A second additional assumption is that the weatherization program does nothing to diminish the source of radon. It is, in fact, possible and perhaps desirable to couple weatherization and radon mitigation efforts, since they involve many of the same skills and if combined would require just one visit by contractors.

Radon concentrations are mitigated by using various methods and techniques and some are listed in Table 5.5.2. The source of this data dates to 1994, and hence one should be careful while quoting this numbers as costs for any economic analysis (Henschel, 1994). It appears that the least costly measures involve investments of on the order of $1000 total and that the most effective ones are "active" and require on-going maintenance and operating expenditures. More recent data on active mitigation measures such as subslab/basement depressurization, crawl space isolation and ventilation indicate that they would cost around $250 per year per dwelling and result in more than 50% reductions in radon concentrations (EPA, 2009d). However, the passive measures still have a reasonable effectiveness (30-70%, in the case of Passive SSD, DTD, and SMD) which would more than make up for the relatively small decrease in ventilation rates, yielding a net decrease in radon for a relatively small expense. The expense of such passive radon control measures is likely to be a relatively minor fraction of the weatherization costs (the latter being on the order of $3000-$10,000 per home, with the more expensive programs involving window replacement).

Table 5.5.2 Radon Mitigation Methods, Their Efficiency and Associated Costs
(Source: Henschel, 1994, Table 1)

Technique	Indoor Radon Reduction Efficiency	Installation Costs (in $)	Operating Costs (in $)/yr
Active Sub Slab and Drain Tile Depressurization (SSD & DTD)	80-99%	800-2500	40-300
Active Block Wall Depressurization (BWD)	99%	1500-3000	70-500
Active Sub Soil and Drain tile Pressurization	To 98%	800-2500	40-300
Passive SSD, DTD and SMD (Sub Membrane Depressurization)	30-70%	500-1500	0-10
Basement Pressurization	50- >90%	500-1500	100-500
Sealing Radon Entry Routes	0- 50% (Highly case specific)	100-2000	0

Although the expense of radon mitigation is not great, neither is it insignificant relative to the expense of the energy efficiency measure. We recommend that selected mitigation be considered as part of the energy efficiency retrofits in those areas with high radon concentrations or, if testing can be undertaken, specific housing units where significantly elevated radon levels are detected. We note that at least two states (Indiana & Kansas) explicitly prohibit radon mitigation from being undertaken as a part of state-sponsored weatherization programs (Indiana, 2009; Kansas, 2009).

Table 5.5.3 summarizes the number of houses, smokers and nonsmokers data used for the analysis.

Table 5.5.3. Houses Indoor Radon levels affected by Efficiency Program

Number of households affected by this measure (Mauer, 2009)	585,590
Number of people holds affected by this measure (@ 2.57 people per household)	1,504,967
Number of Smokers (15.31% of total)	230,411
Number of Non- Smokers	1,274,556

5.3 Methodology

Table 5.5.4 illustrates our calculation of potential additional lung cancers caused by radon. The table uses the county-level breakdown of radon concentrations from Table 5.5.1. We illustrate the methodology using Allegany County data.

- We see that Allegany County has an average indoor concentration of 5.70 pCi/l. We subtract the base (outdoor) radon concentration to obtain, by Equation 5.4, the ratio of initial source strength to air exchange rate (5.7- 0.4 = 5.3 pCi/l).
- This ratio is multiplied by the term (X/Y – 1) where X is the ratio of the new source strength to the original source (100% in this case, as no radon mitigation is taking place) and Y is new air exchange (AE) rate in comparison to original AE rate (87.5 % here, as there is a drop of 12.5% in air exchange.) The obtained value is the change in concentration (5.3×[(1/0.875)-1] = +0.76 pCi/l) from Equation 5.6.
- Allegany County contains 1.25 % of the total Maryland population. As mentioned, we assume that the number of homes weatherized is proportional to county population. Hence we obtain the number of smokers (230,411×1.2524 %= 2885) and non smokers (1,274,556×1.2524% = 15,963) in the county that are affected by this program by multiplying the total number of people in the state that are affected by the natural gas program by 1.25 %.
- Now we multiply the increase in concentration by each of the numbers of smokers (2885×0.76 pCi/l) and non smokers (15963×0.76 pCi/l) affected in the county. The numbers thus obtained are multiplied by respective relative risk coefficients (derived from the concentration – lung cancer table (Table 5.2.2)). The lung cancer risk, based on our original numbers in Section 2.2.4, is 0.01325 per pCi/l/person for a smoker and 0.0018 per pCi/l/person for a non smoker. As a result, in Allegany County there would additional lung cancers (lifetime) in 29 smokers (2885×.76 pCi/l×0.01325 per pCi/l/person) and 22 non smokers (15963×0.76 pCi/l×0.0018 per pCi/l/person). (Divided by 70 years/person, this would yield the change in annual mortality rate.)

