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Energy Efficient and Pollution-Free Space Heating and Cooling in Maryland

A report from the Renewable Maryland Project of the Institute for Energy and Environmental Research (IEER)

Arjun Makhijani and Christina Mills

February 16, 2015

The University of Maryland's entry, which placed first overall, in the U.S. Department of Energy Solar Decathlon 2011
Source: Solar Decathlon 2011 (October 1). (Credit: Stefano Paltera/U.S. Department of Energy Solar Decathlon)

Preface and Acknowledgements

This report is part of a series of works being produced by the Renewable Maryland Project. The project aims to create a roadmap for an energy sector with the following attributes:

- Essentially emissions-free (more than 90 percent reduction relative to 1990) by the year 2050;[1]
- Reasonable cost so that the fraction of income spent on energy by consumers does not exceed current levels (we use 2011 as our baseline year);
- Just and equitable so that all Marylanders, including those with low-incomes, can meet their energy needs without the high burdens that energy bills impose on them today;
- Robust, resilient, and resistant to failure for essential services and quick to recover from breakdowns;
- Democratized and transparent, providing more choices to people of all income levels greater opportunities to participate in various aspects of the electricity system, including electricity generation and demand response.

The first phase of the project, in late 2012 and early 2012 began with consulting various stakeholders and the formation of an Advisory Board, a process in which Stuart Alan Clarke, Executive Director of the Town Creek Foundation, played a central role. The consultations have continued since that time, including Advisory Board meetings that reviewed a draft report on the buildings sector emission reductions and electricity sector modelling and a draft version of the present report, which is the first one to be finalized. The role of the Board, whose members serve in their personal (and not institutional) capacities is as follows:

1. Ensuring that IEER's work is informed by near-term opportunities and careful understanding of what advocacy groups are doing. Reciprocally, there should be enough understanding on the part of advocacy groups to see what a path to climate protection and an emissions-free energy sector would look like.
2. Ensuring that the project remains grounded in - and cognizant of - Maryland's legislative, regulatory and business landscape, a project where vision and pragmatism are linked to ensure that policies will be flexible enough to enable correction.
3. Advising on a communications approach and strategy, which is critical to achieving broad acceptance, adoption, and implementation of an emissions-free energy sector.
4. Helping the project not only to illuminate paths to the long-term vision but also to help identify obstacles that may need to be overcome along the way as well as diversions and dead-ends that would distract or detract from the goal.

The Advisory Board members are:

1. Rebecca Bertram, Program Director, Environment and Global Dialog, Heinrich Böll Foundation, Washington, D.C., office;

[1] The aspirational goal in Maryland's Greenhouse Gas Reduction Act is 90 percent reduction in emissions below the 2006 value.

2. James McGarry, Chief Policy Analyst, Chesapeake Climate Action Center (alternative Tommy Landers, also of the Chesapeake Climate Action Network);
3. Lynn Heller, Baltimore Commission on Sustainability and Vice-President, Abell Foundation;
4. Larissa Johnson,
5. Pranay Kohli, Amidus.
6. Kathy Magruder, Executive Director, Maryland Clean Energy Center;
7. Ed Maibach, Director, Center for Climate Change Communication, George Mason University;
8. Alison Shea, Siemens;
9. Joe Uehlein, Labor Network for Sustainability.

Abby Hopper, who was Energy Advisor to the Governor of Maryland and Director, Maryland Energy Administration (MEA), was also a member until the end of 2014. Her appointment as Director of the Interior Department's Bureau of Ocean Energy Management has meant that she is unable to continue in that capacity. The Project has benefited enormously from her advice and participation.

Overall, it is our assessment that every major sector will need to reduce CO_2 emissions by the target of 90 percent or more by 2050. This report analyzes energy use in and emissions for space heating and cooling in Maryland's residential sector. Space-conditioning in buildings is responsible for almost one-fourth of energy related CO_2 emissions, with the residential sector accounting for over half of that.

Fossil fuels are used for heating in over 60 percent of Maryland households, with natural gas being the most common heating fuel, as well as the most economical at present in the sense that – all other things being equal - it costs the least to heat a house using natural gas compared to electricity or any other fossil fuel. This presents a significant challenge, since it will be necessary to reduce natural gas use for space heating significantly in order to achieve the ambitious long-term (2050) greenhouse gas reduction goals. We have devoted considerable resources to analyzing this topic in part to focus attention on this obstacle and how it may be overcome. Another reason to study this area in detail is that electrification of space heating using highly efficient heat pumps will enable the sector to reduce emissions upstream as Maryland's electricity sector becomes more emissions-free. Maryland's most plentiful renewable resources are solar and offshore wind. We will analyze the electricity sector in detail in a forthcoming report.

We also decided to make an excursion into broader issue of natural gas in this report. The phase out of natural gas is a complex matter. It is important in providing flexible electrical generating capacity and is the fuel of choice for combined heat and power plants; both these technologies are important to a transition to a low-emissions energy future. It has the lowest emissions of any fossil fuel at the point of use. Yet, growth in natural gas use is incompatible with long-term greenhouse gas reduction goals. The problem of natural gas-related emissions is compounded by leaks of methane, which is a powerful greenhouse gas. Methane is the most important constituent of natural gas.

In our analysis, a phase out of natural gas while preserving its important role in the electricity sector and industry for some time will be facilitated by reducing its use elsewhere. Indications are that natural gas resources are plentiful at least for the next several decades. But building new production, use, and export infrastructure risks either huge stranded costs or continued use of natural gas for the long-term, both of which are undesirable. We will explore the issue in more detail in our final report, due to be completed before the end of 2015.

In the same spirit, we have opened the issue of energy justice and heating and cooling issues faced by low-income households. We are preparing a special report on this issue as part of the Renewable Maryland Project.

Besides benefiting from the review of the Advisory Board, we have also been fortunate to have the participation of many other experienced experts in the advisory process. We are especially grateful to Kevin Lucas, who reviewed an early version of the technical calculations for estimating heating and cooling energy use in Maryland households. His review shaped this report in that we decided to model three different types of homes rather than just one, which would not have been representative.

We are also thankful to Joanna Diamond, Director of Environment Maryland, and James Strong of the United Steelworkers, for their participation in the Advisory Board meeting that reviewed a draft of this report, and to Rebecca Ruggles, Director of the Maryland Environmental Health Network, Cheryl Casciani, Chair of the Baltimore Commission on Sustainability, Crissy Godfrey, Director Energy Analysis & Planning Division of the Public Service Commission, Paula Carmody, Director of the Office of People's Counsel, Alice Kennedy, Sustainability Coordinator, Baltimore Office of Sustainability, and Kristin Baja, Climate and Resilience Planner of the Baltimore Office of Sustainability who have given us advice at other times along the way.[2]

As always, only the authors of this report are responsible for its contents, analysis, findings, and recommendations, and any errors that remain.

A most special vote of that is due to the Town Creek Foundation, which has funded the Renewable Maryland Project in its entirety since its inception. It has been a special privilege that Stuart Alan Clarke has shared his sharp insights with us from the start, and has been central to the stakeholder outreach that has been part of our work since the project's inception. We also want to thank Megan Milliken on the Foundation's staff – she has flawlessly organized several stakeholder meetings in the last two years and has participated in them.

Two staff members of IEER contributed to this report in important ways: Annie Makhijani, IEER Project Scientist, did much of the research on the energy and emissions data, Lois Chalmers provided bibliographic assistance, fact checked and proof-read the report and carefully complied the reference list.

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[2] Advice has been proffered in their personal capacity; organizations are noted for identification only.

Executive Summary

Space heating and cooling of buildings accounted for about 28 percent of Maryland's primary energy use in 2011. A third is due to electric heating and an equal amount is due to air-conditioning; the rest is due to the use of fossil fuels for space heating, 75% of which is natural gas. **Space heating and cooling is responsible for almost a fourth of Maryland's total greenhouse gas emissions**.

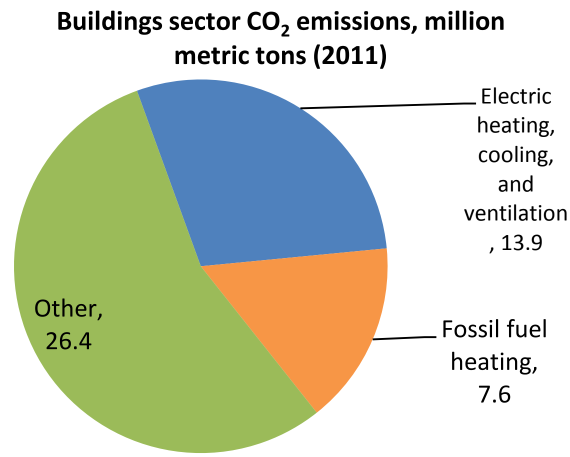

Figure ES-1. Total Maryland buildings sector CO_2 emissions with detail on electric space heating, fossil fuel space heating, and space cooling. Source: IEER, derived from EIA SEDS 2014.

We analyzed the heating and cooling needs of three typical Maryland residences using Baltimore climate data and examined the economics of making the existing systems more efficient by converting them to cold climate heat pumps and geothermal heat pumps. In all cases our analysis included air-conditioning, since it is present in almost all Maryland homes. Much of the analysis is also applicable to commercial sector buildings.

Our recommendations, if pursued, can reduce energy use, reduce CO_2 emissions, and also make the homes and businesses "renewable-grid ready." Maryland's electricity sector accounts for about 40 percent of statewide CO_2 emissions. Given this, the progressive conversion of the grid to far lower emissions per unit of generation is an essential requirement of reducing greenhouse gas emissions 90 percent by 2050.

Efficient electrification of space heating can reduce CO_2 emissions immediately. It also makes the sector "renewable grid ready" and emissions will continue to decline as the CO_2 emissions from electricity generation are reduced.

Main Finding

A 90 percent reduction of CO_2 emissions due to building space conditioning relative to business-as-usual is feasible if a combination of measures are accomplished (Figure ES-2): increased building envelope efficiency, conversion to highly efficient heat pumps, including most of the homes heated with natural gas, and a nearly-emissions-free electric grid. If natural gas conversions are not included, a three-fourths reduction in emissions is still possible, however, this does not include the significant impact of natural gas leaks and the increasing concern about its short-term warming potential.

***Main Recommendation**: Maryland should set stringent carbon reduction standards for new buildings and enact policies and programs to start converting existing buildings, beginning with oil, propane, and electric resistance heating, to highly efficient space-conditioning systems, making them "renewable grid ready."*

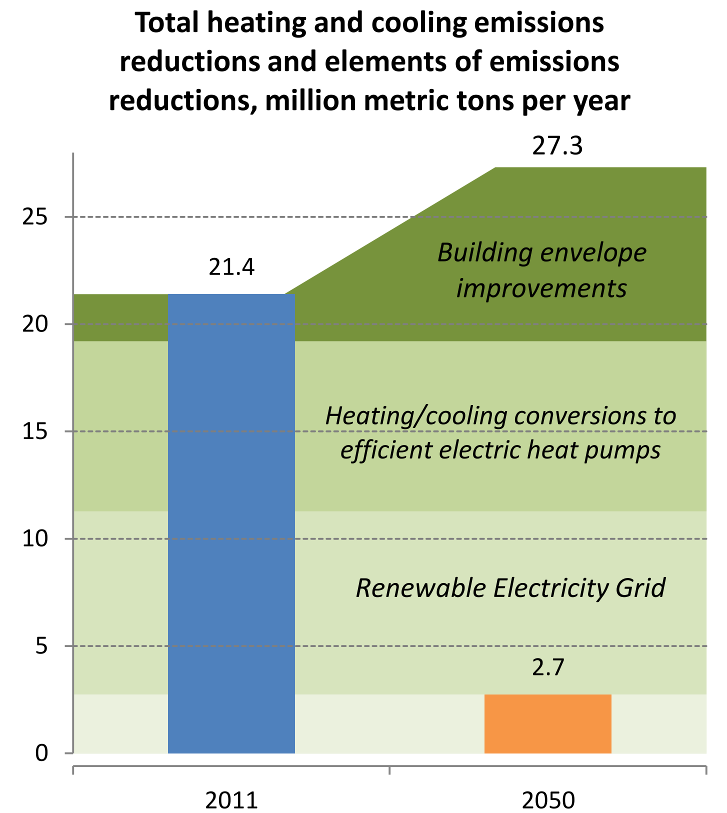

Figure ES-2. CO_2 emissions in 2011 and in 2050 after building envelope improvements, heating and cooling system conversions, and a renewable grid. Source: IEER

Other Findings and Recommendations

Oil and propane conversions

- Converting homes from fuel oil or propane heating and resistance heating to cold climate or geothermal heat pumps is always economical over the 15-year analysis timeframe. The main obstacles are information, split incentives (in the case of renters), and financing (due to high first cost of efficient equipment).

  ***Recommendations**: Create policies to encourage conversion at the time of home HVAC system purchase, home sale or refinancing, and require landlords to upgrade their systems when houses are rented or every 10 years. Financing is the key and a variety of approaches from establishing a Green Bank, to Property Assessed Clean Energy financing, to on-bill financing (with third party funding of the loans) are possible. Complementary policies include bill disclosure, encouragement of the HVAC industry to provide information on the most efficient equipment at the time of retrofitting, mandatory energy bill disclosure and audit at the time of sale of a building, and factoring in energy bills into the mortgage qualification process.*

Low-income rentals

- The split incentive in low-income rental housing can be eliminated if energy costs are rolled into the rent. However, landlords may simply raise the rent, rather than improve building envelopes or upgrade space conditioning in buildings.
__Recommendations__: Implement a low-income pilot project to roll utility costs into the rent, combined with upgrades of building envelope and space conditioning system efficiency. Direct significant rebates towards landlords who make improvements that ensure low overall energy bills for tenants in low income housing. Overall, efficiency incentives should focus on converting low-income households (including owner-occupied ones) and low-income rental property, recognizing the junction between energy security, energy justice, and emissions reductions goals.

HVAC incentives

- The existing incentive structure for HVAC systems is outdated, given that air-to-air cold climate heat pumps have performance closer to geothermal heat pumps than ordinary heat pumps. (Figures ES-3 and ES-4)
__Recommendation__: Combine heating and cooling system performance indicators into a single product of the two. Provide incentives based on the combined heating and cooling performance indicator in a graduated scale beginning at a small incentive for efficiency at the Energy Star label level and increasing to a maximum for efficiency levels similar to geothermal heat pumps.

Natural gas conversions

- The economics of natural gas conversion in existing households to efficient electric heating are more complex. Using the 2012 price, conversion to the most efficient heat pumps is economical in Maryland when there are at least some rebates

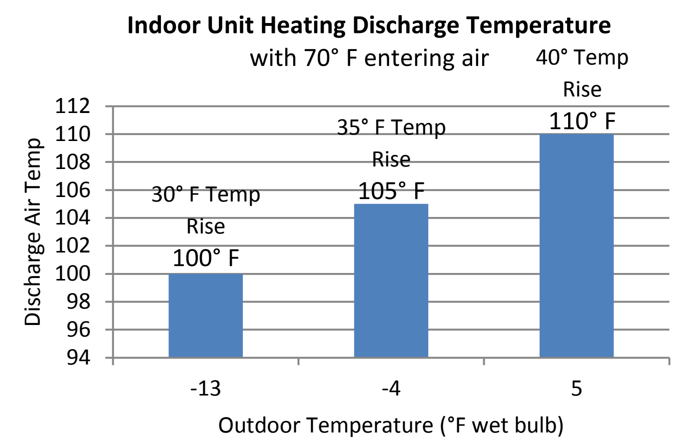

Figure ES-3. Discharge temperatures of Mitsubishi heat pump unit at various low outdoor temperatures. Recreated by IEER from Mitsubishi 2010 p. 7.

