MASSACHUSETTS RENEWABLE HEATING AND COOLING

OPPORTUNITIES AND IMPACTS STUDY

Prepared for:
Massachusetts Department of Energy Resources
Massachusetts Clean Energy Center

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Foreword

We welcome this comprehensive and concise overview of the renewable heating and cooling industry in Massachusetts. The report illustrates that the market for solar hot water on our rooftops, efficient pellet boilers and heat pumps in the Commonwealth is growing and has the potential to take off.

This report shows that the many renewable energy alternatives for traditional heating and cooling technologies represent excellent opportunities for lifetime cost savings, improved environmental quality, significant job creation, and reduced energy imports. We think that this report will provide an ideal starting point for exchanging views and insights with all stakeholders in the Commonwealth, on how to solidify this market and build comprehensive renewable heating and cooling policies.

Thanks to the 2008 Green Communities Act and the efforts of Massachusetts' residents, businesses, and communities, the Commonwealth's position as a leader in clean energy policies, programs, and economic development has been solidified. We're taking advantage of the economic and environmental rewards of investing in energy efficiency and renewable energy. Those investments are creating clean energy jobs, reducing municipal operating costs, and allowing us to use less energy.

Of course, energy efficiency is our first fuel, and renewable energy our second. In October 2011, the Commonwealth was recognized as #1 in the American Council for an Energy-Efficient Economy's annual state-by-state energy efficiency scorecard. Through the Renewable Energy Portfolio Standard, electricity production by renewable resources is increasing steadily, in line with the annual minimum standards. By 2020, 15% of the state's power will be produced by renewable resources.

There is great opportunity for clean energy business development in the Commonwealth, thanks to Governor Patrick and the Legislature. The 2011 Massachusetts Clean Energy Center's Clean Energy Industry Report revealed a 6.7 percent increase in clean energy jobs from July 2010 to July 2011, with nearly 5,000 companies doing clean energy work and employing more than 64,000 clean energy workers. Our solar employment numbers earned Massachusetts a recent ranking among the top ten states in the country by the national Solar Foundation.

This report comes at an important time. While we are making significant progress, many of our residents and businesses are still struggling with high energy bills. Heating and cooling make up about a third of our total energy costs and our greenhouse gas emissions. The average Massachusetts household spends $1,700 per year on heating.

We look forward to helping residents and businesses cope with the energy challenges ahead, so that the state can soon also be recognized as a national leader in renewable heating and cooling.

Mark Sylvia, Commissioner
Massachusetts Department of Energy Resources

Patrick Cloney, CEO
Massachusetts Clean Energy Center

Executive Summary

Within the US, thermal energy comprises approximately one third of energy consumption, representing a major source of fossil-based carbon emissions and import dependence; however, development of low-carbon, renewable energy markets to serve hot water, space heating and space cooling have been slow to develop in the US – in part due to a lack of *integrated* policy support. With the right policy support, it is estimated that renewable thermal technologies – like solar thermal, biomass thermal, advanced biodiesel, and high efficiency heat pumps – could create approximately 5,900 jobs and reduce greenhouse gas (GHG) emissions by over two million tons by 2020 in Massachusetts and the greater New England region. Considering the significant potential for economic development, job creation, and GHG emission reduction benefits, the absence of integrated renewable heating and cooling (RH&C) policy represents a missed opportunity for achieving important economic, social, and environmental benefits. With this in mind, this report represents a first step to assess the opportunities and impacts of renewable thermal technologies in Massachusetts.

The average household in Massachusetts spends about a third or more of total annual energy expenditures on heating and cooling applications. Because Massachusetts thermal markets are based on out-of-state, fossil fuel energy sources – oil, coal, and natural gas – the majority of those expenditures flow out of the region, providing little or no economic benefit to Massachusetts or the greater New England region. Moreover, unlike fossil fuels, most RH&C technologies significantly reduce GHG emissions of buildings, which represent the single largest source of GHG emissions in the Commonwealth. By transitioning to RH&C technologies – like solar thermal, biomass thermal, advanced biodiesel, or high efficiency heat pumps – the Commonwealth can reduce GHG emissions and drive economic growth and job creation.

This report analyzes the opportunities and impacts of greater integration of RH&C technologies into the Massachusetts market. In doing so, it assesses broad market barriers that inhibit development of renewable thermal markets, such as high upfront capital costs, inadequate policy support (or barriers to implementing policy), poor public awareness of RH&C benefits, opaque regulatory standards, and poor inter-industry coordination. The report also briefly examines renewable thermal policies that have driven market development in the US and internationally. In particular, it focuses on policies in European countries like Germany, Austria, Sweden, and the UK, which have developed (or are developing) strong renewable thermal markets abroad.

The report also considers the current state of Massachusetts' existing renewable thermal sectors – assessing the current market status, supply chain, market barriers and drivers, economics, GHG emissions, and job creation potential for each of the four technologies. In the course of the analysis, a (i) business-as-usual and (ii) accelerated market development scenario are presented in order to project potential GHG and job creation impacts in Massachusetts. Key findings for the aggregated renewable thermal industry as well as each sector (e.g. solar thermal, biomass thermal, advanced biodiesel, and high efficiency heat pumps) are summarized below.

Finally, while this report considers various policy approaches and goals for RH&C, it stops short of making formal policy recommendations or targets. This report represents the first step in a larger initiative to explore the potential impacts and opportunities of developing renewable thermal markets in Massachusetts. The Massachusetts Clean Energy Center (MassCEC) and Massachusetts Department of Energy Resources (Mass DOER) will continue to explore key issues and options with stakeholders to develop RH&C in Massachusetts and meet key economic, social, and environmental goals.

Key Findings: Renewable Thermal Opportunities and Impacts in Massachusetts

In the *Massachusetts Clean Energy and Climate Plan for 2020*, policy-makers estimate that by implementing a program to support renewable thermal technologies, the state can displace two million tons of GHG emissions, or slightly more than 2% of total 1990 emissions. Achieving this goal would require a rapid scale-up of the renewable thermal sectors (solar thermal, biomass thermal, advanced biodiesel, and high efficiency heat pumps), with annual growth rates for each RH&C technology ranging from 21% to 97%. While aggressive, these growth rates are not unreasonable, especially when compared to market growth rates seen in Europe. Moreover, depending upon the rate of market growth, the renewable thermal industry is expected to create between 1,600 and 5,900 jobs in Massachusetts and the New England region by 2020.

If displacing fuel oil or electricity, renewable thermal technologies will in almost every case reduce GHG emissions *and* provide lifecycle savings to customers. For example, Figure 1 and Figure 2 below illustrate lifecycle GHG reductions as well as lifecycle costs (or savings) of typical RH&C residential and commercial installations. The blue bars represent GHG reductions (right-hand axis) estimated for a typical installation. The green bars illustrate the lifecycle costs (or savings) associated with a typical installation. For example, a typical residential ground-source heat pump (GSHP) that displaces an electric heating system – abbreviated as "GSHP (Elec)" – is estimated to provide over 300 tons of GHG emission reductions over 20 years (see Table 1 for full list of abbreviations). With current incentives, it will additionally provide those GHG reductions at a net savings of approximately $31,000.

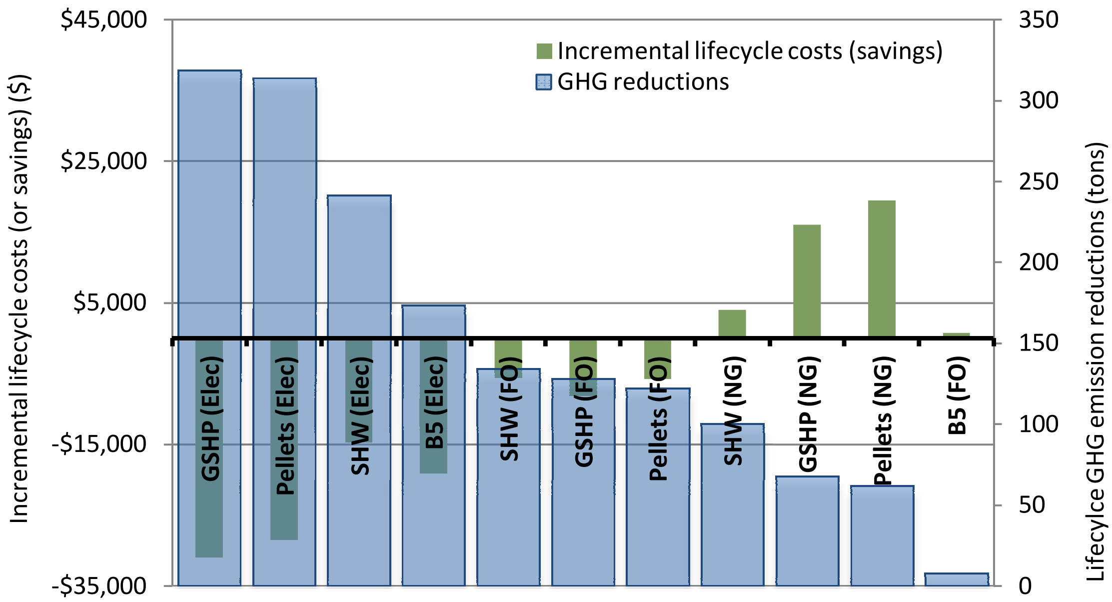

Figure 1: RH&C Residential Installations – GHG reductions and Lifecycle costs (or savings)

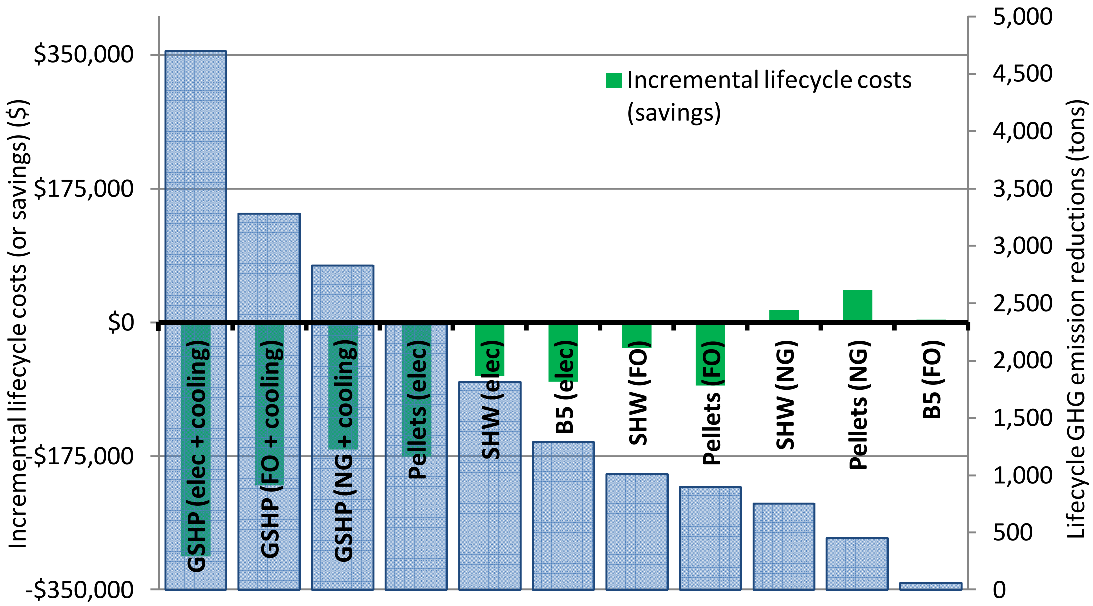

Figure 2: RH&C Commercial Installations – GHG reductions and Lifecycle costs (or savings)

Table 1: Renewable Heating and Cooling (RH&C) Abbreviations for Figure 1 and Figure 2

Abbreviation	RH&C Technology	Fossil Fuel Heating Replaced	Cooling Load Included?
GSHP (elec + cooling)	Ground-source heat pump	Electricity	Yes (commercial only)
GSHP (FO + cooling)	Ground-source heat pump	Fuel Oil	Yes (commercial only)
GSHP (NG + cooling)	Ground-source heat pump	Natural Gas	Yes (commercial only)
Pellets (elec)	Biomass Heating Pellets	Electricity	No
SHW (elec)	Solar Hot Water	Electricity	No
B5 (elec)	Biodiesel (5% blend)	Electricity	No
SHW (FO)	Solar Hot Water	Fuel Oil	No
Pellets (FO)	Biomass Heating Pellets	Fuel Oil	No
SHW (NG)	Solar Hot Water	Natural Gas	No
Pellets (NG)	Biomass Heating Pellets	Natural Gas	No
B5 (FO)	Biodiesel (5% blend)	Fuel Oil	No

When displacing natural gas, GHG reductions from RH&C technologies are less pronounced, though not insignificant. Within the commercial scenarios, individual RH&C systems displacing natural gas heating achieve lifecycle GHG reductions ranging from approximately 450 tons to 750 tons. However, at current and projected natural gas prices and incentive levels, these reductions will come at a cost premium – with the exception of commercial GSHPs, which are also modeled to displace summertime electric cooling loads.

In the final analysis, this study finds that RH&C technologies offer Massachusetts businesses and residents a cost-effective means to reduce GHG emissions and fossil fuel dependency. This is a finding that corresponds with numerous other international assessments of RH&C technologies. In addition, depending upon available policy support, the renewable thermal sectors could serve as a major cleantech growth market and job creation center for Massachusetts and New England.

Key Findings: Solar Hot Water and Space Heating in Massachusetts

With the recent introduction of state residential and commercial solar hot water incentives, Massachusetts policy-makers have laid the foundation to develop a vibrant solar hot water market. With federal and state incentives combined, solar hot water and space heating systems (i.e. solar combi-systems) are very competitive economically – achieving the lowest Lifecycle Cost of Energy (LCOE) of all technologies (fossil and renewable) assessed in this report. Additionally, the MassSAVE HEAT loan enables customers to finance the installation of SHW systems, reducing the upfront costs and financial burden associated with installing solar hot water.

Despite these advantages, stakeholders indicate that a number of other barriers continue to inhibit development of the solar hot water market in Massachusetts, including: poor consumer awareness of SHW benefits; the need for (and additional retrofit costs of) low-temperature space heating distribution systems; costs associated with local permitting and inspections; as well as workforce training needs.

Key Findings: Biomass Thermal in Massachusetts

The biomass central heating market in Massachusetts is currently small, due in part to the absence of federal or state biomass heating incentives and policies. However, stakeholders indicate that with the right market development mechanisms, the biomass heating market could expand significantly, achieving an annual growth rate of 97% or greater. Under such an accelerated growth scenario, biomass heating could provide significant GHG and job creation benefits – estimated at 500,000 tons of GHG reductions and creation of over 2,000 jobs by 2020. The GHG analysis in this report builds on and is consistent with the results of the 2010 Manomet Study of Woody Biomass energy.

Stakeholders identified several barriers slowing development of the Massachusetts biomass heating market. For example, high efficiency (low emission) biomass heating is subject to high upfront costs, especially at the residential level. As a result, in spite of the fact that biomass pellet heating systems have a lower LCOE than electric and fuel oil systems (without incentives), a typical residential system is subject to a long payback. Commercial-scale systems, on the other hand, are more competitive, due in part to improved economies of scale.

Stakeholders also indicate that the Massachusetts biomass heating market lacks the *bulk* fuel distribution infrastructure needed for growth. As a result, the convenience of biomass heating to customers is significantly reduced. Biomass stakeholders suggest that integrating existing fossil fuel distributors (i.e. fuel oil and propane) into the pellet heating market will be essential to drive vibrant market growth, enabling the industry to leverage existing distribution networks to sell pellets or chips (as a new commodity) and diversify heating fuel offerings.

Finally, it is likely that greater regulatory certainty regarding air emission standards for biomass heating will be essential to the development of a vibrant market in Massachusetts and New England. Sound regulations will likely be necessary to ensure development of a high efficiency, low-emission biomass heating market in Massachusetts and across New England. To this end, European countries like Austria and Germany provide good examples of how incentives and regulations can drive development of a clean, low-emission biomass heating industry.

Key Findings: Advanced Biodiesel in Massachusetts

Massachusetts policy-makers emphasize that to achieve significant GHG reductions, the biodiesel industry in Massachusetts must promote *advanced* biodiesel (as opposed to conventional biodiesel), which is defined by the Commonwealth as a fuel which achieves at least a 50% reduction in lifecycle GHG emissions. However, a number of barriers currently inhibit development of a vibrant advanced biodiesel market in Massachusetts. For example, little market data is currently available regarding the growth and development of the advanced biodiesel industry. This is due in part to the current biodiesel market structure and regulatory standards. For example, up to 5% of biodiesel (conventional or advanced) can be blended into distillate fuel oil without differentiating the product, creating a situation where the biodiesel content (advanced or conventional) of fuel is unknown.

Moreover, because higher blends of biodiesel acts like a solvent – *potentially* damaging pumps, gaskets, and other boiler components – many manufacturers in the US will guarantee components under warranty only if using B5 biodiesel blends or less. As a result, uncertainty regarding the biodiesel content of fuel oil entering Massachusetts can deter additional in-state blending due to insurance and warranty concerns. In addition, integrating advanced biodiesel into the existing fuel oil supply is challenging, requiring significant upgrades to wholesale, terminal infrastructure or local distribution networks. Finally, stakeholders indicate that for the biodiesel market to significantly expand in Massachusetts, strong, regional marketing campaigns are needed in addition to consistent, long-term policy support.

Key Findings: High Efficiency Heat Pumps in Massachusetts

The high efficiency heat pump market is poised to grow in Massachusetts and across the US, thanks in part to federal incentives for commercial systems. Nonetheless, stakeholders identified several barriers to development of the high efficiency heat pump market. For example, relative to fossil fuel heating systems, ground-source heat pumps (GSHPs) and air-source heat pumps (ASHPs) are subject to high first costs. This is particularly true for GSHPs installed at the residential level. Nonetheless, the typical residential GSHP system that replaces electric or fuel oil heating is estimated to have a reasonably good payback. In the commercial scenario, payback is very attractive, partially because the commercial scenario analysis takes into account the space heating *and cooling* benefits of GSHPs; the residential scenario takes into account only the space heating benefits of GSHPs.

Other barriers impeding wider adoption of heat pumps include inconsistent regulatory standards with respect to well drilling for GSHPs; customer unfamiliarity with low-temperature ASHPs; and a lack of experienced engineering and design firms for commercial systems. Additionally, stakeholders indicate that both the GSHP and ASHP sectors lack good quality market and industry data. In particular, GSHP stakeholders indicate that comprehensive data about system sizes, installed costs, component costs, and system performance is needed.

This report does not provide a cash flow, GHG, or economic development analyses for ASHPs due to the lack of independent and comprehensive market data on cold-climate ASHPs. The Commonwealth may consider conducting a comprehensive study and pilot program to assess the advantages and disadvantages of cold-climate ASHPs in Massachusetts. More data will be needed to comprehend the effects of heat pumps on electricity peak loads in order to better understand the costs and benefits of greater integration of heat pump technologies.

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CHAPTER 1: MASSACHUSETTS RENEWABLE THERMAL OPPORTUNITY

1.1 Introduction

Renewable thermal technologies – like solar thermal, biomass thermal, high efficiency heat pumps, and advanced biodiesel – present significant opportunities for market growth, green job creation, economic development, and the reduction of harmful greenhouse gas (GHG) emissions in Massachusetts and across the US.

However, in spite of potential benefits, renewable thermal markets in Massachusetts and the US have been slow to develop. This is due in large part to a lack of comprehensive policy support. When compared internationally, US state and federal renewable thermal markets are small, the industries are fragmented, inter-industry coordination (i.e. across solar, geothermal, biomass, and biodiesel) is limited, public awareness is low, and policy remains underdeveloped. By addressing such issues, Massachusetts can take a lead in developing a vibrant renewable thermal industry and, in the process, support climate stabilization, job creation, and economic development initiatives.

Within the US, thermal energy use comprises approximately *one third* of energy consumption,[a] representing a significant source of fossil-based carbon emissions. Within New England, a large portion of the population depends on *imported* heating oil and propane for heating. In Massachusetts, for example, about 40% of households use fuel oil for heating, an economic expenditure that flows almost entirely out of the state.[1] Altogether, the average Massachusetts household spends approximately $1,700 on heating annually – about a third of its total energy costs.[2] By focusing domestic resources and heating expenditures on local RH&C sources like solar thermal, geothermal, biomass thermal, and advanced biodiesel heating oil – instead of imported fossil fuels – the region could capture greater job creation and economic benefits.[b]

However, *comprehensive* policies supporting development of renewable thermal have not emerged in Massachusetts or nationally. This is in stark contrast to other renewable energy sectors – like renewable electricity or renewable transportation fuels – both of which benefit from strong policy and legislative support. As illustrated in Figure 3 below, 29 states (plus DC and Puerto Rico) – including Massachusetts – have passed renewable portfolio standards (RPS), which establish a mandate for renewable electricity production. For example, in Massachusetts, the RPS requires utilities to source 15% of total electric sales from renewable resources by 2020.

Similarly, the federal government has created broad mandates requiring production of renewable transportation fuels like biodiesel and ethanol. Under the Renewable Fuel Standard, the federal government requires 36 billion gallons of renewable fuel to be blended into transportation fuel by 2022. Oil companies (and by extension renewable fuel producers) also benefit from the Volumetric Ethanol Excise Tax Credit (VEETC), which provides an economic incentive currently worth 45 cents/gallon to

[a] Some estimates suggest it is closer to 40% in the Northeast. See: Biomass Thermal Energy Council, et al. (April 2010). *Heating the Northeast with Sustainable Biomass: A Vision for 2025.* Retrieved from www.nebioheat.org/pdf/heatne_vision_full.pdf.

[b] Numerous researchers have documented the local economic benefits of investing in renewable heating technologies. For example, see: 1) NYSERDA's 2008 report *Solar Domestic Hot Water Technologies Assessment*; 2) UMass Political Economy Research Institute's (PERI) 2009 report *The Economic Benefits of Investing in Clean Energy*; 3) the Renewable Energy Policy Project's 2004 report *The Work that Goes into Renewable Energy;* and 4) the U.S. Department of Energy's 2004 report *Buried Treasure: The Environmental, Economic, and Employment Benefits of Geothermal Energy*.

blend and/or purchase ethanol with gasoline.[c] Moreover, a number of states have implemented renewable fuel standards and incentives to complement federal policy.

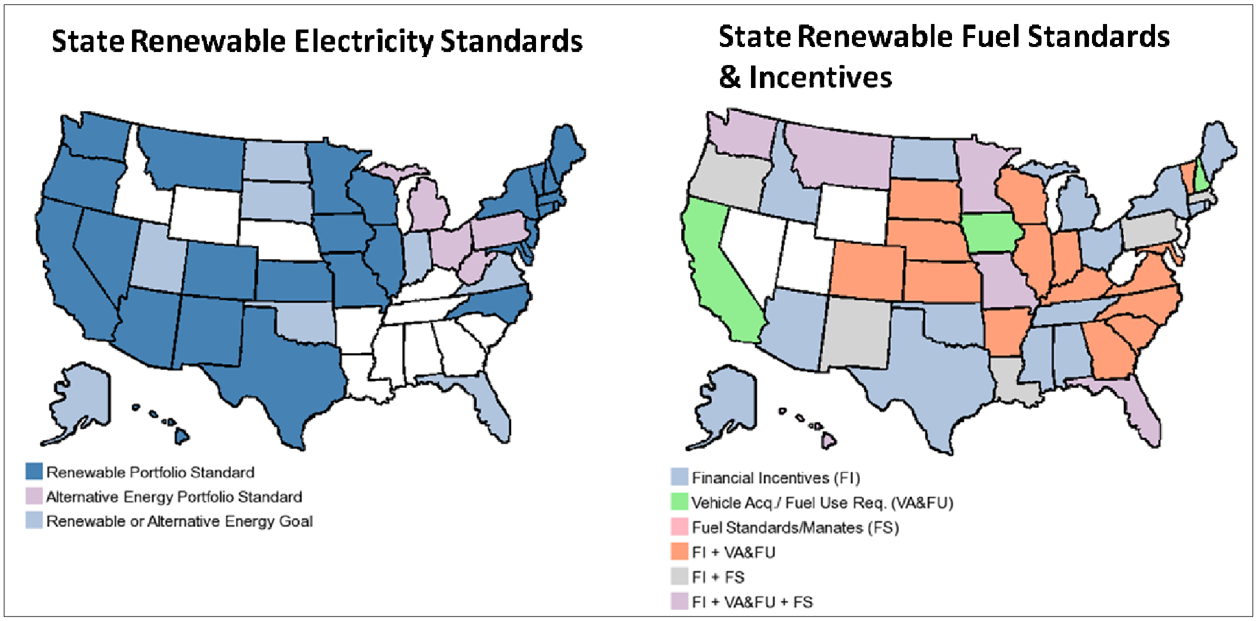

Figure 3: State Renewable Electricity and Fuel Standards (Source: Pew Center on Global Climate Change, 2011)

Because thermal energy comprises such a large portion of total energy use and domestic energy expenditures, the absence of comprehensive renewable thermal policy leaves a significant gap in US and Massachusetts' climate planning, renewable energy policy, and economic development strategy.

Recognizing this, Massachusetts state policy-makers have established an interest to investigate the technical potential and possible policy mechanisms to build a vibrant renewable thermal market, an objective recently supported by an incentive programs for solar water heating. To this end, in the *Massachusetts Clean Energy and Climate Plan for 2020*, state policy-makers indicate that:

> *…support for the nascent solar thermal market is part of a broader goal of developing renewable heating technologies (such as clean biomass heating and efficient heat pumps), to facilitate a market transition to renewable fuels as the dominant fuels for heating purposes by 2050. The policy will also establish robust job and business growth in the renewable thermal sector in the Commonwealth.*

In the *Plan*, policy-makers estimate that by implementing a program to support renewable thermal technologies, the state can displace two million tons of GHG emissions, or slightly more than 2% of total 1990 emissions. Looking ahead, by assessing the opportunities and impacts for renewable thermal in the Commonwealth, this report represents the next step in assessing policies to drive GHG reductions and economic growth by developing a vibrant Massachusetts renewable thermal market.

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[c] No more than 15 billion gallons can be corn ethanol. The remainder is slated to take the form of cellulosic ethanol (16 billion gallons), advanced ethanol (4 billion), and biodiesel (1 billion). Compared with the gasoline it replaces, cellulosic ethanol must reduce global warming pollution by 60 percent; advanced ethanol and biodiesel by 50 percent. Union of Concerned Scientists. (October 2008). Carbon Counts in the 2007 Renewable Fuel Standard. Retrieved from www.ucsusa.org/clean_vehicles/solutions/advanced_vehicles_and_fuels/2007-renewable-fuel.html.

1.2 Summary of Key Findings

The renewable heating and cooling (RH&C) market offers the Commonwealth significant opportunities to create jobs, promote economic development, and cost-effectively reduce GHG emissions in Massachusetts. For example, this analysis conservatively estimates that the RH&C sectors will create between 1,600 and 5,900 jobs by 2020. It additionally projects that RH&C technologies will provide GHG reductions ranging from 500,000 tons (under a business-as-usual scenario) to over two million tons (under an accelerated growth scenario) by 2020. In most cases, it is expected that RH&C technologies can reduce GHG reductions *and* provide lifecycle cost savings to customers.

For example, Figure 4 and Figure 5 illustrate lifecycle GHG reductions as well as lifecycle costs (or savings) of typical RH&C residential and commercial installations. The blue bars represent GHG reductions (right-hand axis) estimated for a typical installation. The green bars illustrate the lifecycle costs (or savings) associated with a typical installation. For example, a typical residential ground-source heat pump that displaces an electric heating system – abbreviated as "GSHP (Elec)" (see Table 2 for full list of abbreviations) – is estimated to provide over 300 tons of GHG emission reductions over 20 years. With current incentives, it will additionally provide those GHG reductions at a net savings of approximately $31,000.

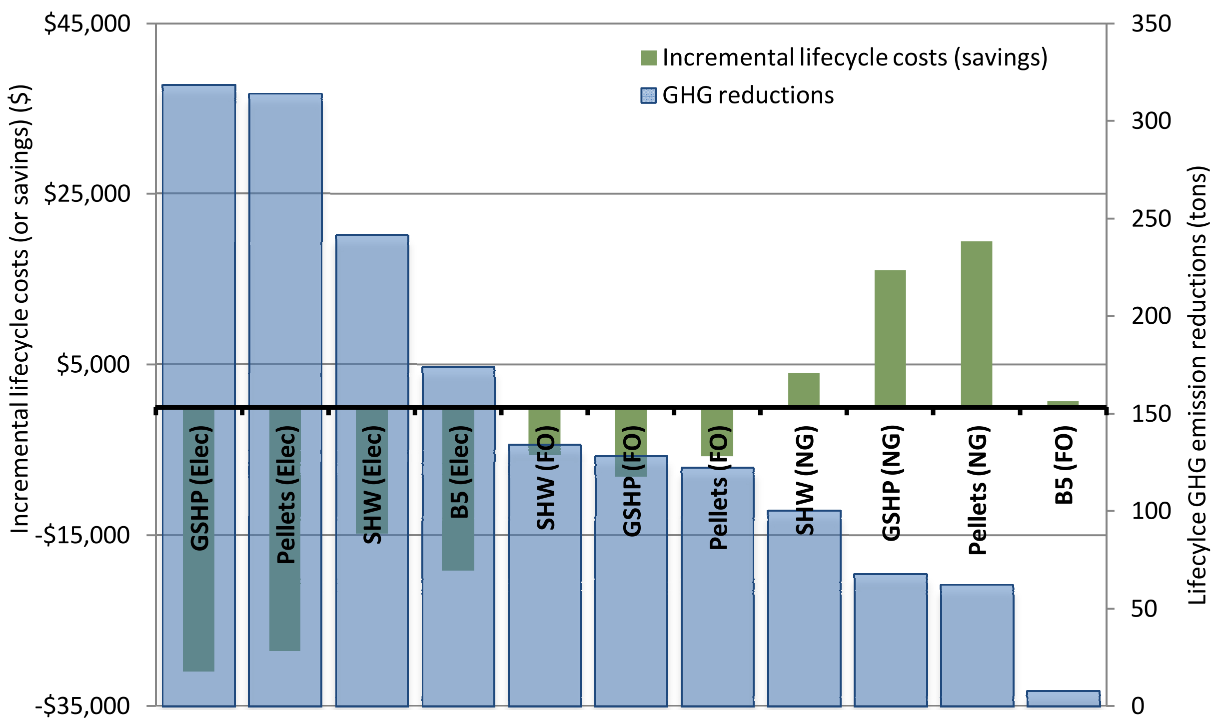

Figure 4: RH&C Residential Installations – GHG reductions and Lifecycle costs (or savings)

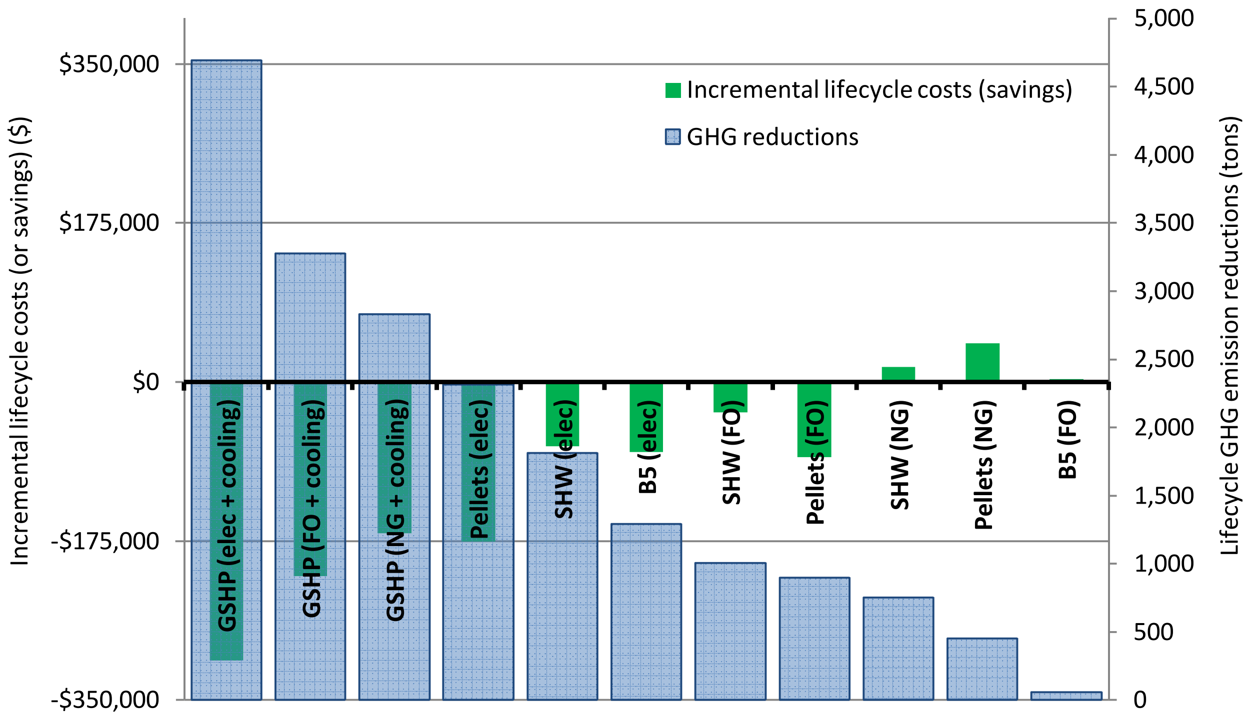

Figure 5: RH&C Commercial Installations – GHG reductions and Lifecycle costs (or savings) [d]

Table 2: Renewable Heating and Cooling (RH&C) Abbreviations for Figure 1 and Figure 2

Abbreviation	RH&C Technology	Fossil Fuel Heating Replaced	Cooling Load Included?
GSHP (elec + cooling)	Ground-source heat pump	Electricity	Yes (commercial only)
GSHP (FO + cooling)	Ground-source heat pump	Fuel Oil	Yes (commercial only)
GSHP (NG + cooling)	Ground-source heat pump	Natural Gas	Yes (commercial only)
Pellets (elec)	Biomass Heating Pellets	Electricity	No
SHW (elec)	Solar Hot Water	Electricity	No
B5 (elec)	Biodiesel (5% blend)	Electricity	No
SHW (FO)	Solar Hot Water	Fuel Oil	No
Pellets (FO)	Biomass Heating Pellets	Fuel Oil	No
SHW (NG)	Solar Hot Water	Natural Gas	No
Pellets (NG)	Biomass Heating Pellets	Natural Gas	No
B5 (FO)	Biodiesel (5% blend)	Fuel Oil	No

Figure 4 and Figure 5 depict a number of important trends. First, if displacing fuel oil or electricity, renewable thermal technologies in almost every case (residential and commercial) reduce GHG emissions *and* provide lifecycle savings. The savings are particularly pronounced for GSHPs in the commercial sector, with emission reductions ranging from 2,800 to nearly 4,700 tons. The commercial

[d] Figure 4 and Figure 5 were constructed using a number of scenario assumptions, which are important to consider when reviewing the outcomes. The approach to developing these scenarios is described in Section 1.4. In addition, key assumptions and inputs are available in Appendix B.

GSHP scenario benefits from the GHG and financial impacts associated with displacing fossil fuel heating *in addition to electric cooling*.

GHG reductions for other RH&C technologies that displace natural gas, on the other hand, are less pronounced, though not insignificant. Within the commercial scenarios, individual RH&C systems displacing natural gas heating achieve lifecycle GHG reductions ranging from approximately 450 tons to 750 tons.[e] However, at current and projected natural gas prices, these reductions will come at a cost premium to customers and the state.

With these GHG emission reduction opportunities in mind, the growth potential of renewable thermal sectors have been assessed in order to project aggregate GHG emission reductions that could contribute to Commonwealth's goal to achieve two million tons of GHG reductions by 2020 (as stated in the *Massachusetts Clean Energy and Climate Plan for 2020*).[3] Achieving this goal would require a rapid scale-up of the renewable thermal sectors, with annual growth rates for each RH&C technology ranging from 21% to 97% or greater. While aggressive, these growth rates are not unreasonable, especially when compared to market growth rates for renewable thermal markets in Europe.[f]

1.3 Report Structure

This report assesses opportunities and impacts of renewable thermal technologies in Massachusetts. It assesses the historical performance of RH&C markets in the Commonwealth, and then, looking forward, it projects potential impacts of RH&C technologies on job creation, GHG emissions, and economic development opportunities. It is important to note that this report represents a *starting point* in assessing policy options for the Commonwealth and does not constitute *official* state policy positions or targets. Going forward, MassCEC and Mass DOER policy-makers indicate that they welcome the opportunity to continue working with stakeholders to explore issues and options to develop a vibrant renewable thermal market in Massachusetts.

The report begins by describing the broad market barriers that inhibit renewable thermal market development, such as high upfront capital costs, inadequate policy support (or barriers to implementing policy), poor awareness of RH&C benefits, opaque regulatory standards, and poor inter-industry coordination. The report then briefly examines the renewable thermal policies that are in play in the US, describing the existing state and federal policies that do currently impact RH&C.

Next, the report looks at the international market, considering the *comprehensive* policies that have emerged in Europe to drive development of renewable thermal markets. In particular, case studies from Germany, Austria, Sweden, and the United Kingdom are examined.

Finally, the report examines the state of Massachusetts' renewable thermal market sectors. In particular, it examines the current market status, supply chain, market barriers and drivers, economics, GHG emissions, and job creation potential for each of four technologies – solar thermal, biomass thermal, high efficiency heat pumps (air-source and ground-source), and advanced biodiesel.

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[e] Compared to natural gas heating, 5% advanced biodiesel blend results in a GHG increase and as a result is not included in this analysis.

[f] For example, the biomass heating industry in Germany experienced an annual growth rate of 40% (or higher in early years) and the ASHP market across the EU has experienced an annual growth rate of 57%. Globally, the renewable heating market for all technologies has averaged growth rates ranging from 15% to 50% annually. For more, see REN21 report. For more, see: REN21. (2011). Renewables 2011 Global Status Report. Paris: REN21 Secretariat.

1.4 Methodology

This report has been developed by Meister Consultants Group (MCG), a Boston-based sustainability consulting firm, in collaboration with state policy-makers at Massachusetts Department of Energy Resources (DOER) and Massachusetts Clean Energy Center (MassCEC). Additional expertise was provided by regional and national renewable thermal professional and business associations, including the Biomass Thermal Energy Council (BTEC), New England Geothermal Professional Association (NEGPA), Massachusetts Oilheat Council (MOC), and Solar Energy Business Association of New England (SEBANE). Input was also sought out from numerous industry stakeholders, policy-makers, and other experts.

DOER and MassCEC hosted a series of workshops with industry stakeholders, facilitated by MCG, to identify key opportunities and barriers to market development for each renewable thermal technology. During the workshops, participants described the current market status and expected growth rates in Massachusetts, major market barriers, as well as key drivers and incentives. Participants also estimated installed costs and efficiencies for typical residential and commercial renewable thermal systems in the region.

Input from stakeholders was validated by primary and secondary sources, such as the existing literature as well as individual interviews with regional experts. Where possible, inputs for typical system costs were also validated with state rebate databases and regional case studies.

Using data collected, residential and commercial/multi-family scenarios were developed for each renewable thermal technology to (i) assess its lifecycle costs in a simple cash flows model, (ii) estimate its GHG reduction potential, and (iiI) estimate its net GHG and economic development potential under a variety of scenarios.

1.4.1 Renewable Thermal Applications and Scenarios

Each renewable technology was modeled to reflect typical real-world applications (see Table 3 below). For example, the report estimates GHG emissions and lifecycle costs of solar hot water and biomass pellet systems providing space heating and domestic hot water in residential and multi-family/commercial buildings. Biodiesel, on the other hand, is modeled to supply space heating only in commercial and residential facilities. Finally, in residential facilities, ground-source heat pumps are assumed to provide DHW and space heating. In commercial applications, ground-source heat pumps are assumed to provide DHW, space heat, and space cooling. Because reliable cost and performance data is not currently available for air-source heat pumps in the Massachusetts market, these systems were not modeled.

Cooling loads are only taken into account in commercial buildings – where it is assumed to be necessary – for high efficiency heat pumps. Heat pumps typically achieve higher operational efficiencies for summertime space cooling loads than they do for space heating loads – and are well suited to offset electricity consumption associated with existing central air conditioning units. Solar hot water, biodiesel, and biomass technologies, on the other hand, are primarily used to offset fossil fuel heating loads – and thus are not considered in the cooling analysis.

Table 3: Renewable heating and cooling (RH&C) applications

Sector	Solar Hot Water (SHW)	Ground-Source Heat Pumps (GSHP)	Biomass (pellets)	Biodiesel
Residential	DHW (40%) Space Heat (40%) --	DHW Space Heat --	DHW Space Heat --	-- Space Heat --
Commercial	DHW (40%) Space Heat (40%) --	DHW Space Heat Cooling	DHW Space Heat --	-- Space Heat --

1.4.1.1 Residential and Commercial Scenarios

Each renewable technology scenario was sized to serve a hypothetical residential and multi-family/commercial building – assuming a peak heating load of 13 kWth and 97 kWth respectively. The models assume buildings are energy efficient, with heating and cooling loads that correspond to rules of thumb outlined by the US Department of Energy (DOE) and interviews with local experts. System sizing was additionally validated using RETScreen. Detailed building assumptions are available in Appendix A.

Cost estimates for fossil fuel heating systems were derived from interviews with Massachusetts HVAC installers and Massachusetts DOER engineers. All systems are assumed to be high efficiency units. For space heating, installations are assumed to have an Average Fuel Use Efficiency (AFUE) of 80% or greater. In all cases, fuel used for hot water production is assumed to be the same as space heating fuel. Cost assumptions for heating systems are available in Appendix A.

Cost estimates for commercial fossil fuel cooling systems varied significantly. Most installers indicated that installation costs depend upon site specific requirements, such as need for or difficulty of installing ductwork. The analysis ultimately assumes that the commercial scenario has 12 units, each with an individual cooling unit. Cost assumptions for commercial cooling systems are available in Appendix A.

1.4.2 Lifecycle (Cash Flows) Assessment

This report provides the lifecycle cost of energy (LCOE) and the simple payback for each of the renewable scenarios described above. LCOE considers the upfront installed costs and the discounted fuel costs of renewable and fossil fuel heating and cooling systems. It provides a simple economic measure of the cost to produce one MMBtu of energy over the system life. If the LCOE for a renewable technology is less than fossil fuel alternatives, then one can assume that a rational person would logically opt to use the RH&C system.

While a helpful economic measurement, LCOE does not necessarily reflect real life decision-making. As a result, this report also provides the simple payback for renewable thermal technologies, which business leaders and decision-makers would be more likely to consider. Simple payback for RH&C technologies is calculated by determining how many years it takes for RH&C fuel savings (relative to fossil fuel alternatives) to pay back the incremental upfront costs of the RH&C installation. The result provides an estimate of the number of years until the installed cost of renewable thermal technologies is "paid back" by fuel cost savings. The lower the payback for a renewable technology, the more likely a business or individual will install it.

Payback results will vary based on the scenario assumptions. In particular, one key input into payback calculation – the *incremental* upfront costs of the renewable thermal system – is higher for systems that require back-up fossil fuel heating than for systems that do not. In this analysis, back-up fossil fuel heating is assumed to be required for SHW, GSHP, and biomass pellet heating systems.[g] Back-up heating is not required for biodiesel systems. For commercial cooling scenarios for GSHPs, back-up fossil fuel cooling is assumed not to be needed. In every case, input from industry leaders has been sought to develop realistic scenario assumptions for the particular renewable thermal technology under consideration.

