Feasibility of Renewable Thermal Technologies in Connecticut

MARKET POTENTIAL

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The Yale team remains solely responsible for any errors or omissions in this report.

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LIST OF ACRONYMS

AEO	Annual Energy Outlook
ACS	American Community Survey
ASHP	Air Source Heat Pump
CBECS	Commercial Buildings Energy Consumption Study
CDD	Cooling Degree Days
CES	Comprehensive Energy Strategy
CO_2e	Carbon Dioxide Equivalent
CT	Connecticut
DEEP	Department of Energy and Environmental Protection
EIA	Energy Information Agency
EPC	Energy Performance Contract
ESCO	Energy Service Company
EUI	Energy Use Intensity (BTU/Square feet)
GC3	CT Governor's Council on Climate Change
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
HDD	Heating Degree Days
NPV	Net Present Value
PACE	Property Assessed Clean Energy
PSD	Program Savings Document
PV	Photo Voltaic
RECS	Residential Energy Consumption Study
RTT	Renewable Thermal Technologies
SCC	Social Costs of Carbon
SEDS	State Energy Data System
SHW	Solar Hot Water
TPO	Third Party Ownership
TRECs	Thermal Renewable Thermal Credits

Executive Summary

Renewable thermal technologies (RTTs) harness renewable energy sources to provide heating and cooling services for space heating and cooling, domestic hot water, process heating, and cooking.[1,2]

In 2014, a total of 344 trillion British thermal units (BTUs) were delivered for stationary energy purposes in residential, commercial, and industrial sectors in Connecticut (CT).[3] Over 60 percent of the energy used in residential and commercial buildings was for space heating and cooling in 2012.[4] Changing from fossil fuels to RTTs in heating and cooling buildings, as well as in heating industrial processes, has the potential to provide a valuable contribution to meeting Connecticut's statutory target of reducing greenhouse gas emissions 80 percent below 2001 levels by 2050.

The purpose of the "Feasibility of renewable thermal technologies in Connecticut" research project is twofold: to assess a realistic contribution from RTTs in achieving Connecticut's transition to a less carbon-intensive economy, and to establish the knowledge necessary for effective policies and strategies to advance RTTs in Connecticut. In addition to this market potential study, the project included a field study on RTT market barriers and drivers.[5]

Although application of RTTs in the industrial sector is promising, both because of the sector's large thermal demand and because it produces waste energy that can be utilized, it has not been included in this study due to its heterogeneity and complexity.

Our analysis estimates a thermal demand in Connecticut buildings of 126 trillion BTUs in 2050, with a sensitivity range of 103–142 trillion BTUs. The lower end of the sensitivity range assumes higher annual rates of deep retrofits and stricter building codes; the upper end of the range assumes that outdoor temperatures will remain at current levels for the next several decades. In fact, however, significantly

1 Cooking is not part of this study.

2 This definition has been adapted by the Renewable Thermal Alliance, a private-public partnership established to develop the infrastructure for large-scale deployment of renewable thermal technologies in Northeast America: http://cbey.yale.edu/programs-research/renewable-thermal-alliance

3 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

4 2013 Connecticut comprehensive energy strategy: http://www.ct.gov/deep/lib/deep/energy/cep/2013_ces_final.pdf

5 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

higher temperatures during both heating and cooling seasons are expected as the region's climate changes,[6] and our analysis indicates that this results in a net reduction in the overall thermal demand of buildings.

Today, approximately 83 percent of the thermal demand of residential and commercial buildings is supplied directly by fossil fuels. Heating and cooling buildings and domestic hot water represent around 12.6 million metric tons CO_2e emissions per year, which corresponds to 30 percent of Connecticut's GHG emissions in 2013.[7] RTTs can play an important role in realizing a low carbon future. However, current market prices, existing installations and infrastructures represent considerable economic challenges to RTTs.

The competition analysis—examining how RTTs compete with traditional thermal technologies—includes seven archetypal categories of existing buildings. The RTTs include three alternative cases for air source heat pumps (ASHPs) representing different end-uses and physical limitations of the existing heating system. The RTT analysis also includes ground source heat pumps (GSHPs), solar hot water (SHW), and biomass. (Biomass pellets are used as a proxy for solid biomass in this study.) To supplement the RTT analysis, the study also examined highly efficient natural gas boilers as an alternative to traditional thermal technologies. Incumbent technologies include fuel oil, natural gas (standard efficiency), and conventional electric technologies (e.g., electric resistance heating). Financial viability has been evaluated on the basis of net present value and simple payback.

The base case assumes that RTTs deliver the end-user's entire annual thermal demand. Generally, heat pumps are assumed to deliver the user's space cooling and heating, and biomass and highly efficient natural gas are assumed to deliver the user's space and water heating. Solar hot water and ASHP water heaters are assumed to deliver the water heating. No financial incentives are included in the base case. No infrastructure costs have been included, with the exception of some heat pump alternatives in which the level of incremental installation costs has been varied to take into account existing building's physical limitations have to some extent been handled by varying the level of incremental installation costs.

Our competition analysis shows that 19 percent of today's thermal demand in Connecticut buildings can be met competitively by RTTs, representing an unrealized potential for reduced annual GHG emissions of 1.4 million metric tons CO_2e.[8] Of particular interest are air source heat pumps to replace conventional electric technologies for space heating and cooling and biomass pellets to replace fuel oil in some commercial settings.

6 U.S. Global Change Research Program, "National Climate Assessment," http://nca2014.globalchange.gov/.

7 See http://www.ct.gov/deep/lib/deep/climatechange/2012_ghg_inventory_2015/ct_2013_ghg_inventory.pdf

8 The GHG emission calculations are based on the RETScreen Expert inventory and rely on its modeling concept.

Fuel prices have a large impact on how competitive RTTs are compared to conventional thermal technologies. Currently at $16.63 per MMBTU,[9] natural gas prices are low, and natural gas boilers out-compete conventional and renewable thermal technologies in most settings.

To reduce GHG emissions by 80 percent in the thermal demand of buildings by 2050 (relative to 2001 levels), the GHG emissions related to thermal end-uses would have to be reduced from 12.6 million metric tons CO_{2e} to approximately 3 million tons CO_{2e}. This would require a considerable reduction in thermal demand in combination with deployment of RTTs and de-carbonized electricity generation. In today's market conditions, an array of interventions is necessary to realize Connecticut mandatory emission reduction targets using renewable thermal alternatives that currently present both favorable and unfavorable economics.

Although replacement of standard gas and fuel oil boilers with highly efficient gas boilers represents one of the cheapest means to reduce GHG emissions today, doing so extensively is not sufficient to reach the target and would lock in fossil fuel technologies that could prevent Connecticut from achieving an 80 percent reduction in GHG emissions by 2050. The high share of natural gas boilers in the commercial sector already represent a barrier to RTTs and thus inhibits Connecticut's ability to achieve needed reductions in GHG emissions. Nevertheless, replacing standard natural gas boilers with highly efficient gas boilers and decarbonizing the gas grid by, for example, injecting biogas from anaerobic digestion could supplement market strategies to promote RTTs.

Projections in this report are illustrations of what may happen given certain assumptions and methodologies. The team has performed several sensitivity analyses to evaluate the impact of potential market changes and policy instruments. Unless otherwise indicated, the practice has been to change only a single parameter at a time.

9 EIA SEDS as of October 2016.

PARAMETER FOR SENSITIVITY ANALYSIS	DESCRIPTION	MAIN IMPACT ON NET PRESENT VALUE COMPARED TO BASE CASE
Base case	See Appendix A for key assumptions	Heat pumps are competitive with conventional electric technologies in most customer categories. Additional costs related to physical limitations such as ductwork are a challenge, particularly in commercial sector settings. Solar water heating as an alternative to conventional electric technologies is competitive in the residential sector and for commercial customers with a considerable demand for hot water. Biomass is competitive as an alternative to fuel oil in many commercial settings. Highly efficient natural gas boilers are generally competitive with conventional electric technologies and fuel oil boilers.
Fuel costs	50 percent increase for incumbent case	All heat pump alternatives and solar water heating are competitive with conventional electric technologies across all customer categories. Biomass is competitive with fuel oil, and highly efficient natural gas boilers are competitive with standard efficient gas boilers.
	100 percent increase for incumbent case	Heat pumps and solar water heating are competitive with fuel oil in several customer categories, particularly in commercial settings. Biomass pellets are competitive with natural gas. Highly efficient natural gas boilers are competitive with standard gas boilers.
	25 percent reduction for proposed case	Only ASHPs for space heating and cooling, and ASHP water heaters remain competitive with conventional electric heating. Solar water heating remains competitive with conventional electric heating in residential sector. Biomass is competitive with fuel oil in all customer groups.
	Solar PV delivers drive energy of proposed case	Solar PV at an installation cost of $2.5 per Watt improves the competitiveness of heat pumps and solar water heating. Although GSHPs still have a negative, net present value due to high incremental installation costs, their operational costs are competitive with those of natural gas boilers.

PARAMETER FOR SENSITIVITY ANALYSIS	DESCRIPTION	MAIN IMPACT ON NET PRESENT VALUE COMPARED TO BASE CASE
Incremental initial costs	25 percent reduction	RTTs are generally competitive with conventional electric technologies. Biomass is competitive with fuel oil in residential sector, and highly efficient natural gas boilers are competitive with standard natural gas boilers in most customer categories.
	RTT for partial load (60 percent of capacity and ~80 percent of load)	In general, renewable technologies become more competitive with traditional thermal technologies.
Carbon price	Carbon price of \$41 per tCO_2	A few additional heat pump alternatives are competitive with conventional electric technologies. Biomass is generally competitive with fuel oil.
Thermal Renewable Energy Certificates (TRECs)	TRECs corresponding to a market price of \$25 per MWh	Impact similar to the carbon price alternative.
Financial terms	25 percent reduction of debt interest rate	Minor impact on NPV.
	25 percent increase of debt term, with economic life of asset as maximum debt term	Minor impact on NPV.
Sets of simultaneous changes	25 percent reduction of • incremental initial costs • electricity prices for the proposed case due to use of solar PV • pellet prices A carbon price of \$120 per tCO_2	Heat pumps and solar water heating are competitive with conventional electric technologies for all customer categories. ASHPs, biomass, and highly efficient natural gas boilers are competitive with fuel oil. Biomass and highly efficient natural gas are competitive with standard natural gas boilers.
	25 percent reduction of • incremental initial costs • electricity prices for the proposed case via use of solar PV 50 percent increase of incumbent case fuel costs	As in previous case but additional heat pump alternatives become competitive. Fuel prices are less predictable than a carbon price.

Table 1 | Overview of sensitivity analysis

With the current market situation, combinations of marketing strategies, financing products, and policy instruments—such as a stricter building code combined with TRECs, soft cost strategies and financing products—are required to make RTTs competitive.

This report concludes with the following recommended market strategies to improve the competitiveness of RTTs, which are supplementing the recommendations of the field study on barriers and drivers: [10]

1. Reduce upfront costs. Initial installation costs have large impacts on how competitive the RTT is and how much capital the customer has to raise upfront. Available strategies:
   - Cost reduction campaigns à la Solarize.[11]
   - Partial-load strategies: using RTTs to displace most of the thermal demand for space heating but not requiring them to cover 100 percent of the capacity needed for peak demand.
   - New business and financing models to eliminate upfront costs and secure 100 percent financing via loans, leases, and property assessed clean energy financing.

2. Implement market interventions to improve the operational cash flow. Available strategies:
   - Packaging RTTs with solar PV and deep renovation.
   - Favorable interest rates and debt terms to reduce risk for private lenders, lend credibility to the technology, and qualify it as environmentally friendly.
   - Carbon pricing.
   - Thermal Renewable Energy Certificates.
   - Explore rate mechanisms that recognize the value of RTTs in reducing demand for natural gas and electricity.

3. Enhance awareness and trust in RTTs through marketing efforts, trusted messengers, and proven installations. Available strategies:
   - Performance verification to show that the technologies deliver as promised and to facilitate new financial models and attract investors.
   - Green Bank involvement in projects and technologies to enhance credibility.
   - Declining block grants.

4. Use the building code and standards to reduce thermal demand and establish a predictable minimum market for RTTs.

This market potential study has not evaluated the feasibility of district energy. District energy and thermal grids may represent opportunities for cheap and clean thermal energy, exploiting waste energy from electricity generation and industrial processes.

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10 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

11 Solarize CT is a community-based program that leverages social interaction to promote the adoption of solar through a group-pricing scheme intended to reduce soft costs. See http://solarizect.com/

CHAPTER 1
Introduction

Background

In 2014 a total of 344 trillion BTUs were delivered for stationary energy purposes in residential, commercial, and industrial sectors in Connecticut.[12] Over 60 percent of the energy used in residential and commercial buildings is for space heating and cooling.[13] Changing from fossil fuels to renewable thermal technologies (RTTs) in heating and cooling buildings, as well as in heating industrial processes, has the potential to provide a valuable contribution to meeting Connecticut's statutory target of reducing greenhouse gas emissions to 80 percent below 2001 levels by 2050.

The purpose of the "Feasibility of renewable thermal technologies in Connecticut" research project is twofold: to assess a realistic contribution from RTTs in achieving Connecticut's transition to a less carbon-intensive economy, and to establish the knowledge necessary for effective policies and strategies to advance RTTs in Connecticut.

The goal of reducing Connecticut's greenhouse gas (GHG) emissions by 80 percent below 2001 levels by 2050 was adopted in the 2008 Global Warming Solutions Act.[14] The Governor's Council on Climate Change (GC3), established in April 2015, is charged with examining the opportunities and challenges as the state pursues to achieve this target.

Analysis by the GC3 to date, has demonstrated that meeting the 2050 target will require a combination of measures across the entire state economy.[15]

The business context for RTTs will be different in 2050 and will be influenced by actions taken today. This can be illustrated by Figure 1, which spans four futures along two axes: thermal electrification versus gas expansion, and individual versus community solutions.

12 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

13 2013 Connecticut Comprehensive Energy Strategy: http://www.ct.gov/deep/lib/deep/energy/cep/2013_ces_final.pdf

14 See https://www.cga.ct.gov/2008/ACT/PA/2008PA-00098-R00HB-05600-PA.htm

15 Analysis presented to the GC3 on July 26th: http://www.ct.gov/deep/cwp/view.asp?a=4423&Q=568878&deepNav_GID=2121

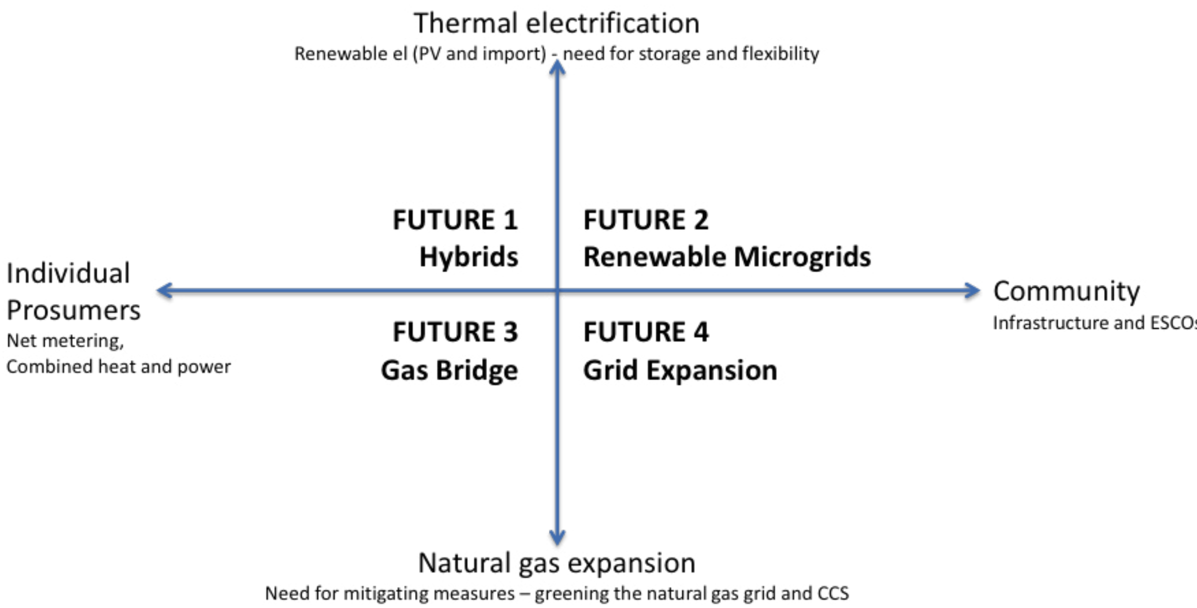

Figure 1 | Possible future competition fields for RTTs. Intended for illustration only.

The market for RTTs in future 1 would be different from that of future 4, with regard to both physical infrastructure and relative prices.

This study has not evaluated the feasibility of district energy. District energy and thermal grids represent opportunities for cheap and clean thermal energy, for instance by exploiting waste energy from electricity generation and industrial processes. These processes have not been included due their heterogeneity and complexity. District energy, community thermal grids and industrial thermal processes can offer important opportunities for RTT.

Framework for the Study

The framework for the project incorporates Connecticut's desire to move toward a cheaper, cleaner, and more reliable energy future while creating economic growth. The study has been guided by the definitions in Table 2.

CHEAPER A fuel source is considered cheaper for the customer when the net lifetime costs represented by the net present value of the technology are lower than that of the alternative that would otherwise have been preferred.	**CLEANER** A technology is considered cleaner when it has lower operating emissions of greenhouse gases (GHG) than the alternative technology that would otherwise have been preferred by the customer.
MORE RELIABLE A reliable energy system: • has enough energy to cover basic end-uses at a reasonable cost at all times • is robust in the face of short- and long-term changes in any individual energy source • is based on several energy sources that interact and complement each other	**ECONOMIC GROWTH**[16] Investment in and deployment of RTTs creates direct, indirect, and induced jobs. Direct economic benefits come from effects created by an investment in clean energy resources.[17] Indirect economic benefits result from changing demands that help produce clean energy technologies.[18]

Table 2 | Key terms for this study. Note: The above definitions present non-binding evaluation criteria and have been formulated to guide the research process.

16 See http://www.ctgreenbank.com/wp-content/uploads/2017/02/CTGReenBank-Memo-CT-Dept-Economic-Community-Development-October142016.pdf

17 e.g., income of local contractor, sales of equipment.

18 e.g., income of supplier companies, sales of materials for the equipment.

Definitions of Technologies

Renewable thermal technologies harness renewable energy sources to provide heating and cooling services for space heating and cooling, domestic hot water, process heating, and cooking.

RTTs utilize a broad range of renewable energy sources that otherwise could be lost. RTTs include:

- Heat pumps, such as air source heat pumps, ground source heat pumps, and heat pump water heaters
- Solid biomass, such as wood chips, pellets, and wood
- Liquid and gaseous biofuels
- Solar thermal technologies
- Waste heat technologies, including district heating and cooling

Different RTTs deliver heating and cooling at different temperature levels. Temperature levels are important to define the suitability of different technologies for meeting specific heat requirements in various end-use sectors. RTTs can range from small domestic applications to large-scale applications used in industrial processes and district heating and cooling networks. As RTTs often utilize locally available energy resources to meet on-site heating and cooling demand, customized solutions are often required.

We have applied the following definition of renewable energy resources:

"**Renewable energy resources** represent the annual energy flows available through sustainable harvesting on an indefinite basis. While their annual flows far exceed global energy needs, the challenge lies in developing adequate technologies to manage the often low or varying energy densities and supply intermittencies, and to convert them into usable fuels. Except for biomass, technologies harvesting renewable energy flows convert resource flows directly into electricity or heat. Their technical potentials are limited by factors such as geographical orientation, terrain, or proximity of water, while the economic potentials are a direct function of the performance characteristics of their conversion technologies within a specific local market setting."[19]

19 Grubler A, Nakicenovic N, Pachauri S, Rogner H-H, Smith KR, et. al. (2014): Energy Primer. International Institute for Applied Systems Analysis, Laxenburg, Austria, p. 40.

