Heating and Cooling

in the

Massachusetts Alternative Portfolio Standard

Report to the Legislature

Executive Office of Energy and Environmental Affairs

Department of Energy Resources

With assistance from

Massachusetts Clean Energy Center

Meister Consultants Group

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Preamble

The *Act relative to competitively priced electricity in the Commonwealth* (S2395, section 46) of July 2012 requires the Executive Office of Energy and Environmental Affairs (EEA), in consultation with the Department of Energy Resources (DOER), to study the inclusion of useful thermal energy in the Alternative Portfolio Standard (APS). Useful thermal energy can be generated with renewable sources, but can also include other alternative energy sources, such as waste heat.

With this report, the Executive Office of Energy and Environmental Affairs fulfills the requirement given by the Legislature.

The report provides an overview of the most important useful thermal applications, their current market status, and their potential in Massachusetts. The report also discusses several important policy aspects for consideration if the Commonwealth incorporates useful thermal energy in the Alternative Portfolio Standard.

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Executive summary

The market for renewable heating and cooling and thermal energy recovery in Massachusetts is growing but small. Increasing the market share of renewable and useful heating and cooling technologies will enable the Commonwealth to address a series of important challenges. These include decreasing dependency of heating fuels that are either costly (oil, propane, electricity), constrained (natural gas), or both. It will help Massachusetts meet greenhouse gas reduction targets, increase energy efficiency, and improve air quality. It is therefore justified to develop additional incentives to support renewable and useful thermal technologies.

The APS is currently undersubscribed, creating a high and undesirable dependency on Alternative Compliance Payments. There is room in the near term to include additional technologies to qualify under the minimum standard of the APS, though depending upon the technologies incorporated – and the growth rate of those technologies – the APS market will likely become quickly constrained in the out years. The APS is designed to accommodate a broad portfolio of alternative technologies, and it already includes Combined Heat and Power (CHP), creating a sound precedent for incentivizing thermal energy production from other technologies. DOER has the discretion to add emerging technologies and this also appears to be the intent of how the Legislature designed the APS.

Eligible technologies

The following technologies are appropriate to include in the APS at this time: biomass, solar hot water, heat pumps, advanced biofuels, biogas. In order to realize the benefits of the useful thermal energy for Massachusetts customers and Massachusetts as a whole, the thermal energy should be delivered to an end user in Massachusetts. Waste heat and cold recovery in industry, wastewater or residential applications also presents a compelling opportunity, but DOER recommends first doing more analysis and gaining experience through pilots before including this in the APS.

Legal Aspects

While the APS statute currently limits applicability to energy generating sources that generate electricity, the Department's definition of alternative energy development clearly favors a broad application of technologies. Therefore the statutory enabling language of the APS should be broadened to apply to "energy generation" as opposed to the narrower "electricity generation". Further, the remainder of the statute is flexible enough to allow for programmatic decisions.

Mechanics of inclusion in the APS

All of the renewable technologies are competitive with fuel oil, propane and electricity on a lifecycle cost basis without AECs, and will perform even better with AECs. Awarding AECs to renewable thermal systems would enable a broader range of heat pumps and wood chip projects to be competitive with natural gas. The APS as it currently stands does however not offer price certainty, which means the AECs will not be banked on at full value, undercutting their usefulness. Furthermore, one of the major hurdles for renewable thermal technologies is their significantly higher upfront cost. Even if higher upfront costs are offset by savings over the lifetime of the installation, one first needs the extra capital to make the investment. DOER therefore recommends considering the second of the two following options:

APS inclusion, option 1: classic performance based AEC minting.

Eligible projects qualify in the APS, and are awarded one AEC per net MWh useful thermal energy they generate in the course of their operational life.

This option has the advantage of being straightforward in terms of necessary regulatory/statutory changes. The drawback of this option is that the AECs will be credited at a discounted value, reducing their usefulness for financing.

APS inclusion, option 2: upfront incentive to the tune of a 5 year strip of AECs.

Eligible projects qualify in the APS, and are awarded a one-time strip of AECs to account for an established time period (5 years, 10 years, etc.) of modeled net energy generation and concomitant AEC generation. No more AECs are awarded after the one time upfront strip.

Compared to the performance based option 1, the upfront incentive can have a significant impact on market growth of renewable thermal technologies at a lower overall cost to ratepayers. This option, limiting AEC credits to only 5 or so years, also generates a lower influx of AEC in the APS, thereby having a lower risk of crowding out the already existing APS technologies like CHP. The upfront incentive option requires more substantial regulatory/statutory changes, but reduces the administrative burdens to small projects of AEC market transactions.

APS Minimum Standard

The study tentatively examined growth of the renewable thermal market under three scenarios, and compared this to how CHP is expected to grow. The preliminary conclusion is that the current minimum standard can become insufficient to accommodate new technologies, thereby potentially crowding out CHP. DOER recommends considering two possible solutions:

- Change the APS minimum standard to a **floating standard**, certainly for the out years, 2015-2020. This standard can be designed to automatically increase with a set percentage point over the preceding year's generation, thereby continuing a pull from the market on AEC values.
- Decrease the influx of AECs by either applying a fraction to the AECs awarded per MWh useful thermal energy, decreasing the number of years that AECs are minted for a given project, or by limiting the list of renewable thermal technologies made eligible for inclusion in the APS.

1 Introduction

The average home or commercial building in Massachusetts spends about a third of its total energy expenditures each year on heating and cooling[1]. Because Massachusetts depends heavily on fossil fuel energy sources, such as oil, coal, and natural gas, the majority of those heating and cooling expenditures flow out of the region, providing little or no economic benefit to Massachusetts or the greater New England region.[2] Renewable thermal technologies and heat recovery present significant opportunities for not only reduction of greenhouse gas (GHG) emissions and improved energy security, but also job creation and economic development.

In spite of the potential benefits, renewable thermal markets serving hot water, space heating, and space cooling have been slow to develop in Massachusetts (and elsewhere in the United States) compared to other renewable energy sectors (e.g. renewable electricity or renewable transportation fuels). Only recently has renewable thermal energy begun to become a focus for incentives or policy targets.

With this in mind, this study describes Massachusetts's progress to date in developing the renewable heating and cooling market. This includes an overview of current residential and commercial/industrial energy use, as well as a description of the APS and other potential policy options that could be deployed to support development of renewable and other useful thermal energy.
The study also provides a high level description of renewable and useful thermal energy technologies and their current market situation in the Commonwealth. To do this, the study draws heavily on the "Renewable Heating and Cooling Opportunities and Impacts" report, commissioned by the Department of Energy Resources (DOER) and the Massachusetts Clean Energy Center (MassCEC) in 2011. In general, this study builds on – and, where appropriate, updates – the analysis completed in the Renewable Heating and Cooling report.

Having set the stage, the study then explores metering and verification requirements for heating and cooling, considering in particular differences from metering requirements for alternative power generation. The legal analysis that follows looks into the different aspects of including thermal in the APS and various considerations that need to be accounted for when doing so.

Finally, the study models the cash-flow impacts of rewarding useful thermal energy generation from renewable thermal technologies with Alternative Energy Credits (AECs), describing the impact of AECs on renewable thermal's cost-competitiveness relative to fossil fueled systems. The final element of analysis models the APS minimum standard through 2020, assessing what portion of the APS minimum standard could be met with the useful thermal energy and how that may impact existing APS technologies such as Combined Heat and Power (CHP).

[1] Massachusetts Clean Energy and Climate Plan 2020, page 2
[2] Meister Consultants Group, Massachusetts Renewable Heating and Cooling Report, Opportunities and Impacts Study, Prepared for DOER and MassCEC, March 2012

The study concludes with an overview of policy options and recommendations.

1.1 Massachusetts progress toward alternative heating and cooling

Through climate and energy planning programs, Massachusetts is paving the way for integrated, comprehensive support of renewable thermal technologies. This includes assessing potential, barriers, and opportunities for renewable thermal in market studies. In addition, the Commonwealth has developed a number of pilot incentive programs to support relevant technologies as well as strategically deployed Alternative Compliance Payment funds from the statewide RPS for pilot projects. Massachusetts' progress in establishing a solid foundation for growth of the renewable heating and cooling sectors is described below.

1.1.1 Planning and Market Studies

In 2008, the Legislature passed and Governor Patrick signed into law the Global Warming Solutions Act, committing Massachusetts to greenhouse gas emission reductions of 25% below 1990 levels by 2020 and 80% below 1990 levels by 2050. The *Massachusetts Clean Energy and Climate Plan for 2020* (hereafter the *Massachusetts 2020 Plan*), which delineates the measures necessary to meet those limits, states 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. The *Massachusetts 2020 Plan* recognizes that achieving this goal will require support for a rapid scale-up of the renewable thermal sectors.

In 2011, DOER and the Massachusetts Clean Energy Center ("MassCEC") commissioned the Massachusetts Renewable Heating and Cooling Opportunities and Impacts Study (RH&C Study), conducted by Meister Consultants Group. The report considered the current state of Massachusetts's existing renewable thermal sectors, including an analysis of supply chains, market barriers/drivers, and economics, as well as projected GHG and job creation impacts. The analysis included stakeholder outreach to the renewable thermal industries to understand the state of the market and confirm economic assumptions. The results illustrated that renewable thermal technologies[3] all represent cost effective and GHG reducing investments when displacing fuel oil or electricity at current market prices. GHG reductions are less pronounced when renewable thermal technologies displace natural gas and may not offer significant savings to the customer due to current natural gas prices, which are at historical lows.

The current study is the next phase of analysis following the RH&C Study. This study builds on the assumptions and results from the RH&C study, using, in some cases, revised estimates and figures that are as relevant and up to date as possible.

[3] Technologies included solar hot water, advanced biodiesel (assuming a B5 blend), ground-source heat pumps, and wood pellet heating systems

1.1.2 Barriers to Development

Despite the potential for lifecycle cost savings of renewable thermal technologies against electric, fuel oil, and (in some cases) natural gas, renewable thermal market growth is inhibited by a few key market barriers.[4]

Most notably, renewable thermal technologies tend to have significantly higher upfront costs than fossil fuel systems. For example, a high efficiency residential wood pellet boiler typically costs between $18,000 and $20,000 in New England. A high efficiency fossil fuel boiler by contrast, typically costs $10,000 or less, representing an upfront cost premium of $8,000 to $10,000 for high efficiency biomass heating systems. Solar thermal and geothermal installations face similar challenges with regard to high upfront costs.

Other barriers include a dominant conventional heating and cooling industry that is not familiar with offering or delivering these technologies, poor public awareness of the economic, environmental, and societal benefits and opaque regulatory standards. Stakeholders also report that hiring adequately trained personnel can be a significant challenge. State policy aimed at addressing these barriers may help drive vibrant market growth in the renewable thermal sector.

1.1.3 Pilot programs

Recognizing the potential for cost-effectively expanding renewable energy generation beyond electricity, DOER and MassCEC are offering a suite of new incentive programs that support renewable thermal technologies in residential and commercial applications. In 2011, MassCEC launched a pilot solar thermal program aimed at providing financial support for system owners in the form of rebates to help with upfront system costs, as well as contractor and inspector trainings to ensure quality installations. The program has helped to address barriers to solar thermal adoption, and enabled collection of project and market data, for which it was awarded a State Leadership in Clean Energy (SLICE) award by the Clean Energy States Alliance in 2012. Due to the success of the pilot program, in June 2012 MassCEC's Board of Directors approved the launch of the Commonwealth Solar Hot Water Program, a $10 million, four and a half year effort to continue to support and grow the solar thermal industry in Massachusetts.

In addition, DOER has dedicated $6 million of Alternative Compliance Payment (ACP) funds to support biomass, high efficiency heat pump, and district energy pilot programs that will be launched in late 2012 and early 2013, through the MassCEC.

The biomass pilot programs will consist of a first-come, first-serve rebate program for residential biomass boilers, and a competitive grant program for commercial, municipal, and agricultural biomass

[4] Breger et al., Taking the Next Step: Driving Renewable Thermal Energy Development in the U.S., WREF Conference Paper, June 2012

boilers. The high efficiency heat pump pilot programs will consist of first-come, first-serve residential rebate programs for air-source and ground-source heat pump systems, and a competitive grant program for commercial, municipal and agricultural ground-source heat pump systems. The district energy pilot program is intended to fund district energy projects using biomass or high efficiency heat pump technology at public schools and municipal facilities. The primary objectives of these pilot programs are to address high up-front system costs, further develop the biomass fuel distribution network and the high efficiency heat pump support network, create consumer and business confidence and awareness of the technologies, and collect industry and system performance data.

1.2 Massachusetts heating & cooling demand, cost and distribution

Space heating and cooling and water heating account for around 54% of total building energy use.[5] The large thermal demand is well-suited for renewable thermal technologies such as solar thermal, biomass thermal and heat pumps. These technologies can help to displace fossil fuels that are currently used for over 95% of the total heating load in Massachusetts.

Additionally, the charts below show the fuels used for water and space heating in residences in Massachusetts. They show that a significant proportion of households in Massachusetts use high cost fuels for heating their home and domestic hot water.

Figure 1 – Fuel use in residential space and water heating in Massachusetts (Sources: Mass Save, Massachusetts Statewide Energy Efficiency Study, 2010 / U.S. Census Bureau, 2012. Data is 2006-2010, 5-year estimates)

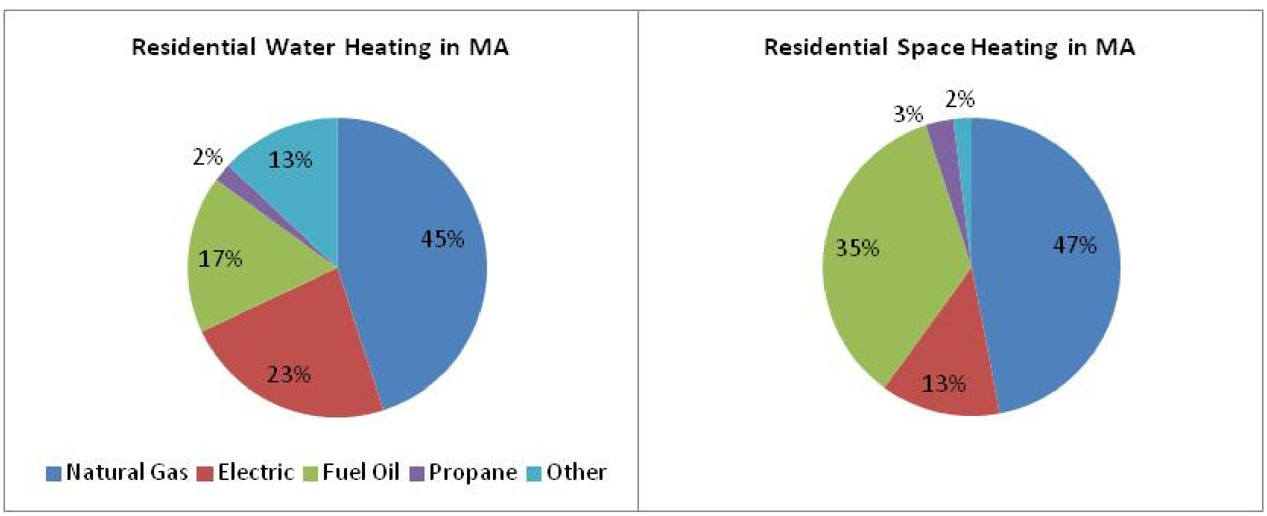
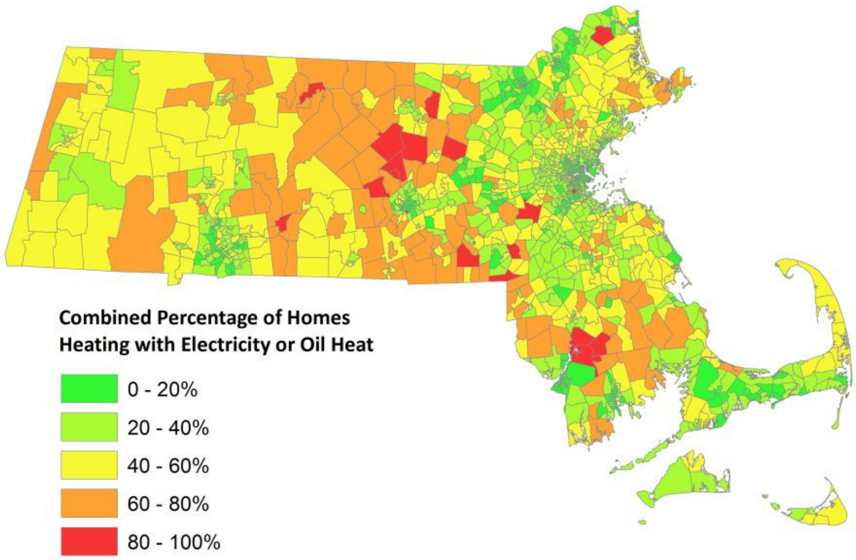


Figure 2 shows how the use of high cost heating fuels is distributed across Massachusetts, primarily reflecting the availability of access to the natural gas distribution network.