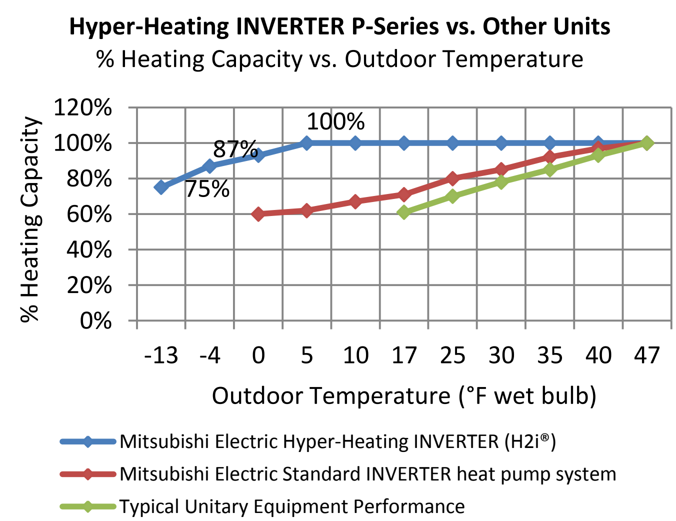

Figure ES-4. Heating capacity of heat pumps at various outdoor temperatures. Recreated by IEER from Mitsubishi 2010 p. 7.

and incentives for efficient heat pump replacements. It is also likely to be economical in new homes, given that costs of installation are generally lower compared to retrofitting. ***Recommendation****: Adopt the Architecture 2030 Challenge for carbon neutral new buildings by 2030 and institute complementary measures such as low-interest financing to facilitate the transition. Begin the conversion from natural gas to efficient electrical systems in existing buildings with public buildings and publicly-owned or subsidized low-income housing.*

Low-income households will be disproportionately affected by rising energy costs. Incentives and policies must prioritize low-income households, both owner-occupied and rentals, in order to achieve energy security, energy justice, and emissions reductions goals.

Natural gas prices

- The current trajectory of natural gas production and use (as projected in the Energy Information Administration's Reference Scenario, as simultaneously increasing production, use, and exports) is estimated to cause a constant dollar increase in residential natural gas prices rise by about 50 percent by 2040. Such increases would cause significant economic distress and energy insecurity in a large number of low-income households. Nationally, this type of policy is also incompatible with the large reductions in greenhouse gas emissions that are needed, especially when natural gas leaks are taken into account.
  Recommendation*: Reduce the use of natural gas in space and water heating in buildings (via envelope efficiency increases and conversion to efficient electric systems), discourage liquid natural gas exports (for example, from Cove Point), and make the Maryland moratorium on fracking permanent. A combination of the above policies in regard to natural gas should be pursued to help maintain reasonable energy costs, help make space heating "renewable grid ready," reduce the impact of natural gas price spikes, contribute to a path of steadily decreasing* CO_2 *emissions while still allowing for natural gas use increases in critical transition uses, notably combined heat and power systems.*

Commercial sector

- The analysis is widely applicable to commercial buildings. In the statewide analysis we have assumed 50 percent of natural gas use for space heating in commercial buildings will convert to efficient electric heat pumps. Already some schools and other buildings are using geothermal heat pumps in Maryland.
  Recommendation: *Encourage conversion from direct fuel use to efficient electric heat pumps in the commercial sector when feasible. Ensure that any remaining direct fuel use for space conditioning is using the most efficient options available, such as combined heat and power which can transition to biogas from natural gas.*

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I. Introduction

Space conditioning (heating and cooling) of buildings is a principal use of energy and a large source of carbon-dioxide (CO_2) emissions. Heating is done by directly burning fossil fuels or via electric heating systems; cooling is generally electrically driven. Space conditioning, by-and-large, remains dominated by inefficient technologies compared to the best ones commercially available today. This is especially true of residential heating, where the direct burning of fossil fuels (natural gas, heating oil, and propane) in buildings and the use of electric resistance heating, the most inefficient technology at present in terms of primary energy use[3], account for over five-sixths of the systems in use in Maryland today. Even when heat pumps are used, the performance in terms of efficiency and comfort of the typical units installed lags considerably behind the best available technology. While the problem is less dramatic in the case of cooling, current air-conditioning units also typically lag far behind the best available technologies in terms of energy performance. Enormous efficiencies are possible through equipment improvement and can be further magnified through improvement of building envelopes and gradual conversion of the grid to non-thermal generation.

Figure I-1 and Figure I-2 show that building space conditioning accounted for almost 28 percent of all primary energy use[4] in Maryland and almost a quarter of all energy sector CO_2 emissions. The fossil fuel space heating-related emissions alone were over 8 percent of the total energy-related CO_2 emissions. We consider space heating in more detail because its transformation is more complex, given the more varied fuels and technologies currently in use.

[3] The inefficiency of resistance heating relative to natural gas and oil furnaces is due to the large thermal losses at central station thermal power plants that characterize present-day centralized generation. Note that the two Tables in KEMA Draft 2011 that show heating technologies are somewhat inconsistent. Table 3-3, which is based on billing data shows 62.3 percent fossil fuel heated homes and 33.8 percent for electrically heated homes; Table 6-12, based on a mix of data, including consumer surveys, shows only 54.6 percent for fossil fuel heated homes but 37.6 percent for electrically heated homes. Table 3-3 is likely to be more accurate for total numbers. However, it does not give a breakdown between electrical heating types or show the fraction of homes with programmable thermostats, which are important to heating energy use estimates.

[4] Primary energy use includes thermal losses at electric power plants (coal and nuclear units typically discharge about two-thirds of fuel inputs as waste heat) as well as transmission and distribution losses. Losses during production and transport of fuels to buildings and power plants are not taken into account. The overall reduction in CO_2 emissions as a result of the transformations explored here will be greater than the estimates in this report when these production and transportation losses are taken into account.

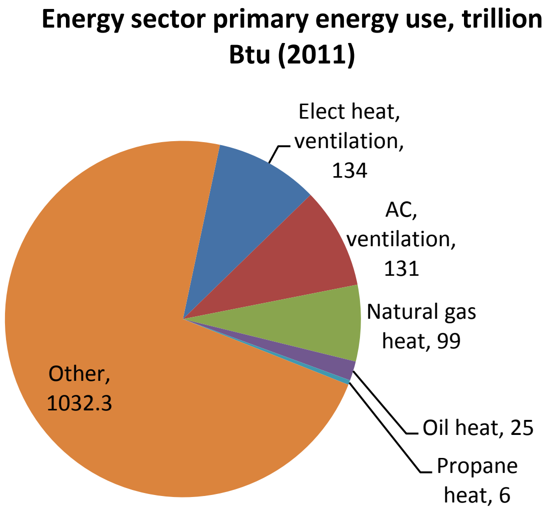

Figure I-1. Primary energy-sector energy use in Maryland, trillion Btu, 2011. Sources: Derived by IEER from EIA SEDS Consumption 2014 Table CT2 and KEMA Draft 2011.

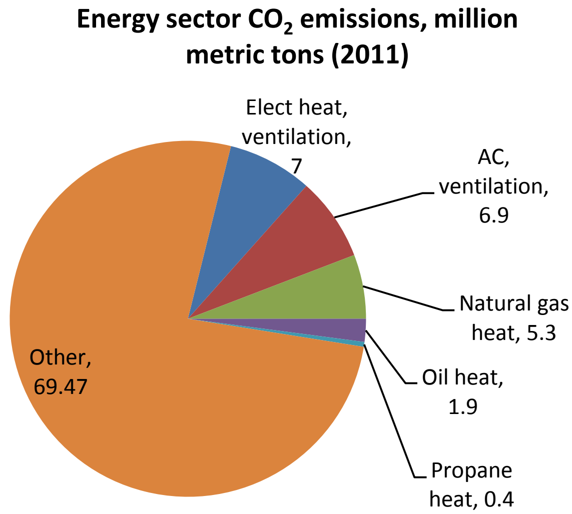

Figure I-2. Energy-sector CO_2 emissions in Maryland, million metric tons, 2011. Source: Derived by IEER from MDE GHG Inventory 2011 and KEMA Draft 2011.

Notes:
1. Natural gas leaks and transportation losses for oil and propane are not taken into account.
2. Thermal losses and transmission and distribution losses in the electricity system are included in the primary energy estimate.
3. Commercial ventilation electricity use is partitioned proportionately to commercial site heating energy and commercial site air-conditioning energy.
3. Residential ventilation energy need for ducted heating and cooling systems is not broken out separately in KEMA Draft 2011 (other than as an air-conditioning efficiency measure in some homes). The energy use and CO_2 emissions estimates for natural gas, oil, and propane heating systems are therefore somewhat underestimated.
4. Maryland's 2011 energy-related CO_2 emissions were 90.97 million metric tons (Source: MDE GHG Inventory, 2011 data). Maryland's total primary energy consumption in 2011 was 1427.3 trillion Btu (Source: EIA SEDS Consumption 2014 Table CT2).

It will be very difficult, if not impossible, to achieve Maryland's long-term goal of reducing greenhouse gas emissions by 90 percent relative to 2006 by 2050 without major changes in building space conditioning. In this report we explore the roles of equipment efficiency, notably conversion of fossil fuel heating and low efficiency electric heating to highly efficient electric units, and the progressive conversion of the grid to lower CO_2 emissions per unit of generation. We also consider the role of building envelope efficiency improvement in the overall goal of reducing greenhouse gas emissions though a transformation of residential and commercial space conditioning.[5]

[5] Much of the data surrounding building energy use was obtained through the *Buildings Energy Data Book* available on the Department of Energy website, http://buildingsdatabook.eren.doe.gov (DOE EERE 2012 BEDB).

Converting fossil fuel based space heating technology to highly efficient electric heat pumps provides an additional benefit when considering decarbonizing the electric sector because they are “renewable grid ready”. That is, highly efficient heat pumps only require electricity to operate and it does not matter whether that electricity is generated by burning fossil fuels or by harnessing the wind or sunlight. Addressing space heating and cooling in this manner – by replacing inefficient electric and fossil fuel powered units with highly efficient heat pumps – sets the stage for Maryland to take the next step in decarbonizing its electric grid and achieving steep greenhouse gas reductions.

Our basic approach for this report was to analyze the energy use, cost, and emissions of various space heating and cooling technologies for three different types of residential units that are representative of the Maryland housing sector. The analysis is also applicable to much of the commercial sector buildings.

II. Overview of Space Heating Across Maryland

A significant majority (about 62 percent) of residences in Maryland are heated by technologies involving the direct burning of fossil fuels -- natural gas, oil, and propane.[6] Further, the use of electric resistance heating is widespread. About a third of all homes are heated with electricity[7] and 63 percent of those use resistance heating[8] (Figure II-1). This means that oil, propane, natural gas, and resistance heating -- technologies that are inefficient relative to the best systems commercially available today -- are being used in the vast majority of Maryland homes (Figure II-2).[9] This fraction is actually higher, since it does not factor in the fraction of existing heat pumps that have relatively low efficiency compared to the best available systems.

[6] KEMA Draft 2011 Table 3-3 (p. 25)

[7] KEMA Draft 2011 Table 3-3 (p. 25)

[8] KEMA Draft 2011 Table 6-12 (p. 70). The KEMA data in Table 6-12 indicate somewhat higher electric heating saturation (37.6 percent) than the data in Table 3-3 (33.8 percent).

[9] Table 3-3 of KEMA Draft 2011 gives the fraction of “wood” and “other heating systems as 3.86 percent (combined), while it is listed as 8.03 percent in Table 6-12.

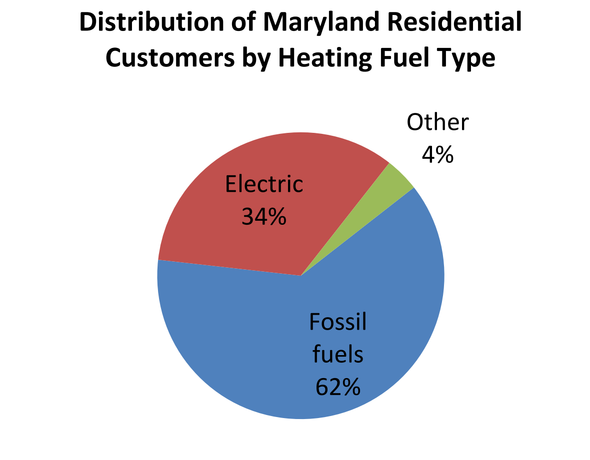

Figure II-1. Heating fuels in the Maryland residential sector. Source: Derived by IEER from KEMA Draft 2011.

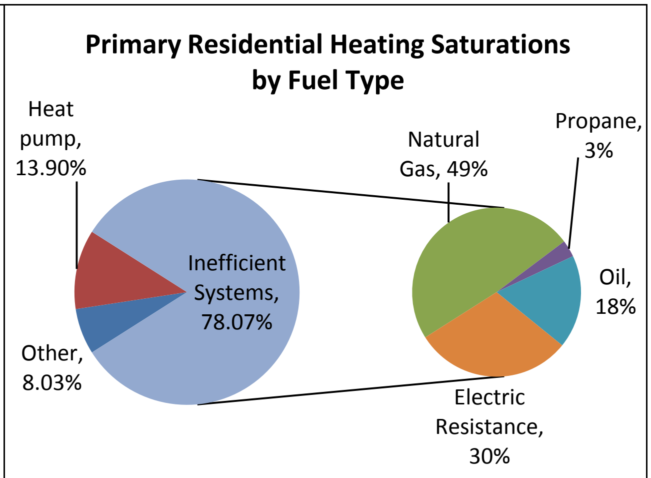

Figure II-2: Residential heating systems in Maryland. Source: Derived by IEER from KEMA Draft 2011.

Note: many heat pump systems can also be inefficient – in the sense of using more primary energy than oil or natural gas systems when electricity generation is dominated by thermal generating stations.

Further, the various space heating systems are not evenly distributed in the different types of residential structures. About two-thirds of single family detached houses use direct burning of fossil fuels (mainly natural gas, but also fuel oil, with a small fraction using propane). Electric heating in such structures is less common than in any other type, and is generally a fifty-fifty mix of heat pumps and resistance heating. Single family attached homes have a somewhat similar pattern, except that electric resistance is more common compared to detached single family structures. Resistance heating is the most common form of space heating in apartment buildings with five or more units – almost half of them have resistance heating and an additional 18 percent use heat pumps. These three types of residential structures account for about 94 percent of all residential units in Maryland.[10] Figure II-3 shows the distribution of types of heating systems in the Maryland residential sector according to the type of structure. Almost 90 percent of homes have central air conditioning (CAC), and 16 percent have room air conditioners. This means that a small fraction of the central air conditioned residences also have room air-conditioners and that well over 90 percent have some form of air-conditioning.