1.4.3 Greenhouse Gas Assessment

GHG reductions for renewable thermal systems were calculated by comparing annual GHG emissions expected from the renewable thermal system to the fossil fuel system it replaces. In most cases, renewable thermal systems resulted in lower GHG emissions than fossil fuel heating systems. A*nnual* GHG reductions are estimated in each of the technology chapters. Lifecycle GHG emission reductions were then calculated by multiplying annual GHG reductions by 20 – the number of years the renewable thermal system would be expected to operate.[h] Results are reported in metric tons.

In every case, the GHG analysis seeks to take into account Massachusetts' most recent GHG policy decisions. For example, GHG emission reductions expected from biomass heating builds upon the work that Massachusetts DOER commissioned under the Manomet Center for Conservation Science's 2010 *Biomass Sustainability and Carbon Policy Study*, which has been subsequently integrated into state regulations. Assumptions for the GHG reduction calculations for each technology are detailed in Appendix B.

1.4.4 Job Creation, Economic Development, and GHG Emission Reduction Scenarios

According to the *Massachustts Clean Energy and Climate Plan for 2020* (the climate plan), renewable thermal technologies could reduce GHG emissions in Massachusetts by two million tons – or slightly more than 2% of total 1990 emissions by 2020. To achieve such reductions, the climate plan suggests that policymakers would develop a "broad program" to encourage market growth of and job creation within renewable thermal sectors, including high efficiency heat pumps, biomass thermal, advanced biodiesel, and solar thermal. [4]

It is important to note, however, that under the climate plan, the Commonwealth has established a firm target to achieve GHG reductions only from solar thermal technologies, committing to 100,000 tons of GHG reductions by 2020 from solar thermal. Nonetheless, the broader renewable thermal target provides the basis for estimating market growth, job creation, and economic development targets used in this analysis.

In order to achieve two million tons of annual GHG reductions by 2020, market growth for all renewable thermal technologies will need to increase significantly. Assuming that historical market growth rates continue into the future, renewable thermal technologies will enable Massachusetts to achieve only about 500,000 tons of GHG emission reductions by 2020 – or about 25% of the two million ton reduction goal. With the right market development program in place, however, the Commonwealth could achieve far greater GHG emission reductions cost effectively. Such a program could also produce significant economic development, job creation, and environmental benefits from RH&C.

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[g] A number of stakeholders have indicated that back-up heating requirements for GSHPs and biomass thermal vary depending upon the design and installation of the system – and in some cases, back-up heating may not be required. However, scenario assumptions are intended to reflect most common practices or assumptions for the Massachusetts market.

[h] The expected life (and warranties) for fossil fuel and renewable heating and cooling systems can vary significantly – typically ranging from 10 years to 40 years. For the sake of simplicity, however, this analysis assumes that 20 years is a standard lifetime a consumer could reasonably expect a heating or cooling system to last.

Ultimately, to assess GHG emissions reduction, economic development, and job creation opportunities, three scenarios were created for each renewable thermal technology:

1. a *Business-As-Usual (BAU) Scenario*, which evaluates growth between 2011 and 2020 at the historical growth rate;
2. an *Accelerated Growth by 2020 Scenario*, which predicts the growth rates necessary for meeting the Commonwealth's two million GHG emissions reduction targets for RH&C; and
3. an *Accelerated Growth by 2050 Scenario*, which evaluates the hypothetical GHG emissions reductions associated with replacing a significant portion of the state's fossil fuel heating with renewables between 2011 and 2050.

Results of the scenario analysis are described in the technology sections in following chapters. For each scenario, economic development benefits of switching from fossil fuel to domestically produced RH&C is estimated. Additionally, job creation benefits resulting from regional renewable thermal industry growth are also estimated. Assumptions for the economic, job creation, and GHG targets are detailed in Appendix B.

CHAPTER 2: RENEWABLE THERMAL BARRIERS AND US POLICIES

2.1 Overview of Renewable Thermal Market Barriers

A number of barriers to renewable thermal markets are commonly cited in the literature. The following five points summarize them, focusing specifically on their applicability in the Northeast. Later in this report, each of these barriers is examined in detail within the specific context of the Massachusetts market for each heating technology.

1. *High Upfront Capital Costs.* Compared with conventional fossil-based heating equipment, renewable thermal has higher capital costs for installation; however, lifecycle costs are generally lower than fossil fuels due to significantly lower fuel and operational costs. In addition, before applying incentives, renewable thermal technologies are more cost-competitive than many traditional (electric) renewables.

2. *Lack of Policy Support (or barriers to implementing policy).* Renewable thermal lacks comparable support from policies and incentives that many traditional renewables receive. In the case of renewable thermal technologies that replace oil/propane fuels, a centralized distribution system and utility does not exist, making it challenging to implement a traditional RPS. In other cases, renewable thermal is categorized as an "energy efficiency" technology and has failed to meet stringent cost-effectiveness requirements for incentive support.

3. *Poor Awareness of Renewable Thermal Benefits.* The benefits of renewable thermal are not well-known among policy-makers, the building industry, or the public. As a secure, clean, domestic energy source, renewable thermal technologies generally provide GHG mitigation, improved air quality, as well as economic benefits to businesses and residents. In many cases, however, renewable thermal technology will profit from better measurements or standards quantifying the level of benefit they provide.

4. *Non-accommodating or Opaque Regulatory Standards.* Emission, efficiency, insurance, and other regulatory standards for renewable thermal technologies are often opaque, non-accommodating, or inadequate. This is often the case because the market is young and industry organizations and regulators have not coalesced around commonly agreed upon standards. In other cases, it is a result of the heating technologies operating under regulatory schemes developed for renewable electricity or energy efficiency technologies. Ultimately, the failure to agree upon common standards results in uncertainty among policy-makers, consumers, and industry stakeholders.

5. *Poor Inter-industry coordination.* There is little recognition of "renewable heating and cooling" – which includes biomass thermal, geothermal, solar thermal, and biodiesel – as a single industry, and as a result, there is little inter-sector coordination, planning, or comprehensive policy-making. Moreover, confusion exists as to whether renewable thermal technologies are energy efficiency or generation technologies or both. Regardless, RH&C is not well addressed under existing efficiency or renewable electricity policies. Finally, few resources exist to support innovation or research in the renewable thermal industry, and New England and the U.S. are falling behind Europe with regard to innovation and technology development on this front.

2.2 Renewable Thermal Policies in the US

Renewable thermal technologies have received limited policy support in the US. At the federal level, renewable thermal policy has been limited to investment tax credits for solar water heating and geothermal heat pumps. Additionally, biomass pellet stoves (but not boilers or furnaces) are eligible for the energy efficiency tax credit (subject to a $300 cap). Biodiesel producers receive support through the RFS and are additionally eligible for the biodiesel tax credit. However, aside from biodiesel, these incentives have not been sufficient to drive large-scale market penetration to serve heating across the country.[5] This section describes several leading policies that have been deployed on the state level in the US to support RH&C.

2.2.1 State Renewable Portfolio Standards

The Renewable Portfolio Standard (RPS) is the "umbrella policy" used by states to drive renewable energy development.[6] As noted earlier, the RPS primarily drives renewable electricity development. However, a number of states have permitted solar hot water systems and other renewable thermal technologies to participate on a limited basis in the RPS.[i]

Outside of these few states, renewable thermal technologies are largely ineligible under the RPS. This is due in part to the structure and funding mechanisms of the RPS. For example, an RPS is usually structured around, and often funded by assessments from, customers' electric production; however, renewable thermal technologies offset a wide diversity of fuels – not just electricity. As a result, most renewable portfolio standards only recognize technologies "that displace electricity, rather than natural gas or fuel oil,"[7] making renewable thermal technologies largely ineligible.

One exception is Arizona, which is one of the few states in the US that allows renewable thermal technologies to participate in its renewable portfolio standard (RPS). Under Arizona's RPS, 15% of the state's electricity demand must be met by renewable resources in 2025. The state explicitly allows "commercial solar pool heating, solar heating, ventilation and air-conditioning (HVAC) systems, solar industrial process heating and cooling, solar space cooling, solar space heating, solar water heating, and geothermal heating (but not cooling) systems" to participate in the RPS.[8] Biomass thermal systems, and the heat and electrical output of renewably fueled combined heat-and-power systems are also allowed under the RPS.

Perhaps most significantly for renewable thermal, Arizona regulations allow renewable resources to displace any conventional energy source, *which include fossil fuels* as well as electricity. As a result, the state has taken a leading role in the renewable thermal market by demonstrating that renewable thermal technologies can be integrated into existing renewable portfolio standards.[9]

Finally, New Hampshire policy-makers have been exploring market development potential for renewable thermal. In 2007, the state commissioned a study to explore the potential of integrating renewable thermal into its existing renewable portfolio standard. The state concluded that it would be difficult to integrate renewable thermal technologies due to challenges in monitoring and verifying heat production. It additionally pointed out that there is no central heating utility, as with electricity, to

[i] For example, at least 13 states including Maryland, Vermont, New Hampshire, Pennsylvania, New York, Indiana, Wisconsin, North Carolina, Texas, Colorado, Hawaii, Nevada, and Arizona allow solar hot water to compete under the RPS. Additionally, biomass heating is also eligible under the RPS in Wisconsin and Arizona. In all states but Arizona, renewable heating technologies can displace only electricity. For additional information, please see: Rickerson, W., Halfpenny, T. & Cohan, S. (2009). The Emergence of Renewable Heating and Cooling Policy in the United States. Science Direct. 27:4:365-277.

obligate with a compliance mandate.[10] Going forward, however, New Hampshire has considered and developed alternative proposals to support renewable thermal, such as direct incentive programs to support bulk-fed wood pellet heating systems.[11]

2.2.2 Rebates and Other Technology-specific Incentives

A number of states have developed technology specific rebate programs to encourage renewable thermal technologies, a few of which are described here. For example, California recently established a $280.2 million solar thermal incentive program to support installations displacing natural gas and electric water heating. The program targets residential as well as multi-family/commercial systems. Among other goals, policy-makers expect to reduce installation costs of SHW systems in California by 16% by increasing market efficiency and innovation as well as increasing consumer confidence and understanding of SHW technology. [12] California has traditionally been a leader in the US solar hot water market, and as a result of this program, many experts expect to see California significantly expand the size of its solar thermal market.

Similarly, using American Recovery and Reinvestment Act (ARRA) funds, Connecticut recently launched a geothermal heat pump rebate program. The program targets residential, commercial, and non-profit systems, providing rebates ranging from $1,050 to $1,750 per ton of air conditioning capacity.[13] The program runs in conjunction with the existing utility geothermal rebate program. As of August 2011, the program has provided rebates for 358 systems and generated more than $25 million in economic activity for the state.[14] The program is slated to expire in 2012, when ARRA funds run out.[15]

New Hampshire also launched a rebate program using ARRA funding, which supports biomass thermal installations. The program provides a 30% rebate, up to $6,000, for residential pellet central heating systems. System costs, however, have fluctuated significantly in New Hampshire – ranging from $15,000 to over $40,000 for residential installations – a result of the relative immaturity of the market. The rebate program is currently undersubscribed, having awarded less than 30 grants over the past year. More recently, however, the state has linked the rebate program with other initiatives, like the Model Neighborhood Program, which seeks to aggregate biomass wood pellet system purchases between 10 to 20 homes in New Hampshire neighborhoods. By aggregating purchases of wood pellet heating systems in local communities, the Model Neighborhood Program aims to increase demand, lower costs, and educate the public regarding the benefit of wood pellet systems.[16]

2.2.3 Conclusion: Renewable Thermal Policy in the US

In spite of the programs described above, the RH&C sector is still an emerging market in the US. To date, it has not received the policy support on the state or federal level required for robust market growth. Where policies have emerged, they have primarily focused on very specific market sectors – like solar hot water in California or bulk-fed wood pellet stoves in New Hampshire – and have not comprehensively addressed the issue of heating energy use and production.

CHAPTER 3: RENEWABLE THERMAL POLICY IN THE EUROPEAN UNION

3.1 EU Renewable Energy and Energy Efficiency Directives

3.1.1 Introduction and Background

European Union (EU) country members have long been clean energy market leaders, enacting regional (EU-wide) and federal policies to encourage development of renewable electricity, renewable transportation, and building energy efficiency. In recent years, EU countries have additionally implemented policies to drive vibrant growth in renewable thermal markets. The following describes the development and implementation of policies across the EU to drive growth of the clean energy sectors, focusing specifically on EU-wide and Member State policies that have enabled robust growth of renewable thermal markets.

Over the past decade, the EU Commission has implemented a number of region-wide directives to encourage development of renewable energy and building energy efficiency. This includes an EU-wide *Renewable Electricity directive*, passed in 2001, requiring member countries to adapt their laws to create a certain percentage of electricity from renewable resources.[17] Similarly, in 2003, the EU Commission passed the *Renewable Biofuels directive*, which requires member countries to ensure a minimum percentage of biofuels replace diesel or petrol for transport purposes.[18] Moreover, in 2002, the EU passed an *Energy Performance of Buildings directive* to improve the energy performance of the building stock. However, comprehensive policy support for RH&C was missing from EU policy. This is significant, because thermal energy comprises approximately 49% of the EU's energy consumption, and – as stakeholders across the region recognized – the EU cannot meet its 2020 climate change and renewable energy goals without addressing thermal energy use.[19]

The EU established the so-called "20-20-20 targets" in 2005, which aim to reduce greenhouse gases by 20%, reduce energy consumption by 20%, and increase renewable energy use to 20% across member states by 2020.[j] In an assessment of these goals, the EU Parliament's Committee on Industry, Research and Energy reported that the EU would not reach its 2010 and 2020 renewable energy objectives without establishing formal targets for RH&C. The Committee called for an increase in renewable energy's contribution to heating and cooling to 25% by 2020. The European Commission later launched public consultations to consider the "Promotion of Heating and Cooling from Renewable Energies."[20]

3.1.2 Renewable Energy Directive

In 2009 and 2010, in response to the above as well as calls from numerous public and private sector stakeholders, the EU made two key policy changes that have enabled robust development of the renewable thermal sector. First, the EU enlarged the scope of the renewable energy directive, requiring member countries to source a certain percentage of energy –including electricity, transportation *and heating* sectors – from renewable resources by 2020. The revised directive replaced the electricity and biofuels directives previously mentioned. And while it did not create an overarching renewable thermal mandate, it does specifically call out the need to incorporate renewable thermal generation

[j] Actual country targets vary considerably, depending upon the resources and status of renewable energy in each country.

technologies into member country's renewable energy planning. To this end,

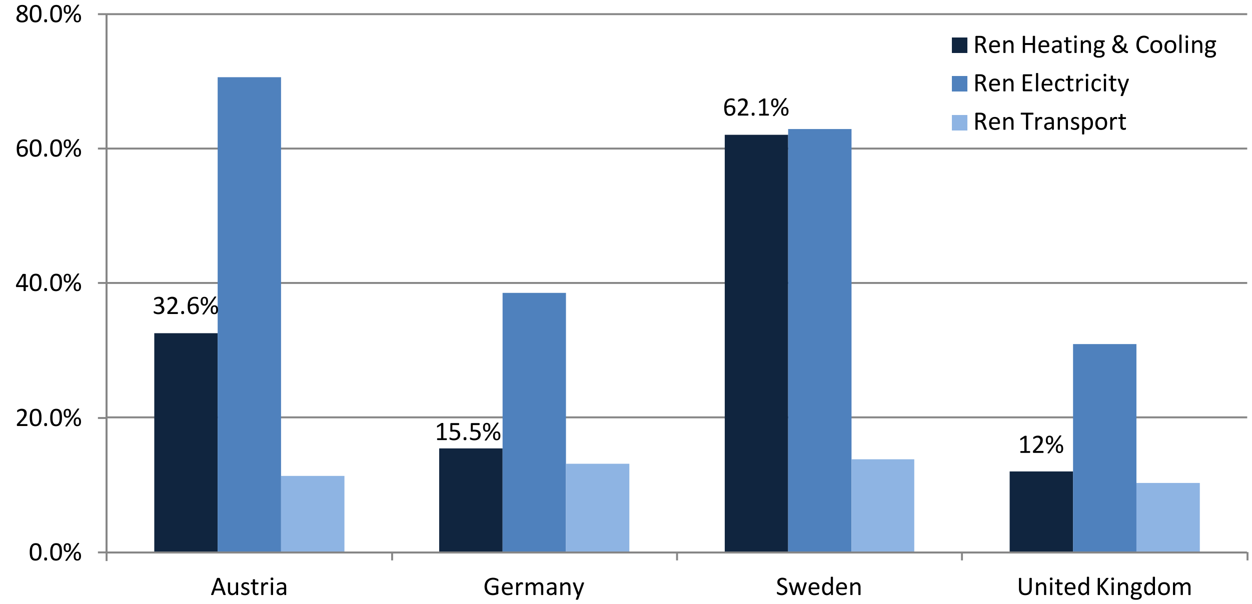

Figure 6 below illustrates the renewable energy targets for electricity, transportation, and heating that Austria, Germany, Sweden, and the United Kingdom (UK) established in order to be in compliance with the new directive.

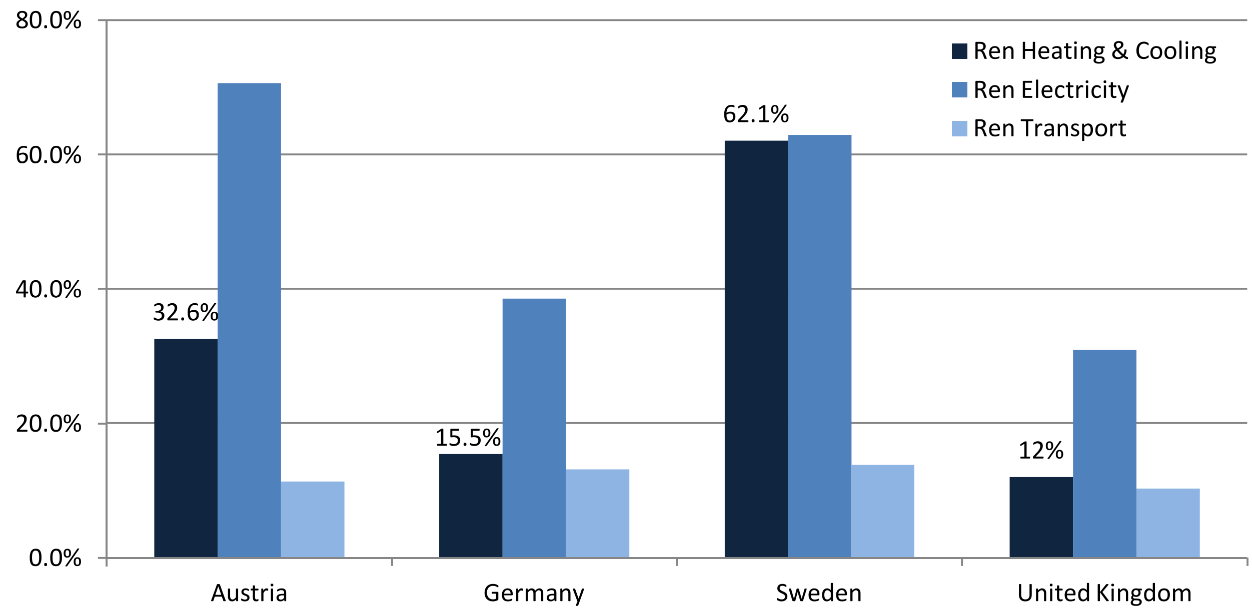

Figure 6: Renewable Electricity, Transportation, and Heating Targets (Source: National Renewable Energy Action Plans, 2010)

3.1.3 Energy Performance of Buildings Directive

In 2010, the EU recast its *Energy Performance of Buildings directive* (EPBD), tightening energy efficiency requirements for new and renovated buildings. In particular, it linked building energy performance to heating, cooling, and power production, thus enabling more efficient and cost-effective production from renewable thermal technologies.

Under the new direction, Member States must ensure that the feasibility of alternative energy production systems (like RH&C) is considered before construction starts in new buildings. Additionally, Member States have to ensure that by 2020 new buildings are 'nearly zero-energy buildings', meaning that a building has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

The EPBD also requires Member States to ensure that energy performance certificates are issued for buildings or units that are constructed, sold, or rented out to new tenants. In addition, certificates are required in all buildings with total useful floor area over 500 m2 (5,382 ft2) and occupied by a public authority. Energy performance certificates may include information such as the percentage of energy from renewable sources and the total energy consumption.

Finally, the EPBD requires Member States to develop inspection requirements for heating and air conditioning systems as well as ensure that guidance and training are made available for those responsible for implementing the directive. Guidance and training shall address the importance of improving energy performance, and shall enable consideration of the optimal combination of improvements in energy efficiency, use of energy from renewable sources and use of district heating and cooling when planning, designing, building and renovating industrial or residential areas.[21]

3.1.4 Member State Policies

With these two policies providing overarching support, countries across Europe have developed aggressive renewable targets for heating (see Figure 6). To achieve these goals, each country has developed policies that encourage development of a wide range of renewable thermal technologies, including solar thermal, biomass thermal, biogas, biofuels, and heat pumps, among others. The following sections briefly assess successful market development and policy support for one or more renewable thermal technologies in Austria, Germany, Sweden, and the United Kingdom (UK). This section provides special focus on key policies that have encouraged market development.

Austria has established a leading renewable thermal cluster. The cluster provides a mix of incentive, regulatory, marketing, and network support for renewable thermal businesses. Section 3.2 briefly assesses the impacts of Austrian cluster policies on the solar thermal market.

For example, **Germany** has established a national *mandate* to derive 14% of energy for heating from renewable resources by 2020.[k] To this end, German policy-makers have provided a range of regulatory, incentive, and financing support for a wide variety of renewable thermal technologies. Section 3.3 focuses on policies driving Germany's biomass heating market in particular.

Sweden has a vibrant renewable energy market, deriving over 50% of its total energy consumption from renewable resources. The country has indirectly encouraged renewable thermal market development through a mix of carbon dioxide (CO2) and energy taxes. Section 3.4 assesses the impacts of these policies on development of its heat pump market.

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[k] Germany's legislative requirement mandates that 14% of heating be derived from renewable heating sources. By contrast, according to the National Renewable Energy Action Plan (NREAP), Germany will need to derive 15.5% of heating from renewable resources to be in compliance with EU and national climate targets.

Finally, the **United Kingdom** is implementing aggressive policy to drive development of its emerging renewable thermal market. The UK's *Renewable Heating Initiative* provides performance-based incentives to facility owners under standard 20-year contracts. Section 3.5 provides a brief overview of the structure and development of performance based incentives for heat in the UK.

3.2 Solar Hot Water (SHW) in Austria

3.2.1 Introduction: Renewable Thermal in Austria

In 2009, renewable sources made up about 27% of total heat production in Austria. As a highly forested country, Austria's high proportion of renewable heat is due primarily to biomass wood heating, which accounts for nearly 18% of total heat production. Solar and ambient heat from heat pumps made up about 3% of total heat production (see Figure 7 below), a small but significant share of Austria's renewable thermal mix.

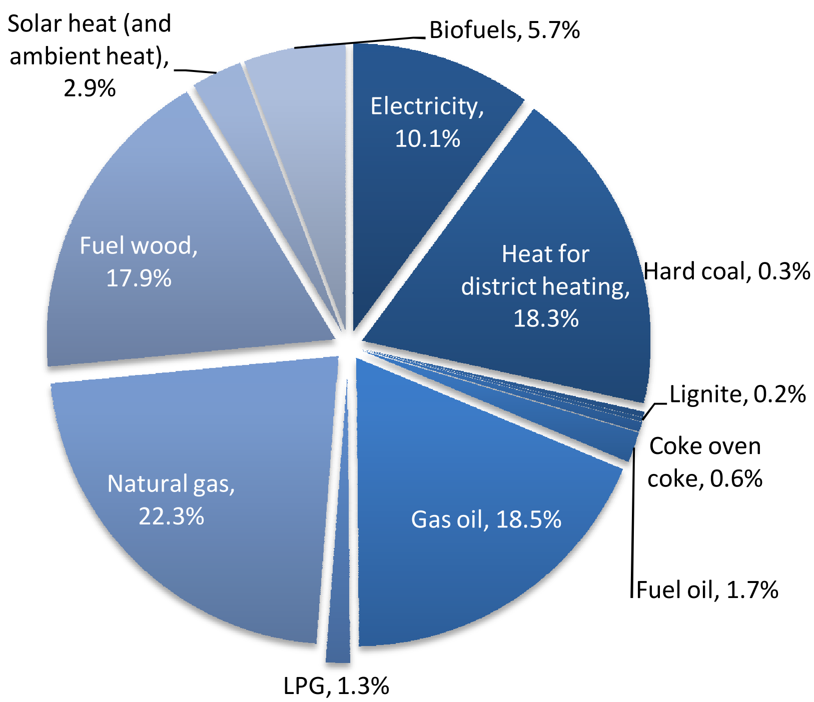

Figure 7: Energy Sources for Space heating and air conditioning in 2009 (Statistik Austria, 2011)

According to the European Solar Thermal Industry, Austria has the "most mature [solar thermal] market in Europe."[22] On a per capita basis, Austria has one of Europe's largest solar thermal markets – with 367 kWth of solar thermal capacity per 1,000 inhabitants (see Figure 8).[l] Regional clusters, like Upper Austria, have achieved even higher penetrations. By comparison, the US has installed approximately 47 kWth per 1000 inhabitants.

[l] Cyprus is the only European country with more solar thermal installed per capita. In terms of total capacity, Germany's solar thermal installations are largest – with 8,880 MWth. For more, see: Weiss, W. & Mauthner, F. (2011). Solar Heat Worldwide: Markets and Contribution to Energy Supply 2009. Prepared for the Solar Heating & Cooling Programme of the International Energy Agency. Retrieved from www.iea-shc.org/publications/downloads/Solar_Heat_Worldwide-2011.pdf.

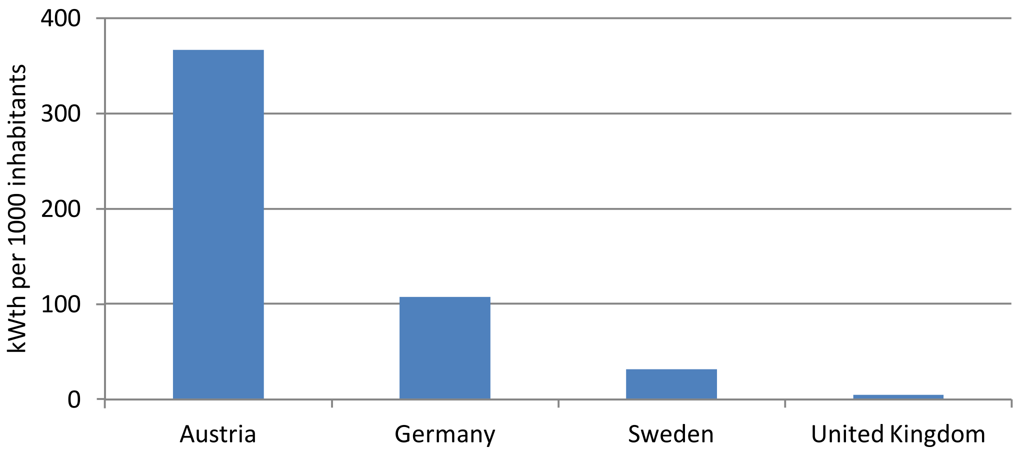

Figure 8: Solar Thermal Capacity (kWth) per 1000 inhabitants in 2009 (Source: IEA, 2011)

3.2.2 Market and Policy Drivers

Austria's federal and state governments have developed a number of complementary policies to drive renewable thermal market development. Interestingly, the role of the federal government is limited primarily to the non-residential sector, providing incentives for businesses that cover up to 30% of investment costs for solar thermal as well as biomass (district heating and CHP) heat pumps systems. The main action in renewable thermal policy occurs regionally, through programs developed and administered by the nine regional states.[23]

In 2009, Austria's nine federal states provided over 55 million Euros in incentive support for solar thermal.[24] The domestic solar thermal industry leveraged this funding to create over 500 million Euros in revenue, installing approximately 365,000 square meters (255 MWth) of solar collectors across the country. Moreover, about 75% of solar thermal collectors manufactured in the country were exported.[25] As a result, more than one third of all solar thermal collectors installed in the European Union were made in Austria.[26]

The state of Upper Austria, in particular, has emerged as a leading solar thermal market and industry cluster. The following considers the approaches that industry stakeholders and policy-makers have taken to leverage resources, eliminate barriers, and drive market development in Upper Austria.

3.2.3 Carrots, Sticks & Tambourines: Developing Upper Austria's Solar Thermal Cluster

Upper Austria currently sources approximately 46% of its heat demand from renewable resources; it aims to meet 100% of its electricity and space heating demand with renewables by 2030. Because it fulfills a number of key policy objectives, solar thermal is considered an energy technology of "strategic importance" within Upper Austria. For example, solar thermal enables the state to (i) stabilize volatile energy costs, (ii) promote energy independence by replacing fossil fuels, and (iii) contribute to climate and energy protection.[27]

The state has focused on three types of policy mechanisms to encourage growth of businesses within the cluster: (i) financial incentives for solar thermal installations, primarily in the form of grants; (ii) regulations and mandates, which require installations on certain buildings, simplify building regulations, and streamline permitting; and (iii) targeted promotional activities like coordinated marketing and training programs. These policies – commonly referred to as carrots (incentives), sticks (regulations and mandates), and tambourines (marketing and training) – have been designed to increase customer demand for solar thermal and support the supply chain.[28] They are briefly examined below.

Carrots. Upper Austria has had a solar thermal grant program in place since 1981, representing one of the longest uninterrupted incentive programs in the world. Incentive levels vary depending upon the size and sector of the solar thermal installation. For example, a typical 100 sq ft installation on a private home receives a grant of about $2,520 (US). Multi-family homes and assisted living facilities receive rebates of about $25/sq ft. Additionally, to receive the rebate, all solar thermal systems must be metered to ensure proper operation year round.

Sticks. Starting in 1999, Austria developed a number of mandates requiring integration of solar thermal systems into the building stock. In most cases, mandates are tied to public buildings or public use of funds (see Table 4 below). For example, new apartment buildings participating in the state housing subsidy program must install a solar or other renewable resource to serve the buildings heating and hot water.

Table 4: Solar Thermal Building Mandates in Upper Austria (Source: O.O. Energiesparverband, 2010)

Sector	Description
Public buildings	Solar thermal required for all new or renovated public buildings
Large, private buildings	Renewable heating and hot water required for all new private sector buildings greater than 10,000 sq ft
State-subsidized apartment buildings	New apartment buildings using state housing subsidy must install solar thermal system (25 sq ft per apartment)
State-subsidized new homes	New homes using state funding (i.e. 95% of new single family homes) must install a renewable thermal system

Upper Austria also simplified the permitting process for solar thermal installations. Systems smaller than 200 sq ft do not require a permit; larger systems need only report the installation to the building authority. There are no permitting fees for solar thermal installations.

Tambourines. In order to promote solar thermal and other renewable thermal technologies, the state energy office, O.O. Energiesparverband, provides 15,000 *free* face-to-face energy consultations to homeowners and public agencies each year. Consultations are also available for businesses, which must pay 25% of the cost share. The remaining 75% is covered by state and federal funding.

Upper Austria additionally worked with industry groups to develop informational campaigns to educate the public and local policymakers about solar thermal. These have ranged from traditional advertising campaigns – using local media and/or billboards – to municipal competitions, wherein local "solar leagues" compete to install the highest amount of solar thermal on a per capita basis.

The state also established training academies to train manufacturers, public agencies, architects, HVAC designers and installers, energy managers in companies, energy service company staff, and auditors on solar thermal installations. Special focus has been given to traditional heating contractors, who often "lack confidence in and knowledge of" solar thermal systems. To this end, in cooperation with state and local schools, vocational training for installers has been developed, enabling young professionals to specialize in renewable energy systems. The curriculum covers design, installation, and servicing of solar thermal facilities as well as biomass and geothermal heat pump systems.

Finally, the O.O Energiesparverband also manages the Okoenergie-cluster, a network of solar thermal, renewable energy, and energy efficiency manufacturers and companies in the state. Currently 150 companies and institutions are part of the network, which “employ more than 6,200 people and generate revenues of more than 2 billion US dollars (or approximately 3.5% of state GDP).”[29] The network provides members support for business development, regional cooperation initiatives, joint marketing programs, and export activities. Additionally, a regional research and development (R&D) program supports product development and ensures competitiveness of the renewable energy and energy efficiency industries.

3.3 Biomass Heating in Germany

3.3.1 Introduction: Renewable Thermal in Germany

Germany is the European market leader in number of solar thermal installations, total biodiesel production,[m] and wood pellet production. It is also the largest consumer of bioenergy in the EU, using over 151 terawatt-hours (TWh) of bioenergy in 2007. This translates into approximately 25 million square meters (269 million square feet) of logs, wood chips, pellets, and briquettes used every year for heating.[30]

In 2008, renewable energy accounted for approximately 7.7% of Germany's heat supply. Over 93% of this was generated from biomass, broadly defined to include biomass liquid, solid, and waste fuels (see Figure 9 below).[31]

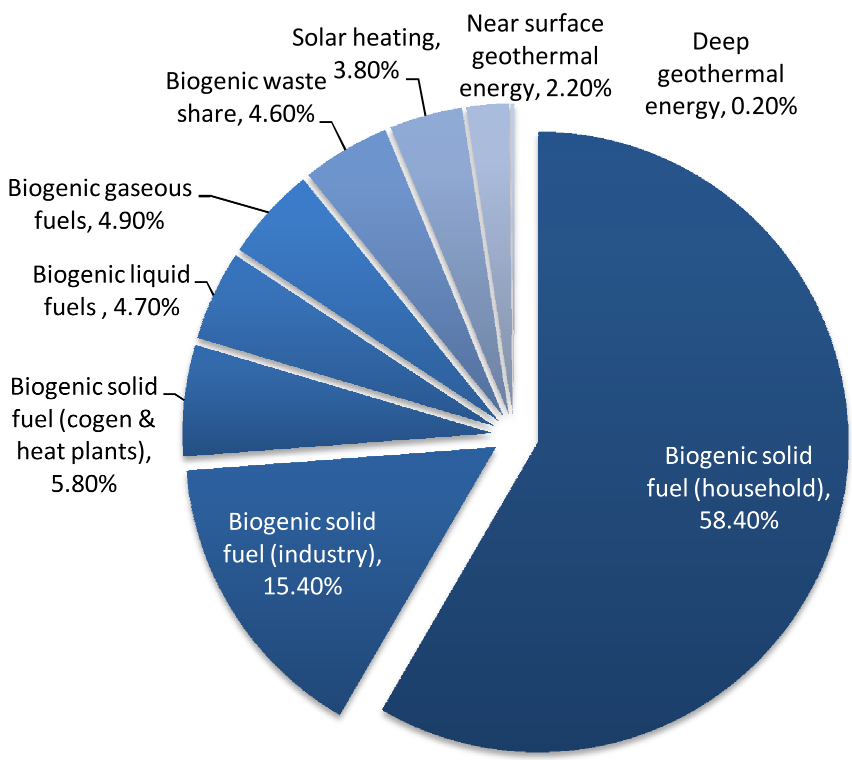

Figure 9: Germany's Heat Generation from Biomass and Other Sources (Federal Ministry of Food, Agriculture, and Consumer Protection, 2009)

Within the German residential (household) sector, biomass provides heat for nearly one in five German households. Of those, the majority (80%) use fireplaces and stoves for wood-based heating, though use of central biomass heating systems (i.e. gasification boilers, pellet heating, and split-log heating) has recently increased significantly. In 2007, for example, approximately 85% of pellet heating systems installed in Germany were central heating systems.[n]

[m] Biodiesel produced in Germany primarily serves the transportation sector.

[n] Interestingly, about half of those were used in combination with solar thermal systems. See Germany Trade and Invest. (October 2009). The German Heating and Cooling Industry: Industry Overview. Retrieved from www.gtai.com.

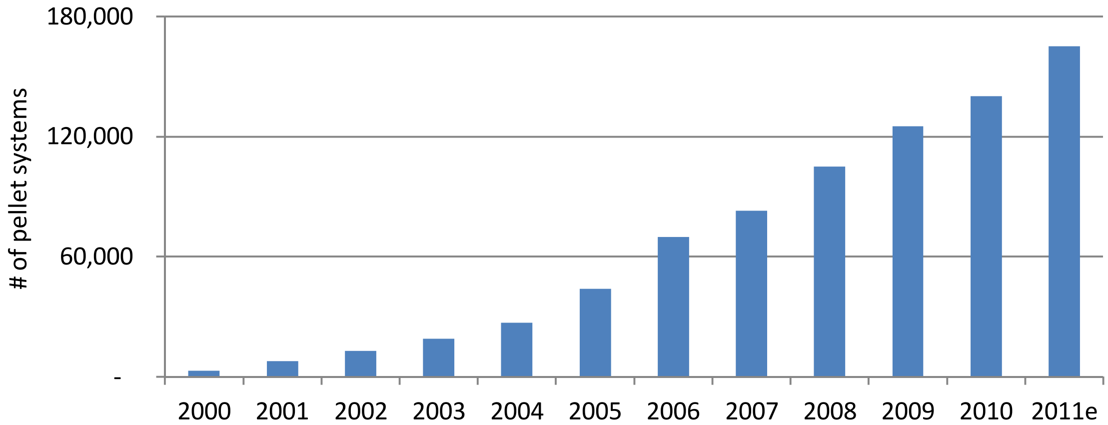

Figure 10: Cumulative Installation of Pellet Heating Systems in Germany (Source: DEPI)

Unsurprisingly, this has benefited the country's wood pellet manufacturers, which produced 1.46 million tons of wood pellets in 2008 (see Figure 11 below). Moreover, between 2000 and 2011, the sector experienced a compound annual growth rate of nearly 40%.

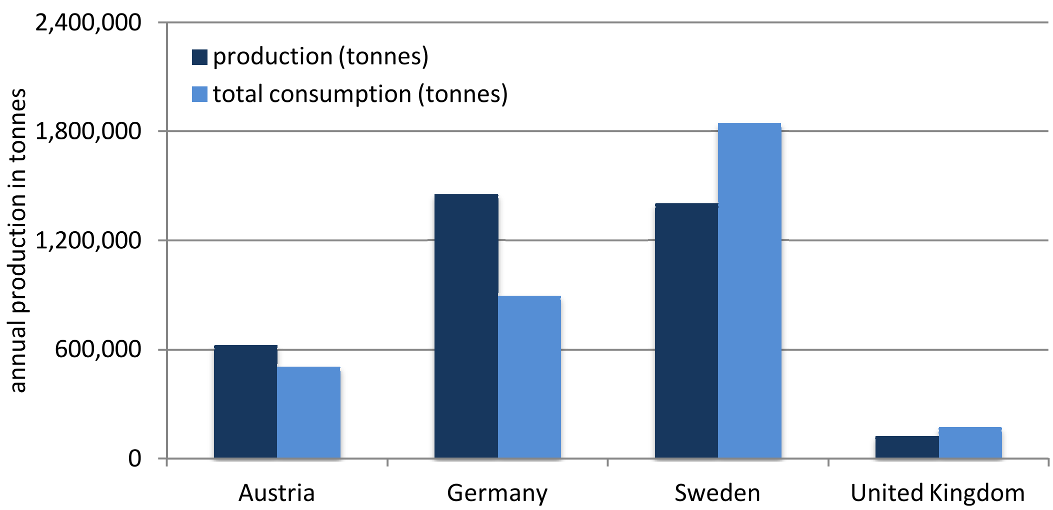

Figure 11: Pellet Production and Consumption in EU countries (Source: Pellet Atlas, 2008)

With this in mind, the following section briefly explores renewable thermal policy and market drivers in Germany, focusing in particular on the wood pellet and biomass heating sector.

3.3.2 Market and Policy Drivers

A key driver of Germany's biomass heating market is the country's forestry industry. Approximately a third of Germany's land area is covered with forests, which contain about 3.4 billion cubic meters of wood stock, the largest supply of wood stock in Europe. The federal state of Bavaria leads Germany's forestry sector,[32] and unsurprisingly also derives the greatest share (over 40%) of its heating from wood pellet systems.

Germany has developed its biomass and renewable thermal markets with strong policy support. In particular, German renewable thermal policies include (i) a market incentive program (Marktanreiseprogram) that provides financing and grants for heat generating equipment in existing buildings and (ii) an obligation under the Renewable Energy Heat Act (EEWärmeG) requiring a national mandate to derive 14% of energy for heating from renewable energy by 2020.[33] The structure and impacts of the Market Incentive Program (MAP) and the Renewable Energy Heat Act (EEWärmeG) are discussed below.

3.3.3 Renewable Energy Heat Act (EEWärmeG) and the Market Incentive Program (MAP)

Under the Renewable Energy Heat Act, Germany requires 14% of building heating to be produced from renewable energy by 2020. The obligation targets primarily *new* residential and non-residential buildings, which must fulfill one of the following requirements: derive 50% of their heating requirement from sustainable biomass (solid and liquid); or 50% from geothermal heat pumps; or 30% from biomass gasification; or 15% from solar thermal.

Additionally, to improve the cost-effectiveness of renewable thermal installations, Germany developed the Market Incentive Program (MAP), which provides grants and financing for renewable thermal systems. The program is funded through an eco-tax, which incrementally increases the tax on fossil fuels and electricity over time.[34]

The program provides grant support for a variety of biomass heating systems, including efficient and low-emission pellet ovens and pellet central heating systems (boilers), and split-log gasification boilers. Systems with capacity between 5 kW and 100 kW receive a 36 euro/kW incentive, with bonuses available for combination systems (using solar thermal) and residential facilities that meet certain energy efficiency requirements (see Table 5 below). According to the International Energy Agency (IEA), the MAP has been the main driver behind innovation and improvement in modern biomass boiler technology. The package of incentives leveled the playing field for biomass pellets relative to conventional fossil fuels.

Table 5: Base, Bonus, and Innovation Incentives for Biomass Heating Facilities in Germany

<table>
<tr><th>Description</th><th>Base Incentive</th><th>Combination bonus (with solar thermal)</th><th>Efficiency bonus</th><th>Innovation incentive</th></tr>
<tr><td>Pellet stove with water heating
5 kW to 100 kW</td><td>36 Euro/kW, 1,000 Euro minimum</td><td rowspan="5">600 Euro</td><td rowspan="5">0.5 x base incentive</td><td rowspan="4">500 Euro per installation</td></tr>
<tr><td>Pellet boiler
5 kW to 100 kW</td><td>36 Euro/kW, 2,000 Euro minimum</td></tr>
<tr><td>Pellet boiler with new thermal storage unit
5 kW to 100 kW</td><td>36 Euro/kW, 2,500 Euro minimum</td></tr>
<tr><td>Split log boiler with heat storage
5 kW to 100 kW</td><td>flat rate of 1,000 Euro per unit</td></tr>
<tr><td>Split log gasification boiler with heat storage
5 kW to 100 kW</td><td>flat rate of 1,000 Euro per unit</td><td></td></tr>
</table>

3.4 Heat Pumps in Sweden

3.4.1 Introduction: Renewable Thermal in Sweden

Sweden aims to be the first oil-free economy in the world by 2020 and has been steadily moving toward that goal over the past several decades.[35] To this end, Sweden has developed a strong renewable energy market, deriving over 50% of its energy from renewable resources. In the process, Sweden has drastically reduced its oil consumption. Within the residential and services sector, for example, Sweden shifted energy production away from oil to electricity, district heating, and bioenergy – a move that reduced oil use by almost 90% since the 1970s.[36] Figure 12 below illustrates the reduction of oil use, and its replacement with renewables and like bioenergy (i.e. biofuels) and heat pumps, in Sweden's large district heating networks.