[5] EIA, Annual Energy Outlook 2012, http://www.eia.gov/forecasts/aeo/

Figure 2 – Geographical distribution of high cost heating fuels in Massachusetts (Source: U.S. Census, 2012)



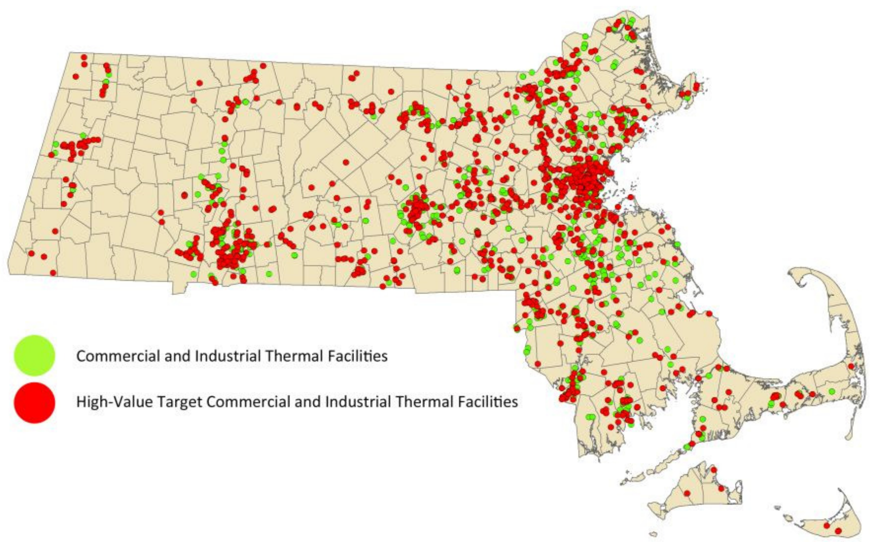
Absent additional incentives, renewable thermal technologies that displace natural gas may currently not be cost-effective, due to natural gas prices being at a historic low in 2012. But there is significant and immediate potential for cost-effective deployment of renewable thermal technologies in the 1.3 million households in Massachusetts heating with fuel oil, electricity or propane[6]. According to the U.S. Energy Information Administration (EIA) in 2009, $1.24 billion of fuel oil is expended for residential heating in Massachusetts (521 million gallons), which averages out to $1,500 (or 651 gallons) per household using fuel oil (EIA table CE2.7 & CE2.12). At the time of writing this report, oil prices are even higher than in 2009, placing a further burden on households and building owners.

Moreover, according to the Massachusetts Statewide Energy Efficiency Study, "about one-third of homes have a heating system that is more than 15 years old." It is more expedient and cost-effective for customers to invest in renewable thermal at the end of life of an existing heating or cooling system. The incremental costs of renewable thermal systems over a conventional fossil fuel system can usually be recouped within about four years (depending upon the fuel used). Such incremental costs are easier to bear when customers are already preparing to make a large capital investment in a heating or cooling system. Such replacements represent significant opportunities for renewable thermal technologies that can operate as the sole heating source for the home (like biomass thermal systems, or heat pumps).

[6] U.S. Census Bureau, 2012. Data for 2006-2010, 5-year estimates

In order to understand the heating and cooling load of the **commercial and industrial sectors** in Massachusetts, information from MassDEP's air pollution database was utilized. MassDEP collects data on all facilities that may emit contaminants to the ambient air. The map in Figure 3 illustrates the locations of commercial and industrial heating systems using non-renewable fuels across Massachusetts. The facilities represented in red have specifically been identified as 'high-value target' facilities, as these facilities are currently heating with high-cost fuels (e.g., fuel oil or propane) and do not utilize cogeneration equipment. They are thus are prime candidates for renewable thermal and heat recovery applications.

Figure 3 – Geographical distribution of industrial thermal energy users in Massachusetts (Source: MassDEP, Emission units database, November 2012)



According to MassDEP data, these commercial and industrial facilities in Massachusetts consume over 143 trillion BTUs per year for heating and cooling purposes. While more than half of these facilities use natural gas, the high-value target facilities using butane, diesel, jet fuel, kerosene, Liquefied Petroleum Gas, fuel oil, propane, or refined oil nonetheless consume a significant amount of energy (over 11 trillion BTUs per year, equivalent to **3,224 GWh**), and therefore represent a large potential for the cost-effective adoption of renewable heating and cooling systems in commercial and industrial buildings.

1.3 Policy options to incentivize useful thermal energy

The renewable heating and cooling sector is still an emerging market that in the U.S. has historically not received the policy support on the state or federal level that would be required for robust market growth. Where policies have emerged, they have primarily focused on very specific market sectors and

have not comprehensively addressed the issue of renewable heating energy use and generation. In the European Union, on the other hand, several countries have in recent years started implementing robust policies to drive growth in renewable thermal markets.
Though this report focuses on inclusion of thermal technologies in the APS, there are multiple policy options that have been tried elsewhere, or may be complimentary options, to support thermal technologies. Table 1 describes the APS and other policy options in some additional detail.

Table 1 – Policy options to support renewable thermal energy

	Precedent	**Opportunity for thermal**	**Concerns**
Alternative Portfolio Standard (APS)	MA APS credits thermal energy from CHP	Performance-based incentive in the form of operating revenue.	Potential crowding out of other APS-eligible technologies. Lack of long term contracts pose a challenge for financing.
Renewable Portfolio Standard (RPS)	14 states and DC recognize renewable thermal technologies in their RPS, mostly focusing on SHW. NH recently adopted legislation to include all renewable thermal technologies as a carve-out in their RPS.	Performance-based incentive in the form of operating revenue.	Electric ratepayers bear the costs associated with thermal technologies. Potential impact on other renewable technologies already in the RPS. Lack of long term contracts pose a challenge for financing.
Tax incentives	Many states, including MA, have tax policies for some renewable thermal technologies, alongside federal tax incentives.	Tax incentives help ease the upfront costs. No compliance obligation on utilities or ratepayers. Incentive amounts can be determined individually for each type of technology.	New tax incentives require challenging changes to the tax code, and result in a reduction of state revenues.
Rebates and competitive grants	Funds for MA rebate programs usually originate from ACP or ratepayer funds, or RGGI auctions.	Rebates and grants help ease the upfront costs of thermal systems.	Utility rebate programs based on may face legal barriers to provide rebates for renewable thermal energy as they are financed through charges on electricity and natural gas.
Renewable energy mandates	EU member states (Germany, Austria) implemented energy goal supported by a requirement for certain buildings to adopt renewable heating and cooling technologies	Mandated market increase for renewable thermal technologies.	In MA a mandate structure could be implemented as an addition to the Stretch Code.

2 Useful thermal technologies

2.1 Description

The following technologies are considered the most common examples of useful thermal applications. It is important to note that this list is not exhaustive. Within the sector, there are a number of very specific applications and new technology development that is occurring. However, this overview provides a good starting point for exploring renewable thermal production and heat recovery technologies. A full technical description of the technologies and their current market is provided in the appendix.

The following are the most common renewable thermal technologies:

- **Biomass**: highly efficient, variable systems with low air emissions, using wood or other biomass such as grasses, in the form of cordwood, pellets or chips.
- **Solar Hot Water**: collectors providing additional heat for space heating, domestic hot water, process heat or other low temperature heating needs. Most SHW installations in the Commonwealth are currently designed and sized to serve DHW only. Solar combi-systems, on the other hand, provide DHW and space heating.
- **Heat pumps**: highly efficient (at least Energy Star or equivalent) systems of compressors/expanders and heat exchangers using the thermal energy of ambient air, water or underground to heat and cool buildings. Heat pumps consume electricity to deliver the useful thermal energy, which needs to be accounted for, but overall energy efficiency gains and greenhouse gas savings can be realized with efficient equipment and under proper installation and operational conditions.
- **Advanced biofuels**: biomass derived liquid fuels delivering at least a 50% reduction in lifecycle GHG emissions as compared to conventional fuel oil.
- **Biogas**: digester gas from Anaerobic Digestion or capped landfills used for heating purposes at the site of capture, or by mixing it in the natural gas pipelines. Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen to create a biogas rich in methane.

In order to realize the benefits of the useful thermal energy for Massachusetts customers and Massachusetts as a whole, delivery of the thermal energy to an end user in Massachusetts is necessary. Otherwise Massachusetts residents will not benefit by decreasing dependency on high cost fuels, improved air quality, and regional energy security.

Thermal heat or cold recovery also presents a compelling opportunity. In industrial applications it entails capturing and reusing the wasted thermal energy in industrial processes. The exact quantity of industrial waste heat is poorly quantified, but various studies have estimated that as much as 20 to 50% of industrial energy consumption is ultimately discharged as waste heat.[7] Similar in principle is recovering waste heat in **waste water pipes** with an advanced heat exchanger. Cost-effectiveness of

[7] BCS Inc., Waste Heat Recovery: Technology and Opportunities in U.S. Industry, prepared for DOE, 2008

these applications varies widely and the equipment tends to be more expensive since it has to screen out the solids and be more robust stainless steel to deal with all the corrosive elements. Finally, in residential or commercial buildings, **heat recovery ventilation** (HRV) is an energy recovery ventilation system exchanging energy between the inbound and outbound air flow. It is a common feature in tightly sealed homes.

2.2 Application, design, and installation requirements

Renewable and useful thermal systems may be designed and installed in a number of different ways depending upon the particular application, building conditions, technology, and user goals. It is beyond the scope of this report to detail the full portfolio of potential scenarios and applications for all thermal technologies. Nonetheless, it is worth highlighting a number of the key design, technology, and building site factors that influence the technical and economic feasibility of renewable and useful thermal technologies. Major factors include:

- **Heating load type and sizing**: depending upon the application, buildings may require low or high-temperature heat for the distribution system. As the name suggests, low-temperature distribution systems like radiant floor heating can effectively distribute heat at relatively low temperatures (generally under 120 degrees F or close to room temperature). High temperature heat distribution, on the other hand, like traditional fin-tube baseboard heaters must achieve much higher water temperatures - sometimes exceeding 200 degrees F – to effectively heat a building.[8] Low-temperature distribution systems enable SHW and heat pumps to be effectively deployed in buildings, whereas chips and pellets can be used for high-temperature heating.[9] Thus, matching the technology to heating distribution and temperature requirements is important. Additionally, heating and hot water load profiles vary by sector and building, depending upon user habits and sector requirements. Thus, buildings have a very wide range of heating and hot water loads – from fairly stable and consistent to highly variable. Some renewable thermal technologies, like pellet heating systems, are well-suited to scale heating up or down to serve variable loads. Others, like GSHPs, are best suited to serve stable, consistent heating and hot water requirements, like those needed to for space heating in office buildings. Still other technologies, like SHW, are intermittent generators, providing heat or hot water only when the sun shines; however, use of a water accumulator tanks to store heat until it is needed can mitigate challenges associated with intermittency.

- **Cooling load**: many thermal technologies can also provide space cooling for buildings. For example, GSHPs and ASHPs are commonly deployed to provide heating in the winter and cooling in the summer. SHW systems can also provide cooling by using thermally activated cooling systems (TACS), though due to high costs, the use of the technology is not currently widespread.

[8] Siegenthaler, J., Renewable Hydronic Heating Home Power, January 2013.
[9] Maker, T., Wood Chip Heating Systems, A Guide For Institutional and Commercial Biomass Installations, 2004

Theoretically, by using a chiller, any heat source can be used to serve cooling loads.[10] In general, though, the cooling from thermal technologies is driven by technology costs, system efficiency, and user needs.

- **Building site and space**: design and installation of thermal systems also depends upon available space at the building site. For example, pellet and chip heating systems require basement or nearby (outside) space for fuel storage and boiler equipment. Similarly, if a building uses a renewable thermal system for baseload heating – and relies on fossil fuel systems to serve peak heating on the coldest days – then the user must ensure they have adequate space for multiple heating units. Moreover, when using multiple heating sources, then users will typically require space for hot water accumulators to store energy from the various heat sources. Some of this equipment requires considerable space for installation, making available space a key consideration in the design and installation of a thermal system.

- **Ground conditions:** of particular importance for GSHPs are ground and drilling conditions at the building site. Massachusetts high bedrock geology typically increases the drilling costs for vertical well GSHP systems. On the other hand, in areas where it is appropriate, groundwater heat pumps may be installed, which use groundwater wells as the source of working transfer fluid for the heat pump. Such groundwater well systems can significantly lower the installed costs for GSHP systems. Site specific conditions frequently dictate the most appropriate ground coupling technology choice and will influence the efficiency and cost of GSHP systems.[11]

- **Roof conditions:** for solar hot water systems, open access to un-shaded roof space is essential. The output of a solar system is proportional to the intensity of sunlight falling on the system. Greater amounts and duration of sunlight increase system performance, though systems can generate energy even on cloudy days. In addition, rooftops must be able to structurally withstand the forces imposed on them (e.g. snow, wind, etc) as well as the weight of the solar thermal system.[12]

As indicated above, many renewable heating and cooling systems can cover the full heating, domestic hot water (DHW), and cooling needs of buildings (e.g. peak systems). Or, they may be designed to cover only a portion of the heating or cooling demand (e.g. baseload systems), relying on auxiliary fossil fuel heat source to cover the peak load on coldest days. Renewable thermal systems can be installed as standalone systems (e.g. biomass or GSHP systems), or as combinations of renewable systems (e.g. SHW and a biomass pellet boiler; or GSHP and SHW). In some cases, combination thermal systems allow for fine-tuning of system size and higher overall system efficiencies and reliability throughout the year.

[10] DOE, Steam Tip Sheet #4, Use Low-Grade Waste Steam to Power Absorption Chillers, http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam14_chillers.pdf

[11] Meister Consultants Group, Massachusetts Renewable Heating and Cooling Report, Opportunities and Impacts Study, Prepared for DOER and MassCEC, March 2012

[12] Solar Boston Permitting Guide, ASHRAE "Solar Energy Use"

Finally, it is important to note that useful thermal applications are generally most cost effective when they displace high cost fossil fuels. At current market prices, these include oil, propane, and electricity. Moreover, installation costs are usually lower if thermal systems are incorporated into new construction; however, retrofitting existing buildings with renewable thermal technologies is also common.

With the above in mind, Table 2 below characterizes typical design requirements and applications for several useful thermal technologies. This table is illustrative only of "typical" design approaches – and not intended to be comprehensive. As noted before, technologies can be adapted to meet a number of design requirements, depending upon the developers' goals, budget, and expertise.