Table 5.5.4 shows these calculations for all counties in Maryland. Note that these numbers are number of cancers over the lifetime of the residents, and presume lifetime exposure to the heightened concentrations. Dividing by 70 years lifetime per person, this yields 48 cancer cases/yr. Thus, these should be viewed as long run "steady state" values, if the residents were exposed to the higher concentrations for many years. So the near term increase in cancer cases would be much smaller.

5.4 Results and Sensitivity Analysis

One source reports that average 40 % of the smokers and 25 % of the non smokers affected with radon related lung cancers die (Montgomery DEP, 2007). Hence, based on our assumptions, we would predict a total of 1131 (= [1924 Total affected smokers×0.4 deaths/ smokers] + [1445 Total affected non smokers×0.25 deaths/non smokers]) deaths (lifetime) due to rise in radon concentrations. Assuming an average lifetime of 70 years, this would be about 16 = 1131/70 deaths per year, in the long term.

However, if instead we the adjusted risk rates from Section 2.2.4 were used, the annual deaths would instead be 16×(22,000/6641) which is equal to 53 deaths per year.[18] Recall that the adjusted risk rate was based on increasing the dose-response coefficients in order to result in total death rates that are consistent with estimates of national annual mortality. Thus, there is significant uncertainty concerning the impacts of radon mortality stemming from the uncertainty about the response of mortality to radon concentrations discussed in Section 2.2.4.

Since the air exchange (AE) rate is uncertain, we also consider cases in which it is decreased by 6% and 25% (Y value of 94% and 75%) instead of 12.5%. Then the average increase in the radon concentration for entire Maryland State would be 0.28 pCi/l and 1.47 pCi/l (in the base case it was 0.63, for a decrease in AE of 12.5 %) respectively. Instead of 53 deaths per year, the result would instead by 23 and 112 for the two rates (based on the adjusted mortality rates). (Using the original unadjusted rates, the deaths would be 8 to 31 deaths/year.) Hence the model is extremely sensitive to changes in assumed air exchange rates.

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[18] As a check, we calculate the long run change in the number of radon-induced deaths another way. The total number of people that would be affected by the program is 1,504,967. This implies there are 407 (=1489×1.5M/ 5.5M) deaths per year due to radon in the proposed number of houses currently. Average indoor radon concentration for Maryland is 4.8 pCi/l. The increment due to decrease in air exchange is 0.63 pCi/l from Equation 4.6. This implies an increase of 13.1 % in the concentration levels. Assuming linearity of deaths with concentration levels, we have an additional 54 (= 407×13.1%) deaths per annum due to the decrease in air exchange rates.