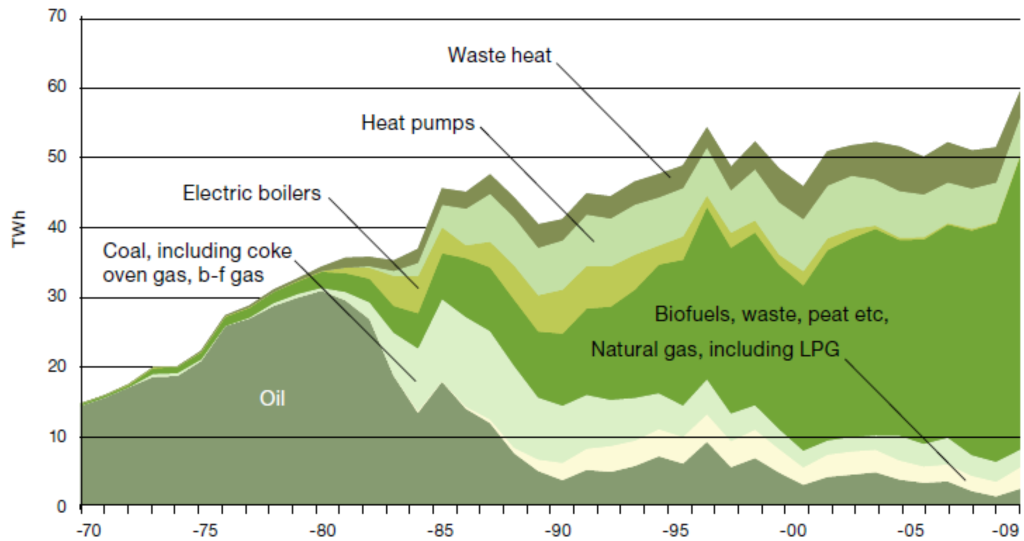

Figure 12: Energy Input for District Heating (Source: Swedish Energy Agency, 2010)

As with other countries, the use of bioenergy has supported much of Sweden's transition to renewable heat. However, Sweden's unique energy policies – which deploy a mix of environmental, energy, and carbon taxes – have indirectly enabled the heat pump market to become very competitive with traditional fossil fuels.[37] Sweden now has developed Europe's largest heat pump market; over 40% of the heat pumps installed in European Union are located in Sweden. Figure 13 below depicts the Sweden's heat pump market relative to the other countries examined in this report.

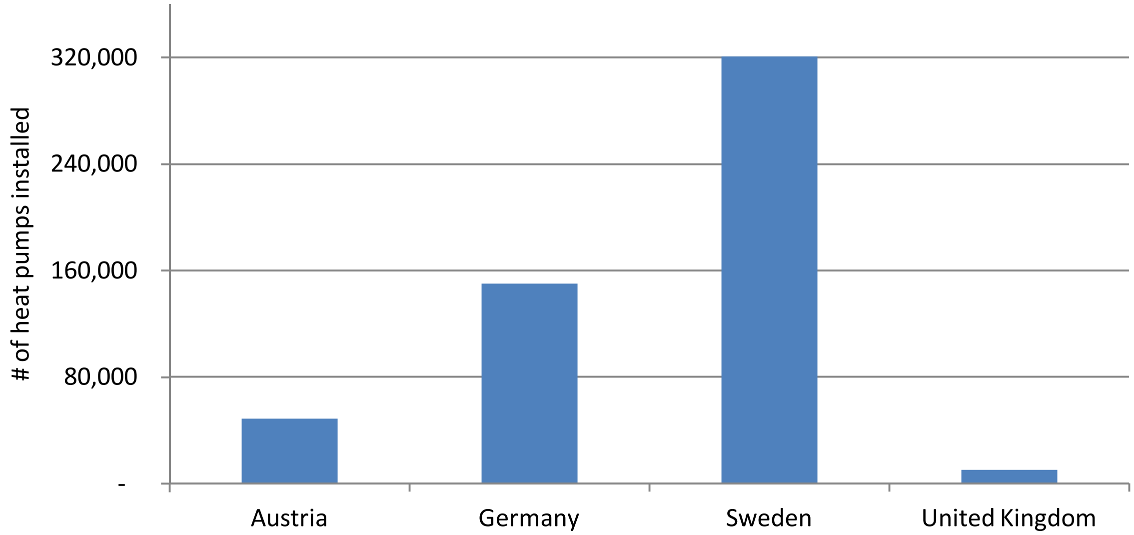

Figure 13: Cumulative Number of Heat Pumps Installed by Country (Source: EurObserv'ER Heat Pump Barometer, 2009)

Lastly, it is worth noting that though ground source heat pumps (as opposed to air source heat pumps) have historically dominated Sweden's market, more recently, market share for air-source heat pumps has increased. The European Heat Pump Association, for example, estimates that air source heat pumps sales reached 469,370 units in 2008 in key European markets,[o] an annual increase of 56.8% from 2007. Ground source heat pump installers, by contrast, installed only 107,022 units, growing by only 10.6% during this same period.[38]

Table 6: Annual Sales of Air- and Heat-Source Pumps (Source: EurObserv'ER, 2009)

	2007	2008	Growth
Ground source heat pumps (GSHPs)			
Brine-to-water	74,126	85,787	16%
Water-to-water	9,907	11,090	12%
Direct expansion-water heat pump	4,925	5,445	11%
Direct expansion heat pump	7,814	4,700	-40%
Total	*96,772*	*107,022*	*11%*

Air source heat pumps (ASHPs)			
Air-to-water (heating only)	97,408	200,978	106%
Heat recovery heat pumps	32,025	45,245	41%
Reversible heat pumps (heating and cooling)	166,551	223,147	34%
Total	*295,984*	*469,370*	*59%*

3.4.2 Market and Policy Drivers

According to some industry stakeholders, Sweden has served as the "international role model" for heat pump market development.[39] The country pioneered a number of early installations in the 1970s, though like many renewable energy technologies at that time, heat pumps suffered from poor product

[o] Key European markets include Austria, Finland, France, Germany, Italy, Sweden, Norway and Switzerland.

performance, denting the reputation of the industry for many years following. In the 1980s, the Swedish government sponsored a number of high profile heat pump projects, including the installation of water heat pumps in the Swedish Royal Family's Drottningholm Castle, which helped the industry get back on its feet. Product performance also improved significantly.[40] During this time, Sweden also introduced new building regulations, which stipulated that the supply temperature of heating systems should not exceed 55 degrees Celsius (151 degrees Fahrenheit), significantly lower than the 80 degree Celsius (176 degree Fahrenheit) supply temperature of standard radiator systems. This made buildings built since 1984 "fundamentally more suited to heat pumps than buildings with higher temperature systems."[41]

The real driver of the heat pump market in Sweden, however, is the country's high energy prices and taxes, which have leveled the playing field for heat pumps and other renewable thermal technologies. As a result of Sweden's energy tax policies – in addition to a couple rebate and tax incentive programs – Sweden has developed the most mature heat pump market in Europe.[42]

3.4.3 Energy and Carbon Taxes in Sweden

Sweden's Energy and Carbon taxes were initially implemented to help finance public activities; however, since the 1990s, the energy and environmental benefits of tax policies have become increasingly more important to policymakers and the public. According to the Swedish Energy Agency, present energy taxation is aimed at: (i) improving energy efficiency; (ii) favoring use of bioenergy; (iii) creating incentives to reduce the environmental impacts of companies; and (iv) creating conditions to encourage the domestic production of electricity.[43]

Sweden's energy taxes are structured around a variety of environmental and energy factors. For example, taxes are levied on energy sources based on the energy content of fuels, the volume of carbon dioxide emitted (except for bioenergy fuels and peat), as well as the amount of sulfur dioxide and nitrogen oxide emitted. Interestingly, the electricity sector is exempt from energy and carbon dioxide taxes, though it is subject to sulfur dioxide and nitrogen oxide levies.

The heat sector, on the other hand, is subject to energy, carbon dioxide, and in certain cases, sulfur dioxide and nitrogen oxide taxes.[44] As a result, renewable thermal technologies like heat pumps, can achieve reasonably quick paybacks. For example, Bosch, an international heat pump manufacturer and supplier, reports that as a result of high energy taxes on conventional heating fuels, heat pumps can pay for themselves "in as little as three to five years."[45]

Additionally, Sweden has at times provided direct incentives to encourage use of renewable thermal technologies like heat pumps. For example, from 2006 to 2010, the country provided grants worth 3,500 Euro to support geothermal heat pumps that replaced electric storage heaters or oil boilers in buildings. Additionally, homes heated with oil are eligible for tax rebates if they switch to renewable resources for heating. Ultimately, however, the indirect support provided by taxing fossil fuels has been the primary driver of heat pumps and other renewable thermal technologies.[46]

3.5 United Kingdom and the Renewable Heating Incentive

3.5.1 Introduction: Renewable Heating in the United Kingdom

The United Kingdom has *not* historically focused on developing the renewable thermal sector. On the contrary, as illustrated in Figure 14, natural gas serves the heating needs of the majority of businesses and homes in the country, providing approximately 69% of total heat in 2008. Electricity follows, providing slightly more than 14% of heat. Oil and contracted heat sales[p] make up about 12%. Renewable thermal serves only 1.5% of heat.[47]

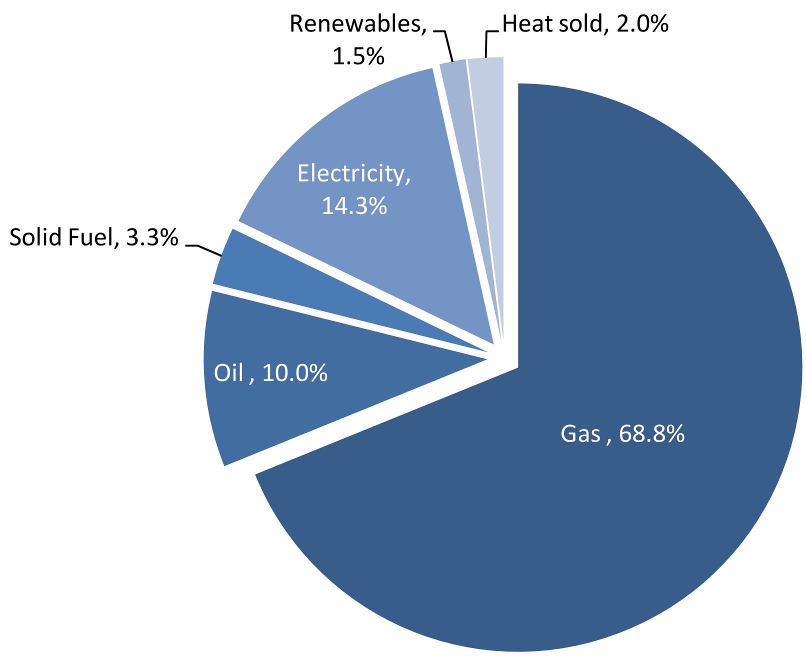

Figure 14: UK Heating Fuels in 2008 (Source: DECC, 2011)

Accordingly, of the four European countries considered here, the United Kingdom has the least mature renewable thermal market. However, the UK recently established aggressive renewable thermal targets and is putting an incentive program in place, which is designed to change this picture. The following section briefly explores the policy drivers for the UK's emerging renewable thermal market.

3.5.2 Market and Policy Drivers

According to the UK Department of Energy and Climate Change (DECC), "increasing renewable heat is key to the UK meeting its renewable energy targets, reducing carbon emissions, ensuring energy security and helping to build a low-carbon economy."[48] As a result, the government has committed to source approximately 12% of its total heat demand from renewable resources by 2020.

In support of these goals, DECC recently launched the Renewable Heating Initiative (RHI), a market incentive program that provides performance-based incentives[q] to increase uptake of renewable thermal technologies including the heat pumps, solar thermal, and biomass sectors.[49]

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[p] Heat sold includes heat sold and produced under contract. This includes things like community heating schemes and/or CHP plants.

[q] Additionally, under the Renewable Heat Premium Payment, residential customers are eligible for capacity-based incentives (i.e. rebates). However, over time, residential users will also shift to performance-based incentives.

Unlike other European incentive programs described here, the RHI is a fully performance-based incentive program for heating. Similar to the country's feed-in tariff for electricity, the RHI provides renewable thermal system owners stable cash payments over 20 years for the production of heat. As illustrated in Table 7, RHI rates are based on the cost of generation. They have been designed to provide a rate of return around 12% for each technology. According to DECC, this will provide a "kick-start" to the market and "encourage high growth quickly."[50]

Table 7: UK Renewable Heating Initiative Rates by Technology (Source: DECC, 2011)

Tariff Name	Eligible Technology	Eligible Size	Tariff Rate (pence/kWh)
Small biomass	Solid biomass; Municipal solid waste (includes CHP)	Less than 200 kWth	Tier 1: **7.9**
			Tier 2: **2.0**
Medium biomass		200 kWth to 1,000 kWth	Tier 1: **4.9**
			Tier 2: **2.0**
Large biomass*		1,000 kWth and above	**2.7***
Small ground source	Ground-source heat pumps; water-source heat pumps; geothermal	Less than 100 kWth	**4.5**
Large ground source		100 kWth and above	**3.2**
Solar thermal	solar thermal	Less than 100 kWth	**8.5**
Biomethane	Biomethane injection and biomass combustion, except from landfill gas	Biomethane all scales, biomass combustion <200 kWth	**6.8**

*currently being revised

Incentive payments are made on a quarterly basis and calculated by multiplying the appropriate tariff by the amount of eligible renewable heat generated. For example, if a solar thermal installation (less than 100 kWth) produced 8,000 kWh of heat in Q1 of 2012, then it would be eligible for a 680 pound incentive payment (8.5 pence x 8,000 kWh).

DECC assessed a range of possible installations to develop the RHI rates. Tariffs were ultimately calculated based upon the needs of a reference installation, "which represents (in most cases) roughly the mid-point of all the installations covered by the tariff in question."[51] Moreover, tariffs are designed to account for the full *additional* cost of renewable heat, meaning that "they do not compensate for the *full* cost either of the renewable heat equipment or any fuel used by the renewable heat equipment, but only for the *additional* cost of such equipment and fuel above that of the fossil fuel alternative."[52]
It is worth noting that incentive payments do *not* vary for the fuel being replaced. This tends to benefit installations in rural areas, which do not have access to the gas grid, and thus use more expensive fuel like oil or electricity. DECC justifies this approach due to greater assumed GHG emissions achieved by offsetting oil or electricity over natural gas.[r]

3.5.3 Metering Renewable Heat Production

In order to calculate the incentive payment, regulators require facility owners to meter and report heat production quarterly. Metering requirements depend upon the complexity of the installation. As illustrated in Figure 14 below, regulators define installations as either "simple" or "complex." Simple systems are typically those that can answer no to the following questions.

[r] DECC reports: a higher proportion of rural than urban areas tend to lack access to the gas grid and organizations not connected to the gas grid, for example small rural businesses, tend to have higher heating costs due the use of more expensive fuels. Therefore, those off the gas grid will have the potential to benefit most from the RHI and this type of switching will also produce the greatest environmental benefit as off gas grid fuels have higher carbon emissions.

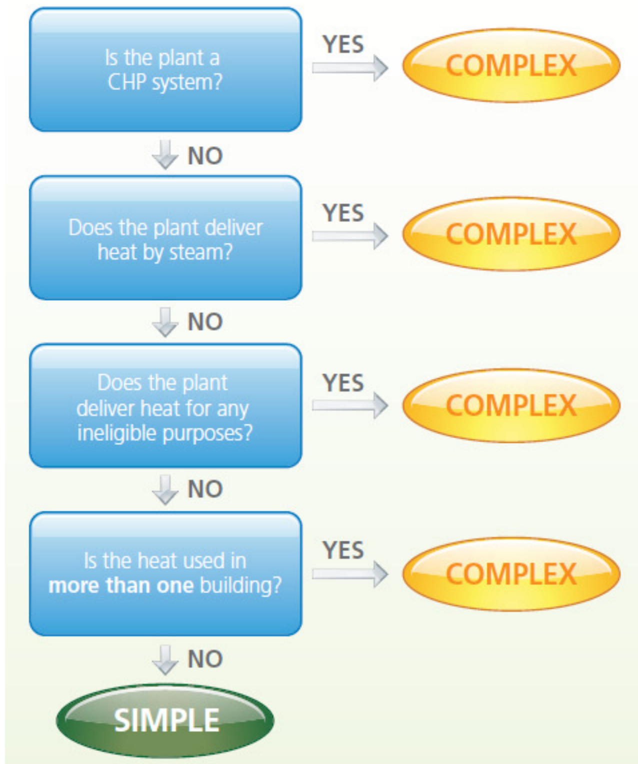

Figure 15: RHI Simple and Complex Meter Requirements (Source, Ogfem, 2011)

Simple systems must meter only the heat *produced* by the eligible installation. For example, a solar thermal facility serving only one building via radiant floor heating would be classified as a simple facility, and thus would only have to install one meter to measure useable heat produced for space, water or process heating (all eligible uses). On the other hand, systems deemed complex must measure heat in three quantities: (i) the heat generated by the eligible installation; (ii) the total heat generated by all plants supplying heat to the heating system of which the installation forms part; and (iii) the heat used for eligible purposes by the heating system.[53]

Finally, for most renewable thermal sectors, DECC determined it is possible to "deem" (or estimate) required heat demand to ensure that systems are sized appropriately. DECC has developed guidelines to discourage system over-sizing and the production of unused (or vented) heat. However, due to the complexity of building occupancy and usage for small and medium biomass systems, it has not been possible to deem heat demand. As a result, DECC developed a two-tiered system for small and medium biomass (see Table 7), which links the full tariff with the capacity of the installation. The higher tier 1 tariff is applied until production reaches the "tier break," after which point the facility receives payments at the lower tier 2 rate. Tier 2 rates are designed only to offset costs associated with fuel, not with capital costs.[s]

[s] The tier break is calculated by multiplying the system capacity by 1,314 peak load hours (1,314 is equivalent to 15% of the year). Thus, the biomass installation may receive the full tariff, assuming it operates at peak load for 15% or less time annually. Thereafter, it is eligible for the significantly reduced tier 2 rate.

CHAPTER 4: SOLAR HOT WATER AND & SPACE HEATING

4.1 Introduction

Solar hot water (SHW) systems can be used to generate heat for domestic hot water (DHW) and space heating. When both uses are deployed, the system is referred to as *a solar combi-system*. Most SHW installations in the Commonwealth are currently designed and sized to serve DHW only. However, this report emphasizes the potential for solar combi-systems, which, due to their size, can provide additional opportunities for energy savings and GHG reductions in Massachusetts.

The following section provides a brief overview of the technology and then describes the current market status, supply chain, and market barriers and drivers for SHW combi-systems. It additionally assesses typical project economics for residential and commercial project scenarios as well as GHG emission reductions and job creation potential for the Massachusetts SHW market.

4.1.1 Key Findings and Conclusions

At the current market growth rate,[t] the Massachusetts solar hot water market is on-track to meet – and exceed – the 100,000 ton GHG reduction goal established by the *Massachusetts Clean Energy and Climate Plan for 2020*. If space heating with solar hot water (e.g. solar combi-systems) becomes more commonplace, GHG savings could be even greater. In total, the Massachusetts SHW market is expected to create nearly new 1,500 jobs by 2020 under a business-as-usual (BAU) scenario.

Under an accelerated growth scenario,[u] GHG emission reductions and job creation would be even greater. In this case, solar hot water could reduce GHG emissions by 500,000 tons and create over 3,300 new jobs by 2020.

With the recent introduction of state residential and commercial solar hot water incentives, Massachusetts policy-makers have laid the foundation to develop a vibrant solar hot water market (please see www.masscec.com/solarhotwater for information about the Commonwealth Solar Hot Water program). With federal and state incentives combined, solar hot water combi-systems achieve the lowest LCOE of all technologies (fossil and renewable) assessed in this report. Residential SHW combi-systems additionally achieve payback between four and 12 years. Payback for commercial systems is even faster, estimated between two and five years. Finally, the MassSAVE HEAT loan enables customers to finance the installation of SHW systems, reducing the upfront costs and financial burden associated with installing solar hot water.

Despite these advantages, stakeholders indicate that a number of other barriers continue to inhibit development of the solar hot water market in Massachusetts, including: poor consumer awareness of SHW benefits; the need for (and additional retrofit costs of) low-temperature space heating distribution systems; costs associated with local permitting and inspections; as well as workforce training needs. Looking ahead, to achieve the market growth, job creation benefits, and GHG reductions associated with the accelerated growth scenario, policy-makers will need to address these barriers to SHW.

[t] Under the business-as-usual (BAU) scenario, the SHW market is estimated to grow by approximately 34% annually.

[u] Aggressive annual market growth rate is assumed to be 44%.

4.2 SHW Technology, Market Status and Value Chain

4.2.1 Technology Overview

Because it is rarely cost-effective (or technically feasible) to size a SHW system to cover 100% of heating load, SHW requires auxiliary (back-up) heating, which is commonly served by the existing fossil fuel system. To this end, DOE reports that combi-systems should provide a solar fraction of 40% to 80% of a home's heating needs.[54] Within Massachusetts, most combi-systems are designed to meet slightly less, between 30% and 50% of the DWH and space heating load.

The design of SHW heating systems depends upon the local climate as well as building readiness, customer aesthetics, and customer budget. SHW configurations typically include solar collectors, water storage tanks, piping, insulation, valves, gauges, and fittings. Depending upon the complexity of the installation, they may also require heat exchangers, pumps, and controllers. Because of Massachusetts' cold climate, systems must also provide freeze protection during the winter. With this in mind, the following briefly discusses the basic design and installation of SHW systems, considering in particular SHW collectors, controls and pumps, freeze protection, and the integration of combi-systems into the existing heat distribution system.

4.2.1.1 Solar Collectors

Solar collectors concentrate the sun's energy to heat transfer fluid, turning solar energy into usable heat for space and water heating. Typically installed on building rooftops (though sometimes ground-mounted), each collector panel consists of a network of pipes filled with water or glycol (heat-transfer fluid), which is distributed across the panel surface and heated by the sun. Collector sizes vary, though they typically measure four by eight feet in size.[55] Two types of solar collectors –flat plate (glazed and unglazed) and evacuated tubes – are in use in Massachusetts.

Flat plate collectors consist of an absorber plate—a sheet of copper, painted or coated black—bonded to pipes that contain the heat-transfer fluid. The pipes and copper are enclosed in an insulated metal frame and, in glazed collectors, topped with a sheet of glass (glazing) to protect the absorber plate and create an insulating air space.[56] In unglazed flat-plate collectors, commonly used for swimming pool heating, the insulating properties of the glazing are not in use, resulting in decreased efficiencies of the panels at lower air temperatures. For applications outside of pool heating, unglazed collectors are generally not appropriate for heating in the Northeast.

In evacuated tube collectors, each absorber plate is contained within a glass tube from which all air has been evacuated – creating a vacuum. Because a vacuum is a better insulator than air, these collectors have much better heat retention than the glazed design of flat-plate collectors – especially in cold climates.[57] They also tend to be more expensive than flat plate collectors.

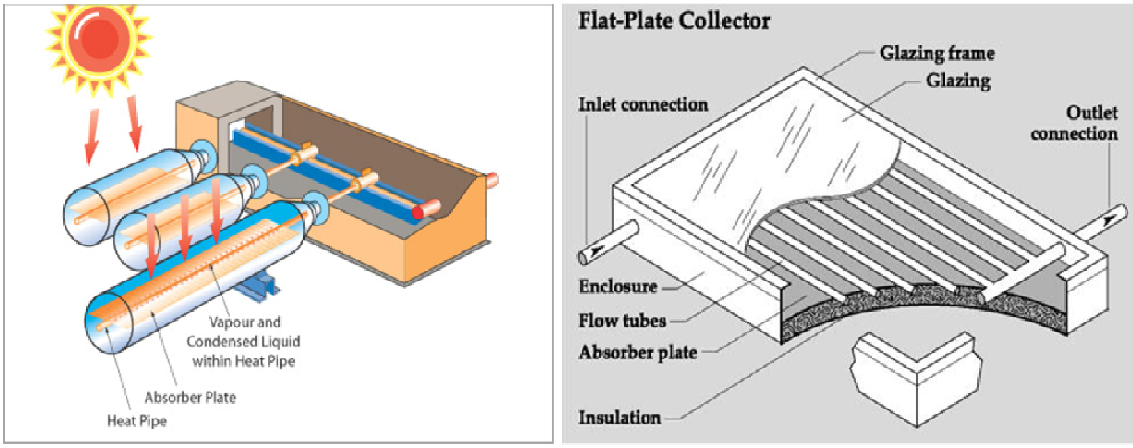

Figure 16: Evacuated Tube and Glazed Solar Collectors (Source: RETScreen, 2005)

Depending upon panel design and efficiency, the temperature of the heat-transfer fluid will vary. For example, on a typical summer day (sunny and warm), the fluid in the solar collectors reach 140°F to 180°F (60°C-80°C). On a clear winter day (sunny and cold), it can reach 120°F to 150°F (50°C-65°C). When it´s cloudy and warm, collectors can reach 70°F to 90°F (20°C-30°C), and when it´s cloudy and cold, 50°F to 60°F (10°C-15°C).[58] Massachusetts installers report that panels typically deliver heat around 120°F in the New England winter. As long as the temperature in the fluid in the collector is greater than that of the incoming cold water, then the SHW system is saving energy for the user.[59]

4.2.1.2 Controls and Pumps

After the heat-transfer fluid is heated in the panel, the heat must be transferred from the panels to the building’s hot water system. In active systems, pumps and other mechanical systems move the fluid from the panels to hot water tanks.[v] In this case, controls and temperature gauges sense when fluid in the collector is hotter than the water in the storage tank, which turns the pump on and circulates the fluid – moving heat from the collector to the water storage tank. When the tank is hotter than the collector, the pump is turned off, thus preventing heat loss through the solar collector. This function is usually performed by a differential thermostat control system, which compares heat sensor readings from the storage tank and collectors and switches on the pump accordingly.

4.2.1.3 Stagnation and Freeze Protection Design

Massachusetts is subject to cold winters, and solar heating systems must be designed to withstand freezing conditions. Because water expands when it freezes, the pipes of a SHW system will burst when temperatures drop, causing potentially significant and costly damage to the system. As a result, SHW systems in Massachusetts are typically designed to use glycol (antifreeze) or a drainback mechanism – both of which protect the system from damage during freezing conditions.

Similar to antifreeze in cars, glycol systems prevent damage in SHW systems by using a mix of water and antifreeze as the heat transfer fluid.[w] The use of glycol requires a closed loop (indirect) system design,

[v] In contrast to active (forced-circulation) systems, passive systems do not use mechanical systems to move the heat transfer fluid, relying instead on thermodynamic properties of the system. In this case, a third system design – the passive thermosyphon system – could be employed, though it is not currently in wide use in Massachusetts.

[w] However, solar hot water systems use nontoxic propylene glycol instead of highly toxic ethylene glycol used in most automobiles. For more information, see: Marken, C. (February & March 2011). Solar Hot Water: System Types and Applications. Home Power. 141. Retrieved from http://homepower.com/view/?file=HP141_pg48_Marken.

meaning that the glycol never mixes with the hot water used in a building. Instead, as the glycol heats up in the collector, heat is transferred from the glycol to the hot water tank through a heat exchanger, which usually consists of a copper coil located inside the hot water tank (see Figure 17 below).

Closed loop drainback systems, on the other hand, typically use water as the heat transfer medium.[x] To protect against freezing, drainback systems are designed so that water drains back to a reservoir during cold conditions, leaving the collectors and piping filled with air (see Figure 17 below). To ensure proper operation, the collectors and piping must be sloped at an appropriate angle so that the system fully drains.[60]

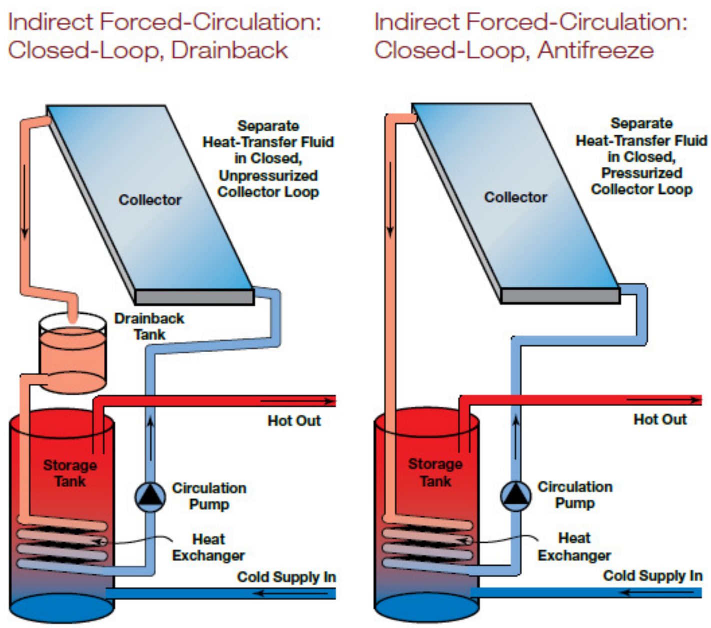

Figure 17: Closed-Loop Drainback and Glycol (antifreeze) SHW Systems (Patterson, n.d.)

In addition to freeze protection, Massachusetts installations must also provide safeguards against stagnation, which is a condition in which heat transfer fluids boil off in the collector due to prolonged solar exposure with no cooling flow. In systems using glycol, the glycol will break down under high temperatures. Systems may be protected against stagnation by using advanced controllers (with thermal cycling functions or a vacation/holiday mode), which keep heat transfer fluids from overheating. Alternately, heat dump radiators or properly sized expansion tanks and relief valves can protect the system by allowing the system to dump (dissipate) heat that is not needed.

4.2.1.4 Combi-systems and Space Heating

Figure 18 below illustrates a typical solar combi-system design. In this setup, the SHW system heats water that is stored in the hot water tank. The water then travels from the tank through an auxiliary heating system (i.e. a boiler), which heats the water to higher temperatures (if necessary). The hot water is then circulated throughout the building via the existing heat distribution system.

[x] Glycol is also used in some cases, creating system redundancies to protect against freezing conditions.

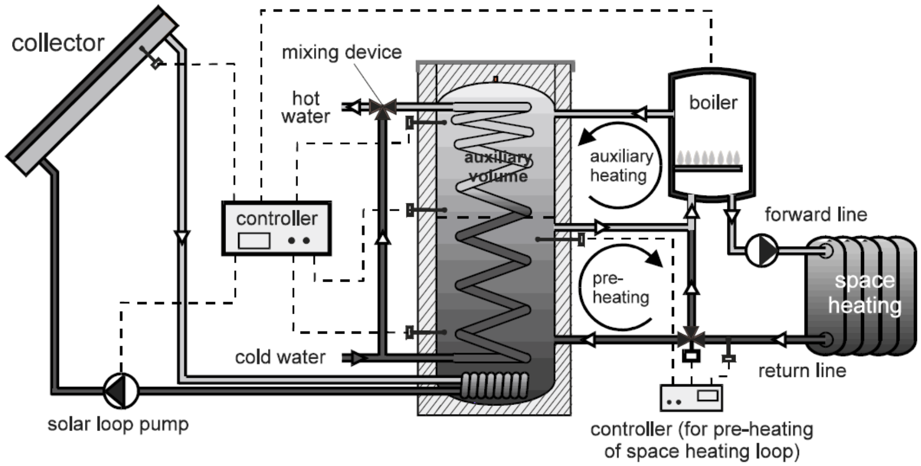

Figure 18: Combisystem Design for Solar Space and Water Heating (Drueck, H., Heidemann, W. & Mueller-Steinhagen, H., 2004)

For the solar combi-system to operate effectively in Massachusetts, it must be integrated into a low-temperature heat distribution system – like radiant floor or radiant baseboard heating. In low-temperature heat distribution systems, the circulating water is close to room temperature, which is ideal for SHW. For example, installers report that typical SHW systems in Massachusetts can heat water to temperatures around 120 degrees Fahrenheit during the winter. By contrast, high temperature heat distribution systems (like a traditional radiator distribution system) circulate water at much higher temperatures – between 122°F and 175°F (50°C and 80°C respectively). As a result of high water temperature requirements, SHW is inadequate for space heating employing high temperature heat distribution.

4.2.2 Market Status and Value Chain

The US SHW market has experienced slow, albeit fairly stable, growth over past decades, averaging a compound annual growth rate (CAGR) of 6% from 1991 to 2008.[61] Market growth has been concentrated in a number of key geographic and market sectors. In 2009, for example, nearly two-thirds of solar collector shipments went to five states: Florida, California, Arizona, Hawaii, and Oregon. Additionally, according to the National Renewable Energy Lab (NREL), approximately 50% to 60% of systems shipped in 2008 were used for heating and hot water applications.[y]

Within Massachusetts, between 118 installations (383 kW) and 375 installations (1,219 kW) were installed each year for DHW and/or space heating in Massachusetts from 2006 to 2009 (see Figure 19 below). In 2008, it is estimated that the number of Massachusetts installations for DHW and space

[y] This is in contrast to EIA statistics, which report that over 80% of collectors shipped in the US (measured by collector area) consist of low-temperature (unglazed, pool heating) collectors. EIA's measure likely overstates the size of the US pool heating market. This is because DHW and space heating installations require less collector area than pool heating. Correcting for this variation, NREL arrived at its assessment that 50-60% of systems shipped in 2008 were used for heating and hot water. For more information, see: Goetzler, W. (2011). Low Cost Solar Hot Water Heating Webinar: Market Overview and Examples from Other Markets. Prepared for US DOE Building Technologies Program. Retrieved from http://apps1.eere.energy.gov/. p. 9.

heating surpassed pool heating.[z] In total, the solar DHW and space heating sector experienced a compound annual growth rate of 47% over these four years.[aa]

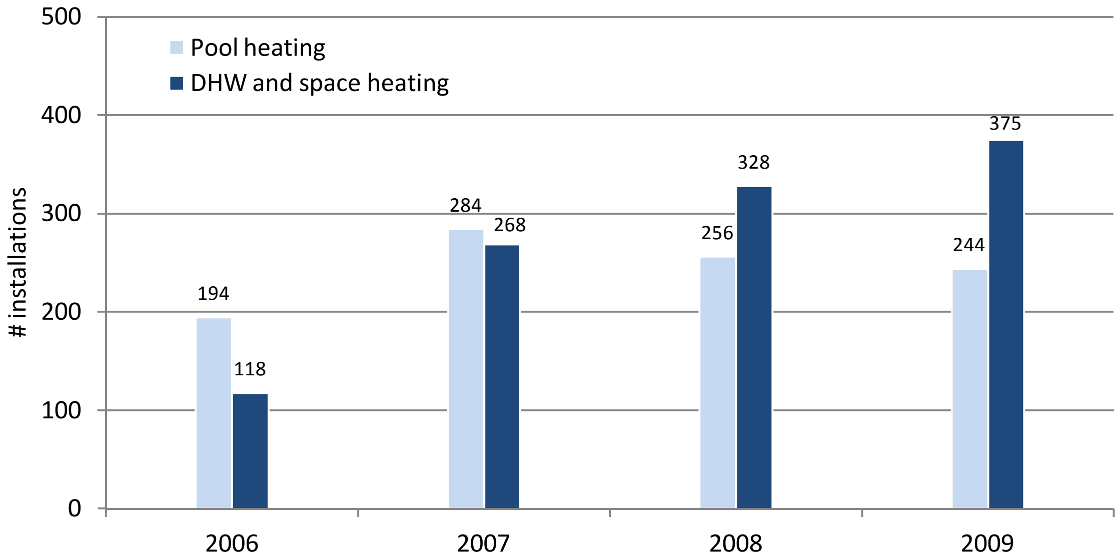

Figure 19: Estimated Annual SHW Installations in Massachusetts (EIA, 2010 and internal analysis)

Finally, Massachusetts' SHW market growth is supported by manufacturers and installers across the region. Fifteen solar collector manufacturers are active in the Northeast.[62] At least five manufacturers of collectors, tanks, or other solar heating components have facilities located in Massachusetts. And approximately 50 solar hot water installers are active in the state, many of whom have incorporated solar hot water into businesses such as plumbing, solar photovoltaics (PV), or oilheat/HVAC distribution.[bb]

4.3 Drivers and Barriers

4.3.1 Market Drivers

The Massachusetts SHW market is driven primarily by the cost of fossil fuels (electric, natural gas, and oil) as well as federal and state incentives. For example, installers anecdotally report that when fossil fuel prices increase, the number of inquiries for SHW installations also increases. Currently, SHW is particularly appealing when replacing electric resistance or fuel oil heating systems (see Section 4.4.2).[cc]

SHW installers also depend upon a number of state and federal incentives to be competitive with fossil fuels. At the federal level, residential and commercial SHW installations are eligible for the federal investment tax credit (ITC), worth 30% of the installed cost. Systems installed at commercial sites may

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[z] The total Massachusetts solar heating market (including pool heating, domestic hot water, and space heating) experienced a compound annual growth rate of approximately 7.3% - which mirrors national growth rate.

[aa] Data collected by the Massachusetts Clean Energy Center (MassCEC) validates these EIA-based estimates. In February 2011, MassCEC implemented a rebate program for residential solar hot water and space heating systems. Between February and August 2011, the state received 118 residential SHW applications, totaling 730 kW of solar heating capacity.[aa] Assuming this growth continues for the second half of the year, and adding capacity for the state's commercial SHW market, the state is on track to continue the growth pattern estimated from EIA data.

[bb] For a complete list of solar hot water installers, see: Solar Energy Business Association of New England (SEBANE). (n.d.). Solar Yellow Pages: Solar Hot Water. Retrieved from http://sebane.com/sebane_info/members_list.asp?id=13.

[cc] Paybacks include current incentives.

additionally benefit from five-year Modified Accelerated Cost Recovery System (MACRS) depreciation, which typically provides tax benefits worth 20% (or more) of the system's installed cost.[dd]

Similarly, at the state level, residential customers currently benefit from a rebate based on the collector energy production rating worth up to 25% of the system cost or $3,500. Residential customers are also eligible for a tax credit worth 15% of the system cost up to $1,000. Commercial customers are eligible for a grant up to $10,000 to assess the feasibility of installing SHW for their building and a construction rebate worth up to $30, 000 per installation. In total, current incentives can cut the cost of a SHW system in half, significantly improving project economics.

Finally, under MassSAVE, the Massachusetts energy efficiency program, customers can finance SHW through the HEAT loan program. The HEAT loan provides residential and commercial customers with financing up to $25,000 at a 0% interest rate. Terms last up to seven years.[63] Nonetheless, the SHW market continues to face a number of barriers to development, which are explored below.

4.3.2 Market Barriers

Major market barriers to the SHW market include: (i) high first costs, (ii) need for low-temperature (radiant) heat distribution systems, (iii) poor consumer awareness of benefits, and (iv) workforce training, inspection, and permitting challenges. Each barrier is discussed in detail below.

4.3.2.1 High First Costs

SHW stakeholders indicate that high capital costs of SHW remain a barrier to market development. For example, a typical residential solar combi-system costs approximately $11,500 in Massachusetts (after incentives). This is comparable to the cost of a fossil fuel boiler and hot water heater; however, as noted in Section 4.2.1, a solar combi-system cannot replace a fossil fuel system. Instead, a combi-system must be installed *in addition to* the existing fossil fuel heating system.

With this in mind, when evaluating the installed cost of a SHW system, customers should assess the upfront cost of SHW relative to the potential for fossil fuel costs savings over time. In spite of the potential for significant cost-savings, SHW systems represent a large capital outlay, which does not offset the need for a back-up heating system, thus inhibiting many customers from installing systems. Nonetheless, it is expected that the recently implemented residential and commercial solar hot water rebate programs, in addition to the Massachusetts HEAT loan, will mitigate the impact of high first costs on the solar market.

4.3.2.2 Poor Consumer Awareness of Benefits

Installers indicate that consumers are commonly unaware of the benefits of solar hot water. DHW is not metered by most businesses and residents, and as a result, potential customers do not see the cost of energy associated with DHW use (typically 20% of the total heating bill). With regard to solar combi-systems, many customers are simply unaware that they can serve their space heating load with solar. The application has not gained widespread acceptance in the US, as it has in parts of Europe.

SHW is also commonly confused with its more popular renewables like solar PV. Moreover, because SHW cannot be net metered back to the utility (like PV) – and is commonly not metered at all – some customers believe it lacks the certainty of solar PV. These challenges are compounded by the high incentives, and profit margins, that drive growth of the solar PV market.

[dd] Based on simple NPV cash flows analysis, assuming a 12% depreciation rate and 35% tax rate.

4.3.2.3 Workforce Training, Inspections, and Permitting Challenges

SHW systems are complex, requiring expertise in plumbing, structural loading, as well as solar design. For these reasons, installers report that it takes six to 18 months to train an employee as a fully qualified installer. This requires a significant investment in training for companies.

Moreover, the complexity of solar hot water installations adds to permitting and inspection requirements, making the permitting process time-consuming and expensive. Within Massachusetts, SHW installations generally require building and plumbing permits, and many inspectors are unfamiliar with appropriate design and safety requirements for solar hot water. Stakeholders indicate that building, plumbing, and electrical inspectors generally require better training to assess solar hot water systems.

4.3.2.4 Need for Low-temperature (radiant) heat distribution

As discussed in Section 4.2.1.4, for solar combi-systems to operate effectively in Massachusetts, they must be integrated into a low-temperature heat distribution system. However, many buildings in Massachusetts, commercial buildings in particular, use high-temperature heating systems (i.e. forced air or a traditional radiator distribution system). In such cases, solar combi-systems would be inappropriate unless customers retrofitted their heat distribution system, which would significantly increase the cost of installation. Of course, customers with high-temperature heating systems could install SHW to serve only their domestic hot water load.

4.4 Lifecycle Cost Assessment

The following section assesses lifecycle costs and payback for solar combi-systems in residential and multi-family/commercial buildings. As illustrated in Table 8 below, this scenario assumes that solar combi-systems are used to provide DHW and space heating for residential and commercial/multi-family facilities.

Table 8: Solar Hot Water Scenario

	SHW	GSHP	Biomass - pellets	Biodiesel
Residential	**DHW** **Space Heat** **--**	DHW Space Heat --	DHW Space Heat --	-- Space Heat --
Commercial	**DHW** **Space Heat** **--**	DHW Space Heat Cooling - elec	DHW Space Heat --	-- Space Heat --

System sizing requirements for residential and commercial/multi-family buildings as well as solar hot water systems are detailed in Appendix A. Using these assumptions, solar combi-systems have been modeled to provide a solar fraction of 40%.

4.4.1 Installed Costs

Installed costs for solar combi-systems were arrived at using data provide by the MassCEC Commonwealth SHW residential rebate program and the Low-income SHW program for multi-family facilities. Fossil fuel heating system assumptions and fuel costs are detailed in Appendix A.

Since February 2011, MassCEC has collected data on installed costs for residential SHW systems (DHW and combi-systems) that apply for the Commonwealth Solar Hot Water rebate. As illustrated in Figure 20 below, installed costs reported by installers for solar combi and DHW systems vary widely within

Massachusetts, ranging from $1,700 and $2,800 per kWth (or between approximately $114 and $180 per ft^2). The average system costs $2,250 per kWth ($148 per ft^2).