Table 2 – Differentiating factors for "typical" applications of useful thermal technologies

Conditions & Requirements		**Biomass - pellet**	**Biomass - chip**	**Solar hot water**	**Heat pump - GSHP**	**Heat pump - ASHP**	**Biofuel**	**Biogas (pipeline)**	**Thermal recovery**
Heating Load	**Temperature?** High (H) or Low (L)	H + L	H + L	L	L	L	H + L	H + L	L
	Load Variability? Steady (S) or Variable (V)	V	S	V	S	S	V	V	V
Cooling load	**Typically provides cooling?** Yes (Y) or No (N)	N	N	N	Y	Y	N	N	N
Roof space	**Roof requirements?** Yes (Y) or No (N)	N	N	Y	N	N	N	N	N
Sectors typically served	Residential (Res) Commercial (Com) Industrial (Ind)	Res Com --	-- Com Ind	Res Com Ind	Res Com --	Res Com --	Res Com Ind	Res Com Ind	Res Com Ind
Ground conditions	**Geology requirements?** Yes (Y) or No (N)	N	N	N	Y	N	N	N	N
Building site and space	**Equipment space requirements?** Small (S) or Large (L)	S	L	S	L	S	S	S	S/L

3 Metering and verification

Monitoring the performance of renewable thermal technologies, like renewable power generating technologies, is important in order to understand and appropriately document the actual performance of the system. Accurate measurements are critical for a performance-based incentive, such as an APS. In addition, monitoring helps to ensure long-term and optimal operation throughout the life of the system. When a renewable thermal system is installed in addition to a backup heating system, the backup system may take over for a malfunctioning renewable thermal system, providing the heat requirements for the building without the system owner realizing that the renewable thermal system is no longer working.

Monitoring thermal systems, while feasible, is more complicated than monitoring renewable electric systems, and therefore more expensive. Metering for smaller-scale renewable thermal systems can be disproportionately expensive, but due to economies of scale, becomes more affordable for larger-scale systems.

For **solar hot water**, metering systems that meet the Commonwealth Solar Hot Water performance monitoring requirements typically cost between $1000 and $1500 (total installed costs). There are more basic metering systems that cost around $500, which may help to identify system failures but may not be able to individually isolate solar contribution to the DHW load.[13] Similarly, metering equipment for **GSHP** costs $1,000 for an average residential heat pump.[14] Metering equipment costs for **biomass** systems are very system specific, but average around $2,000.[15]

While meters are recommended to provide the production data necessary for calculating the appropriate incentive credits, production estimations could be used for smaller-scale systems. For example, under Maryland's Renewable Portfolio Standard, residential systems may utilize the annual energy estimate provided by the Solar Rating and Certification Corporation (SRCC) for a particular system, while non-residential or commercial solar water heating systems must be measured with a meter that satisfies the requirements of the International Organization of Legal Metrology (OIML).

3.1 Technology specific monitoring

Monitoring equipment solutions are specific to the technology, and therefore monitoring a solar thermal system may be different than monitoring geothermal. The challenge is to monitor and reward each renewable thermal facility in a practical way that represents the net contribution of useful renewable thermal energy provided. The United Kingdom's Renewable Heating Incentive (RHI) program calculates payments by multiplying the measured eligible heat by a tariff that is specific to the size and type of the technology.

In the RHI, two types of meters are permissible: heat meters or steam meters. Heat meters are devices used to measure the thermal energy provided by a source, or delivered to a use by a liquid. Heat meters include two major components: the flow sensors (which measure the flow rate of the liquid) and a pair of temperature sensors (which measure the temperature difference between the relevant pipes (the input and the return). The heat meter uses these quantities to calculate the amount of heat generated or used. Heat meters may be purchased and installed as a single "packaged" heat meter or as separate components. For larger or industrial uses, heat is often delivered in the form of steam, rather than as a liquid. In order to measure the thermal energy provided or used, a steam meter requires a flow sensor, temperature sensor and pressure sensor in order to calculate the cumulative energy which has been delivered to a specific load.

[13] Christie Howe, Massachusetts Clean Energy Center
[14] Chris Williams, Heatspring Institute
[15] Rob Rizzo, Massachusetts Department of Energy Resources

Another option specific to **biomass and biofuel** is to meter the fuel **input**, as opposed to the heat output, along with periodic independent verification of the system efficiency.

Specific to **biogas injection** to the gas network, the volume of gas injected and its calorific value would need to be metered. Additionally, it will be important to know the volume and gross calorific value of any propane added to the biomethane, plus details about any external heat input to the biogas plant which made the biogas used to produce biomethane (such as heat from natural gas or other renewable heat technologies).

3.2 Metering standards

Detailed performance specifications for heat meters must be clearly stipulated. Most of Europe including the UK requires meters to follow European Standard EN 1434. Within the US, there is currently an effort underway to develop a US Heat Metering Standard, led by ASTM International and the International Association of Plumbing and Mechanical Officials (IAPMO) as directed by the U.S. Environmental Protection Agency. For Massachusetts, the metering standard for the APS program will need to specify the type of equipment, accuracy and sensors used, and the quantity and location of the data points gathered. These standards will help to ensure that the generated credits are based on the thermal energy actually being delivered to the home or building, not just the thermal energy being captured and stored. Additionally, more than one meter may be required, as under the RHI, "for steam boilers, CHP and systems supplying heat to premises or processes located on different sites" to ensure that only eligible heat attributable to the eligible installation is supported.[16] Currently, the Massachusetts APS program does provide guidelines[17] for metering thermal energy from CHP systems, which can serve as a starting point for adding useful thermal energy.

Metering requirements will also need to address the method of reading the meter and reporting the data. For example, a physical meter read could be conducted by an agent or the system owner as is done with Massachusetts' Solar Carve-Out Program for the purposes of generating Solar Renewable Energy Certificates (SRECs) from residential solar photovoltaic systems. Or, a remote meter read could be required and accessed over the internet on a periodic basis. While the reliability and accuracy of the data readings would likely increase with automatic meter readings, the increased functionality of the meter to transmit data over the internet could be more complicated and/or costly. Requirements should furthermore address how frequently the data should be transmitted. In general, the more frequent and granular the data provided, the more useful for monitoring and ensuring optimal system operation. Metering reports typically range from quarterly or annual data to hourly or sub-hourly.

Lastly, heat meters operate successfully only when installed correctly. Drastic variations in performance are often due to inconsistent installation practices, which may range from improper placement of sensors to erroneous configuration entries, as many renewable thermal system installers are not trained

[16] OFGEM, Renewable Heat Incentive (RHI) Frequently Asked Questions – Metering, http://www.ofgem.gov.uk/e-serve/RHI/Documents1/Renewable%20Heat%20Incentive%20FAQs%20-%20metering.pdf

[17] DOER, APS Guideline on Eligibility and Metering of Combined Heat & Power projects, June 2011, http://www.mass.gov/eea/docs/doer/rps-aps/aps-chp-guidelines-jun14-2011.pdf

or practiced in the installation and operations of metering systems. Developing and communicating consistent installation and verification procedures will help to establish valid and accurate performance information. Independent verification of the metering system and data is recommended, as is done with SRECs generated under the Solar Carve-Out Program, and will help to identify and troubleshoot metering installation, configuration, and connectivity issues.

3.3 Metering to avoid rebound effect

One potential drawback of a performance-based incentive is that the more heat (or cooling) a renewable system provides, the greater the payments that system may be eligible to receive. This may encourage renewable energy system owners to heat or cool homes and businesses more than they would normally. This is called the "rebound effect." It will be important to consider how the incentives and the requirements of an incentive program could help to encourage rational and reasonable use of the system, or conversely, to discourage unreasonable use of the system. For example, in a pilot program testing the use of mini-split ASHP in Connecticut and Massachusetts, in some instances higher cooling use was observed after the new systems were installed.[18]

In general, the cost of operating the system and the fuel used in the case of biomass/biofuels should outweigh the potential additional incentive from inclusion in the Massachusetts APS, thereby preventing wasting heat or cooling.

4 Legal analysis

4.1 Eligible technologies

The DOER enabling statute (M.G.L. c. 25A, § 3) has a broad, technology blind, definition of alternative energy development. While specific technologies, like solar energy, are identified, the non-specific categories of "renewable non-depletable and recyclable energy sources" in the definition permit for a broad treatment of alternative energy development in the Commonwealth, potentially allowing for the inclusion of thermal technologies.

The statute identifies five specific types of energy generating sources eligible for the APS, none of which are thermal energy (M.G.L. c. 25A, § 11F1/2). The APS does allow for an administrative proceeding by which DOERmay add new alternative energy technologies. To date, however, no thermal applications have been added to the APS through this process.

Even if this administrative proceeding is utilized, only alternative energy generating sources that generate electricity may be incorporated into APS regulations without a statutory change. As such, renewable thermal technologies cannot be incorporated into the APS absent an amendment to M.G.L. c.

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[18] Swift J. et al., Ductless Heat Pumps for Residential Customers in Connecticut, The Connecticut Light & Power Company, 2010.

25A, § 11F1/2. The APS could allow for thermal by amending the third sentence of paragraph (a) to read, "For the purposes of this section, an alternative energy generating source is one which generates *energy* using…."

4.2 Programmatic authority

Statutory authority for the APS is brief and absent details pertaining to the structure of the program, rather, the statute establishes the basic framework for the APS, allowing the regulatory process to make most programmatic decisions. In particular, the APS statute does not dictate the procedure to measure energy output by a particular system, a requirement to meter, or the assignment of partial or whole Alternative Energy Credits, rather, these are detailed through regulations. Absent explicit statutory authority, DOER can make programmatic decisions in order to meet the purposes of the underlying statute.

There is also no minimum or maximum standard established by the Alternative Portfolio Standard statute (M.G.L. c. 25A, § 11F1/2), allowing for further regulatory flexibility. In fact, the current minimum standard for the APS is set by regulation (220 C.M.R. 15.07). A minimum standard set by the 2008 Green Communities Act states that "at least 20% of the Commonwealth's electric load" be from "new, renewable and alternative energy generation" by 2020 (§ 116 of Chapter 169 of the Acts of 2008). The Renewable Portfolio Standard is statutorily required to hit 15% by 2020, leaving the remaining 5% of the renewable and alternative minimum standard to be made up by the APS. As the Green Communities Act requirement is "at least 20%," and as the APS statute is silent on minimum and maximum standards, DOER is able to set the minimum standards it determines necessary to meet the purposes of the APS statute.

While the APS statute currently limits applicability to energy generating sources that generate electricity, DOER's definition of alternative energy development clearly favors a broad application of technologies. Further, the remainder of the statute is flexible enough to allow for programmatic decisions to foster useful thermal energy development.

5 Financial analysis of APS inclusion of useful thermal

The following section provides a high level assessment of the maximum potential impact of Alternative Energy Credits (AECs) on renewable thermal technologies, including solar hot water, biomass thermal (chips and pellets), GSHPs, and ASHPs. Due to the technical variability and site specific requirements, other useful thermal and energy recovery technologies were not modeled in this analysis. Scenarios were developed to illustrate the potential impacts of AECs on the levelized cost of energy (LCOE) of renewable thermal technologies – compared to fossil fuel base cases.

5.1 Scenario description

Two scenarios – total load and baseload heating – have been developed to evaluate the impacts of AECs on the cost effectiveness of renewable thermal technologies relative to fossil fuel heating alternatives.

- **Total thermal load scenario:** this scenario assumes that the full existing heating and domestic hot water (and/or cooling) system in a 15,000 square foot building must be replaced (e.g. an end-of-life replacement). Either a new high efficiency fossil fuel system or a new renewable thermal system will be installed, which will provide 100% of the building's heating and hot water energy needs. The Lifecycle Cost of Energy (LCOE) is calculated to compare (i) **the capital and fuel costs** for a new renewable thermal system (net incentives) divided by total energy generation, and (ii) **the capital and fuel costs** for a new fossil fuel system (net incentives) divided by total energy generation. Each is calculated over a 20 year period.

- **Baseload thermal scenario:** in this scenario, it is assumed that a fossil fuel system already exists in the building, serving the heating and domestic hot water (and/or cooling) needs of the occupants. A new renewable thermal system will be installed, which will displace 80% to 90% of energy production from the existing fossil fuel system. The fossil fuel system would continue to provide peak heating; thus, this scenario compares capital and fuel costs of renewable thermal systems with fuel costs only of fossil fuel systems. In other words, the LCOE is calculated to compare (i) **the capital and fuel costs** for a new renewable thermal system (net incentives) divided by total energy generation and (ii) **the fuel costs only** of the existing fossil fuel system divided by total energy generation. Each is calculated over a 20 year period.

Within each scenario, various heating or cooling applications were modeled. For example, in the total thermal load scenario, GSHPs and ASHPs were modeled to provide 100% of the heating, DHW, and cooling load of the building. On the other hand, because biomass does not typically serve cooling loads, chips and pellets were modeled only to provide heating and hot water. Similar variations were explored in the baseload scenario.

It is important to note that sizing renewable thermal technologies to serve different size loads can have a significant impact on the system's upfront costs. For example, in this scenario, a biomass system can be sized down to about half the capacity if it is designed to serve only 80% of the heating load, relying on an existing fossil fuel system to provide additional heat on the coldest days. Table 3 below illustrates the percentage of heating and cooling load modeled for each renewable thermal technology in the two scenarios.

Table 3 - Percent of energy provided by energy systems under "total thermal load" and "baseload thermal" scenarios

	Total Thermal Load			Baseload Thermal		
	Heating	DHW	Cooling	Heating	DHW	Cooling
GSHP	100%		100%	80-90%		~100%
ASHP	100%		100%	80-90%		~100%
Chips	100%		n/a	80-90%		n/a
Pellets	100%		n/a	80-90%		n/a
SHW	n/a		n/a	0%	49%	n/a

In addition, regional data and industry leaders also report that a number of other variables vary widely, which may affect the economics for heating and cooling systems. As a result, a range of installed costs, fuel cost, discount rates, and other relevant assumptions for each thermal system are provided in the appendix. For renewable thermal systems, this includes:

- High and low installed costs (on a $/kWth basis) based on a variety of design approaches for renewable thermal systems;
- High and low renewable thermal fuel price escalators;
- High efficiency assumptions for all systems (75% or greater or a COP of 2.7 or greater, see appendix for additional detail).

In order to award only net energy generation the electricity used by heat pumps for their own operation is subtracted from the thermal energy generated by the GSHPs and ASHPs, by converting the heat pump's own electricity consumption into BTUs. Going forward DOER shall analyze the option to use primary energy to generate the electricity used by the heat pump, in the calculation of the net thermal energy generated by heat pumps (see Appendix D – Calculating AEC values, for a more extensive discussion). The parasitical load for the other thermal technologies is considered to be negligible.

To simplify the analysis, a single LCOE was estimated for each fossil fuel system. Though it was ultimately deemed beyond the scope of this report, a more robust analysis of system costs and inputs – with detailed stakeholder input – is recommended in the future.

The results for commercial size applications are discussed below. The results for residential applications are very similar, and are included as an appendix.

Industrial heat or cold energy recovery is not modeled in this study. While interesting, the applications are too diverse and site specific to capture in a general modeling exercise. This should also be the subject of more detailed analysis going forward.

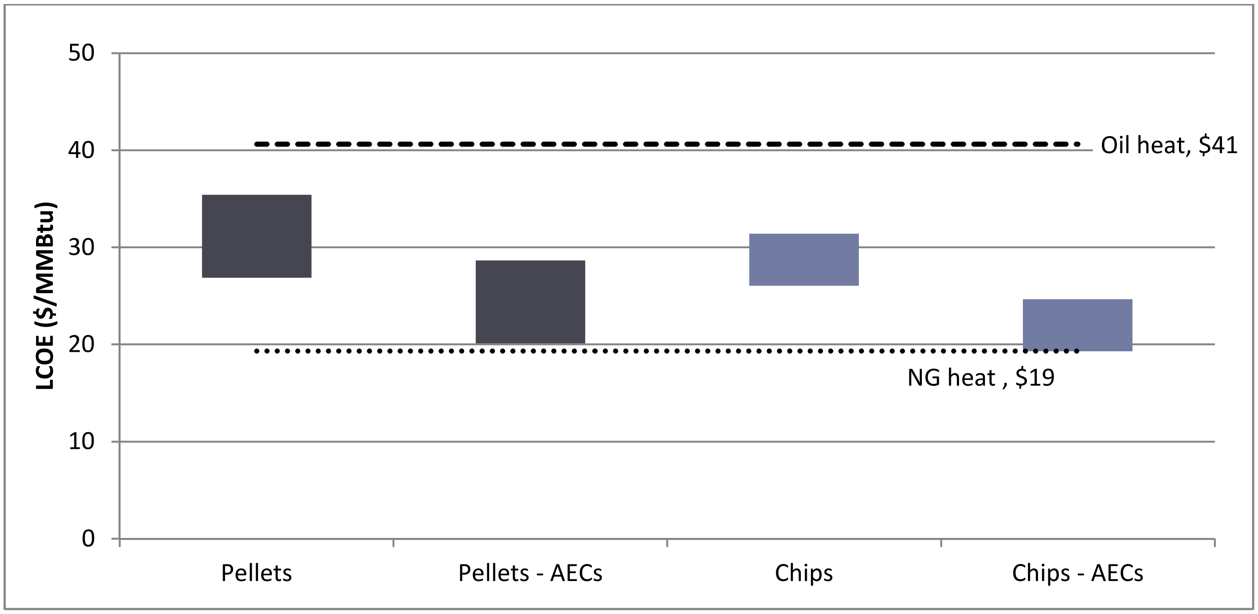
5.2 Total Thermal Load Scenario

Within the total thermal load scenario, all renewable thermal systems showed lower LCOEs than electric heating and cooling alternatives.