Table 5.5.4. Calculation of Additional Lung Cancers due to Rise in Radon Concentrations Based on Original Lung Cancer Risk Rates (see Section 2.2.4)									
County Name	**Indoor Radon**	**source/AE**	**Change in Concentration**	**Population % of**	**Total**	**Total**	**Additional Lung cancers**		**TOTAL Additional**
	(pCi/L)	**(C- Co) (pCi/l)**	**(pCi/l)**	**total MD**	**SMOKERS**	**Non Smokers**	**Smoker**	**Non Smoker**	**Lung Cancers**
Allegany County	5.70	5.30	0.76	1.25	2885.78	15963.18	28.95	21.76	**51**
Anne Arundel County	4.10	3.70	0.53	9.02	20779.92	114947.87	145.53	109.36	**255**
Baltimore County	4.90	4.50	0.64	13.89	32012.79	177084.47	272.68	204.91	**478**
Baltimore City	2.10	1.70	0.24	11.08	25529.06	141218.58	82.15	61.73	**144**
Calvert County	7.10	6.70	0.96	1.62	3734.53	20658.24	47.36	35.59	**83**
Caroline County *	1.00	0.60	0.09	0.58	1334.60	7382.57	1.52	1.14	**3**
Carroll County	12.10	11.70	1.67	3.09	7117.86	39373.69	157.64	118.46	**276**
Cecil County	3.80	3.40	0.49	1.85	4257.45	23550.82	27.40	20.59	**48**
Charles County	2.40	2.00	0.29	2.50	5752.04	31818.43	21.78	16.36	**38**
Dorchester County *	1.20	0.80	0.11	0.56	1294.60	7161.31	1.96	1.47	**3**
Frederick County	13.90	13.50	1.93	4.12	9490.47	52498.26	242.52	182.24	**425**
Garrett County	5.50	5.10	0.73	0.52	1203.87	6659.42	11.62	8.73	**20**
Harford County	5.30	4.90	0.70	4.35	10029.00	55477.19	93.02	69.90	**163**
Howard County	7.10	6.70	0.96	4.96	11426.03	63205.14	144.91	108.89	**254**

Kent County	4.90	4.50	0.64	0.35	805.83	4457.60	6.86	5.16	**12**
Montgomery County	4.90	4.50	0.64	16.77	38633.10	213705.89	329.07	247.29	**576**
Prince George's County	2.80	2.40	0.34	14.69	33858.59	187294.86	153.81	115.59	**269**
Queen Anne's County	2.30	1.90	0.27	0.83	1919.95	10620.54	6.90	5.19	**12**
Saint Mary's County	2.40	2.00	0.29	1.82	4202.81	23248.61	15.91	11.96	**28**
Somerset County *	1.10	0.70	0.10	0.46	1071.19	5925.48	1.42	1.07	**2**
Talbot County	1.00	0.60	0.09	0.63	1445.81	7997.78	1.64	1.23	**3**
Washington County	11.60	11.20	1.60	2.56	5890.57	32584.75	124.88	93.84	**219**
Wicomico County *	0.80	0.40	0.06	1.61	3713.07	20539.51	2.81	2.11	**5**
Worcester County *	0.80	0.40	0.06	0.88	2021.41	11181.78	1.53	1.15	**3**

TOTAL= 3370 lifetime or 3370/70 = 48 cancers/year

5.5 Recommendations

It is recommended to consider the coupling of weatherization measures with low cost radon mitigation measures in counties with high indoor radon concentrations (Montgomery County, Baltimore County, Carroll County, Anne Arundel County and Washington County), or to avoid installations in homes with the highest radon concentrations. These five counties constitute about 45 % of the state's population. Radon mitigation is especially important for efficiency measures that might result in reduction of air exchange rates such as window replacements. The average annual cost of active radon mitigation methods would be in the range of $250/house (inclusive of fixed and operating costs) (EPA, 2009d), while passive measures would be approximately $1000 total.. By contrast, the costs of various measures in the efficiency program range around $1500-$3000 except for window replacement, which is above $10,000 per unit, and duct sealing which is around $330. Alternatively, there exist combined heat exchangers/ventilation fans that could increase ventilation rates (and thus decrease radon concentrations) without appreciably increasing heat loss. Adoption of such measures together with weatherization will ensure that Maryland residents will obtain both economic and environmental benefits from the proposed natural gas weatherization programs.

6. Environmental Tobacco Smoke Impacts

This section of the report addresses the indoor air pollutant Environmental Tobacco Smoke. We estimate the possible implications of the proposed energy efficiency program for ETS-caused lung cancer and mortality. Section 6.1 introduces the problem, Section 6.2 describes the model and Section 6.3 presents the results and sensitivity analysis. In Section 6.4 we present recommendations.

6.1 Introduction

The primary issue from ETS is respirable suspended particulates (RSP). These cause various types of respiratory illness, lung cancer, and also deaths. RSP contain various polyaromatic hydrocarbons such as benzo-pyrene and amines. Hence by modeling the concentration of RSP we can get an estimate of associated health costs, taking advantage of estimates of health impacts as a function of concentrations of RSP. A sophisticated approach to analysis of ETS can involve modeling RSP concentrations over time using multiple zones in a dwelling (Ott, 2002; NRC, 1986). However, we instead follow an analysis similar to our analysis of radon in Section 5.4.3 using a single compartment and a constant RSP source with an average rate over the entire day. The single compartment model is a reasonable estimation approach even though it slightly over predicts the average concentrations (NRC, 1986).