Market Definitions

This study analyzes the market potentials of various thermal technologies according to the framework shown in Figure 2.[20]

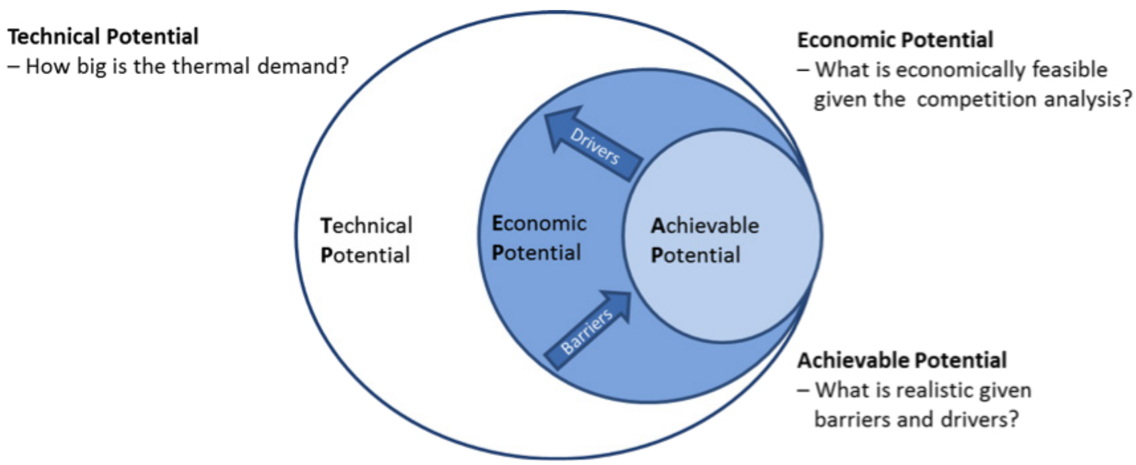

Figure 2 | Framework for market potentials.

TECHNICAL POTENTIAL

Technical Potential, also known as Total Addressable Market, is the theoretical maximum amount of thermal energy use that could be served by renewable thermal technologies, disregarding all non-engineering constraints such as cost-effectiveness and the willingness of end-users to adopt the technologies. It is often estimated as a "snapshot" in time assuming immediate implementation of renewable thermal technologies.

The technical potential for RTTs in Connecticut has been estimated and analyzed in Chapter 4: Technical Potential—Demand Analysis.

20 The market definitions are based on the framework offered by the National Action Plan for Energy Efficiency (2007). Guide for conducting energy efficiency potential studies. Prepared by Philip Mosenthal and Jeffrey Loiter, Optimal Energy, Inc. www.epa.gov/eeactionplan

ECONOMIC POTENTIAL

Economic Potential, also known as Serviceable Available Market, refers to the subset of the technical potential that can be cost-effectively served by renewable thermal technologies as compared to conventional thermal technologies. Both technical and economic potential are theoretical numbers that assume immediate implementation of renewable thermal technologies, with no regard for the gradual "ramping up" process typically in deployment of new technologies. In addition, they ignore market barriers to ensuring actual implementation of renewable thermal technologies. Finally, they consider only the costs of renewable thermal technologies themselves, ignoring any programmatic costs (e.g., marketing, analysis, administration) that would be necessary to deploy them widely.

The economic potential for RTTs in Connecticut has been estimated and analyzed in Chapter 5: Economic Potential—Competition Analysis.

ACHIEVABLE POTENTIAL

Achievable Potential, also known as Serviceable Obtainable Market or maximum achievable potential, is the amount of thermal energy use that RTTs can realistically be expected to serve assuming the most aggressive program scenario possible (e.g., providing end-users with payments for the entire incremental cost of the RTT).

The achievable potential takes into account real-world barriers to convincing end-users to adopt renewable thermal technologies, the non-measure costs of delivering programs (for administration, marketing, tracking systems, monitoring, and evaluation, etc.), and the capability of programs and administrators to ramp up program activity over time.

This report analyzes current technical and economic potential associated with RTT deployment in Connecticut. Barriers and drivers have been mapped through a field study documented in a separate report.[21]

21 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

CHAPTER 2
State of the Market

The residential sector is the largest user of energy, with a net consumption of 171 trillion BTUs in 2014; this is followed by the commercial sector, (112 trillion BTUs) and then the industrial sector (62 trillion BTUs).[22]

The mix of energy sources for thermal purposes, estimated at 200 trillion BTUs, varies across the sectors as shown by Figure 3.[23]

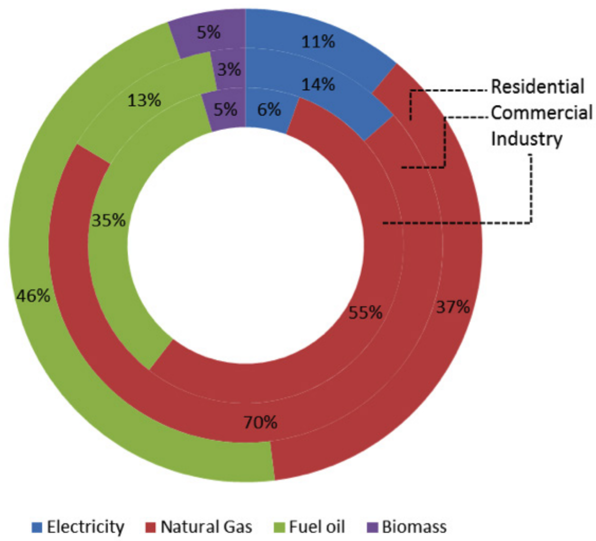

Figure 3 | Estimated current mix of energy sources for thermal purposes. Sources: EIA SEDS, AEO 2015 and own analysis in chapter 4.

As can be seen from Figure 3, the residential and industrial sectors have a high share of fuel oil, while natural gas dominates the commercial sector. The share of thermal demand supplied by electricity may comprise electrically driven heat pumps. However, the share of heat pumps in Connecticut appears to be low.

The number of RTT installations can be estimated based on feedback from the industry and sample surveys: the Connecticut Geothermal Association[24] indicates that the number of residential and commercial GSHPs installed in Connecticut per year is approaching 700. New construction seems to

22 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

23 The current mix of energy sources for thermal purposes has been estimated based on the technical potential from Chapter 4, the consumption by energy sources from EIA SEDS 2014 and the energy by end-use from AEO 2015.

24 Email correspondence August 28th, 2016

dominate the installations. Residential wood use was 339 thousand cords-equivalent of wood in 2014 and 3.9 trillion BTUs for commercial and industrial wood and biomass waste use that same year.[25] The Biomass Thermal Energy Council indicates that cumulative installations of biomass in Connecticut are fairly low and slow-building, explained by a higher rate of natural gas connections in CT than in other New England states.[26] Solar assisted thermal systems were supported through The Connecticut Clean Energy Fund (CCEF), the predecessor to the Connecticut Green Bank, from 2009 through 2013. Two different programs together funded 278 residential and 86 commercial solar thermal installations, and industry representatives indicate that the market has slowed down since then.[27]

In 2014, NMR Group concluded a sample survey among 180 single-family homes that also registered thermal systems.[28] The number of respondents to the study secured a confidence interval of 90 percent. Based on this study and the number of single-family homes in Connecticut in 2013, the total number of RTT installations for space heating in Connecticut has been estimated according to Table 3.

RTT	SINGLE-FAMILY HOMES	SHARE OF HOMES IN EACH PRIMARY FUEL CATEGORY	ESTIMATED TOTAL INSTALLATIONS (AS OF 2013)
ASHP	Primary source	1.7 percent	14,740
	Secondary source	2.8 percent	24,560
GSHP		0.6 percent	4,910
Solar assisted system		1.1 percent	9,820
Biomass[29]	Pellets	1 percent	8,841
	Wood	1 percent	8,841

Table 3 | Estimated total number of renewable thermal installations for space heating in Connecticut in 2013. Sources NMR Group and DCED.[30,31]

25 See http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_ww.html

26 Email correspondence September 21st, 2016

27 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

28 NMR Group Inc (2014): Single-Family Weatherization Baseline Assessment.

29 Due to rounding of percentages in Table 6-1 of the NMR study, the number of homes with wood and pellet installations is reported here as identical.

30 See http://www.ct.gov/ecd/cwp/view.asp?a=1106&q=250640

31 See 2000 Census of Population and Housing: http://www.ct.gov/ecd/LIB/ecd/20/14/2000censushousingandhousing.pdf

The number of detached and attached single-family homes was 884,120 in 2013. Based on this, the NMR study indicates that approximately 565,840 households used fuel oil as the primary energy source for space heating. 9 percent of the homes of the NMR study had installed ASHP for space cooling, and GSHP provided cooling to 1 percent of the homes.

A separate field study conducted by Yale University[32] shows that the RTT market is thin, with only a few installers providing RTTs and most of these focusing on specific technologies. With the exception of ductless ASHPs, the supply side of RTTs is characterized by low demand, low rates of cooperation across technologies, and a general discontent with the level of financial support, particularly compared to solar PV. An inadequate supply chain for pellets is perceived as another challenge. There have been issues related to the quality of installations of some RTTs, and there is a general difficulty finding qualified employees for this sector.

The demand side, on the other hand, experiences difficulties finding installers. This creates concerns related to future maintenance and replacement of RTTs. However, even more prevalent seems to be the customer awareness of RTTs, including their basic use and their distinction from solar PV. Financing options are generally unknown to the customers, who often are highly cost conscious and price sensitive at the time of the investment decision.

32 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

CHAPTER 3
Methodology

Overall Framework

The role of RTTs in achieving Connecticut's GHG reductions was studied with a bottom-up approach that analyzes the cost effectiveness of competing thermal technologies. The analysis was first done on a project level; then results were aggregated on the state level.

The technical potential represents the estimated maximum size of the state's market for thermal energy at different points in time, including the end-uses of space heating, space cooling, and water heating. The competitiveness of RTTs compared to conventional thermal technologies was analyzed for different customer categories using a commercially available tool, RETScreen Expert developed by CanmetENERGY Research Center at Natural Resources Canada.[33] (Appendix D).

The most competitive technology was chosen as the preferred technology for each customer segment and its particular thermal end-use. The economic evaluations on project levels were aggregated and calibrated to correspond to the technical potential.

Figure 4 presents the steps of this approach graphically.

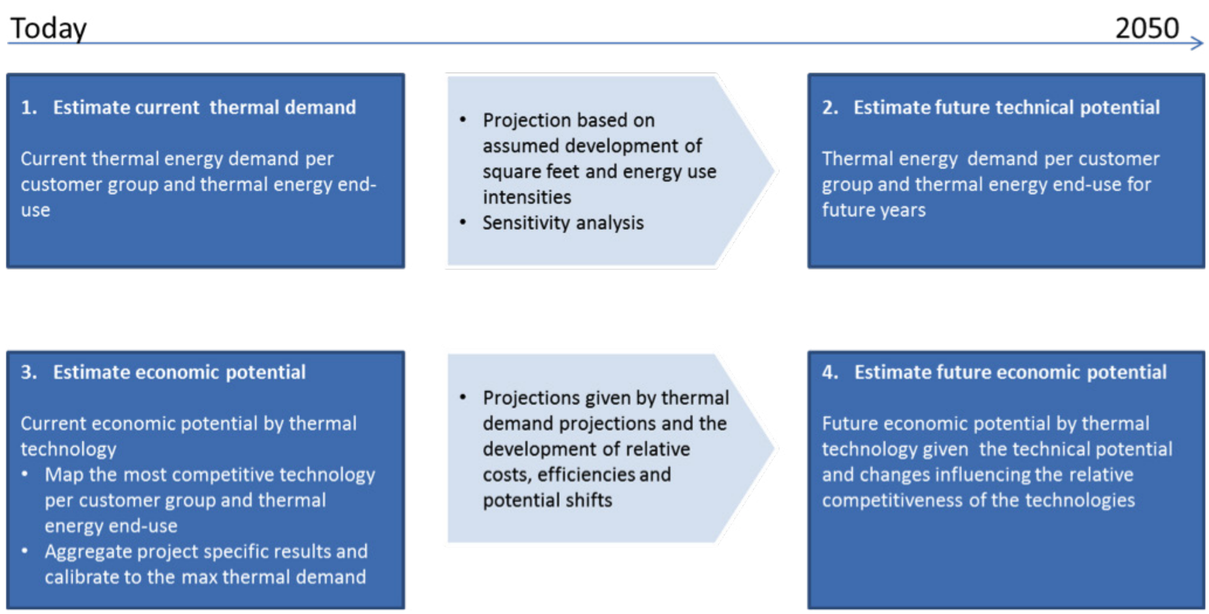

Figure 4 | The overall methodological framework for estimating technical and economic potential for RTTs.

33 http://www.nrcan.gc.ca/energy/software-tools/7465

The study has attempted to use data at a state or regional level where available. The EIA Annual Energy Outlook (2015) has also been an important reference for several assumptions in the analysis.

STEP 1—ESTIMATE THE CURRENT THERMAL DEMAND

First, the current demand for thermal energy end-uses per customer group was estimated. The aggregate demand for space heating, space cooling, and water heating was calculated by multiplying the total square footage of the existing building stock, differentiated by customer category, with the respective Energy Use Intensity (EUIs).

STEP 2—ESTIMATE FUTURE THERMAL DEMAND

The technical potential was estimated till 2050. For space heating, space cooling, and water heating, the technical potential was estimated by multiplying the square footage of existing building stock, projected new buildings, and projected demolitions by the respective EUIs, known and projected. The projected EUIs for the future periods were established using the current EUIs adjusted for an annual energy efficiency rate in the year in question.

Sensitivity analyses were established to highlight the uncertainty related to future projections. The sensitivity analyses highlight the impacts of applying different references for current average EUIs, energy efficiency rate, outdoor temperature levels, and required building standards of new buildings.

The technical potential was used to calibrate the estimated economic potential per customer group and end-use for the different years being studied.

STEP 3—ESTIMATE THE CURRENT ECONOMIC POTENTIAL

The modeling on a project level seeks to evaluate the cost-competitiveness and cleanness of RTTs against incumbent technologies. The simulations let decision-makers understand how different technologies perform, and how different assumptions and incentive structures affect competitiveness.

Running scenarios, we can provide a quantitative understanding of how much each RTT affects the use of fossil fuels, and thus reduces GHG emissions in Connecticut.

The simulation results for each archetypal customer were scaled to the state level using respective thermal load data and growth rates for representative customer groups. Lifecycle costs and benefits are considered using simple cash-flow and NPV models. In addition, the performance of the RTTs in terms of delivered thermal related end-use services is used to calculate the impact on GHG reductions relative to the state-level goals.

The conceptual steps for estimating the economic potential based on project evaluation are illustrated in Figure 5.

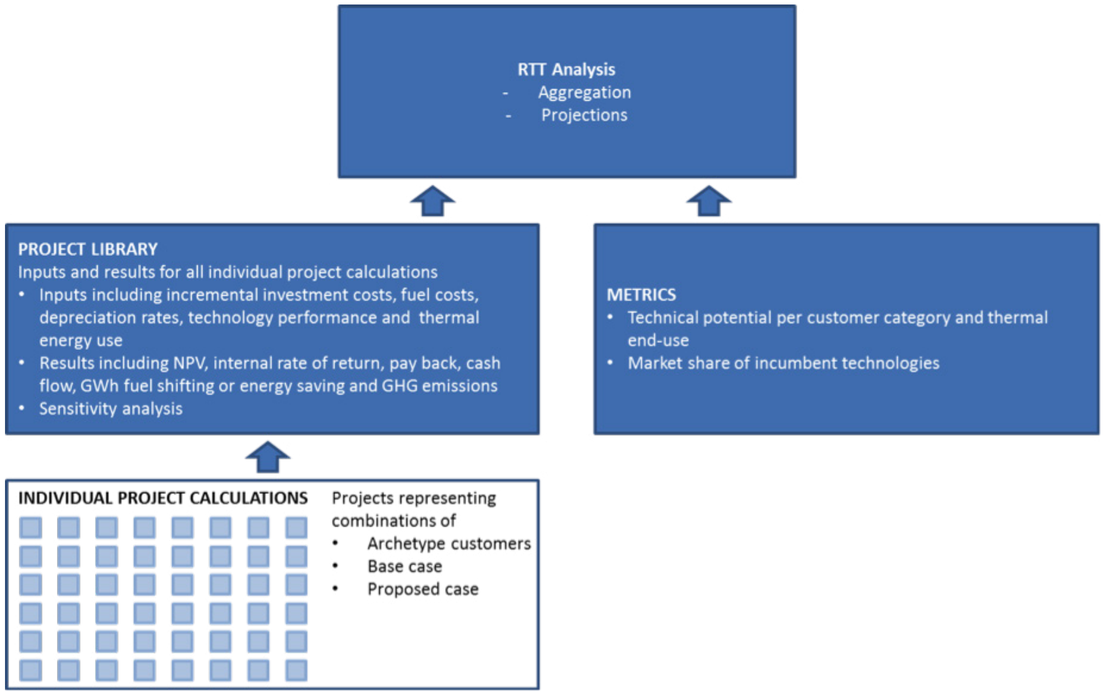

Figure 5 | Concept for estimating the economic potential for RTTs.

In order to analyze the cost effectiveness of RTTs, the research team applied RETScreen Expert due to its flexibility, inclusion of a broad range of technologies, ability to generate energy and emission changes, as well as its complex financial analysis capabilities. The model allows for comparing base cases representing incumbent or conventional technologies to the proposed cases of different RTTs. In addition to RTTs, highly efficient natural gas boilers were included to the analysis.

The model calculations of this study include:

- 7 archetypal customers
- 3 incumbent thermal technologies
- 7 proposed renewable or highly efficient thermal technology alternatives

The combinations of incumbent thermal technologies and proposed RTTs for all archetypal customers represent individual projects that constitute a “project library” of input and output data.

The “RTT analysis” aggregates individual results to a state level using input and results from the project library as well as metrics from the technical potential analysis.

STEP 4—ESTIMATE FUTURE ECONOMIC POTENTIAL

The economic potential was projected to 2050 by linear extrapolation of the individual project calculations within the scope of the technical potential.

The economic potential is influenced by the relative competitiveness of the technologies, given by investment costs, fuel prices, financial incentives and policies, performance of thermal technologies, and type of thermal end-uses served by each technology. The projected technical potential defines the maximum market that the different technologies compete within.

Sensitivity analyses were established to highlight the uncertainty of the competition analysis. The sensitivity analyses highlight the impacts of applying different relative costs and prices of the technologies as well as financial incentives and instruments.

Future Projections and Shifts

The projections assume linearity between today and 2050. There may be several shifts that can cause a break in this linearity, such as new superior technological solutions, new policies, economic shifts, or changes in other parts of the energy system.

Shifts, to some extent, will be interrelated, e.g. a new technology solution can be facilitated through policy choices and experiences of climate change. We have studied implications of a set of policy alternatives through the sensitivity analysis, but have only to a limited extent accounted for shifts due to innovations or future policies.

The market diffusion of novel and energy-efficient technologies is often prevented by high initial costs. Economies of scale and improvements of technologies can drive down costs and improve the competitiveness of the technologies. The cost-benefit performance of technologies can be improved through technological learning, which can be mapped through so-called learning rates. The technological learning rate quantifies the rate at which the costs decline with each doubling of cumulative production.

The learning rates of RTTs have been studied to a lesser extent than those of technologies for electricity generation, such as solar PV. Weiss et al (2010)[34] have reviewed some RTTs as part of their study of energy demand technologies. They find learning rates of energy demand technologies of 18 percent +/- 9 percentage points. Residential heat pumps are found to be in the upper end of this range, and conventional residential heating technologies in the lower end. Learning rates for heat pumps will, however, depend on the degree of site specificity.

34 Weiss, Martin; Martin Junginger; Martin K. Patel and Kornelius Blok (2010): A review of experience curve analyses for energy demand technologies. Journal of Technology Forecasting and Social Change 77 (2010), 411–428

Learning rates for different technologies, from heat pumps to conventional boilers, show time dependency and variability depending on the system boundaries chosen for analysis. Quality of data, choice of period, costs included in the analysis etc. influence the results, which limits the applicability of the learning curve approach for modeling technology change in energy and emission scenarios.

Most RTTs included in this analysis are globally mature technologies experiencing incremental improvements over time. The market for RTTs in Connecticut, however, appears to be immature. An immature market influences cost levels through lack of volume both in acquisition and installation.

Learning rates will impact the analysis only to the extent that they differ across technologies. We assume that the relative competitiveness of technologies remains the same. However, reduced incremental costs of RTTs compared to conventional alternatives is highlighted through the sensitivity analysis.

Addressing GHG Emissions

The analysis has shown which technology would be a customer's "first choice" from a purely economic point of view. These "first choices" are then used to estimate the change in GHG emissions that would result from replacing one thermal technology with another. The GHG emission calculations are based on the RETScreen Expert inventory and rely on its modeling concept. The GHGs included are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The GHG emission factors are fixed for the entire lifetime of the project. The following emission factors have been applied in this study:

- Electricity: 0.281 $kgCO_{2e}$ per kWh (0.302 $kgCO_{2e}$ per kWh including transmission losses), which corresponds to the average mix of energy sources delivered to the New England ISO grid
- Biomass pellets (refuse-derived pellets): 0.036 $kgCO_{2e}$ per kWh
- Fuel oil: 0.252 $kgCO_{2e}$ per kWh
- Natural gas: 0.179 $kgCO_{2e}$ per kWh

GHG emission factors depend on the carbon accounting method and data that is applied. The RETScreen Expert GHG emission factors are based on the IPCC Guidelines for National GHG Inventories.[35] This inventory represents average values for direct GHG emitted relative to a defined amount of activity such as energy demand.