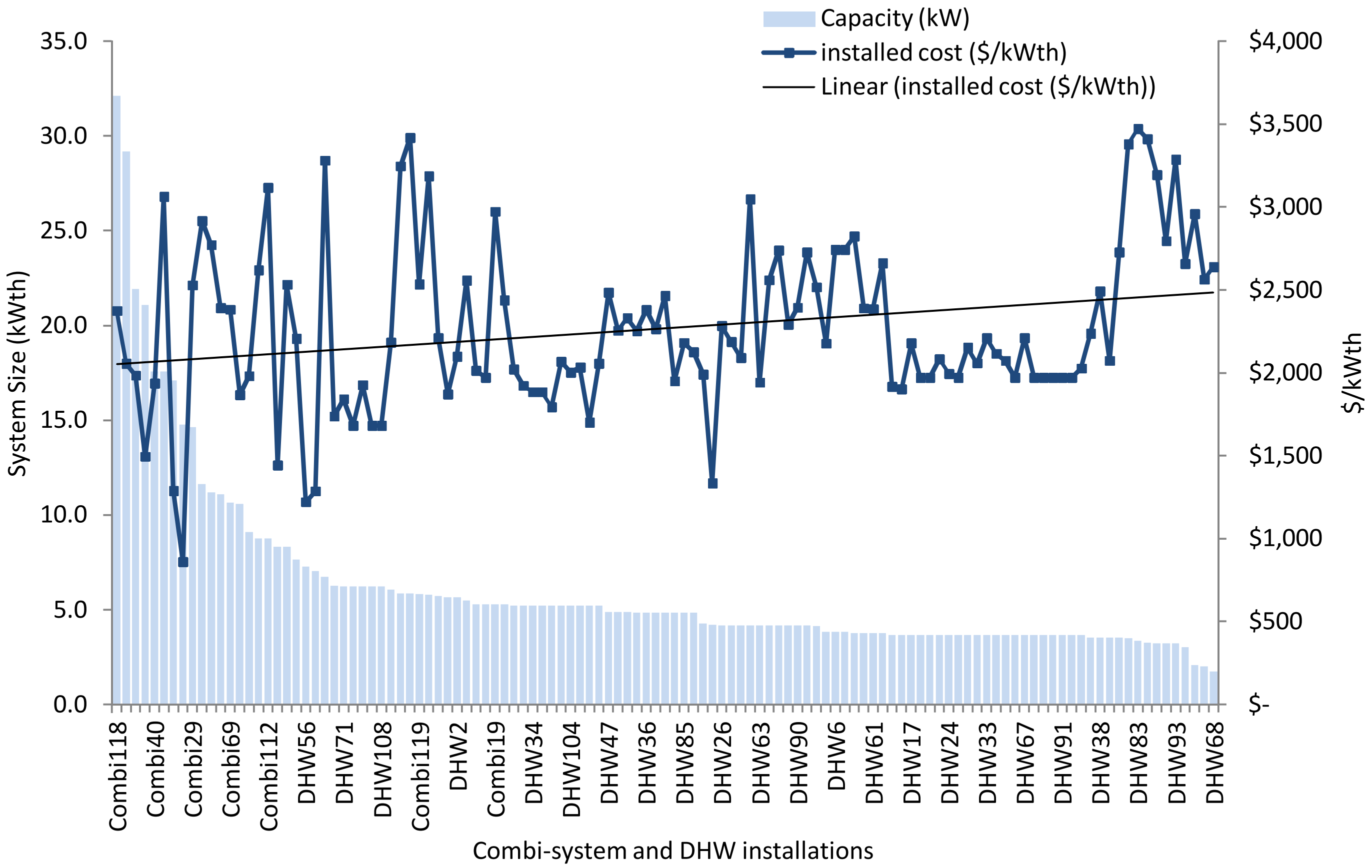


Figure 20: Installed Costs of Solar Combi and DHW Systems in Massachusetts (Source: MassCEC, 2011)

Similarly, MassCEC has installed cost data for SHW systems at 11 multi-family/commercial facilities across the state. Installed costs for commercial facilities tend to be lower than residential systems. Of eleven multi-family/commercial facilities analyzed, costs ranged from $1,412 to $2,763 per kWth (or $92 to $180 per ft^2) – with a weighted average of $1,750 per kWth ($113 per ft^2).

4.4.2 Life-cycle Cost of Energy: Residential Scenario

The residential SHW scenario assumes that solar hot water provides approximately 40% of annual space heating and domestic hot water load. It additionally assumes that the existing fossil fuel heating system provides back-up heating. By producing energy from the sun, SHW reduces fossil fuel use (and costs) of the existing heating system. However, the upfront costs to install a residential solar hot water system are not insignificant for a typical household. By this analysis, assuming a resident can monetize all available incentives, a household will spend approximately $7,800 to install a solar hot water system.[ee] Nonetheless, the economics for solar hot water are still reasonably compelling. The charts below

[ee] We estimate a solar hot water system, which offsets 40% of space and DHW load, will cost consumers approximately $16,650 for a 7.4 kWth system. This cost is reduced by incentives valued at approximately $8,840. It is important to note that solar hot water receives more incentives in Massachusetts than any other renewable heating technology.

illustrate the typical lifecycle costs and simple payback of solar hot water relative to fossil fuel alternatives.

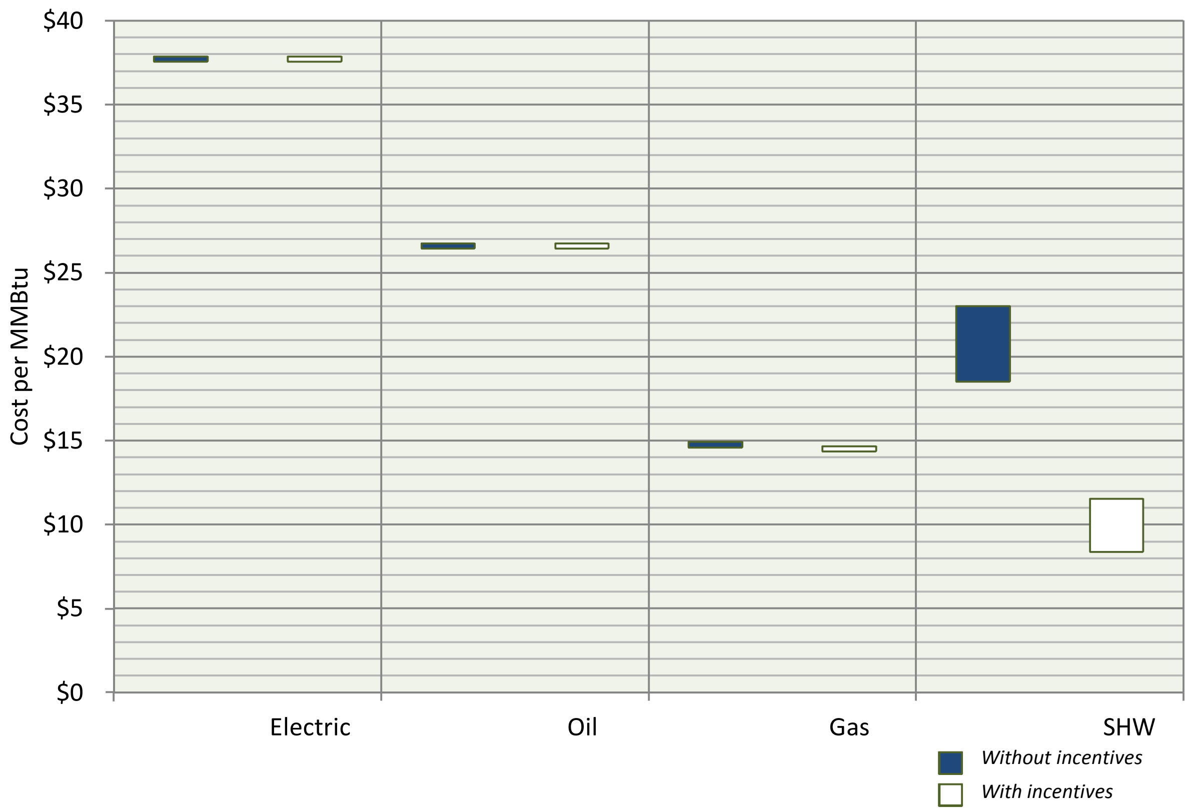


Figure 21: LCOE of Typical Residential Solar Combi-System in Massachusetts Compared to Fossil Fuel Alternatives

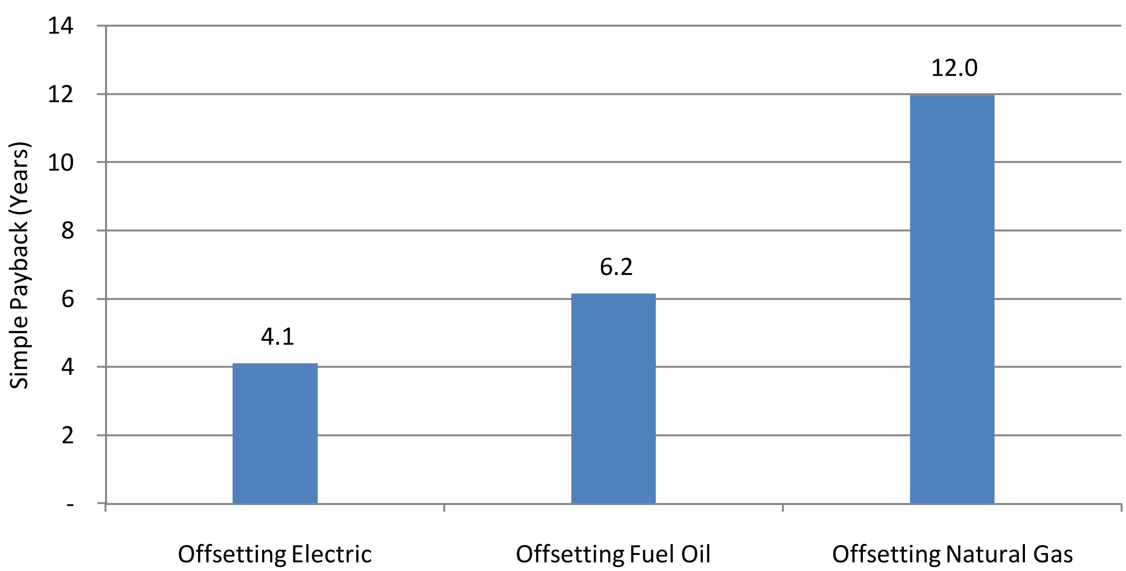


Figure 22: Payback of Typical Residential Solar Combi-System in Massachusetts

Relative to electric hot water and space heating, solar hot water is a very attractive option for residential customers. Customers can achieve a payback within 4.1 years. Moreover, over the lifetime of the system, residents will pay nearly $28 less for every MMBTU of heat produced by a solar hot water system than by an electric heating system.

Relative to fuel oil hot water and space heating, solar hot water additionally provides a good alternative for customers seeking to minimize fuel oil consumption and costs. Over the lifetime of the system, customers would pay nearly $17 less per MMBTU of heat produced from solar hot water. Additionally, it will take customers using fuel oil only about 6.2 years to recoup the initial upfront investment for a solar hot water system.

Relative to natural gas hot water and space heating, the economics for SHW systems are less attractive, achieving a payback of 12.0 years; however, the LCOE of solar hot water is still considerably lower – about $4.5 less per MMBTU than natural gas.

In summary, at $10/MMBTU of heat, solar hot water has the lowest levelized cost of energy of all residential technologies explored for heating. SHW is the most competitive renewable thermal technology when compared to natural gas, though this is due, in part, to the strong incentive support that SHW already receives, benefiting from the 30% ITC, state tax deductions, as well as state rebates.

4.4.3 Life-cycle Cost of Energy: Commercial Scenario

This commercial scenario assumes that solar hot water provides approximately 40% of annual space heating and domestic hot water load. It additionally assumes that the existing fossil fuel heating system will provide back-up heating. Like the residential scenario, the upfront costs to install a solar hot water system are high. Assuming a commercial facility can monetize all available incentives, system owners will still spend approximately $43,317 in the first year to install a solar hot water system.[ff] Nonetheless, the economics for commercial solar hot water are compelling. The charts below illustrate the typical lifecycle costs and simple payback of solar hot water relative to fossil fuel alternatives.

[ff]We estimate a 71 kWth solar hot water system, which offsets 40% of space and hot water load in a multifamily building, will cost approximately $125,000. This cost is reduced by state and federal incentives valued at approximately $53,000 (30% ITC and state commercial rebate of $25,000 or 25%). In addition, commercial facilities will receive tax benefit from the 5-year MACRS schedule. It is important to note that solar hot water receives more incentives in Massachusetts than any other renewable heating technology.

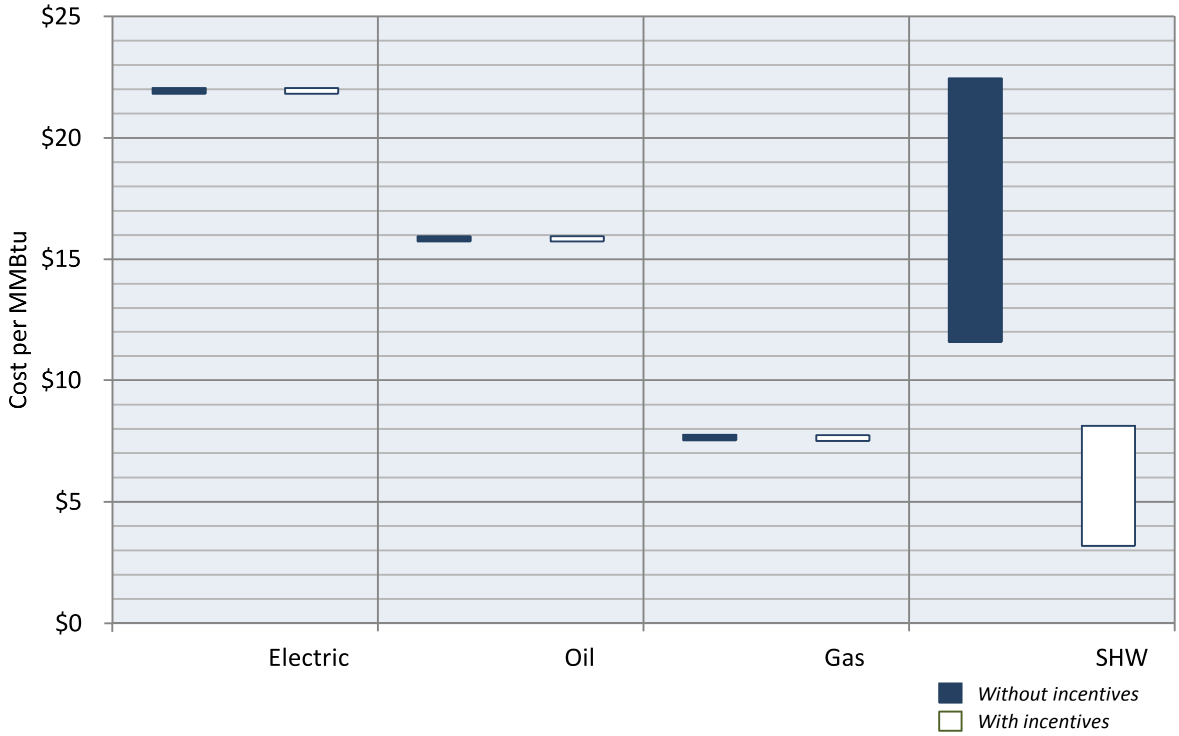


Figure 23: LCOE of Typical Commercial Solar Combi-System in Massachusetts Compared to Fossil Fuel Alternatives

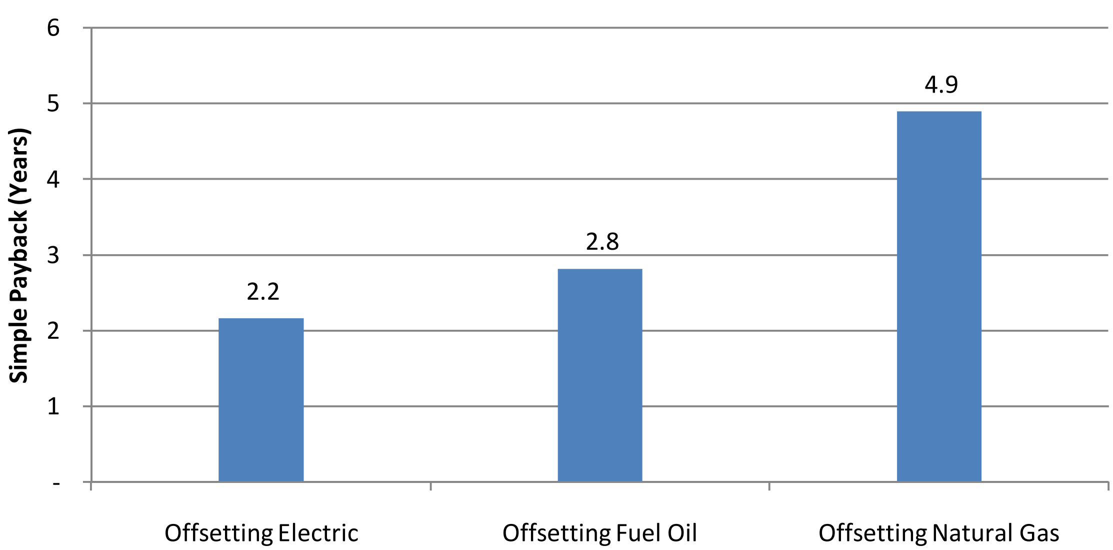


Figure 24: Payback of Typical Commercial Solar Combi-System in Massachusetts

Relative to electric hot water and space heating, solar hot water is a very attractive option for customers replacing electric resistance heating. Customers can achieve a payback within 2.2 years. Moreover, over the lifetime of the system, commercial facilities will pay nearly $18 less for every MMBTU of heat produced by a solar hot water system than by an electric system.

Relative to fuel oil hot water and space heating, solar hot water additionally provides a good alternative for customers seeking to minimize fuel oil consumption and costs. Over the lifetime of the system, customers would pay nearly $12 less per MMBTU of heat produced from solar hot water. Additionally, it takes customers using fuel oil only about 3.8 years to recoup the initial upfront investment for a solar hot water system.

Relative to natural gas hot water and space heating, the economics for systems replacing natural gas are also good, with a payback of 4.9 years. Additionally, the LCOE of solar hot water is considerably lower than natural gas.

In summary, with current incentive support, commercial solar hot water presents an excellent option to offset fuel consumption from fuel oil, electric resistance heating, and natural gas – assuming customers can monetize all available federal and state incentives. Finally, at $3.9/MMBTU of heat, solar hot water has the lowest levelized cost of energy of all commercial technologies explored here (fossil fuel and renewable thermal).

4.5 Greenhouse Gas Assessment

GHG reductions from SHW combi-systems are calculated by estimating GHG emissions avoided from fossil fuel systems.[gg] In Figure 25 and Figure 26 below, the red bars illustrate the GHG emissions resulting from a typical solar hot water combi-system (e.g. from electric pumps, etc.). The green bars represent the GHG emissions avoided by replacing fossil fuel heating systems with a solar combi-system. For example, a typical residential solar-combi-system replacing electric heating reduces GHG emissions by 12 tons annually. Emission reductions are greatest for systems offsetting electricity, followed by oil, and then natural gas.

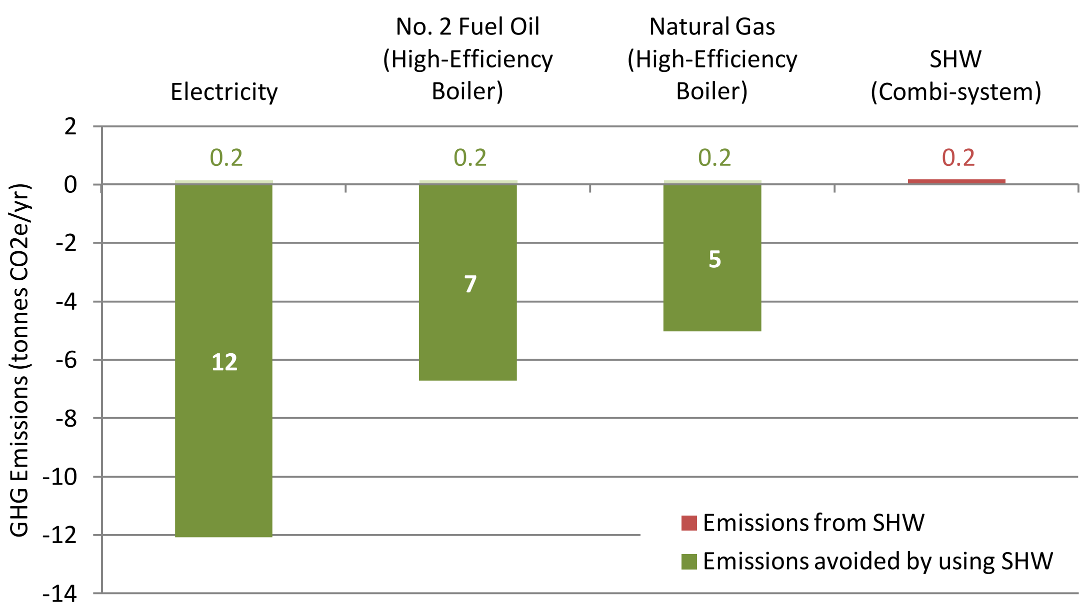


Figure 25: Annual GHG Emissions Avoided by Residential Solar Combi-Systems

[gggg] Emissions for SHW are negligible, associated with the electricity required to run pumps.

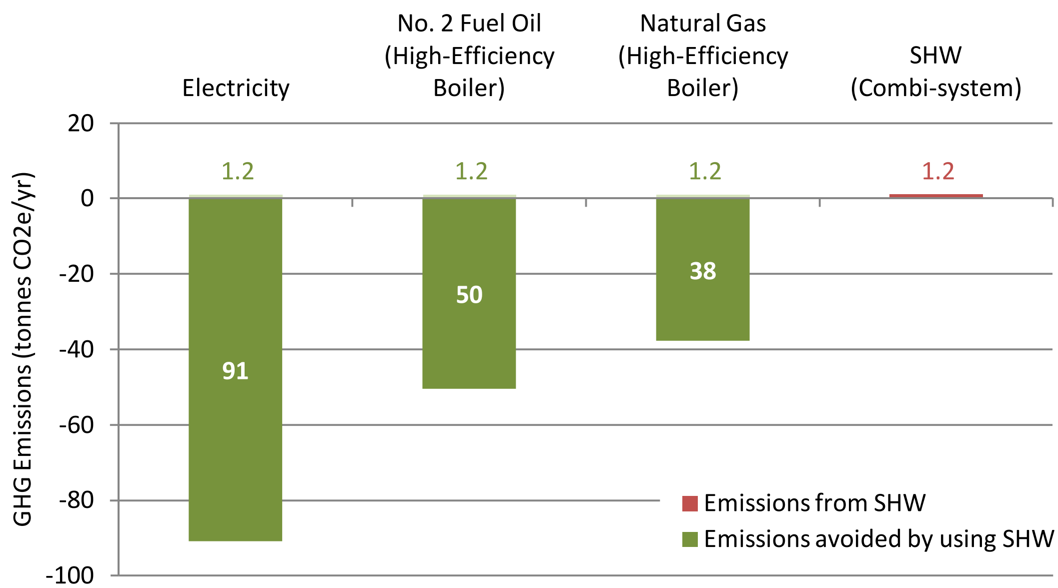


Figure 26: Annual GHG Emissions Avoided by Commercial Solar Combi-Systems

4.6 Job Creation, Economic Development, and GHG Emission Reduction Scenarios

The *Massachusetts Clean Energy and Climate Plan for 2020* established a modest target to achieve 100,000 tons of GHG reductions by 2020. However, for purposes of this analysis, MassCEC and Mass DOER estimate that solar hot water has the potential to achieve significantly greater GHG reductions – approximately 25% of the two million renewable thermal GHG reduction target or about 500,000 tons.[hh] As illustrated in Table 9 below, it is estimated that this would also create thousands of manufacturing, installation, and servicing jobs in Massachusetts.

Table 9: Solar Hot Water and Space Heating GHG Emission Reduction and Job Creation Scenarios

Solar Hot Water and Space Heating Scenario	Annual Market Growth Rate	Annual GHG Emission Reductions	Jobs Created
BAU by 2020	34%	267,637	1,494
Accelerated Growth by 2020	44%	500,000	3,316
Accelerated Growth by 2050	n/a	1,407,207	n/a

The Building as Usual (BAU) scenario uses the historic growth rate of solar hot water in Massachusetts to estimate emissions, jobs, and economic benefits by 2020. Historically, the solar hot water market in Massachusetts has grown at an average rate of 34% annually.[ii] At this growth rate, it is expected that the solar thermal market will achieve approximately 268,000 tons of GHG emission reductions in 2020.[jj] It is also estimated that the industry could create nearly 1,500 jobs within 10 years if such growth is sustained.

[hh] The GHG reduction target of 25% is for illustrative purposes only. It does not constitute a formal target for the Commonwealth of Massachusetts.

[ii] This is broken down into two key sectors: (i) the DHW and space heating sector, which has grown at a rate of 47% annually (from 2006 to 2009), and (ii) the pool heating sector, which has grown at a more modest rate of approximately 8% over this same period. A weighted average of 34% was used to reflect the combined growth of these sectors.

[jj] This assumes that 27% of SHW installations replace electric heating and 73% replaces fuel oil heating.

The Accelerated Growth by 2020 scenario projects the average annual market growth rate required to meet the accelerated solar hot water GHG reduction target of 500,000 tons. In order to achieve this goal, the solar hot water market would need to see its average annual growth rate increase to 44%.[kk] If this goal is achieved, an estimated 3,300 new jobs could be created by 2020 and over $220 million could be retained in the region through avoided expenditures on out-of-state fossil fuels.

The Accelerated Growth by 2050 scenario assumes that a certain percentage of the state's fossil fuel systems are replaced with a mix of renewable thermal technologies by 2050 (based on assumptions laid out in the Massachusetts Clean Energy and Climate Plan for 2020) and projects the associated GHG emissions reduction benefits. This analysis shows that replacing 5% of existing natural gas, 25% of existing electric,[ll] and 20% of existing fuel oil heating systems would yield GHG emissions reductions of over 1.4 million tons.

[kk] This would be a growth rate of 59% for the DHW and space heating sector and 10% for the pool heating sector.
[ll] For residential buildings only. It is assumed that no commercial/multi-family facilities use electric heating.

CHAPTER 5: BIOMASS THERMAL

5.1 Introduction

The biomass central heating market in Massachusetts consists of the installers and distributors that service biomass central heating systems and the wood fuel producers (pellet, chip, and cordwood) that process or manufacture fuel for biomass heating systems. The following section provides a brief overview of the technology and then describes the current market status, supply chain, and market barriers and drivers for these sectors. It also assesses typical project economics for residential and commercial project scenarios. Finally, it assesses the GHG emission reductions and job creation potential for the Massachusetts biomass heating market.

5.1.1 Key Findings and Conclusions

Compared with other renewable thermal technologies like solar hot water or ground-source heat pumps, the Massachusetts biomass *central* heating market is small. Stakeholders estimate that fewer than 30 systems are currently installed in the Commonwealth. Accordingly, under the business-as-usual scenario, the Massachusetts biomass heating market is projected to reduce GHG emissions by fewer than 45,000 tons and create only 177 jobs by 2020.

The small size and slow development of the biomass thermal market is due, in part, to the absence of federal or state biomass heating policies. However, stakeholders indicate that with the right market development mechanisms, the biomass heating market could expand significantly, achieving an annual growth rate of 97% or greater. Under such an accelerated growth scenario, biomass heating could provide significant GHG and job creation benefits – estimated at 500,000 tons of GHG reductions and creation of over 2,000 jobs by 2020.

Stakeholders identified several barriers slowing development of the Massachusetts biomass heating market. For example, biomass heating is subject to high first costs, especially at the residential level. As a result, in spite of the fact that biomass pellet heating systems have a lower LCOE than electric and fuel oil systems (without incentives), a typical residential system is subject to a long payback – estimated between seven and 15 years. Commercial systems, on the other hand, are more competitive, due in part to improved economies of scale, and can achieve payback within two and five years if replacing fuel oil or electric heating. Finally, though not fully assessed in this report, it is estimated that biomass chip heating systems are even more competitive, providing an aggressive payback even when compared with natural gas.[mm]

Stakeholders also indicate that the Massachusetts biomass heating market lacks the basic infrastructure needed for growth. For example, most biomass fuel distributors do not have trucks or equipment necessary to make *bulk* deliveries of wood chips or pellets to customers. As a result, convenience of biomass heating to customers is significantly reduced. Biomass stakeholders suggest that integrating existing fossil fuel distributors (i.e. fuel oil and propane) into the biomass heating market will be essential to drive vibrant market growth, enabling the industry to leverage existing distribution networks to sell biomass (as a new commodity) and diversify heating fuel offerings.

Finally, the biomass heating market is subject to considerable regulatory uncertainty, especially with regard to air emissions. For example, the US Environmental Protection Agency reports that emissions

[mm] Similarly, GHG emission reductions from biomass chips were similar to biomass pellets. Only slight differences were noted on an annual installation basis.

from residential wood combustion represent “one of the largest source categories” of direct particulate matter emissions;[64] however, biomass heating air emission regulations are inconsistent (or non-existent for small-scale systems) across the New England region. This creates regulatory risk for the industry, especially as policy-makers consider the impacts of an expanded biomass heating market on public health. It is likely that greater regulatory certainty regarding air emission standards for biomass heating will be essential to the development of a vibrant market in Massachusetts and New England. To this end, European countries like Austria and Germany provide good examples of how incentives and regulations can drive development of a clean, low-emission biomass heating industry.

5.2 Biomass Heating Technology, Market Status and Value Chain

5.2.1 Technology Overview

Figures Figure 27 below illustrates typical biomass wood pellet boiler and a commercial biomass chip combustion systems. Biomass central heating systems consist of wood pellet, wood chip, and split-wood furnaces and boilers as well as the accompanying fuel storage and feeding, emission control, and HVAC infrastructure. The cost and efficiency of biomass heating systems can vary significantly, depending on the level of automation and the design of the combustion process. System efficiencies can range from 60% to 90% (or higher). According to the US Department of Energy, modern centralized wood heating systems typically achieve efficiencies around 80%,[65] though many high-efficiency European systems can achieve efficiencies in excess of 90%.[66]

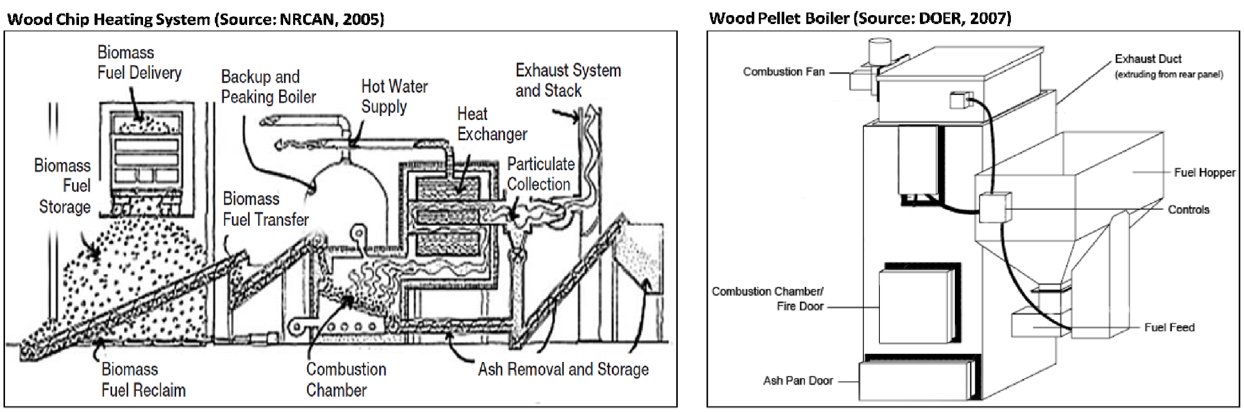


Figure 27: Typical Wood Heating Systems in Massachusetts (NRCAN, 2005 and DOER, 2007)

It is worth noting that biomass heating units may be deployed as a building’s stand-alone heating system or in tandem with existing fossil fuel heating systems. In the latter case, the biomass heating unit generally serves baseload heating requirements – about 70% to 80% of a building’s heat load – with the existing fossil fuel system deployed to serve peak heating requirements. This approach can enable facility owners to lower fossil fuel use (and lifecycle energy costs), while minimizing upfront installation costs of biomass heating systems (by purchasing a smaller system). According to regional stakeholders, this is the most common approach for biomass heating installations today, especially within the residential market.

With this in mind, the following briefly discusses the basic infrastructure and design of biomass thermal systems. In particular, it provides an overview of the wood chip and pellet production process, biomass heating fuel delivery mechanisms, as well as biomass boiler/furnace combustion and integration into the heat distribution system.

5.2.1.1 Wood Chip and Pellet Production

Wood chips and pellets are typically sourced from lumber mills or other forest product processing facilities. Wood chips are most commonly used at institutional, large commercial, or industrial facilities as well as at medium to large-scale combined heat and power facilities. Wood pellets, on the other hand, are typically used at small commercial facilities or for residential boilers and stoves. The following briefly describes the production of wood chips and pellets.

Wood chips can be manufactured from a wide variety of waste wood or roundwood. Within Massachusetts, they are commonly sourced from clean waste sources such as from log-to-lumber manufacturing at local sawmills. Chip texture is the chief quality control issue for sawmills or chipping plants as is maintaining a uniform chip size.[67] Additionally, chip users must consider the moisture content of wood chips, as moisture content affects the heating value of the wood. At harvest, wood chips typically have a moisture content of 35% to 50%.

Wood pellets may be manufactured from roundwood though, like chips, are more often sourced from cheaper waste residues such as sawdust and shavings from sawmills and secondary wood product manufacturing such as furniture, flooring, cabinetry or millwork factories. If made from roundwood, a number of steps, including debarking, chipping, mechanical grinding, and drying, must be completed. Clean wood residues, on the other hand, require somewhat less preparation because they are much smaller, drier, and mostly bark free. Like chips, managing the moisture content of the wood is a critical element of the pelletization process. For pellets, moisture content must be kept within a range of about 9 to 12% (wet basis) just prior to pelletizing. If the wood is too dry, the heat build-up induced by friction in the pelletizer will burn the surface. If too wet, the trapped steam pressure will weaken internal bonds and increase likelihood of breakage and dust during handling.

Once properly dried, wood pellet particles are sorted by size and large pieces are mechanically refined. Steam conditioning is sometimes used to soften the lignin binding in order to facilitate pellet formation during extrusion and shape consolidation later in the process.[68] Following these preparations, particles are extruded through dies and the emerging cylinders are cut to appropriate lengths. The hot pellets are then cooled to allow the lignin to reset and form a hardened, compact unit. Finally, the finished product is bagged or shipped in bulk to market.[69]

5.2.1.2 Fuel Delivery Mechanisms for Central Biomass Heating Units

In commercial facilities, pellet fuel delivery is accomplished either by trucks that auger the fuel into a storage bin or through pneumatically operated trucks that use air to blow pellets into storage. Modern pellet delivery trucks are able to precisely meter pellet delivery by the ton to each customer, thus insuring accuracy in billing. This convenience is recognized by industry as an important tool to increase distribution and market penetration.

Within residential areas, pellets are currently purchased and transported by the customer in 40 pound bags. Bulk delivery for residential units is not common in the Northeast as it is, for example, in more mature markets in Europe. At commercial facilities, where bulk delivery is required, fuel can be stored in a variety of structures, though it is ideally contained in a large bin or silo to protect it from contaminants and precipitation.[70] Fuel is delivered into the heating system via the biomass fuel reclaim and transfer systems, which, depending upon system design, can be automated. Fully automated systems, while more expensive, decrease the need for human intervention to operate them.[71] Regional installers and policy-makers generally report that the convenience afforded by automated, bulk-fed systems is necessary to drive widespread market growth in the Northeast.[72]

In automated systems, fuel is usually delivered into the combustion chamber by a screw auger. A metering bin measures the flow of fuel into the combustion chamber. Within the combustion chamber, the fuel is burned under controlled conditions by a system regulating air inflow in response to heat demand.[73]

5.2.1.3 Combustion and Heat Distribution

Combustion process sophistication varies significantly depending on system design and initial capital investment. To this end, a control system regulates the inflow of air in response to heat demand. In automated biomass combustion systems, fuel flow is also regulated. Additionally, many combustion chambers support the burning feedstock on a grate, enabling airflow up through and over the burning biomass fuel, which helps facilitate complete combustion. In more sophisticated larger industrial systems, the grate moves in order to evenly distribute the fire bed, conveying the biomass fuel through zones of different under-fire airflow, and pushing the ash to the end of the combustion chamber. Hot exhaust gases exit the combustion chamber and pass through a heat exchanger, into a secondary combustion chamber containing a heat exchanger, or, if the heat exchanger is in or around the combustion chamber, directly into an exhaust system.[74]

It is important to note that the efficiency and air emissions resulting from biomass heating system depends in large part upon the type of combustion process employed. Two-stage combustion, as is commonly deployed in European countries like Germany or Austria, is essential to reducing emissions and increasing efficiency. As illustrated in Figure 28 below, in the primary combustion zone of a two-stage boiler, biomass is dried by the heat within the combustion chamber and then devolatilized, whereby volatile gases (i.e. the fraction of biomass that is turned into gas when heated) ascend to the secondary combustion zone. In the secondary combustion zone, volatile gases from solid combustion are further burned. The reaction in the secondary combustion zone must be as complete as possible to achieve low emission heating from biomass.[75]

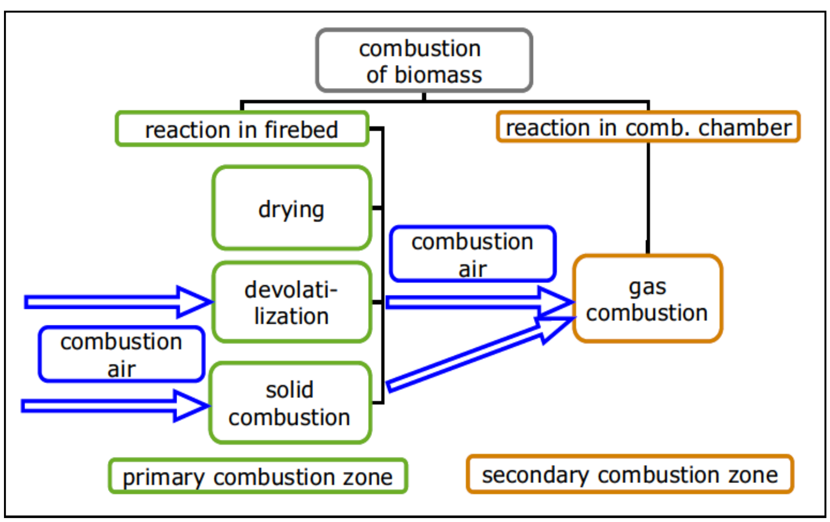


Figure 28: Primary and Secondary combustion zone in biomass combustion (Source: NYSERDA, 2010)

Heat is then transferred to the building distribution system via the heat exchanger. Large biomass combustion systems may use boilers, with thermal steam, or propylene glycol as the heat transfer medium. Alternately, within the Northeast, hot water distribution through super-insulated pipe is becoming the most common means of distributing heat, even in large commercial or district heating scenarios.[76] Ash must be removed from the system either manually or automatically. Fly ash may deposit in the secondary combustion chamber or the heat exchanger (necessitating cleaning), escape out the flue, or be taken out of suspension by a particulate collection device (exhaust scrubber). MassDEP regulates particulate emissions from combustion systems.

The exhaust system and stack vent combustion gases to the atmosphere. Small systems use the natural draft resulting from the buoyancy of the warm exhaust; larger systems rely on the fans feeding air into the combustion chamber to push out the exhaust gases, or draw the exhaust gases out with a fan at the base of the chimney. In addition to the equipment described above, instrumentation and control systems of varying sophistication oversee the operation of a biomass combustion system, modulate the feed of air and, in automated systems, fuel, in response to demand, and maintain safe operating conditions.[77] In very high efficiency systems, moisture is removed from flue gas to further reduce the exhaust gas temperature, thus achieving higher efficiencies.[78]

5.2.1.4 Market Status and Value Chain: Central Heating Systems

Official estimates of the market size and growth rate for biomass central heating systems are not currently collected by industry or public agencies. As a result, the exact size and status of the biomass heating market is difficult to estimate. However, stakeholders in Massachusetts indicate that biomass heating is an emerging market, estimating that fewer than 100 pellet or chip central heating systems are installed across the state.[nn] Some experts estimate that the actual number of installed systems is likely far fewer. Stakeholders additionally report that the market is poised for growth and that a 30% annual growth rate in Massachusetts is a reasonable assumption in the near-term. With the right market development conditions, some stakeholders report that market growth rates of 100% or greater are feasible.79

The regional market for biomass central heating systems is currently served by a few specialty manufacturers, installers, and distributors. Within New Hampshire, for example, about eight installers serve the entire state. According to program managers at the New Hampshire Public Utilities Commission, this is twice the number that served the state over a year ago. Similarly, the Massachusetts Department of Energy Resources estimates that approximately 10 manufacturers of biomass heating systems are active in the state.[80]

Installation of central heating systems – biomass or fossil fuel – are typically tied to the fuel distribution sector. For example, most distributors of heating oil also sell, install and service heating systems. Biomass heating stakeholders suggest that the market is currently limited by a lack of fuel distributors who sell biomass fueled heating systems. In order to build a more robust boiler distribution network, stakeholders suggest that fuel delivery companies will likely need to have significant participation in the biomass market.

5.2.1.5 Market Status and Value Chain: Wood Chip and Pellet Production

If sourced close to their final use destination, wood chips can be of the lowest-cost biomass feedstock available. However, wood chips contain almost half their weight in water, and, as a result, have high transportation and handling costs due to their low bulk density.[81] Transportation represents the highest variable affecting costs in the wood chip value chain.[82] Moreover, the supply of biomass chips are

[nn] This is in stark contrast to the residential wood pellet stove market, which is tracked by the Barbeque, Patio and Hearth Association and has enjoyed strong growth across the New England region. The US wood pellet stove market has expanded at a compound annual growth rate of 18.7% over the past decade and has enjoyed fluctuating support from federal tax incentives.

subject to other historical seasonal markets, which fluctuate based upon demand, for example, of chips for paper manufacturing in Maine or New York or utility-scale biomass electric power generation in other northeastern states.

The wood pellet market has experienced significant growth over the past decade. Pelletization densifies wood, increasing the energy content per unit volume to nearly that of coal. It additionally reduces the water content from approximately 50% to about 3-6%, thus enhancing its heating value by reducing the heat of vaporization and stack-gas losses. Moreover, with less water content than chips or raw wood, wood pellets burn more completely, reducing harmful particulate emissions. Finally, the pelletization process reduces transportation and handling costs by increasing energy density and reducing size;[83] nonetheless, like chips, transportation remains a significant cost driver of wood pellets.