[10] KEMA Draft 2011 Tables 3-3 and 6-12

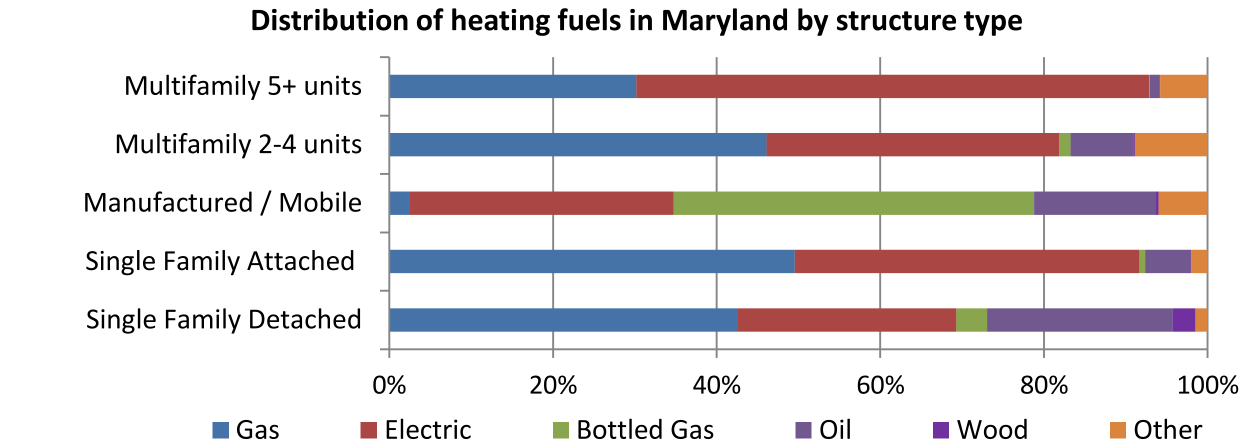

Figure II-3. Distribution of heating fuels in Maryland by structure type. Source: Derived by IEER from KEMA Draft 2011 Table 3-3 and Table 6-12.

There is a particular complication when it comes to rental housing. The split incentive, which occurs when owners of buildings do not pay the utility bills, is a serious problem. Specifically, it prevents renters from realizing the benefits of the most efficient space conditioning technologies. Because low-income people are more likely to be renters rather than homeowners,[11] it affects low-income people disproportionately.[12]

III. Case Study Analysis Methodology

We approached our technical and economic analysis of space heating and cooling by focusing on three prototypical residences that would be illustrative of the range of housing in Maryland:

1. Case Study #1: a large, detached, single-family home in suburban Maryland, approximately 2,500-3,000 square feet
2. Case Study #2: an average sized detached or attached single-family home in Baltimore, approximately 1,500-2,000 square feet; this calculation would be approximately valid for single family attached homes, such as are common on Baltimore.
3. Case Study #3: a single apartment unit in a large building.

For case studies #1 and #2 we examined the primary energy use, economics, and emissions over 15 years for replacing the existing space heating and cooling systems with:

a) Natural gas heating and central air conditioning

[11] About 68 percent of homes in Maryland are owner-occupied (US Census Maryland 2014); for low-income people who receive heating energy assistance, the figure is about 31 percent (Maryland PSC 2013 Appendix A, Attachment G (MEAP table)).

[12] Almost 70 percent of low-income households which get electricity bill assistance are renters (Maryland PSC 2013 Appendix A, Attachment G (EUSP table)); in the general population, about two-thirds of the households are homeowners; see US Census Maryland 2014.

b) Oil heating and central air conditioning[13]
c) Electric resistance heating and central air conditioning
d) A non-Energy Star rated air-to-air heat pump
e) An Energy Star rated air-to-air heat pump[14]
f) A cold climate air-to-air heat pump
g) A geothermal heat pump[15]

For case study #3 we examined the monthly energy costs, energy use, and emissions over 15 years of replacing the existing space conditioning system with:

a) Natural gas heating and central air conditioning
b) Oil heating and central air conditioning[16]
c) Electric resistance heating and central air conditioning
d) A non-Energy Star rated air-to-air heat pump
e) An Energy Star rated air-to-air heat pump[17]
f) A cold climate air-to-air heat pump

The framework for the analysis is a situation where the existing heating and cooling equipment is replaced at the end of its useful life. The analysis includes consideration of cost, energy use, and emissions from replacement of the existing system with either the same technology or one of the heat pump alternatives. The individual household heating and cooling energy use for each type of technology was determined using publicly available Energy Star workbooks. In the case of the apartment, central air-conditioning and mini-split heat pumps are treated as equivalent, since the system is small.

[13] Because the performance and economics of oil and propane are so similar we did not analyze these fuels separately. The findings for oil heating can be applied to propane heating systems.
[14] Energy Star rating is applied to all heat pumps with a HSPF (Heating Seasonal Performance Factor) of 8.2 or greater and a SEER (Seasonal Energy Efficiency Ratio) of 14.5 or greater (Energy Star Heat Pump Criteria 2014). This analysis uses the minimum ratings for the Energy Star heat pump replacements.
[15] Both vertical and horizontal wells were considered for the economic analysis since their costs are significantly different. Their energy performance is the same.
[16] Because the performance and economics of oil and propane are so similar we did not analyze these fuels separately. The findings for oil heating can be applied to propane heating systems.
[17] Energy Star rating is applied to all heat pumps with a HSPF of 8.2 or greater and a SEER of 14.5 or greater (Energy Star Heat Pump Criteria 2014). This analysis uses the minimum ratings for the Energy Star heat pump replacements.

Why Geothermal Heat Pumps?

Geothermal heat pumps are the most efficient of all electrical heating and cooling systems, though some air-to-air heat pumps are now getting close in performance. The efficiency of heat pumps is highest when the heat source or sink is closest in temperature to the desired indoor temperature. Geothermal heat pumps are the most efficient because they use the constant temperature of the earth about four feet or more below the surface (approximately 55 °F) as a source of energy rather than outside air, which is used by air-to-air heat pumps.

In general, the efficiency of any heat pump, is greater than 100 percent of site energy input. This is because a heat pump by its design gathers “free” energy from the environment and adds it to the electricity input. However, geothermal heat pumps cannot be used in all circumstances. For instance, there is sometimes not enough room for a drilling rig to be set up on the property; horizontal loops need a large land area, which is often not available. And geothermal heat pumps are likely to be unsuitable for large multi-unit apartment buildings.

Fortunately, the best available air-to-air heat pumps now available, called “cold climate heat pumps,” have a performance level that is not far from that of geothermal heat pumps. Such air-to-air heat pumps also have a much lower first cost.

What are cold climate heat pumps?

Most heat pumps use "air-to-air" technology – that is they extract heat from cold air in the winter, pump it up to a higher temperature, and deliver it to the indoors. The cycle is reversed in the summer, when heat is extracted from inside the home and dumped outdoors. Heat pumps use special fluids, called refrigerants, that boil at low temperatures; this boiling allows the extraction of heat from cold outdoors air in the form of the latent heat of vaporization. At 47° F outdoor temperature, a typical heat pump will deliver about three times as much heat as the electrical energy needed to run it. A major problem with traditional heat pumps is that they are very inefficient at temperatures close to freezing. Below freezing temperatures they fail to extract significant heat from the outdoors; this forces the use of resistance heating elements, which is much like heating a home with incandescent light bulbs (without the benefit of the light). The temperature of the supplied air is also often below the body temperature of about 98 °F, giving rise to a frequent complaint of poor quality heat in winters.

In contrast, cold climate heat pumps use special refrigerants that boil at very low temperatures – below 0° F –and can therefore deliver superior performance and comfort at cold temperatures comparable to the most extreme that are experienced in Maryland. Figure III-1 shows the temperature of the air supplied indoors at various outdoor temperatures; Figure III-2 shows the factor by which the electrical energy input is multiplied at various temperatures by a high-end cold climate heat pump. The most efficient devices also provide air conditioning at efficiencies that are roughly double that of typical, non-Energy Star air conditioners.

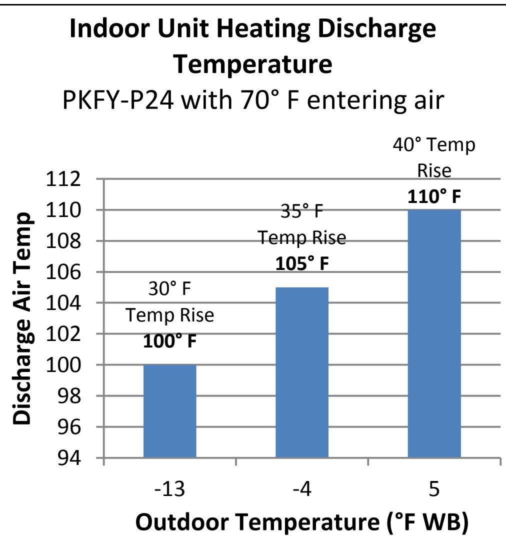

Figure III-1. Discharge temperatures of a cold climate heat pump at various outdoor temperatures. Source: Recreated by IEER from Mitsubishi 2010 p. 7.

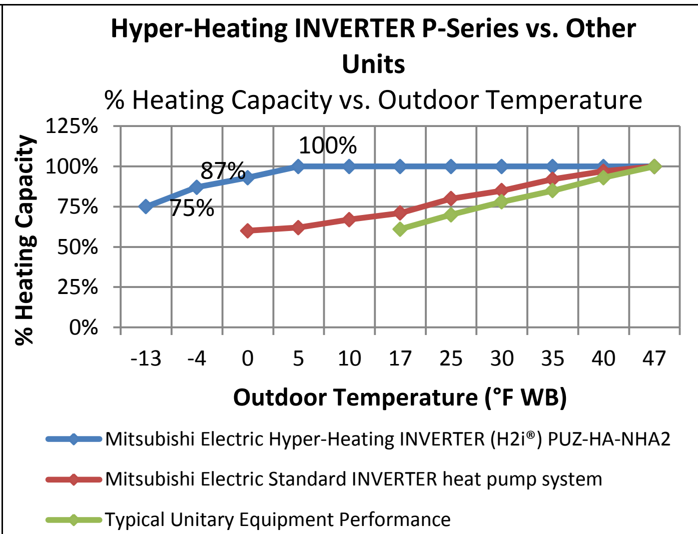

Figure III-2. Performance factors of typical heat pumps compared to highly efficient cold climate heat pumps. Source: Recreated by IEER from Mitsubishi 2010 p. 7.

IV. Residential Energy Use and Emissions from Space Conditioning

Figure IV-1 and Figure IV-2 show the primary energy use and CO_2 emissions in an average size single-family home in Baltimore with various heating system replacements. The calculations assume no change in the efficiency of Maryland's existing sources of electricity generation or the CO_2 emissions per unit of electricity generation feeding the heat pumps. All case studies showed a similar pattern between the various technologies.

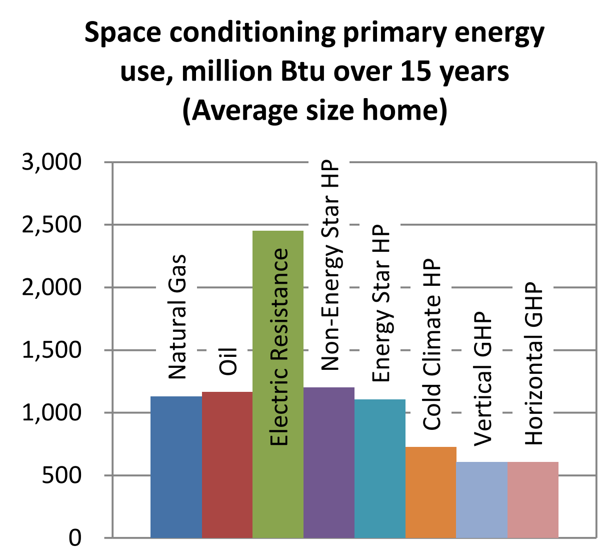

Figure IV-1. The primary energy use over 15 years of space conditioning, in million Btu, for an average size single-family home in Baltimore, Maryland. Natural gas, oil, and electric resistance heating systems include the primary energy for central air conditioning. The heat pumps include primary energy for both heating and cooling. Source: IEER.

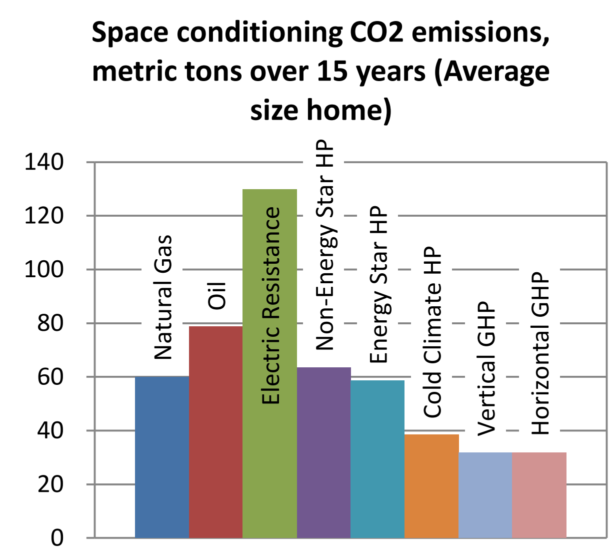

Figure IV-2. The CO_2 emissions from space conditioning in metric tons, over 15 years, for an average size single-family home in Baltimore, Maryland. Natural gas, oil, and electric resistance heating systems include the emissions from central air conditioning. The heat pumps include emissions from both heating and cooling. Source: IEER.

In all three case studies, the cold climate heat pumps and geothermal heat pumps used less energy than any of the other alternatives, and consequently had the lowest emissions. Electric resistance heating had the highest primary energy use due to the thermal losses generation in the present-day electricity system.[18] The difference in primary energy will be magnified over

[18] Most generation today is thermal generation, in which about two-thirds of the fuel is discharged as waste heat at the power plant. With such a system, it would take a heat pump with an average coefficient of performance of about 3 to equal a high-end natural gas system. Typical heat pumps cannot achieve such performance in Maryland or colder climates. Cold climate heat pumps and geothermal heat pumps can. With an 80 percent non-thermal renewable grid (plus combined cycle power plants), a cold climate heat pump would be more than three times as efficient as an Energy Star natural gas furnace; and a geothermal heat pump even more so.

time as the grid acquires larger fractions of solar and wind energy, which have no thermal losses associated with them. In fossil fuel heated homes, only the primary energy requirements due to cooling decline as the grid becomes more renewable; in contrast, both heating and cooling primary energy use declines when heat pumps are used. In a grid that is consists nearly completely of solar, wind, and hydropower (plus storage), the energy use for the heat pump systems would be about one-third that shown in Figure IV-1 and the CO_2 emissions would be close to zero.

Figure IV-3 and Figure IV-4 compare primary energy use and CO_2 emissions for a cold climate heat pump in a single family detached home with the present grid configuration (which is mainly thermal generation) and grid with 80 percent non-thermal renewable generation and 20 percent thermal generation.

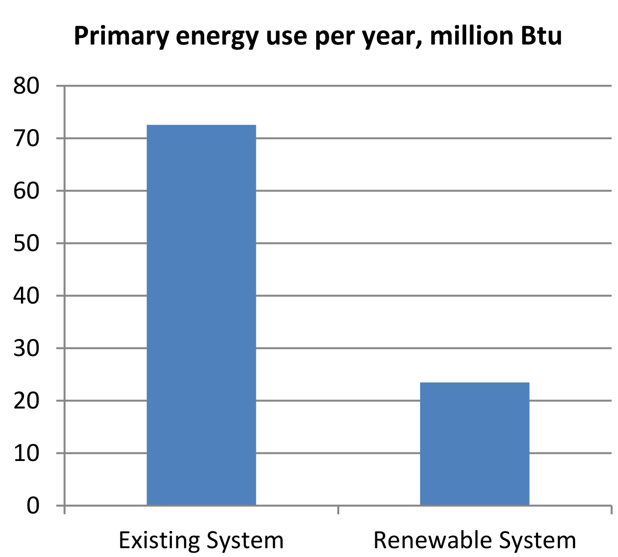

Figure IV-3. Total primary energy use per year of a cold climate heat pump in a larger than average single-family home in Baltimore, MD. Source: IEER.