The RETScreen inventory was chosen to make sure that the GHG emission factors are calculated according to a uniform methodology across energy sources. This implies applying average GHG

35 The RETScreen GHG emission factors take into account emerging rules for carbon finance. The emission analysis section of RETScreen Expert was developed in collaboration with the United Nations Environment Programme and the Prototype Carbon Fund at the World Bank. More information on GHG emissions factors in RETScreen Expert can be found in the model's user manual.

emission factors for the energy sources, which may not capture the variability of emissions by the origination of the energy sources. The IPCC framework furthermore focuses on direct emissions rather than emissions over the entire lifecycle of the energy source. GHG emissions in extraction, transportation, transformation into usable fuels and combustion may vary both across and within categories of energy sources.

It was outside of the scope of this study to map local GHG emission factors based on the origin of the energy sources.

As shown by the Oil-Climate Index of the Carnegie Endowment for International Peace,[36] total GHG emissions from the highest-emitting oil are about 60 percent higher than for the lowest-emitting oil. The Oil-Climate Index addresses both the issue of averages not capturing the full range of observed variability in emissions and the issue of including emissions throughout the lifetime of the fuel. Due to the wide range of emissions from global oils, it matters which oil is burned. Natural gas faces similar issues, where extraction and transformation potentially can cause large variability in emissions depending on the origin of the natural gas.

Unlike CO2 emissions factors for fossil fuels, factors for biomass[37] combustion are not directly included in energy sector accounting. This accounting convention is based on the rationale that CO2 of biogenic origin is part of the natural carbon cycle: carbon stored in biomass fuel has been sequestered from the atmosphere relatively recently, and it is assumed that when the fuel is burned the carbon released will be offset by carbon taken up when new biomass is grown. The assumption is made without regard for the specific forest husbandry policies and practices prevailing in the region where the biomass was harvested, even though these policies and practices strongly influence the rate of carbon uptake. A lifecycle carbon accounting framework based on New England biophysical characteristics and forest management practices has been applied in some studies comparing biomass to fossil fuels.[38]

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36 See http://carnegieendowment.org/2015/03/11/know-your-oil-creating-global-oil-climate-index-pub-59285

37 Biomass is defined as any organic matter derived from plants or animals available on a renewable basis. Biomass used for energy includes wood and agricultural crops, herbaceous and woody energy crops, municipal organic wastes as well as animal manure. Biomass feedstock can be provided as a solid, gaseous or liquid fuel, and can be used for generating electricity and transport fuels, as well as heat at different temperature levels for use in the building sector, in industry and in transport. Source: International Energy Agency (IEA)(2014): Heating without global warming. Market developments and policy considerations for renewable heat.

38 Manomet Center for Conservation Sciences (2010): Massachusetts biomass sustainability and carbon policy study: Report to the Commonwealth of Massachusetts Department of Energy Resources. Buchholz, Thomas, and John Gunn (2016): Northern Forest wood pellet heat greenhouse gas emissions analysis methods summary.

The biogenic emissions framework of the IPCC Guidelines for National Greenhouse Gas Inventories represents the most widely accepted framework for national reporting of biogenic GHG emissions, although application of this framework in the European Union and elsewhere is subject to criticism.[39]

Emissions inventories, such as those compiled by the US EPA, also address emissions from land use, land-use change, and forestry. To the degree that bioenergy production affects the amount of carbon stored on land, it will impact the emissions or absorption of carbon reflected in the national greenhouse gas inventory. However, by convention, these emissions are not attributed to the energy sector, even when they stem from use of combustion technologies.[40]

Scientists have explored various ways to estimate the potential climate impact of biogenic CO_2 emissions. Such estimates invariably focus on hypothetical scenarios involving the terrestrial carbon cycle. They range from analyses based on individual stands of trees or crop plantations[41] to integrated land use models also incorporating agricultural and forestry economics.[42] In general, such assessments find that policies that enhance terrestrial carbon storage are beneficial and can be reconciled with bioenergy use. Notably, however, aggressive use of bioenergy in the absence of policies designed to enhance terrestrial carbon storage can be counterproductive, at least in the short and medium term.

In short, both the type of biomass used and local land-use management influence land use-related GHG emissions from biomass. The adequacy of biomass stock in New England and the adequacy of the region's forest husbandry policies and practices were not taken into account in this study.[43] Neither was the origin of fuel oil or natural gas applied in the region.

39 See, e.g.: Warren Cornwall (2017): Biomass under fire: Is wood a green source of energy? Scientists are divided. Science Magazine. http://www.sciencemag.org/news/2017/01/wood-green-source-energy-scientists-are-divided. John Upton (2015): Pulp fiction: The European accounting error that's warming the planet. Climate Central. http://reports.climatecentral.org/pulp-fiction/1/.

40 US EPA (2016): Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014. EPA 430-R-16-002. See in particular footnote (a) to the summary table and Section 3.10.

41 Cherubini, F., G. P. Peters, T. Berntsen, A. H. Strømman, and E. Hertwich (2011): CO_2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. GCB Bioenergy 3(5): 413–426.

42 Klein, D., F. Humpenöder, N. Bauer, J. P. Dietrich, A. Popp, B. Leon Bodirsky, M. Bonsch, and H. Lotze-Campen (2014): The global economic long-term potential of modern biomass in a climate-constrained world. Environmental Research Letters 9(7).

43 For several reasons, CT DEEP does not agree with the methodology this study adopted for biomass: (a) the emissions factor adopted for biomass combustion does not account for the region's existing forestry practices, even though forestry practices strongly influence the lifecycle GHG emissions associated with using the region's woody biomass as fuel; (b) the analysis of biomass's potential contribution to meeting the state's thermal demand does not account for the extent of the commercial biomass pellet market that can be maintained with biomass feedstock's sustainably harvested in New England; (c) extensive development of biomass as a thermal fuel in Connecticut likely would conflict with the state's statutory goals for complying with National Ambient Air Quality Standards for criteria pollutants; and (d) claims about the market potential of biomass combustion in Connecticut and the GHG benefits associated with this potential should be considered in the context of other air pollutants.

A further caveat is that in this study the GHG calculations use “biomass pellets” as a proxy for solid woody biomass. The RETScreen Expert inventory provides factors for two solid biomass fuels: “biomass” (meaning woody biomass) and “refuse-derived pellets.” The latter—selected for this study—has a substantially higher GHG value and therefore represents a conservative alternative within the IPCC framework. Gaseous or liquid fuels produced with biomass feedstock were not analyzed.

This study focuses on GHG emissions only. Air-pollutants such as particulate matters are not considered.

Limitations and Boundaries

Though this bottom-up approach facilitates detailed analysis of specific technologies, thermal demand categories, and financial models, it has its limitations.

Analyses have been done for a set of archetypal customers for the residential and commercial sectors using a variety of RTTs. The RTT choice for each setting is nuanced, as capital for investments, surface area, orientation of exterior surfaces, incumbent fuel type, and end-uses can vary greatly. Given the complexity and potential permutations, we have addressed some of the most common customer categories, technologies, and end-uses. We recognize this assumption as a limitation, albeit a necessary one, to this project. The building categories that have been analyzed cover buildings of different sizes and with varying thermal energy needs, as can be seen from Table 4.

RESIDENTIAL	COMMERCIAL		
• Single-Family home • Apartment building	• Hotel • Medium office	• Education • Food Services	• Hospital inpatient

Table 4 | Archetype customers established for economic evaluation.

The economic and environmental evaluations are defined by the boundaries of the analysis. The boundaries have implications as to which costs and benefits are included, and the level and differentiation of prices and GHG emission factors. This is illustrated by Figure 6.

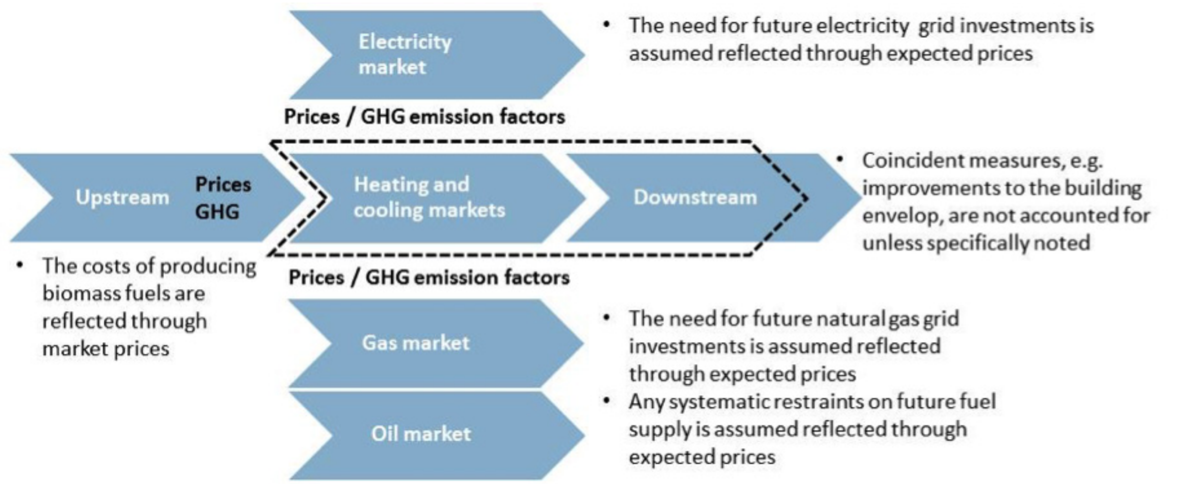


Figure 6 | Boundaries to the analysis.

The dotted arrow represents the boundaries of the economic analysis, and the interaction with the energy system at large. The upstream parts of the value chain, such as the production of processed biofuels, are represented through market prices delivered to the facility. Any future changes in the overall energy system are expected to be accounted for through price projections, where applicable.

The price projections of this study are based on the growth rates applied in the AEO 2015. The average electricity rates and natural gas rates of Connecticut are the base of the projections. Recent decisions[44] to cancel plans for added natural gas pipeline capacity were not known at the time of publishing AEO 2015.

Although RTTs can effectively help alleviate peaks in the energy demand of Connecticut by diversifying the pool of energy supply and delivering services balanced throughout the day and night, it is necessary to be aware of the features of the different RTTs compared to conventional alternatives. RTTs have different impacts on the electricity and gas loads depending on their drive energy, efficiency over the year, and which energy source they replace. This has not been subject to analysis in this study.

RTTs often utilize locally available energy resources to meet the specific on-site heating and cooling demand of one or several buildings, thus customized solutions are often required. Though the bottom-up approach allows for some representation of specific conditions, the need for simplicity and conciseness limits modeling of the full range of combinations of existing technologies and resources. The following assumptions have been made regarding the investment choices of the customers:

44 October 25th, 2015: DEEP press release on canceling the natural gas RFP.

INCUMBENT ENERGY SOURCES	RENEWABLE THERMAL TECHNOLOGIES AND THERMAL END-USES
• Space cooling is based on electricity • Space heating and hot water is based on the same energy source: electricity, fuel oil, or natural gas • Space heating based on electricity is provided by electric baseboard	• ASHP delivers space heating and cooling • GSHP delivers space heating and cooling • SHW delivers hot water • Bio delivers space heating and hot water • Efficient natural gas boilers deliver space heating and hot water • ASHP water heaters deliver hot water

Table 5 | Assumptions for technology choices.

To avoid additional complexity in the analysis, the RTTs have been modeled to deliver the whole thermal demand of a building over the year, that being for space cooling, heating or hot water. Even if the incremental installation costs are given per installed capacity, this may exclude some financially favorable solutions. Oversizing RTTs should be avoided both to restrict installation costs and secure efficient operations; and keeping the incumbent energy source for peak load operations may be desirable. See chapter 6.2.2 for an analysis of some partial load alternatives.

ASHPs and SHW are considered a supplementary technology to the incumbent. Even if these technologies are applied as primary energy source, the incumbent technology often has to be kept as a backup. The implication of this classification for the analysis is related to assumptions on avoided costs. See Appendix A.

CHAPTER 4
Technical Potential—Demand Analysis

The demand for hot water, space heating, and cooling in the state of Connecticut represents the total technical potential for thermal technologies.[45]

The time frame of the analysis extends to 2050, with 2014 as the basis for the projections and EUIs established for residential and commercial customers.

The technical potential for buildings is driven by the expected development of square footage of different building categories and the EUIs for thermal purposes. Expected energy efficiency rates for different customer categories have been applied. The projections have been informed by the AOE and CT residential housing and population data.

Assumptions for Demand Projections

The assumptions cover the methodology of estimating floor space, EUIs, as well as the base case for the relevant customer segment.

The total number of housing units is assumed to grow at a net rate corresponding to the expected population growth as estimated by Connecticut State Data Center.[46]

The projections for commercial thermal demand through 2050 have considered AEO New England growth factors for different categories of commercial customers and AEO projections of square feet by distribution of the New England workforce by category.

Temperature change impacts on space heating and cooling have been considered to affect heating and cooling days as follows, based on AEO for New England:

- Annual rate for heating degree days -0.5 percent
- Annual rate for cooling degree days 0.9 percent

Cooled space relative to heated space has been considered to remain unchanged in the base case.

45 Thermal energy demand for cooking, clothes drying, and other thermal uses is not included in this study.

46 2015–2025 Population projections for Connecticut. November 1, 2012 edition

CUSTOMER SEGMENT	BASE CASE ASSUMPTIONS
Residential	• Renovation affects 1 percent of the floor space per year. These renovations reduce the need for space heating by 25 percent, on average • Technical systems for space and water heating representing 3 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain for space and water heating is 15 percent, on average
Commercial	• Renovation affects 0.4 percent of the floor space per year. These renovations reduce the need for space heating by 20 percent and space cooling by 20 percent, on average • Technical systems for space heating representing 2 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain is 15 percent, on average • Technical systems for water heating representing 2 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain is 20 percent, on average. • Technical systems for space cooling representing 3 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain is 30 percent, on average.

Table 6 | Base case assumptions on technical demand potential.

Residential Sector

The population of Connecticut is 3.597 million[47] and lives predominantly in single-family homes.[48] According to the 2000 Census, 64 percent of residential units were single-family homes. The rest of the residential building base consists predominantly of multi-family buildings.

The aggregated residential technical potential is estimated to be 88.6 trillion BTUs by 2050 in the base case, with a sensitivity range between 73.1 and 100.4 trillion BTUs.

- Building age, performance, and size are all important drivers of thermal demand in the residential sector.
- Older houses predominate, and they also have higher EUIs, thus presenting a viable retrofit opportunity in the future.
- Cooled space is negligible in comparison to space and water heating, but climate impacts and increased CDD could drive demand for cooling in the future.
- Through 2050, residential thermal demand declines, at different rates depending on factors such as regulations on energy efficiency (building codes), and retrofit rates and depths.
- The reference case of an 80 percent reduction in residential thermal energy demand implies a technical potential of 24 trillion BTUs in 2050.[49] To achieve this, a more-than 5.5 percent annual rate of deep retrofit would be required until 2050, *ceteris paribus*.

47 See http://www.census.gov/quickfacts/table/PST045215/09

48 EIA defines a Single Family Home as follows: "A housing unit, detached or attached, that provides living space for one household or family. Attached houses are considered single-family houses as long as they are not divided into more than one housing unit and they have independent outside entrance." http://www.eia.gov/consumption/residential/terminology.cfm#m

49 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from residential thermal energy demand envisioned here is hypothetical.

ENERGY USE INTENSITIES

The EUIs applied in the analysis are differentiated by thermal purpose and type of residential building, as can be seen in Figure 7.

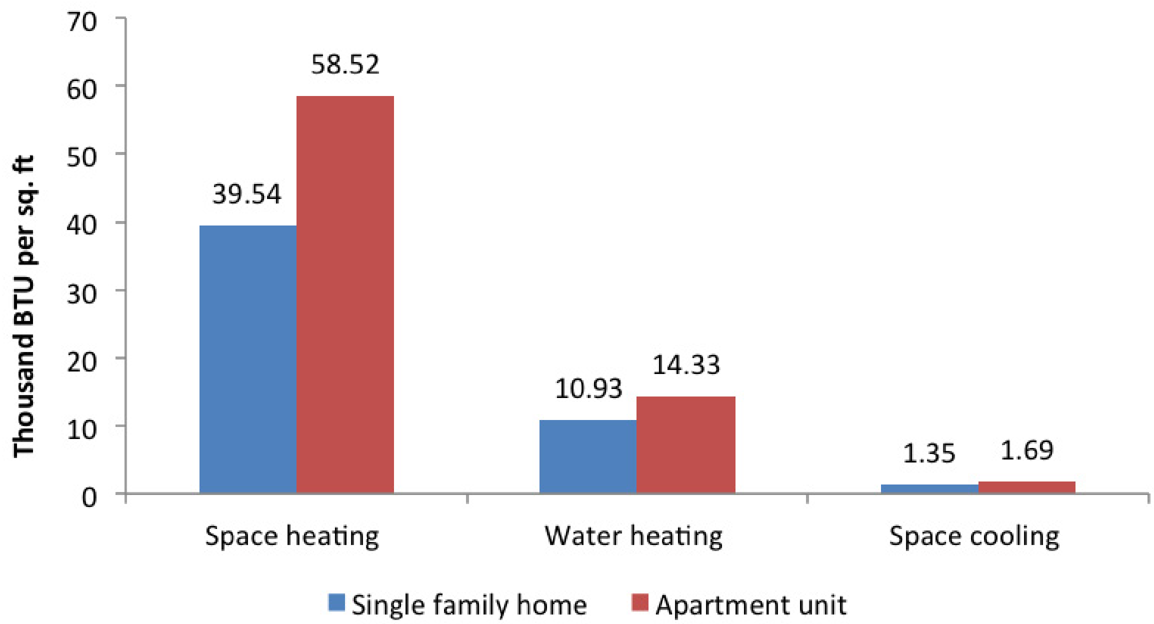


Figure 7 | Residential energy use intensity per square feet (2014 mean values), Source: RECS 2009 and PSD 2016.

Space heating per square foot is significantly higher in apartment units than in single-family homes. This can be explained by a higher share of conditioned space of the total square feet of the housing unit.

The EUIs for cooling are low, mainly due to a low share of central cooling in residential buildings in Connecticut.

The EUIs for space heating of buildings undergoing demolition has been estimated based on the weighted average age of the buildings built before 1960 and their EUIs for space heating (see Figure 9). The EUIs for newly constructed single-family homes are based on the 2016 PSD.

Assumptions for the cooling EUIs in new buildings are the same as for existing; thus cooling values in new buildings may be underestimated. Buildings undergoing demolition are assumed to not have space cooling.

ESTIMATED THERMAL ENERGY DEMAND

The size of the building is an important driver for thermal energy demand of residential buildings. The square footage has been established for CT through the number of homes in different categories, the average square feet, and growth rates of population and demolitions.