6.2 Box Model

6.2.1 Model Setup

Using the principle of conservation of mass, we can write, as in Section 4.2.1 (Chao, 1997)

(Change in concentration over time) =

- (Decay+ Absorption) + (Change due to air exchange with outside) + Source… (6.1)

Or:

$$dC/dt = -(r + AB) \times C + AE \times (C_o - C) + Source \quad \text{.... (6.2)}$$

where the notation is the same as in Section 5.2. As in Section 5.2, we can consider the steady state concentration by setting dC/ dt = 0 and thereby solving for concentration C as follows:

$$C = (Source + AE \times C_o)/ (r + AB + AE) \quad \text{.....(6.3)}$$

Of course, this assumes a constant source term over time, which is manifestly not the case for ETS. However, because of the linearity of the differential equation (6.2), we know that the average concentration will equal the solution of that equation (via 6.3), given the average Source input. Therefore, the solution to (6.3) represents the average concentration over a long period of time, given the average input of ETS.

The ambient air is often considered free of RSP for studies, and hence the background concentration C_o is assumed to be zero, unlike the radon case. We assume that there is no decay and hence the value of r would also be zero. This implies the concentration levels of RSP could be defined using the simplified stead state equation:

$$C = Source/ (AB + AE) \quad \text{...(6.4)}$$

The source is the average production rate of RSP from smoking in the residential unit. This is obtained by dividing the total emitted mass per hour of RSP by the volume of the building. We can calculate the change in concentrations due to change in air exchange rates using Equation 6.4.

6.2.2 Structural and Parameter Assumptions Used in the Box Model

As mentioned earlier in this report, average air exchange rates (AE) for residential units primarily vary from 0.5 to 0.9 (per hour) depending on the age, location and type of construction of a building. For Maryland, a value of 0.59 (per hour) is used here (EPA, 1997, Table 17-9). This value is reasonable, as other studies in the Northeast (e.g., New York) estimated the AE value of 0.55 (EPA, 1997, Table 17-9). This value is also in good agreement with various other sources (NRC, 1986).

The value of absorption rates (surface deposition in this case) (AB) ranges from 0.3 to 1.8/hr and depends upon the particle dimensions, humidity, surface characteristics, turbulence, etc. Typically, a particle deposition rate of 0.2 to 0.8 per hour is seen for ideal mixing in occupied spaces (NRC, 1986). For our purpose, we assume 0.5/hr (midpoint of the spread). Also, this is consistent with a study by Leaderer and Cain (1983) who found the deposition rate contributes nearly as much as ventilation (here, 0.59/hr) to the decay term in tobacco smoke modeling.

To derive the source term, we first consider its units, which by (5.1) must be mass/volume/hour. The emission rate of RSP is assumed to be 26 mg/cigarette (NRC, 1986). According to Center for Disease Control in 2004, the average number of cigarettes smoked by a smoker is 16.8 per day. The emission rate per hour will be total emitted RSP (26 [mg/cigarettes]×16.8 [cigarettes/day]) mg divided by 24 hours of the day. The average volume of a single family residential unit is assumed to be 450 cubic meters (derived from the value of 2000 square foot floor area times an assumed height of room is 8 feet) (EV Studio, 2008). As a result, the Source term is 0.04 mg/hour/m^3.

We note that the precise value of the source term is actually unimportant to the conclusions of the analysis. It will be the proportional increase in concentration that matters, as will be explained below.