Biomass chips and pellets heating systems provide consumers a more cost-effective means of producing heating and hot water compared with fuel oil heating systems – based on current cost assumptions. However, the LCOE of natural gas systems are considerably lower than LCOEs of pellet and chip systems.

With this in mind, an AEC value of $5.86/MMBtu ($0.02/kWh) applied[19] over 20 years would further improve economics of chip and pellet systems compared to fuel oil and electricity. Moreover, it would additionally enable the most cost-effective chip and pellet systems to approach the cost of heating with natural gas.

Figure 4 – Financial analysis, total thermal load scenario, commercial size biomass systems

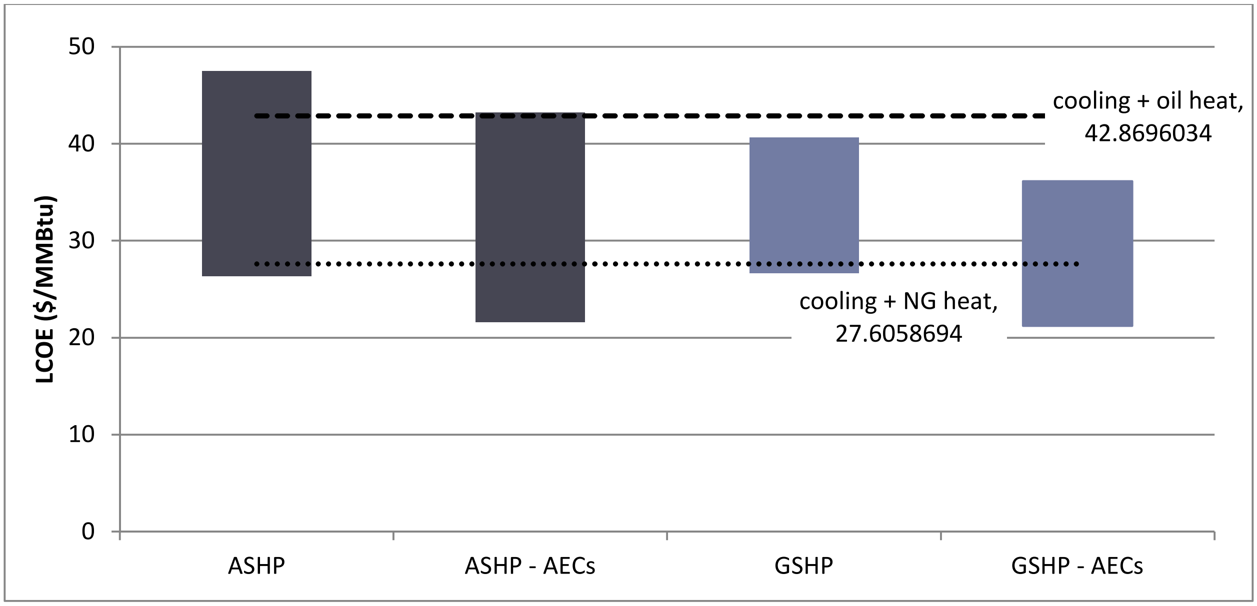


Similarly, in most cases, **GSHP and ASHPs** provide a more cost-effective means of providing heating, cooling, and hot water compared with fuel oil heating systems and conventional cooling systems[20] – based on current cost assumptions. Moreover, the most cost competitive ASHP and GSHP systems have an LCOE within the range of natural gas heating and conventional cooling systems as well. With the addition of $5.86/MMBtu ($0.02/kWh) AECs, applied over 20 years, GSHPs and ASHPs are generally competitive – and in many cases have lower LCOEs- than gas-fired heating and conventional cooling.

[19] 1 MWh thermal energy delivered receives 1 AEC, which is assumed to have a market value of $20/AEC or $0.02/kWh, consistent with the high end of current market values for AECs in the APS

[20] Conventional cooling systems are here assumed to be mini-splits with COPs equivalent to 2.5 for summertime cooling. The cold-climate, inverter-driven ASHP systems modeled as the renewable thermal technology, by contrast, are expected to have improved efficiencies – with year round seasonal COPs equivalent to 2.75 to 3.3 or greater.

Figure 5 - Financial analysis, total thermal load scenario, commercial size heat pump systems

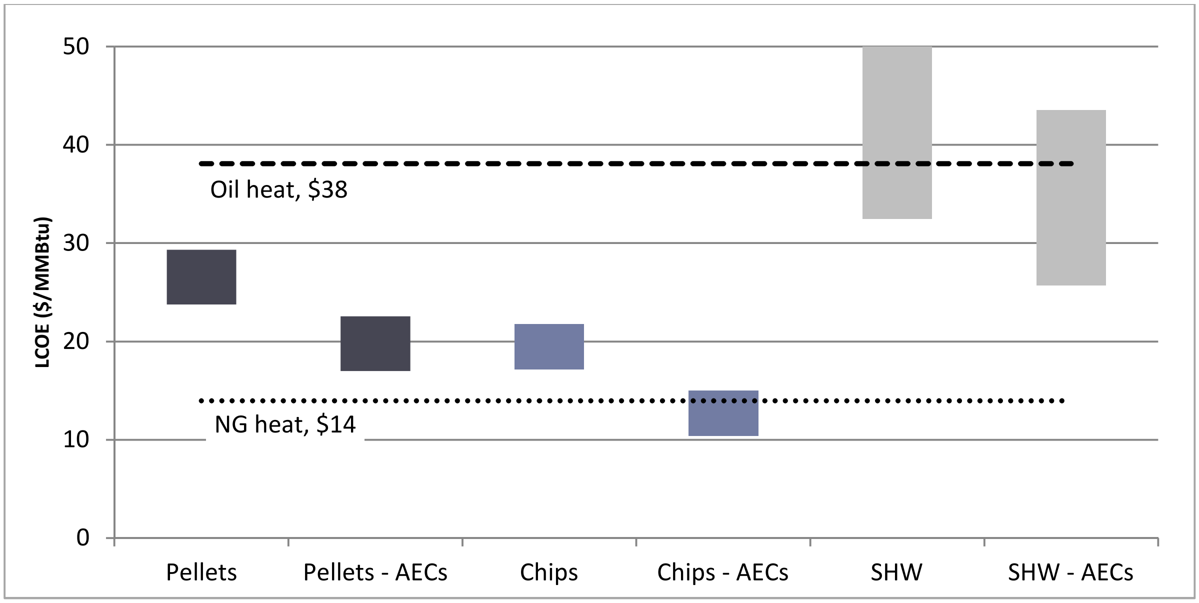


5.3 Baseload Thermal Scenario

Within the baseload thermal scenario, all renewable thermal systems showed lower LCOEs than electric heating and cooling alternatives. Biomass chips and pellets heating systems provide consumers a more cost-effective means of providing heating and hot water compared with fuel oil heating systems – based on current cost assumptions. The same is often true for solar hot water, though in worst case scenarios, the LCOE of SHW is higher than fuel oil.

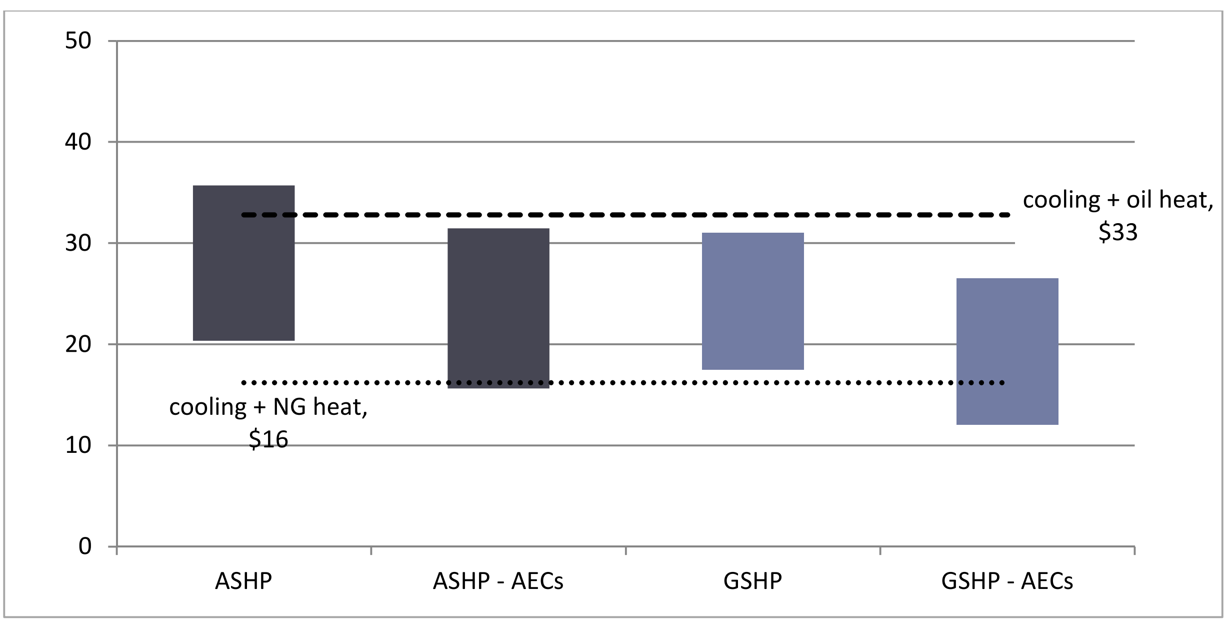
On the other hand, the LCOE of natural gas remains slightly lower than chips or pellets; however, it is important to note that under the baseload scenario, chips and pellets are more competitive than they are under the total thermal load. This is to be expected, when renewable thermal systems serve as the baseload heating system only, capital costs can be significantly reduced, though they can continue to provide 80-90% of the heat needed. Moreover, with the addition of $5.86/MMBtu ($0.02/kWh) AECs, chip heating systems are cost competitive with natural gas.

Figure 6 - Financial analysis, baseload scenario, commercial size biomass & solar systems



Similarly, GSHP and ASHPs provide a more cost-effective means of providing heating, cooling, and hot water compared with fuel oil heating systems and conventional cooling systems – based on current cost assumptions. Moreover, in some cases, the LCOE of GSHP systems approach natural gas and conventional cooling systems. The addition of $5.86/MMBtu ($0.02/kWh) AECs significantly improves the economics for GSHP and ASHP systems compared to natural gas.

Figure 7 - Financial analysis, baseload scenario, commercial size heat pump systems



5.4 Takeaways from total thermal load and baseload thermal scenarios

The analysis in Sections 5.2 and 5.3 concluded that the additional revenue from AECs sales can improve the business case for renewable thermal technologies. If renewable thermal technologies were able to receive a 20-year stream of AEC revenue at $0.02/kWh, this could significantly improve their competitive position compared to oil and natural gas prices.

All of the thermal technologies analyzed in this study are currently competitive with fuel oil and electricity under most assumptions when conservatively sized to supply the energy for the total thermal load and using currently available incentives. In the case of systems that displace fuel oil and electricity, AEC revenue would primarily increase the income of systems that could already be profitably developed. While not modeled, the results for renewable thermal systems displacing propane are expected to be in line with the conclusions for heating oil and electricity.

With regard to natural gas, the analysis shows that:

- ASHPs and GSHPs are "right on the line" in terms of the ability to compete with natural gas without AEC revenues. It is possible that some top performing projects could be profitably developed when displacing natural gas. In these cases, AEC revenues would enable a broader range of systems beyond the "best of the best" to be feasibly developed and displace natural gas.
- Wood chip projects do not appear to be competitive with natural gas without additional incentives. With AEC revenues, it is likely that some very competitive projects could be successfully developed.
- For wood pellets and for solar thermal, the analysis shows that AEC revenues would further improve an already good economic performance displacing natural gas, but would not enable either technology to cross the threshold into successful competition with natural gas.

5.5 Financing renewable thermal projects with AECs

The analysis above is for illustrative purposes in order to explore the impact that AEC values – at their maximum – could have on project economics. In reality, AEC values are determined in the marketplace, based on the supply and demand of AECs at any given time. Over time, AEC values could fluctuate between a price of $0/MWh and the price ceiling set by the ACP rate ($21/MWh in 2012).

The APS market in Massachusetts is fairly unique in the United States in that there are no other markets that currently allow a comparable mix of alternative energy resources to compete under similar market rules and conditions. As described in a recent report from the National Renewable Energy Laboratory, several states now allow renewable thermal and alternative energy resources to satisfy portfolio standard requirements.[21] However, as of now there are few lessons to be learned from these markets that would be applicable to Massachusetts. First, several of the policies are fairly new and have not yet had a chance to generate relevant data about market performance. Second, several of the policies do not use tradable renewable energy credits as is done in Massachusetts, and instead procure resources

[21] Heeter, J., & Bird, L., Including alternative resources in state renewable portfolio standards: Current design and implementation experience, National Renewable Energy Laboratory, 2012

under contracts that are negotiated or competitively bid. Finally, for the few established markets that do use tradable credits, there is relatively little publicly available data available.

Although it is difficult to make direct comparisons, experience from other tradable credit markets can be utilized as benchmarks for the AEC market. Broadly, tradable credit markets are inherently volatile with prices swinging back and forth between floor and ceiling values as supply and demand respond to market conditions. This dynamic has been modeled in studies on wind in tradable credit markets[22] and was also evident during efforts to model potential solar credit market designs[23]. Observations of historical credit prices in the U.S. confirm the reality of these observed price fluctuations, with credit prices under many state RPS regulations fluctuating significantly[24].

The volatility of tradable credit markets means that future project revenues are uncertain. In other words, the $20/MWh assumed in the analysis cannot be guaranteed. This revenue uncertainty has important implications for alternative energy project development. Projects seeking external financing may have trouble securing capital based on the projected income from AECs, since many investors and financiers do not consider the uncertain revenues from tradable credits to be "bankable." Projects that are "self-financed" using a company's balance sheet may also have trouble securing the necessary internal approval for the same reason. Even if the projects are approved, the revenue streams from tradable credits may be discounted or not taken into consideration when financing decisions are being made. Put another way, the decision on whether or not a project is profitable – and whether or not to build a project – may not made assuming the full value (or sometimes any value) for tradable credit revenues[25].

Several consequences of the volatility of tradable credit markets are therefore that: 1) projects that require additional revenue to be constructed may not be built since the AEC revenue is not considered reliable enough to "take to the bank", 2) investors and financiers may raise the cost of capital to reflect the risk of volatile revenues, which can increase project costs and inflate overall policy costs and 3) projects that can be built are able to capture excess profits from AEC revenues, which they may not require.