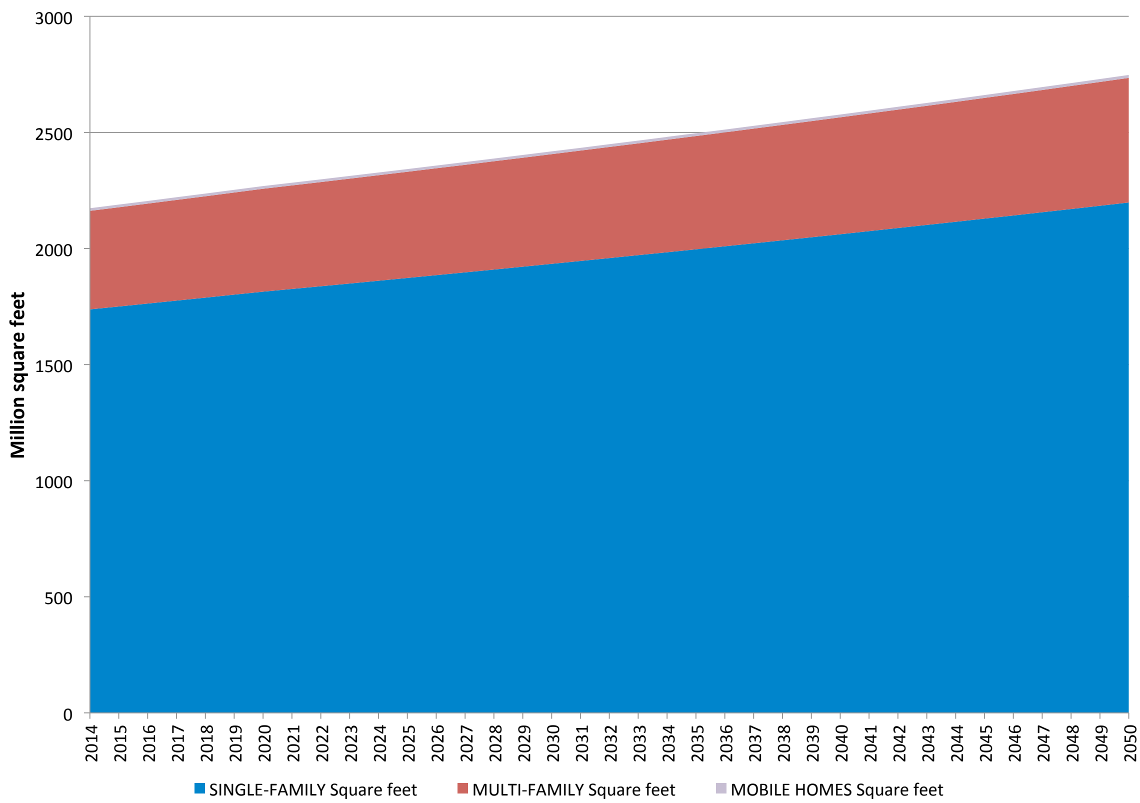


Figure 8 | Estimated heated floor space for occupied housing units, 2014–2050. Sources: CT DECD, American Community Survey, RECS 2009 and AEO 2015.[50]

The estimation shows a relatively steady building base over the time period.

The share of new residential buildings is relatively negligible compared to the existing building base. According to the analysis, approximately 89 percent of the estimated heated residential base in 2050 will have already been built. This represents a viable opportunity for RTTs and underlines the importance of replacing thermal installations at housing renovations.

50 Mobile homes are excluded from the rest of the analysis.

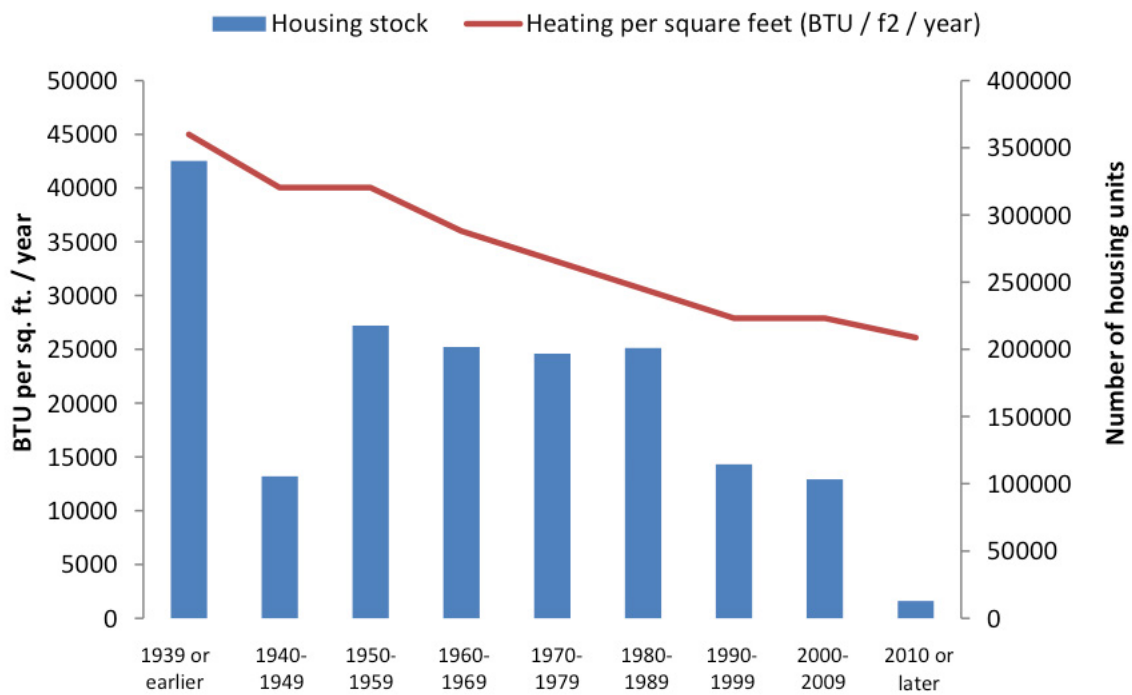


Figure 9 | Age Distribution of CT Housing. Sources: ACS 2014 and PSD 2016.

It is important to note the relation between building performance and age. As seen in Figure 9, the heating intensity declines for more recently constructed buildings. Older construction tends to have more air and heat leaks, which contribute to a higher demand for heating and cooling. In relation to age, it is also worth mentioning that relatively old buildings (built in 1939 or earlier) have a high representation in the distribution. The rate of new buildings has gradually declined since 1989.

The prevalence of older constructions has a direct relationship to the opportunity to install RTTs versus conventional technologies when retrofitting the building or heating system.

The size of buildings impacts its energy demand. This study assumes that the distribution between single-family and multi-family homes remains unchanged over time.

Energy demand is also related to occupancy levels and number of people per house. The occupancy rate distinguishes whether a building has occupants or is generally vacant. Data from the CT Department of Economic and Community Development[51] shows a great variation of vacancy rates across the state,

51 See http://www.ct.gov/ecd/cwp/view.asp?a=1106&q=250640

ranging from 3 to 38 percent (Tolland and Cornwall, respectively). While the average is 8 percent, it is challenging to forecast future social dynamics; occupancy nonetheless has implications on the energy demand of buildings.

The annual energy efficiency improvement rate applied to new construction is 0.73 percent for space heating, reflecting the historic development of Figure 9.

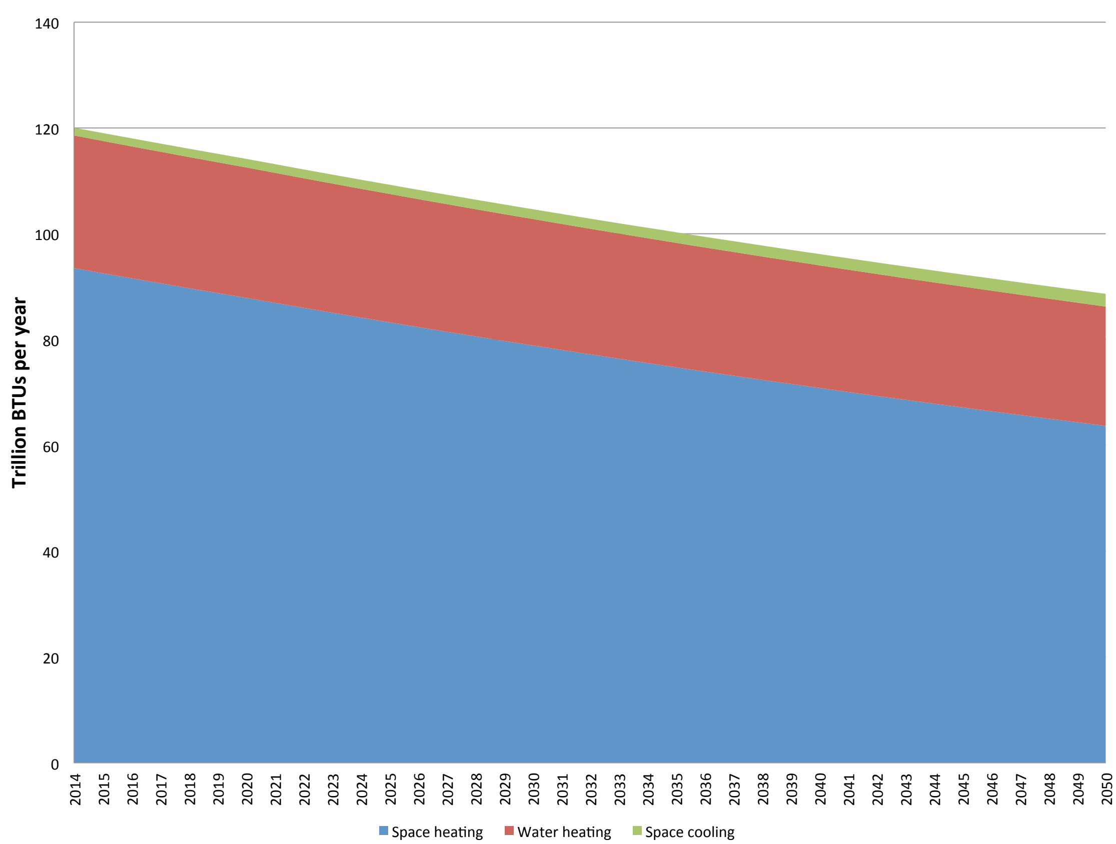


Figure 10 | Estimated residential thermal energy demand, 2014–2050.

The overall thermal energy demand follows a downward trend through 2050, despite the slight increase in the housing square footage. This decrease constitutes a lower burden on the electric and natural gas grid, and is a result, among other things, of the assumed rate of retrofit and energy efficiency.

The average EUI for space heating becomes 1.63 percent more efficient each year and remains the dominant thermal end-use.

Water heating is, expectedly, the second largest demand. The average EUI for water heating becomes 0.92 percent more efficient each year.

Looking to 2050, it is relevant to note the negligible contribution of cooling to the aggregate demand. With the potential increase in CDD and various other climate impacts, cooling may become a more sought after service and thus considerably drive the demand curve, particularly if trends shift from local units to centralized cooling systems. This explains the positive annual growth rate of average EUI for space cooling of 0.71 percent.

SENSITIVITY ANALYSES

Sensitivity analyses have been run against the base case above to account for the uncertainty of thermal demand. Table 7 describes one analysis as it reflects an increased share of cooled space and unchanged outdoor climate.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
75 percent cooled space	Cooled space as a share of heated space increases: • From 50 percent to 75 percent for single-family homes • From 41 percent to 75 percent for multi-family homes This can be caused by increasing the number of homes with installed air conditioning or by cooling a larger space in homes with cooling already installed.[52]	The technical potential is estimated at 89.8 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.
No climate change	The number of HDD and CDD is assumed to be the same in the future as today. Base case assumes change rates of -0.5 and 0.9 for respectively HDD and CDD.	The technical potential is estimated at 100.4 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.

Table 7 | Sensitivity analyses residential sector. Share of cooled space and lower outdoor temperature.

Figure 11 shows the sensitivity alternatives related to a higher share of cooled space and other outdoor temperatures:

52 According to RECS2009, 75 percent of homes had air condition installed and 23 percent had central air conditioning.

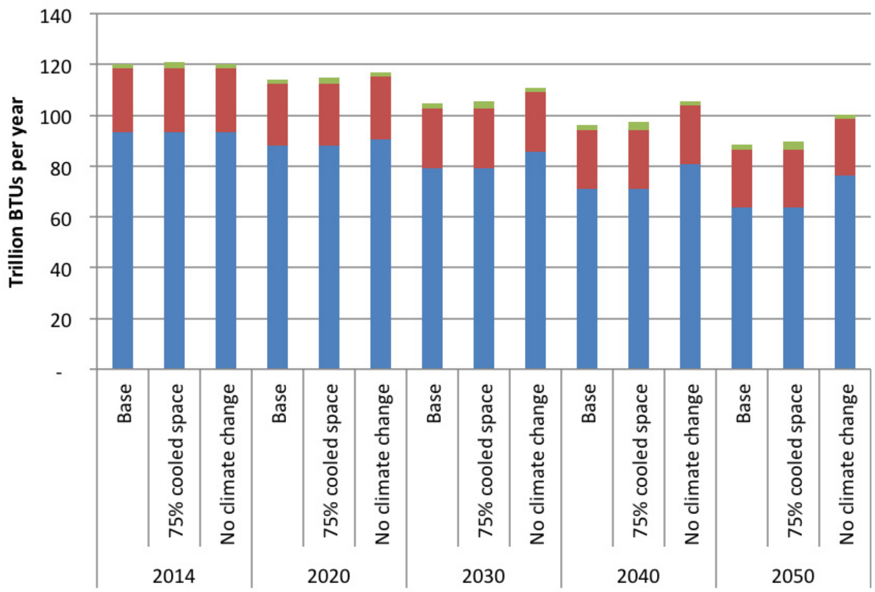


Figure 11 | Sensitivity analyses residential sector. Share of cooled space and lower outdoor temperatures.

Table 8 describes another set of sensitivity analyses allowing for an overall increase in energy efficiency of buildings through retrofits and stringent "passive house" standards.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
New Passive	Assumes passive house standard for all new residential homes. The passive house standard assumes an EUI of 4,755 BTUs per square foot of space heating and cooling.	The technical potential is estimated at 81.3 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.
DR @ retrofit	Assumes all renovation is a deep retrofit corresponding to a 75 percent reduction in energy to space and water heating. The annual renovation rate remains at 1 percent per year.	The technical potential is estimated at 73.1 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.
Minus 80 percent[53]	Assumes 80 percent reduction of total thermal energy demand by 2050.	The technical potential is estimated at 24.0 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.

Table 8 | Sensitivity analyses residential sector. Assumptions on energy efficiency.

53 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from thermal energy demand envisioned here is hypothetical.

Table 11 shows the sensitivity related to a more ambitious standard for new buildings and a higher rate of deep retrofit.

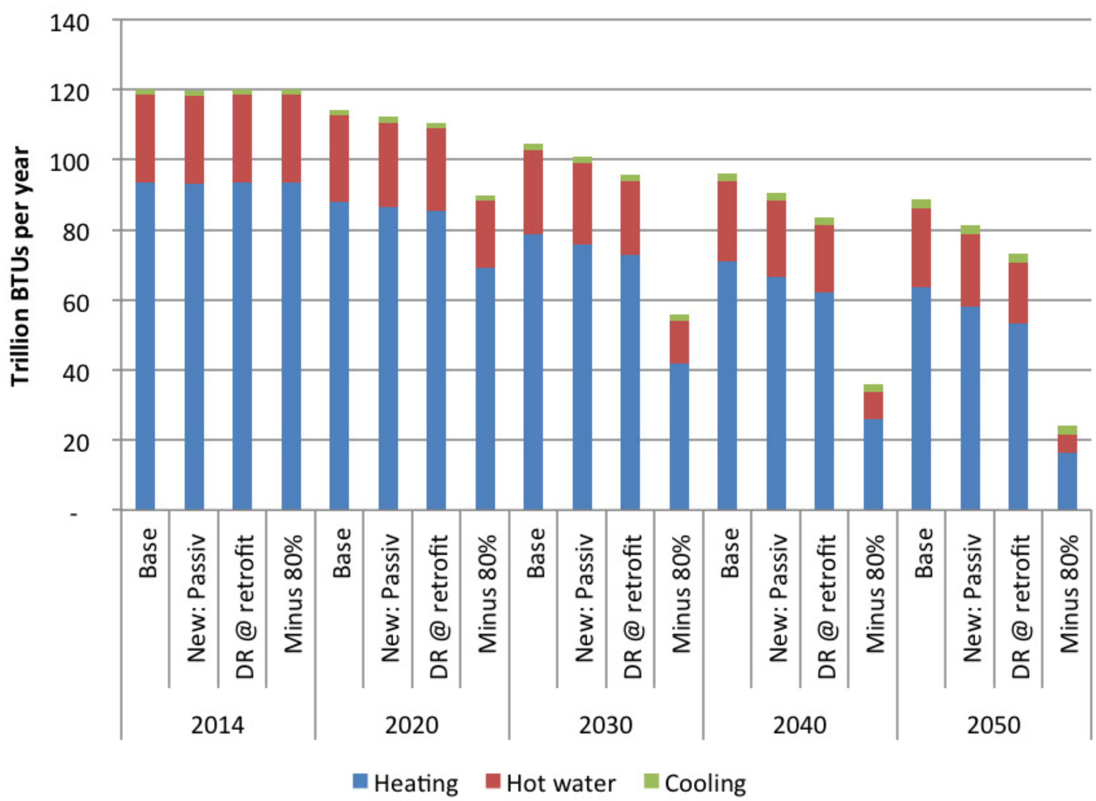


Figure 12 | Sensitivity analyses residential sector. Assumptions on energy efficiency.

In all sensitivity analyses, cooling remains a small portion of the total demand. In a 75 percent increase of the total cooled space there is a small increase by the end of the period.

The sustained levels of thermal demand over time translate to the need for reliable, affordable, and environmentally friendly sources of energy.

The sensitivity analysis on energy efficiency rates precludes a more rapid overall decrease in thermal demand due to efficiency measures. The assumptions for the sensitivity analysis of “Passive house” and “DR @ retrofit” speak to the importance of building codes in a transition to an efficient and low-carbon building base.

Commercial Sector

Although the energy demand of this sector is lower than in residential, extensive and steady growth of commercial office space is expected.

The technical potential of the commercial sector is estimated to 37.2 trillion BTUs in 2050 in the base case, with a sensitivity range between 30.3 and 41.3 trillion BTUs

- As the rate of new building is assumed to be high in the commercial sector, ambitious building codes can provide a considerable contribution to lowering thermal energy demand.
- While reducing the need for space heating through stricter codes, the need for space cooling may increase.
- Warmer winters and summers will provide a net reduction in thermal energy demand.
- The reference case of an 80 percent reduction in commercial thermal energy demand implies a technical potential of 9.8 trillion BTUs in 2050.[54] To achieve this, an annual rate of deep retrofit of around 4.7 percent would be required until 2050, *ceteris paribus*.

54 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector. The 80 percent reduction in emissions from commercial thermal energy demand envisioned here is hypothetical.

ENERGY USE INTENSITIES

The EUIs of different subsectors from the commercial sector relay important information about where the greatest opportunities and challenges lie.

Figure 13 shows the aggregated EUIs applied to existing commercial buildings in this study.

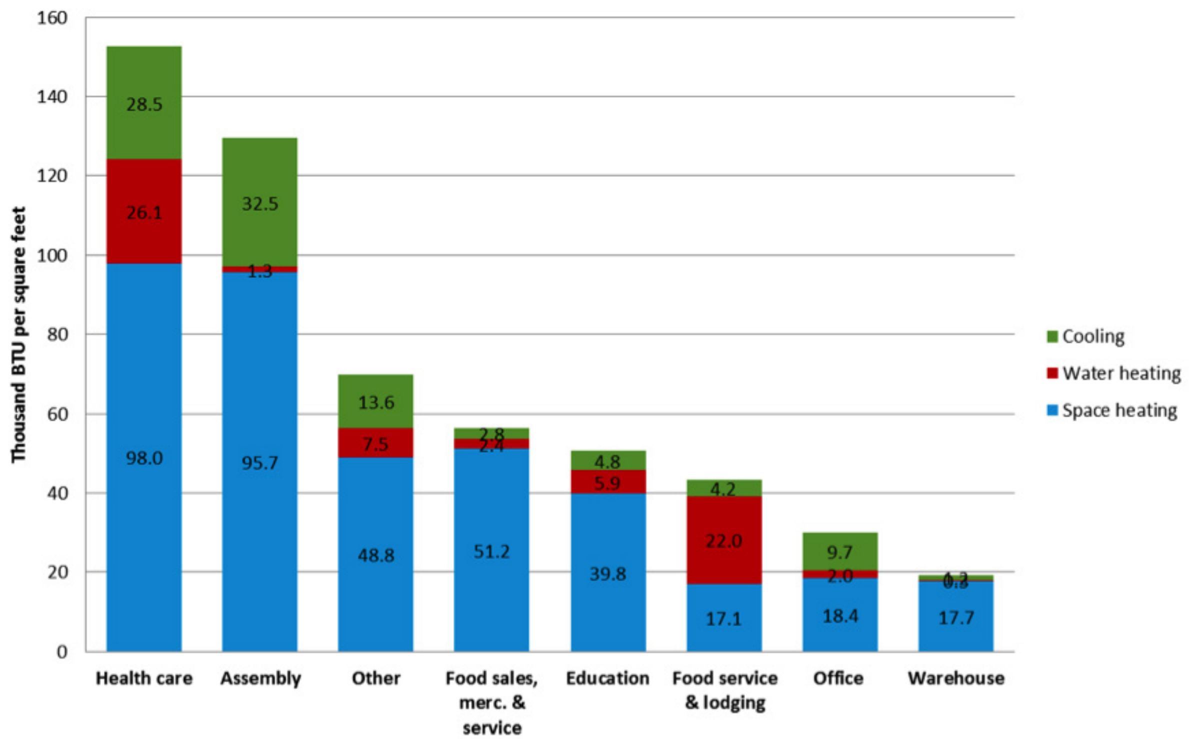


Figure 13 | Commercial Energy Use Intensity per square feet (2014 mean values). Source: CBECS 2012.