Historically, US wood pellet mills have served the residential pellet stove market. More recently, however, wood pellet manufacturers have expanded operations to serve bulk European wood pellet needs for heating and co-firing. As a result, US wood pellet production is expected to become an important renewable energy export market for some US companies, particularly in the southeast U.S.[84]

Table 10: Wood Pellet Mill Capacity in the Northeast (Source: C. Niebling, 2011)

State	Location	Manufacturer	Estimated Production Capacity (Thousand Tons Per Year)
ME	Ashland	Northeast Pellet	20-30
ME	Corinth	Corinth Wood Pellet	60-75
ME	Athens	Maine Wood Pellet	60-80
ME	Strong	Geneva Wood Pellet	60-80
NH	Jaffrey	New England Wood Pellet	85
New Hampshire Total Capacity			**285-350**
VT	N. Clarendon	Vermont Wood Pellet	15-25
Vermont Total Capacity			**15-25**
NY	Massena	Curran Renewable Energy	50-60
NY	LaFargeville	Associated Harvest	5-10
NY	Schuyler	New England Wood Pellet	85
NY	Deposit	New England Wood Pellet	85
NY	Arcade	Dry Creek (BioMaxx)	40-50
NY	Addison	InstantHeat	20-30
New York Total			**285-320**
PA	Youngsville	Allegheny Wood Pellet	40-50
PA	Ulysses	PA Pellet (BioMaxx)	30-40
PA	Troy	Barefoot	30-40
PA	Mifflintown	Energex	60-80
PA	Palmerton	Great American	20-30
PA	Garards Fort	Greene Team Pellet Co.	30-40
PA	Summerhill	Wood Pellets Co.	10-20
PA	E. Berlin	Penn Woods Products	10-20
Pennsylvania Total			**230-320**
RI	Rumford	Inferno	30-40
Rhode Island Total			**30-40**

Finally, in contrast to wood chips, wood pellet production has been robust – with about 26 wood pellet mills operating in the Northeast, though none currently operate in Massachusetts. As illustrated in the Table 10 below, New Hampshire, Vermont, Pennsylvania, and New York dominate the wood pellet manufacturing market in the region.

5.3 Drivers and Barriers

5.3.1 Market Drivers

Lifecycle cost savings, relative to fossil fuels, represent the primary driver for the biomass heating market in Massachusetts. Despite high upfront installed costs, biomass heating systems have a history of relatively stable and low fuel costs compared to other delivered heating fuels. Green chips and pellets have been consistently cheaper, or at least competitive (on a per ton of pellet equivalent basis), with most fossil fuels, enabling customers to achieve aggressive paybacks if replacing fuel oil or electric heating systems. Moreover, green chips and wood pellets are not subject to the high degree of volatility that impact fossil fuels.

Lastly, many customers are attracted to biomass heating because it can represent a cost-effective way to install renewable energy and reduce dependence on foreign fuels. This is especially true for larger commercial or institutional systems replacing fuel oil or propane, which can achieve a relatively short payback and eliminate consumption of foreign petroleum-based fuels, while providing GHG reductions.

5.3.2 Market Barriers

As with other renewable thermal technologies, major market barriers to the biomass heating market include: (i) high first costs and lack of policy support, (ii) lack of readily-available and reliable bulk fuel delivery infrastructure, (iii) poor consumer awareness of benefits, (iv) opaque home finance and insurance requirements, and (v) regulatory challenges. Each barrier is discussed in detail below.

5.3.2.1 High First Costs and Lack of Policy Support

Relative to natural gas, propane or fuel oil heating systems, biomass central heating systems have high capital costs. For example, though installed costs vary widely, a fully-automated, bulk-fed residential system typically costs about $1,615 per kWth, or $21,000 for a 13 kWth system.[oo] By contrast, a high efficiency fuel oil system of comparable size costs approximately $8,775.

Stakeholders indicate that manufacturing costs for biomass heating boilers are high in part because market demand for boilers is low, making the economies of scale in manufacturing unattractive. Additionally, incompatible U.S. and international boiler standards make it challenging to integrate high efficiency European units into the Northeastern market. This compounds the challenge of high first costs, by providing a disincentive for foreign manufacturers to establish facilities in the region, which could drive down material costs.

Finally, biomass central heating systems are not eligible for federal or Massachusetts state incentives. This is in contrast to nearly every other renewable energy technology, which receive a 30% federal tax credit as well as a variety of state or utility incentives. As a result, biomass heating stakeholders indicate

[oo] According to DOER regulators, installed costs of residential biomass pellet systems do not necessarily scale with system size. For example, it is common for a 13 kWth pellet system and a 20 kWth system to both cost around $20,000. On the other hand, commercial systems do typically achieve economies of scale, which is reflected in the cost (per kWth) of the system.

that wood pellet and chip heating systems are disadvantaged when competing with other renewable energy technologies or with the more established fossil fuel heating industry.

5.3.2.2 Lack of Fuel Delivery Infrastructure

As would be expected in an emerging market, Massachusetts lacks infrastructure for biomass central heating systems and fuel delivery. Most fuel distributors do not have trucks or equipment necessary to make bulk deliveries of wood chips or pellets to customers. Biomass stakeholders suggest that integrating existing fossil fuel (i.e. fuel oil and propane) distributors and installers into the biomass heating market will be essential to drive market growth, enabling the industry to leverage existing distribution networks to sell biomass (as a new commodity) and diversify heating fuel offerings. Transitioning the existing fuel supply network from fossil fuels to biomass, however, is challenging due to high investment requirements in new infrastructure to service biomass commodities. For example, a typical wood pellet truck capable of making pneumatic bulk pellet deliveries can cost up to $250,000, which represents a large investment (and significant barrier) for a typical fuel oil distributor, especially if demand is lacking from his customer base.

This results in a chicken-or-egg dilemma: fossil fuel distributors/installers do not sell and install biomass heating systems (or invest in biomass heating infrastructure) because customer demand for biomass fuel is low. At the same time, customers are not demanding the installation of biomass heating systems because distributors lack the infrastructure to reliably supply biomass chips and pellets. To overcome this challenge, stakeholders suggest that the region needs to establish anchor customers, who will drive demand for bulk wood pellet and chip deliveries. Anchor customers could include large institutions – such as schools, municipalities, or private companies – that require 500 to 1500 tons annually of wood pellets or chips. Industrial heat consumers (e.g. food processing or paper mills) utilizing pellets with wood powder suspension burner technology could represent annual demand of up to 10,000 tons.

A similar strategy is cluster development, whereby a community collection of commercial and residential end-users—typically coordinated through a combination of governmental financial and educational support—demonstrate sustained and significant demand for biomass fuels.[pp] By driving demand, anchor customers will enable existing fossil fuel distributors to justify investment costs in biomass infrastructure, help build the market, and ultimately drive down costs.

5.3.2.3 Poor Consumer Awareness of Benefits

A number of stakeholders report that customers often lack awareness or are simply uninformed of the benefits of biomass heating systems. In some cases, customers are unaware of technical advances made over past years in the biomass heating sector, which have made biomass a more efficient and convenient heating option than it has been in the past. In other cases, customers are unaware that biomass heating is a renewable energy source that can provide lifecycle cost savings compared to fossil fuel alternatives. In still other cases, customers express uncertainty regarding the safety, reliability, or environmental impacts of biomass heating systems. Stakeholders indicate that improved and expanded customer education and marketing initiatives are essential to growing the Massachusetts market.

[pp] In Europe, the State of Upper Austria *("*Oberösterreich") has successfully deployed this model to achieve renewable heating exceeding 45% of overall demand. For more information, see: Biomass Thermal Energy Council (BTEC). (June 2011). Brit, Brussels and Biomass: The European Path Toward Renewable Heating. Prepared for the US Forest Service Wood Education Resource Center. Retrieved from http://biomassthermal.org/resource/Webinars/WERC_Webinar_6_final.pdf.

5.3.2.4 Home, Insurance, and Financial Appraisal Barriers

Because modern biomass central heating technology is relatively new to the New England market, a number of appraisers in the financial and real estate communities are unsure how to properly evaluate it. To this end, local lenders have indicated that Fannie Mae and Freddie Mac – the nation's largest mortgage finance lenders – may not purchase mortgages of houses with biomass as the primary heating system. While considerable uncertainty clouds this issue, it could have a chilling effect on the biomass market. Stakeholders indicate that resolving the issue will likely depend upon home inspectors' appraisal of biomass central heating systems. If appraisers determine that the heating system is reliable and "common to the region," then the mortgage buyers like Fannie Mae and Freddie Mac will likely continue to purchase mortgages of homes with biomass as the primary heating system.[85]

Similarly, some insurance companies will not currently insure biomass central heating systems. In such cases, insurance companies have expressed concerns regarding the performance, safety, inspection, and repair of technologies with which they are unfamiliar. In New Hampshire, for example, this has been problematic for vendors seeking to integrate high-efficiency European biomass heating systems into the market. European models have the added challenge of using different (and often unfamiliar) designs and materials relative to standards with which US appraisers and inspectors are accustomed.[86] In Maine, on the other hand, biomass heating companies have overcome similar challenges with insurance companies by educating appraisers about the operation and safety performance of biomass heating technologies.

Ultimately, because modern biomass central heating units do not have a long track record of performance in the Northeast, appraisers in the insurance, financial, and real estate communities are often unsure how to properly evaluate them. Stakeholders indicate that the central challenge revolves around educating appraisers in the financial and insurance sectors.

5.3.2.5 Uncertainty of Emission Regulations and International Safety Standards

According to a recent report by the US Environmental Protection Agency (EPA), emissions from residential wood combustion represent "one of the largest source categories" for direct particulate matter.[87] While this is due in large part to the notoriously poor emission profiles of older wood burning devices, even newer high efficiency biomass units have high emissions (for CO, NO_x, So_2) relative to traditional fossil fuel heating systems, if installed without back-end emission control technology (see Figure X below).[qq] In some cases, such as particulate matter emissions of wood pellet units, typical emission rates are not well known.

In spite of this, as of the writing of this report, the US has established "limited or no emission regulations" for residential or small commercial biomass heating units. For example, only indoor woodstoves are subject to federal regulations (e.g. New Source Performance Standards); indoor wood furnaces and boilers, on the other hand, are not subject to any federal emission regulations.[rr] Further, under recently re-proposed EPA Area Source air emission limits, small commercial biomass heating systems (<10 MMBTU/hr) are only subject to biennial work practice standards. Updated Area Source regulations are expected to undergo public review and promulgation in late 2011 and early 2012, respectively.

[qq] Data is currently unavailable for pellet boiler PM and SO_2 emissions. See: NESCAUM and Rick Handley and Associates. (2009). Biomass Boiler & Furnace Emissions and Safety Regulations in the Northeast States: Evaluations and Options for Regional Consistency. Prepared for the Massachusetts Department of Energy Resources by CONGEG Policy Research Center, Inc.

[rr] It is worth noting that the EPA is slated to release residential New Source Performance Standards for residential installations soon.

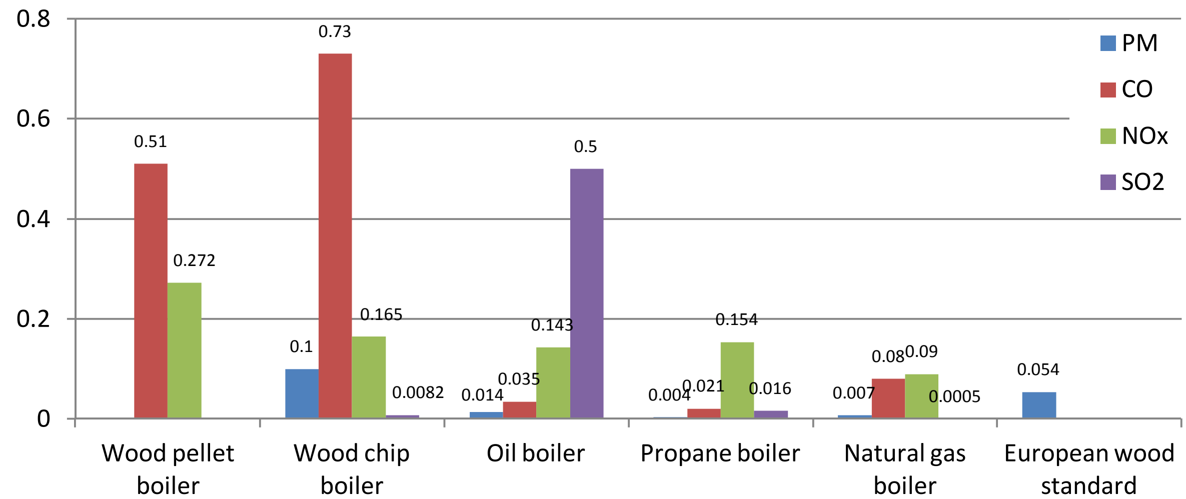


Figure 29: Particulate Matter Emissions from Typical Heating Systems (Source: DOER, 2009 and NESCAUM, 2009)

In some cases, states have sought to fill gaps in federal biomass emissions policy by regulating heating units that meet a certain size threshold. As illustrated in Table 11 below, Northeastern states have each developed emission standards regulating industrial, commercial, and institutional boilers between one and 10 MMBTUs in size. Massachusetts, for example, has adopted one of the most stringent emission requirements for boilers in the region, requiring boilers one MMBtu or greater to limit particulate matter emissions to 0.10 to 0.20 lbs/MMBtu.[ss] However, state regulations do not affect most residential or small commercial systems, which are below one MMBTU in size.

Table 11: Northeast State Emission Requirements for Industrial, Commercial & Institutional Boilers (Source: NESCAUM, 2009)

STATE	EMISSION THRESHOLD	LIMIT(S)
Connecticut	Unit has the potential to emit (PTE) 15 tons per year of any air pollutant	Case-by-case best available control technology (BACT)
Maine	10 MMBtu (aggregated)	Case-by-case BACT
Massachusetts	1 MMBtu[tt]	0.10 to 0.20 lbs/MMBtu
New Hampshire	Greater than 2 MMBtu	0.3 lbs/MMBtu
New Jersey	1 MMBtu	Case-by-case BACT
New York	Greater than 1 MMBtu	0.6 lbs/MMBtu
Rhode Island	Greater than 1 MMBtu	Case-by-case BACT; Recent determination 0.20 lbs/MMBtu
Vermont	Greater than 90 HP	Case-by-case BACT; Recent determination 0.20 lbs/MMBtu

Ultimately, the patchwork of emission policies across the northeast makes it challenging for manufacturers to manage compliance across the region, creating uncertainty in the biomass heating market. Moreover, state policy-makers encounter tension between the public's emerging interest in renewable biomass heating and concerns with environmental impacts of emissions, which inhibits

[ss] The EU standard is stricter. For more information, see: NESCAUM and Rick Handley and Associates. (2009). Biomass Boiler & Furnace Emissions and Safety Regulations in the Northeast States: Evaluations and Options for Regional Consistency. Prepared for the Massachusetts Department of Energy Resources by CONGEG Policy Research Center, Inc.

[tt] This is for non-automatic fed boiler combustion. Emission regulations for automatic fed boiler combustion 3 MMBtu or greater are different.

development of comprehensive biomass policy. *As a result, stakeholders indicate that overcoming uncertainty in emission regulations, establishing agreed upon emission standards, and improving the efficiency (and emissions profile) of biomass systems is essential for robust market development.*[88]

In contrast to the US, European wood-fired boilers are subject to strict emission regulations (based on heat output and feeding device) and generous incentives, which have spurred efficiency and innovation. As a result, European systems tend to burn cleaner and more efficiently than US units. A recent assessment of European biomass technologies from the New York State Energy Research and Development Authority (NYSERDA), for example, reports that "over the last 30 years average efficiencies of biomass boilers have increased from approximately 55% to more than 90%...and the average CO-emissions have decreased from 15,000 to less than 50 mg/m3…."[89] Massachusetts stakeholders suggest that by incorporating European biomass heating technologies into the Northeast market, US policy-makers could stimulate growth of high efficiency, low-emission biomass heating systems – thus alleviating many of the challenges discussed above.

To date, however, this has not happened, in part because of the cost premium associated by high efficiency European biomass boilers, but also because of differences in European and US boiler safety standards. In order to meet US safety standards, manufacturers must have boilers tested and certified by third party laboratory – an expensive process that is often not justified based on expected sales in the northeast.[90] A number of studies have assessed the pros, cons, and differences of US and European safety standards. As a recent study by the Northeast States for Coordinated Air Use Management (NESCAUM) reports, there are *not* significant differences in safety requirements between the EU and US, especially for residential and small commercial units under one MMBTU.[uu] The report concludes that few technical reasons should prevent a manufacturer located in the EU from obtaining the certification required for the US market and that "less costly safety certification options" should be evaluated to certify biomass boilers for sale in the US residential and small commercial markets.[91] In fact, two northeastern states, New Hampshire and Vermont, have enacted legislation allowing boilers certified to approved European standards to be legal for installation in these states without a U.S. certification such as that promulgated by the American Society of Mechanical Engineers (ASME).[92]

5.4 Lifecycle Cost Assessment

The following section assesses lifecycle costs and simple payback for biomass heating systems in residential and multi-family/commercial buildings. As illustrated in Table 12 below, this scenario assumes that biomass pellets are used to provide DHW and space heating for residential and commercial/multi-family facilities.

[uu] According to NESCAUM, "A comparison of the safety performance of the prescriptive U.S. code (ASME BPVC-Section IV) and the performance-based European standards (ENE-303-5) does not indicate any significant safety risks between boilers built to either requirement. However, the complexity of meeting the ASME prescriptive standard may be a deterrent for entry into the northeast market for EU manufacturers whose boilers are EN 303-5 compliant. Many states are concerned that opening up the northeast market to non-ASME certified European technologies could raise liability issues for states." NESCAUM and Rick Handley and Associates. (2009). Biomass Boiler & Furnace Emissions and Safety Regulations in the Northeast States: Evaluations and Options for Regional Consistency. Prepared for the Massachusetts Department of Energy Resources by CONGEG Policy Research Center, Inc.

Table 12: Biomass Thermal (Pellets) Scenario

	SHW	GSHP	Biomass - pellets	Biodiesel
Residential	DHW Space Heat --	DHW Space Heat --	**DHW** **Space Heat** **--**	-- Space Heat --
Commercial	DHW Space Heat --	DHW Space Heat Cooling - elec	**DHW** **Space Heat** **--**	-- Space Heat --

System sizing requirements for residential and commercial/multi-family buildings are detailed in Appendix A. Using these assumptions, biomass heating systems have been modeled to calculate simple payback and levelized cost of energy (LCOE) for typical residential (13 kWth) and commercial/multifamily (97 kWth) installations.

5.4.1 Installed Costs

Installed costs for biomass heating systems in the northeastern market vary widely. This is a result in part of the region's incipient market as well as differences in technical specifications like system design, efficiency, and level of automation.

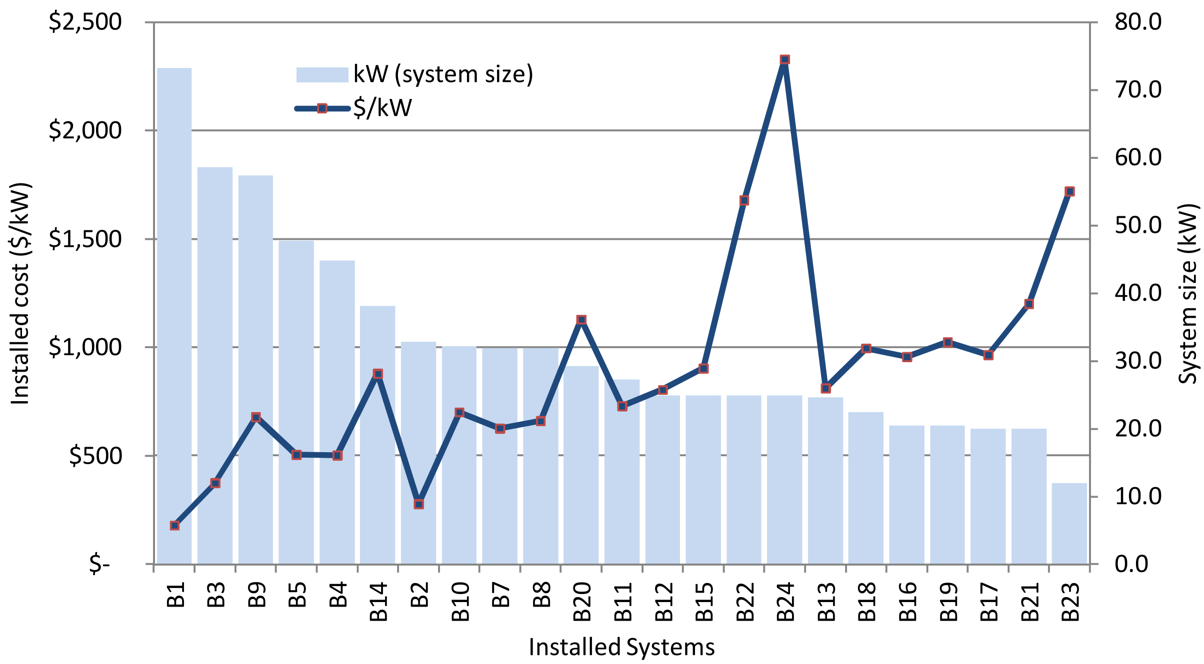


Figure 30 illustrates installed costs for comparable systems (bulk fed wood pellet systems under 75 kW) installed in New Hampshire's pilot residential rebate program. Installed costs ranged from $181 to over $2,329 per kWth. Economies of scale are achieved for larger systems, though within this small sample, systems under 30 kWth show wide variability in installed cost, making reliable cost estimates difficult to develop.

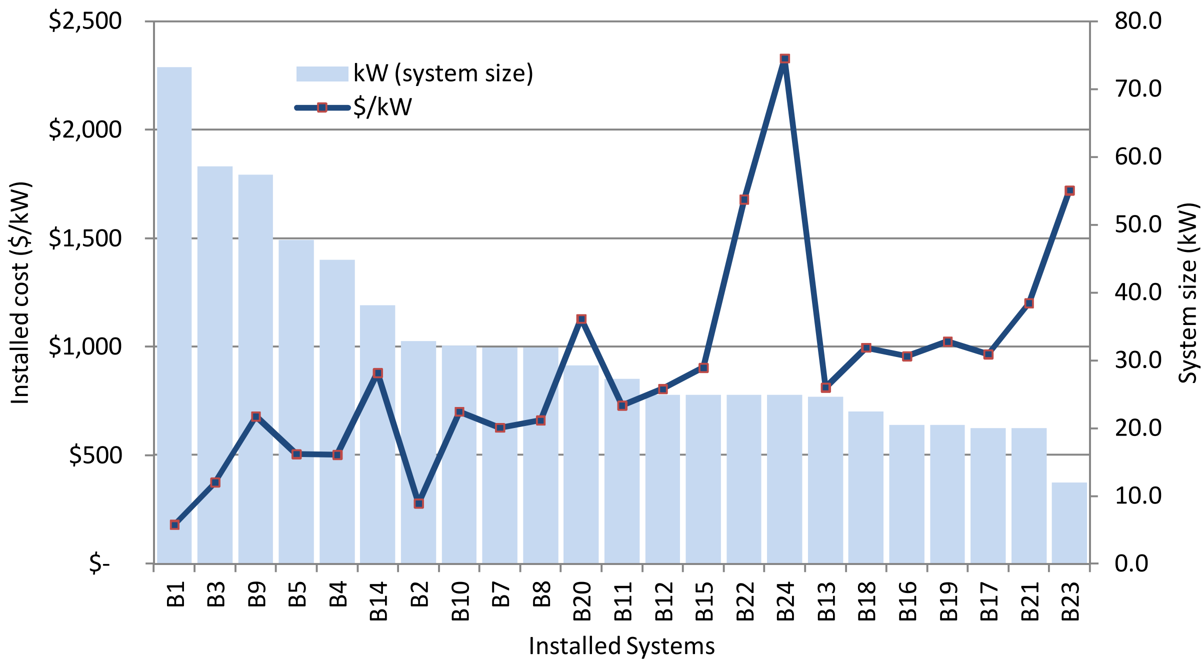


Figure 30: Installed Cost ($/kW) and System Size for Bulk-fed Residential Biomass Boilers in NH (Source: NH PUC, 2011)

Ultimately, this analysis assumes residential that residential pellet systems cost $1615 per kWth.[vv] For commercial pellet systems, it is assumed that customers benefit from economies of scale, resulting in a cost of approximately $500 per kWth. This is supported by estimates provided by biomass thermal stakeholders as well as the New Hampshire rebate data. For full range of cost estimates, see Scenario assumptions in Appendix A.

5.4.2 Lifecycle Costs of Energy: Residential Scenario

The residential biomass pellet scenario assumes that pellet heating is the primary heating source for heating and hot water in a household; however, it additionally assumes that the household uses its existing fossil fuel heating system as a back-up (redundant) heating system. As a result, a homeowner would have two heating systems – a biomass pellet and fossil fuel back-up heating system. The installed cost for the biomass pellet heating system is significant – at approximately $21,000 for a 13 kWth (44,000 BTU/hr) system.[ww] Figure 31 and Figure 32 below illustrate the typical lifecycle costs and simple payback of biomass pellet heating relative to fossil fuel alternatives.

[vv] Stakeholders estimated that a 25 kWth residential system would cost approximately $875 per kWth (or slightly over $21,000 per kWth). However, according to regulators in Massachusetts, *small* residential systems costs do not currently scale down with size. Thus, a 13 kWth and 25 kWth system would both be assumed to cost approximately $21,000 (resulting in wide variability on a $/kWth basis). Moreover, the NH data shows enormous variability in installed costs (based on size) for systems under 30 kWth. As a result, a conservative estimate of $1615 per kWth was established – based on installed costs of several high efficiency small (20 kWth or less) installations pulled from the New Hampshire data.

[ww] These assumptions significantly impact the payback metrics for biomass heating systems. For example, the analysis is built around a 13 kWth (44,000 Btu/hr) system, estimated to cost approximately $21,000. It is important to note that this scenario assumes biomass requires fossil fuel back-up heating.

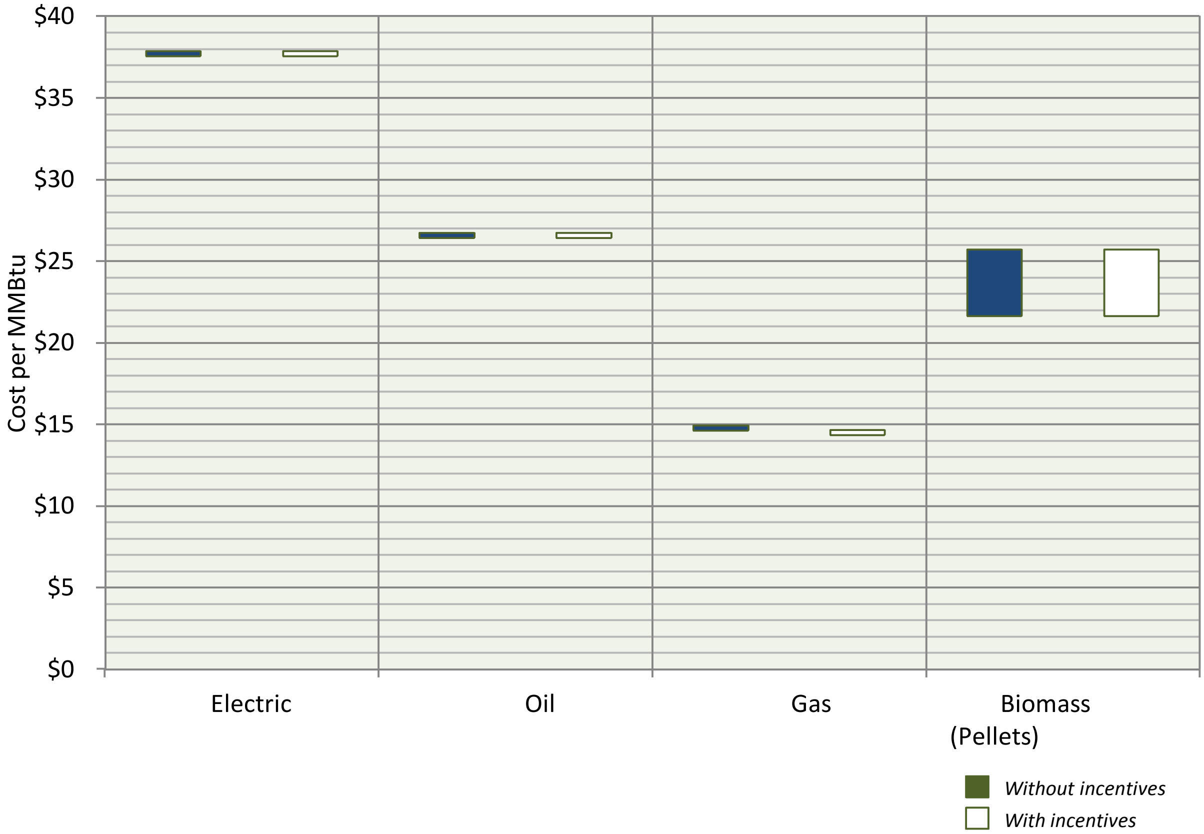
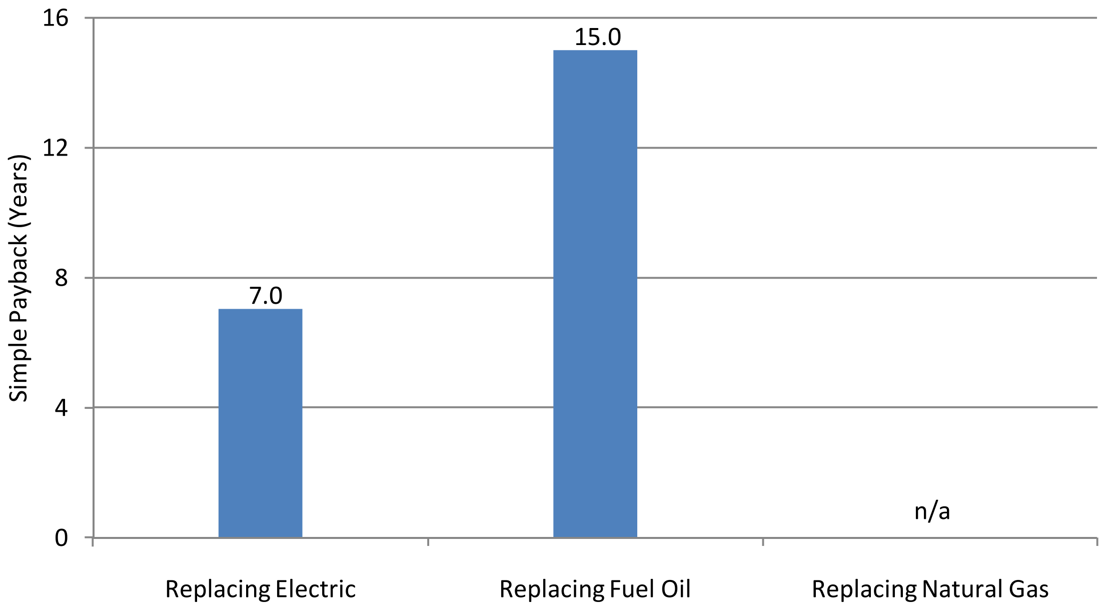


Figure 31: LCOE of Typical Residential Biomass Pellet Heating System in Massachusetts Compared to Fossil Fuel Alternatives



Note: Average costs, no incentives. Blanks indicate no payback (costs exceed savings).

Figure 32: Payback of Typical Residential Biomass Pellet Heating System in Massachusetts

Relative to electric hot water and space heating, a residential biomass pellet system achieves a payback of seven years. Over the lifetime of the system, residents will pay about $14 less for every MMBTU of heat produced by a biomass pellet system than by an electric system.

Relative to fuel oil hot water and space heating, a residential biomass pellet system is achieves a 15 year payback. Customers pay nearly $3 less per MMBTU of heat produced from biomass pellet heating than from fuel oil systems.

Relative to natural gas water and space heating, residential biomass thermal is not a compelling replacement. As pellet fuel costs are estimated to be higher than natural gas, it does not achieve payback. Moreover, customers are expected to pay about $9.3 more per MMBTU of heat produced by pellets (compared with natural gas) over the lifetime of the system.

In summary, biomass pellet heating at the residential scale does not present a financially compelling alternative for residential for fossil fuel systems – at least at current incentive levels.[xx] As illustrated in the next section, however, the case changes significantly for larger biomass pellet systems that achieve lower costs due to improved economies of scale.

5.4.3 Lifecycle Costs of Energy: Commercial Scenario

The commercial biomass pellet scenario assumes that pellet heating is the primary heating and hot water system for a commercial facility; however, like the residential case, it additionally assumes that the commercial facility uses its existing fossil fuel heating system as a back-up heating system. As a result, the commercial facility owner would have two heating systems – a biomass pellet and fossil fuel back-up heating system. The installed cost for the biomass pellet heating system is significant – at approximately $48,350 for a 97 kWth (331,000 Btu/hr) system.[yy] The charts below illustrate the typical lifecycle costs and simple payback of biomass pellet heating relative to fossil fuel alternatives.

[xx] It is possible, though not currently common, for biomass pellet systems to be the sole heating source for a household. In such a case, if the biomass heating system were an end-of-life replacement for biomass heating, the payback would be improved significantly as the customer would only be concerned with the incremental upfront costs of biomass heating.

[yy] These assumptions significantly impact the payback metrics for biomass heating systems. For example, the analysis is built around a 13 kWth (44,000 Btu/hr) system, estimated to cost approximately $21,000. It is important to note that this scenario assumes biomass requires fossil fuel back-up heating.

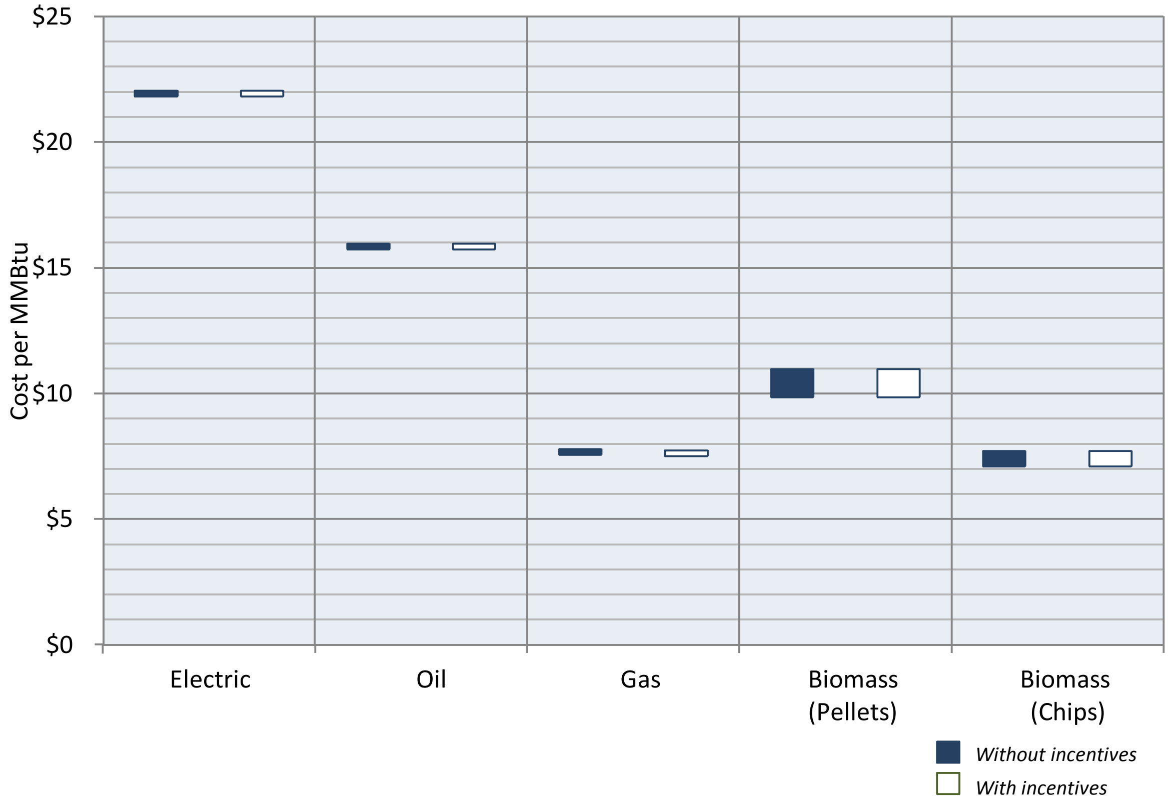


Figure 33: LCOE of Typical Commercial Biomass Heating Pellet System in Massachusetts Compared to Fossil Fuel Alternatives

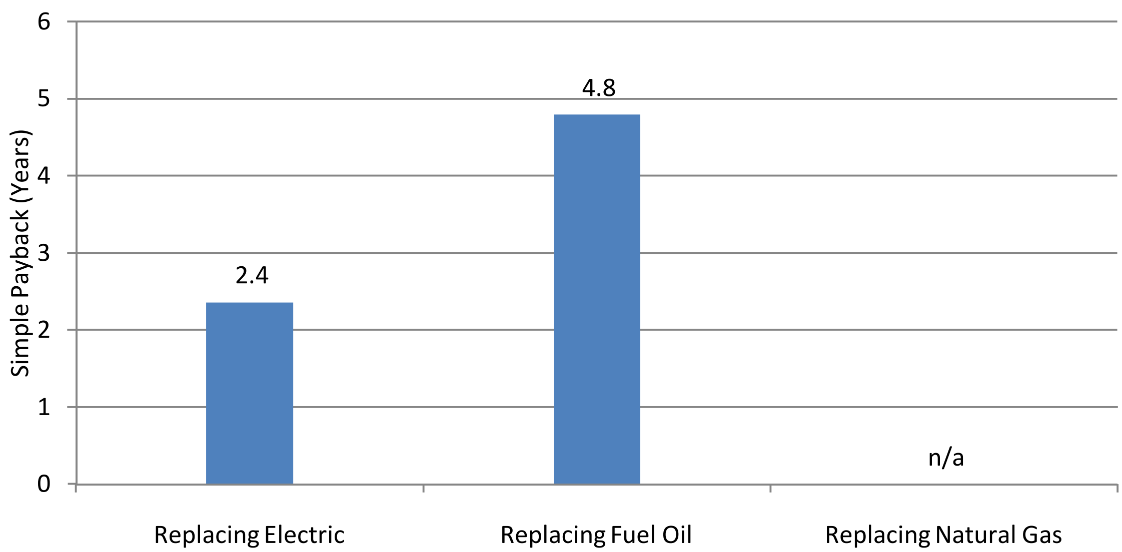


Figure 34: Payback of Typical Commercial Biomass Pellet Heating System in Massachusetts

Relative to electric water and space heating, a commercial biomass pellet system represents an extremely attractive option for customers. Customers can achieve payback within three years. Moreover, over the lifetime of the system, commercial facilities will pay about $11.5 less for every MMBTU of heat produced by a biomass pellet system than by an electric system.

Relative to fuel oil water and space heating, a commercial biomass pellet system also represents an attractive alternative, achieving payback in less than 5 years. Customers pay $5.4 less per MMBTU of heat produced.

Relative to natural gas water and space heating, however, commercial biomass pellet systems are less compelling. As pellet fuel costs are estimated to be higher than natural gas, it does not achieve payback. Moreover, customers are estimated to pay about $2.8 more per MMBTU of heat produced by pellets (compared with natural gas) over the lifetime of the system.

In summary, because biomass commercial pellet systems can achieve economies of scale, biomass pellet heating presents a highly competitive alternative to heating with electricity and fuel oil. However, because biomass pellets are projected to be more expensive than natural gas, it does not present a compelling replacement option for natural gas heating.

5.5 Greenhouse Gas Assessment

GHG reductions from biomass pellet heating systems are calculated by estimating GHG emissions avoided from fossil fuel systems. Emission reduction estimates for biomass heating are based on the Manomet study and ongoing regulatory development by DOER, which take into account the carbon debt and dividends of various biomass feedstock.[zz] In Figure 35 and Figure 36, the gray bars illustrate the GHG emissions (over a 20 year period) resulting from a typical fossil fuel system. The blue bars represent the GHG emissions (over a 20 year period) from biomass heating systems using various fuel stocks (e.g. forest thinning, forest residues, and a mix of both). The difference between the fossil fuel emissions and the biomass heating emissions represents the GHG emission reductions from biomass thermal. For example, a typical residential biomass heating system using "100% thinning" feedstock and replacing an electric heating system will ultimately reduce GHG emissions by 11 tons over 20 years (e.g. 21 tons – 10 tons = 11 tons). Emission reductions are greatest for systems offsetting electricity, followed by fuel oil, and then natural gas.

[zz] This is based on the most recent DOER model available for biomass GHG emission reductions as of November 2011.

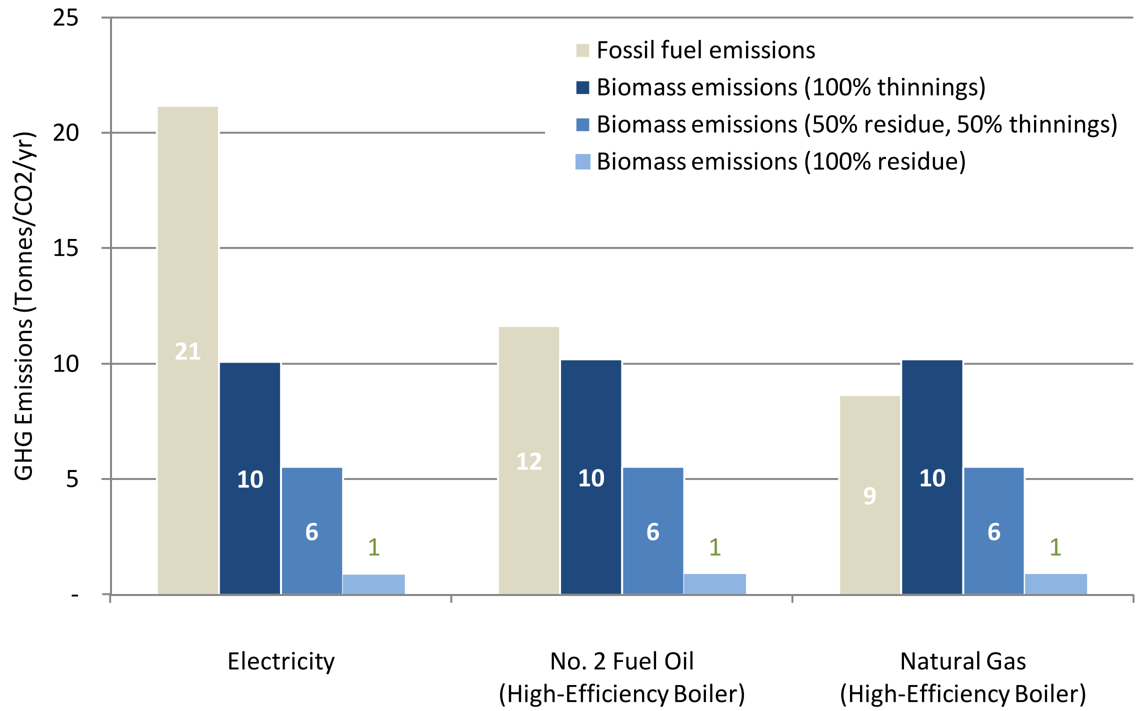


Figure 35: Annual GHG Emissions Avoided by Residential Biomass Pellet Heating Systems

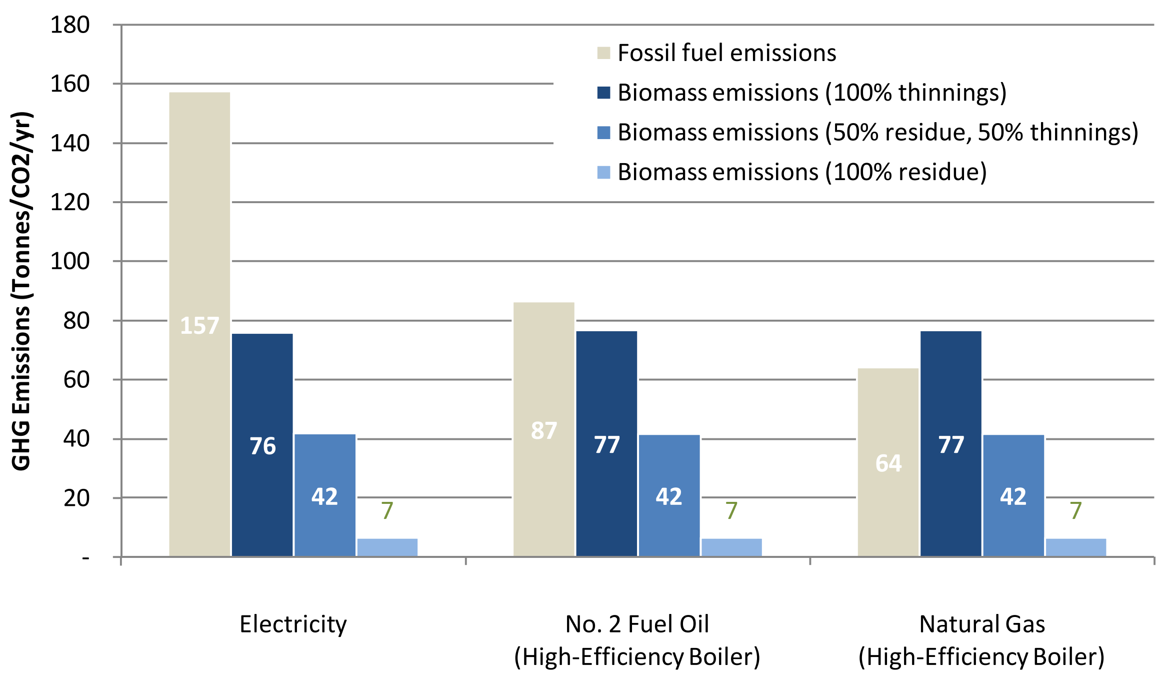


Figure 36: Annual GHG Emissions Avoided by Commercial Biomass Pellet Heating Systems

5.6 Job Creation, Economic Development, and GHG Emission Reduction Scenarios

The *Massachusetts Clean Energy and Climate Plan for 2020* does not establish a formal target for GHG reductions from biomass thermal. However, for purposes of this analysis, MassCEC and Mass DOER estimate that biomass heating has the potential to achieve 35% of the two million tons of GHG reductions from renewable thermal by 2020 – or approximately 700,000 tons, assuming that biomass heating feedstock is composed of 50% residues and 50% forest thinnings.[aaa] As illustrated in Table 12 below, it is also estimated that this will result in significant job creation associated with in-region fuel production and distribution. Though not estimated in this analysis, additional jobs could *also* be created if the state were to attract new manufacturing facilities for biomass conversion technologies.