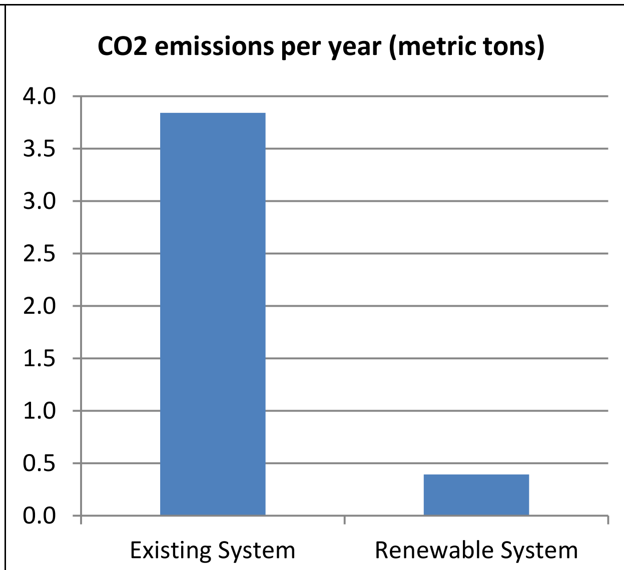

Figure IV-4. Total CO_2 emissions per year of a cold climate heat pump in a larger than average single-family home in Baltimore, MD. Source: IEER.

Note: 1. The definition of a renewable system is a placeholder for a more complex one under development by IEER. It assumes 90 percent of generation will come from non-thermal renewable energy and all remaining thermal generation is from natural gas-fueled combined cycle power plants.

V. Economics of Transforming Residential Heating and Cooling

We also considered the economics of replacing heating and cooling systems in other existing households. We used cost data provided by the heating, ventilation, and air conditioning (HVAC) industry and current Maryland energy prices in our analysis. With that as the basis, we estimated the state-wide implications of reducing energy use for space heating in the residential and commercial sectors. In the commercial sector, including large multifamily buildings, combined heat and power can - and should - play a major role as well. This will be analyzed more fully as part of the overall electricity sector analysis in a future Renewable Maryland Project report, but is discussed briefly in a later section.

The figures below show the total cost of heating and cooling system replacements over 15 years for single-family homes in Baltimore, Maryland. The costs include the initial purchase price, with incentives[19], fuel costs, and the cost of air conditioning. These costs have been discounted to the present (i.e., to the time of replacement of the HVAC system).[20] Both oil and electric resistance heating are **significantly** more expensive than all other options in all scenarios.[21] This remained true even when state, and utility incentives for heat pumps were removed from the analysis.

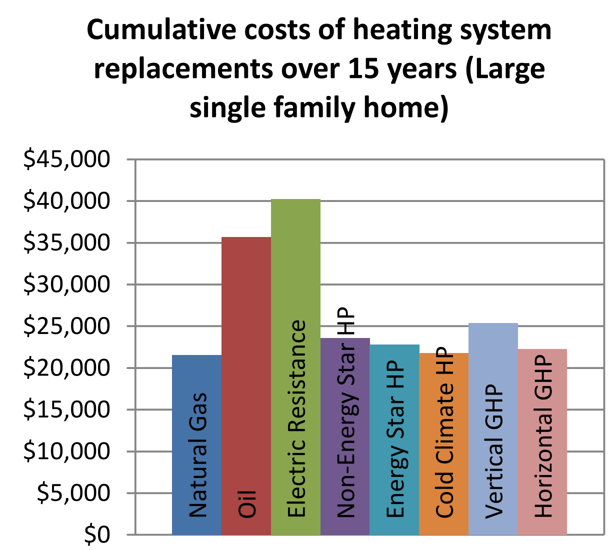

Figure V-1. The cumulative costs of various heating and cooling systems over 15 years for a large single-family home in Baltimore, Maryland. Source: IEER.

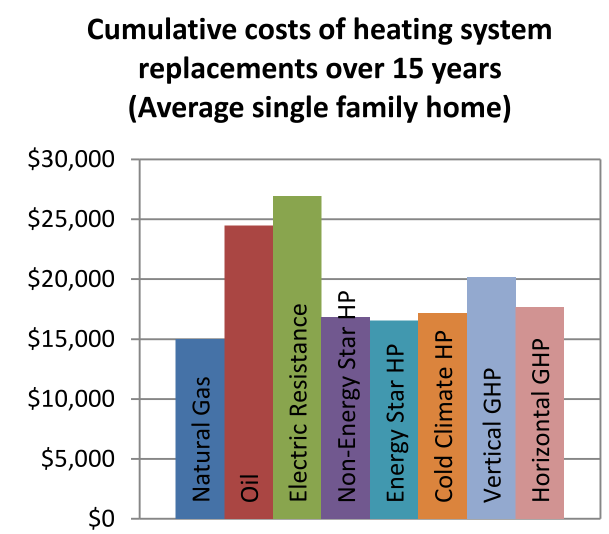

Figure V-2.The cumulative costs of various heating and cooling systems over 15 years for an average sized single-family home in Baltimore, Maryland. Source: IEER.

Note: in both Figure V-1 and Figure V-2 the values reflect financing of the heat pump systems at 4 percent, include all current state and utility rebates but no federal tax credit, and incorporate the residual value of geothermal heat pump equipment after 15 years.

[19] Incentives included only state and utility rebates for efficient heat pumps. We did not include the 30 percent federal tax credit for geothermal heat pumps in this analysis.

[20] A 5 percent discount rate, including a 2 percent inflation rate, was used in the calculations. Electricity and natural gas prices were assumed to rise at the inflation rate – that is, they were assumed to be constant in real dollar terms. Discounting values future costs less than present costs on the theory that today's money, if invested would grow to a larger sum in the future. Discounting reflects that by reducing the present value of future costs.

[21] We have not taken detailed account of the steep fall in crude oil prices, and the associated fall in fuel oil prices, since mid-2014. We briefly discuss the implications in Section VII-B below.

A. Electric Resistance and Oil Space Heating

In all instances, regardless of home size, both electric resistance and oil space heating with air conditioning is more expensive, consumes the most energy, and consequently results in the highest associated emissions. Because the economics for propane are similar to those of oil, the results for an oil heated household can be applied to a propane heated household. Figure V-3V-3 compares the total costs over 15 years of electric resistance or oil heating plus air conditioning with cold climate heat pumps, while Figure V-4 shows the primary energy use associated with these technologies (including electricity system thermal losses). Higher primary energy use, with the current mix of fuels for electricity generation today, results in higher emissions. **The life-cycle economic comparisons provide a strong economic, energy, and environmental case for replacing resistance heating, fuel oil, and propane heating wherever the structures allow it.**

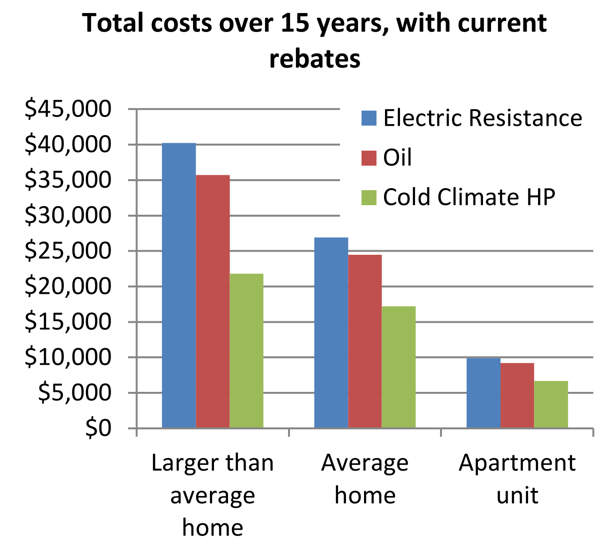

Figure V-3. Present value of the cumulative cost of electric resistance and oil heating with air conditioning, and the best available air-to-air heat pump for all three case studies considered in the analysis. Includes financing of cold climate heat pumps at 4 percent and all currently available state and utility rebates. Source: IEER.

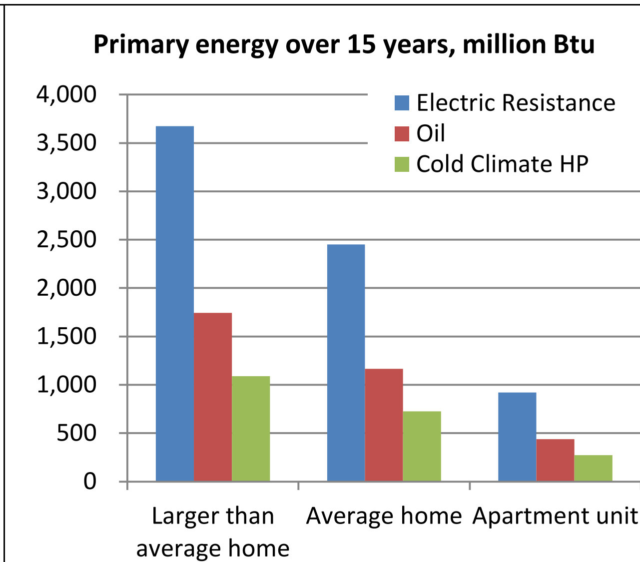

Figure V-4. Primary energy in million Btu for electric resistance and oil heating with air conditioning, and the best available air-to-air heat pump for all three case studies considered in the analysis. Primary energy includes thermal losses at the generating station and the transmission and distribution losses on the electric grid. Source: IEER.

B. Residual Value of Efficient Heat Pumps

The analysis period used in this report is 15 years. This is the typical life of conventional HVAC equipment; it is also a reasonable time-frame over which a homeowner would evaluate economics; it is intended to reflect the amount of time that homeowners on average will stay in their homes.[22] However, the lifetime of geothermal systems extends considerably beyond 15

[22] Emrath 2013

years, with the geothermal well having a lifetime estimated at 50 years and the heat pump unit having a lifetime of 25 years. We took these longer lifetimes into account in our 15-year comparison period by estimating the residual value of the geothermal heat pump. We used straight-line depreciation to estimate the value of the two components – 10 years, or 40 percent remaining for the heat pump out of an expected life of 25 years; 35 years out of 50 (or 70 percent) remaining for the geothermal well. We then discounted these value to the present as we did for all future dollar amounts.[23]

Figure V-5 shows the effect of including residual value of a geothermal heat pump system in the overall estimate of differences in cost between such a system and natural gas plus central air-conditioning.

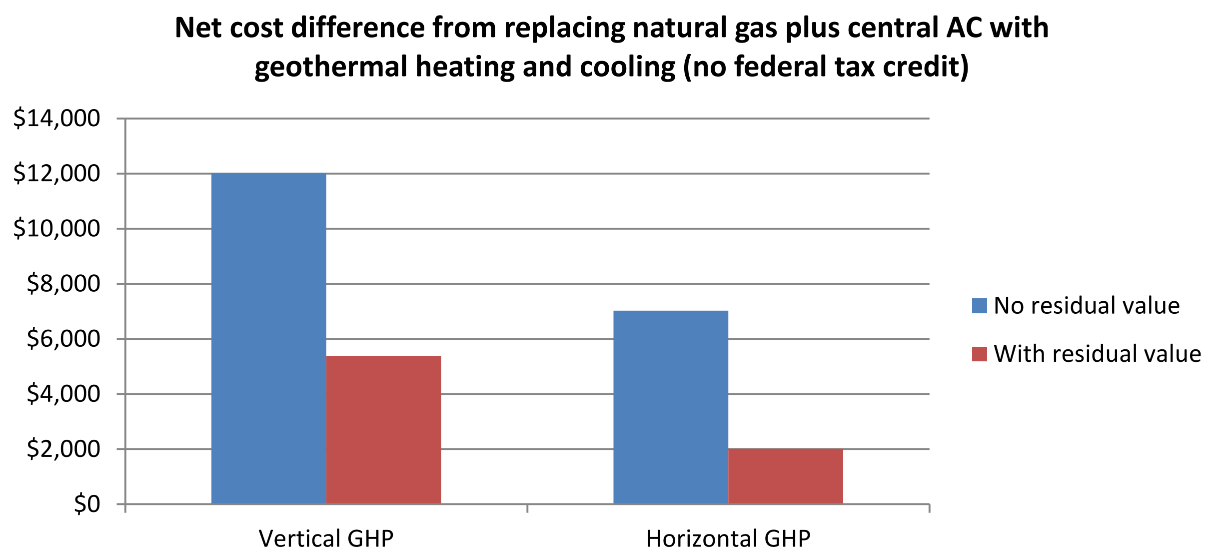

Figure V-5. Comparing effect of residual value calculations on the total net costs of vertical and horizontal GHP replacements of natural gas heating systems in a large single family home in Maryland. Values assume cash purchase and include all available state and utility incentives for geothermal heat pumps but no federal tax credit. Source: IEER.

[23] For example, a 3-ton vertical geothermal well with a lifetime of 50 years is estimated to cost $10,000. After 15 years the remaining value of the well would be: $10,000 * (35/50), or $7,000. We could also estimate the residual value at 25 years and estimate the energy savings between years 15 and 25 compared to other equipment. The present value of the residual value estimated by this method is not very different. Therefore we just used the simpler, more conventional straight-line depreciation approach to make the estimates used in this report. This approach enabled us to "keep it simple" and in line with the way an informed homeowner might make HVAC investment decisions.

C. Rental Housing

Across Maryland approximately 12 percent of households are rental units in multi-family buildings. Of those households, the vast majority are in buildings with five or more units.[24] However, we should note that this is not the case in the City of Baltimore, where half the households rent, but only about 21 percent of the total housing units are in buildings with five or more units.[25] With regard to rental housing, highly efficient mini-split heat pumps are often a viable technology option for buildings under 10 stories.[26] Table V-1 shows the monthly energy cost for various heat pump units and the cost differentials with other space-conditioning systems.

Table V-1. Monthly cost impacts on energy costs for a single apartment unit replacing electric resistance heating with a mini-split heat pump, discounted over 15 years to present value. Negative figures, in red and parenthesis, show a monthly savings for heat pumps.

	@ 2012 price	@ EIA price projection
Non-Energy Star HP	$2.40	$1.05
Energy Star HP	$0.61	($0.79)
Cold Climate mini-split HP	($7.64)	($9.27)

Note: air conditioning is included in all cases

There are at least four, quite different, situations in terms of evaluating space conditioning equipment replacement in apartments:

- *The apartments are owner-occupied and owners pay all energy bills*
  In this case, the owner has an incentive to install the more efficient equipment if it is economical. However, condominium units may need access to common space for installing outdoor equipment, notably condenser units.
- *The apartments are owner-occupied and owners pay electricity but not heating bills*
  In this case, installation of cold climate heat pumps would reduce common fuel bills for heating as well as bills for maintenance and replacement of that equipment. Condo owners will have increased energy expenses for heating. The adjustments in such cases can be made by reducing condo fees.
- *Apartments are rented and renters pay all energy bills*
  This is the true spilt-incentive case. Apartment building owners have no incentive to install equipment that have higher first costs, since they get none of the benefits of the reduced energy bills. Arrangements of this type may typically use resistance heating as the technology of choice, given its low upfront costs. In such cases, to encourage the adoption of cold climate heat pumps, an energy-service provider approach may be adopted, where landlords can raise the rent by an amount that captures most, but not all, of the energy bill reductions.
- *The apartments are rented and renters pay electricity but not heating bills*

[24] KEMA Draft 2011 Figure 5-1 (p. 42)
[25] This includes occupied and unoccupied housing. Data from ACS Housing Baltimore City 2011-2013.
[26] Dentz, Podorson, and Varshney 2014

In this case, space heating is provided by common heating units such as oil or gas boiler systems. By replacing these units with efficient heat pumps, the building owner benefits from reduced heating fuel costs and reduced expenses for maintenance and replacement of heating equipment. At the same time renters will have reduced air-conditioning costs but their electric bills are likely to be higher since it now includes heating. Designing a win-win situation would require some reduction in rent to compensate for the now renter-paid heating costs. The institutional and regulatory mechanisms for doing so in situations other than publicly-owned housing or government-subsidized housing may be difficult.