Health Care and *Assembly*[55] are the most energy intense categories in terms of space heating. Providing a reliable energy source that sustains life-supporting and supply chain operations is particularly crucial for *Health Care*.

Health Care also dominates water heating, followed by the *Food Service* and *Lodging sectors*. *Assembly* is the most space-cooling-intense sector, followed by *Health Care*.

The annual energy efficiency improvement rates applied to the EUIs of new construction and demolitions are 0.55 percent for space heating and 0.32 percent for cooling, informed by the AOE 2016.

55 Assembly: Buildings in which people gather for social or recreational activities, whether in private or non-private meeting halls

ESTIMATED THERMAL ENERGY DEMAND

The size of buildings along with the type of business they house is an important driver for thermal energy demand of commercial buildings. The square footage for the Connecticut commercial building stock has been established using AEO 2015 projections for New England. The projected distribution of employees relies on NAICS sectors and states, and has been applied to elaborate on the Connecticut commercial square feet.

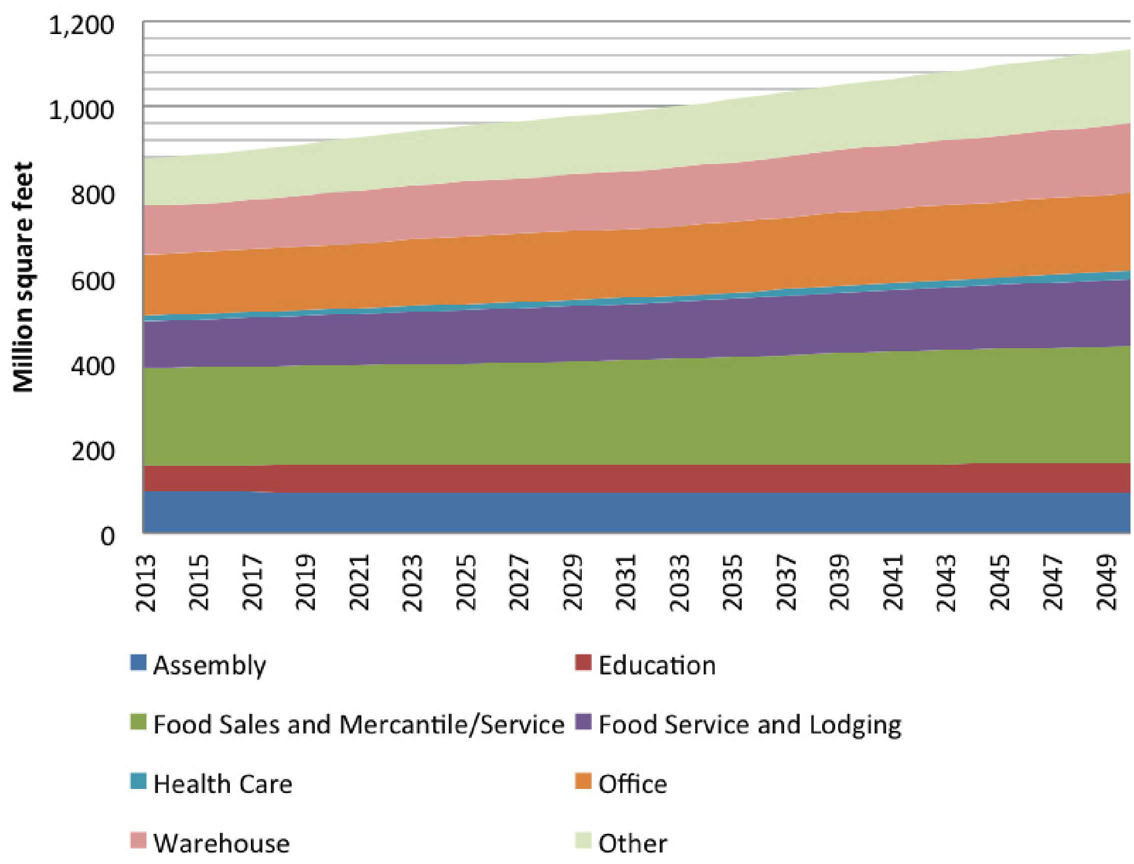


Figure 14 | Estimated floor space, commercial customers in CT. Sources: Elaborated from the AEO 2015 and the US Census Bureau.

The commercial space in Connecticut is dominated by *Food Sales* and *Mercantile/Service* buildings in particular, followed by *Office*.

The highest net positive annual growth of floor space is found in the category *Other*, followed by *Health Care, Warehouse*, and *Food Services and Lodging*. With the exception of *Assembly*, all commercial building categories have an expected net positive annual growth of floor space over the period.

Health Care occupies a moderately small portion of commercial floor space, but is the most energy intense in terms of BTUs per square feet and per year. Second to it in terms of BTUs per square feet and per year are the *Assembly* buildings.

Unlike the residential sector, the expected growth in new commercial construction is significant. According to the analysis, approximately 37 percent of the estimated commercial space in 2050 will have already been built, corresponding to an annual rate of new constructions of 2 percent.

New construction is more likely to have higher energy efficiencies through a better building envelope, as well as overall improved performance through more efficient technologies and enhanced energy management. New commercial buildings represent an important opportunity for RTTs.

There is an overall reduction in aggregate commercial thermal demand through 2050. Space heating declines most drastically, while space cooling demand increases slightly. Overall, the high rate of new construction in the commercial sector precludes a gradual transition to efficiency and reduced demand.

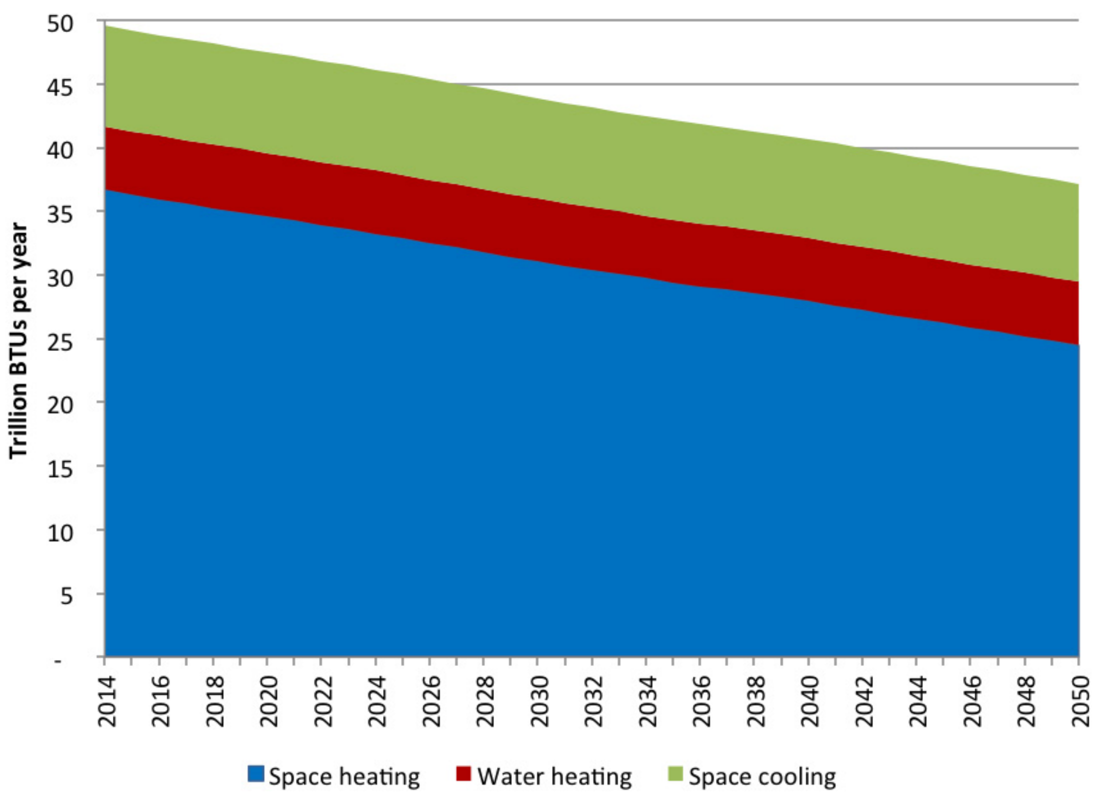


Figure 15 | Estimated commercial thermal demand by end-use. 2014–2050.

The average EUI for space heating becomes 1.76 percent more efficient, water heating becomes 0.68 percent more efficient and space cooling 0.76 percent more efficient each year.

The development can be explained by:

- New, more efficient commercial buildings replacing old inefficient ones at a high rate.
- Increased outdoor temperatures causing a reduction in the number of heating degree-days and an increase in the number of cooling degree days.
- Structural changes, where commercial buildings with high EUIs increase their share of the total floor space. Examples are *Health Care, Food Service and Lodging*, and *Other.*
- Energy efficiency achieved through renovations and replacement of less efficient technologies.

The largest commercial consumers of thermal end-uses are estimated to be the *Food Sales* and *Assembly* sub-sectors. Given their expansive floors spaces, they present a viable opportunity for RTTs.

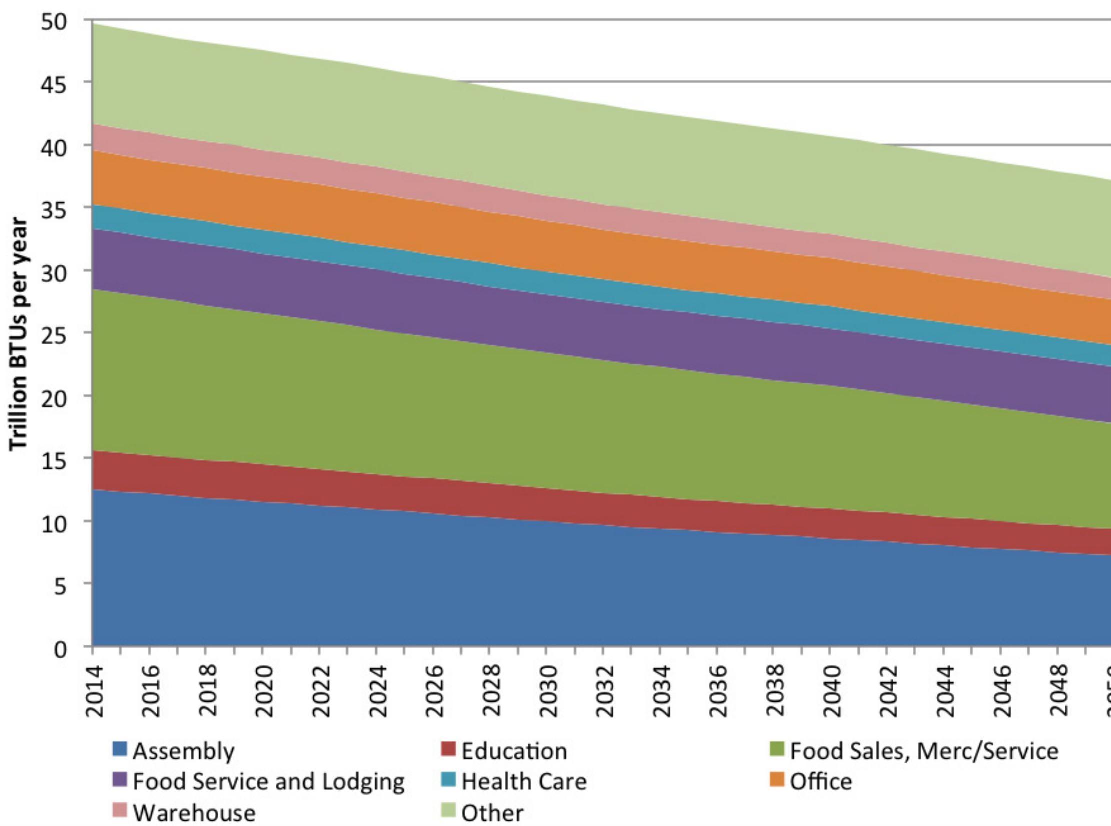


Figure 16 | Estimated commercial thermal energy demand by sector. 2014–2050.

SENSITIVITY ANALYSES

The following sensitivity analyses have been performed to analyze variations in the commercial thermal demand as a result of different references for EUIs.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
Buildings Energy Data Book (BEDB) EUIs[56]	The EUIs from the BEDB were applied for existing buildings. The EUIs have been adjusted for CT relative to the national HDD and CDD, as well as national energy efficiency growth rates from the AEO.	The technical potential is estimated at 37.4 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
International Energy Conservation Code (IECC) for New Construction[57]	The EUIs for new commercial buildings built today are based on the IECC 2012. The categorization of commercial sectors deviates from CBECS, and assumptions have been made to adapt the estimated IECC values to categorization used in this study.	The technical potential is estimated at 30.3 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
CBECS 2003	Based on the EUIs from CBECS 2003, adjusted to 2014 values for the growth of the regional HDD and CDD for the period 2003–2014 (AEO 2016).	The technical potential is estimated at 41.3 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.

Table 9 | Sensitivity analyses commercial sector. Alternative references for EUIs.

56 Department of Energy, Buildings Energy Data Book, table 3.1.13: http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.13

57 As calculated by Pacific Northwest National Laboratory in the study "Energy and energy cost savings analysis of the IECC for commercial buildings", 2013 (PNNL-22760).

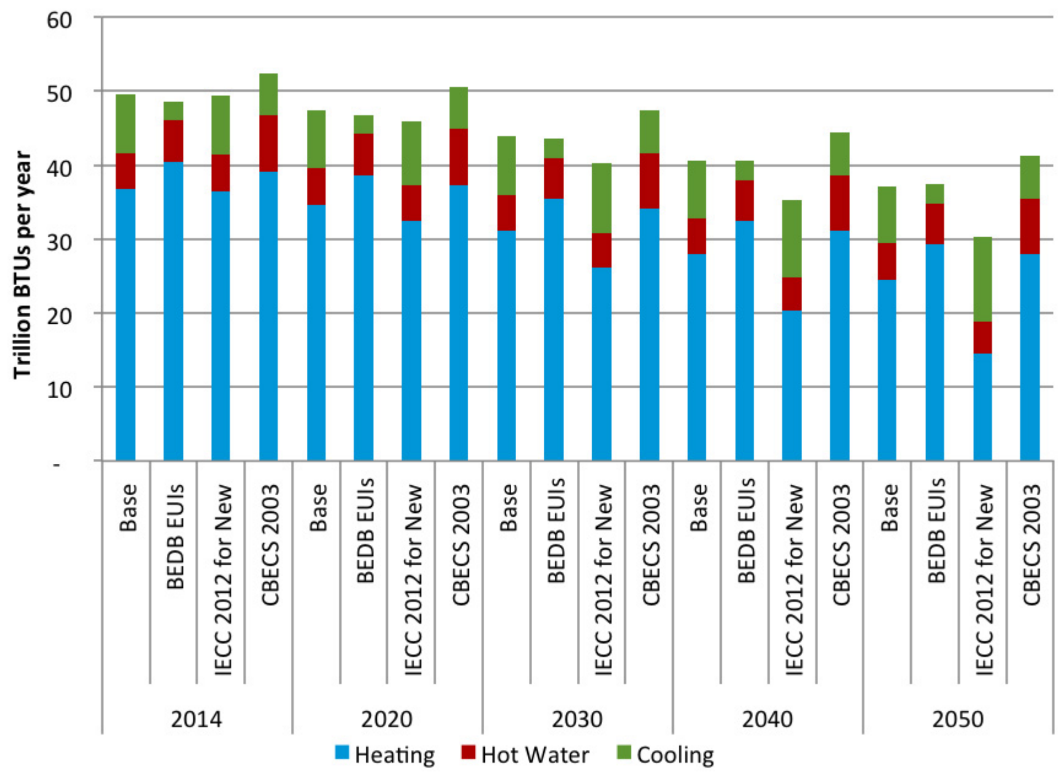


Figure 17 | Sensitivity analyses commercial sector. Alternative references for EUIs.

The BEDB EUIs preclude deviations from the base case on the distribution of thermal energy between both end-uses and customer groups. This results in a higher estimated technical potential with a higher share of space and water heating and a considerably lower share of space cooling.

The IECC 2012 EUI values for new commercial construction drive down technical potential in 2050 considerably. An ambitious building code in a customer segment with a high share of new construction makes a difference. The 2016 Connecticut State Building Code (CSBC) based on the International Code Council's 2012 International Codes is effective for projects in which permit applications were made on or after October 1, 2016.[58]

The CBECS 2003 sensitivity analysis concludes with higher space and water heating demand (but lower cooling demand) compared to the base case. The base case assumes EUIs from CBECS 2012, and the difference can be explained both by energy efficiency between 2003 and 2012, as well as the selection of participants.

58 See http://das.ct.gov/images/1090/NR_Connecticut_Codes_Final.pdf

Another set of sensitivity analyses assumes a higher share of energy efficiency and a choice of outdoor temperatures. Assumptions are presented in Table 10.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
No climate change	The number of HDD and CDD is assumed to be the same in the future as today.	The technical potential is estimated at 40.4 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
DR @ retrofit	Assumes that all renovations are deep retrofits corresponding to a reduction of all thermal end-uses of 75 percent. The annual renovation rate remains at 0.4 percent per year.	The technical potential is estimated at 34.6 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
Minus 80 percent[59]	Based on base case assumptions except for annual renovation rate and extent of retrofit. For 80 percent reduction in today's energy consumption, approximately 5.5 percent of the commercial floor space has to be renovated each year at an achieved reduction of thermal energy use of 75 percent.[60]	The technical potential is estimated at 9.8 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.

Table 10 | Sensitivity analyses commercial sector. Assumptions on energy efficiency and outdoor temperature.

59 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from thermal energy demand envisioned here is hypothetical.

60 As a comparison, the new built rate in the AEO is assumed to be 2 percent per year.

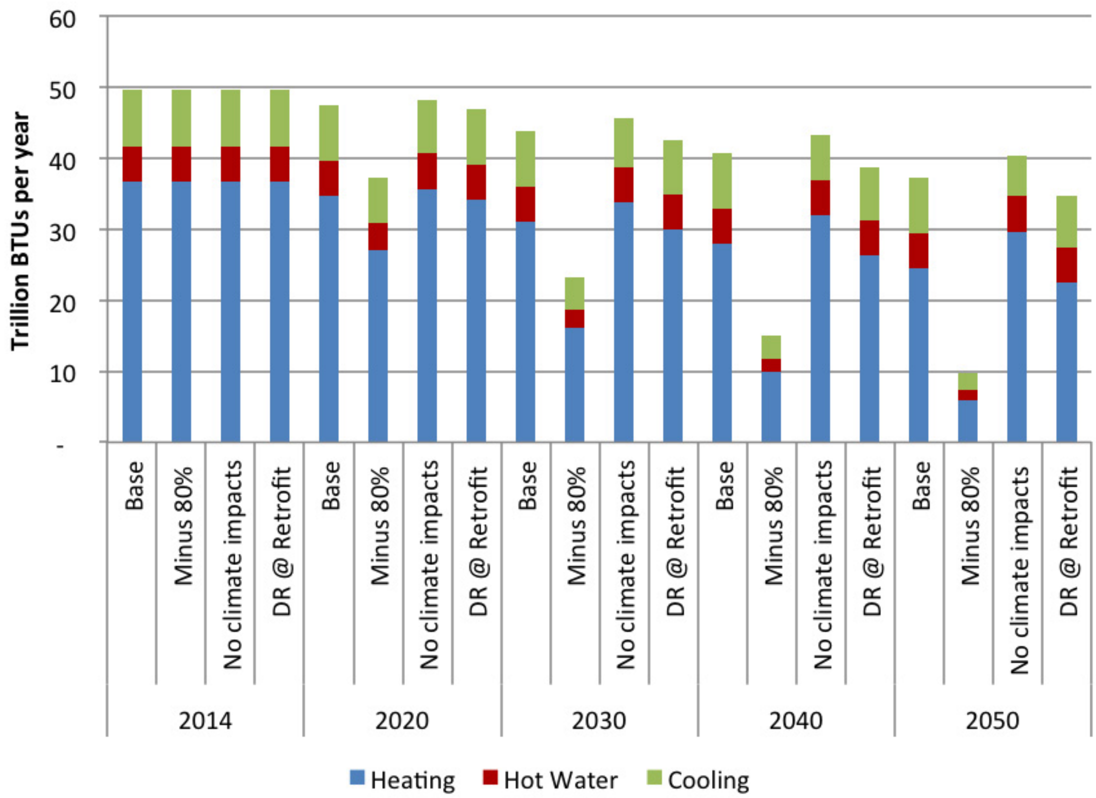


Figure 18 | Shows the results of the 3 sensitivity analyses.