6.3 Results and Sensitivity Analysis

6.3.1 Base Case Results

Using the above modeling methodology and parameter assumptions, assuming perfect mixing and a single smoker, we calculate the equilibrium average concentration.

$$C = (26[\text{mg/cigarette}]\times 16.8[\text{cigarettes/day}]\times 1000[\mu\text{g/mg}]) / (24\,[\text{hr/day}]\times 450[\text{m3}])$$

$$/(0.59 + 0.50)[1/\text{hr}]$$

$$= 37.\,1\ \mu\text{g/ m}^3.$$

The value of 37.1 μg/m^3 is in agreement with various studies (NRC, 1986). For example the RSP concentration indoors is 29 μg/m^3 according the book *Exposure Analysis* by (Ott et al, 2007). To calculate the increase on the RSP concentrations we use this value of 37.1 μg/m^3 as base. With a reduced air exchange of 0.52 (87.5% ×0.59), we calculate the new steady state concentration as 39.8 μg/m^3. Hence the percent increase in the concentration is 7.25%. Note that is about half the assumed 12.5% decrease in air exchanges – this is because the air exchange is responsible for only about half the decay of ETS, with absorption and settling responsible for the rest. Note also that this percent increase does not depend on the original calculated value of C, so the large uncertainties in that calculation will not matter.

According a study by Waters (2008), second hand smoke (SHS) causes $596.6 million per year in health costs losses for child and adult exposure in Maryland. He calculates this number by estimating that SHS will lead to 1577 adult and 24 child deaths per year and various hospitalization costs (Waters, 2008). This study was for entire Maryland population which is around 5.5 million people. However, second hand smoke risks from the work place are nearly same as the household second hand smoke risks (Hazelden, 2001). Therefore, the costs attributable to ETS in the home is approximately $300M/yr in Maryland, and the number of deaths would be about 800 adults and 12 children.

The residential energy efficiency programs that we are considering (Section 3.1) would affect around 1.5 million people in the state out of the population of 6 million. Hence, the current economic losses due to ETS in houses considered for sealing measures could be estimated to be around $80M/yr =(1.5/5.5) × $ 300 M/yr. Assuming that the dose-response relationship is linear and proportional to concentrations, the additional burden from ETS would be $6M per year. This is because we have an increase of 7.25 % in ETS concentrations (7.25%×$80 M/yr= $6M/yr). In terms of deaths, again assuming proportionality between deaths and concentration, the number of additional deaths would be (1577+24 total deaths)×(0.5 home deaths/total deaths)×(1.5/5.5) × 7.25 %, or about 16 additional deaths. As in the case of radon, this is a steady-state number that would only be realized after a number of years of exposure to higher ETS concentrations, and would not be experienced right away.

6.3.2 Sensitivity Analysis

The outcome is robust with respect to the air exchange rates in comparison with radon model. When the air exchange rate is decreased by 25% rather than 12.5%, the increase in the concentration is only 14.75% (compared to the base case increase 7.25%). One can observe that the ETS impact is relatively insensitive to the chosen parameters compared to radon box model. This is due to the fact that there is an additional removal term for ETS (surface deposition) that is not present in the radon model.

Also, we undertook a sensitivity analysis with respect to the deposition rate. If the deposition rate was 0.1 per hour instead of 0.5 per hour as assumed in the model, the increase in concentrations and health costs would be 11.9% instead of 7.25% as calculated. This brings the percentage impact closer to the radon levels, because ETS behaves more like a conservative substance (like radon) with that smaller deposition rate. The reason for choosing a lower bound of 0.1 per hour value for deposition is that there exist studies that estimate deposition rates as varying from 0.1 per hour to 1.8 per hour (NRC, 1986). Use of the higher rates (say 1.5 per hour) would result in an increase of 4 % in concentration (and, thus mortality, given linearity of the models) instead of 7.25 % in the base case.

6.4 Conclusions and Recommendations

The simple one compartment model predicts the natural gas program would incur an additional economic burden of roughly $6M and 16 deaths in Maryland per annum in the long run. This estimate may be biased to the high side for a couple of reasons. The calculation does not separate the effects of residential ETS and workplace ETS risks. Also, the costs mentioned in the Waters (2008) study include a variety of costs such as deaths and injuries from fires and other accidents caused by ETS, which account for about 1 % of the economic losses (Waters, 2008).

To avoid increased risks associated with second hand smoke, priority might be placed upon weatherization of houses without smokers for those weatherization measures that decrease ventilation rates. Or, if there are smokers resident, extra measures could be taken to increase ventilation, as mentioned in the recommendations of Section 5.5. This could drastically lower the additional costs that might arise due to the increase in the ETS concentrations, and if average ventilation rates increase rather than decrease as a result, the weatherization programs would have an unambiguously positive public health impact.