The above arrangements are theoretical approaches that need to be evaluated. One or more pilot projects could help devise the most practical approaches.

Finally, we note that the condition of the structures should be sound enough to justify investments in new HVAC systems. If the structures need significant improvement, the considerations are more complex and beyond the scope of this report.

D. CO_2 Emissions Credits and Renewable Energy Credits

We have also analyzed the potential economic impact of credits for CO_2 emission reductions as well as the Renewable Energy Credits for which geothermal heat pumps are eligible in Maryland. These do not change the essentials of the economic analysis. Table V-2 below compares the present values of CO_2 emissions over 15 years for a large single family home, assuming a carbon price of $35 per metric ton.[27] The economics of including a CO_2 price are even less favorable for an average size single family home given the somewhat high initial equipment costs for geothermal systems at that size.

Table V-2. Impacts of a $35 per metric ton price on CO_2 emissions on the incremental 15-year costs for heating and cooling system compared to a natural gas plus central AC for a large single family home in Maryland. Source: IEER.

	Cumulative incremental costs of system, no CO_2 price	**Cumulative incremental costs of system with CO_2 price of $35/mt**	**Change in incremental costs due to CO_2 price**
Energy Star HP	$1,596	$1,729	$132
Cold Climate HP	$613	$582	($30)
Vertical GHP, no tax credit	$4,153	$3,374	($779)
Horizontal GHP, no tax credit	$1,111	$97	($1,014)

Note: Values reflect all currently available state/utility rebates, include financing of equipment at 4 percent, and have been discounted to present values with a 5 percent discount rate. The geothermal systems also include any remaining residual value after 15 years. The federal tax rebate is not included. A negative number means a cost

[27] This figure is based on the U.S. government's determination of the social cost of carbon. It is the geometric mean of the values for 2020 of 12, 43 and 65 escalated to 2011 dollars (rounded) (Interagency Working Group 2013 Table 2 (p. 13)).

decline when there is a price on CO_2 emissions, because the emissions with the heat pump system are lower than with a natural gas plus central AC system.

VI. Financing Issues

The much higher first cost of cold climate heat pumps and geothermal heat pump systems makes financing the key issue, even when such systems are economical[28] on a life cycle basis. Therefore, the main practical issue with replacing oil, propane, resistance, and, in many instances, natural gas heating systems with the best available heat pumps is the higher upfront costs of the heat pump. Therefore, financing is the key issue in the practicality of broad adoption. We examined two financing options:

- Financing, with no down payment, at an effective rate of 4 percent per year. This would be the effective interest rate if the heat pump is financed with a home mortgage or home refinancing with good credit.[29]
- Financing, with no down payment, at 8 percent per year. This generally makes the most efficient heat pump options uneconomical.

For homes currently heated by resistance heating, fuel oil, or propane, the total costs of replacing the present systems with the most efficient heat pumps (cold climate or geothermal) remains economical at either financing rate. Thus the main cost issue relates to the replacement of natural gas plus air-conditioning with heat pump systems.

Table VI-1 shows the change in monthly costs (energy bills plus financing costs) from replacing a natural gas plus air-conditioning system with the most efficient heat pumps (cold climate and geothermal) for a large and an average size single family home. For purposes of comparison the monthly energy bills for heating and cooling are assumed to be constant throughout the year, as is typical in bill payment schemes that even out monthly bill fluctuations. Financing is assumed to be at 4 percent. All costs are discounted at a 3 percent real discount rate, plus a 2 percent inflation rate. A negative value means that the average monthly cost for the heat pump system in question are lower than if the natural gas plus air conditioning system had simply been replaced with a new one.

Two natural gas and electricity cost scenarios are shown: (i) constant real costs: natural gas at $12 per million Btu, electricity at $0.14 per kWh and (ii) the EIA reference projection for

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[28] For our purpose here the term "economical" means that the present value of the upfront costs of the heat pump equipment and the total lifetime operating costs (including replacements) is less than the present value of the upfront costs and total lifetime costs of operating a fossil fuel heating system with central air conditioning. Impacts on monthly customer utility bills are considered in a separate analysis.

[29] Current (August 2014) 30-year mortgage rates are about 4.27 percent (New York Times, August 14, 2014, p. B8). A 25 percent tax bracket would mean an effective rate of just 3.2 percent. We have used a higher rate of 4 percent as an element of conservatism. It is also approximately the rate of home equity loans with a good credit rating. That rate for a loan up to $75,000 was 4.02 percent, as reported in the New York Times, August 14, 2014, p. B8. The effective rate would be lower if an itemized deduction could be taken for such a home equity loan, as it generally can if the loan is used to improve the home. See Internal Revenue Service website explanations at http://www.irs.gov/publications/p936/ar02.html#en_US_2013_publink1000230008 (IRS 2013).

residential natural gas and electricity costs, which estimates about 1.5 percent and 0.4 percent per year real-dollar cost increases in natural gas and electricity, respectively (see Considerations Relating to Natural Gas below).

Table VI-1: Incremental impacts on total monthly cost (payment for the HVAC system plus fuel/electricity cost) incurred by going to efficient heat pump systems from natural gas plus air-conditioning. Costs include residual values of the geothermal heat pump equipment after 15 years and all utility and state rebates. Negative numbers (red and in parenthesis) mean a cost decrease.

	Large single family home		**Average single family home**	
	No incentives	Current state and utility rebates	No incentives	Current state and utility rebates
Cold Climate HP @ 2012 fuel price	$6	$3	$16	$13
Cold Climate HP @ EIA price projection	($1)	($3)	$12	$9
Vertical GHP @ 2012 fuel price	$41	$23	$48	$30
Vertical GHP @ EIA price projection	$35	$16	$44	$26
Horizontal GHP @ 2012 fuel price	$24	$6	$34	$16
Horizontal GHP @ EIA price projection	$18	($0.49)	$30	$12

Notes: 1. All values represent cumulative 15-year present value of cost differences between the various systems discounted to a present value at 5 percent and divided by 180 (the number of months in 15 years) to obtain a monthly value. The monthly present value for the heat pump system in question is subtracted from the natural gas system to obtain the cost difference.
2. Heat pump systems financed at 4 percent per year.
3. The natural gas plus air-conditioning system initial replacement is assumed to be paid for in cash.
4. No federal tax credit for geothermal heat pumps is assumed in this analysis.

We also performed the above calculation at a zero real discount rate (that is, with a discount rate equal to the rate of inflation of 2 percent assumed in this study). The results are along the same lines as those in Table VI-1 above, except that the cost differences are accentuated. That is, the cost increases are greater and the cost savings are greater as well, for the respective cases. None of the cases change from a cost increase to a decrease or vice versa. If the discount rate is increased to 7 percent, the results remain qualitatively the same, but the cost differences shrink.

Some general conclusions can be drawn from the above financing analysis:

1. For all households, replacing electric resistance heating, fuel oil, and propane heating plus air conditioning with efficient heat pump systems (cold climate or geothermal) remains economical when financed, independent of incentives and financing interest rate.
2. Geothermal heat pumps with federal, state, and utility incentives are more economical than natural gas plus air conditioning, when financed at an effective rate of 4 percent. Cold climate heat pumps are somewhat more expensive because they do not benefit

from federal or state subsidies or rebates, despite performance that is not far from geothermal heat pumps. Cold climate heat pumps currently have only a modest utility rebate, but if a performance-based incentive structure is applied the economics of these systems compared to natural gas becomes more favorable. (A proposal for a performance based incentive is discussed in Appendix A.)

3. Efficient cold climate heat pumps without subsidies are comparable to (within $2 per month) or more economical than natural gas plus air conditioning at the EIA's natural gas and electricity price projections. The reverse is true if the prices of natural gas and electricity stay constant in real dollars.

VII. Considerations Relating to Natural Gas

A nearly-emissions-free energy sector in Maryland by 2050 will require the phase-out of the vast majority of natural gas use, which was 199 trillion Btu in 2011.[30] This accounted for over ten percent of the State's greenhouse gas emissions even before the effect of methane leaks from the natural gas production system are taken into account.[31] Moreover, the leaks are much higher than indicated by Maryland's current greenhouse gas inventory because it excludes emissions that are not within in the state's boundaries.[32]

The worsening prognosis for climate, as evidenced by the sea-level rise now expected from Antarctica on a much shorter time scale than previously anticipated,[33] and the loss of summer ice in the Arctic indicate the need for much more thorough action on greenhouse gas emissions than before. Specifically, it is important to take into account the much higher 20-year warming potential of methane, since some threshold phenomena, such as severe or complete summer Arctic ice melting may occur on this time scale.[34] Even the Department of Energy has begun to use both a 100-year and 20-year global warming potential for methane in some of its evaluations.[35]

At the same time, we recognize that natural gas has important useful attributes, such as lower pollution at the point of use and flexible power station operation that can support the growth of renewables. It is therefore important to sort out the role of natural gas within a framework of greenhouse gas reduction goals.

[30] EIA SEDS Consumption 2014 Table CT2

[31] CO_2 emissions due to natural gas combustion amount to about 5.3×10^{-8} metric tons per Btu; this gives total CO_2 emissions of 10.5 million metric tons due to natural gas combustion, compared to total greenhouse gas emissions of 95.8 million metric tons in 2006, Maryland's reference year for reducing emissions (MDE GHG Inventory).

[32] MDE GHG Inventory

[33] See, for instance, the interview with an Antarctic glaciologist in Jamail 2014.

[34] These issues are discussed in some detail in Makhijani and Ramana 2014, Section V.B. The twenty year warming potential of methane is about 3 times higher than the 100-year value.

[35] See, for instance, DOE 2014.

We raise these concerns in the context of a report on space heating and cooling because direct use of natural gas for heating does not provide a bridge to an emissions-free future.[36] We do recognize that currently natural gas for heating plus central air conditioning is generally more economical over a 15-year timeframe than electrical heating systems, given present Maryland natural gas prices. But if its use as a bridge fuel in the electricity sector (including in combined heat and power systems) is to be made compatible with a direction of an emissions-free energy sector, policies must be directed towards reducing its direct use for heating in buildings where it is the least difficult to replace from a technical standpoint. Moreover, replacement of natural gas with highly efficient electric heating systems makes the space-conditioning end-use renewable-ready. This is because it is easiest and generally most economical to convert solar and wind energy, the most plentiful renewable resources, to electricity.[37] Reducing natural gas use in space and water heating can allow its use in the electricity sector (including combined heat and power (CHP) development on a significant scale) while helping moderate natural gas prices.

Our analysis indicates that new natural gas supply, such as that obtained by hydraulic fracturing, is not needed if coordinated policies on efficiency and renewables are adopted in regard to space conditioning in the residential and commercial sectors. It appears especially necessary to discourage new natural gas supply from hydraulic fracturing since some new evidence indicates that leaks at some drilling sites may be much larger (a hundred or even a thousand times larger) than estimated by the Environmental Protection Agency (EPA).[38]

A. Increases in Natural Gas Prices

We used a constant dollar reference price for natural gas price of $12 per million Btu in our analysis. However, as is well known, natural gas prices are quite volatile. Figure VII-1 shows the history of natural gas prices for residential customers in Maryland.

[36] We define an "emissions-free" energy system as one that has CO_2 emissions less than 10 percent of Maryland's 1990 emissions.

[37] Solar thermal space heating systems with heat storage have been built even in cold climates. However, these are much more expensive than any of the systems discussed here.

[38] Caulton et al. 2013

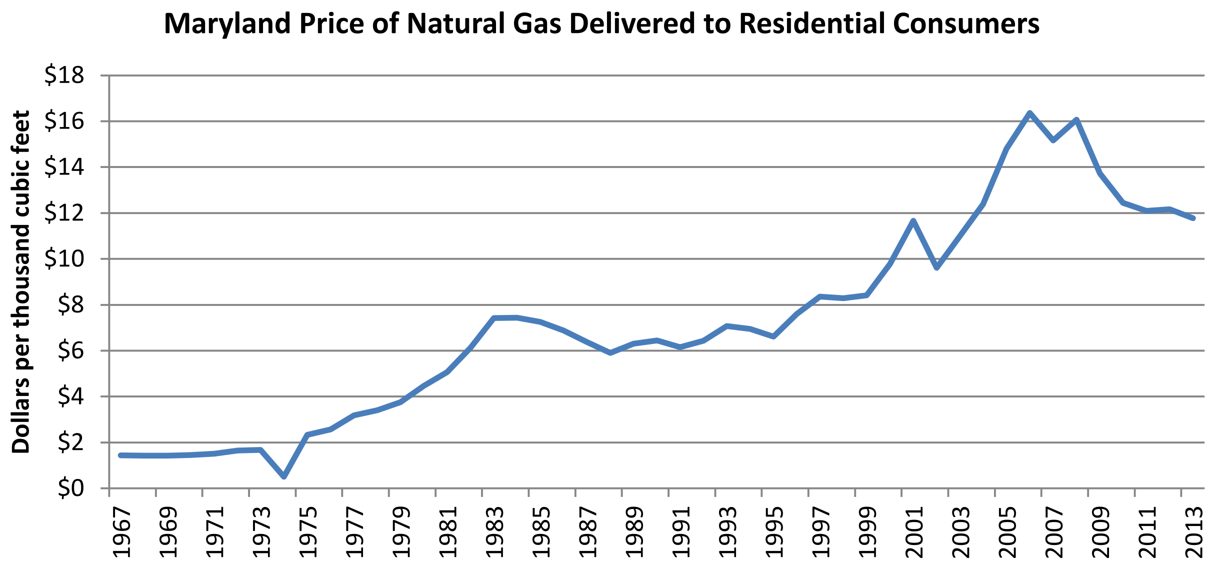

Figure VII-1. Price of natural gas in current dollars per thousand cubic feet delivered to residential customers in Maryland from 1967-2013. Source: EIA Natural Gas Maryland Price 2014

The importance of connecting the various aspects of natural gas use into a coherent policy is illustrated by the analysis of natural gas prices, production, and consumption by the Energy Information Administration in its 2014 *Annual Energy Outlook*. It projects increasing use of natural gas in electricity generation, a large increase in liquid natural gas exports, increases in other uses, and large increases in production over the next quarter of century. Thus, even though production would increase by about 50 percent between 2012 and 2040, wholesale and retail natural gas prices would *still* increase in real terms. Specifically, the EIA estimates a constant dollar increase of about 1.5 percent increase per year in the residential sector and 1.7 percent per year in the commercial sector out to the year 2040.[39] Such increases would severely harm low-income households and small businesses. The Renewable Maryland Project will address energy equity issues in detail in a future report; but it is already well-known that energy assistance funds have been declining in recent years, even as the needs of low-income families for such assistance have increased.

No careful observer of natural gas prices would expect reality to track the EIA's projections. That is not because they are wrong but because the specific production and consumption and trading estimates are the best business-as-usual (or reference) case that can be prepared with present knowledge. As such, it is therefore suitable starting point for considering policy.

The EIA estimate would have the price of residential natural gas increase in constant dollars from $12 in 2012 in Maryland to about $18 per million Btu in 2040. At the latter price, almost all efficient heat pumps would be economical without any incentives. In order to better grasp the relationship of natural gas prices to the economics of a transformation of space heating, we

[39] EIA AEO 2014 Table A3

analyzed the break-even price at which the various efficient heat pump systems would become economical. Figure VII-2 shows the results of that analysis. Even when cold climate heat pump systems are financed at a rate of 4 percent, they are close to economical today with constant natural gas prices.