In a No climate change sensitivity analysis, the technical potential remains steady over time with a slight decline.

Space cooling retains its relative ratio across the sensitivity alternatives. Overall, it plays a more significant role than in the residential sector, due to the implicit cooling needs of some of the services in the commercial sector.

Under the Minus 80 percent sensitivity analysis, the thermal energy use in the commercial sector in 2050 is estimated to be approximately 80 percent lower than 2014. An aggressive rate of deep renovations would drive the technical potential to as low as 9.8 trillion BTUs.

CHAPTER 5
Economic Potential—Competition Analysis

The financial competitiveness of technologies providing thermal services has been analyzed and the economic potential has been estimated. Main findings include:

- The economic potential for RTTs in residential and commercial building is currently around 31 trillion BTUs, representing 19 percent of the estimated thermal demand.
- RTTs are more competitive in the commercial sector than the residential sector.
- Heat pumps are financially favorable as a robust thermal solution replacing conventional electric technologies across all customer groups and end-uses.
- There is large, untapped, and financially favorable potential to replace old fuel oil in residential and commercial buildings with highly efficient natural gas boilers and biomass pellets. The adaptation of highly efficient natural gas boilers at a large scale will not offer sufficient reduction of GHG emissions to reach Connecticut's climate targets.
- Any existing fuel oil boiler replaced by a new fuel oil or standard natural gas boiler represents a lost opportunity for a cheaper and cleaner future.

Case Study Results

Different combinations of incumbent and proposed alternative thermal technologies have been analyzed for different archetypal customers, with financial viability and impact on GHG emissions quantified.

The competition analysis—examining how RTTs compete with conventional thermal technologies—is based on the assumptions in Appendix A, and detailed results by customer category can be found in Appendix B.

Physical limitations related to existing buildings have to some extent been handled through the level of incremental installation initial costs. See Appendix A for more information.

Financial incentives are not included in the competition analysis and will be discussed separately in the sensitivity analysis of Chapter 6. Appendix E offers an overview of current financial incentives in Connecticut.

The competition analysis assumes the relative installation costs of the technologies to remain unchanged over the period. The impacts of changes in relative installation costs between RTTs and conventional technologies are considered in the sensitivity analysis.

Due to the need for simplification, the analysis contains some limitations that may influence the financial feasibility of RTTs. Specifically:

- To avoid additional complexity in the analysis, the RTTs have been modeled to deliver the whole thermal demand of a building over the year, that being for space cooling, heating or hot water. Even if the incremental installation costs are given per installed BTU/h, this may exclude some financially favorable solutions. Oversizing RTTs should be avoided both to restrict installation costs and secure efficient operations; keeping the incumbent energy source for peak load operations may be desirable.
- Some RTTs can supply thermal end-uses in addition to those we have incorporated in our case studies. These could influence the financial evaluation.
- Technologies that provide low-temperature heat may have difficulty delivering enough heat to existing buildings on the coldest days. Improvements of the building envelope to accommodate heat pumps have not been accounted for.
- Economies of scale, particularly for the commercial sector, may be underestimated in the study.
- Some customer categories may face regulatory and technical requirements related to their thermal load that pose limitations on RTTs. For example, strict requirements stipulate hot water temperatures for certain processes in food and healthcare.
- Potential costs of gas grid connection or electricity grid upgrades have not been accounted for.

Table 11 summarizes the competition analysis, with the range of simple payback and cases with positive NPV marked in green.

RTT USED	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity	5–15	5–15	5–15	5–15	5–15	5–15	5–15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
ASHP space heating and cooling with ductwork needed	Electricity	5–15	5–15	5–15	>15	5–15	5–15	>15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
ASHP Hot Water	Electricity	<5	<5					
	Fuel Oil	>15	>15					
	Natural Gas	>15	>15					
GSHP space heating and cooling	Electricity	5–15	5–15	5–15	>15	>15	>15	>15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
Solar Hot Water	Electricity	5–15	5–15	>15	5–15	5–15	>15	>15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
Biomass space heating and hot water	Fuel Oil	5–15	>15	5–15	5–15	5–15	5–15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
Highly efficient natural gas	Electricity	<5	<5	<5	5–15	<5	<5	5–15
	Fuel Oil	<5	<5	<5	<5	<5	<5	5–15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15

Table 11 | Case study results for different combinations of incumbent and proposed technologies for different archetype customers.

- Replacing conventional electric technologies with ASHPs for space heating and cooling is a financially favorable alternative across all customer categories.
- ASHP water heaters are financially feasible alternatives to electric water heaters for residential customers. ASHP water heaters for commercial hot water demand have not been included in the analysis.
- SHW is a financially feasible alternative to electric water heaters for residential customers and commercial customers with high demand for hot water per square foot.
- GSHPs are financially feasible alternatives to conventional electric technologies for space heating and cooling for customer groups with a large total number of hours of use and high demand for space heating per square foot.
- Biomass-pellet boilers are a financially feasible alternative to fuel oil for commercial customers with a large demand for space heating and hot water per square foot.
- Highly efficient natural gas boilers are a financially feasible alternative to both conventional electric boilers and fuel oil for space and water heating across customer categories.

Overall Economic Potential in Connecticut

The competition analysis found the most cost efficient combination of incumbent and proposed technologies for archetypal customer. The total market for thermal energy, as estimated by the base case of the demand analysis of Chapter 4, was split across winning technologies, accordingly.

If several combinations of incumbent and proposed technology are favorable for an archetypal customer, the most favorable has been applied. The results are discussed from two scenarios:

1. Competitive RTTs have priority: efficient natural gas is excluded as an alternative to the incumbent.
2. Efficient natural gas included: efficient natural gas is included as an alternative to the incumbent.

RESIDENTIAL SECTOR

Residential demand for hot water and space heating and cooling was estimated to be 120 trillion BTUs in 2014. Fuel oil was the dominant energy source (46 percent), followed by natural gas (37 percent), electricity (11 percent), and biomass (5 percent). The total GHG emissions related to this residential thermal demand is estimated to be 9.1 million tons of CO2 equivalent.[61]

61 Estimations are based on the thermal demand estimated in Chapter 4, the consumption by energy sources from EIA SEDS 2014, the energy by end-use from AEO 2015, the GHG emission factors from Chapter 3, and the efficiency assumptions from Appendix A.

SCENARIO 1—COMPETITIVE RTTS HAVE PRIORITY

The economic potential of RTTs in the residential sector is estimated to be 16.2 trillion BTUs when highly efficient natural gas boilers are excluded from the analysis and competitive RTTs have priority. This is 14 percent of the estimated technical potential (see Figure 19).

- ASHPs replace thermal demand for space heating and cooling currently based on conventional electric technologies. Although GSHPs have a positive NPV for multi-family homes, they are less favorable than ASHPs.
- SHW has a positive NPV, but is less favorable than ASHP water heaters, which serve the domestic hot water demand with electricity as an incumbent.
- Biomass is not considered financially favorable through the competition analysis, but we assume that biomass maintains its current share of the demand for space heating and hot water.
- Under current market conditions, none of the RTTs are considered financially favorable to fuel oil or natural gas as the primary energy source, and we assume that the customer keeps or reinvests in the incumbent technology.

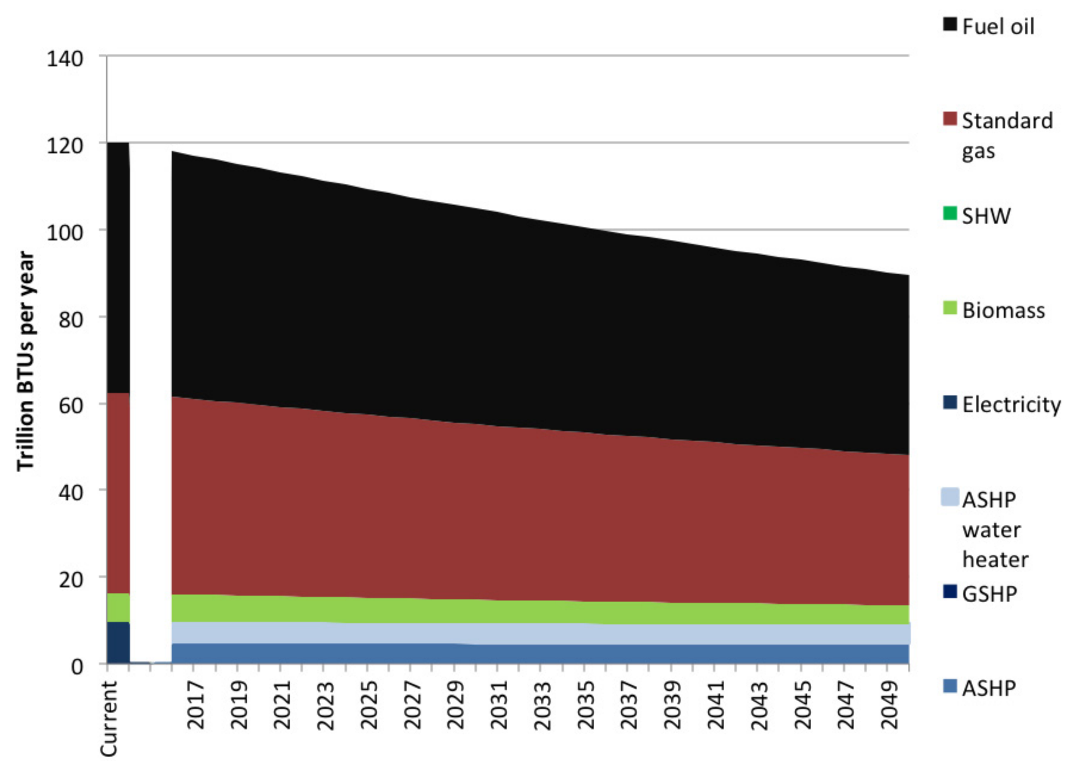


Figure 19 | Preferred thermal technology, excluding highly efficient natural gas boilers. Residential sector.

While energy efficiency is driving total thermal demand down over the period, fossil fuels will continue to dominate as energy sources if relative prices remain the same and customers are allowed to reinvest in incumbent technologies. Cooling is provided by ASHPs, water and space heating by a combination of thermal technologies. As a consequence of increased demand for cooling, the share of RTTs increases to 15 percent by 2050.

SCENARIO 2—EFFICIENT NATURAL GAS INCLUDED

The economic potential of RTTs in the residential sector has been estimated at 11.9 trillion BTUs when highly efficient natural gas is included in the competition analysis. This is 10 percent of the estimated technical potential (see Figure 20).

- In the current market, highly efficient natural gas seems to be the most financially favorable technology for replacing fuel oil and conventional electric technologies for space and water heating.
- Cooling is an additional service that may lead to ASHPs being chosen over efficient natural gas boilers. Cooled space has been used as a key for splitting the relevant part of the market between ASHPs and efficient natural gas boilers.[62]
- The demand for space cooling is served by ASHPs.
- Highly efficient natural gas replaces the demand that currently is served by fuel oil.

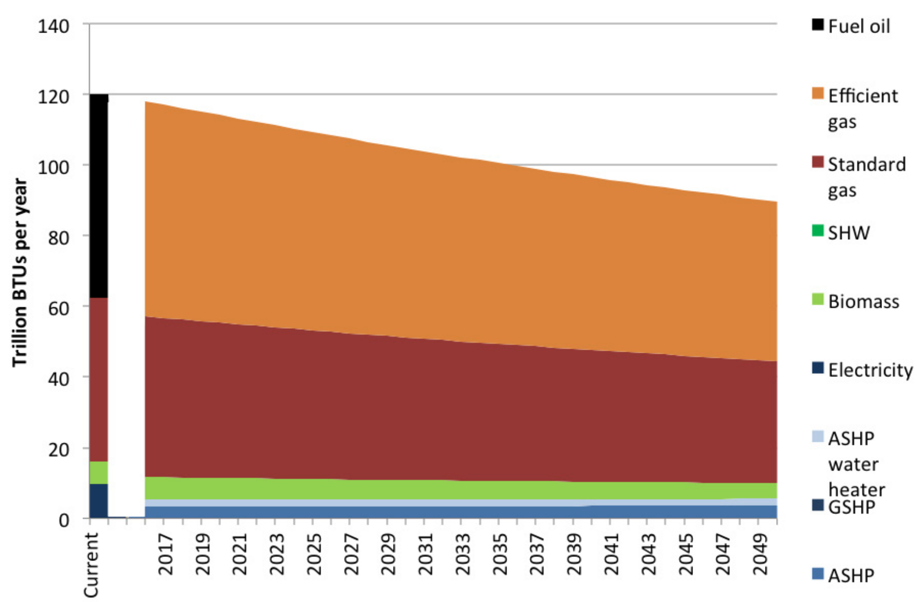


Figure 20 | Preferred thermal technology, including highly efficient natural gas boilers. Residential sector.

62 The cooled area of single-family and multi-family homes is 50% and 41%, respectively (RECS 2009).

Natural gas will be the main energy source when highly efficient natural gas boilers are included in the competition analysis. There are a few elements that have to be taken into consideration in this analysis:

- No connection fees have been included for natural gas grid expansions.
- No costs related to storage and transportation of natural gas have been included.

The economic potential for highly efficient natural gas boilers for customers located far from the existing gas grid may therefore be overestimated.

As a consequence of increased demand for cooling, the share of RTTs increases slightly over the period.

COMMERCIAL SECTOR

The commercial demand for hot water and space heating and cooling is estimated at 49.6 trillion BTUs for 2014. Natural gas was the dominant energy source (70 percent), followed by electricity (14 percent), fuel oil (13 percent), and biomass (3 percent). The total GHG emissions related to the commercial thermal demand have been estimated at 3.5 million tons CO2 equivalents.[63]

SCENARIO 1—COMPETITIVE RTTS HAVE PRIORITY

The economic potential of RTTs in the commercial sector has been estimated to be 15.4 trillion BTUs when highly efficient natural gas boilers are left out of the competition and competitive RTTs have priority. This is 32 percent of the estimated technical potential (see Figure 21).

- ASHPs replace thermal demand for space heating and cooling currently based on conventional electric technologies. Although GSHPs have a positive NPV for *Education* and *Health Care*, they are less favorable than ASHPs.
- SHW has a positive NPV for *Food Service* and *Health Care* and fulfills hot water demand, with electricity as the incumbent.
- With the exception of *Office* buildings, biomass appears to be a financially feasible alternative to fuel oil for space and water heating.
- The current demand served by biomass is assumed to continue being served by biomass.
- We assume that the customer keeps or reinvests in the incumbent technology when none of the RTTs are competitive.

63 Estimations are based on the estimated thermal demand from Chapter 4, the consumption by energy sources from EIA SEDS 2014, the energy by end-use from AEO 2015, the GHG emission factors from Chapter 2, and the efficiency assumptions from Appendix A.

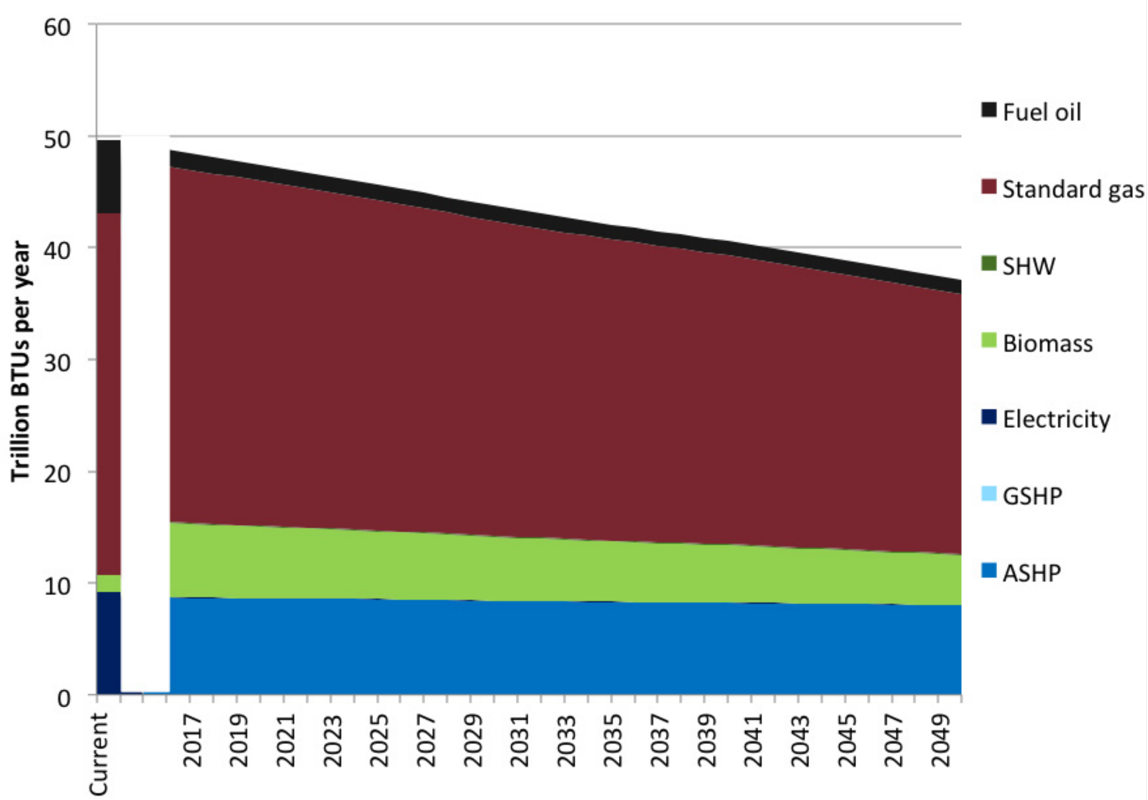


Figure 21 | Preferred thermal technology, excluding highly efficient natural gas boilers. Commercial sector.

While the total thermal demand is expected to be reduced over the period as a consequence of energy efficiency and structural changes, the demand for space cooling is expected to rise due to a warmer climate. As a consequence, the share of RTTs will increase to 34 percent over the period. Natural gas will maintain its dominant position in the commercial sector if the current market conditions prevail. With biomass pellets coming up as a financially favorable alternative to fuel oil, the issue of fuel availability should be investigated. Thin supply chains for biomass pellets may add transportation costs in some areas of the state.

SCENARIO 2—EFFICIENT NATURAL GAS INCLUDED

The economic potential of RTTs in the commercial sector has been estimated to be 10.2 trillion BTUs when highly efficient natural gas boilers are included in the analysis. This is 21 percent of the estimated technical potential (see Figure 22).

- Highly efficient natural gas seems to be the most financially favorable technology for replacing fuel oil and conventional electric technologies for space and water heating.
- Cooling is an additional service that may lead to ASHPs being chosen over efficient natural gas boilers. ASHPs serve the demand for space cooling and space heating currently served by conventional electric technologies.
- Highly efficient natural gas boilers replace the demand that currently is served by fuel oil.
- Biomass is less financially favorable than efficient natural gas boilers, and we assume that biomass maintains it current share of the demand for space heating and hot water.

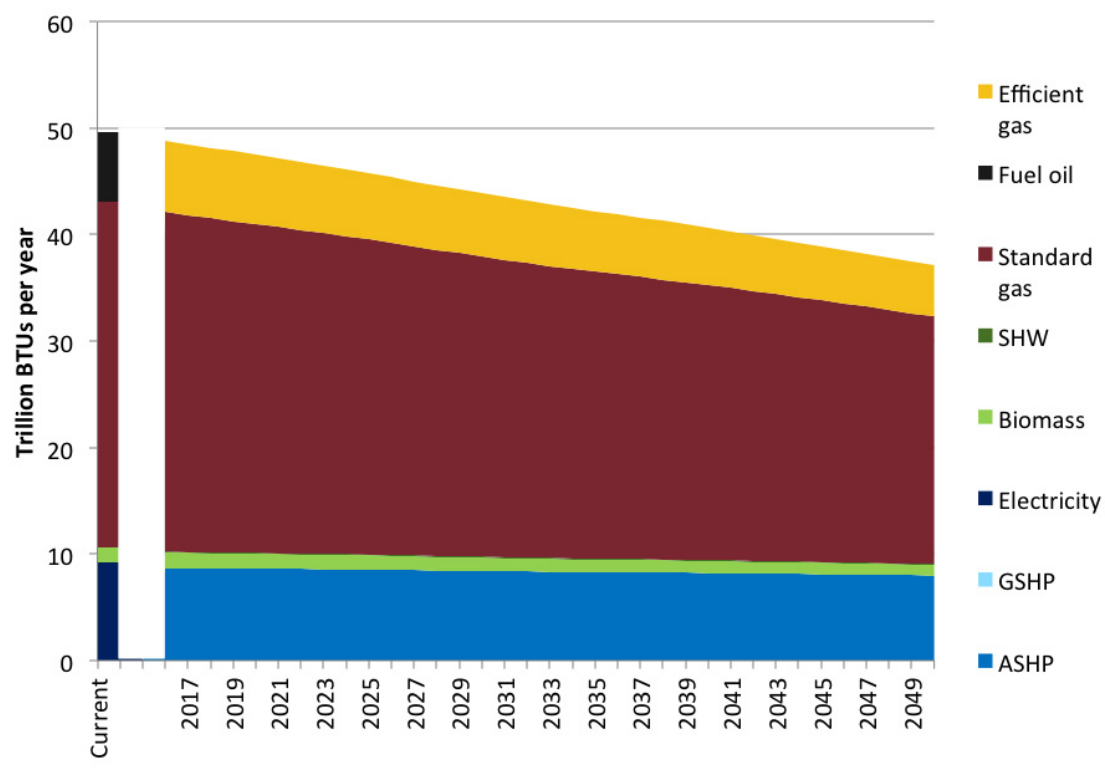


Figure 22 | Preferred thermal technology, including highly efficient natural gas boilers. Commercial sector.