Table 13: Biomass (Pellet) Heating GHG Emission Reduction and Job Creation Scenarios

Biomass Thermal	Annual Market Growth Rate	Annual GHG Emission Reductions	Jobs Created
BAU by 2020	20%	43,875	177
Accelerated Growth by 2020	97%	700,000	2,165
Accelerated Growth by 2050	n/a	3,766,687	n/a

The Building as Usual (BAU) scenario uses the historic growth rate of biomass pellet heating in Massachusetts to estimate emissions, jobs, and economic benefits by 2020. Stakeholders estimate that the biomass thermal market has historically grown by approximately 20% annually. At this growth rate, it is expected that the biomass thermal market will achieve nearly 44,000 tons of GHG emission reductions, or about 6% of the biomass thermal's allocated portion of the 2020 target established by MassCEC and Mass DOER. It is additionally expected that the industry could create roughly 177 jobs within 10 years.

The Accelerated Growth by 2020 scenario projects the market growth rate required to meet the accelerated biomass thermal GHG reduction target of 700,000 tons. In order to meet this goal, the biomass heating market would need to see its average annual growth increase to 97%. If this goal is achieved, over an estimated 2,000 new jobs could be created by 2020. It is also estimated that over $385 million could be retained in the region through avoided expenditures on out-of-state fossil fuels.

The Accelerated Growth by 2050 scenario assumes that a certain percentage of the state's fossil fuel systems are replaced with a mix of renewable thermal technologies by 2050 (based on assumptions laid out in the *Massachusetts Clean Energy and Climate Plan for 2020*) and projects the associated GHG emissions reduction benefits. This analysis shows that replacing 7% of existing natural gas, 35% of existing electric,[bbb] and 28% of existing fuel oil heating systems would yield GHG emissions reductions of over 3.7 million tons.

[aaa] The GHG reduction target of 35% is for illustrative purposes only. It does not constitute a formal target for the Commonwealth of Massachusetts.

[bbb] For residential buildings only. It is assumed that commercial/multi-family facilities would not typically employ electric heating.

CHAPTER 6: ADVANCED BIODIESEL

6.1 Introduction

This chapter provides an overview of the space heating market for biodiesel in Massachusetts. Unlike the other renewable technologies discussed in this report, adopting low-level blends of biodiesel and No. 2 distillate ("conventional fuel oil") requires no up-front capital investment. While this lowers the barriers to its adoption, especially where fuel oil boilers already exist, the growth of the biodiesel market is constrained by a number of other challenges discussed below.

The following section provides a brief overview of the technology and then describes the current market status, supply chain, and market barriers and drivers. It also assesses typical project economics for residential and commercial project scenarios. Finally, it assesses the GHG emission reduction and job creation potential for the Massachusetts biomass heating market.

6.1.1 Key Findings and Conclusions

Massachusetts policy-makers emphasize that to achieve significant GHG reductions, the biodiesel industry in Massachusetts must promote *advanced* biodiesel, which is defined by the Commonwealth as a fuel which achieves at least a 50% reduction in lifecycle GHG emissions. The Massachusetts DOER reports that waste-derived biofuels as the only form of biodiesel that currently meets the 50% GHG reduction threshold necessary to qualify as advanced biodiesel.[ccc] Statistics on advanced biodiesel, however, are not tracked in Massachusetts, and as a result the current size and status of the market is hard to define. Nonetheless, industry stakeholders indicate that there is significant under-realized potential for producing advanced biodiesel.

Keeping in mind the lack of good market data, MassCEC and Mass DOER estimate that under a business-as-usual scenario, advanced biodiesel will be able to reduce GHG emissions by approximately 34,000 tons by 2020. Under an accelerated growth scenario, MassCEC and Mass DOER estimate that advanced biodiesel could reduce GHG emissions by 100,000 tons by 2020. This is equivalent to the production and integration of approximately 11.6 million gallons of advanced biodiesel or about 2.4% of commercial and residential fuel oil use. Though not estimated here, the production of such volumes of advanced biodiesel could create or save a significant number of jobs in Massachusetts.

A number of barriers currently inhibit development of a vibrant advanced biodiesel market in Massachusetts. For example, as indicated above, little market data is currently available regarding the growth and development of the advanced biodiesel industry. This is due in part to the current biodiesel market structure and regulatory standards. For example, up to 5% of biodiesel (conventional or advanced) can be blended into distillate fuel oil without differentiating the product, creating a situation where the biodiesel content of fuel is unknown.

Moreover, because higher blends of biodiesel acts like a solvent – *potentially* damaging pumps, gaskets, and other boiler components – many manufacturers in the US will guarantee components under warranty only if using B5 biodiesel blends or less. As a result, uncertainty regarding the biodiesel content of fuel oil entering Massachusetts can deter additional in-state blending due to insurance and warranty concerns.

[ccc] However, research in this area is ongoing and the DOER's determination is subject to ongoing review of evidence submitted by interested parties, as well as the results of additional studies as they become available.

In addition, integrating advanced biodiesel into the existing fuel oil supply is challenging, requiring significant upgrades to wholesale, terminal infrastructure that could range in costs from $500,000 to $3 million. Upgrades to enable local distribution networks to blend advanced biodiesel are equally prohibitive. Finally, stakeholders indicate that for the biodiesel market to significantly expand in Massachusetts, strong, regional marketing campaigns are needed in addition to consistent, long-term policy support.

6.2 Biodiesel Technology, Market Status and Value Chain

6.2.1 Technology Overview

A replacement for petroleum-based fuel oil, biodiesel is manufactured from a wide range of renewable sources including organic waste oils and greases, plant oils, and animal fats. It is produced through a process called transesterification,[93] wherein oil or fat is reacted with an alcohol in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide). Glycerin is produced as a byproduct.

Because it is manufactured from organic substances, biodiesel has a number of advantages over conventional fuel oil. It is non-toxic, biodegradable, and renewable. It reduces air pollution and lowers GHG emissions, and it can be produced domestically, improving energy security and the domestic economy. However, biodiesel must be properly manufactured, blended, and managed or it can cause problems at lower temperatures or in equipment that was not designed to accommodate its unique properties. In addition, the feedstock selected to manufacture biodiesel is a significant determinant of the environmental impacts of biodiesel production and use.

Additionally, biodiesel is rarely, if ever used by itself. Pure (100%) biodiesel is typically blended with conventional petroleum-based heating oil to create a biodiesel blend. Such blends are commonly identified by the ratio of conventional oil to biodiesel. For example, “B5” refers to a mixture of 95% conventional fuel oil and 5% biodiesel. In space heating applications (particularly in Massachusetts), blends of B5 and below are common. Blends up to B20 are more common in transportation applications.

Biodiesel feedstocks include a variety of oils and greases, including plant oils (e.g. soybean, cottonseed, and canola oils), recycled cooking greases (often termed “yellow grease”), and animal fats (e.g. beef tallow, pork lard). Though each feedstock produces biodiesel that is chemically similar, feedstock choice does impact environmental attributes as well as certain physical properties that affect operation. In particular, feedstock choice affects the fuel’s reaction to colder temperatures, its combustion, as well as tailpipe emissions.[94]

For example, as illustrated in Table 14 below, depending upon feedstock, biodiesel’s cloud point (the point at which crystals begin to form) can range from 35 to 60°F. It can be even higher for animal fats or frying oils that contain a high proportion of saturated fats.[95] As crystals form, biodiesel begins to gel, eventually reaching its pour point, or the temperature at which biodiesel is too solid to flow. Pour points range from 23 to 50°F, depending upon the feedstock selected.[96] Obviously, biodiesel with a high cloud or pour point is not well-suited for cold weather use. In some case, however, the cold weather properties of biodiesel may be improved with additives.

Table 14: Cold flow data for various B100 fuels[97]

Test Method for B100 Fuel	Cloud Point (ASTM D2500) deg. F	Pour Point (ASTM D97) deg. F
Soy Methyl Ester	32	25
Canola Methyl Ester	26	25
Lard Methyl Ester	56	55
Edible Tallow Methyl Ester	66	60
Inedible Tallow Methyl Ester	61	59
Yellow Grease 1 Methyl Ester	--	48
Yellow Grease 2 Methyl Ester	46	43

The feedstock used in the production of biodiesel also affects its GHG emissions, especially for plant-based (i.e. soy, canola) feedstock. This is due, in large part, to the impacts of direct and indirect land use decisions on GHG emissions. Feedstock cultivation involves both the production and absorption of carbon dioxide, and the net effect is the subject of some debate. Much of the uncertainty revolves around the complex impacts that increased demand has on land use both in the U.S. and globally. Though crops absorb CO_2 as they grow, cultivation usually involves emissions-intensive fertilizer, equipment, and most significantly, release of emissions trapped in soil and forests as they are cleared and tilled to meet increased demand for agricultural products.

A key distinction is thus drawn between conventional biodiesel and advanced biodiesel. The latter is defined by the Commonwealth of Massachusetts as a fuel which achieves at least a 50% reduction in lifecycle GHG emissions as compared to conventional fuel oil.[98] Based on an assessment of various GHG accounting methodologies, the Massachusetts DOER has identified waste-derived biofuels as the only form of biodiesel that currently meets the 50% GHG reduction threshold necessary to qualify as advanced biodiesel. However, research in this area is ongoing and the DOER's determination is subject to ongoing review of evidence submitted by interested parties, as well as the results of additional studies as they become available.

6.3 Market Status and Value Chain

Conventional biodiesel consumption in the US has increased rapidly over the past ten years, from ten million gallons in 2001 to over 220 million gallons in 2010.[99] National biodiesel consumption is expected to grow to at least one billion gallons by 2012.[100] Little data on consumption is available at the state level. However, regional stakeholders suggest that a significant portion of the No. 2 distillate fuel entering the state already contains low levels of conventional biodiesel (B5 or below). A reasonable estimate of 1% to 3% biodiesel blend would mean that biodiesel provides roughly eight million to 30 million gallons of heating fuel. This is equivalent to approximately 0.4% to 1.2% of total energy consumed for household heating.[ddd]

State-level statistics on *advanced* biodiesel are also not well tracked. Although estimates specific to biodiesel were not provided, the Massachusetts Advanced Biofuels Task Force estimated that by 2025 between 100 and 380 million gallons of gasoline equivalent of advanced biofuels (including all biofuels – not just biodiesel) could be produced in-state for space heating and transportation applications.[eee]

[ddd] This assumes 800 million to one billion gallons of fuel oil consumed in Massachusetts annually. (M. Ferrante, personal communication, November 2011).

[eee] It is important to note that this estimate includes all biofuels and is not just limited to biodiesel estimates. For more information, see: Commonwealth of Massachusetts. (Spring 2008). Advanced Biofuels Task Force Report. Retrieved from www.mass.gov/governor/docs/biofuels.pdf. p. 22.

Industry stakeholders also indicate that there is a significant under-realized potential for producing advanced biodiesel in the state.[101]

The biodiesel value chain in Massachusetts is dominated by import terminals and retail fuel distributors, though a couple advanced biodiesel manufacturers also operate in the state. **Error! Reference source not found.** illustrates the various points in the value chain from import to end use and shows the complexity and heterogeneity of the biodiesel value chain.

B100 transactions (represented by light green lines) generally involve the sale of biodiesel imported by out-of-state suppliers and sold to in-state distributors. Biodiesel is blended (typically at fuel terminals) with imported conventional petroleum (represented by black lines) and may be co-mingled with pre-blended out-of-state shipments of biodiesel. Fuel retailers then complete the transaction by distributing the blended product to end users.

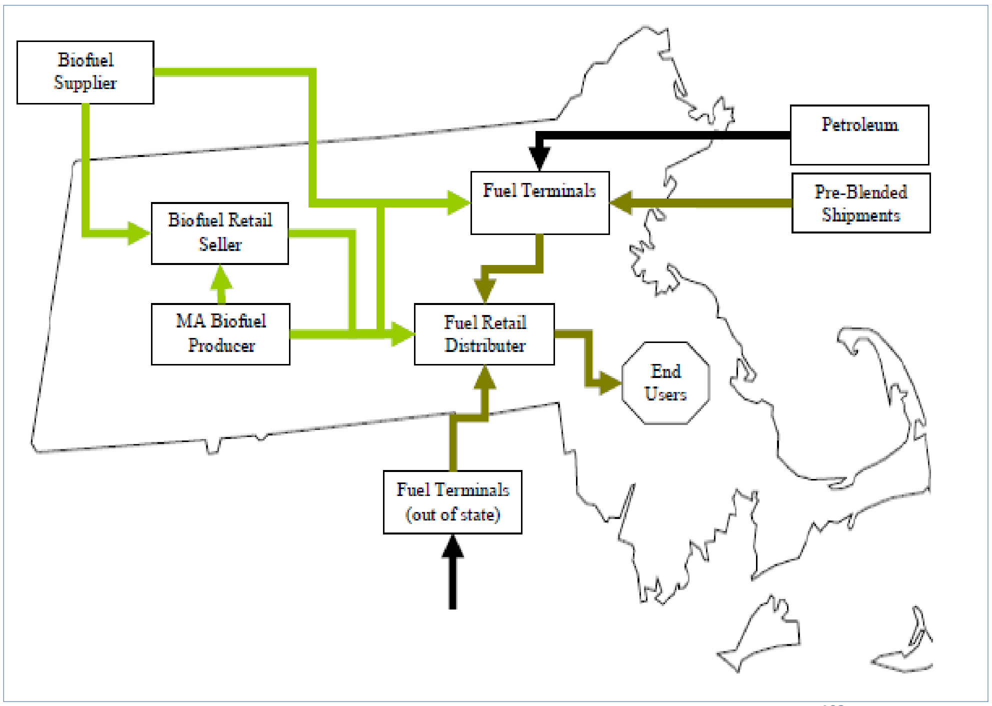


Figure 37: The Biodiesel Value Chain in Massachusetts (DOER, 2010)[102]

6.3.1 Manufacturing

Currently two facilities actively produce advanced biodiesel in Massachusetts: Billerica-based Baker Commodities and Cape Cod Biofuels based in Sandwich, Massachusetts. At least two other facilities exist in the state, although industry experts indicate they are not currently operating.[103] The National Biodiesel Board lists production capacities for the Baker and Cape Cod facilities to be 15,000,000 gallons per year and 500,000 gallons per year, respectively.[104] Actual production data is not currently available.

6.3.2 Wholesale Fuel Terminals

Conventional fuel oil enters the region from domestic or international markets at fuel terminal facilities located throughout Massachusetts and neighboring states (see Figure 38). Blending of conventional fuel oil and biodiesel typically happens at these terminals where product is loaded onto tanker trucks at the "rack" (fueling station) for distribution to retailers and end users.

There are approximately 36 wholesale terminals (including large ocean liner terminals and smaller inland facilities) operated by 30 companies located in or near Massachusetts.[105] However, the retail fuel oil distribution market tends to be more localized due to the high cost to retailers of transporting fuel long distances. In other words, although there may be many fuel terminals located in and near Massachusetts, an individual retail distributor may have economical access to only a few. For example, while no single terminal operator's share of the Massachusetts fuel terminal market is greater than 15%, the Boston market is dominated by two terminal operators which enjoy a combined 55% market share.[fff] Many of the largest terminals in the state are owned by major diversified energy companies, including Magellan Midstream, Global Companies, ExxonMobil, CITGO, Gulf, Irving, and Sprague.[106]

Fuel terminals play a significant role in shaping the Massachusetts biodiesel market. Due to the capital costs of blending equipment, very few retail distributors are blending biodiesel themselves; instead they rely on the product offerings at the terminals. Product offerings at terminals are thus a strong determinant of the biodiesel content of heating oil sold throughout the state.

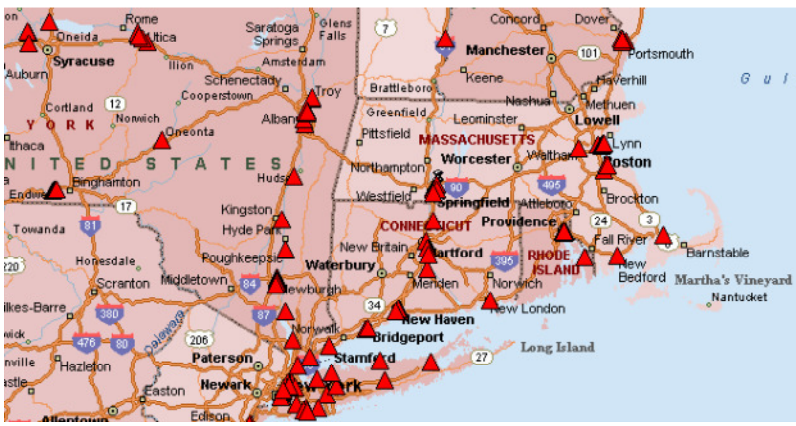


Figure 38: Fuel Oil Terminals in the Northeast (Hastings et al, 2007)

6.3.3 Retail Distribution

Retail distribution of heating oil in Massachusetts is diffuse and heterogeneous. At last count, of the 715 Massachusetts dealers registered with the National Oilheat Research Alliance (NORA), approximately 70 distributed biodiesel.[107] The home heating oil delivery market is characterized by strong customer loyalty, especially from customers whose heating equipment was also installed or serviced by the fuel oil dealer. Anecdotal evidence also suggests that, in some cases, selling biodiesel has proven to be an effective marketing and customer acquisition tool for retailers that are seeking to differentiate themselves from other suppliers.

6.4 Drivers and Barriers

6.4.1 Market Drivers

The market for biodiesel has been driven primarily by two federal policies: (i) a tax credit for biodiesel blenders and (ii) a Renewable Fuel Standard (RFS), which mandates increasing levels of use of biodiesel and other renewable fuels. Massachusetts adopted a similar mandate in 2009, but its implementation

[fff] Market share calculated by Hastings et al. based on percent of total storage capacity. For more information, see: Hastings, J., Mitton, M., and Williams, M. (2007). Report On Petroleum Products Markets In The Northeast. ERSGroup: 59-60. Retrieved from www.statecenterinc.org/docs/Complete_Petroleum_Report_09-07-07.pdf.

has been suspended due to concerns over costs and logistics. The following briefly discusses federal and state policy drivers.

First, the IRS provides a $1.00 per gallon excise tax credit ("blender's credit") for the blending of biodiesel and conventional fuel oil.[ggg] This credit was originally implemented as part of the JOBS Act of 2004 and took effect at the beginning of 2005. It has been renewed a number of times and is currently set to expire again at the end of 2011. A proposal for a three-year extension is pending in both the US House and Senate,[108] but no major actions have yet been taken as of the preparation of this report.[109]

Second, the Energy Policy Act of 2005 created a federal Renewable Fuel Standard (RFS), which mandates the use of a predetermined quantity of renewable fuel each year, including biodiesel (see **Error! Reference source not found.**).[110] The Energy Independence and Security Act of 2007 established a revised Renewable Fuel Standards (RFS2) which makes two key changes to the original RFS. First, RFS2 sets higher volume requirements, mandating the use of 12.95 billion gallons of renewable fuel in 2010 and increasing to 36 billion by 2022. That includes a carve-out for 1 billion gallons of biodiesel by 2012 (amounts in subsequent years are to be determined but will not be less than 1 billion).[111] RFS2 also sets required levels of GHG emissions reductions thresholds that each fuel will be required to meet. For biodiesel this threshold is set at 50% compared to conventional fuel oil.

Table 15: Renewable Fuel Volume Requirements for RFS2 in billion gallons (EPA, 2011)

Year	Biomass-based diesel requirement	Advanced biofuel requirement	Cellulosic biofuel requirement	Total renewable fuel requirement
2008	n/a	n/a	n/a	9.0
2009	0.5	0.6	n/a	11.1
2010	0.65	0.95	0.1	12.95
2011	0.80	1.35	0.25	13.95
2012	1.0	2.0	0.5	15.2
2013	A	2.75	1.0	16.55
2014	A	3.75	1.75	18.15
2015	A	5.5	3.0	20.5
2016	A	7.25	4.25	22.25
2017	A	9.0	5.5	24.0
2018	A	11.0	7.0	26.0
2019	A	13.0	8.5	28.0
2020	a	15.0	10.5	30.0
2021	a	18.0	13.5	33.0
2022	a	21.0	16.0	36.0
2023[+]	b	B	b	b

[a] *To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.*
[b] *To be determined by EPA through a future rulemaking.*

"Obligated parties" under the mandate include fuel producers, importers, and blenders and each party is assigned a proportional share of the total obligation. Compliance is tracked using a tradable fiat commodity designated with Renewable Identification Numbers (RINs), which represent the regulatory compliance attribute of a fixed volume of renewable fuel. A February 2010 rulemaking by the EPA identified "biodiesel from soy oil and renewable diesel from organic waste oils, fats, and greases" as compliant with the 50% GHG threshold required by RFS2.[112]

[ggg] A blending event is defined as the creation of a mixture which contains at least 0.1% diesel fuel.

In addition to federal policy, the Massachusetts market also benefits from state and regional policies. For example, within Massachusetts, the state agency fuel requirement mandates the use of at least B5 blends in all state-owned diesel vehicles,[113] and an executive order that sets a target for biodiesel use in state facilities that escalates from B3 in 2007 to B10 in 2012.[114] New York's recent B2 mandate for heating oil is also driving a shift to biodiesel among many regional distributors that serve local suppliers in Massachusetts as well.[115]

The regional nature of the fuel supply means that incentives and mandates can have an impact well beyond their jurisdiction. As the heating oil supply responds to the increased demand, availability of biodiesel blends will increase. Perhaps more significantly, the biodiesel content of standard fuel oil supplies will also increase, particularly in the western part of the state where wholesalers and retailers serve markets in both New York and Massachusetts and choose to carry only biodiesel blends in order to comply with the New York State mandate.

6.4.2 Market Barriers

The development of the Massachusetts biodiesel market is hindered by a number of barriers, including unclear standards and fuel content, high up-front costs for distributors, a lack of consumer awareness, warranty and insurance coverage issues, and inconsistent policy support. Each barrier is addressed below.

6.4.2.1 Unclear Standards and Fuel Content

In 2008, the American Society for Testing and Materials (ASTM) released specifications for B100 (ASTM D6751) while also revising its standards for oilheat (ASTM D396) in order to accommodate biodiesel blends up to B5.[116] These standards have helped accelerate biodiesel's acceptance and diffusion into the market by allowing biodiesel blends of up to 5% to be effectively treated as if they were conventional fuel oil. However, the D396 provision has also created uncertainty that inhibits further blending. By allowing biodiesel to be blended up to B5 without differentiating the product from conventional heating oil, the standard often creates a situation where the biodiesel content of fuel oil is unknown, particularly when pre-blended supplies are brought into the state. Not knowing the existing biodiesel content can deter further blending due to concerns around warranty and insurance coverage for blends exceeding 5%.

6.4.2.2 High Up-front Costs for Wholesale and Retail Distributors

High capital investments required to distribute and sell biodiesel are a deterrent for both wholesale and retail distributors. For example, only a handful of wholesale terminals in Massachusetts currently have the equipment needed to store, blend, and dispense biodiesel.[117] Terminal upgrades to incorporate biodiesel blending are expensive, costing anywhere from $500,000 to $3 million per facility.[118] Moreover, within Massachusetts, capital costs for biodiesel blending are increased due to biodiesel's susceptibility to cold temperatures. As noted in Section 6.2, the pour point for B100 is higher than conventional fuel oil and, as a result, B100 will gel or solidify faster than conventional fuel oil in cold or moderate temperatures. As a result, biodiesel's physical properties can complicate storage and transportation in cold climates. Thus, insulated or heated storage and piping is usually needed, particularly to transport biodiesel from storage to the truck rack, which adds considerable expense to biodiesel storage and distribution.[hhh]

[hhh] Industry experts in Massachusetts have indicated that cold temperatures are a significant consideration for biodiesel distribution during the major heating season from October through April.

Finally, small retailers do not have the equipment necessary to store and distribute multiple types of fuel – like petroleum-based fuel oil and biodiesel. And like terminal facilities, retail distributors indicate that they cannot cover the costs of capital upgrades to blend biodiesel downstream. As a result, distributors are left with the option of either converting their entire inventory to biodiesel (if available at nearby terminals) or selling conventional heating oil only.

6.4.2.3 Consumer Awareness

Stakeholders have expressed a need for stronger marketing and consumer awareness campaigns to build greater demand for the product. The National Biodiesel Board (NBB) recently launched a national advertising campaign, seeking to raise consumer awareness of biodiesel.[119] The NBB has also run campaigns in New York, but industry stakeholders report that it met with limited success, hindered in part by funding. Due to the geographic diversity and high number of oilheat dealers across the state, direct consumer education channels are inherently decentralized.

Stakeholders also note that greater clarity is needed regarding the environmental benefits of biodiesel in order to expand consumer awareness and demand. Between 2000 and 2007, over 900,000 homes in the northeast have switched from oil heat to another fuel source, costing the industry an estimated $53 billion in sales.[120] Although this phenomenon is likely due in large part to the falling cost of natural gas, environmental attributes may be playing a role as well.

6.4.2.4 Warranty and Insurance

Building codes are geography-specific and vary in their reliance on ASTM standards for determining acceptable heating fuels. In Massachusetts, tying building codes, product warranties, or insurance coverage to ASTM 396 (which allows biodiesel content in heating oil up to 5%) effectively limits biodiesel use to B5 blends or lower. However, differences in building standards across state jurisdictions complicate biodiesel distribution across the region. For example, in New Hampshire and upstate New York, some dealers sell B10, B20, or even B100. A number of Massachusetts biodiesel distributors pick up product at terminals in Providence, R.I. or Albany, N.Y.[121] and many serve customers in multiple states. Hence the inconsistent application of ASTM standards to biodiesel blends complicates distribution in border markets.

In addition, because the solvent-like properties of biodiesel increases at greater blends, most pumps, gaskets, and other boiler components in the US are protected under warranty only up to B5. In contrast, many European-made pumps can handle blends up to B100, though these and other European-made products currently have a limited presence in the US. Ultimately, according to the NBB, known tanks and systems are compatible with fuel blends up to B20; however, due to the lack of long-term experience, many oil burner manufacturers are not taking formal positions on biodiesel or explicitly covering blends higher than B5 in their warranties.[122]

6.4.2.5 Inconsistent policy support and policy implementation barriers

The federal blenders credit (discussed in Section 6.4.1) was first extended through 2008, but Congress allowed it to lapse at the end of the year before retroactively extending it. As a result, consumption declined from a high of 358 million gallons in 2007 due largely to the lapse. Production followed a similar pattern after reaching a high of 678 million gallons in 2008.[123] The credit was later reinstated retroactively and extended but for only a year at a time. The credit is currently set to expire again at the end of 2011. This unpredictability has hindered the growth of the biodiesel market in the US by creating uncertainty that restricts investment.

In addition, the regional nature of the heating oil market in New England complicates the formulation and implementation of state-level policies designed to encourage use of biodiesel. For example, establishing a biodiesel mandate would require determining at which point along the value chain to apply compliance obligations. If applied to wholesale and retail distributors, differing mandates could require distributors to maintain supplies of state-specific fuels if they serve customers in multiple jurisdictions. This would create significant logistical challenges and costs for regional suppliers or smaller retailers serving border communities.

6.5 Lifecycle Cost Assessment

The following section assesses lifecycle costs and payback for biodiesel systems in residential and multi-family/commercial buildings. As illustrated in Table 16 below, this scenario assumes that biodiesel is used for space heating applications in residential and commercial/multi-family facilities.

Table 16: Advanced Biodiesel Scenario

	SHW	GSHP	Biomass - pellets	Biodiesel
Residential	DHW Space Heat --	DHW Space Heat --	DHW Space Heat --	-- **Space Heat** --
Commercial	DHW Space Heat --	DHW Space Heat Cooling - elec	DHW Space Heat --	-- **Space Heat** --

System sizing requirements for residential and commercial/multi-family buildings as well as systems using biodiesel are detailed in Appendix A. Using these assumptions, systems using biodiesel have been modeled to calculate simple payback and levelized cost of energy (LCOE) for typical residential (13 kWth) and commercial/multifamily (97 kWth) installations.

6.5.1 Installed Costs

Installed costs for systems using biodiesel are assumed to be comparable to heating systems using conventional fuel oil. Based on feedback from Massachusetts installers as well as available case studies, it is estimated that conventional residential fuel oil system costs range from $8,450 to $9,100.[iii] Commercial system costs are estimated to range from $24,000 to $28,000.[jjj]

6.5.2 Life-cycle Cost of Energy: Residential Scenario

The residential biodiesel scenario assumes that a B5 advanced biodiesel blend replaces conventional fuel oil in the existing boiler or heating system. When assessed against other fossil fuels – like electricity or natural gas – the analysis assumes that the heating system using advanced biodiesel is an end-of-life replacement for the pre-existing fossil based heating systems. In both cases, the incremental upfront costs for converting to advanced biodiesel is essentially nil. However, due to the higher fuel costs associated with advanced biodiesel, it does not always present a financially attractive alternative to conventional fuel oil. Figure 39 below illustrates the LCOE of biodiesel and fossil fuels. Because payback is instantaneous when replacing electric systems and never achieved when replacing natural gas and fuel oil, the payback analysis is not presented graphically.

[iii] Assumed to be a 13 kWth (44,000 BTU/hr) system with 85% efficiency.
[jjj] Assumed to be a 97 kWth (331,000 BTU/hr) system with 85% efficiency.

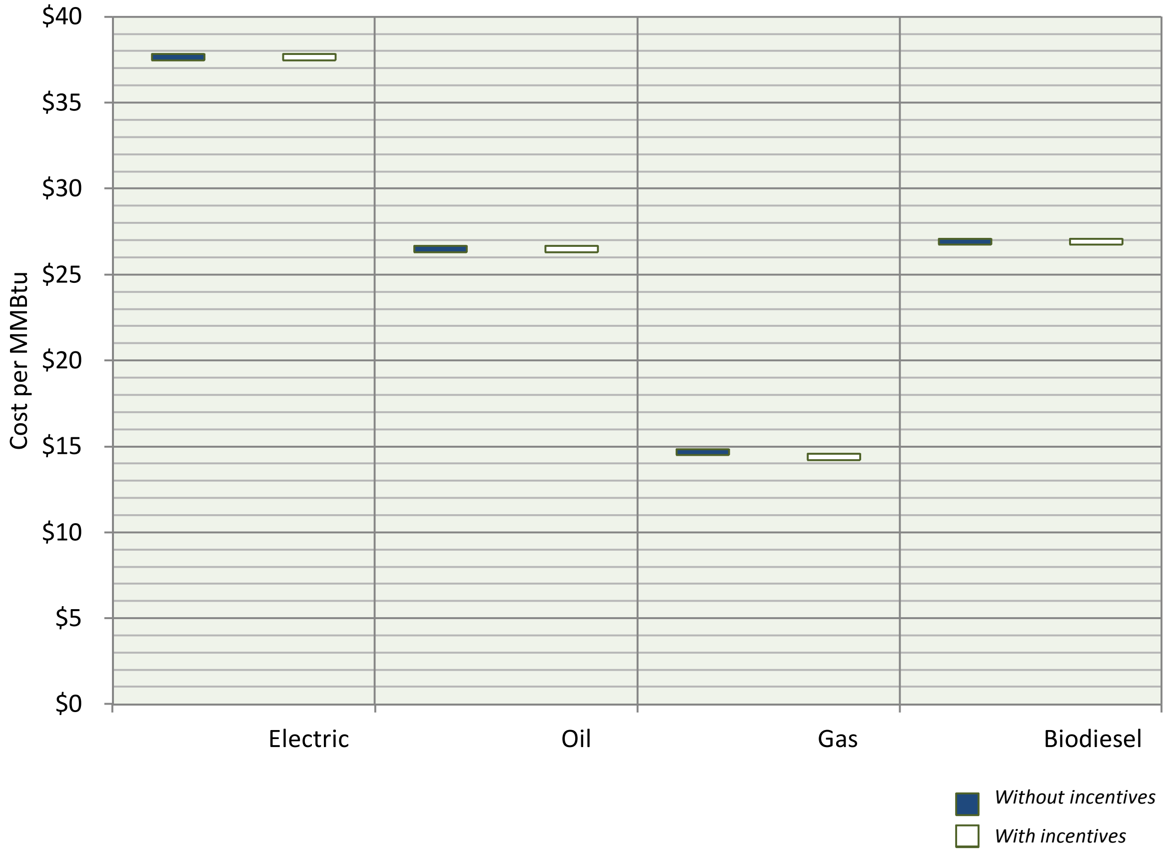


Figure 39: LCOE of Typical Residential Biodiesel Heating System in Massachusetts Compared to Fossil Fuel Alternatives

Relative to electric space heating, advanced biodiesel is a very attractive option, capable of achieving payback instantaneously. This is because the installed costs for a system using advanced biodiesel are assumed to be comparable to an electric heating system and the fuel costs for advanced biodiesel (on an MMBTU basis) are considerably lower. Moreover, over the lifetime of the system, residents will pay about $20.1 less for every MMBTU of heat produced by a biodiesel system than by an electric system**.**

Relative to fuel oil hot water and space heating, advanced biodiesel is less compelling. This is because advanced biodiesel is assumed to be more expensive than conventional fuel oil. As a result, customers using a biodiesel blend will pay slightly more per MMBTU of heat than if they had used conventional fuel oil. Payback is not achieved.

Relative to natural gas hot water and space heating, biodiesel does not result in financial savings. This is because advanced biodiesel is assumed to be more expensive than natural gas. As a result, customers using an advanced biodiesel blend will pay slightly more per MMBTU of heat than if they had used natural gas. Payback is not achieved.

In summary, at current low level blends, biodiesel results in significant and cost-effective GHG savings if it replaces electric heating in the residential scenario. At current and expected costs of natural gas and conventional fuel oil, however, advanced biodiesel does not present a financially attractive option.

6.5.3 Life-cycle Cost of Energy: Commercial Scenario

Like the residential scenario, the commercial biodiesel scenario assumes that a B5 advanced biodiesel blend replaces conventional fuel oil in the existing boiler or heating system. When assessed against other fossil fuels – like electricity or natural gas – the analysis assumes that the advanced biodiesel heating system is an end-of-life replacement for the pre-existing fossil based heating systems. In both cases, the incremental upfront costs for converting to advanced biodiesel is essentially nil. However, due to the high fuel costs associated with advanced biodiesel, it does not always present a financially attractive replacement for fossil fuel heating systems. Figure 40 below illustrates the LCOE of biodiesel and fossil fuels. Like the residential scenario. Because payback for commercial biodiesel systems is instantaneous when replacing electric systems and never achieved when replacing natural gas and fuel oil, the payback analysis is not presented graphically.

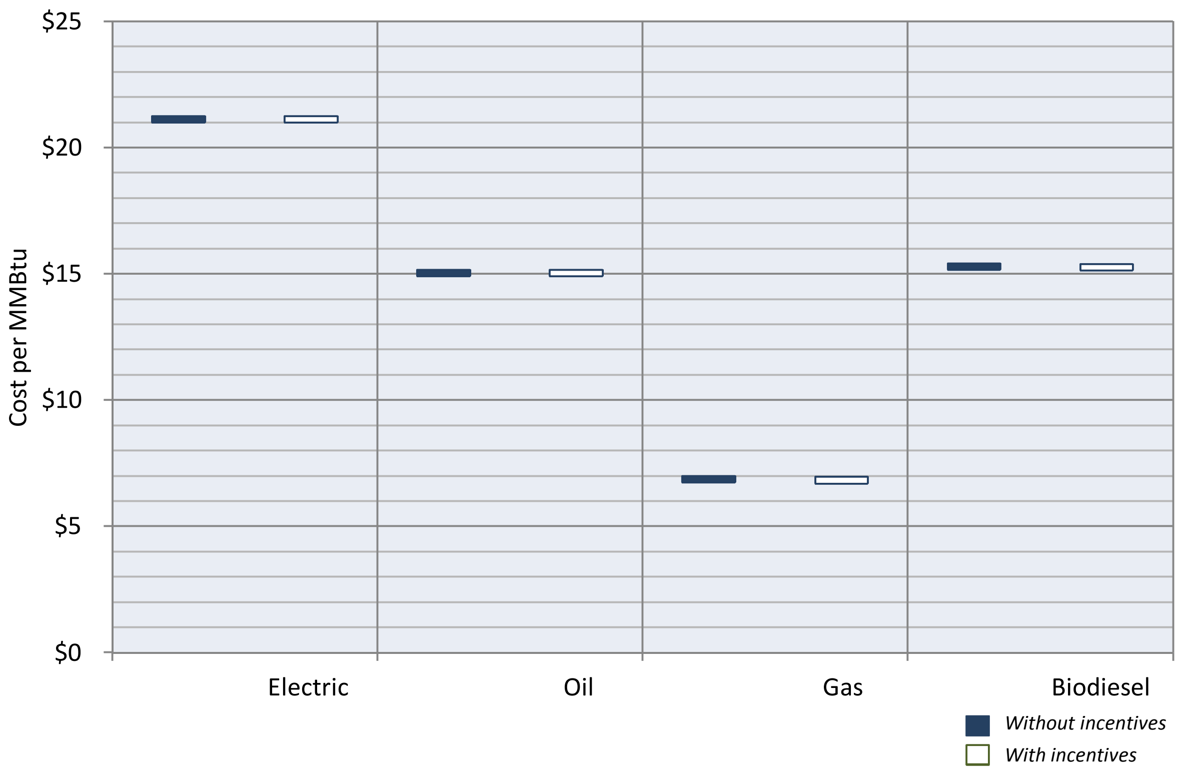


Figure 40: LCOE of Typical Commercial Biodiesel Heating System Compared to Fossil Fuel Alternatives

Relative to electric space heating, advanced biodiesel is a very attractive option, capable of achieving payback instantaneously. This is because the installed costs for a system using advanced biodiesel are assumed to be comparable to an electric heating system and the fuel costs for advanced biodiesel (on an MMBTU basis) are considerably lower. Moreover, over the lifetime of the system, residents will pay about $5.9 less for every MMBTU of heat produced by a biodiesel system than by an electric system**.**

Relative to conventional fuel oil space heating, advanced biodiesel is less compelling. This is because advanced biodiesel is assumed to be more expensive than conventional fuel oil. As a result, customers using a biodiesel blend will pay slightly more per MMBTU of heat than if they had used conventional fuel oil. Payback is not achieved.

Relative to natural gas space heating, biodiesel does not result in financial savings. This is because advanced biodiesel is assumed to be more expensive than natural gas. As a result, customers using an advanced biodiesel blend will pay slightly more per MMBTU of heat than if they had used natural gas. Payback is not achieved.

In summary, at current low level blends, biodiesel results in significant and cost-effective GHG savings if it replaces electric heating in the commercial scenario. At current and expected costs of natural gas and conventional fuel oil, however, advanced biodiesel does not present a financially attractive option.

6.6 Greenhouse Gas Assessment

GHG reductions from advanced biodiesel systems are calculated by estimating GHG emissions avoided from fossil fuel systems.[kkk] In Figure 41 and Figure 42 below, the red bars illustrate the GHG emissions resulting from a typical B5 advanced biodiesel blend. The green bars represent the GHG emissions avoided by replacing fossil fuel heating systems with advanced biodiesel. For example, a typical residential system replacing electricity with advanced biodiesel (B5) reduces GHG emissions by about nine tons annually. However, by contrast, a typical residential system replacing natural gas with advanced biodiesel (B5) results in an increase of GHG emissions by approximately two tons. In other words, heating systems using B5 advanced biodiesel blends do not achieve GHG reductions when compared with natural gas heating.

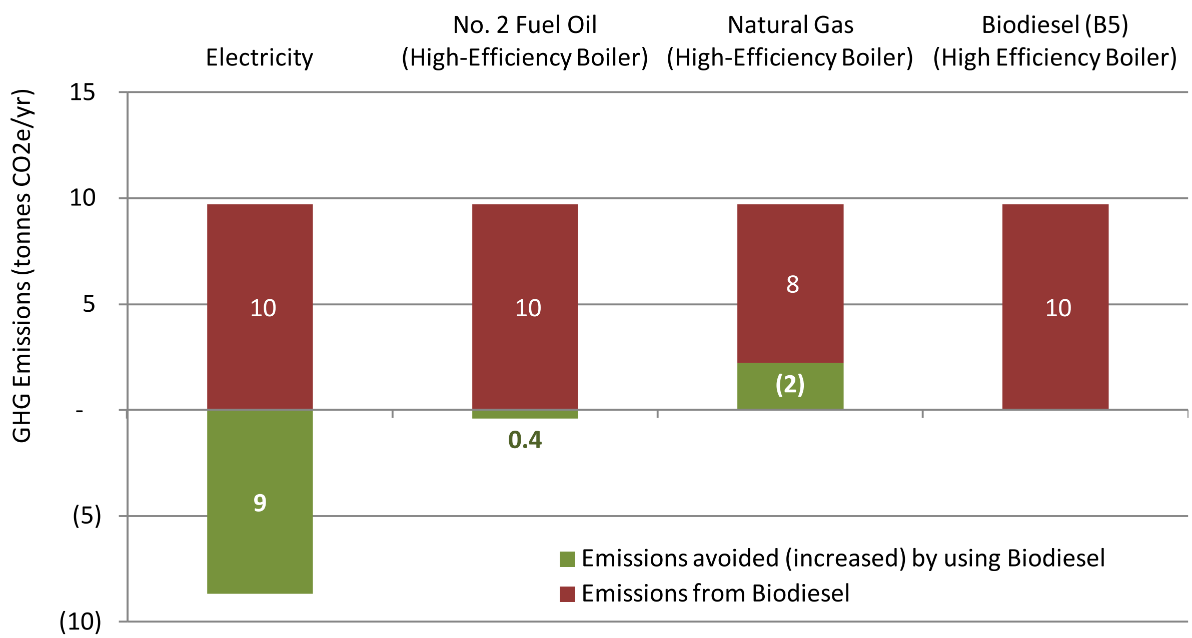


Figure 41: Annual GHG Emissions Avoided by Residential Biodiesel Heating Systems

[kkk] GHG reductions were calculated using the Environmental Protection Agency's factor for GHG reductions associated with biodiesel from waste grease.