There are currently no publications which empirically ground these critiques in U.S. experience with renewable thermal, CHP, or other alternative energy resources.[26] A recent study on CHP concluded that

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[22] Ford, A., Vogstad, K., & Flynn, H.. Simulating price patterns for tradable green certificates to promote electricity generation from wind. Energy Policy, 35(1), 91-111, 2007

[23] Flynn, et al.. System dynamics modeling of the Massachusetts SREC market. Sustainability, 2, 2746-2761, 2010

[24] Bird, L. et al.. Solar renewable energy certificate (SREC) markets: Status and trends, National Renewable Energy Laboratory, 2011 / Wiser, R., & Barbose, G., Renewables portfolio standards in the United States: A status report with data through 2007, Berkeley, CA: Lawrence Berkeley National Laboratory, 2008

[25] Baratoff, M. C., et al., Renewable power, policy, and the cost of capital: Improving capital market efficiency to support renewable power generation projects. Ann Arbor, MI: University of Michigan, Erb Institute for Global Sustainable Enterprise. Prepared for UNEP/BASE Sustainable Energy Finance Initiative, 2007

[26] The study on thermal energy in the RPS in New Hampshire concluded that a thermal RPS would be administratively challenging, but did not explore the issue of thermal RECs (New Hampshire Office of Energy and Planning, 2008). A recent study about integrating renewable thermal into the RPS in Maine assumes a reduced value for thermal renewable energy credit markets as a result of oversupply, but does not draw broader

the tradable credit market created under the APS has been a motivator for CHP project development[27]. Interviews with alternative energy developers and financiers active in the Northeast, also confirms that the APS has been useful in supporting the economic performance of new CHP plants. At the same time, however, developers acknowledge that when AEC values are built into project pro formas, they are included at a discount to adjust for future uncertainties. Developers also stated that the assumed value of AECs would be adjusted downward or discounted entirely if it appeared likely that the market price could trend sharply downward in the future.

There are several approaches that could be used to make AEC revenue streams more "bankable." First, policy makers could use the ability to adjust the overall APS target so that demand could be increased if there appeared to be a risk that the market was oversupplied to the point that credit prices were at risk of crashing. Such approaches, however, require the market to be carefully managed and may not be sufficient to reassure investors. Policy makers can also consider mechanisms that provide revenue certainty to developers. These may include energy credit price floors, long-term contracts, and upfront rebates calculated to reflect expected system output over time. These options are discussed in greater detail in the final chapter of this report.

6 Thermal market development

As noted in section 1.3, inclusion of useful thermal energy in the APS requires careful consideration of the impact this would have on the market for the other eligible technologies. Possible impacts of inclusion of useful thermal energy could be twofold: they could either crowd out the existing technologies, or lower the market prices for the Alternative Energy Credits if useful thermal energy would be much more cost-efficient than the existing technologies.

As of December 2012, a total capacity of 50.5 MW is qualified under the APS. The vast majority of this capacity is combined heat and power (CHP), with only 3 MW qualified as flywheel storage.[28] As a result, future projected growth of current APS technologies focuses on CHP.

Two possible scenarios were developed: a high and a low growth scenario, reflecting a range of reasonable growth rates based on APS market development over the past 3 years. The high growth scenario assumes a growth rate of 25% per year for CHP; the low growth scenario assumes a growth rate of 20% per year. In reality, market growth may be (and very likely will be) less gradual. The CHP market is currently a very dynamic environment, impacted by the historically low natural gas prices. This makes it hard to predict future growth. Also, the Massachusetts CHP market to date consists mostly of

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conclusions about potential thermal REC trends or financier perspectives (Strauss, 2012). Outside the US, a recent report on experience Sweden concludes that tradable credit markets did not support a significant amount of new CHP capacity and provided excess rents to projects that participated in the market – but these results are not readily transferable to the US (Bergek & Jacobsson, 2010).

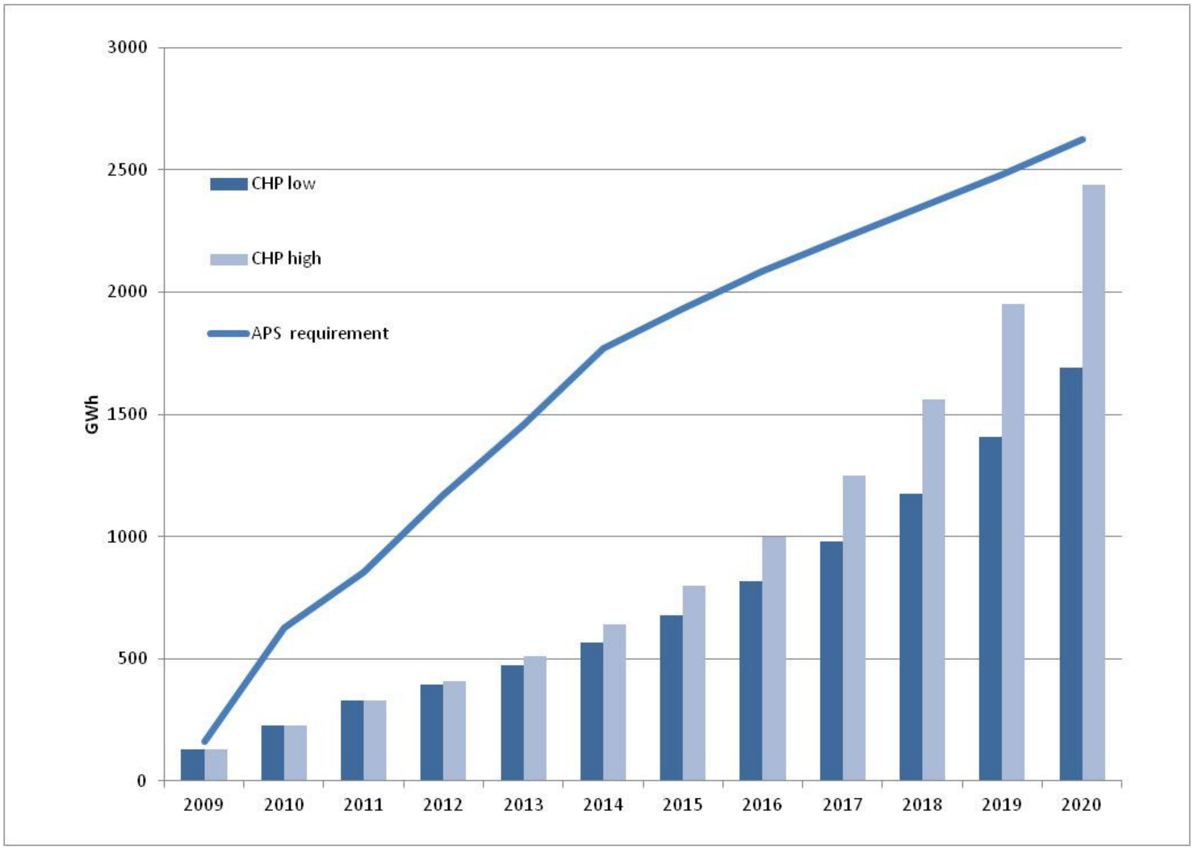
[27] KEMA, Project 1C Combined Heat & Power Market Characterization, Massachusetts Energy Efficiency Programs' Large Commercial & Industrial Evaluation, 2011

[28] List of APS qualified units: http://www.mass.gov/eea/docs/doer/rps-aps/aps-qualified-units.xls

relatively small units. If one of two larger utility scale CHP units were to become qualified, this would result in a sudden jump in qualified capacity under the APS.

Figure 8 shows the projected CHP growth under the two scenarios and compares it to the APS minimum standard as it is set to increase per the current regulations.

Figure 8 – Projected CHP growth compared to APS minimum standard



As the projections show, if CHP growth rates continue as they have in the past, undersupply of the APS will continue in the near term. However, market undersupply would become narrower in later years closer to 2020. This indicates that, especially in the short term, there may be room to accommodate useful thermal energy in the APS list of eligible technologies.

It is hard to predict how the CHP market will grow, and it is even harder to predict how adding useful thermal to the APS might impact the market. Therefore, three scenarios were developed to model market growth with useful thermal technologies, using business as usual growth (BAU) of the renewable thermal technologies to date in the state and targets for 2020 relating to renewable thermal energy, which are detailed in the Massachusetts Clean Energy and Climate Plan for 2020.[29]

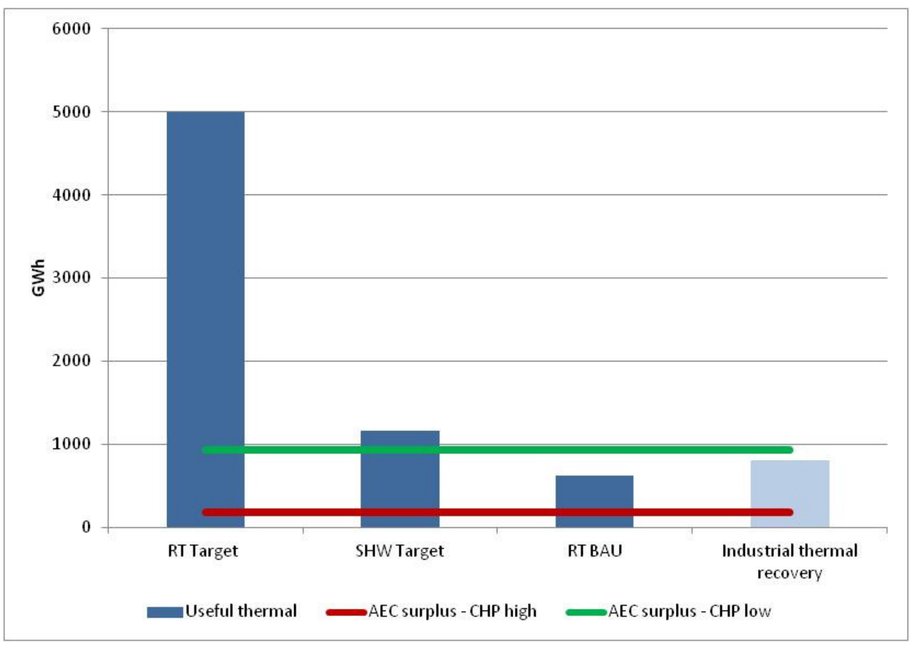
[29] Massachusetts Clean Energy and Climate Plan 2020, Section "Developing a mature market for solar thermal water and space heating", http://www.mass.gov/eea/docs/eea/energy/2020-clean-energy-plan.pdf

Renewable thermal growth scenarios include:

- Business as Usual (RT BAU): continued growth of renewable thermal technologies at the rate observed in recent years, taking into account the expected impact of the Commonwealth Solar Hot Water Program.
- Solar hot water target (SHW Target): same as BAU, but with the solar hot water target included in the Clean Energy and Climate Plan.
- Renewable thermal target (RT Target): using the overall renewable thermal energy target included in the Clean Energy and Climate Plan.

The results of the scenarios are summarized below, expressed as energy generation in 2020. Figure 9 further shows how the expected energy generation by renewable thermal technologies compares to the available capacity under the minimum standard, in 2020, in the two CHP growth scenarios discussed earlier (see Figure 8). In this comparison, it is assumed that 1 MWh of thermal generation is awarded 1 Alternative Energy Credit (AEC). For GSHPs and ASHPs the AECs cash flows were discounted to reflect only net energy generation (subtracting electricity used by the heat pump itself).

Figure 9 – Estimated useful thermal AEC supply vs. estimated AEC surplus in 2020



Note that in order to meet the SHW target included in the Clean Energy and Climate Plan, a doubling of the growth rate for all renewable thermal technologies will be needed. In order to meet the overall indicative renewable thermal target, these growth rates will again have to be significantly increased.

The results in Figure 9 indicate that only in the BAU renewable thermal growth case with low CHP growth is there enough room under the APS minimum standard to accommodate renewable thermal. In all other scenarios, the minimum standard is too constraining in 2020. This can be interpreted as an indication that including useful thermal in the APS, under the current minimum standard, risks crowding out CHP if the targets set forth by the Clean Energy and Climate Plan are to be met.

These projections do not include waste heat recovery. Analysis of the DEP database of reporting emission units results in the data summarized in Table 4. This indicates that useful thermal recovery in the industrial sector in Massachusetts is potentially of the same order of magnitude as renewable thermal development. Industrial thermal recovery potential is also included in Figure 9.

Table 4 – Industrial energy use in Massachusetts and useful thermal recovery potential

Industrial energy use	**GWh**
Total thermal energy use (excludes power generation, flares and CHP)	41,911
High-value target energy use (high cost fuels)	3,224
Thermal recovery potential (assuming 25% of high-value target energy use can be recovered)	806

Note that the assumption of awarding one AEC per MWh useful thermal energy generation can be adjusted to a higher or lower fraction of an AEC, in a formulaic manner. The APS has precedent in using a formulaic approach in the case of how CHP and flywheels are awarded AECs. The results of the analysis in this chapter would naturally change accordingly.

7 Policy options and recommendations

The market for renewable thermal and thermal recovery in Massachusetts is growing but small. Increasing the market share of useful thermal technologies will enable the Commonwealth to address a series of important challenges. These include decreasing dependency on fossil heating fuels that are either very costly (oil, propane, electricity), constrained (natural gas), or both; meeting greenhouse gas reduction targets; increasing energy efficiency; and improving air quality. It is therefore justified to develop additional incentives to support useful thermal technologies.

Inclusion of useful thermal in the APS is one potential pathway to support useful thermal technologies. The APS is currently undersubscribed, creating a high dependency on Alternative Compliance Payments, which is not desirable. This analysis shows that there is room to include additional technologies to qualify under the minimum standard of the APS, though depending upon the technologies incorporated – and the growth rate of those technologies – the APS market will likely become quickly constrained, potentially leading to a crash in AEC prices and a halt to further development.

Nonetheless, the APS is designed to accommodate a broad portfolio of alternative technologies, and it already includes CHP, creating a sound precedent for incentivizing thermal energy production from other renewable technologies. Adding other emerging technologies is at the discretion of DOER and appears to be the intent of how the Legislature designed the APS. However, incorporating multiple, new useful thermal technologies without crashing AEC prices, would likely require APS policy adjustments to either the minimum standard (e.g. increasing the minimum standard) or the eligibility term of systems (e.g. limiting the term of eligibility of any particular installed system).

7.1 Recommended Technologies

The following renewable thermal technologies seem appropriate to include in the APS at this time:

- **Biomass**: highly efficient, variable systems with low air emissions, using wood or other biomass such as grasses, in the form of cordwood, pellets or chips.
- **Solar Hot Water**: collectors providing additional heat for space heating, domestic hot water, process heat or other low temperature heating needs.
- **Heat pumps**: highly efficient (at least Energy Star or equivalent) systems of compressors/expanders and heat exchangers using the thermal energy of ambient air, water or underground to heat and cool buildings. Only the net thermal energy generation of the heat pumps is awarded AECs, thereby incentivizing the most efficient systems. It is an outstanding question whether the cooling by heat pumps would be included in the useful thermal energy generation. The legislature, or DOER, might contemplate adding building efficiency requirements to the qualification of applications of heat pumps in the APS.
- **Advanced biofuels**: biomass derived liquid fuels delivering at least a 50% reduction in lifecycle GHG emissions as compared to conventional fuel oil.
- **Biogas**: digester gas from Anaerobic Digestion or capped landfills used for heating purposes at the site of capture, or by mixing it in the natural gas pipelines. In the latter case an analysis will be needed of issues around importing pipeline biogas from outside the state.

In order to realize the benefits of the useful thermal energy for Massachusetts customers and Massachusetts as a whole, the delivery of the thermal energy to an end user in Massachusetts should and can be required. Otherwise Massachusetts residents will not benefit by decreasing dependency on high cost fuels, improved air quality, and regional energy security.

Thermal recovery in industrial facilities also presents a compelling opportunity, though it seems to be too early to include waste heat and thermal recovery in the APS at this time. Applications are very diverse and site specific. DOER recommends first devoting additional resources to analyzing the potential of industrial thermal recovery, as well as implementing pilot incentive programs to collect more data on the applications and their economics. This will provide needed information for potential future inclusion of waste heat and thermal recovery technologies in the APS. It may also make more sense to better address waste heat recovery through the Mass Save efficiency programs.

7.2 Legal aspects

While the APS statute currently limits applicability to energy generating sources that generate electricity, DOER's definition of alternative energy development clearly favors a broad application of technologies. Therefore the statutory enabling language of the APS should be broadened to apply to "energy generation" as opposed to the narrower "electricity generation".