Natural gas will be the dominant energy source when highly efficient natural gas boilers are considered in the financial analysis. Similar to the residential sector, distance to the current natural gas grid would impact the feasibility of highly efficient natural gas boilers replacing fuel oil.

Given the current and assumed market conditions, a considerable share of thermal demand will continue being served by standard natural gas boilers. Due to low natural gas prices and incremental investment costs, existing thermal demand served by standard natural gas boilers may be the most challenging share of thermal demand to turn cleaner absent market interventions.

As a consequence of increased demand for cooling, the share of RTTs increases slightly over the period.

Estimated GHG emissions

The GHG emissions of different combinations of thermal technologies have been estimated for the scenarios described in Table 12.[64]

	THERMAL TECHNOLOGIES		
	Competitive RTTs have priority	**Efficient natural gas boilers included**	**Competitive RTTs have priority, GSHPs replace fuel oil, efficient gas boilers replace standard boilers**
Current electric grid mix (GHG emission factor 0.301 $kgCO_2e$/kWh)	Scenario 1a	Scenario 2a	Scenario 3a
75 % renewable electricity by 2050 (GHG emission factor 0.075 $kgCO_2e$/kWh	Scenario 1b	Scenario 2b	Scenario 3b

Table 12 | Scenarios for combinations of thermal technologies and electricity generation.

- The b-scenarios are based on a gradual change of energy sources in the electricity generation. Achieving 75 percent renewables by 2050 corresponds to the scenarios presented to the Governor's Council on Climate Change on September 8th, 2016.
- Scenario 3 represents a situation in which more RTTs and efficient gas boilers are installed than the competition analysis suggests. The thermal demand is supplied by RTTs where RTTs were found to be competitive in scenario 1. Fuel oil as an energy source is fully replaced by GSHPs, and standard natural gas boilers are replaced by highly efficient natural gas boilers. This scenario would imply replacing incumbent technologies with several technologies that are not competitive at today's prices.

64 For reasons spelled out in footnote 43 in chapter 3.3, DEEP's view is that the GHG emissions reductions that this section associates with biomass combustion are not reliable.

RESIDENTIAL SECTOR

The GHG emissions of the energy sources delivering thermal service to meet current residential demand are estimated to be 9.1 million tons CO_{2e} per year.

Figure 23 shows the estimated GHG emissions related to residential thermal demand through 2050 given different combinations of thermal technologies at the customer end, and different energy sources used for electricity generation.

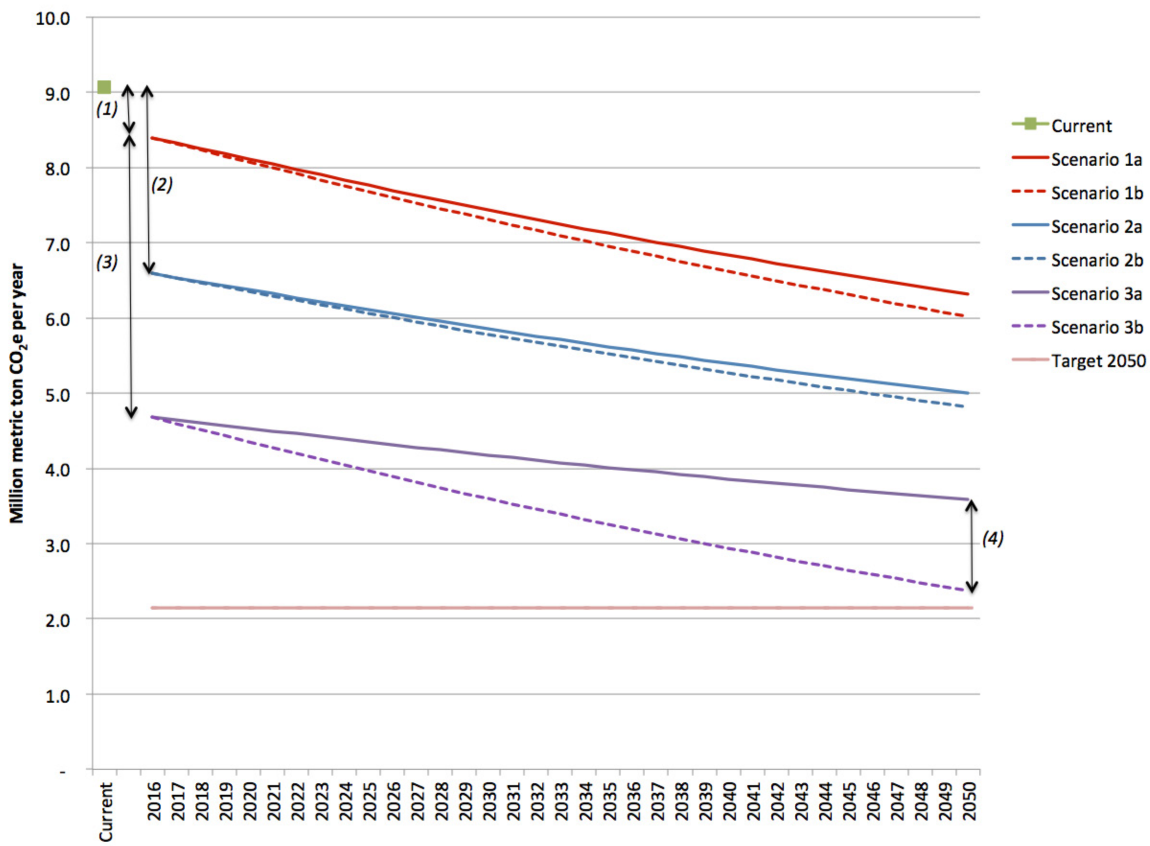


Figure 23 | Estimated GHG emissions for different combinations of thermal technologies. Residential sector.

- Installing all competitive RTTs from scenario 1 would bring an immediate reduction of 0.6 million tons CO_{2e} per year (1). This represents a financially viable but unrealized potential for reduced GHG emissions.
- Installing competitive efficient gas boilers and RTTs, represented by scenario 2, would bring an immediate reduction of 2.4 million tons CO_{2e} per year (2). This represents a financially viable but unrealized potential for reduced GHG emissions.

- Competitive RTTs and an expedited replacement of existing fuel oil and gas boilers with GSHPs and efficient natural gas boilers would reduce the GHG emissions by close to 50 percent of the current levels (3).
- With greater shares of heat pumps, a 75 percent renewable electricity mix would add a reduction of 1.2 million tons CO_2e by 2050 in scenario 3 (4).
- With scenario 3, the GHG emissions in 2050 are estimated at 2.4 million tons CO_2e. An 80 percent reduction of GHG emissions relative to 2001 would represent a target of around 2.1 million tons CO_2e.[65]

Achieving significant emissions reductions requires meeting thermal demand with a combination of a high share of RTTs and cleaner electricity. Replacing standard natural gas and fuel oil boilers with highly efficient natural gas boilers will give immediate GHG reductions, but not enough to achieve long term targets. Market interventions are necessary to realize RTT alternatives with both favorable and unfavorable economics.

65 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from thermal energy demand envisioned here is hypothetical.

COMMERCIAL SECTOR

The GHG emissions of energy sources delivering thermal service to meet current commercial demand are estimated to be 3.5 million tons CO_{2e} per year.

Figure 24 shows the estimated GHG emissions related to commercial thermal demand through 2050 given different combinations of thermal technologies at the customer end, and different energy sources used for electricity generation.

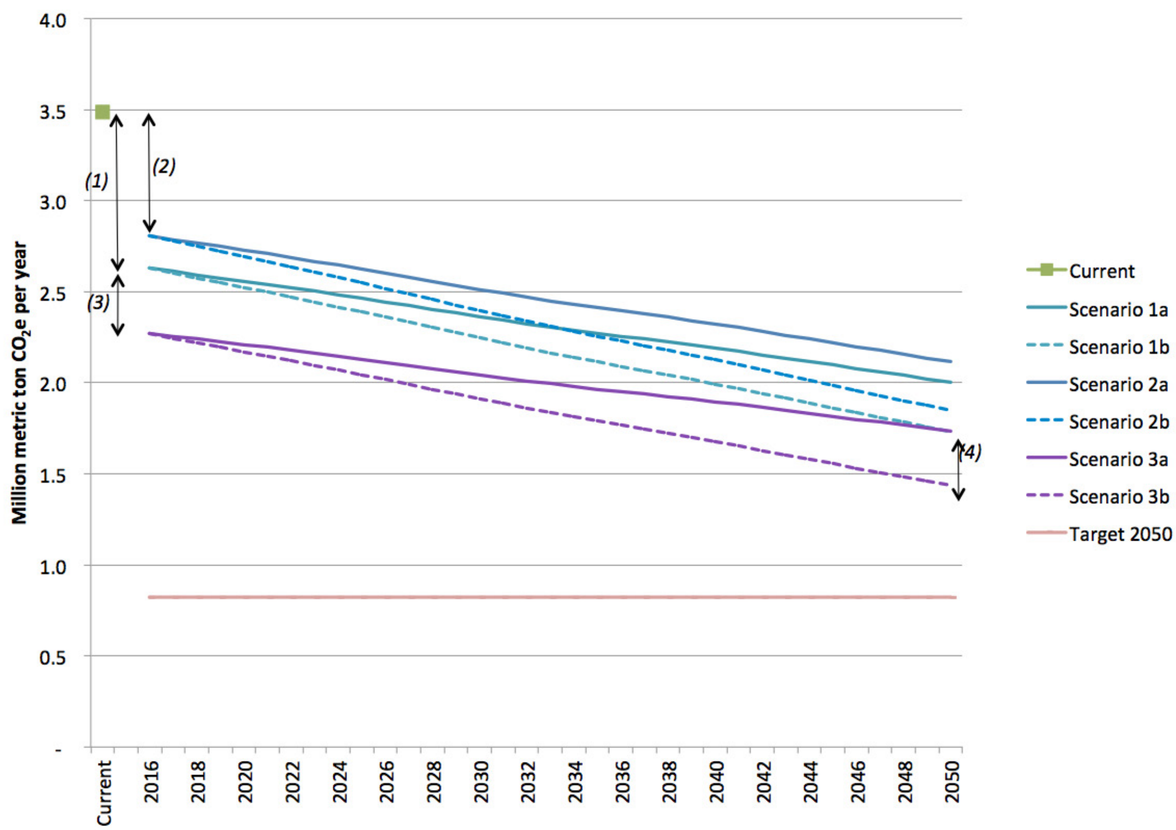


Figure 24 | Estimated GHG emissions for different combinations of thermal technologies. Commercial sector.

- Installing all competitive RTTs from scenario 1 would bring an immediate reduction of 0.8 million tons CO_{2e} per year (1). This represents a financially viable but unrealized potential for reduced GHG emissions.
- Installing competitive RTTs and efficient gas boilers (scenario 2) would bring an immediate reduction of 0.7 million tons CO_{2e} per year (2). This represents a financially viable but unrealized potential for reduced GHG emissions.

- Competitive RTTs and an expedited replacement of existing fuel oil and gas boilers with GSHPs and efficient natural gas boilers would reduce the GHG emissions to close to 65 percent of the current levels (3).
- With greater shares of heat pumps, a 75 percent renewable electricity mix would add a reduction of 0.4 million tons CO_2e by 2050 in scenario 3 (4).
- With scenario 3b, the GHG emissions in 2050 are estimated to be 1.6 million tons CO_2e. An 80 percent reduction of GHG emissions relative to 2001 would represent a target of around 0.8 million tons CO_2e.

While including financially favorable highly efficient natural gas boiler results in the lowest GHG emissions for the residential sector (scenario 2), excluding highly efficient natural gas boilers and allowing financially favorable RTTs to gain ground provides the lowest GHG emissions in the commercial sector (scenario 1). This is due to biomass pellets being financially favorable for commercial customers.[66] The GHG emission factor applied for biomass in this study was 0.036 $kgCO_2e/kWh$.

Realizing significant emissions reductions requires thermal demand to be served by a combination of a high share of RTTs and cleaner electricity. Replacing standard natural gas and fuel oil boilers in the commercial sector with highly efficient natural gas boilers will give GHG reductions, but not enough to achieve long term targets. Market interventions are necessary to realize alternatives both with favorable and unfavorable economics.

Although replacement of standard gas and fuel oil boilers with highly efficient gas boilers represents one of the cheapest means to reduce GHG emissions today, doing so extensively is not sufficient to reach the target and would lock in fossil fuel technologies that could prevent Connecticut from achieving an 80 percent reduction in GHG emissions by 2050. The high share of natural gas boilers in the commercial sector already represents a barrier to RTTs and thus inhibits the state's ability to achieve needed reductions in GHG emissions. Replacing standard natural gas boilers with highly efficient gas boilers and decarbonizing the gas grid by, for example, injecting biogas from anaerobic digestion could supplement market strategies to promote RTTs.

Removing the competitive biomass alternatives from the RTT mix, or applying a higher GHG emission factor, would increase the gap between the target and what the scenarios can achieve.

66 See chapter 3.3 for more information on the GHG emission factors used.

CHAPTER 6
Sensitivity Analysis

We have included sensitivity analyses both to test the solidity of the findings and to analyze the implications of market interventions.

Figure 25 summarizes a set of market interventions to increase the diffusion of RTTs in Connecticut.[67]

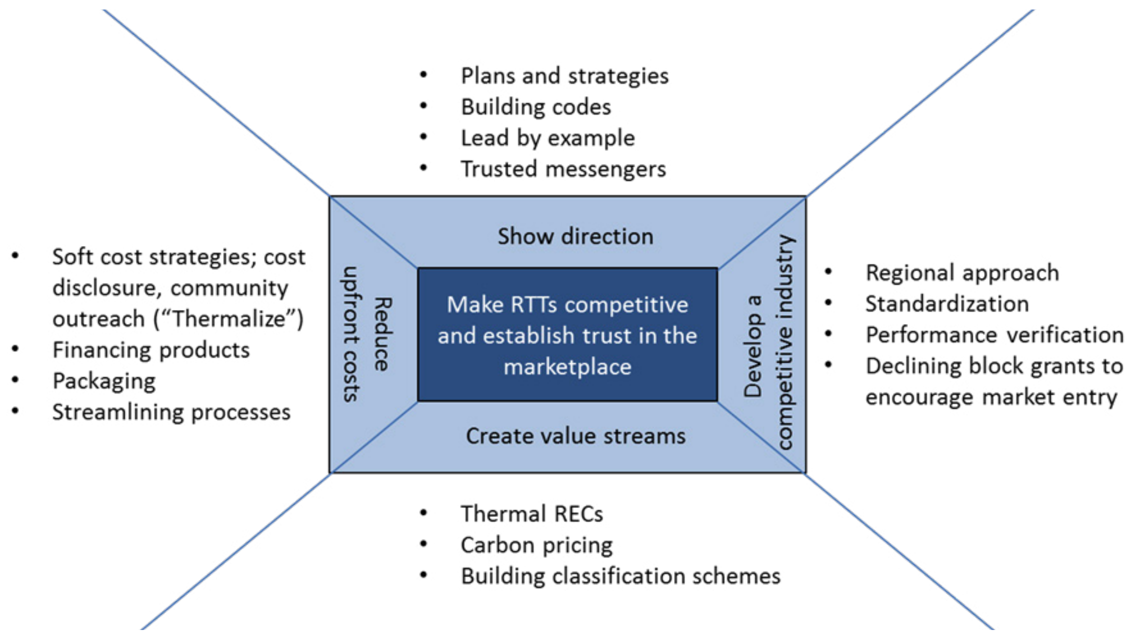


Figure 25 | Market interventions to increase the diffusion of RTTs.

The market interventions in Figure 25 consist of a range of regulatory measures, financial products, and marketing strategies. The analysis of this report focuses on the interventions that can be quantified through costs or revenue streams. However, a combination of regulations, financial incentives, and marketing efforts pulling the same direction will have a larger impact on RTT deployment than stand-alone measures.

The most influential parameters in the sensitivity analysis are incremental initial costs, fuel costs of incumbent case, and fuel costs of proposed case. Which is most influential varies from case to case, but the order of magnitude is typically that shown by Figure 26.

67 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

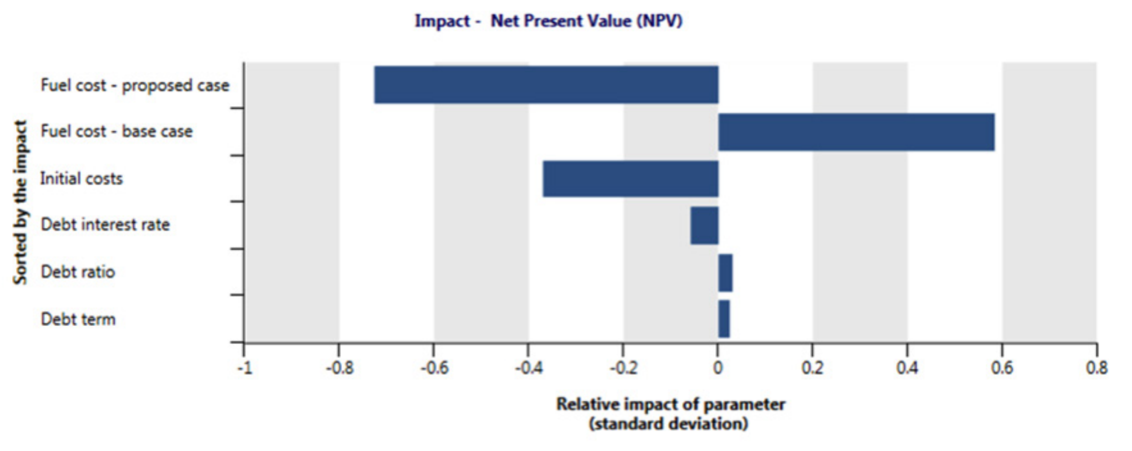


Figure 26 | Relative impacts of parameter from the financial evaluation. Example: ASHP replacing fuel oil in single-family homes.

The general trend presents the overwhelming importance of fuel costs to the competitiveness of the proposed (RTT) versus the base alternative (incumbent technology). Incremental initial costs have the greatest impact in cases including GSHPs, although fuel costs strongly influence even this technology. Overall, debt ratio, debt term, and debt interest rate are of relatively little significance to project economics. However, financial conditions are important for other reasons, such as reducing the upfront costs, shifting customer cash flow, and establish trust in the solution.

The importance of fuel costs in the financial analysis is evident from Figure 27 as well. Taking fuel content and efficiency of heating equipment into consideration, this shows the operating fuel costs of different heating alternatives for residential customers (assumptions in Appendix A).