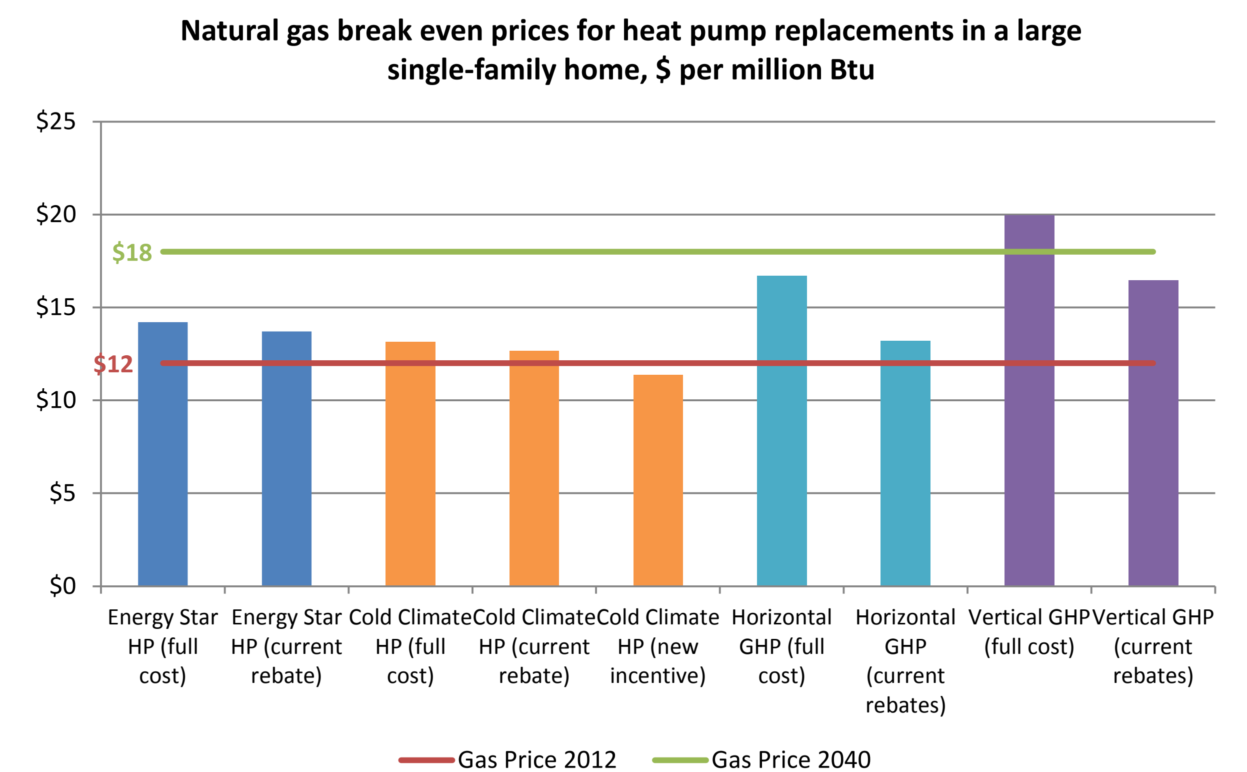

Figure VII-2. Gas break-even prices for a large single-family home in Baltimore, Maryland, for a variety of heat pump systems. Values include financing of system cost at 4 percent and residual values of geothermal heat pump equipment. Source: IEER.

However, as noted above, there is an interest in preventing a steady real cost increase of residential and commercial heating costs. This requires a broader consideration of natural gas policy. Our analysis indicates that a combination of reducing most natural gas use for space and water heating through a combination of efficiency and efficient heat pump use, a ban on fracking and exports, and reasonable natural gas prices appear to be compatible. This national analysis can inform Maryland policy in the same way that national and global climate analysis have informed Maryland's goals and actions in reducing greenhouse gas emissions.

B. Natural Gas-Related Greenhouse Gas Emissions

We note here that from the point of view of greenhouse gas emissions, the EIA's 2014 *Annual Energy Outlook* reference case for natural gas[40] is completely unsustainable; it implies direct

[40] EIA AEO 2014 Table A13

CO_2 emissions of about 1.7 billion metric tons by the year 2040.[41] In addition, a leak rate of 1 percent about 140 million metric tons of CO_2-equivalent methane leaks on a 100-year averaging basis and over 430 million metric tons of CO_2-equivalent if the averaging time is 20 years, given total CO_2 equivalent emissions ranging from almost 1.9 billion to about 2.2 billion metric tons.[42] If leaks are higher than the EPA now assumes, the problem would be much worse. For reference, total greenhouse gas emissions in 2011 were about 6.7 billion metric tons CO_2-equivalent and CO_2 emissions from fossil fuel combustion, including electricity generation, were about 5.3 billion tons.[43] The comparable figures for the year 1990 were 5.1 and 4.7 billion metric tons. It is clear that no reasonable path to deep reductions in greenhouse gas emissions (90 percent reductions relative to 1990 or even 2011) can be achieved without greatly reducing natural gas use; two of the most opportune areas are its direct use for space and water heating in buildings.

C. Fuel Oil Prices

A comment on the decline in crude oil prices -- and, hence also fuel oil prices -- is in order. Oil prices have fluctuated significantly the past decade and also over the longer period since the first oil shock of 1973. The calculations in this report do not reflect the peak of fuel oil prices; neither do they reflect the recent decline since mid-2014. On a very approximate basis, crude oil at about $50 per barrel would imply fuel oil at about $16 per million Btu compared to the $26 per million Btu assumed in our calculations. Figure VII-2 above shows that all efficient heat pumps would be economical at that price, except vertical-well geothermal heat pumps with no rebates or incentives.

VIII. Emissions-Free Heating and Cooling

Residential space heating and cooling can be made **emissions-free** at no net extra cost with rooftop solar energy if the cost of residential solar is in the range of $2.20 per watt or less and the solar generation is net-metered. At present levels of solar incentives in Maryland, and if

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[41] We use an emission factor of $5.30*10^{-8}$ metric tons per Btu of natural gas burned. The EIA projection for consumption in the year 2030 is 31.63 quadrillion Btu (EIA AEO 2014 Table 13).

[42] EPA GHG Inventory 2013 Table 3-44, indicates and overall leak rate of 1.4 percent over the whole natural gas system from production to consumption. But EPA estimates that leak rates have been declining. IEER estimated that the EPA Clean Power Plan implied a leak rate of 1.04 in the year 2030. We used a leak rate of 1 percent in the above calculation. Leak rates may be much higher. See Makhijani and Ramana 2014, Section V.B, for the details of how the calculations were done, references and a discussion of some of the implications. The most recent assessment of the Intergovernmental Panel on Climate Change (its fifth) of the global warming potential of methane relative to CO_2 is 34 for the 100-year average and 86 for the 20-year average (IPCC 2013, Chapter 8, p. 714). The IPCC 2013 values cited in this footnote include carbon-climate feedbacks. However, the 20-year value even without those feedbacks is almost the same: 84; the 100-year value is 28. We used 28 for the 100-year value and 86 for the 20-year value to illustrate the range of total CO2-equivalent emissions implicit in the EIA AEO 2014 reference projection for natural gas.

[43] EPA GHG Inventory 2013 Table ES-2

using net metering, the break-even price of solar energy is about $3.50 per watt.[44] *It is possible, especially with group purchases, to get residential solar installations in Maryland at less than the latter price today.* In addition to the energy savings and utility bill savings, there is increasing evidence that solar panels on a rooftop increase the resale value of the home.[45]

There are of course other ways to reduce greenhouse gas emissions than transitioning to efficient heat pumps. We used the analysis above to develop a multi-layered picture of emission reductions by 2050 specifically in the space-conditioning sector, following these steps[46]:

1. Start with building efficiency (an average of 30 percent envelope improvement statewide by 2050)
2. Transform all resistance heating, and almost all fuel oil, and propane heating plus all air conditioning to highly efficient electric heat pump systems.
3. Increase natural gas system efficiency from the current average of about 84 percent,[47] to the most efficient available today (97 percent).
4. Convert the electricity system to a low emissions system, with direct emissions per megawatt-hour generated averaging about 10 percent of the 2011 level.
5. Convert about two-thirds of residential natural gas use for space heating to highly efficient electric heat pump systems.[48]
6. Convert half of commercial natural gas use to highly efficient electric systems (see Section X below).

Figure VIII-1 summarizes the analysis for energy and Figure VIII-2 for CO_2 emissions, if all the above steps are realized. The analysis shows that significant improvements in building envelope efficiency measures plus a conversion of all the areas that are currently economical to highly efficient heat pumps (i.e., resistance, fuel oil, and propane heating and air conditioning), can only reduce emissions from this sector by about half – good, but a long way from Maryland's aspirational goal of 90 percent emission reductions by 2050. Adding a transformation of the electricity grid to one with far lower emissions would bring the reductions to about three-fourths of the 2011 total. This does not take into account natural gas leaks. It is therefore clear that to one can go most of the way without making conversions from natural gas to efficient electrical systems, but one cannot achieve the very high-levels of reductions to which Maryland aspires would require moving away from natural gas for space

[44] We assume a $50 value for solar renewable energy credits (SRECs) for 5 years and zero after that. This is conservative; SRECs were trading at about $150 each in late 2014 (SREC Trade 2015). The largest present incentive for an individual owner is the 30 percent federal income tax credit.
[45] Hoen et al. 2011
[46] A growth factor of about 27 percent is used to account for growth in homes and commercial square-footage.
[47] Estimated by IEER from KEMA Draft 2011.
[48] Roughly 38 percent of the state uses natural gas for either space heating or water heating (KEMA Draft 2011 Tables 6-12 and 6-14 (pp. 70 and 72)). Many homes with boilers can be converted using mini-split heat pumps which do not need ducts.

heating for the most part in the residential sector and in about half of the commercial sector as well.[49]

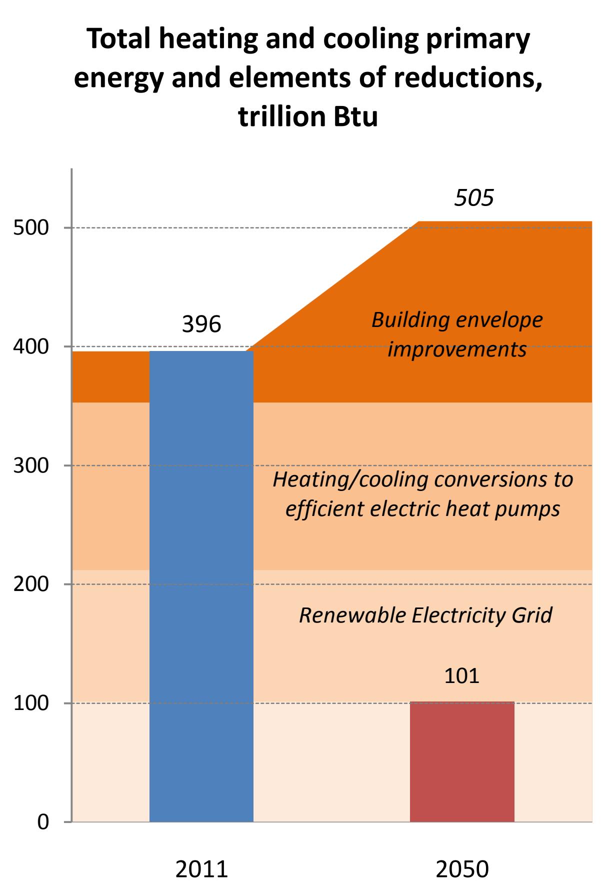

Figure VIII-1. Total heating and cooling primary energy use in Maryland and elements of energy use reductions in 2050. Includes thermal, transmission, and distribution losses. Source: IEER.

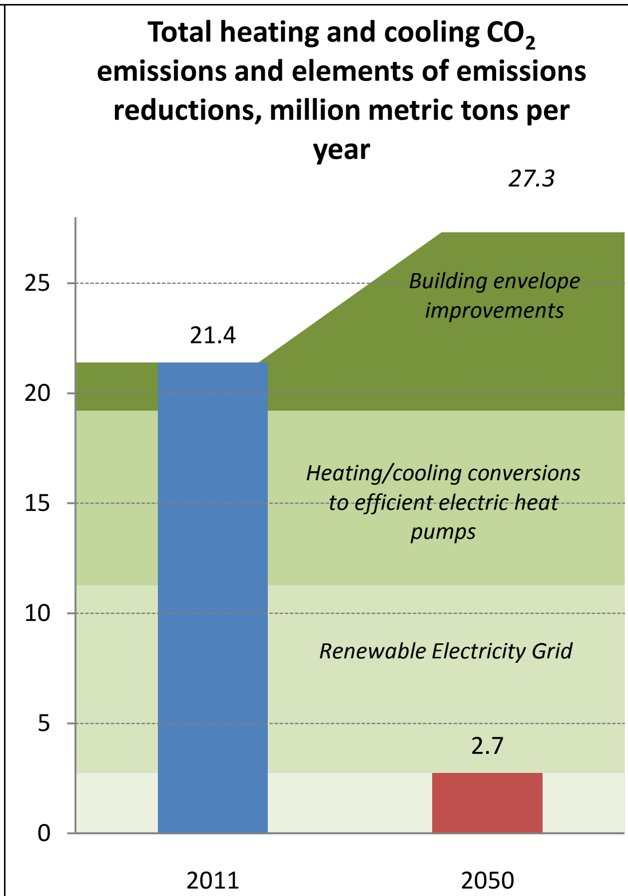

Figure VIII-2. Total heating and cooling CO_2 emissions and elements of emissions reductions in 2050. Source: IEER.

IX. Jobs and Economic Development

This report does not aim to provide a quantitative analysis of jobs and economic development potential from a transformation of the heating and cooling sector in Maryland. Rather, we provide a brief discussion here of the areas in which Maryland can become a leader in the mid-Atlantic region while also achieving greenhouse gas reduction goals.

[49] The scenario we have examined achieves a 90 percent reduction relative to business-as-usual but only about 87.4 percent relative to 2011. Additional reductions can be obtained by converting buildings in the commercial sector to combined heat and power systems and using renewable biogas in place of remaining natural gas uses.

There are three primary areas identified in our research that, if Maryland is serious about its greenhouse gas reductions, could also become economic engines for the state:

1. *Offshore wind*
   It is no secret that Europe has been leading the charge with regards to offshore wind energy, with hundreds to over a thousand of megawatts installed every year.[50] The current plan for Maryland to build 200 MW of offshore wind is not enough to encourage manufacturers to locate in the state. A much more aggressive, binding, and supported target for offshore wind would create the market stability necessary for industry to open facilities in the state, providing good, well-paying jobs for many Marylanders.

2. *Building technologies*
   The building technologies arena provides opportunities in two ways: first, existing workforce development, so that people and businesses already in the state have the knowledge and expertise to work with leading edge building technologies; and second, job creation through encouragement of new businesses to locate and open factories, stores, offices, etc., in Maryland. This job creation potential is significant when considering the last area of economic development: cold climate heat pumps.

3. *Cold climate heat pumps*
   While cold climate heat pumps are not yet common in the United States, they are quite common in Asia and parts of Europe. Making a commitment for transitioning space heating and cooling to these highly efficient systems sends a message to the manufacturing companies that there will be a strong market for their product. If combined with other incentives or encouragement, such as special tax zones or expedited permitting, large international companies may seek to set up facilities in Maryland to meet the demand.