7. Conclusions

The proposed natural gas energy efficiency programs have various impacts upon air emissions from gas appliances. There is a reduction in nitrogen oxides and carbon monoxide tonnage that is emitted from combustion of fuel. The value of NO_x emissions reductions based on our calculation would be about half a million dollars to five million dollars per annum, based upon typical furnace and water heater emissions rates and the value of NO_x allowances. In other words it is around one to seven dollar savings per weatherized household per year.

However, the program might result in additional health impacts due to increases in indoor radon and second hand smoke concentrations resulting from decreased ventilation rates.

Assuming a 12.5% decrease in ventilation rates, no additional radon mitigation measures, and no effort to avoid installations in Maryland locations with high radon risks, the number of additional deaths could be several dozen per year, with accompanying economic costs in the tens of millions of dollars/yr. However, these calculations are highly uncertain, perhaps even speculative. Furthermore, even if they are approximately correct, such effects would not be experienced until well into the future, as the impact of increased concentrations is not felt immediately.

Increases in radon risks from stepping up residential natural gas efficiency programs can be largely avoided, however. As a precaution, we recommend that in those Maryland counties with relatively high radon risks one or more of the following steps be taken for homes with high radon concentrations: (a) installation of inexpensive passive measures for radon mitigation at the same time as weatherization measures, (b) installation of energy-efficient home ventilation equipment with heat exchangers, and/or (c) avoiding installation of energy efficiency measures that result in reduced ventilation. Coupling weatherization with such measures can help ensure that Marylanders benefit both economically and environmentally from the proposed residential natural gas efficiency program.

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VI. Summary and Conclusion

The Regional Greenhouse Gas Initiative (RGGI) is one approach for the state of Maryland to curb its greenhouse gas emissions by creating a mechanism that establishes a market price for emissions from electricity generation. At current permit prices, utilities are not expected to heavily seek offsets for their emissions by investing in more efficient residential natural gas consumption. As a result, an opportunity exists for the state to allocate part of its revenue from permit auctions to promoting residential natural gas use efficiency and thus state-wide emissions reductions that go beyond those that would be accomplished by RGGI alone.

This report quantifies the possibilities to influence, over time, natural gas use and associated carbon dioxide emissions (a primary greenhouse gas) in the residential sector through seven efficiency measures:

- Furnace replacement (increase furnace fuel usage efficiency to 92 %)
- Improvements in ceiling insulation(improving the thermal resistance value from current level/standard to R-38[19]) and improved wall insulation (increase the thermal resistance value from current level/standard to R-13)
- Replacement of windows (replace single pane with Energy Star windows)
- Duct sealing (reduce the air leakage for crawl spaces and basements)
- Replacement of water heaters (improve efficiency to 67%)
- Wrapping the water heater pipes (insulating up to 10 ft of pipe)

The results suggest that wall insulation and duct sealing are very cost effective measures. The average single-family household could save between $400-$500 in the first year with an investment of $3,000 in the most cost-effective energy efficiency improvements. Depending on specific technologies and different climate scenarios, efficiency improvements could reduce total residential natural gas consumption in Maryland by 8-18 percent. Likewise, Maryland could see a 14-18 percent reduction in CO_2 emissions from residential natural gas consumption as a result of efficiency improvements.

On the basis of this quantification we explore optimal choices of efficiency measures – either alone or in combination with others – for alternative budget allocations to a residential natural gas use efficiency program. We find that with a funding budget (limit) starting at $5 million

[19]The R value is a measure of thermal resistance which is the ratio of temperature difference across the material to the heat flux through it. As the R value increases the resistance increases and hence less heat is lost.

and going up to $100 million, achieving a reduction goal of 1 million tons of CO_2 would take between $155 and $264 million or between $157 and $283 million of total spending on efficiency measure installation and equipment.

Investments in efficiency result in new business opportunities for firms providing efficiency measures and energy savings for households, all of which, in turn, may impact the state's economy through the generation of investments, employment and wages. An analysis of the direct, indirect and induced effects of advancing natural gas use efficiency in Maryland suggests that the installation of energy-conserving devices would support more than 80,000 jobs, not all new as some might be absorbed by excess construction employment, and nearly $11 billion in economic activity. Additionally, direct savings to consumers could support between 4,000 and 5,000 jobs and yield between $400 and $500 million in economic activity.