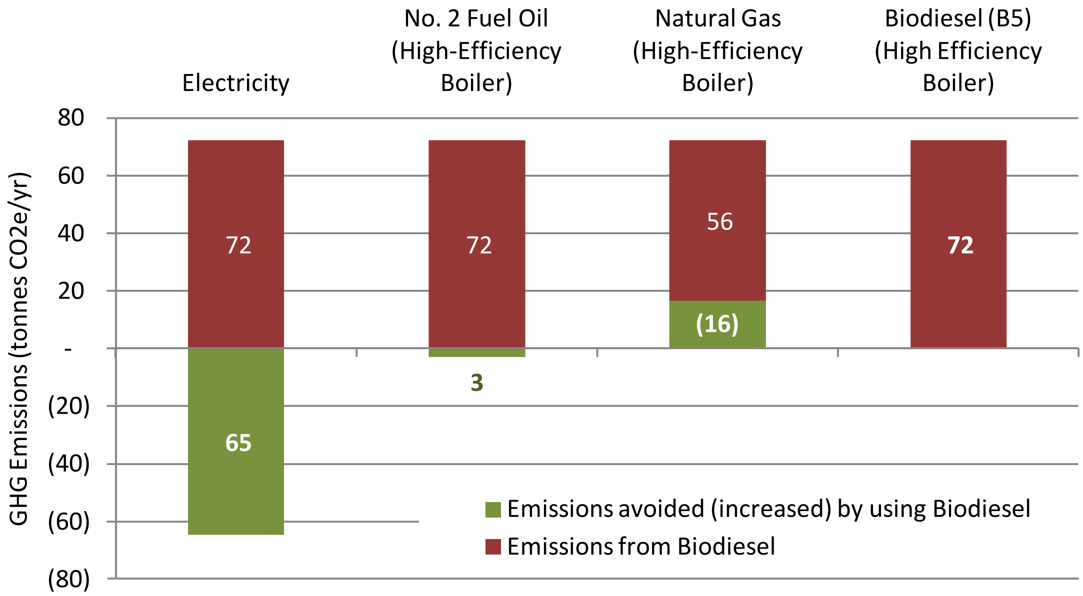


Figure 42: Annual GHG Emissions Avoided by Commercial Biodiesel Heating Systems

6.7 Job Creation, Economic Development, and GHG Emission Reduction Scenarios

The *Massachusetts Clean Energy and Climate Plan for 2020* does not establish a formal target for GHG reductions from advanced biodiesel. However, for purposes of this analysis, MassCEC and Mass DOER estimate that advanced biodiesel has the potential to achieve 5% of the two million tons of GHG reductions from renewable thermal by 2020 – or approximately 100,000 tons.[lll] Additionally, though job creation estimates were unavailable for this analysis, this could also result in modest new job creation associated with in-state manufacturing of advanced biodiesel.

Table 17: Advanced Biodiesel GHG Emission Reduction Scenarios

Advanced Biodiesel	Annual GHG Emission Reductions
BAU by 2020	34,484
Accelerated Growth by 2020	100,000
Accelerated Growth by 2050	309,353

The Building as Usual (BAU) scenario estimates the near-term potential for the advanced biodiesel market in Massachusetts and projects associated GHG emissions reductions. While Massachusetts does have a small number of in-state advanced biodiesel production facilities, there is no data available on the advanced biodiesel content of existing fuel oil consumed in the Massachusetts market. Although stakeholders report that much of the fuel supply entering the state contains a small percentage of (conventional) biodiesel, at most a negligible amount is advanced biodiesel. For purposes of this analysis, advanced biodiesel consumption in fuel oil was assumed to be zero. As a result, a market growth rate could not be calculated. In place of market growth, this scenario assumes that additional

[lll] The GHG reduction target of 5% is for illustrative purposes only. It does not constitute a formal target for the Commonwealth of Massachusetts.

advanced biodiesel production comes on line between 2011 and 2020, increasing the total quantity of advanced biodiesel blended into fuel oil consumed in the state (see Appendix B). A conservative estimate of nearly 0.8% advanced biodiesel by 2020 would mean that advanced biodiesel provides roughly four million gallons of heating fuel in 2020. This would yield about 34,000 tons of GHG reductions.

The Accelerated Growth by 2020 scenario projects the growth required to meet the advanced biodiesel GHG reduction target of 100,000 tons. In order to meet this goal, approximately 11.6 million gallons of fuel oil would need to be replaced with advanced biodiesel by 2020. This translates to roughly a 2.4% advanced biodiesel blend in all commercial and residential fuel oil heating applications. If this goal is achieved, this analysis further estimates that over $262 million would be retained in the region by replacing expenditures on foreign fuel with locally produced renewable thermal fuels.

The Accelerated Growth by 2050 scenario assumes that a certain percentage of the state's fossil fuel systems are replaced with a mix of renewable thermal technologies by 2050 (based on assumptions laid out in the Massachusetts Clean Energy and Climate Plan for 2020) and projects the associated GHG emissions reduction benefits. This analysis shows that replacing 5% of existing fuel oil with advanced biodiesel (i.e. a B5 advanced biodiesel blend) would yield GHG emissions reductions of approximately 309,000 tons.

CHAPTER 7: HIGH EFFICIENCY HEAT PUMPS

7.1 Introduction

Heat pumps are an increasingly popular choice for building owners in the Commonwealth, and new and emerging technologies have the potential to help Massachusetts meet its climate commitments. This section examines two heat pump technologies that have high potential to provide low-cost, low-carbon climate control solutions in the New England region. The first section explores ground source heat pumps (GSHPs), an established technology with a decades-long record of successful use throughout the United States. The second section looks at a new generation of efficient air source heat pumps (ASHPs). These ductless, inverter-driven heat pumps have been successfully used in both Europe and Asia to provide heating and cooling solutions in regions with climates similar to Massachusetts and represent a promising technology for Massachusetts emerging heating and cooling market.

Market barriers and opportunities were assessed for both GSHPs and ASHPs; however, because reliable market data on the performance and costs of ASHPs is not available for Massachusetts or New England, this chapter stops short of an assessment of ASHP lifecycle costs, GHG emissions, and economic development impacts performed for other renewable thermal technologies.

7.2 Key Findings and Conclusions

At current market growth rates,[mmm] the Massachusetts GSHP market is on-track to provide 160,138 tons of GHG reductions and create approximately 69 jobs by 2020. Under an accelerated growth scenario,[nnn] GSHPs could achieve 700,000 tons of GHG reductions and create approximately 485 jobs by 2020. While not projected here, the development of a vibrant ASHP market in Massachusetts also has the potential to significantly increase the GHG emission reduction and economic development benefits in the region.

Stakeholders identified several barriers to development of the high efficiency heat pump market. For example, relative to fossil fuel heating systems, GSHPs (and ASHPs) are subject to high first costs. This is particularly true for GSHPs installed at the residential level. Nonetheless, the typical residential GSHP system that replaces electric or fuel oil heating is estimated to have a reasonably good payback, ranging from five to and 10 years respectively. In the commercial scenario, payback is even lower, estimated to be less than three years for systems replacing natural gas, fuel oil, and electricity. This is due, in part, because the commercial scenario analysis takes into account the space heating *and cooling* benefits of GSHPs; the residential scenario takes into account only the space heating benefits of GSHPs.

Other barriers impeding wider adoption of heat pumps include inconsistent regulatory standards with respect to well drilling for GSHPs; customer unfamiliarity with low-temperature ASHPs; and a lack of experienced engineering and design firms for commercial systems. As a result, some stakeholders indicate that many installations may suffer from poor design or improperly sized installations, which require the use of expensive, inefficient, and environmentally detrimental supplemental resistance heating systems.

Additionally, stakeholders indicate that both the GSHP and ASHP sectors lack good quality market and industry data. In particular, GSHP stakeholders indicate that comprehensive data about system sizes,

[mmm] Historical annual market growth rate for GSHPs is estimated to be between 20% and 25%.
[nnn] Aggressive annual market growth rate is assumed to be 47%.

installed costs, component costs, and system performance is needed. To this end, this report stops short of a cash flows, GHG, and economic development analysis for ASHPs due the lack of independent and comprehensive market data on cold-climate ASHPs. Going forward, the Commonwealth may consider conducting a comprehensive study and pilot program to assess the advantages and disadvantages of cold-climate ASHPs in Massachusetts. Finally, greater data will likely be needed to understand the effects of heat pumps on electricity peak loads in order to better understand the costs and benefits of greater integration of heat pump technologies.

7.3 Ground Source Heat Pumps

Ground source heat pumps (GSHPs) are a class of heating and cooling technology that use the earth's stable ground temperature to provide high efficiency heating and cooling to buildings throughout the year. Ground source heat pump technologies have been in use for more than seventy years.[ooo] GSHPs can use the earth as a renewable heat energy source during the heating season and a heat sink during the cooling season. By contrast, traditional air source heat pumps (ASHPs) that extract and deposit thermal energy into the outside air must serve their highest heating and cooling loads during times when ambient air temperatures are their lowest and highest respectively, making them a less efficient option.

Ground source heat pumps have been classified as both energy efficiency and renewable energy technologies, and some disagreement exists within the industry as to how best to classify them. Ground source heat pumps use grid supplied electricity to extract thermal energy from the earth, and in well designed systems, the ratio of renewable energy extracted to grid energy consumed may be as high as 5.5 to 1. Whether they are creating energy, or using energy more efficiently, is a matter of perspective, and many utilities outside Massachusetts include GSHPs under their energy efficiency programs, while several state energy offices have chosen to provide GSHP rebates as part of their renewable energy programs. The classification of GSHP technologies as efficiency or renewable energy technologies may have implications for incentive funding and policy development under existing Massachusetts legislative mandates.

7.3.1 Technology Overview

Typical ground source heat pumps are composed of two major system elements – the earth coupling system and the mechanical (above ground) system. The earth coupling system is the primary heat transfer system for exchange of heating and cooling energy with the ground. The mechanical (above ground) system consists of the heat pump, heat distribution, and other mechanical components located near or inside the building. Each major system element is discussed in Sections 7.3.1.1 and 7.3.1.2 below.

7.3.1.1 Earth Coupling Design Types

There are a range of earth coupling methods and variety of different naming conventions within the industry. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) adopted the following classifications system for ground source heat pump technologies:[ppp] (i) Groundwater Heat Pumps (GWHPs), (ii) Ground-Coupled Heat Pumps (GCHPs), and (iii) Surface Water Heat Pumps (SWHPs). Each of these technologies has its own advantages and disadvantages, and many

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[ooo] US Department of Energy (DOE). (February 2011). Geothermal Heat Pumps. Retrieved from www.energysavers.gov/your_home/space_heating_cooling/index.cfm?mytopic=12640.

[ppp] RETScreen International. (2005). Clean Energy Project Analysis: RETScreen Engineering & Case Studies Textbook: Ground-Source Heat Pump Project Analysis Chapter. Prepared for Natural Resources Canada (NRCAN). Catalogue No.: M39-110/2005E-PDF. p. 12.

industry participants have developed specialized expertise in a particular technology. Site specific conditions will frequently dictate the most appropriate ground coupling technology choice.[124] The following section gives a brief overview of each of the earth coupling methods and describes some of the design considerations inherent in each.

First, *Groundwater Heat Pumps* (or open-loop systems) use groundwater wells as the source of working heat transfer fluid for the heat pump. These systems directly extract water from a source groundwater well and circulate it through the heat pump unit in the building (see Figure 43 below).

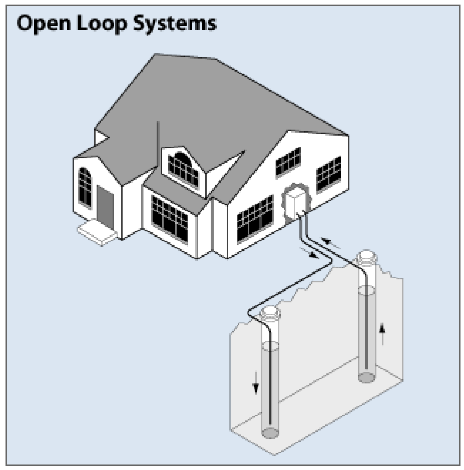

Figure 43: Groundwater Heat Pump System (US DOE, February 2011)

A number of potential configurations can be used for this type of system, from single standing-column wells to multiple wells. In a multiple well system, groundwater is pumped from one well, passed through the heat pump, then returned to the ground in a separate well. Open loop systems of this type can also be designed to discharge groundwater into nearby water bodies. Alternately, a single standing column well can also be used as the groundwater source. In this configuration, the GSHP both extracts and returns groundwater from the same well. Single standing column well systems may be less efficient than multiple-well systems; however, this configuration requires less drilling and may result in significant first-cost savings. Open loop systems of all types may be designed to control the temperature of the discharge well by bleeding a small percentage of the return water flow from the system. The use of ground water (as opposed to antifreeze fluid) as the heat transfer fluid in GWHPs provides for more robust heat exchange and leads to higher heating and cooling efficiency for these types of systems.

Next, *Ground-Coupled Heat Pumps* (or closed-loop heat pumps), achieve heat transfer by circulating an antifreeze fluid in a closed piping circuit. As illustrated in Figure 44 below, GCHPs can be configured in two ways, vertical well and horizontal loop fields. In a vertical loop configuration, a series of wells are drilled and heat exchange piping is inserted into the boreholes. The circulating fluid moves through the loops and thermal energy is exchanged between the circulating fluid and the ground through the loop piping. In horizontal loop systems trenches are dug in an area around a building, and flexible piping containing the heat transfer loop are buried under the ground. Because drilling is not required, horizontal loop ground coupling is typically less expensive than vertical well systems; however significant land area may be required to achieve suitable system sizes.

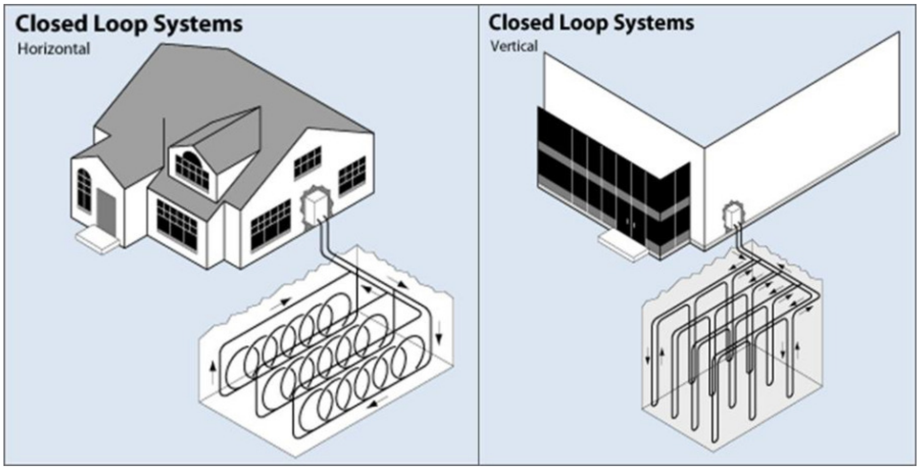

Figure 44: Closed Loop Ground Coupling Systems (US DOE, February 2011)

Because closed loop systems are designed to have a barrier between the earth and the heat transfer fluid, they are generally less efficient at transferring heat than ground water GSHP systems. Closed loops systems may be preferred in areas where groundwater is not close to the surface, or where environmental regulations prevent the use of open loop systems. Closed loop systems also benefit from reduced operations and maintenance costs, as the chemical composition of the heat transfer fluid can be tightly controlled leading to lowered system corrosion.[125]

Finally, *Surface Water Heat Pumps* are the least common design option of the three. These systems use nearby water bodies as both the source and sink of heat transfer fluids. Surface water heat humps may range in size from residential systems to large scale district cooling systems. Surface water heat pump systems are a niche market, and this technology likely has limited applicability in Massachusetts due to the absence of suitable sites in the state.

7.3.1.2 Mechanical (above ground) Heat Pump Design Types and Efficiencies

As with earth coupling methods, the heat pump and other mechanical (above ground) systems also vary to suit the needs of different building types. Heat pumps are specifically manufactured for either closed- or open-loop ground coupling. This is required due to differences in the properties of ground water or anti-freeze heat transfer fluids. Heat pumps are also designed as either "water-to-air" systems, which serve buildings with forced air heating and cooling, or "water-to-water" models, which are designed for buildings with hydronic heating.

Under the Energy Star program, the U.S. EPA rates the efficiency and performance of GSHPs. Because efficiency varies due to design options, Energy Star criteria are defined for a number of system types. For example, GSHPs are rated on both their heating efficiency (Coefficient of Performance or COP) as well as their cooling efficiency (Energy Efficiency Ratio or EER).[qqq] Energy Star additionally maintains a multi-tiered performance rating scale, with the best performing units receiving higher tier ratings.[rrr] Table 18 lists Energy Star efficiency criteria for the most efficient tier (Tier 3) of heat pumps starting in 2012.[126] The higher the EER or COP, the more efficient the heat pump's cooling and heating efficiency

[qqq] COP is the ratio of heating or cooling of a heat pump (or other refrigeration appliance) to the energy consumed by the system under designated operating conditions. The EER is the ratio of output cooling (in Btu/hr) to input of electrical power (in Watts) at a given operating point. For a detailed discussion on HVAC system rating methodologies, readers should consult www1.eere.energy.gov/femp/pdfs/26014.pdf

[rrr] Energy Star rating requirements are revised on a regular basis, and new guidelines are set to go into effect in January 2012.

respectively. The current list of Energy Star GSHPs includes more than 3,400 models from 25 manufacturers.

Table 18: Energy Star Efficiency Requirements for Geothermal Heat Pumps (Energy Star, n.d.)

Tier 3 Requirements (Effective January 1, 2012)		
Product Type	**EER**	**COP**
Water-to-Air		
Closed Loop Water-to-Air	17.1	3.6
Open Loop Water-to-Air	21.1	4.1
Water-to-Water		
Closed Loop Water-to-Water	16.1	3.1
Open Loop Water-to-Water	20.1	3.5
Direct Ground Exchange (DGX)		
DGX	16	3.6

7.3.2 Market Status and Value Chain

7.3.2.1 Overview

The U.S. Energy Information Administration conducts an annual survey of domestic ground source heat pump manufacturers in the US. Figure 45 below shows the total annual shipments of geothermal heat pumps by tons from 2004 to 2009 based on EIA's domestic manufacturer survey data. While this survey does not include imports from foreign manufacturers, it is a good indicator of growth trends of the national geothermal heat pump market.

The data indicate steady market growth during the previous decade with a marked flattening of the growth trajectory between 2008 and 2009. This market retrenchment may be associated with the recent economic downturn and the general decrease in building activity throughout the country. Of note, the data does not include 2010, the first full year when residential systems were eligible for the uncapped 30 percent investment tax credit.

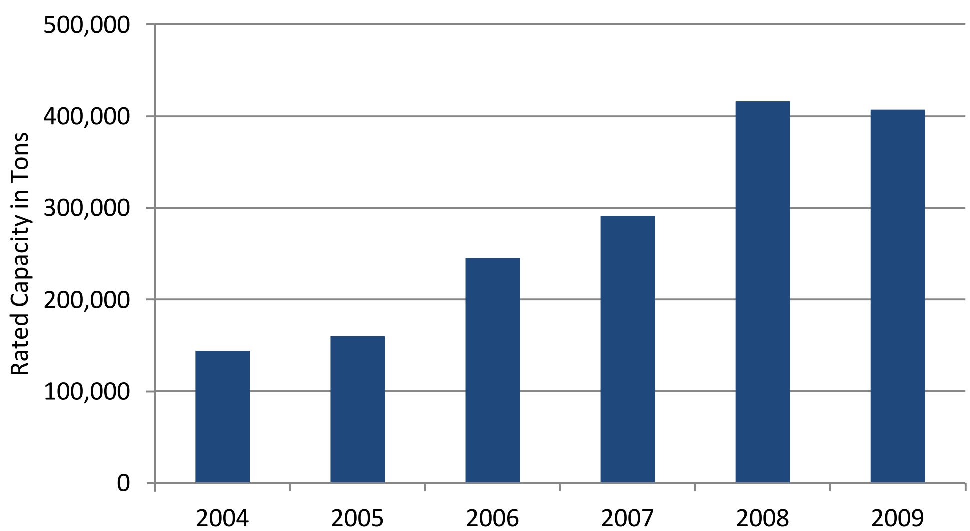

Figure 45: EIA Geothermal Heat Pump Shipments in Rated Tons, 2004-2009 (EIA, 2009)

Of the 27 geothermal heat pump manufacturers who responded to the most recent EIA survey, none were located in New England. The majority of manufacturing capacity is found in Florida, Indiana, Oklahoma, South Dakota, and Texas. EIA also tracks GSHP shipments by ton by destination state. In 2009, Massachusetts ranks 31st, in terms of shipments received, well below the national median in absolute shipments. Massachusetts ranked 39th in the nation when shipments are adjusted for population (i.e. shipments per capita). [127]

Within Massachusetts, the Massachusetts Department of Environmental Protection (MassDEP), under its authority to regulate underground injection wells, permits drilling for ground-coupled GSHPs, thus enabling one to estimate the number of systems installed in the state. Figure 46 details the permit applications approved by MassDEP between 2004 and 2010 (differentiated between open and closed loop systems), showing that between approximately four and 101 GSHPs have been installed each year. This corresponds to a compound annual growth rate (CAGR) of approximately 24% annually.

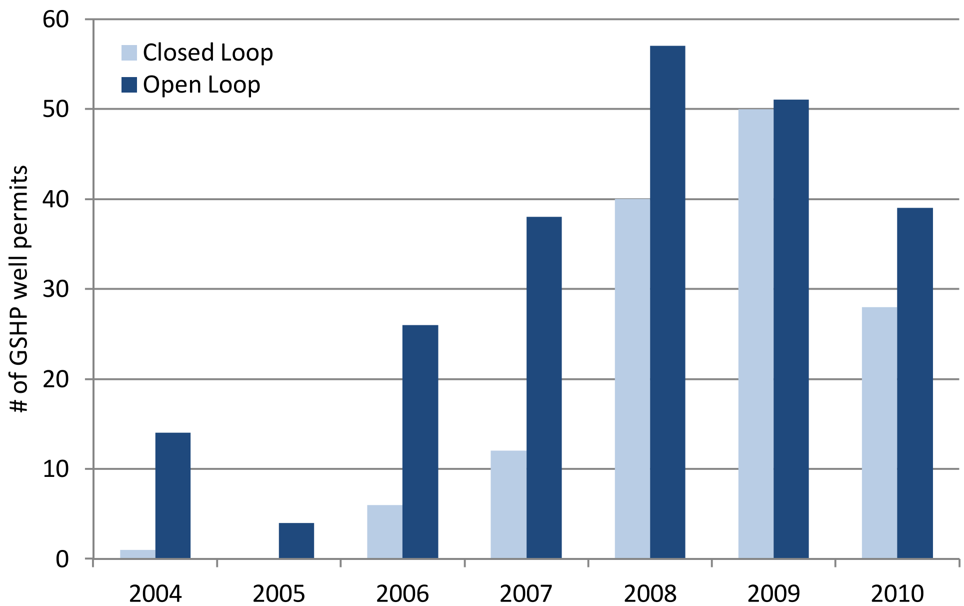

Figure 46: Geothermal Heat Pump Drilling Applications (MassDEP, 2010)

While Massachusetts has not experienced growth as robust as other states in the US, it does have a growing GSHP market. Continued (and/or increased) growth of the GSHP market requires a strong market value chain, which includes a number of specialized professions including well drillers, system designers and HVAC installers. The following section briefly discusses each of these trades and characterizes its current market status in Massachusetts.

7.3.2.2 Well Drilling

GSHP stakeholders indicate that drilling capacity is a potentially limiting factor to increased growth of the Massachusetts GSHP market. According to MassDEP, however, 40 firms applied for GSHP drilling permits from 2001 to 2010. Given that 376 well sites are reported in the database, this would indicate that the average Massachusetts GSHP drill operator drilled fewer than 10 total wells over the last decade.

However, a closer assessment of the data reveals that most of the GSHP drilling activity in the state was completed by only a few companies. In fact, five drilling companies completed nearly half of all GSHP wells drilled between 2001 and 2010. While it is difficult to draw conclusions from this limited dataset, it appears that of the Massachusetts drilling companies capable of serving the GSHP market, most do not depend on GSHP projects as a key business driver at this time.

Stakeholder interviews have also indicated that existing drillers interested in entering the GSHP market will need to make significant capital investments to drill closed loop GSHP wells. This was cited as a potentially significant barrier to market expansion in the Commonwealth. Given that high drilling costs are a major market barrier for wider adoption of GSHP technologies, this may be a worthwhile area for further policy focused research.

7.3.2.3 System Installation

The International Ground Source Heat Pump Association (IGSHPA) is a leading GSHP installer training organization, which maintains a list of all accredited installers on its website. According to IGSHPA, 204 accredited GSHP installers are located in Massachusetts. IGSHPA does not differentiate between installers active in the market, and those that primarily install and service other HVAC technologies; however, when considered with GSHP shipment data from EIA for 2008 and 2009, IGSHPA data provides a useful foundation for developing an estimate of accredited installer capacity utilization in Massachusetts. EIA reports 3,054 total tons of GSHP were shipped to Massachusetts in 2009, meaning that, on average, accredited installers in the state could be expected to install approximately 15 tons of GSHP in 2009. This is roughly equivalent to the total capacity of three single family homes. This high-level data analysis would seem to indicate that the Massachusetts GSHP market is not currently constrained by installer capacity.

7.3.2.4 Engineering, Design, and Architectural Services

Industry stakeholders indicate that dedicated engineers or architects are not typically employed for residential scale GSHP installations and that the residential sector is well-served by GSHP installers, who have the skills necessary to provide the engineering services required for residential jobs. However, larger and more complicated GSHP installations often require the services of dedicated engineers or architects. According to IGSHPA, only three system designers are listed as accredited design professionals in Massachusetts,[128] though stakeholders indicate that several engineering firms from New Hampshire, Maine, and Connecticut commonly provide design support. With this in mind, stakeholders indicate that approximately six engineering firms consistently provide commercial GSHP design services. This supports industry stakeholder sentiments that, in general, *typical* building design firms do *not* have significant experience with commercial-scale GSHP technologies, and that relatively few firms have invested in developing this niche expertise.

7.3.3 Drivers and Barriers

7.3.3.1 Market Drivers

The growth of the Massachusetts GSHP market is fueled by a number of key drivers at the local, regional, and national levels. As with many types of renewable energy systems, the federal energy Investment Tax Credit (ITC) is available to both home owners and businesses who install GSHP systems. The ITC currently provides a 30% tax credit for homeowners who invest in GSHPs and a 10% tax credit for business owners. The Energy Improvement and Extension Act of 2008 expanded the ITC to 30% for residential systems, significantly improving the economics of GSHPs for homeowners across the country.[sss]

In addition to the ITC, the IRS allows business owners who invest in GSHPs to depreciate their investment using the 5-Year Modified Accelerated Cost Recovery System (MACRS) schedule. In addition, business owners can qualify for 100 percent federal bonus depreciation in 2011. Typically, the system life of mechanical (above ground) components lasts 25 years. Ground loop components usually have a life over 50 years.[129] Given these long book lives, the 5-Year MACRS allowance provides a significant tax benefit to system owners.

Massachusetts also has some of the most aggressive and best funded utility-sponsored energy efficiency programs in the nation.[130] Utilities currently support a subsidized financing program called the HEAT Loan. This program provides qualifying home owners with zero percent financing up to seven years on loans up to $25,000. High efficiency GSHPs (with a COP greater than 3.3) are currently eligible to benefit from the HEAT Loan.

Finally, a number of non-financial drivers and larger social trends have encouraged market growth of GSHPs. For example, in recent years, the number of central cooling systems in the northeast HVAC market has increased. In 2009, for example, 18 percent of New England homes reported owning central cooling systems, an increase from 14 percent from 2005.[131] Within Massachusetts, approximately 3% of residential cooling systems are heat pumps.[132] Overall, the region-wide increase in central cooling technology would indicate a benefit to the growth of the residential GSHP market.[ttt]

Additionally, stakeholders indicate that many large commercial-scale geothermal systems recently installed in Massachusetts have been in buildings seeking environmental certification from organizations like Leadership in Energy and Environmental Design (LEED). Under current LEED new construction guideline, GSHPs enables buildings to qualify for points in a variety of categories.[uuu] It is likely that adoption of voluntary building labeling standards such as LEED will also drive development of the GSHP market among commercial building owners in the future.

7.3.3.2 Market Barriers

A 2008 study by the U.S. Department of Energy's Oak Ridge National Lab identified key barriers to development of the national GSHP market. These barriers, listed in order of priority, include: (i) high first cost of GSHP systems to consumers; (ii) lack of consumer knowledge and/or trust or confidence in GSHP system benefits; (iii) lack of policymaker and regulator knowledge and/or trust or confidence in GSHP system benefits; (iv) limitation of GSHP design and business planning infrastructure; (v) limitation of GSHP installation infrastructure; and (vi) lack of new technology and techniques to improve GSHP system cost and performance.[133] Oak Ridge National Laboratory's assessment largely parallels market

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[sss] It is worth noting that as with all federal tax credits, tax-exempt organizations (like non-profits and government entities) cannot take advantage of this incentive. While innovative financing mechanisms involving tax-equity investors have been developed by the private sector to help overcome this issue, according to regional stakeholders, third-party ownership models for GSHPs have not made a significant impact on the tax-exempt GSHP market. This is generally true for all renewable heating technologies.

[ttt] It is also important to note that the continuation of this trend has implications for summer-time peak load management. The issues of peak demand management and the potential for state support of GSHP technology to mitigate this problem are significant benefits that are not quantified in this report but further examination of this topic may be warranted.

[uuu] A detailed discussion is beyond the scope of this report. However, for additional information, please see: Carda, R. (n.d.). Let Geo LEED the Way. Prepared for Geo Connections. Retrieved from www.geoconnectionsinc.com/downloads/Let_Geo_LEED_the_Way.pdf.

barriers identified by New England GSHP industry stakeholders, which are detailed in the following sections.

7.3.3.2.1 High First Costs

The most significant barrier to widespread adoption of GSHP technology – cited by both industry stakeholders and existing literature – is the comparatively high upfront capital investment cost of GSHPs compared to conventional heating and cooling systems. According to the Connecticut Clean Energy Fund, installed costs averaged $8,856 per cooling ton for residential closed loop GSHP systems. Conventional oil fired boilers installed in Massachusetts, by contrast, average approximately $2,400 per residential heating ton.

However, as indicated in Section 7.3.1, the installed costs of GSHPs can vary significantly, depending upon the complexity, geography, and building requirements of the GSHP system. For example, stakeholders indicate that residential GSHP systems can cost as little as $4,500 per ton – with standing column or open diffusion systems costing less than closed loop systems. Industry sources also indicate that the ground coupling system can cost between 40 and 60 percent of total system installed costs, a fact supported by numerous published reports and national surveys.[134] Ultimately, the cost and complexity of ground coupling is a major factor behind the first-cost price difference of traditional HVAC systems and GSHPs.

Other factors driving the high first cost of GSHPs systems include:

- small market share leading to underinvestment by potential market participants including drillers, installers and designers;[135]
- low volume of GSHP manufacturing compared to ASHP and other HVAC technologies;[136]
- high customer acquisition costs due to poor public awareness or trust in GSHP technology;[137]
- regulatory and permitting uncertainty in some Massachusetts municipal jurisdictions;[vvv]
- unexpected site conditions may add significant risk premiums to GSHP estimates as system designers try to account for unknown drilling conditions;[138] and
- Massachusetts' high bedrock geology, which increases drilling costs for vertical well systems.

7.3.3.2.2 Inadequate Market and Industry Data

Industry stakeholders indicate that high quality market data is needed to grow the GSHP market in Massachusetts. While the Massachusetts DEP tracks installed systems by issuing drilling permits, more comprehensive data about system sizes, installed costs, component costs, and system performance is needed to increase market knowledge and transparency in Massachusetts. To this end, national studies assessing GSHP installation costs have typically *not* had good quality datasets to guide policy.[www]

System level performance data is also not widely available. A comprehensive effort to develop high quality system performance data would assist policymakers evaluate the benefits of GSHP systems, and additionally improve the industry's profile and credibility with potential building owners. Stakeholders indicate that more advanced monitoring technologies are beginning to be incorporated into some GSHP

[vvv] Stakeholders indicated that local public health boards in some Massachusetts municipalities refuse to approve GSHP installations in their jurisdictions

[www] As part of this study, the Connecticut Clean Energy Fund was contacted regarding their American Recovery and Reinvestment Act funded GSHP rebate program. Connecticut program officials provided data detailing installed GSHP costs for each of the 360 systems installed under their program. The CTCEF intends to make this market data public in the near future, and when published, this will be the most comprehensive database of GSHP installations in New England.

units, and that the adoption of this new technology could make detailed system performance data more accessible in the near future.

7.3.3.2.3 Lack of Local Regulatory Knowledge

Industry stakeholders indicate that regulatory hurdles, while not a major barrier to GSHP technology at the state level, do affect market growth at the local level. For example, local jurisdictions have caused occasional issues for installers and building owners seeking to install GSHPs. Local boards of health and building inspectors are commonly unfamiliar with GSHP technologies and, as a result, have been known to place undue regulatory burdens on systems installed in their municipalities. Industry stakeholders suggest that an outreach and education campaign to better inform local authorities about the proper design and installation parameters for GSHP systems could potentially alleviate these issues.

7.3.3.2.4 Local Property Taxes

Renewable energy technologies including solar PV, wind, solar thermal and hydro facilities are exempt from local property taxes in the Commonwealth.[139] However, residential and business GSHP systems are not exempt from property taxes, and industry stakeholders indicate that uncertainty around the potential tax implications of GSHP installations remains a concern for many building owners. The high investment cost of GSHP systems could significantly add to the assessed value of a home or other buildings and trigger an increase in local property taxes. While this was cited as a cause of uncertainty for the industry, further study may be warranted to determine if local jurisdictions are currently increasing assessed values of buildings with GSHP technologies.

7.3.3.2.5 Limitation of GSHP Installation Infrastructure

The existing HVAC infrastructure of many Massachusetts buildings is a challenge for the GSHP retrofit market. Industry experts report that high temperature hydronic heating systems make up a significant market share of heating systems in Massachusetts' building stock. There is a limited selection of GSHPs that can reach the high temperatures needed for traditional hydronic heating systems, although new high-temperature heat pumps marketed for the boiler replacement market are available from a growing number of manufacturers.[140] Regardless of the ability for GSHP systems to provide high-temperature heating needed for typical hydronic systems, building owners who wish to take advantage of the cooling benefits of GSHPs may need to incur the additional cost of installing duct work throughout a building to distribute conditioned air. This additional cost, however, would be incurred for any building owner who does not currently have duct work and is interested in installing traditional central cooling.

7.3.3.2.6 General Market Conditions

Several macro market conditions were also cited by stakeholders as ongoing barriers to wider adoption of GSHP technology. Given the complexity of retrofitting buildings with GSHP systems, the new construction market is particularly well suited for GSHP technologies; however the recent economic downturn and the continued struggles of the new-construction housing market have limited GSHP market growth potential. The recent economic downturn has also negatively affected the balance sheets of many home and business owners both making them less inclined to make large investments in unfamiliar technologies and limiting credit availability.

Industry stakeholders also cite the current low costs of natural gas as another market barrier. The comparative costs of heating fuel are a critical component in any decision to adopt GSHP technologies, and the record low costs of natural gas is a disincentive to invest in GSHPs. However, this market barrier should be contrasted with the recent increases in cost of delivered heating oil, which is likely driving some adoption of GSHP in areas that do not have access to natural gas service.

7.3.3.2.7 Inadequate GSHP Design and Business Planning

Improperly designed GSHP systems are also a significant industry concern. Poorly designed systems that are undersized for the building load may require the use of expensive, inefficient and environmentally detrimental supplemental resistance heating systems. Improperly designed or installed systems with backup resistance heating can also have a net negative effect on utility peak loads, a particular concern for Massachusetts utilities. This can be especially problematic if building owners in the Massachusetts market are switching from fossil fuel heating systems to an electric-driven GSHP system.

7.4 Lifecycle Cost Assessment

The following section assesses lifecycle costs and payback for GSHP systems in residential and multi-family/commercial buildings. As illustrated in Table 19 below, this scenario assumes that GSHPs are used for space heating and hot water applications in residential facilities. They are assumed to serve space heating, space cooling, and hot water applications in commercial/multi-family facilities.

Table 19: GSHP Scenario

	SHW	GSHP	Biomass - pellets	Biodiesel
Residential	DHW Space Heat --	**DHW** **Space Heat** **--**	DHW Space Heat --	-- Space Heat --
Commercial	DHW Space Heat --	**DHW** **Space Heat** **Cooling – elec**	DHW Space Heat --	-- Space Heat --

System sizing requirements for residential and commercial/multi-family buildings are detailed in Appendix A. Using these assumptions, GSHP systems have been modeled to calculate simple payback and levelized cost of energy (LCOE) for typical residential (13 kWth) and commercial/multifamily (97 kWth) installations.

7.4.1 Installed Costs

Installed costs for GSHP systems in the northeastern market vary widely. This is a result in part of the relatively small market as well as differences between technical specifications. For example, costs vary widely based on system efficiency, design (e.g. open- or closed-loop systems), and installer or designer experience. For example, installers estimate that open-loop, standing column systems can cost as little as $7,000 per ton, whereas data collected from Connecticut's GSHP rebate program for closed loop systems indicated average costs of nearly $9,000 per ton.

Ultimately, this analysis assumes residential that residential GSHP systems cost $7,500 per ton or approximately $27,730 for a 3.6 ton system.[xxx] For commercial GSHP systems, it is assumed that drilling costs increase as the system size increases, resulting in an installed cost of $11,500 per ton or

[xxx] This assumes that a residential facility will require a 13 kWth (3.6 ton) system to provide heating. We estimate such a system will cost $27,730, which is reduced by the 30% ITC to approximately $19,411. According to IGSHPA and other experts, a back-up heating system is recommended for GSHPs. As a result, the incremental upfront costs for a GHSP include its installation costs less the value the ITC.

approximately $316,200.[yyy] These estimates are within the range provided by GSHP stakeholders as well as Connecticut rebate data.[zzz] For full range of cost estimates, see scenario assumptions in Appendix A.

7.4.2 Life-cycle Cost of Energy: Residential Scenario

The residential GSHP scenario assumes that GSHPs provide all or nearly all of heating and hot water for a household. Additionally, as recommended by IGSHPA, the analysis assumes that GSHPs require back-up fossil fuel heating.[aaaa] In developing this scenario, Massachusetts policy-makers considered the potential advantages and drawbacks of incorporating cooling loads into the residential GSHP scenario – and how that may impact policy decisions going forward. While space cooling increases the comfort of households, incentivizing its use could also increase total energy use and, as a result, greenhouse gases emitted across the state. To this end, it is estimated that only 29% of households in Massachusetts currently employ *central* air conditioning.[bbbb] Most residences report using air conditioning on a limited basis – usually at night. And over 50% say they use air conditioning two or fewer days during the week in the cooling season.[141] However, the implications of space cooling on GHG emissions are not clear and further study is warranted.[cccc]

In this analysis, however, because central cooling makes up a relatively low share of heating and cooling use in residential building stock, the residential scenario does not consider the benefits (or costs) of cooling associated with fossil fuels or GSHP units. On the other hand, cooling load is included in the commercial scenario, where it is assumed that space cooling is more likely to be necessary for the safe and comfortable operation of buildings.[dddd] In this manner, policy-makers have sought to balance the advantages and disadvantages of including cooling loads into the GSHP scenarios. With these assumptions in mind, Figure 47 and Figure 48 below illustrate the typical LCOE and simple payback of typical residential GSHP installations.

[yyy] Several stakeholders at NEGPA indicate that the installed cost estimate of $11,500/ton for commercial systems is conservative. They note that some commercial GSHP systems (e.g. standing column systems) can achieve installed costs as low as $7,000/ton due to reduced drilling costs.

[zzz] This assumes that commercial facilities install a 97 kWth (27 ton) system. We estimate such a system will cost approximately $316,283, which is reduced by the 10% ITC to approximately $284,000. The system is further assumed to offset 100% of heating and cooling load and to be an end of life replacement, which requires back-up heating but not back-up cooling. As a result, a customer would *not* need to install a fossil fuel cooling system. An electric cooling system is estimated to cost approximately $150,000 for a building of this size. Thus, the *incremental* installed cost for the geothermal system equals approximately $134,000 (installed costs – incentives – cooling system costs otherwise spent).

[aaaa] According to IGSHPA, a back-up heating system is recommended for GSHPs. Some stakeholders have noted, however, that IGSHPA auxiliary heating recommendations are targeted primarily toward closed loop systems – and that not all GSHPs require back-up heating. In cases where back-up fossil fuel heating is not required, and the GSHP constituted an end-of-life replacement for a fossil fuel heating system, then the project payback would be significantly lower, as energy savings would have to payback only the incremental costs of GSHP over a fossil fuel heating system.

[bbbb] Though a much higher share (53%) are estimated to have room only air conditioning (e.g. window units). For more information, see: Siems, A. (2009). Massachusetts Residential Appliance Saturation Survey (RASS). Prepared for Cape Light Compact, National Grid, NSTAR, Unitil, and WMECO.

[cccc] For example, NEGPA stakeholders note that the efficiency of a GSHP will be impacted by its application. NEGPA points out that systems used for cooling and heating are more efficient than systems used for heating only, and that customer demand for summertime space cooling is high. However, the impacts of widespread adoption of residential central cooling – on summertime electric peak load, for example – is not clear and is furthermore beyond the scope of this report.

[dddd] As a result, the payback is significantly improved for commercial systems compared to residential systems, because the commercial scenario takes into account both heating and cooling loads. Cooling loads are all assumed to be electric.