If the performance standards for heating and cooling are to be as high as the best available heat pump technology, almost the entire housing stock will need to include such equipment. This stock, including new and existing households will be on the order of 3 million units by 2050. In addition, a large portion of commercial sector buildings (including public buildings) would also need retrofitting, with many or most of the rest using combined cooling, heating and power (CCHP) technology. A large number of direct and indirect jobs would be created by such a transformation. In addition, if there were certainty in the policy of the conversions (through suitable efficiency standards and requirements for rental and owner-occupied housing), Maryland would have a strong basis on which to attract the manufacturers of advanced heat pumps to the state. Success, while not guaranteed, would require, at a minimum, that Maryland be an early adopter of the needed policies so as to provide certainty regarding the minimum expected market size. On this basis, manufacturing could also serve the needs of states in the entire mid-Atlantic region. This thinking is, of course, similar to the concept of the

[50] EWEA 2014. See chart in Fig. 11 (p. 10).

legislation regarding offshore wind, which is likely to make Maryland among the leading states in this arena.

X. Commercial Buildings

The analysis thus far has focused on residential heating and cooling. However, much of the research can also be applied to the commercial sector. Nationally, most commercial square footage is in low-rise buildings – in fact, over three-fourths of the floor space is in buildings with three floors or less, counting the ground-level floor.[51] Geothermal heat pumps and cold climate heat pumps can and are being used in such buildings.[52] The International Ground Source Heat Pump Association states that geothermal heat pumps can be used on "almost any commercial property" including high rise buildings.[53] The State of Maryland provides grants for both small and large geothermal heat pump systems under the "Commercial Clean Energy Grant Program."[54]

We applied 2011 natural gas and electricity prices for the commercial sector in Maryland to the analysis outlined above, assuming similar capital costs for HVAC equipment, and got results similar to the residential sector analysis. Very little oil or propane is used for heating in the commercial sector,[55] with the majority being electric or natural gas. Air conditioning is generally all electric. Of course, the height of the building is just one issue. Retrofitting also involves consideration of the type of existing system that is to be replaced with highly efficient heat pumps.

In our energy and CO_2 analysis (Figure VIII-1 and Figure VIII-2 above) we assumed that 50 percent of commercial buildings that use natural gas would be converted from natural gas to highly efficient heat pumps (cold climate or geothermal) by the year 2050. As noted, efficiency can also be increased by using combined heat and power systems, which are especially suited to large buildings. An analysis of CHP systems will be integrated into the broader analysis of the electricity sector that IEER is producing as part of the Renewable Maryland Project.

[51] DOE EERE 2012 BEDB Table 3.2.3

[52] For instance, see the list at Chesapeake Geosystems 2014 (http://chesapeakegeo.com/maryland).

[53] See the website of the International Ground Source Heat Pump Association, at http://www.igshpa.okstate.edu/geothermal/commercial.htm (IGSHPA 2014).

[54] See the website of the Maryland Energy Administration at http://energy.maryland.gov/Business/cleanenergygrants/index.html (MEA 2014).

[55] Maryland commercial sector energy use data by fuel are detailed in EIA SEDS Consumption 2014 Table CT5. The overall combined use of propane and fuel oil in this sector is low relative to natural gas (10.8 trillion Btu compared to 66.6 trillion Btu in 2012). National data for the commercial sector in 2010 show that propane use for heating in this sector is negligible, fuel oil use is 0.22 quadrillion Btu and natural gas use is 1.65 quadrillion Btu (DOE EERE 2012 BEDB Table 3.1.4).

XI. Recommendations

Our recommendations regarding a transformation of the space conditioning sector recognize there are two important conclusions from this analysis:

- There is a great deal of "low hanging fruit" in the form of upgrading costly and relatively inefficient space conditioning systems. This requires low-cost financing and split incentive issues to be addressed; and
- To achieve Maryland's goal of deep greenhouse gas reductions by 2050, it will be essential to achieve a significant reduction in natural gas use in the buildings sector by means that include a conversion to highly efficient electrically-driven systems that can be powered by renewable energy in the long-term.

While these recommendations are based on Maryland data, the analysis in this report indicates that they are broadly applicable across the United States since the composition of the building heating systems across the country is quite similar to Maryland. One caveat, of course, is that electricity and natural gas prices can vary significantly from region to region, so that this analysis is only a general indicator for other parts of the United States. Our preliminary analysis indicates that converting oil, propane, and resistance heating to highly efficient heat pumps is generally economical, while converting natural gas to highly efficient heat pumps is economical in areas of high natural gas prices like New England but not at present in places where natural gas prices are moderate or low, for instance, in Minnesota.

A. Existing Buildings

The analysis in this report shows that there are clearly two categories of systems when we consider the economics of reducing greenhouse gas emissions in space conditioning:

- **Fuel oil, propane, and electrically heated homes**: Homes heated with fuel oil, propane, or resistance heating are about 40 percent of the total households in Maryland. Replacing them with highly efficient heat pumps is always economical. In addition about 14 percent of homes have heat pumps.[56] It is generally economical to replace existing heat pump systems with newer highly efficient systems, except for vertical well geothermal heat pumps without incentives due to the high initial costs.
- **Natural gas heated homes:** The economics of replacing natural gas heating plus central air-conditioning depends on the nature of incentives and the price of natural gas. Much of this report is a detailed consideration of the costs and benefits of replacing existing natural gas space heating with highly efficient heat pumps.

1. Fuel Oil, Propane, and Electrically Heated Homes

Since conversion of these homes to highly efficient heat pumps is always economical, the main issues are information and financing. Maryland should set a target of retrofitting these homes with building envelope improvements and installation of highly efficient heat pumps in all cases

[56] KEMA Draft 2011 Table 6-12

where it is feasible by 2040. Particular attention should be given to low-income households which stand to benefit greatly from a reduction in monthly energy costs.

2. Natural Gas Heated Homes

For owner-occupied homes, the most likely time (other than at the time of major renovations) to apply requirements for energy system upgrades is at the time of home sale or of replacement of an existing heating or cooling system. Regarding upgrades at the time of sale, four principal approaches could be used alone or in combination:

a. Energy bill disclosure at the time of sale.
b. Require full energy audit and full disclosure of results with real estate data about the home.
c. Include estimated energy bills with evaluation of mortgage principal, interest, and taxes for potential buyers.
d. Require upgrading of building envelope, appliances, including heating and cooling systems, that are below certain efficiency levels as a condition of sale or refinancing.

The research suggesting increased resale value due to the presence of solar PV panels supports recommendations a, b, and c above. The premium achieved when selling a home with solar PV is due to the understanding that the operating costs of the home will be lower because of the on-site generation.

We recognize that a requirement for significant upgrades of heating and cooling systems as a condition of sale or refinancing would likely be resisted by the real estate industry. Enacting the first three measures above as a start would provide a significant increase of attention to energy issues during real estate transactions.

However, the analysis in this report indicates the need for extensive transformation of existing buildings both in terms of increasing efficiency of the envelopes and of moving away from fossil fuels and inefficient electric systems to highly efficient ones, even as the grid becomes cleaner. All these elements are needed to achieve high levels of CO_2 emission reductions. So at some point, a mandatory requirement may well become necessary. One way to avoid such difficult questions would be to persuade homeowners to benefit from converting to efficient systems while they are in their homes at the time of normal replacement of an existing system (see section on financing below).

For rental housing, including both detached and multi-family units as well as commercial leases, the same requirements as (a) and (b) above could apply when a residential building or business location is rented. If there is not significant movement within a few years, mandatory upgrades could be required at the time of renting or every ten years, whichever is sooner.

a) Low income households

Consideration of low-income housing is critical to achieving emissions reductions goals. About 361,000 households were eligible for heating energy or electricity bill assistance in 2011, under the prevalent criterion of 175 percent of the federal poverty level. Under the maximum allowable federal criterion, over 645,000 Maryland households would have been eligible;[57] the latter figures is about 30 percent of the Maryland households.[58] Given that large fraction, the issue of space conditioning energy has both energy justice and greenhouse gas reduction implications.

There are many types of low-income housing. Low-income families may be homeowners or renters; they may reside in publicly-owned housing or publicly subsidized units; or they may reside in privately owned structures. We note here that the problem should be less difficult in those instances where low-income people own their homes. This is the case for about 31 percent of Marylanders who received heating energy assistance in FY 2013. An additional 22.5 percent live in public housing or publicly subsidized housing.[59] IEER will cover this issue in more detail in an energy justice report that is being produced as part of the Renewable Maryland Project. For the present we recommend the following:

- Intensify efforts to reach and finance the conversion of owner-occupied low-income homes heated by oil, propane, and electrical heating (notably resistance heating) to highly efficient heat pumps. Financing and information are more critical in these cases, since the conversion is economical.
- Reserve at least 30 percent of the funds available for rebates, subsidies, and incentives for efficiency and HVAC systems for owner-occupied or rented low-income homes (that ensures funds are available in proportion to the households that are low-income, as defined by the criterion of being below 60 percent of the state's median income).
- Set a target of retrofitting all publicly-owned housing units
- Require all publicly-subsidized homes to be retrofitted for efficiency and highly efficient heat pump systems wherever technically feasible.

B. New Construction and Major Renovations: Towards Carbon Neutral

Our analysis has been centered on the costs of retrofitting existing residential buildings. As noted above, much of it also applies to commercial sector buildings. The economics of making new buildings efficient and renewable grid ready are, however, more favorable than retrofitting. Developers of new buildings can acquire equipment at lower costs. Retrofitting also implies significant customer acquisition costs for HVAC equipment installers (in the form of

[57] LIHEAP 2011 Notebook, Tables B-1 and B-2. Maryland uses 175 percent of the federal poverty level as its criterion of assistance with heating and electricity bills. The maximum allowed federal criterion is the larger of 60 percent of the state median income or 150 percent of the federal poverty level. For Maryland the 60 percent of median income is the higher of the two values.

[58] US Census Maryland 2014

[59] Maryland PSC 2013 Appendix A, Attachment G (pdf p. 41)

bids that do not result in orders). Removal and disposal of existing equipment also adds to retrofitting costs. Solar electricity systems costs for new construction would be also lower than for retrofits for similar reasons. Finally, distributed solar installation costs are declining. Community purchases can be made in the Washington, D.C., area for less than $3 a watt, before any incentives are factored in. Similar considerations, though not to the same extent, apply to major renovations of buildings.

These factors are combined with the analysis in this report to support the adoption of much more vigorous goals for carbon emission reductions for new buildings. While we have only analyzed heating and cooling here, these end uses represent the largest category of overall energy use and the majority of fossil fuel use in buildings. Moreover, almost all the rest of the major energy uses in buildings (with the exceptions of water heating and cooking) use electricity; they can therefore be powered by renewable electricity and generally also made more efficient.[60] Fossil fuel water heating can also be powered by electrical heat pump systems, but these are not yet as efficient as cold climate heat pumps.[61]

It appears justified to adopt the following goals recommended by Architecture 2030 for new buildings and major renovations:[62]

- 80 percent reduction in CO_2 in 2020
- 90 percent in 2025
- 100 percent (i.e., carbon neutral in 2030)

We also note that making cities and buildings carbon neutral by 2050 has recently been adopted as a goal by the International Union of Architects. This includes existing buildings.[63] Note that for locations where sufficient solar photovoltaics cannot be installed, purchased power agreements[64] are possible that would ensure a supply of renewable electricity for the buildings in question.

C. Combining Heating and Cooling Performance Incentives

Cold climate heat pumps have performance that is closer to that of geothermal heat pumps than the performance of ordinary heat pumps and sometimes even heat pumps that meet the minimum Energy Star criteria. Yet, geothermal heat pumps benefit from generous federal incentives and substantial state incentives while cold climate heat

[60] A complete analysis including appliances and water heating will be part of IEER's electricity sector report of the Renewable Maryland Project.
[61] IEER will cover water heating in the context of an analysis of the electricity sector in Maryland in a later report.
[62] Architecture 2030 (2014) p. 5. We have omitted the 2016 goal of 70 percent reductions in this report, since there would not be sufficient time to adopt and implement the goal in Maryland, given the date of the present report.
[63] UIA World Congress 2014
[64] As distinct from acquisition of renewable energy credits. A purchased power agreement ensures that a system is installed to meet the electricity requirements of the purchaser, though, of course, all the electricity generated is fed into the grid; in rooftop systems a significant fraction is consumed at the site of the solar installation.

pumps are generally lumped with other air-to-air heat pumps which qualify only for a $500 maximum utility rebate.

This seems to have been an unintended bias. Air-to-air heat pumps that do not perform well at low temperatures have been the norm. But given the advances in the technology, we believe that incentives for space conditioning should be restructured to be based on performance, not technology. Heating and cooling system performance indicators should be combined into a single indicator. Incentives should be set so that they recognize and encourage the use of highly efficient space conditioning technology. The Energy Star heat pump performance level could be set as the minimum to get a rebate (set at the current utility rebate level). The rebate could max out at the level of performance of high-end geothermal heat pumps (currently set at $3,000 for the state rebate and $500 for the utility rebate). A detailed description for how this type of incentive structure might look is included at the end of this report.[65]

D. Financing

A principal issue for owner-occupied housing is financing of the efficient replacement systems, which have higher initial costs. The analysis above showed that an effective mortgage rate interest on a 15-year loan makes almost cold climate heat pump replacements of natural gas plus central air conditioning systems cost-effective. See Table VI-1 above.

There are also a number of other avenues for financing at reasonable cost, which can also be used for converting natural gas plus air-conditioning systems:

- Establish a ***green bank*** to provide low-interest financing for highly efficient electric space heating and cooling technologies.[66] A handful of other states have green banks and can provide insight into how this can be achieved.
- Extend the ***Maryland Clean Energy Center (MCEC) tax-exempt financing*** to the residential and commercial sectors. MCEC is a non-profit organization created by the state of Maryland that can currently issue tax-exempt bonds for financing energy efficient investments in public sector and non-profit buildings.[67]
- Implement ***Property Assessed Clean Energy (PACE) financing*** in the residential sector. While it is available for commercial projects, the use of PACE financing for residential projects has been stymied by opposition from the Federal Housing Finance Agency (FHFA). However, a number of cities and counties, mainly, but not only, in California,

[65] We are not arguing against the federal tax incentive for geothermal heat pumps, which basically addresses the added cost of the geothermal well. The federal incentive is currently set to expire at the end of 2016 so we have chosen to not include it as an option in our analysis.
[66] "A green bank is a public or quasi-public financing institution that provides low-cost, long-term financing support to clean, low-carbon projects by leveraging public funds through the use of various financial mechanisms to attract private investment so that each public dollar supports multiple dollars of private investment." See the website of the Coalition for Green Capital at http://www.coalitionforgreencapital.com.
[67] MCEC MHELP 2014 and MCEC MCAP 2014

have made PACE financing available in the residential sector despite lack of approval by the FHFA by creating a reserve fund to protect FHFA in the event of default.[68]

- Encourage homeowners with good credit to utilize ***home equity loans*** which can be obtained at rates only moderately higher than long-term mortgage rates. Further, depending on the specific facts and circumstances, an energy system might be considered a substantial home improvement, in which case the interest on a loan taken out to finance the system might be deductible as interest on home acquisition indebtedness. Under these circumstances the net interest rate would be comparable to or even lower than a long-term mortgage rate, making conversion from natural gas to efficient heat pumps affordable.
- Work with utilities to establish ***on-bill repayment*** for installing solar and geothermal heat pump and cold climate heat pump systems. This type of program has already seen success in other states.[69] The low-cost financing could be provided by tax-exempt bonds, such as those that can be issued by the Maryland Clean Energy Center. That way the utility does not have to perform the function of a bank but can serve to smooth the process of funding the projects.

E. Addressing the Split Incentive

Almost a third of Maryland families live in rented housing.[70] If significant reductions in emissions associated with space conditioning are to be achieved, the split incentive in rental housing must be addressed. There are three categories of rental housing – (i) where the landlords (private or public) pay all of the energy bills, (ii) where they may pay either the heating bill or the electricity bill but not both, and (iii) where they only pay the energy bills for the common areas in multi-unit buildings. Category (i) has no spilt incentive, and the landlord has significant financial incentive to convert to more economical space-conditioning systems, install more efficient appliances, and also get electricity from onsite solar PV. There is a partial split incentive in the second category.