Benefits from improved natural gas use extend beyond immediate cost savings and economic benefits. Ancillary benefits may accrue in the form of improved indoor and outdoor air quality because of decreased burning of a fossil fuel. However, additional costs may accrue in the form of increased morbidity and mortality if better insulated, tighter sealed homes reduce leakage of indoor air pollutants such as radon and second hand smoke. Our analysis indicates that the NO_X reductions associated with a large-scale residential natural gas energy efficiency program are worth approximately $.5 million dollars to over $4 million per year, or about $0.5 to $7.50 per participating household per year. However, after several decades of decreased ventilation levels in households, deaths resulting from high concentrations of radon could be in the range of 10 to 100 per year. As a consequence, deployment of efficiency improvements needs to be sensitive to existing environmental conditions (radon concentrations) and household characteristics (presence of second hand smoke).

Overall, the results of the study suggest economic, environmental and potential health benefits from promoting increased natural gas use efficiency. The results have been derived on the basis of the best available aggregate data for the Mid- and South Atlantic region and the State of Maryland. More accurate estimates could be derived with improved information about housing stock and equipment characteristics, knowledge about "free rider" and spillover effects, more detailed assumptions about administrative costs associated with a residential natural gas energy efficiency program, and the division of program costs among households, the state, and others. A comprehensive energy auditing program for the residential sector in Maryland could provide much of that information and could help target efficiency improvements.

VII. Acknowledgements

The authors wish to thank all of those who provided valuable input to and assistance for this study. Specifically, we want to acknowledge the valuable assistance of Maggie Eldridge with the American Council for an Energy-Efficient Economy. We appreciate the contributions of Colleen Horin, Kerry Rodgers, Sean Williamson and Kim Ross from the Center for Integrative Environmental Research at the University of Maryland.

VIII. Research Team Biographies

University of Maryland

Andrew Blohm, MPP, has been a Faculty Researcher at CIER since June 2008. He graduated from the School of Public Policy at the University of Maryland in December 2005 with a Masters in Public Policy in the International Development specialization. He has a background in economics having majored in International Economics at the University of Florida. Andrew has been working on a variety of research topics while at CIER including investigating the impacts of climate change on urban areas, notably infrastructure and vulnerable populations; examining the economic impacts of climate change on specific sectors of the Pennsylvania economy; analyzing the health impacts of extreme heat days in cities; and studying the link between growth patterns and average household energy consumption with aims to guide the formation of a Development Plan for the State of Maryland. Future research topics include continuing analysis of the health impacts of extreme heat days and working to create a decision support framework for more sustainable energy infrastructure design and implementation.

Steven Gabriel, PhD, is an Associate Professor in the Civil and Environmental Engineering Department and the School of Public Policy at UMD with additional appointments in CIER, the Applied Mathematics and Scientific Computation Program, and the Smith School of Business. He serves as Co-Director of the Master of Engineering and Public Policy Program. He has over 25 years' experience in industry and the academy in mathematical modeling and analysis of infrastructure systems with applications in energy, the environment, transportation, and telecommunications. He has an MS in Operations Research from Stanford University, and an MA and PhD in Mathematical Sciences from the Johns Hopkins University. Prior to joining the UMD, he served as a project manager for energy modeling at ICF Consulting, a postdoctoral researcher at Argonne National Laboratory, an Operations Research Analyst at Arthur D. Little, Inc., a Systems Analyst with Technology Systems, and a Market Analyst for a kerosene heater company.

Joanna Mauer, MPP, is a Physical Scientist at the U.S. Environmental Protection Agency. She received an MPP from the University of Maryland School of Public Policy in 2009 with a specialization in environmental policy. She has a BS in Civil and Environmental Engineering from Cornell University, and she worked on rural water supply and sanitation as a Peace Corps volunteer in the Dominican Republic.