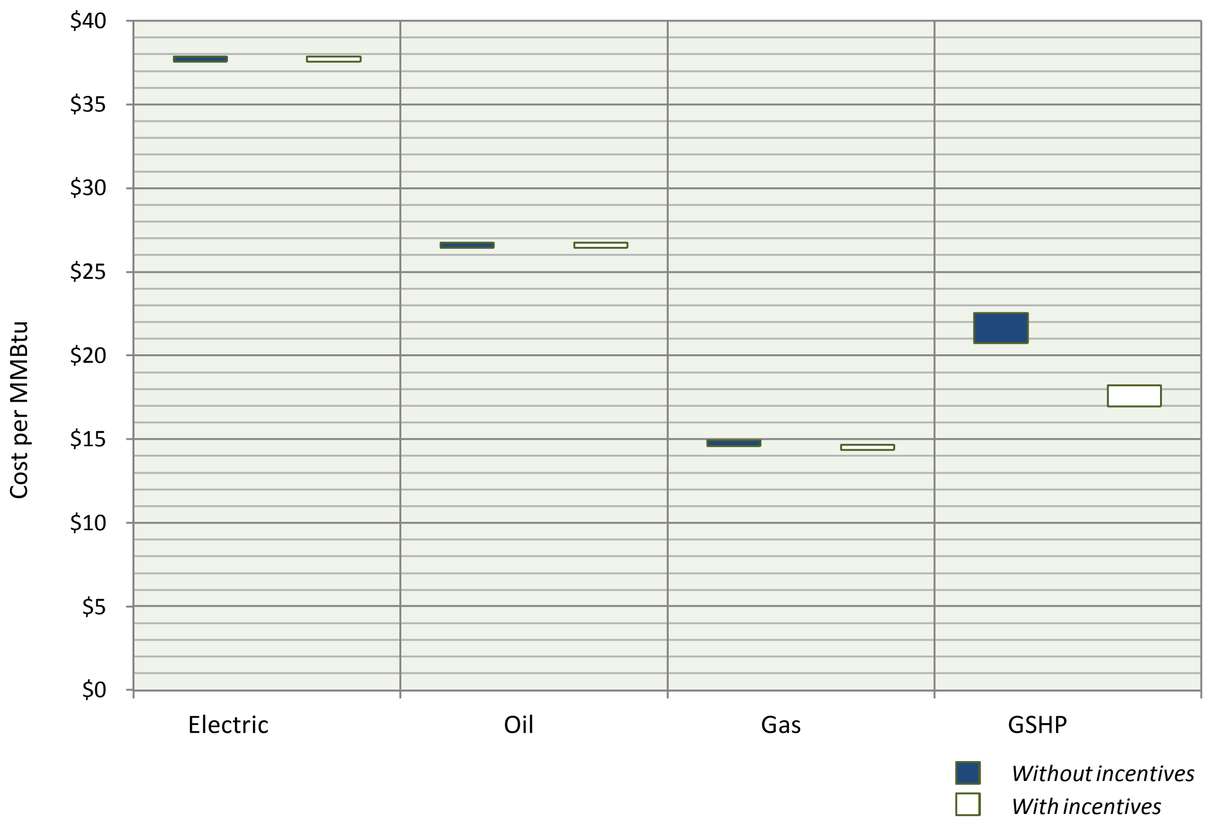
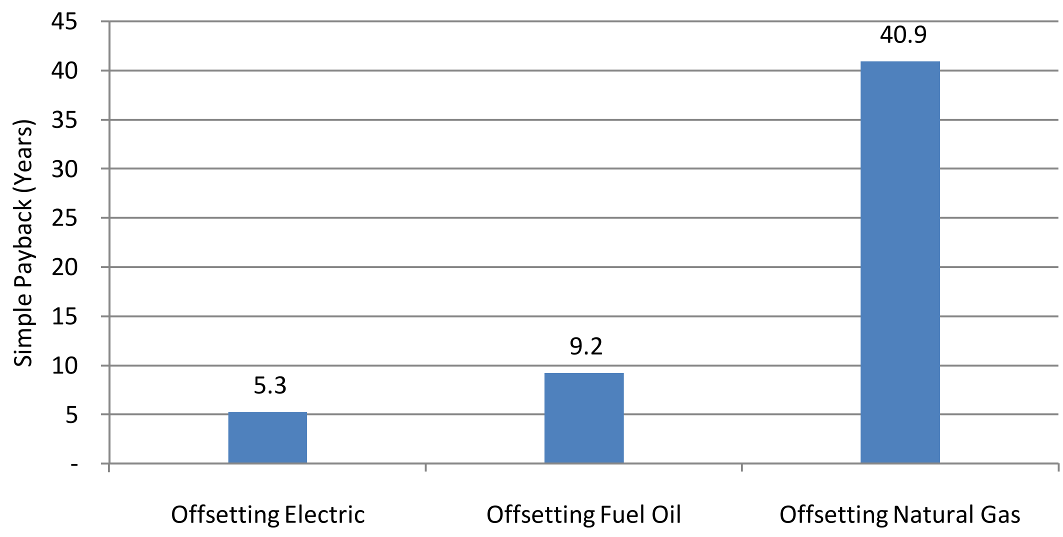


Figure 47: LCOE of Typical Residential GSHP System in Massachusetts Compared to Fossil Fuel Alternatives



Note: Average costs, with incentives.

Figure 48: Payback of Typical Residential GSHP System in Massachusetts

Relative to electric hot water and space heating, a typical residential GSHP system achieves payback within 5.3 years. Over the lifetime of the system, residents will pay $20 less for every MMBTU of heat produced by a GSHP than by an electric heating system.

Relative to fuel oil hot water and space heating, it will take customers approximately 9.2 years to recoup the upfront investment of a GSHP. Over the lifetime of the system, customers would pay nearly $10 less per MMBTU of heat produced.

Relative to natural gas water and space heating, a residential GSHP is not a compelling option. On average, over the 20 year life of the system, customers would pay approximately $3 more per MMBTU of heat delivered from GSHPs. Payback exceeds the assumed 20 year life of the system.

In summary, GSHPs present a compelling replacement for electric resistance heating – both from a GHG and financial perspective. In addition, as illustrated in the next section, due to the potential for cost-effective GHG reductions, it is worthwhile for Massachusetts policymakers to encourage market development for systems to replace fuel oil use. However, at current natural gas prices, residential GSHPs do not represent a particularly compelling economic case. Natural gas additionally offers the least value in terms of GHG reductions.

7.4.3 Life-cycle Cost of Energy: Commercial Scenario

The commercial GSHP scenario assumes that a GSHP is an end-of -life replacement for fossil fuel based space heating, hot water, *and space cooling system*. It additionally assumes that GSHPs require a back-up fossil fuel heating system, but not back-up cooling.[eeee] As a result, a customer would not need to install a fossil fuel cooling system. Figure 49 and Figure 50 below illustrate the typical LCOE and simple payback of typical commercial GSHP installations.

[eeee] This assumes that commercial facilities install a 97 kWth (27 ton) system. We estimate such a system will cost approximately $316,283, which is reduced by the 10% ITC to approximately $284,000. The system is further assumed to offset 100% of heating and cooling load and to be an end of life replacement, which requires back-up heating but not back-up cooling. As a result, a customer would *not* need to install a fossil fuel cooling system. An electric cooling system is estimated to cost approximately $150,000 for a building of this size. Thus, the *incremental* installed cost for the geothermal system equals approximately $134,000 (installed costs – incentives – cooling system costs otherwise spent).

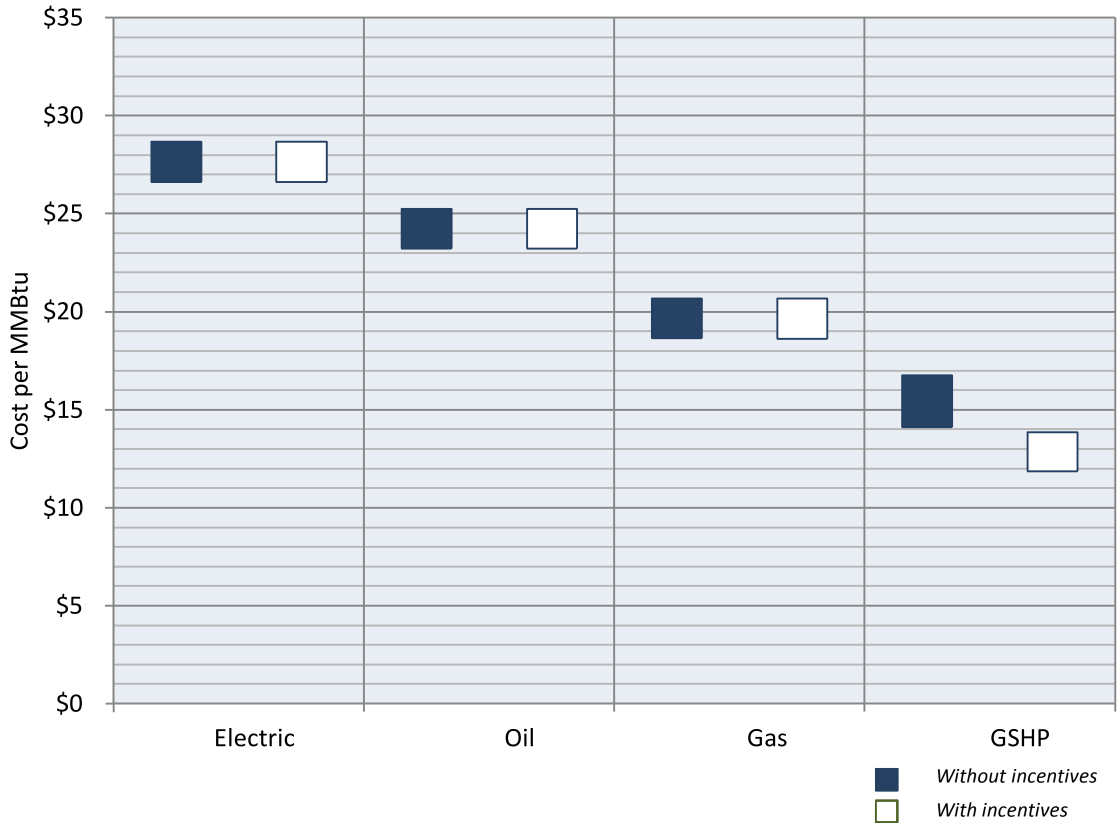
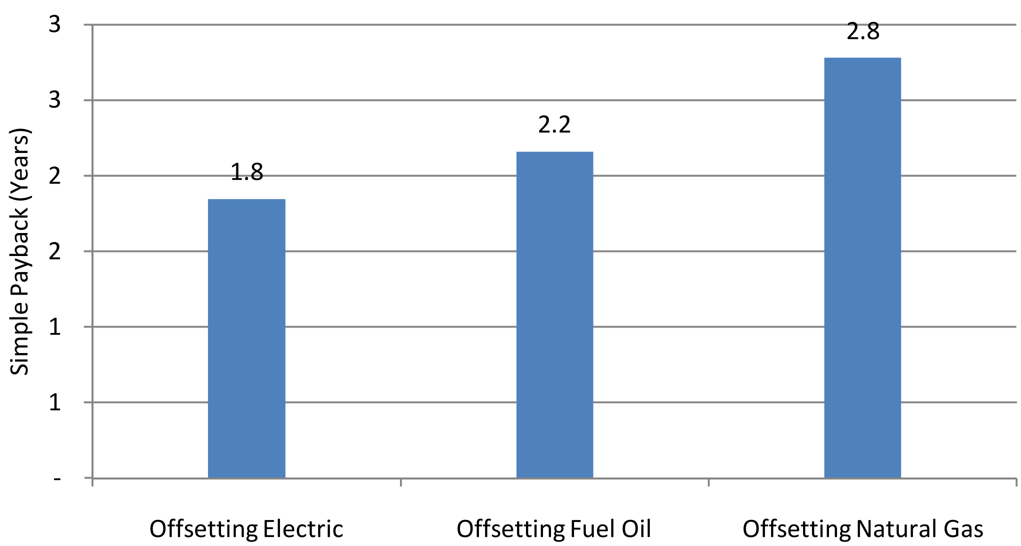


Figure 49: LCOE of Typical Commercial GSHP System in Massachusetts Compared to Fossil Fuel Alternatives



Note: Average costs, with incentives.

Figure 50: Payback of Typical Commercial GSHP System in Massachusetts

Relative to electric hot water and space heating and electric space cooling, commercial GSHPs are an attractive option, achieving payback of upfront incremental investment costs within 1.8 years. Moreover, over the lifetime of the system, commercial facilities will pay nearly $15 less for every MMBTU of heat produced by a GSHP than by an electric system.[ffff]

Relative to fuel oil hot water and space heating and electric space cooling, GSHPs also present a compelling option for commercial customers. Over the lifetime of the system, customers would pay nearly about $11 less per MMBTU of heat produced, and can recoup the incremental upfront cost of the investment within 2.2 years.

Relative to natural gas water and space heating and electric space cooling, commercial GSHPs are also competitive, achieving a payback for upfront incremental costs within 2.8 years. On average, over the 20 year life of the system, customers would pay nearly $7 less per MMBTU of heat delivered from GSHPs.[gggg]

In summary, commercial GSHPs present a compelling economic case to replace natural gas, electric, and fuel oil systems. This is due, in large part, because the GSHP scenario takes into account energy savings achieved by displacing electric cooling loads. Ultimately, as discussed in the next section, commercial GSHP's offer a compelling case to achieve cost-effective GHG reductions.

7.5 Greenhouse Gas Assessment

GHG reductions from GSHP systems are calculated by estimating GHG emissions avoided from fossil fuel systems. In Figure 51 and Figure 52 below, the red bars illustrate the GHG emissions resulting from a typical GSHP system (e.g. from electric pumps, etc.). The green bars represent the GHG emissions avoided by replacing fossil fuel heating systems with a GSHP. For example, a typical residential GSHP system replacing electric heating reduces GHG emissions by 16 tons annually. Emission reductions are greatest for systems offsetting electricity, followed by oil, and then natural gas.

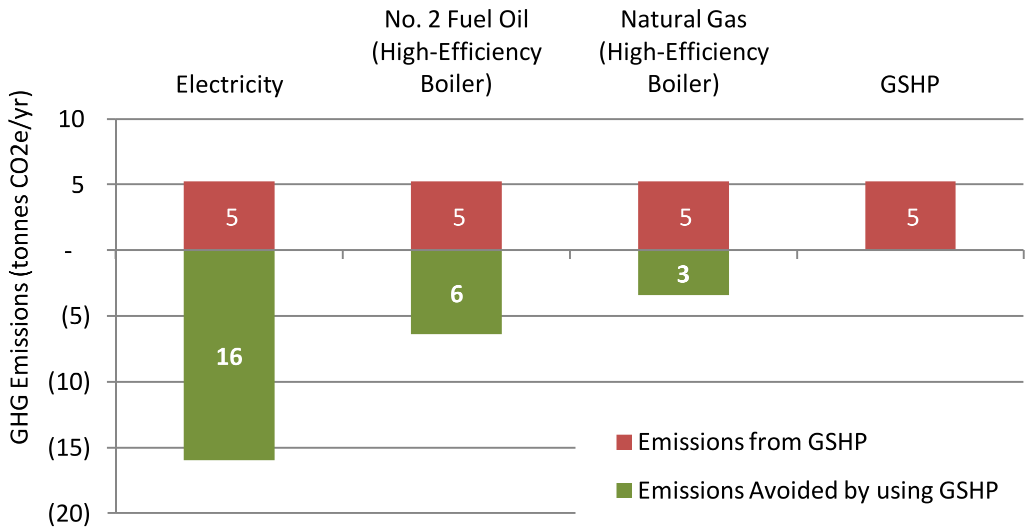


Figure 51: Annual GHG Emissions Avoided by Residential GSHP Systems

[ffff] This assumes that heat pumps provide 100% of the heating load. However, according to IGSHPA and other experts, a back-up heating system is still recommended.
[gggg] Economics are improved for commercial systems compared to residential systems, because the commercial scenario takes into account both heating and cooling loads. Cooling loads are all assumed to be electric.

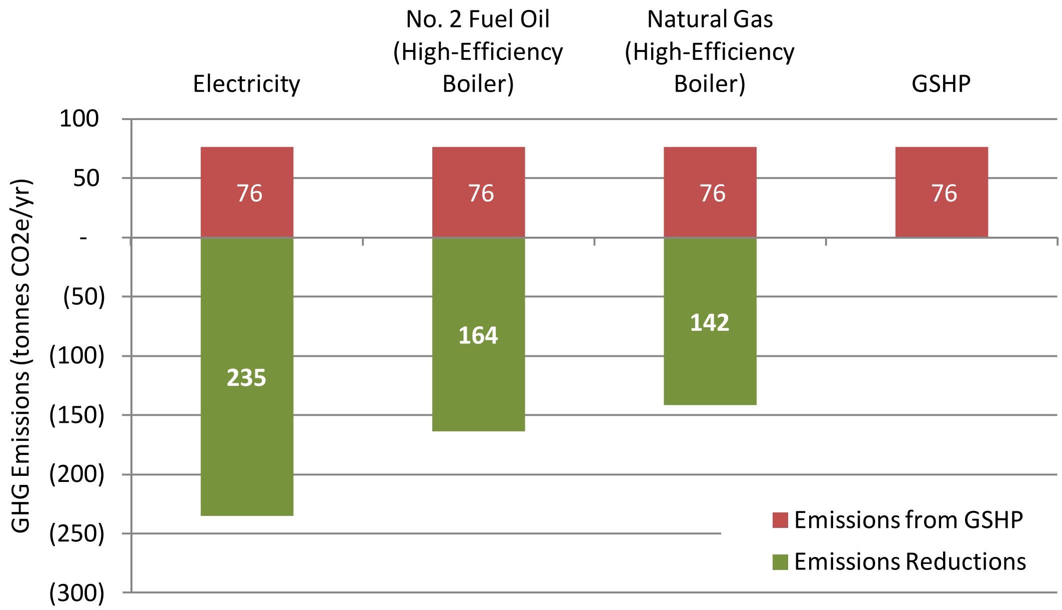


Figure 52: Annual GHG Emissions Avoided by Commercial GSHP Systems

7.6 Job Creation, Economic Development, and GHG Emission Reduction Scenarios

The *Massachusetts Clean Energy and Climate Plan for 2020* does not establish a formal target for GHG reductions from ground-source heat pumps. However, for purposes of this analysis, MassCEC and Mass DOER estimate that GSHPs have the potential to achieve 35% of the two million tons of GHG reductions from RH&C by 2020 – or approximately 700,000 tons.[hhhh] As illustrated in Table 20 below, it is estimated that this will result in significant new job creation associated with system installation process. Though stakeholders indicated that new manufacturing was unlikely in the short-term, additional jobs (not included in this analysis) could *also* be created if market growth were strong enough to attract new GSHP manufacturing facilities in the region.

Table 20: GSHP GHG Emission Reduction and Job Creation Scenarios

Ground-Source Heat Pumps	Annual Market Growth Rate	Annual GHG Emission Reductions	Jobs Created
BAU by 2020	21%	160,138	69
Accelerated Growth by 2020	47%	700,000	485
Accelerated Growth by 2050	n/a	3,919,614	n/a

[hhhh] The GHG reduction target of 35% is for illustrative purposes only. It does not constitute a formal target for the Commonwealth of Massachusetts.

The Building as Usual (BAU) scenario uses the historic growth rate of GSHP market in Massachusetts to estimate emissions, jobs, and economic benefits by 2020. Stakeholders and market data[iiii] indicate that the GSHP market has historically grown by 20% to 25% annually. At this growth rate, it is expected that the GSHP market will achieve just over 160,000 tons of GHG emission reductions, or about 23% of the GSHP's allocated portion of the 2020 target established by MassCEC and Mass DOER. It is expected that the industry could create over 69 jobs within 10 years if such growth is sustained.

The Accelerated Growth by 2020 scenario projects the market growth rate required to meet the accelerated GSHP GHG reduction target of 700,000 tons. In order to meet this goal, the GSHP market would need to see its annual growth rate increase to approximately 47%. If this goal is achieved, an estimated 485 new jobs could be created by 2020. It is also estimated that over $424 million would be retained in the region by through avoided expenditures on out-of-state fossil fuels.

The Accelerated Growth by 2050 scenario assumes that a certain percentage of the state's fossil fuel systems are replaced with a mix of renewable thermal technologies by 2050 (based on assumptions laid out in the Massachusetts Clean Energy and Climate Plan for 2020) and projects the associated GHG emissions reduction benefits. This analysis shows that replacing 7% of existing natural gas, 35% of existing electric,[jjjj] and 28% of existing fuel oil heating systems would yield GHG emissions reductions of over 3.9 million tons.

[iiii] From MassDEP GSHP well drilling permits

[jjjj] For residential buildings only. It is assumed that no commercial/multi-family facilities use electric heating.

7.7 Low Temperature Air Source Heat Pumps

Air source heat pumps (ASHPs) have a long history of serving heating and cooling demands in warm climates, though because typical heating season minimum temperatures in the Northeast are well below the performance range of *typical* air source heat pumps, they have not been widely adopted in the Northeast. However, more recently, a new generation of heat pumps, referred to alternatively as ductless mini-splits and Variable Refrigeration Flow (VRF) heat pumps, are currently available from a number of foreign manufacturers, which present a potentially cost-effective and energy efficient heating and cooling option for buildings in New England. To this end, ductless mini-split and VRF heat pumps have been widely adopted in Europe and Asia to serve both heating and cooling loads.

Unfortunately, little reliable data is publicly available to model the costs and performance of these new generation ASHPs in New England. The current market for VRF heat pumps appears to be small (relative to even other renewable thermal technologies), and according to stakeholders, conventional energy efficiency rating systems do not adequately reflect the efficiency advantages presented by low-temperature VRF technology. For these reasons, the following section provides an overview of the technology, describes the current market status, as well as existing market drivers and barriers. However, due to a lack of regional market data, this section stops short of the lifecycle cost, GHG, and economic development analyses performed for other renewable thermal technologies.

Finally, as with GSHPs, debate exists within the industry and the regulatory community regarding how best to classify air source heat pump technologies. Because air source heat pumps extract energy from the atmosphere, providing a renewable supply of heating or cooling capacity, the argument can be made that air source heat pumps should be classified as a renewable energy technology. These systems, however, do rely on grid-electricity for a portion of their operating power. It should be noted that National Grid and NSTAR, two Massachusetts investor owned utilities, conducted a residential ductless mini-split pilot in 2007 and 2008 as part of their energy efficiency programs.[142] Also, Massachusetts utility energy efficiency program administrators currently provide mini-split rebates as part of the Cool Smart energy efficiency program.[143]

7.7.1 Technology Overview

Several manufacturers currently offer heat pump technologies that are designed to serve as the primary heating system in cold weather climates.[144, 145] Traditional ASHPs have proven to be an inefficient heating technology in cold-weather climates, resulting in very high energy consumption (and energy bills) in extreme cold weather periods. However, the advent of ductless mini-splits and Variable Refrigeration Flow (VRF) heat pump technologies has significantly improved the potential of ASHPs to provide efficient heating in low-temperatures.

The term “ductless mini-split” refers to the *non-ducted* nature of the heating and cooling system. In this configuration, the heat transfer medium is typically distributed via three inch tubes or pipes instead of large HVAC air ducts. This makes the technology a good retrofit option for buildings using hydronic heating, radiant panels, or even space heaters.[146] Additionally, mini-splits provide flexibility for zoning – or heating and cooling of individual rooms. For example, many models have as many as four indoor air-handling units (for four zones or rooms) connected to one outdoor unit. Because each zone has its own thermostat, air conditioning for that space only needs to occur when someone is there. Additionally, ductless systems mitigate efficiency losses associated with duct losses in traditionally ducted HVAC systems. Ducted systems also require significant capital investments in retrofit situations. Altogether, eliminating these efficiency losses and system costs can save building owners significant energy and money.[147]

The term "Variable Refrigeration Flow" (VRF) refers to the inverter technology used in the heat pump. Inverter based heat pumps, unlike traditional air source heat pumps, can throttle back the compressor of the ASHP, thus reducing its electric load and heat output. In other words, as the indoor temperature approaches the desired temperature, the inverter control adjusts to "low capacity" operation to maintain the desired temperature. By contrast, traditional ASHP compressors have a fixed heating and cooling capacity, which controls indoor temperature by either fully starting or fully stopping the compressor,[148] which is a considerably less efficient means of heating and cooling a building.

It should be noted that not all "Variable Speed Mini-Split and Multi-Split Heat Pumps" are rated for low temperatures. Some have very poor performance in cold climates and will require electric resistance or fossil back-up power, while others may perform well at 5^{o} F. As illustrated in Figure 53 below, models on the market today are typically advertised to have minimum operating temperatures of -13^{o}F and rated to provide full heating capacity at 5^{o}F.[149],[kkkk] Figure 53 also details the relative heating performance of a Mitsubishi "Hyper-Heating" inverter-driven heat pump system, sufficient for low-temperature operation, as well as a standard inverter-driven Mitsubishi product and a typical standard central heat pump.[llll] According to this analysis, only the Hyper-Heating model could provide 100% heat in the Massachusetts climate.

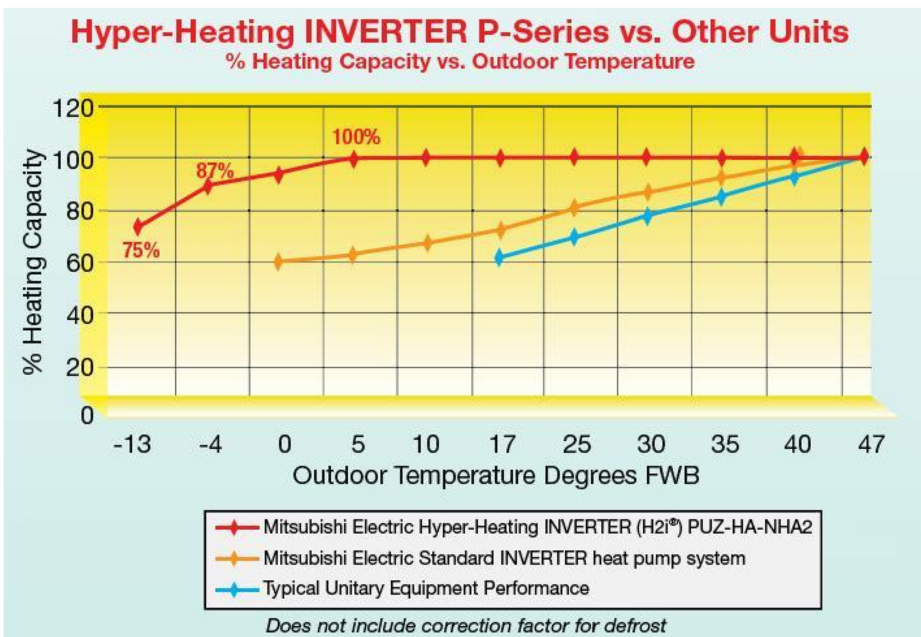


Figure 53: Mitsubishi Hyper-Heating heating capacity curve (Mitsubishi, 2011)

The NSTAR/National Grid pilot – which involved 124 systems installed in both Massachusetts and Connecticut – found that ductless mini-splits were an effective energy savings technology and that customers were generally satisfied with both heating and cooling system performance. It should be noted that the pilot was designed to provide mini-split systems for buildings with primary electric heating and either central or window unit air conditioning – and not for buildings with existing fossil fuel

[kkkk] Units installed as part of the 2007/2008 utility pilot were typically rated to provide heating to 17^{o}F.
[llll] Additionally, Energy Star and the Consortium for Energy Efficiency maintain a database of Energy Star Qualified mini-split air source heat pump products. A small fraction of these products are rated to perform at low temperatures.

heating systems. Also, the majority of heat pumps installed in the pilot were Mitsubishi Mr. Slim models that were not rated for extreme low temperature heating.

As with GSHP systems, any incentive program that encourages switching from fossil fuel heating to high-efficiency heat pump technologies will have to carefully consider the potential effects of increased winter-time peak loads as well as the summer-time use of newly installed cooling capacity in buildings that may not have previously had cooling systems. Proper system sizing is also a potential concern as systems that cannot effectively meet heating loads may frequently rely on electric resistance backup heating elements that can significantly impact grid loads.

7.7.2 Market Status and Value Chain

Massachusetts regulated utilities currently offer a $500 rebate for ductless mini-split systems that meet certain efficiency criteria as part of the Cool Smart program. This initiative is targeted at residents and has a primary goal of encouraging homeowners to install high-efficiency cooling systems in their homes. It is not clear from program materials whether the Cool Smart initiative has been designed to encourage homeowners to switch heating fuels.

Two heat pump manufacturers currently offer dedicated cold climate inverter-driven heat pumps in the Massachusetts market.[mmmm] According to the Consortium for Energy Efficiency, ten manufacturers offer mini-split heat pumps that qualify for the existing utility rebate program. [150] Stakeholders indicated that, if demand for cold climate heat pumps increases, a number of manufacturers, both foreign and domestic, could enter the market with new products.

Market stakeholders report that installation of ductless mini-split and VRF heat pumps is a relatively straightforward process when compared to other central HVAC technologies. Additionally, product manufacturers are eager to train existing HVAC professionals to install their systems. As the market for low temperature heat pumps grows in Massachusetts, it is reasonable to conclude that the state's HVAC installer base will be able to install and service this new technology.

7.7.3 Drivers and Barriers

7.7.3.1 Market Drivers

As previously mentioned, Massachusetts investor owned utilities currently offer rebates for qualifying ductless mini-split heat pump systems. In addition to direct rebates, these systems may qualify for no-cost financing under the HEAT Loan program. Current HEAT Loan guidelines allow qualifying homeowners to borrow up to $25,000 for heat pumps systems that meet specific efficiency requirements.[nnnn]

Additionally, home owners are currently eligible to receive a 10% tax credit up to $500[151] for installation of Energy Star qualified air source heat pumps. This tax credit is set to expire at the end of 2011. The extent to which this incentive is driving current high efficiency air source heat pump installations in Massachusetts is unknown.

Finally, commercial building owners who install high efficiency heat pumps may be able to take advantage of the federal corporate energy efficiency tax deduction.[152] This per square foot tax

[mmmm] These include Mitsubishi and Daikin.
[nnnn] with a HSPF of 3.3 or greater

deduction is calculated using building modeling software and is highly specific to individual building conditions. It is unknown whether this federal tax deduction is a significant driver of high-efficiency air source heat pump installations as no public data about the program is currently available.

7.7.3.2 Market Barriers

Major market barriers to the low-temperature ASHP market include: (i) high first costs, (ii) unclear or inadequate efficiency rating systems, and (iii) maintaining proper system design requirements. Each barrier is discussed in detail below.

7.7.3.2.1 High First Costs

The average cost of ductless mini-split systems in the utility pilot was $2,715 per ton in all four utility territories. Interestingly, the systems installed in the Massachusetts portion of the pilot had higher average installed costs ($3,199 per ton in National Grid territory and $4,104 in the NSTAR territory). The report indicates that the Connecticut Power and Light pilot participants, who paid an average of $2,100 per ton, benefited from a bulk procurement of mini-split heat pumps from a single vendor.[153] This indicates, as with other renewable thermal technologies in this study, that low demand for mini-split heat pumps systems may be a significant cause of high market prices for the technology.

7.7.3.2.2 Unclear or Inadequate Efficiency Rating Systems

Stakeholders indicated that current product rating protocols do not fully capture the energy savings benefits of inverter-driven heat pumps. Because of their inherent ability to precisely supply heating and cooling loads efficiently at less than 100% loads, these systems are inherently more efficient than standard heat pump systems. This efficiency gain, however, is not reflected in the current efficiency ratings used for heat pumps, making it challenging to compare their performance relative to traditional heat pump technology. Rating industry stakeholders commented that while some of the performance benefits of inverter-driven heat pumps are not captured by standard rating methodologies, a number of mini-split systems do currently qualify for Energy Star certification and utility program benefits.[154]

7.7.3.2.3 Maintaining Proper System Design Requirements

As with other building heating technologies, proper design and installation are key factors of good system performance. This is a particular concern with heat pump technologies, as systems that are undersized will need supplemental heating support from fossil fuel or resistance heating backups during periods of extreme cold. Additionally, since heat pumps must be sized to service both heating and cooling loads, properly sizing systems to serve the primary load of concern (i.e. either heating or cooling) may lead to inefficient performance during the other climate conditioning season. Proper system design and installation will be critical to the ongoing efforts of the heat pump industry to gain credibility in the Massachusetts market.

APPENDIX A: ASSUMPTIONS FOR FINANCIAL ANALYSIS

Building size and efficiency assumptions

HEATING SYSTEM	RESIDENTIAL	COMMERCIAL
Building Size (sq ft)	2,000	15,000
Heating Load Calc (Btu/hr/sq ft)	22	22
Peak heating load (kW)	13	97
Annual heating (MMBTUs)	89	662
Annual water heating (% of heating)	15%	15%
Annual water heating (MMBTUs)	13	99
Annual water & space heating (MMBTU)	***102***	***761***

COOLING SYSTEM	RESIDENTIAL	COMMERCIAL
Building Size (sq ft)	n/a	15,000
Cooling Load Calc (Btu/hr/sq ft)	n/a	22
Peak cooling load (tons)	n/a	27.4
Peak cooling load or unit size (Btu/hr)	n/a	330,174
Annual cooling (kWh)	n/a	176,000
Annual cooling (MMBTU)	n/a	***600***

Renewable Heating and Cooling (RH&C) scenarios

Sector	Solar Hot Water (SHW) 1/	Ground-Source Heat Pumps (GSHP) 2/	Biomass (pellets)	Biomass (chips) 3/	Biodiesel
Residential	DHW (40%) Space Heat (40%) --	DHW Space Heat --	DHW Space Heat --	-- -- --	-- Space Heat --
Commercial	DHW (40%) Space Heat (40%) --	DHW Space Heat Cooling	DHW Space Heat --	DHW Space Heat --	-- Space Heat --

1/ SHW combi-systems were assumed to supply 40% of total building load for space heating and DHW.
2/ GSHP systems can meet a building's cooling needs with a small additional capital investment. However, cooling was only included in the financial analysis for the commercial scenario due to absence of central cooling systems in most Massachusetts homes.
3/ Biomass thermal chip systems are generally only financially viable at commercial scale.

Cost and efficiency assumptions

Technology	Sector	Installed Cost per unit (Heating) 1/	Total Installed Cost (Heating) 1/	Installed Cost (DHW)	Installed Cost (Cooling)	Efficiency	Fuel Btu Content	Fuel cost	Fuel cost escalator
Natural Gas	Residential		$8,450 - $9,100	$1,500		85% [a]	1 MMBtu/ Mcf	$13.26/ Mcf [f]	0.97% [f]
	Commercial		$24,000 - $28,000	$18,000				$10.94/ Mcf [f]	
Electric	Residential		$8,450 - $9,100	$1,500		99% (heating); [b] 80% (cooling)	0.0034 MMBtu/ kWh [b]	$0.1473/ kWh [f]	3.00%
	Commercial		$24,000 - $28,000	$18,000	$120,000-180,000			$0.1410/ kWh [f]	
Fuel Oil	Residential		$8,450 - $9,100	$1,500		85% [a]	0.1387 MMBtu/ gal [b]	$3.32/ gal [e]	3.22% [f]
	Commercial		$24,000 - $28,000	$18,000				$3.32/ gal [e]	
SHW	Residential	$2,000 - $2,500/kW	$14,800 - $18,500	Included in heating		80% system derate factor; 7659% efficiency (accounts for pump use of electricity)	0.0034 MMBtu/ kWh [b]	$0.1473/ kWh [f]	3.00%
	Commercial	$1,412 - $2,763/kW	$77,660 – 151,965	Included in heating				$0.1410/ kWh [f]	
GSHP	Residential	$7,000 - $8,000/ton	$25,882 - $29,579	Included in heating		400% (heating); 330% (cooling)	0.0034 MMBtu/ kWh [b]	$0.1473/ kWh [f]	3.00%
	Commercial	$7,000 - $13,000/ ton	$275,028 - $357,536	Included in heating	Included in heating			$0.1410/ kWh [f]	
Biodiesel	Residential		$8,450 - $9,100			85% [a]	0.1387 MMBtu/ gal [b]	$3.37/ gal [e]	3.22% [f]
	Commercial		$24,000 - $28,000					$3.37/ gal [e]	
Biomass (Pellets)	Residential	$800 - $1,700/kW	$21,000	Included in heating		80%	17 MMBtu /ton [c]	$240/ton [g]	3.22% [f]
	Commercial	$400 - $600/kW	$38,680 - $58,020	Included in heating				$220/ton [g]	
Biomass (Chips)	Commercial	$491 - $600/kW	$47,520 - $58,080			75% [c]	5.74 MMBtu/ ton [d]	$40/ton [g]	3.22% [f]

1/ Prices exclude incentives; tax and other incentives factored into analysis are identified below.

2/ SHW efficiency was derived to reflect the electricity required to operate the pump.

Sources:

[a] Set equal to MassSAVE standard for high-efficiency boilers

[b] EIA heating calculator

[c] Manomet study

[d] USFS Fuel value calculator

[e] DOER (5 cent premium for Biodiesel) based on stakeholder workshop

[f] EIA

[g] Stakeholder workshops

Tax credits, rebates, and other incentives

Technology	Residential Scenario				Commercial Scenario				
	ITC	Other Tax Credit	Comm. Solar	Rebates	ITC	Other Tax Credit	Comm. Solar	Rebates	Depreciation
Natural Gas		*		$500		**		$500	20-yr straight line
Electric		*				**			20-yr straight line
Fuel Oil		*				**			20-yr straight line
SHW	30%	15% up to $1,000	Up to 25% or $3,500		30%	**	Up to 25% or $25,000		5-yr MACRS
GSHP	30%				10%	**			5-yr MACRS
Biodiesel		*				**			20-yr straight line
Biomass (Pellets)						**			20-yr straight line
Biomass (Chips)						**			20-yr straight line

* Residential tax credits for fossil fuel systems expire in 2011 and were hence excluded.

** Commercial tax credit of $1/sq ft applies to any retrofit and was hence excluded

Other assumptions applicable to all scenarios and technologies

Input	Residential	Commercial
Year Installed	2011	
System life	20 yrs	
Discount Rate	6%	12%

APPENDIX B: ASSUMPTIONS FOR ECONOMIC DEVELOPMENT & GHG ANALYSIS

Assumptions for "Business as Usual (BAU) by 2020" Scenario

Economic development benefits, jobs, and GHG reductions associated with increased market penetration of RH&C are projected based on the assumptions detailed below. In addition, annual fuel cost expenditures derived in the financial analysis portion of this study were used in the calculation of economic development benefits.

	Starting point in Year 1		Annual Growth Rate		Jobs 1/	Fuel Costs - 2/		GHG Emissions Reductions 3/
SHW	814	installed in 2010	34%	Wtd avg. increase in *new installations* each year	1 job/1000 sq ft installed	97%	of fuel expenditures staying in region	2 tons CO2/yr per unit for DHW & space heating; 17 tons CO2/yr per unit for pools
GSHP	49	installed in 2010	21%	Increase in *new installations*	108 hours/ residential installation 698 hours/ commercial installation	97%	of fuel expenditures staying in region	9 tons CO2/yr per unit for residential; 183 tons CO2/yr per unit for commercial
Biomass 4/	30	existing boilers in 2011	20%	Increase in *new installations*	342 jobs per 100,000 tons of pellets	100%	of fuel expenditures staying in region	9 tons CO2/yr per unit for residential; 64 tons CO2/yr per unit for commercial

	Starting point in Year 1	Target Advanced Biodiesel Use		Jobs 1/	Fuel Costs - 2/		GHG Emissions Reductions 3/
Advanced Biodiesel 5/	~0% advanced biodiesel in existing fuel oil supply	4.0	million gals/yr by 2020	Data not available	0-1%	of fuel expenditures staying in region	86% reduction vs. fuel oil for advanced biodiesel portion

1/ All scenarios assume 1 job = $37,000 in income.
2/ For fuel expenditures for fossil fuel systems, the percent assumed to stay in the region's economy is 0% for natural gas, 97% for electricity (reflecting the % of electricity generated in the region according to EIA data), and 0% for fuel oil. "Region" is defined to include MA, VT, NH, ME, CT, RI, and NY. Fuel cost savings further assume RH&C options are replacing electric systems 27% of the time and fuel oil 73% of the time (except for biodiesel which is assumed to replace fuel oil only). This reflects the current distribution of each type of fossil fuel system in MA homes, as reflected in EIA data (RECS 2009 Table HC1.8). EIA data from Table 1.6B (Net Generation by State) for YTD June 2011 and Table 5.4B (Retail Sales of Electricity to Ultimate Customers) for YTD June 2011.

3/ GHG reductions based on the GHG intensities shown in this appendix, weighted based on the assumption that they are replacing electric systems 27% of the time and fuel oil 73% of the time (except for biodiesel which is assumed to replace fuel oil only). This reflects the current distribution of each type of fossil fuel system in MA homes, as reflected in EIA data (RECS 2009 Table HC1.8).

4/ Also assumes the addition of between 6 and 10 "anchor" or large commercial systems consuming 750 tons/year beginning in 2014.
5/ Assumes average of B0 (effectively no advanced biodiesel in home heating oil) for state currently, escalating to 4,000,000 gal of advanced biodiesel by 2020.
Fuel cost savings assumes 100% of the (increasing) biodiesel portion of the fuel is retained in the regional economy, but 100% of the remaining fuel oil portion leaves the region.

Additional Assumptions for “Accelerated Growth by 2020” Scenario

The 2020 accelerated growth scenario assumes that growth of renewable thermal markets contributes additional GHG reductions to the state’s established 2020 climate goals (a 27% reduction below 1990 levels), as set forth in the *Massachusetts Clean Energy and Climate Plan for 2020*. As laid out by the climate plan, this analysis assumes that two million tons of additional CO2 reductions could be achieved from renewable thermal technologies. Each RH&C technology was estimated to achieve a share (or percentage) of the total two million ton GHG reduction goal of the renewable thermal CO2 reduction goal. The GHG reduction share of each RH&C technology is based on a high level assessment and should be considered as an illustrative target only. It provides a rough approximation of GHG reductions that may be possible for each RH&C technology. It does *not* constitute a formal GHG reduction target for Massachusetts. Using these illustrative targets, a required market growth rate was then calculated to estimate the “Accelerated Growth by 2020” scenario using the same assumptions as in the 2002 BAU scenario.

	Targeted Annual Emissions	Target RH&C Avoided Emissions share (%)	Annual Emission Reduction Targets
GHG REDUCTION GOALS			
2020 Goal (27% reduction) 1/	68,620,000		25,380,000
Accelerated GROWTH			
Renewable Heat 1/	--	100%	2,000,000
Solar Thermal	--	25%	500,000
Heat Pumps	--	35%	700,000
Biomass	--	35%	700,000
Advanced Biodiesel	--	5%	100,000

1/ Source: Based on Massachusetts Clean Energy and Climate Plan for 2020 Plan

Assumptions for "Accelerated Growth by 2050" Scenario

The 2050 accelerated growth scenario assumes that a certain percentage of the state's fossil fuel systems are replaced with a mix of renewable thermal technologies by 2050, as shown in the table below.

RESIDENTIAL	# Households using fuel in 2011*	% replaced by RH&C by 2050	**% switching to indicated RH&C option**			
			SHW	GSHP	Biomass	Biodiesel
RH&C avoided emissions share		100%	25%	35%	35%	5%
*From **Natural Gas***	1,300,000	20%	5%	7%	7%	0%
*From **Electricity***	300,000	100%	25%	35%	35%	0%
*From **Fuel Oil***	800,000	80%	20%	28%	28%	5%
	*Source: EIA RECS 2009 Table H-1.8					
COMMERCIAL	Trillion Btu Consumed in MA in 2011**	% replaced by RH&C by 2050	**% switching to indicated RH&C option**			
			SHW	GSHP	Biomass	Biodiesel
RH&C avoided emissions share		100%	25%	35%	35%	5%
*From **Natural Gas***	73.7	20%	5%	7%	7%	0%
*From **Electricity***	n/a	0%	0%	0%	0%	0%
*From **Fuel Oil***	19.1	80%	20%	28%	28%	5%
	**Source: EIA SEDS Table C6; assumes all oil and gas is for heating					

GHG Emissions Intensities of Fossil Fuels

Fuel Type	**Emissions Intensity**	**Source**
Electricity	1.54 Lbs. CO2/kWh	DOER
Natural Gas	23 kgC/MMBtu	Manomet study
Heating Oil	31 kgC/MMBtu	Manomet study

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