Further, the remainder of the statute is flexible enough to allow for programmatic decisions to foster useful thermal energy development. In particular, the APS statute does not dictate the procedure to measure energy output by a particular system, a requirement to meter, or the assignment of partial or whole Alternative Energy Credits, rather, these are detailed through regulations. Absent explicit statutory authority, DOER can make programmatic decisions in order to meet the purposes of the underlying statute.

7.3 Mechanics

7.3.1 Optimal financial leverage by AECs

Inclusion of renewable thermal technologies in the APS can support accelerated market growth for these technologies. All of the renewable technologies are competitive with fuel oil, propane and electricity on a lifecycle cost basis without AECs, and will perform even better with AECs. Awarding AECs to renewable thermal systems would enable a broader range of heat pumps and wood chip projects to be competitive with natural gas. Wood pellet systems and solar thermal show strong economics compared to electricity and oil, though AECs would likely not enable them to cross the threshold to compete with natural gas.

Altogether, this speaks in favor of including renewable thermal technologies in the APS, along with the current technologies.

It is, however, necessary to include renewable thermal technologies in the APS in a way that takes into account the nature of energy credit markets discussed in Section 5.5. These tend to show a scarcity of long term contracts and volatility of market prices of AECs, which does not appear to significantly improve financing of projects.

This study assumes useful thermal technologies receive AECs at the rate of one AEC per delivered MWh, subtracting electricity use in the case of heat pumps. A BTU to MWh conversion, wherein 3,412,000BTUs are equal to 1 MWh, is widely used to convert thermal energy into electrical or fossil fuel displacement.[30] The impact on project economics has been calculated assuming that the maximum value of AECs is credited in the cash flows.

However, in reality without price certainty, the AECs will be credited at a discounted value, begging the question: will the desired growth of useful thermal actually result from this inclusion? Furthermore, as discussed in Section 1.1.2, one of the major hurdles for renewable thermal technologies is that they face significantly higher upfront costs than fossil fuel systems. Even if higher upfront costs are offset by savings over the lifetime of the installation, one first needs the extra capital to make the investment.

This speaks in favor of including renewable thermal technologies in the APS in a way that translates AECs into an upfront incentive.

[30] Massachusetts DOER, APS Guideline for CHP, June 14, 2011 Edition: “3,412 thousand Btu of Useful Thermal Energy of input fuel being equivalent to one MWh of electrical energy”, http://www.mass.gov/eea/docs/doer/rps-aps/aps-chp-guidelines-jun14-2011.pdf

With this in mind, DOER identifies two potential pathways for incorporating renewable thermal technologies into the APS. The latter option seems to offer the best prospects for supporting the renewable thermal market.

<u>APS inclusion, option 1: classic performance based AEC minting.</u>

Eligible projects qualify in the APS, and are awarded one AEC per MWh of useful thermal energy generated. The useful thermal energy is netted taking into account the internal energy used by the equipment (e.g. electricity use by heat pumps) and only rewards delivered useful energy (e.g. hot water used for heating in the building, not the heat delivered to a hot water storage tank).

This option has the advantage of being the most straightforward in terms of necessary regulatory/statutory changes.

<u>APS inclusion, option 2: upfront incentive to the tune of a 5 year strip of AECs.</u>

Eligible projects qualify in the APS, and are awarded a one-time strip of AECs to account for an established time period (5 years, 10 years, etc.) of modeled energy production and concomitant AEC generation. The useful thermal energy is netted taking into account the internal energy used by the equipment (e.g. electricity use by heat pumps) and only rewards delivered useful energy (e.g. hot water used for heating in the building, not the heat delivered to a hot water storage tank). No more AECs are awarded after the one-time upfront strip.

Compared to the performance based option (#1), the upfront incentive (#2) can have a significant impact on market growth of renewable thermal technologies at a lower overall cost to ratepayers. This option, limiting AEC credit to only 5 or so years, also generates a lower influx of AECs in the APS, thereby having a lower risk of crowding out the existing APS technologies.

The upfront incentive option requires more substantial regulatory/statutory changes, but reduces the administrative burdens to small projects of AEC market transactions. The link between the issued AECs and the real thermal energy generation over the lifetime of the project is less clear in this option, which may require further assessment. AECs get used as an upfront grant to reduce capital needs, much like how the efficiency grants are deployed in the MassSave program.

One advantage of the upfront incentive is that the AEC strips can be tailored to reflect longer or shorter payback times, if DOER deems it necessary to incentivize one technology more or less than another.

DOER proposes to distinguish two options for retail suppliers to submit the “upfront AEC strip” for compliance with the APS requirements:

- All AECs of the strip can be used for compliance **in the year they are issued**. This eliminates the risk of creating extra costs to the retail supplier buying the AECs. This option potentially creates a significant influx of AECs in the APS, which may be less of an issue in the early years – but might crowd out existing APS technologies if the APS minimum standard is not adjusted in later years.

- AECs get used **in the compliance year they are modeled for** (e.g. over 5 years, 10 years, or whatever term is deemed appropriate). This would allow for a true up of the issued strip with the real useful thermal energy generation of the project. In this scenario, retail suppliers have to buy the whole strip upfront and can only recover the cost over the course of the 5 years. They could be required to do so, or they could be incentivized by a multiplier of AECs on top of the AECs awarded to the project, equivalent to the lost time value of the upfront cost of the AECs to the supplier. Alternatively, DOER can set up a revolving fund to buy and sell the upfront strips of AECs, initially funded by ACP funds, but these funds may not be sufficient beyond a pilot phase. Note however that the accuracy of the modeled generation will be heavily influenced by evolving weather patterns and/or other factors beyond control of normal true-up mechanisms.

7.3.2 Adjust minimum standard

The study tentatively projected growth of the renewable thermal market under three scenarios, and compared the associated AEC generation from useful thermal to the current and expected AEC growth scenarios of existing APS technologies, under a high and low growth scenario. One needs to be cautious in drawing conclusions from this exercise, as both the growth of current APS technologies and renewable thermal is challenging to predict. This is especially true for heating and cooling use, which will be highly dependent upon future weather patterns (e.g. hotter summers or colder winters will influence heating and cooling demand and associated AEC production).

However, in only one of the six modeled scenario combinations did the current APS minimum standard allow for enough room to accommodate addition of new technologies. This was in the case that renewable thermal was added to the APS, but no additional growth of renewable thermal compared to business as usual was expected to result from this inclusion. Arguably, this is the least likely (and desirable) scenario, as the intent of the inclusion is to have an additional growth impact.

In all other scenarios, the preliminary conclusions are that the current minimum standard will be insufficient in accommodating new technologies in the near term.

There are three potential responses to this situation:

- Change the APS minimum standard to a **floating standard**, certainly for the later years, 2015-2020. As the growth of the thermal market is hard to predict, and it is not advised to set the standard at a level that creates unnecessary ACP payments, it is recommended to implement a floating standard. This standard can be designed to automatically increase with a set percentage point over the preceding year's generation, thereby continuing demand for AECs. Creating a standard that floats, but is always set for three forward years, may be feasible and reduce compliance uncertainty to load serving entities. Note that DOER is investigating – at the request of the Legislature – ways to reduce the RPS Class II minimum standard, which can balance a minimum standard increase for the APS.

- **Decrease the influx of AECs** by either applying a fraction to the AECs awarded per MWh of useful thermal energy, decreasing the number of years that AECs are minted for a given project, or by limiting the list of eligible renewable thermal technologies in the APS.
- **Do not intervene**. Let the supply of AECs fill up the minimum standard and thereby limit the market growth up to the current APS minimum standard. Competition of renewable thermal with current APS technologies is likely in this case, as is greater market risk for AEC prices to drop towards zero.

Note that currently the APS is undersupplied, with resulting high ACP payments[31]. ACP payments for the APS were $7.8 million in compliance year 2010 and $12 million in compliance year 2011. Including new technologies could therefore result in substantially reduced ACP reliance.

7.3.3 Metering

In the case of renewable thermal, where technologies are included in the APS and awarded AECs on a performance basis, all projects will need to meter and report their thermal energy generation. Standardized verification of the metering equipment will have to ensure proper operation. Small scale projects could be allowed to model their output with certified modeling software. Before allowing this, more research is needed to assess the validity of models, in order to create more confidence in their predictions.

Alternatively, smaller projects might have simplified metering and reporting requirements, similar to the current provisions in the DOER guidelines[32] for CHP systems smaller than 10 kW.

In the case AECs are awarded as an upfront incentive option, metering requirements could be relaxed to allow residential projects not to meter, but require an inspection every two years. Residential biomass systems would need to submit fuel supply (chips, pellets) reports to demonstrate continued operation as renewable heating systems. Commercial and industrial applications should still be required to meter and report in order to track their thermal energy generation. The relative cost of the metering is less prohibitive in the case of larger systems.

The Legislature or DOER could provide a claw-back option whereby the incentives can be partly or entirely recovered in case irregularities are found.

7.4 Complimentary policy measures

Realizing the benefits of renewable heating and cooling requires a comprehensive approach to market development, which includes the following elements: (1) financial incentives or programs to help overcome high first costs, (2) expanded consumer awareness, (3) integration of renewable thermal

[31] The 2012 ACP rate for the APS is $21.02/MWh - http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/rps-aps/retail-electric-supplier-compliance/alternative-compliance-payment-rates.html
[32] Massachusetts DOER, APS Guideline for CHP, June 14, 2011 Edition

technologies into building codes and renovation requirements, and (4) consistent stakeholder and workforce training initiatives to build capacity within the renewable thermal market.[33]

Combinations of incentive types are also possible and such incentives can be implemented via grants, rebates, tax incentives, or some other payment mechanisms. This study discussed various options in Section 1.3.

One particular option in Massachusetts might be to extend the Mass Save HEAT loan program to include all renewable thermal technologies. Currently only solar hot water is an eligible application, and there has been some limited experience with HEAT loans for biomass boilers as part of ARRA funded efforts in 2010-2011.

[33] Breger et al., Taking the Next Step: Driving Renewable Thermal Energy Development in the U.S., WREF Conference Paper, June 2012

Appendix A – Technical description of Useful Thermal Technologies

The following technologies are considered the most common examples of useful thermal applications. It is important to note that this list is not exhaustive. Within the sector, there are a number of very specific applications and new technology development that is occurring. However, this list provides a good starting point for exploring renewable thermal production and heat recovery technologies.

Biomass

In general, biomass is organic matter. When mentioned in the context of energy, biomass is renewable plant material and vegetation growing above the earth's crust or agricultural waste. Biomass thermal energy is the use of biomass for space and domestic water heating, process heat, and the thermal portion of combined heat and power[34]. Extremely clean and highly efficient biomass combustion technology is rapidly becoming available in the domestic US marketplace. Efficient fuel distribution systems are in place to expand the adoption of central heating systems in home and business heating, industrial process heat, district heating of campuses, business parks, or whole communities, and combined heat and power.

Most commonly, **biomass heating systems** use split wood or high quality wood pellets or chips for fuel. Wood pellets and chips are typically sourced from lumber mills or other forest product processing facilities. Pellets may also be produced from grasses or other plants.

Biomass central heating systems consist of furnaces and boilers as well as the accompanying fuel storage and feeding, emission control, and HVAC infrastructure, plus a hot water accumulator tank for thermal energy storage - if necessary. Some pellet boilers can modulate efficiently to meet fluctuating demand and hence do not need thermal storage, while other boilers operate best at constant and full load, in which case storage is needed to meet fluctuating demand and reduce wear and tear of the system[35]. The cost and efficiency of biomass heating systems can vary significantly, depending on the level of automation and the design of the combustion process.

To ensure that biomass energy also delivers climate benefits through reduced GHG emissions, DOER considers in this report systems that meet guidelines developed for woody biomass in power generation. These guidelines are based on the Manomet study,[36] which concluded that the time needed to pay off the carbon debt and begin accruing the benefits of biomass energy will be shorter for thermal and CHP technologies than for electric power generation, when the same forest management approaches are used in harvesting wood. Importantly, encouraging biomass heating and cooling provides market opportunities needed by the forest and wood products industries for low-valued residue wood supplies and will provide greater GHG benefits than supplying these resources to electric-only power plants.

[34] https://www.biomassthermal.org/
[35] http://www.maineenergysystems.com/blog/?tag=boiler-modulation
[36] http://www.manomet.org/manomet-study-woody-biomass-energy

Massachusetts Biomass Heating Market

Stakeholders in Massachusetts indicate that biomass heating is an emerging market, estimating that fewer than 100 pellet- or chip-based central heating systems are installed across the state. 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[37].

Unlike wood chips, wood pellet production has been robust and has experienced significant growth over the past decade– with about 26 wood pellet mills operating in the Northeast, though none currently operate in Massachusetts. New Hampshire, Vermont, Pennsylvania, and New York dominate the wood pellet manufacturing market in the region.[38]

Solar thermal

Solar hot water (SHW) systems use the sun to heat water. SHW systems are typically used to generate heat for domestic hot water (DHW), pool heating, and space heating. Most SHW installations in the Commonwealth are currently designed and sized to serve DHW only. Solar combi-systems, on the other hand, provide DHW and space heating and offer additional opportunities for energy savings and GHG reductions.

Most solar water heating systems for buildings have two main parts: a solar collector on the roof and a storage tank that holds the water that is heated by a fluid that is circulated through the collectors. Because it is rarely cost-effective (or technically feasible) to size a SHW system to cover 100% of a building's heating load, SHW requires auxiliary (back-up) heating. The back-up heating can be served by renewable biomass, high efficiency heat pumps, or existing fossil fuel systems.

Commercial and industrial buildings can use the same solar technologies that are used for residential buildings[39]. Nonresidential buildings can also use solar thermal technologies for applications that would be impractical for a home, including ventilation air preheating, solar process heat, and solar cooling. Space cooling can be accomplished using thermally activated cooling systems (TACS) driven by solar energy. However, because of current high costs, TACS have not achieved widespread use in Massachusetts or elsewhere.[40]

Massachusetts Solar Hot Water Market

Through MassCEC's Commonwealth Solar Hot Water Pilot Program, 320 residential and commercial-scale SHW systems totaling more than 27,000 square feet in collector area (equivalent to about 5 million kBTU/year) and over $3.8 million in total project costs were awarded construction rebates during the

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[37] Meister Consultants Group, Massachusetts Renewable Heating and Cooling Report, Opportunities and Impacts Study, Prepared for DOER and MassCEC, March 2012

[38] Ibid.

[39] http://www.nrel.gov/learning/re_solar_process.html

[40] IEA, Technology Roadmap, Solar Heating and Cooling, 2012

16-month pilot program. Massachusetts' SHW market growth is supported by manufacturers and installers across the region. Fifteen solar collector manufacturers are active in the Northeast. At least five manufacturers of collectors, tanks, or other solar heating components have facilities located in Massachusetts. 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.[41]

Heat pumps

A heat pump is a device that transfers thermal energy from a heat source to a heat sink. Heat pumps can move thermal energy in a direction which is opposite to the direction of spontaneous heat flow. Heat pumps consume electricity to deliver the useful thermal energy, though overall energy efficiency gains and greenhouse gas savings can be realized with efficient equipment and under proper installation and operational conditions. Heat pumps are often considered both an energy efficiency investment and a form of renewable energy generation. The technology has advanced significantly in recent years, and performance has increased considerably, now making it also a good fit for colder winter regions like Massachusetts. When designing an incentive program, and for the purposes of this report, DOER and MassCEC only consider the most advanced performing (high efficiency) systems, which use variable speed condensers and can be deployed in cold climates like Massachusetts.

A common source or sink for heat in smaller installations is the outside air, as used by an **air-source heat pump** (ASHP). Larger installations handling more heat, or in tight physical spaces, often use **water-source heat pumps** (WSHP). In this case, the heat is sourced or rejected in water flow (e.g. from wells or ponds), which can carry much larger amounts of heat through a given volume than air flow can carry.