Matthias Ruth, PhD, is the Roy F. Weston Chair in Natural Economics, Director of CIER at the Division of Research, Professor at the School of Public Policy, and Co-Director of the

Engineering and Public Policy Program at UMD. His research focuses on dynamic modeling of natural resource use, industrial and infrastructure systems analysis, and environmental economics and policy. His theoretical work heavily draws on concepts from engineering, economics and ecology, while his applied research utilizes methods of non-linear dynamic modeling as well as adaptive and anticipatory management. In the last decade, Ruth has published 12 books and over 100 papers and book chapters in the scientific literature. He collaborates extensively with scientists and policy makers in the USA, Canada, Europe, Oceania, Asia and Africa.

Ruth's recent interdisciplinary research projects include an assessment of impacts of climate change policies on technology choice, resource use and emissions, and an integrated assessment of climate change impacts on urban infrastructure systems and services. The former project is targeted towards an identification of "smart" energy and climate change policies - policies that promote significant efficiency improvements without jeopardizing economic performance. The latter project cuts across social and engineering sciences, computer modeling, planning and policy making with the goal of generating consensus about mitigation and adaptation strategies to address climate change in an urban context. Ruth teaches nationally and internationally courses and seminars on economic geography, microeconomics and policy analysis, ecological economics, industrial ecology and dynamic modeling at the graduate and PhD levels, and on occasion conducts short courses for decision makers in industry and policy.

John Hopkins University

Benjamin F. Hobbs, PhD, is the Theodore M. and Kay W. Schad Professor of Environmental Management in the Department of Geography and Environmental Engineering at The Johns Hopkins University, Baltimore, MD (JHU), where he has been on the faculty since 1995. He also holds a joint appointment in the Department of Applied Mathematics and Statistics. From 1977-79, he was Economics Associate at Brookhaven National Laboratory, National Center for Analysis of Energy Systems. He later joined the Energy Division of Oak Ridge National Laboratory from 1982-1984. Between 1984 and 1995, he was on the faculty of the departments of Systems Engineering and Civil Engineering at Case Western Reserve University, Cleveland, Ohio. He serves on the California ISO Market Surveillance Committee, the Public Interest Advisory Committee of the Gas Technology Institute, and as an Advisor to the Netherlands Energy Research Center (ECN). Hobbs earned a PhD in environmental systems engineering from Cornell University in 1983, where his dissertation concerned deregulated power markets. He has published widely on electric utility regulation, economics and systems analysis, and environmental and water resources systems. He was named a Presidential Young Investigator by the National Science Foundation in 1986 and is a Fellow of the IEEE. During 2009-2010 he is on leave at the University of Cambridge, where he is an Overseas Fellow at Churchill College.

Vijay Ganesh Kesana, M.S.E., was a Research Associate in the Department of Geography and Environmental Engineering at The Johns Hopkins University. He is presently a graduate student in Operations Research at the University of Delaware. He also holds a Bachelor of Technology in Paper and Pulp Technology from Indian Institute of Technology, Roorkee.

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Daraius Irani, PhD, is the director of the Applied Economics Group at the Regional Economic Studies Institute (RESI) and serves as project manager on numerous projects at RESI and does numerous economic outlook presentations to organizations across Maryland. He has been the principal investigator for numerous economic and fiscal impact studies for developers, corporations and government agencies in the State. In these studies, he examined the direct, indirect and induced economic and fiscal impacts of the proposed development or project. For many of these projects, a cost/benefit analysis was undertaken. Prior to joining RESI in 1997, Irani was the senior economist at the Santa Barbara Economic Forecasting project where he developed county level economic forecasts for Santa Barbara, San Luis Obispo, and Ventura Counties, California. In addition, he co-authored several reports including an analysis of the oil and gas industry and the tourism sector in the Central Coast of California. Irani received his PhD and his MA from the University of California, Santa Barbara.

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Yihsu Chen, PhD, is an Assistant Professor in the School of Engineering and the School of Social Sciences, Humanities and Arts of the University of California, Merced. He received a BS degree in environmental science from Tunghai University, Taiwan, and a Master's degree from the Harvard University, Cambridge, MA, in 1999. He earned a PhD degree in the area of energy and environmental economics from the Department of Geography and Environmental Engineering, Whiting School of Engineering, Johns Hopkins University. His publications are in the area of examining the interactions of electricity power sector and environmental regulations.