An approach that would eliminate the split incentive would be for landlords to pay the energy bills where they do not now and integrate these costs into the rent. There are, however, some downsides to such an arrangement.

- There is no guarantee that rental properties would actually be improved; landlords may just pass on rising energy costs in the form of higher rents – and fail to lower the rent if rates declined.
- It takes away the incentive for renters to conserve energy. For this reason, landlords may also look upon the arrangement as a risk for them without commensurate benefit.

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[68] PACE Now 2014

[69] See the overview factsheet produced by the Environmental Defense Fund (EDF 2015), or the NYSERDA program in New York at NYSERDA 2015

[70] US Census Maryland 2014

Despite these drawbacks, the arrangement would have the major advantage of overcoming the spilt incentive if it could be coupled with requirements for rental properties to meet energy efficiency standards. The burden of such a requirement could be eased by preferentially directing incentives and rebates towards landlords whose buildings and equipment (including appliances) meet stringent efficiency standards, especially in the case of low-income housing. Such an arrangement would be the efficiency equivalent of what appears to have been a successful solar project for low-income housing in Denver, Colorado. We describe it in some detail here as it may be very relevant to designing a pilot program for low-income rental housing in Maryland.[71]

In Denver, a consortium of groups consisting of non-profit, for profit, and government entities installed 12 solar PV systems that supply electricity to 30 low-income families. The project also included job training for residents as well as an energy conservation incentive program. The low-income housing development had been rehabilitated and retrofitted with efficient appliances before the start of the project and some efficiency retrofits were also done before the solar project was begun. The systems were sized to equal 85 percent of the average annual electricity use of the units based on analysis of one calendar year of bills prior to the start of the project.

The housing is part of a rent voucher program for low-income families, subsidized by the U.S. Department of Housing and Urban Development (HUD). Voucher recipients normally pay 30 percent of their income towards rent. The contract must specify which utilities the landlord will provide and which are paid by the renter. HUD makes up the difference between the rent and a market rate determined by HUD. This type of subsidized housing is commonly known as "Section 8" housing.[72]

In this particular case, electricity bills before the solar systems were installed had been paid by the renters. But that changed with the solar installations, which are owned by an investor. The electricity is sold to the Northeast Denver Housing Center/Del Norte Housing Development Corporation under a Purchased Power Agreement. The PV system will be purchased by NDHC/Del Norte in year seven. The benefit for the owner of the PV was described as follows:

> For the first scenario, the building owner can set these utility allowances and increase the rental payments based on the allowances published by the local Public Housing Authority. These are calculated by HUD in the state of Colorado

[71] The description of the low-income housing solar development is based on Dean et al. 2011, except as noted. IEER became aware of this as the result of a solar energy study (Sanders and Milford 2014) commissioned by the Abell Foundation.

[72] HUD Contract Form 2015. The details of utility payments are specified in the contract signed by the renter and landlord. For rental determination, see HUD Section 8 2015: Housing Choice Vouchers Fact Sheet, on the web at http://portal.hud.gov/hudportal/HUD?src=/topics/housing_choice_voucher_program_section_8. The 30 percent payment is for housing units that conform to an overall rent payment standard; it includes utilities. If the rent for the unit exceeds the payment standard, the family must pay more; the renter's payment is capped at 40 percent of income. The Department of Housing and Urban Development pays the balance.

> and published based on average energy usage of the tenants. In the first scenario, integrating PV into the utility billing system is relatively simple. Any savings from the PV system will be savings to the owner and/or investors. For example, if the PV system produces $10,000 per year in electricity, the owner and/or investors capture that savings, as determined by the financing structure put in place for the PV system. [Dean et al. 2011 p. 4]

Since tenants no longer pay the electricity bills, the energy allowance is reduced by $25 per month.[73] In effect the rent increases by $25 in exchange for zeroing out the tenants' electricity bills.[74] It was recognized that the arrangement posed a disincentive for energy conservation by renters. A program to encourage efficiency and involve the renters in reducing usage has been put into place (in addition to the efficiency improvements that were made at the start of the project). NDHC/Del Norte has an incentive to ensure the program's success because the solar electricity does not cover all of the electricity usage and NDHC/Del Norte must pay the utility for any excess over the solar generation; they also get paid by the utility for net exports to the grid. The excess can be up to 20 percent of annual electricity use.

We propose a similar pilot project involving perhaps 10 to 20 low-income rental homes in Baltimore either in publicly-owned or publicly-subsidized housing. But in this case, efficiency improvements of the building envelope and appliances would be combined with the installation of highly efficient heat pumps. Cold climate air-to-air heat pumps should be used, given that they are likely to be more widely technically feasible in rental housing. It could also be desirable to add a solar PV component similar to the NHDC/Del Norte project in Denver; this will yield insights into how low-income housing may be made carbon-neutral or something approaching that goal. We will examine that aspect in more detail as part of a forthcoming report on energy justice and low-income housing.

Finally, a peer-to-peer approach to inform and educate renters could be made part of such a demonstration program. One company, Opower, has already had significant success by adopting the basic approach of informing people about the levels of energy consumption in households and businesses with that of their neighbors, including more efficient energy users.[75]

F. Natural Gas Policy

Natural gas is arguably the most difficult of the fossil fuels to address, in part because of its plentiful supply, relatively low cost, and its actual and potential use in a large variety of applications. It is also emerging as one of the most problematic areas in global warming due to leaks during production and transportation and its very high warming impact in the relatively short term (two to three decades). A phase-out of the vast majority of natural gas use in Maryland, or possibly nearly all of it, will be needed by 2050 in order to achieve 90 percent

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[73] Hawthorne personal communication 2014

[74] Dean et al. 2011 p. 5

[75] See the Opower website at http://opower.com/solutions/energy-efficiency.

reduction in greenhouse gas emissions. A combined approach to the phase-out of most of natural gas should include:

- Discouragement of direct use of fossil fuels, including natural gas, for space and water heating in new buildings, using the incentive structure outlined above.
- Orientation of incentives so that fossil fuels and electric resistance for space heating in existing buildings are replaced by the most efficient heat pump systems, considerably beyond the present minimum required for an Energy Star label.
- Encouragement of greater CHP development in the commercial sector, already underway in Maryland.
- Development of biogas resources to replace natural gas in the long term in CHP systems and for other uses of methane, such as crop drying, where elimination of propane or natural gas may be difficult.

Two policies, one to discourage natural gas production and the other to discourage liquid natural gas exports would complement the above set of recommendations:

- Convert the moratorium on hydraulic fracturing into a permanent one.
- Discourage the export of liquefied natural gas, for instance from Cove Point.

The last two points, while made briefly here, are important for the larger goal. Large investments in new fossil fuel production and transportation infrastructure would create pressures for continued use so that the investments provide the return anticipated; if not the result would be considerable stranded costs that some consumers and/or stockholders would bear.

G. Commercial Sector Transformation

Transformation of space heating and cooling in the commercial sector from direct fossil fuel use to efficient electric technologies must be part of the state's overall plan for meeting a 90 percent reduction in greenhouse gas emissions. There is very little oil or propane use in the commercial sector, thus the focus should be on transitioning from natural gas to efficient electric systems. The use of combined heat and power in large buildings, using natural gas and transitioning to biogas, is an important step in this transformation. Additional incentives should be focused on upgrading small commercial buildings to cold climate and geothermal heat pumps, as feasible.

XII. Description of Performance-based Incentives for Efficient Heat Pump Systems

The current incentive structure for space heating and cooling systems does not encourage the adoption of the most efficient technology – notably cold climate heat pumps. The existing incentives in Maryland for space heating and cooling systems are rebates based on whether a particular unit meets the criteria for an Energy Star label, regardless of its performance. We focus here on cold climate heat pumps because they have an energy performance that is more closely related to geothermal heat pumps, but currently only benefit from a $500 rebate.

A. Calculating the incentive structure

We first had to establish the minimum and maximum performance limits for determining the incentive amount. We chose the requirements for Energy Star labelling as our minimum performance standard that would merit an incentive at the lowest level and geothermal heat pump, which is the most efficient device, as our maximum performance standard. In this proposal we use the existing state and utility rebate amounts to determine both the upper and lower incentives. The below table summarizes these values.

Table XII-1 Minimum and maximum incentive levels and the associated combined performance factors for calculating a new performance-based incentive for efficient heat pumps.

	HSPF	SEER	Combined Performance Factor (HSPF x SEER)	Total incentive amount
Energy Star rating	8.2	15	123	\$500
Geothermal HP	14.7	30	440	\$3,500

The framework for the incentive is that increasing efficiency in performance should be encouraged with an associated increase in incentives available. Thus we calculated a dollar amount of per unit of performance increase that can be applied to any technology that falls between the Energy Star label criteria (HSPF = 8.2 and SEER = 15) and that of high-performing geothermal heat pumps (HSPF = 14.7 and SEER = 30) according to the following calculation:

$$\frac{\$(Max\ incentive - Min\ incentive)}{(Max\ combined\ performance - Min\ combined\ performance)} = \frac{Incentive\ amount}{unit\ of\ performance\ increase}$$

Using the information from Table XII-1 in the above equation, we get a value of \$9.46 per unit increase in performance.

$$\frac{(\$3{,}500 - \$500)}{(440 - 123)} = \frac{\$9.43}{unit\ increase\ of\ performance}$$

This amount would apply for each unit increase above a minimum combined performance factor of 123. All technologies that meet this minimum level of performance will get the minimum \$500 incentive, while higher performing units will get additional incentives at \$9.46 per unit of performance improvement.

A limit of 50 percent of the total installation cost or the maximum possible incentive would be an appropriate restriction on any single project. Since a single unit of performance is a rather fine mesh, it may be convenient to increase incentives in steps of 50 units. We will illustrate the incentives at \$9.43 per unit for the purposes of this description.

B. Results of performance-based incentive as applied to case studies

Next we took the above performance-based incentive structure and applied it to our case study analysis for natural gas plus central air conditioning and all heat pump replacements[76]. Table XX summarizes these calculations. The natural gas plus air-conditioning is the reference case and no incentives are applicable to it. We discuss natural gas-related incentives separately below.

Note that we have combined the state and utility rebates into a single incentive, based on a "combined performance factor" (CPF). They can be maintained as separate using the same graded approach for calculating the amount of each. In these calculations, we assumed that the federal tax incentive has expired and only state and utility incentives are available. The calculations of relative economics therefore depend only on state policies. Of course, any federal incentives would improve the economics of the most efficient heat pumps.

Table XII-2: Performance-based incentive calculations for heat pump replacements. Source: IEER.

	"CPF" [note 1]	Total new incentive	Current state + utility incentives
Natural Gas + CAC	28.6	$0	$0
Non-Energy Star HP	100	$0	$0
Energy Star HP	123	$500	$500
Cold Climate HP	260	$1,792	$500
Cold Climate Mini-split HP [see note 3]	312	$2,082	$300
Geothermal HP	441	$3,500	$3,500

Notes:

1. "CPF" stands for combined performance factor and is the product of the technology's HSPF and SEER.
2. Minimum incentive is applied when the combined performance factor is equal to an Energy Star rated air-to-air heat pump. In this example that number is 123.
3. For the cold climate mini-split heat pump the minimum incentive is $300[77], which is equal to the currently available incentive for ductless mini-split heat pumps that are Energy Star rated.
4. Numbers may not add up due to rounding.
5. The new incentive is calculated by adding the minimum incentive amount ($500) with the product of the unit's CPF and the performance increase value. For this example, the cold climate heat pump has a CPF of 260, which means it qualifies for the minimum incentive of $500. Added to that is $1,292, which is equal to $9.43 multiplied by the difference between 260 and 123, which is 137.

Using the large single family home example, Figure XII-1 shows that the performance-based incentive makes a cold climate heat pump a cost-effective (over 15 years) replacement for an existing natural gas plus central AC system, with or without financing of the heat pump.

[76] Installing efficient heat pumps to replace oil and electric resistance heating systems with central AC, are already highly economical without any incentives and are not included in this particular analysis.

[77] The rebate programs for various utilities in Maryland can be found, by utility, at http://www.dsireusa.org/incentives/index.cfm?state=md (DSIRE Maryland 2014)

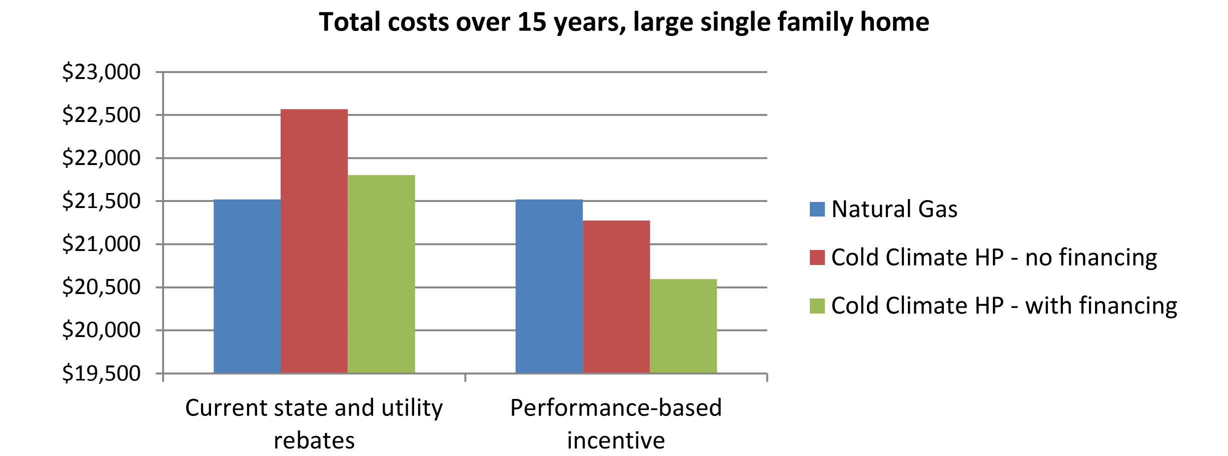

Figure XII-1. Comparison of current rebates and performance-based incentive for natural gas plus central AC and a cold climate HP system for a large single-family home in Maryland. Financing at 4% interest rate is considered for the cold climate HP unit only. All costs are shown discounted over 15 years. Source: IEER.

C. Incentives for natural gas space heating

Utility rebates are currently available for Energy Star natural gas furnaces. For instance, Baltimore Gas & Electric gives rebates of $300 to $400 for Energy Star natural gas furnaces.[78] This improves efficiency from about 78 percent to 92 percent or more.[79] The best available furnaces have efficiencies of over 98 percent.[80] There is a case to be made for incentivizing the best natural gas furnaces and a case to be made against it.

The case for it, at this time, is that with the present grid structure there would be only a modest difference in primary energy use between the best natural gas furnace and a cold climate heat pump, provided the air conditioner associated with the natural gas furnace is upgraded. There would also not be a significant difference in CO_2 emissions, provided that the uncertainties associated with natural gas leaks throughout the system, especially due to hydraulic fracturing, are set aside.

However, as we have shown, a continuation of large-scale natural gas use is not compatible with the Maryland goal of 90 percent greenhouse gas reductions by 2050. Further, there is a case to be made that the reference case for natural gas may involve significant natural gas price increases, changing the relative economics of cold climate and geothermal heat pumps relative to natural gas heating plus central air conditioning.

An initial step that would aid in the long-term transition would be to eliminate the incentives for natural gas space heating (and water heating) and apply those sums to cold climate heat pumps, especially for low-income households.

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78 DSIRE Maryland 2014 BGE Home Rebates
79 BGE Smart Energy 2014
80 Energy Star Furnaces 2014

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