Geothermal heat pumps or **ground-source heat pumps** (GSHP) use underground heat exchangers as a heat source or sink, and water as the heat transport medium. This is possible because below ground level, the temperature is relatively constant across the seasons, and the earth can provide or absorb a large amount of heat. Ground-source heat pumps work in the same way as air-source heat pumps, but exchange heat with the ground via water pumped through pipes in the ground, either in deep vertical wells or horizontal loops close to the surface. Ground-source heat pumps can achieve higher energy efficiencies - but the need for a ground heat exchanger requires a higher initial capital cost than ASHP in exchange for lower annual operating costs.

A promising new opportunity is to use domestic waste water as a source of heat, via **sewer drain water heat recovery**, as sewer water is often warmer than cold winter ambient temperatures. The system is a closed loop that enables building owners to tap into the thermal energy provided by the sewer infrastructure. Heat exchange with the building's existing hot and cold water loop occurs at the heat pump without any source interaction between the two systems. Some vendors are proposing to use drain water as a pre-heating system for a normal DHW system, but due to this application being more an energy efficiency measure, those applications fall outside of the scope of this study.

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[41] Meister Consultants Group, Massachusetts Renewable Heating and Cooling Report, Opportunities and Impacts Study, Prepared for DOER and MassCEC, March 2012

Massachusetts Heat Pump Market

Massachusetts has a growing **ground source heat pump** market. 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. In the period 2004-2010 an average of 50 GSHPs have been installed each year, with a compound annual growth rate of approximately 24% annually.[42]

While no geothermal heat pump manufacturers are currently located in Massachusetts, according to the International Ground Source Heat Pump Association, 204 accredited GSHP installers are located in Massachusetts. However, only three system designers are listed as accredited design professionals in Massachusetts, which 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 what has to date been a niche expertise.

Two manufacturers currently offer dedicated cold climate inverter-driven **air source heat pumps** in the Massachusetts market. According to the Consortium for Energy Efficiency, ten manufacturers offer mini-split heat pumps that qualify for Massachusetts Utilities' Cool Smart rebate program.

Mini-split heat pumps are composed of an outdoor unit, and an indoor mounted evaporator unit, which are connected via small refrigerant tubes that run through a three inch opening in the wall or ceiling. They are very popular in Japan and Europe. Because these systems do not use the air ducts of a typical central air conditioning system, they are also called "ductless" mini-splits. **Variable Refrigerant Flow** (VRF) technology uses smart integrated controls, variable speed drives, refrigerant piping, and heat recovery to provide products with attributes that include high energy efficiency, flexible operation, ease of installation, low noise, zone control, and comfort using all-electric technology[43].

Stakeholders indicate that, if demand for cold climate heat pumps increases, a number of manufacturers, both foreign and domestic, could enter the market with new products. The installation of ductless mini-split and Variable Refrigerant Flow (VRF) heat pumps is a relatively straightforward process when compared to other central heating, ventilation and air-conditioning (HVAC) technologies. Additionally, product manufacturers are eager to train existing HVAC professionals to install their systems.

<u>Advanced biofuels</u>

A replacement for petroleum-based fuel oil, **biodiesel** is manufactured from a wide range of renewable sources. Biodiesel can be used by itself, though this is rarely the case. Pure biodiesel is typically blended with conventional petroleum-based heating oil to create a biodiesel blend that can be used in boilers (or vehicle engines) without the need for technical adaptations. Such blends are commonly identified by the ratio of biodiesel to conventional oil. For example, "B5" refers to a mixture of 5% biodiesel and 95% conventional fuel oil. In space heating applications (particularly in Massachusetts), blends of B5 and

[42] Meister Consultants Group, Massachusetts Renewable Heating and Cooling Report, Opportunities and Impacts Study, Prepared for DOER and MassCEC, March 2012

[43] Amarnath, A, Electric Power Research Institute, Variable Refrigerant Flow: An Emerging Air Conditioner and Heat Pump Technology, 2008

below are common. Blends up to B20 are more common in transportation applications, but can require a preheating element to cope with the cold seasons of the year.

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.

A key distinction is 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.[44] 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.
Massachusetts Biofuels Market

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). This biodiesel is blended for economic reasons at refineries and is typically not reported or tracked. A reasonable estimate of 1% to 3% biodiesel blend would mean that biodiesel provides roughly 8 million to 30 million gallons of heating fuel annually. Industry stakeholders indicate that there is a significant under-realized potential for producing advanced biodiesel in the state. 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.

Retail distribution of heating oil in Massachusetts is diffuse and heterogeneous. Anecdotal evidence suggests that, in some cases, selling biodiesel blends, often at B5 under the name of "Bio-heat", has proven to be an effective marketing and customer acquisition tool for retailers that are seeking to differentiate themselves from other suppliers.[45]

Biogas

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen. It is used for industrial, agricultural and public health purposes to manage organic waste and/or to release energy. Anaerobic digestion produces a **biogas**, consisting of methane, carbon dioxide and traces of other gases. This biogas can be used directly for heating, or in combined heat and power systems. With greater capital investment, the gas can be upgraded to natural

[44] An Act Relative to Clean Energy Biofuels, M.G.L. 94, § 295G1/2 2008 and 225 CMR 14.00 (RPS Class I regulation)

[45] Meister Consultants Group, Massachusetts Renewable Heating and Cooling Report, Opportunities and Impacts Study, Prepared for DOER and MassCEC, March 2012

gas-quality biomethane for injection in the natural gas distribution pipelines. The biogas can also be compressed for use as vehicle fuel (CNG).

Massachusetts Biogas Market

There are currently about twelve operational anaerobic digestion facilities in Massachusetts, the oldest of which were installed in the 1980s. The systems are located at wastewater treatment plants, dairy farms and food processing facilities, with the primary feedstock being sewage sludge, manure, and food processing byproducts. At least half of the systems have a combined heat and power component.

Several recent and imminent modifications in Massachusetts regulations have been designed to encourage the development of anaerobic digestion facilities. Some of the changes are intended to streamline the siting of new facilities. Others are designed to increase revenues through wider eligibility for net metering and the Alternative Energy Portfolio Standard. Additional incentives are available to help study the feasibility and development of anaerobic digestion facilities. Importantly, the Massachusetts Department of Environmental Protection is publicly discussing a ban on the landfilling or incineration of organic wastes by the larger generators of such materials, starting in 2014. Such a ban would create demand for alternative facilities that can accept organic materials. As a result, developers are actively investigating anaerobic digestion opportunities in Massachusetts and the industry appears poised for substantial growth.

North American experience with anaerobic digestion lies primarily in technology suitable for relatively large facilities, which can cost in the millions of dollars to construct. Due to efficiencies of scale with these technologies, a relatively small number of large facilities appear more likely than a large number of small facilities. However, it is possible that technologies suitable for smaller "distributed" installations will also gain a foothold.

Thermal energy recovery

A wholly different set of useful thermal technologies enable the capture of waste heat or cold in residential or industrial applications. Key technologies are described below.

Industrial waste heat/cold refers to energy that is generated in industrial processes without being put to practical use. Waste heat/cold recovery entails capturing and reusing the wasted thermal energy in industrial processes for heating, cooling or for generating mechanical or electrical work. Combined heat and power installations are a very common example of the latter. Sources of waste heat include hot combustion gases discharged to the atmosphere, heated products exiting industrial processes, and heat transfer from hot equipment surfaces. The exact quantity of industrial waste heat is poorly quantified, but various studies have estimated that as much as 20 to 50% of industrial energy consumption is ultimately discharged as waste heat.[46] While some waste heat losses from industrial processes are inevitable, facilities can reduce these losses by improving equipment efficiency or installing waste heat recovery technologies.

[46] http://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf

Three basic types of waste heat recovery equipment are in common use today, including recuperators, regenerators, and exhaust gas boilers/steam generators.[47] R**ecuperators** are gas-to-gas heat exchangers placed on the stack of the oven or exhaust of a prime mover in a combined heat and power (CHP) installation. They transfer heat from the outgoing gas to incoming combustion air without allowing streams to mix. All recuperator designs rely on tubes or plates to transfer heat. They are the most widely used waste heat recovery devices. **Regenerators** are rechargeable storage devices for heat. They can be installed on ovens, prime movers and chemical reactors and with steam condensate. It is an insulated container filled with material capable of absorbing and storing large amounts of thermal energy. Lastly, **waste heat and exhaust gas boilers/steam generators** are similar to conventional boilers except they are heated by the waste heat stream, not their own burner.

According to a report[48] prepared by BCS for the US Department of Energy (DOE), industrial boilers account for about 70% of industrial energy use, and these systems typically incorporate heat recovery. Meanwhile, analysis of other processes showed that heat recovery is frequently used with clean gaseous streams in high capacity furnaces. However, heat recovery is less common in applications that have dirty exhaust streams and/or in small-scale applications. Several furnaces continue operating at efficiencies below 50% due to high exhaust temperatures. Additionally, while the BCS study focused on gaseous exhaust streams, it was concluded that alternate sources of waste heat can be significant and require further investigation. Large quantities of low-temperature waste heat are available in cooling water. Additionally, significant heat is lost from hot equipment surfaces (e.g., aluminum cell sidewalls) and from product streams (e.g., cast steel, blast furnace slag, etc).

The BCS study found that opportunity areas for waste heat recovery can be grouped as follows:

- low-temperature waste heat sources,
- optimization of existing waste heat recovery systems,
- high-temperature systems where heat recovery is less common (chemical composition, material constraints, and cost/economies of scale are key barriers, and
- non-fluid sources typically not considered for heat recovery

Not all waste heat is practically recoverable. The amount of recoverable waste heat depends on many factors, including waste heat temperature, quantity, accessibility, quality/cleanliness, corrosiveness, and intended use. Simple payback periods of less than one year to five years are often realizable, and savings associated with productivity gains may improve the payback. The economics are often very site specific and complicated, and a qualified specialist familiar with these systems is needed ensure proper calculation of benefits of waste heat recovery systems. As a result, this report does not attempt to generalize the economics of useful thermal recovery.

[47] http://www.pem-mag.com/Features/boiling-over-learn-what-works-with-waste-heat-recovery-in-industrial-facilities.html
[48] http://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf

The U.S. Department of Energy (DOE) offers a number of resources[49] to assist facility managers with evaluation of potential benefits and payback period of a waste heat recovery system. Additionally, facilities in Massachusetts can solicit the services of the Industrial Assessment Center[50] at UMass Amherst for technical assistance.

Interesting opportunities also exist to recover **waste cold energy** for cooling purposes. For example, applications exist to use the surplus cold energy generated at LNG terminals from the evaporation of the methane gas. This option appears to have extremely short payback times[51], is explored in Italy, France and Singapore, and could be an option for the Boston LNG terminal.

Similar in principle is recovering waste heat in **waste water pipes** with an advanced heat exchanger. Cost-effectiveness of these applications varies widely and the equipment tends to be more expensive since it has to screen out the solids and be more robust stainless steel to deal with all the corrosive elements. But it is technically feasible, and at least two companies[52] serve the US market.

Finally, in residential or commercial buildings, **heat recovery ventilation** (HRV) is an energy recovery ventilation system using equipment known as a heat recovery ventilator, heat exchanger, air exchanger, or air-to-air heat exchanger which employs a counter-flow heat exchanger (countercurrent heat exchange) between the inbound and outbound air flow. A common feature in tightly sealed homes, an HRV system exchanges stale air from inside with fresher outdoor air, while capturing heat from inside air before it is moved outdoors.

[49] http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/wasteheatrecovery_factsheet.pdf
[50] http://www.ceere.org/iac/iac_auditing_home.html
[51] http://www.aidic.it/pres09/webpapers/57Shuhaimi.pdf
[52] Nova Thermal Energy (China) and Huber SE (Germany)

Appendix B – Assumptions for Total Thermal Load and Baseload Thermal Scenarios

The following section details assumptions used in the LCOE analysis for Section 5. Using best available data, the tables below represent a range of estimated installed cost and sizing estimates for 2,000 and 15,000 square foot, high efficiency buildings. Heating and cooling system sizes were estimated using RETScreen heating and cooling analysis software.

Though it was ultimately deemed beyond the scope of this report, a more robust analysis of system costs and inputs – with detailed stakeholder input – is recommended in the future. In particular, future analyses may assess a wider range of system sizes as well as a detailed analysis of installation costs for building retrofits with various heat distribution systems and/or other requirements.

BUILDING ASSUMPTIONS

Building Assumptions	Residential	Commercial
Building Size (sq ft)	2,000	15,000
Type	Single family	Multi-family
Heating Load Calc (Btu/hr/sq ft)	22	22
Cooling Load Calc (Btu/hr/sq ft)	11	11

COMMERCIAL FOSSIL FUEL SYSTEMS

Technology	Natural Gas	Fuel Oil	Electricity	Cooling
Heating Capacity (MMBtus/hr)	0.33	0.33	0.33	--
kWth	97	97	97	-- --
Cooling capacity (Tons)	--	--	--	14
kWth	--	--	--	48
Annual Heating (MMBtus) / **DHW (MMBtus)**	740	740	740	-- --
Cooling (MMBtus)	--	--	--	305
Heating system efficiency	85%	85%	99%	-- --
Cooling system efficiency	--	--	--	COP of 2.5
Fuel Costs	$11.07 per Mcf	$3.55 per gal	$0.145 per kWh	$0.145 per kWh
Fuel price escalator	0.97%	3.22%	3%	3%
Installed cost estimate	$44,000	$44,000	$44,000	$116,000 (combined heating and cooling system cost)

COMMERCIAL RENEWABLE THERMAL TECHNOLOGY SYSTEMS

Technology	**GSHPs**		**ASHPs**		**Chips**		**Pellets**		**SHW**
Scenario	Total Thermal Load Scenario	Baseload Thermal Scenario	Total Thermal Load Scenario	Baseload Thermal Scenario	Total Thermal Load Scenario	Baseload Thermal Scenario	Total Thermal Load Scenario	Baseload Thermal Scenario	Baseload Thermal Scenario
Heating Capacity (MMBtus/hr)	0.33	0.13 to 0.16	0.33	0.13 to 0.16	0.33	0.13 to 0.16	0.33	0.13 to 0.16	--
kWth	97	37 to 48	97	37 to 48	97	37 to 48	97	37 to 48	15 to 29 kWth for DHW; 66 to 132 kWth for combi
Cooling capacity (Tons)	28	11 to 13	28	11 to 13	--	--	--	--	--
kWth	97	37 to 48	97	37 to 48	--	--	--	--	--
Annual Heating (MMBtus)	740	595 to 668	740	595 to 668	740	595 to 668	740	595 to 668	36 to 72 Mmbtus for DHW; 148 to 296 MMBtus for combi
DHW (MMBtus)									
Cooling (MMBtus)	305	299 to 305	305	299 to 305	--	--	--	--	--
Heating system efficiency	COPs ranging from 3 to 5		COPs ranging from 2.7 to 3.3		75%		80%		70% for DHW; 50% for combi
Cooling system efficiency					--		--		
Fuel Costs	$0.15/kWh		$0.15/kWh		$40/ton		$220/ton		$0.15/kWh
Fuel price escalator	3% to 5%		3% to 5%		3% to 5%		3% to 5%		3% to 5%
Installed cost range	$193,071 to $234,444	$73,646 to $113,596	$96,536 to $220,653	$36,823 to $106,914	$108,000 to $132,000	$41,419 to $63,959	$38,800 to $70,100	$29,600 to $56,400	$23,611 to $70,471
Cost per capacity	$7,000 to $8,500 per ton		$3,500 to $8,000 per ton		$1,113 to $1,360 per kWth		$400 to $722 per kWth	$800 to $1200 per kWth	$100 to $150 per sq ft

RESIDENTIAL FOSSIL FUEL SYSTEMS

Technology	Natural Gas	Fuel Oil	Electricity	Cooling
Heating Capacity (MMBtus/hr)	0.044	0.044	0.044	--
kWth	13	13	13	--
Cooling capacity (Tons)	--	--	--	2
kWth	--	--	--	7
Annual Heating (MMBtus)	99	99	99	--
DHW (MMBtus)				--
Cooling (MMBtus)	--	--	--	41
Heating system efficiency	85%	85%	99%	--
Cooling system efficiency	--	--	--	COP of 2.5
Fuel Costs	$13.83 per Mcf	$3.94 per gal	$0.155 per kWh	$0.155 per kWh
Fuel price escalator	0.97%	3.22%	3%	3%
Installed cost estimate	$10,275 (heating & hot water system)	$10,275 (heating & hot water system)	$10,275 (heating & hot water system)	$6,000

RESIDENTIAL RENEWABLE THERMAL TECHNOLOGY SYSTEMS

Technology	GSHP	ASHP	Pellets	SHW
Scenario	Total Thermal Load Scenario	Total Thermal Load Scenario	Total Thermal Load Scenario	Baseload Thermal Scenario
Heating Capacity (MMBtus/hr)	0.044	0.044	0.044	--
kWth	13	13	13	--
				--
Cooling capacity (Tons)	3.7	3.7	--	--
kWth	13	13	--	--
Annual Heating (MMBtus)	99	99	99	--
DHW (MMBtus)				8.2
Cooling (MMBtus)	41	41	41	--
Heating system efficiency	COPs ranging from 3 to 5	COPs ranging from 2.7 to 3.3	80%	70%
Cooling system efficiency			--	--
Fuel Costs	$0.155/kWh	$0.155/kWh	$220/ton	$0.155/kWh
Fuel price escalator	3% to 5%	3% to 5%	3% to 5%	3% to 5%
Installed cost range	$25,876 to $29,572	$12,938 to $29,572	$16,640 to $24,960	$7,062 to $9,417
Cost per capacity	$7,000 to $8,000 per ton	$3,500 to $8,000 per ton	$1,200 to $1,950 per kW	$100 to $160 per sq ft

Appendix C – Residential Scenarios

The following section provides graphs for residential scenarios. In this case, only the total thermal load scenario was modeled for the renewable thermal technologies. The only exception is solar hot water, which requires back-up heating. For all other technologies, it is generally not expected that significant cost savings could be achieved by sizing down residential systems to serve baseload heating only. DOER recognizes that some exceptions may exist and welcomes feedback in the future regarding installed cost reductions that could be achieved by sizing renewable thermal systems to serve only baseload heating within the residential sector.

The **residential total thermal load scenario** assumes that the full existing heating and domestic hot water (and/or cooling) system in a 2,000 square foot single family building must be replaced (e.g. an end-of-life replacement). Either a new high efficiency fossil fuel system or a new renewable thermal system will be installed, which will provide 100% of the building's heating and hot water energy needs. The Lifecycle Cost of Energy (LCOE) is calculated to compare (i) **the capital and fuel costs** for a new renewable thermal system (net incentives) divided by total energy generation, and (ii) **the capital and fuel costs** for a new fossil fuel system (net incentives) divided by total energy generation. Each is calculated over a 20 year period.

Within this scenario, various heating or cooling applications were modeled. For example, in the total thermal load scenario, GSHPs, ASHPs, and biomass pellet systems were modeled to provide 100% of the heating and DHW load of the building. Additionally, because ASHPs and GSHPs can also provide cooling, the impact of the cooling load was also assessed.

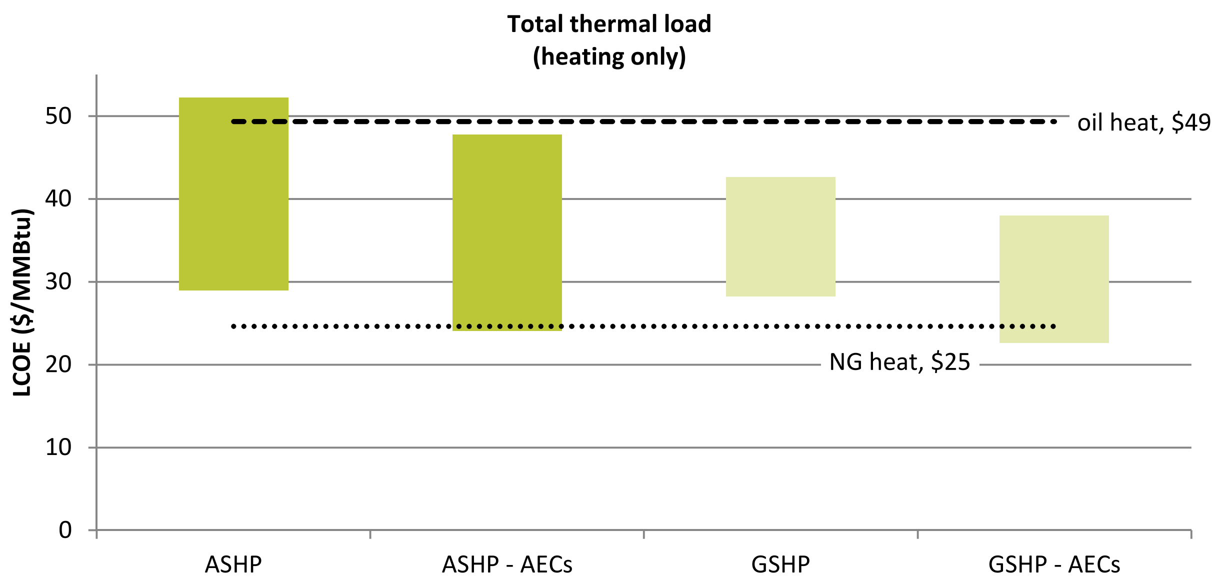
Regional data and industry leaders also report that a number of other variables vary widely, which may affect the economics for heating and cooling systems. As a result, a range of installed costs, fuel cost, discount rates, and other relevant assumptions for each thermal system were assessed. For renewable thermal systems, this includes:

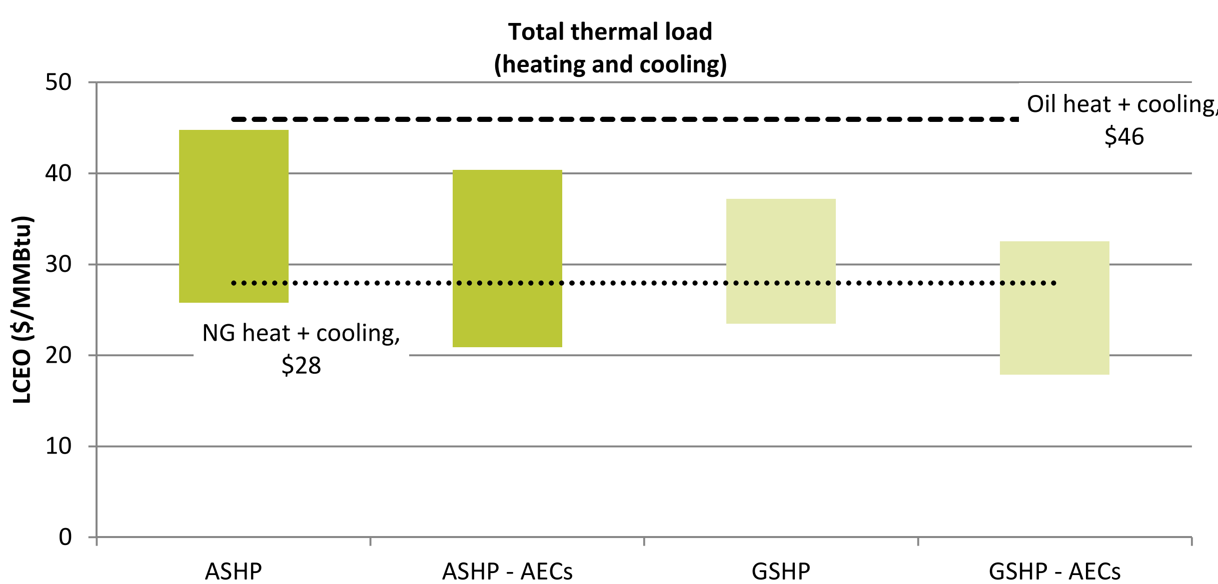
- High and low installed costs (on a $/kWth basis) based on a variety of design approaches for renewable thermal systems;
- High and low renewable thermal fuel price escalators;
- High efficiency assumptions for all systems (75% or greater or a COP of 2.7 or greater).

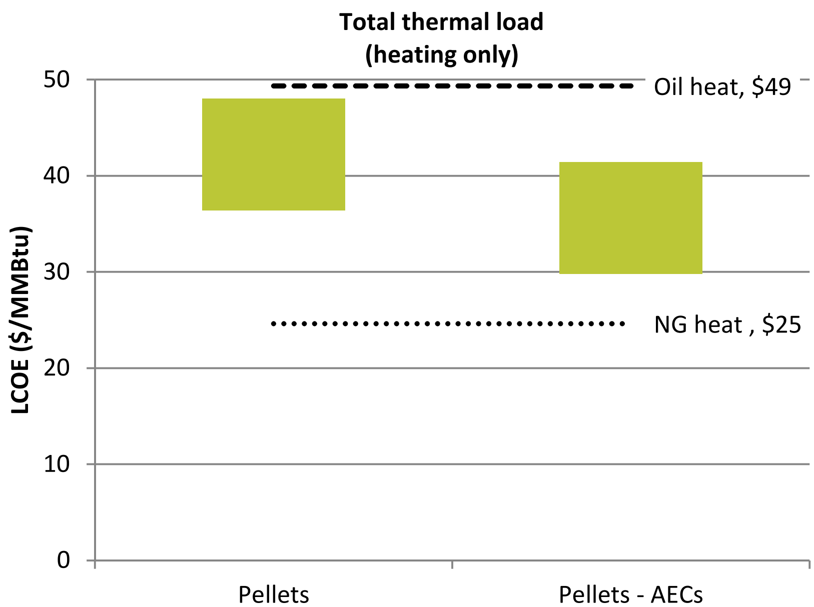
In order to award only net energy generation the electricity used by heat pumps for their own operation is subtracted from the thermal energy generated by the GSHPs and ASHPs, by converting the heat pump's own electricity consumption into BTUs. Going forward DOER shall analyze the option to use primary energy to generate the electricity used by the heat pump, in the calculation of the net thermal energy generated by heat pumps. The parasitical load for the other thermal technologies is considered to be negligible.

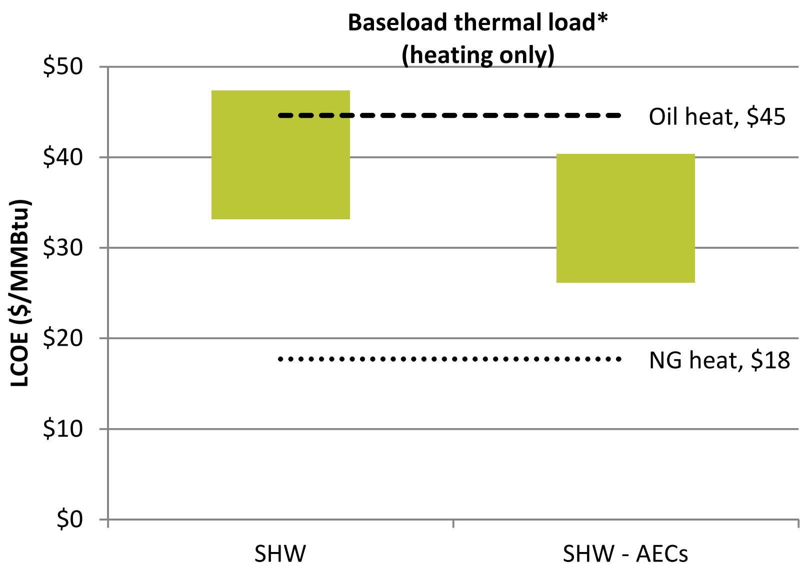
To simplify the analysis, a single LCOE was estimated for each fossil fuel system. Though it was ultimately deemed beyond the scope of this report, a more robust analysis of system costs and inputs – with detailed stakeholder input – is recommended in the future.

The results of the analysis are presented in the charts below.









* Compared to fossil fuel costs only. All other residential scenarios compare fossil fuel and capital costs to renewable thermal systems.

Appendix D – Calculating AEC values

AECs may be generated for renewable thermal technologies using a variety of methodologies. Within the context of this report, the authors sought to apply a methodology that is simple to use and also reflects the value of useful and renewable thermal energy production, which results in greenhouse gas emission reductions.

AECs were valued using the following calculation for each technology:

- **Biomass pellets:** 1 AEC per MWh-equivalent useful heat generated
- **Biomass chips:** 1 AEC per MWh-equivalent useful heat generated
- **Solar hot water:** 1 AEC per MWh-equivalent useful heat generated
- **GSHPs:** 1 AEC per MWh-equivalent useful heat generated less electricity consumed
- **ASHPs:** 1 AEC per MWh-equivalent useful heat generated less electricity consumed

In the case of biomass pellets and chips, it is assumed that renewable fuels (pellets and chips) are used, which meet regulatory requirements established by DOER based on results from the Manomet study. Overall system efficiency was assumed to be around 80%. Thus, AECs could be calculated by measuring total annual energy content of fuel consumed and multiplying it by 80%. Alternately, it could be calculated by measuring the total useful heat output from the biomass system and applying 1 AEC for every MWh-equivalent of useful heat produced.

In the case of SHW, solar energy is the primary fuel source. Any electricity consumed to run pumps, controls, or electronics for the SHW system was considered to be negligible and thus not incorporated into the AEC calculation. Overall system losses were assumed to be 30% for DHW systems and 50% for combi-systems. Thus, total annual AEC production could be calculated by measuring total annual energy produced by panels and multiplying it by a factor of 50% to 70%. Alternately, it could be calculated by measuring the total useful heat output from the system and applying 1 AEC for every MWh-equivalent of useful heat.

In the case of advanced heat pumps, the calculation takes into account electricity consumed by the heat pumps, which can vary considerably based upon the heat pumps co-efficient of performance (COP or efficiency rating). Thus, total annual AEC production equals annual energy production from heat pumps less the annual electric energy directly consumed by heat pumps.

In all cases, a simple BTU conversion to MWh conversion was used, wherein 1 MWh is equal to 3.412 MMBtus, consistent with APS CHP Guidelines.

Primary energy AEC calculations

The AEC calculation for Combined Heat and Power under the APS guidelines[53], takes into account conversion and transmission losses associated with the electricity and conventional heat generation the CHP facility is replacing. The AEC formula effectively awards AECs for the primary useful energy

[53] http://www.mass.gov/eea/docs/doer/rps-aps/aps-chp-guidelines-jun14-2011.pdf

generation. A similar approach can be taken when calculating AECs for useful thermal energy generation from renewable heating and cooling technologies using a significant amount of electricity or fossil fuels. In such a case, the AEC calculation would be discounted for efficiency losses in the generation and transmission losses between the point of electricity generation and the point of electricity use. The APS CHP Guideline puts forward a standard overall efficiency of 33% for electrical energy delivered to the end-use from a central plant via the grid.

Electricity consumed by heat pumps would thus be divided by 0.33 to take into account primary energy consumption. This reduces the AECs awarded to heat pumps significantly. In fact, only heat pump systems with COPs greater than 3.3 would be able to generate AECs. There is however logic to only rewarding the useful thermal energy generation over and above the energy that was originally necessary to generate the electricity that drives the heat pump.

Sample calculations for heat pumps with COPs of 3 and 5 are provided in the table below. The example uses a GSHP in a commercial building, providing the full heating and cooling load.

Table 5 – AEC calculation for heat pumps based on Direct and Primary energy use

Scenario	COP	Thermal generation (MMBtus)	Electricity Use (MMBtus)	# of AECs per year	Value per year ($5.86 / AEC)
Direct energy use	3	1045	349	696	$4,080
Primary energy use	3	1045	1058	0	$0
Direct energy use	5	1,045	209	836	$4,900
Primary energy use	5	1,045	633	412	$2,413

In the “direct energy use” scenario, AECs are generated by subtracting **on-site** energy (electricity) use from total thermal generation. This is the methodology employed throughout the report. In the “primary energy use” scenario, AECs are generated by subtracting **primary** energy use from total thermal generation.