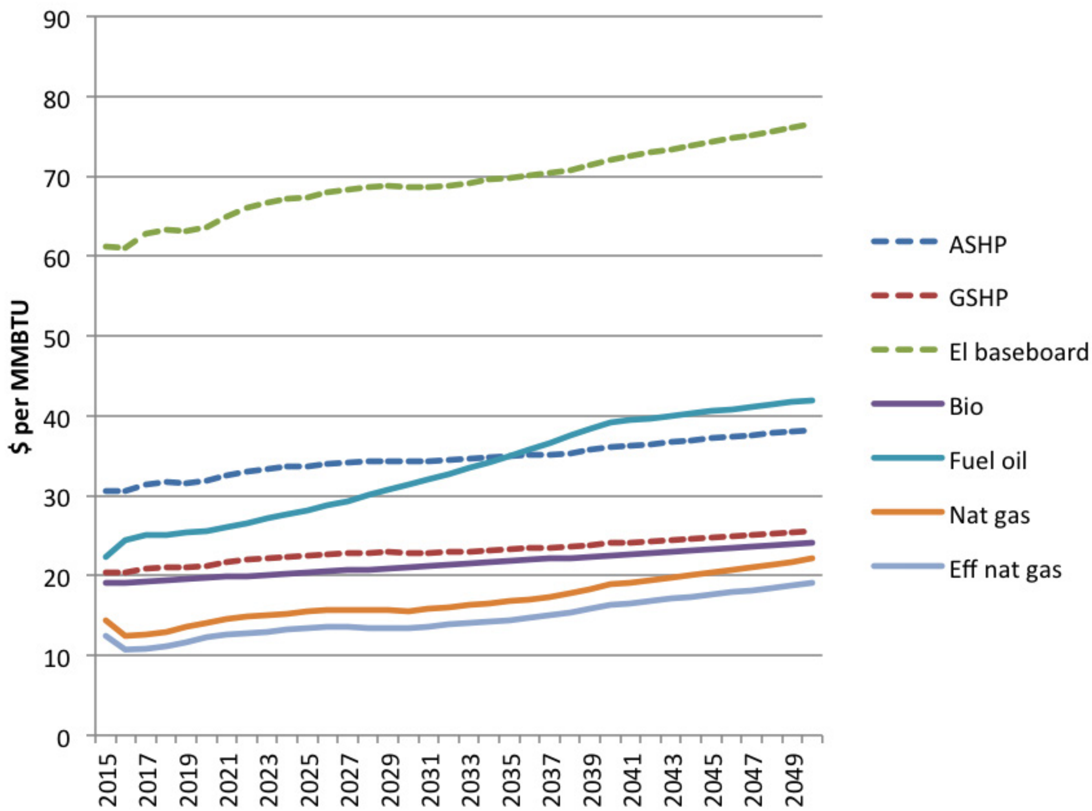


Figure 27 | Projected operational fuel costs for different energy sources for heating technologies (2013 prices). Residential sector.

Electricity for heating is currently considerably more expensive than fuel oil and natural gas, and projections through 2050 continue the trend. In order to pay for the higher installation costs of RTTs, the operational costs have to be proportionately lower for RTTs than for the conventional alternatives. With current price assumptions, operational fuel costs are lower than fuel oil for GSHPs and biomass, but higher than natural gas.

To analyze the most influential parameters and possible market interventions, we have included the sensitivity analysis shown by Table 13.

PARAMETER	DESCRIPTION OF ANALYSIS
6.1 Fuel costs	6.1.1. 50 percent increase of incumbent case
	6.1.2. 100 percent increase of incumbent case
	6.1.3. 25 percent reduction of proposed case
	6.1.4. Solar PV delivers drive energy of proposed case
6.2. Incremental initial costs	6.2.1. 25 percent reduction (whole load installation)
	6.2.2. RTT for partial load (60 percent of capacity and ~80 percent of load)
6.3 Carbon price	Carbon price corresponding to the social cost of carbon
6.4. Thermal Renewable Energy Certificates (TRECs)	TRECs corresponding to market prices
6.5. Financial terms	6.5.1. 25 percent reduction of debt interest rate
	6.5.2. 25 percent increase of debt term, with economic life of asset as maximum debt term
6.6. Sets of simultaneous changes	6.6.1. 25 percent reduction of initial costs, 25 percent reduction of electricity prices for the proposed case due to use of solar PV, 25 percent reduction of pellet prices and a carbon price of $120 per tCO2
	6.6.2. 25 percent reduction of initial costs, 25 percent reduction of electricity prices for the proposed case due to use of solar PV, and a 50 percent increase of incumbent case fuel costs

Table 13 | Sensitivity analysis applied to the financial evaluation of RTTs. Numbering referring to chapter.

For sensitivity analyses 6.1 through 6.6 only one parameter has been analyzed at a time. Sensitivity analysis 6 shows the sensitivity of changing several parameters at a time.

6.1—Fuel Costs

Fuel costs, both for the incumbent and the proposed case, have a large impact on the competitiveness of the RTTs. Change of relative prices are particularly relevant.

Prices of different energy sources have varied extensively over the last 25 years, as shown by Figure 28.

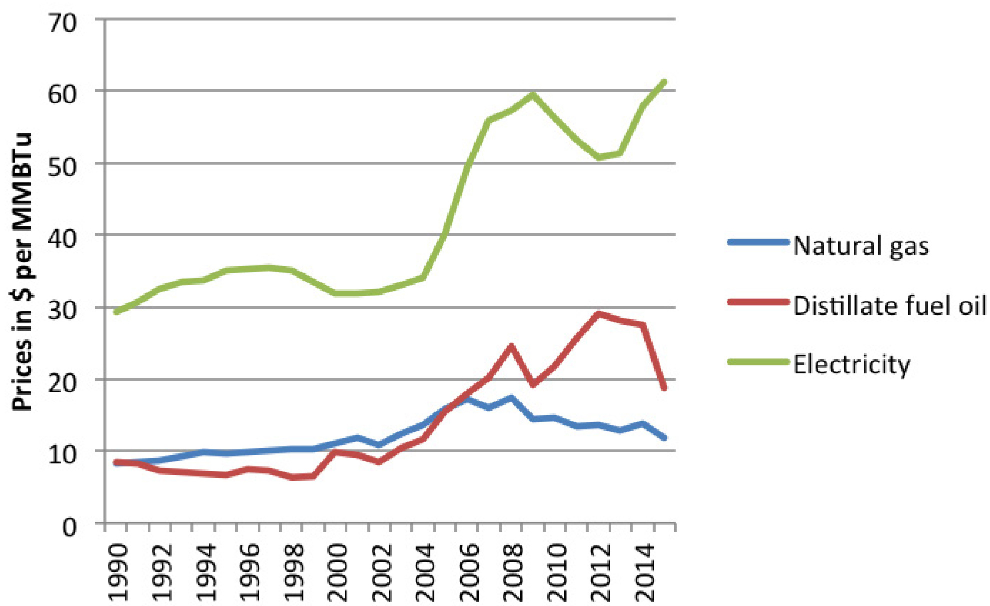


Figure 28 | Annual residential energy prices in Connecticut for the period 2000–2015 (nominal values). Source: EIA SEDS

Figure 28 shows larger price shifts for fuel oil and electricity than for natural gas over the period. Natural gas prices have been lower than fuel oil prices in the residential sector since 2005. The volatility within one year can be considerable as well. In 2015 the monthly residential natural gas prices varied between \$11 and \$21.5 per MMBTU and the weekly residential fuel oil prices varied between \$16.4 and \$25.1 per MMBTU.

As energy prices are volatile and may change considerably over time, we have analyzed the sensitivity of changes in fuel costs.

With the exception of sensitivity analysis 6.1.4—solar PV delivering the drive electricity for the proposed cases—both incumbent and proposed cases have been adjusted for alternatives where the energy source is the same for both cases.

50 PERCENT FUEL COST INCREASE FOR INCUMBENT CASE

Table 14 shows the implication for RTT competitiveness based on a 50 percent increase in fuel costs for the incumbent case.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 14 | Sensitivity analysis for a 50 percent increase of incumbent fuel costs. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of increasing the fuel costs of the incumbent case by 50 percent are

- Heat pumps to replace conventional electric heating and traditional air-conditioning become competitive for all customer categories.
- ASHP water heaters to displace fuel oil for residential hot water become competitive for single-family homes.
- SHW is a competitive alternative to electricity for water heating across all customer segments.
- Biomass for space heating and hot water is competitive with fuel oil in all customer categories.
- Highly efficient natural gas boilers become economically feasible alternatives to standard natural gas boilers. Generally, higher fuel costs makes more energy efficient alternatives using the same fuel attractive.

100 PERCENT FUEL COST INCREASE FOR INCUMBENT CASE

Table 15 shows the implication for RTT competitiveness based on a 100 percent increase in fuel costs for the incumbent case.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 15 | Sensitivity analysis for a 100 percent increase of incumbent fuel costs. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of increasing fuel costs of the incumbent case by 100 percent are:

- Heat pumps become a competitive alternative to fuel oil in many customer segments, including the more expensive heat pump systems.
- Heat pumps to replace conventional electric heating and traditional air-conditioning become competitive for all customer categories.
- ASHP water heaters to displace fuel oil for residential hot water become competitive.
- SHW is a competitive alternative to electricity for water heating and for fuel oil in several customer categories.
- Biomass for space heating and hot water is competitive with fuel oil and standard natural gas boilers in all customer categories.
- Highly efficient natural gas boilers are competitive alternatives to standard natural gas boilers. Generally, higher fuel costs makes more energy efficient alternatives using the same fuel attractive.

25 PERCENT FUEL COST REDUCTION FOR PROPOSED CASE

Table 16 shows the implication for RTT competitiveness given a 25 percent reduction of fuel costs for the proposed case.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 16 | Sensitivity analysis for a 25 percent reduction of fuel costs of the proposed case. Green cells indicate cases with positive NPV in the incumbent case, orange cells indicate cases that turn positive and blue cells indicate cases that turn from positive NPV in base case to negative NPV in the sensitivity analysis.

The main implications of reducing the fuel costs of the proposed case by 25 percent are:

- Replacing conventional electric technologies with heat pumps becomes less attractive when electricity purchased from the grid becomes cheaper. The operational expenses of both the proposed and incumbent case are reduced and the savings are lower.
- Replacing a standard gas boiler with a highly efficient gas boiler becomes less attractive. Lower gas prices will lower the operational expenses of both the proposed and incumbent cases. The benefit of a more efficient boiler is reduced.
- Biomass pellets for space heating and hot water is competitive for fuel oil in all customer categories.

SOLAR PV DELIVERS THE DRIVE ELECTRICITY OF THE PROPOSED CASE

Combining solar PV with electricity-driven RTTs offers an opportunity to reduce both the operational costs of RTTs and the GHG emissions related to the technology. The impact on GHG emissions for residential sector was illustrated in scenario 3b of Figure 23; the impacts on operational fuel costs are illustrated in Figure 29.

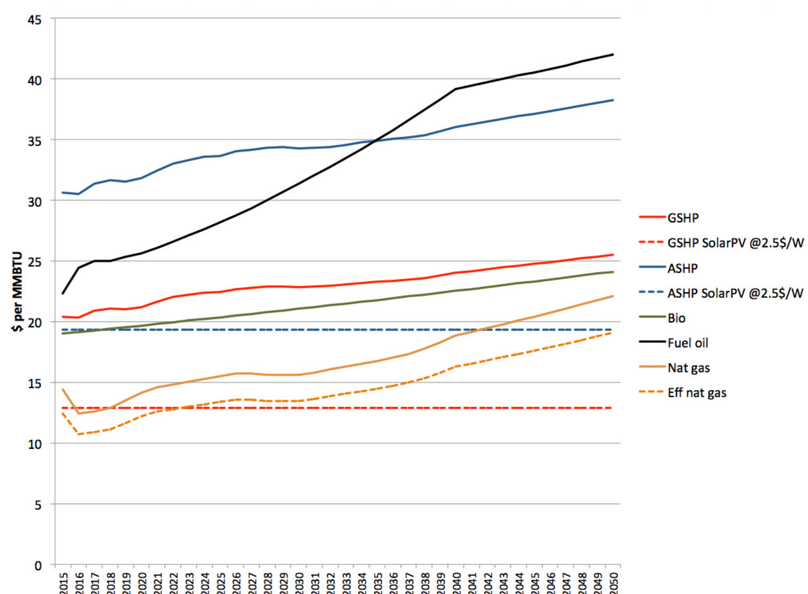


Figure 29 | Projected operational fuel costs for different energy sources for heating technologies. Residential sector.

The Solarize CT campaign,[68] initiated under the SunShot program and championed by the CT Green Bank, is a viable example of a community-based model that aggregates installations and streamlines the supply chain. In 2013, the program reported that since its beginning all participating towns had doubled their solar installations while homeowners saved at least 24 percent on the per-watt cost of

68 http://solarizect.com/

solar PV.[69] The solar PV market currently sees installation costs of $3 per Watt, tax credits taken into consideration.[70] Expectations are that the installation costs of solar PV will continue to drop.

Figure 29 compares the costs of electricity for operating a GSHP on grid electricity versus a solar PV. At installation costs of $2.5 per Watt,[71] GSHPs combined with solar PV have operational fuel costs at levels similar to natural gas. An installation cost of $2.5 per Watt corresponds to a 36 percent reduction of electricity prices.

Table 17 shows the implication for RTT competitiveness of a 36 percent reduction of the electricity costs of heat pumps and SHW as a consequence of bundling with solar PVs installed at $2.5 per Watt.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							

Table 17 | Sensitivity analysis for a combining heat pumps with solar PV at $2.5 per Watt. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

69 http://beccconference.org/wp-content/uploads/2013/12/BECC_gillingham.pdf

70 State incentives of $0.4 per Watt are not included.

71 Solar PV assumes 30 percent tax rebate

Combining solar PV with heat pumps and SHW offers a competitive financial case for the customer, given an expected future cost reduction of the installation of solar PV. The generation profile of the solar PV can influence this result, though, and should be looked into.

6.2—Incremental Initial Costs

High upfront cost appears to be one of the most important barriers to RTTs, both because it reduces the economic feasibility and because it increases the hurdle of mobilizing capital. Market interventions that reduce high upfront costs would have a positive impact on the competitiveness of RTTs, and successful programs and financial incentives influencing on initial costs have been implemented both for RTTs and other technologies:

- The Solarize CT campaign resulted in installation cost reductions of 13 percent as installation costs went from $3.45 to $3 per Watt.
- The HeatSmart Thompson pilot in New York State resulted in an average cost reduction of 20 percent.
- The current CT residential subsidies cover 3–5 percent of the incremental installation costs.
- Solar thermal installations placed in service by end of 2019 are given a tax rebate of 30 percent, after which the size of the credit is ramped down.

25 PERCENT REDUCTION OF INCREMENTAL INITIAL COSTS

The implications of reducing initial costs by 25 percent are shown by Table 18.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 18 | Sensitivity analysis for a 25 percent reduction of initial costs. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of reducing initial costs by 25 percent are:

- Heat pumps are competitive in almost all customer categories, replacing conventional electric technologies for heating and cooling.
- SHW is competitive in all customer categories except Office, replacing electric water heating.
- Biomass for space heating and hot water becomes competitive, replacing fuel oil in residential buildings.
- Highly efficient gas boilers become competitive against standard gas boilers in most customer categories.

RTTS FOR PARTIAL LOAD

To avoid additional complexity in the analysis, RTTs have been modeled to deliver the whole thermal demand of a building. Oversizing RTTs should be avoided both due to installation costs and efficient operations, and keeping the incumbent energy source for peak load operations may offer higher profitability. Partial-load strategies, such as the RTT providing thermal services to parts of the building or during parts of the year have not been included in the general competition and sensitivity analyses.

To gain insight into the economic implications of dimensioning the RTT for partial load, the RTT still being the primary thermal energy source, calculations have been done for residential GSHPs and ASHPs dimensioned for 60 percent of peak heating load. An installed capacity of 60 percent of peak heating load can typically deliver 80 percent of the demand for space heating due to the shape of the thermal demand curve over the year. The incumbent fuel oil boiler is used on the coldest days. The results are indicated by Figure 30 and 31.

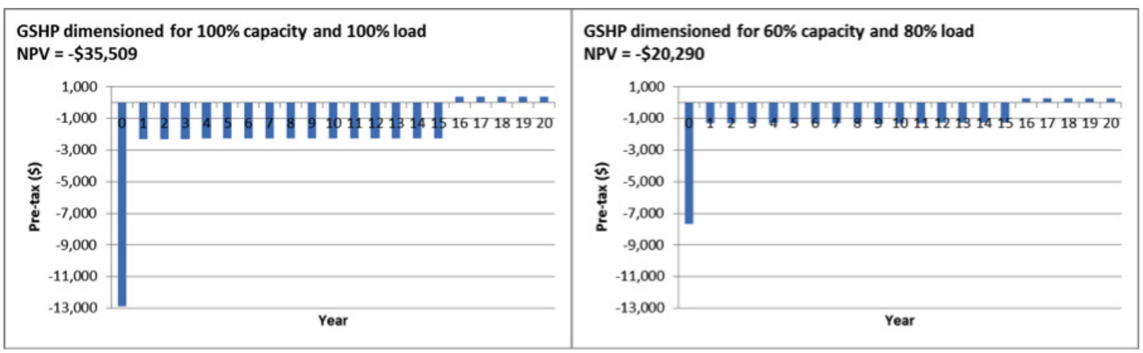


Figure 30 | Net present value and cash flow for a residential GSHP replacing fuel oil for respectively full and partial load.

When dimensioning the residential GSHP for 60 percent of the estimated peak heating load instead of 100 percent, the customer can save on installation costs. This can be seen from Figure 30, as the initial costs of year 0 change from just below $13,000 to $7,600. This case study shows an improvement in NPV of some 40 percent.

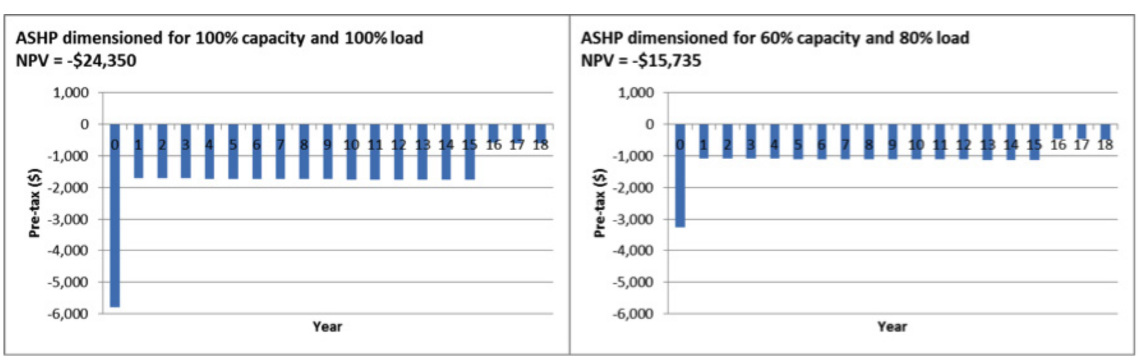


Figure 31 | Net present value and cash flow for a residential ASHP replacing fuel oil for respectively full and partial load.

When dimensioning the residential ASHP for 60 percent of estimated peak heating load instead of 100 percent, the customer can save on installation costs. This can be seen from Figure 31, as the initial costs of year 0 change from just below $6,000 to just above $3,200. The case studied shows an improvement in NPV of some 35 percent.

Allowing for strategies where the RTT is supplemented by the incumbent thermal technology at peak thermal demand will often improve the financial case.

6.3—Carbon Pricing

"The "social cost of carbon" (SCC) is a concept that reflects the marginal external costs of emissions; it represents the monetized damage caused by each additional unit of carbon dioxide, or the carbon equivalent of another greenhouse gas, emitted into the atmosphere." [72]

Many countries have begun accounting for the SCC in regulatory decisions and implementing market mechanisms to incentivize individuals and organizations to consider the full costs of their action on society. Examples include carbon taxes, or cap-and-trade systems, like the Regional Greenhouse Gas Initiative (RGGI) of the Northeast and Mid-Atlantic States of U.S. and the European Emissions Trading System (EU ETS).

The EPA and other federal agencies use the SCC to estimate regulatory climate benefits.[73] In our study we have included a carbon price corresponding to the EPA SCC with a 3 percent discount rate:

- A carbon price of $41 per metric ton CO_2e[74]
- The carbon price is applied over the whole lifetime of the asset
- An annual escalation rate of 1.9 percent

Table 19 shows the implication for RTT competitiveness of a carbon price as described above.[75]

72 Kotchen, Matthew J. (2016): Which social cost of carbon? A theoretical perspective. National Bureau of Economic Research, Working Paper 22246

73 https://www.epa.gov/climatechange/social-cost-carbon

74 United States central estimate for 2015 (Interagency Working Group 2013)

75 For reasons spelled out in footnote 43 in Chapter 3.3, DEEP maintains that the cost-competitiveness benefits described here as accruing to biomass from SCC are not reliable.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 19 | Sensitivity analysis for a carbon pricing alternative. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of a carbon price corresponding to the SCC are:

- Biomass pellets to replace fuel oil for space heating and hot water will be competitive across all customer categories.
- Heat pumps to replace conventional electric technologies for space heating and cooling will be competitive in a few additional customer categories.

The influence on the economics of RTTs depends on the set value of the carbon price, but it is undoubtedly a positive point of leverage for changing the relative operational fuel costs in favor of low-emitting technologies. However, the carbon price has to be around $90 per metric ton CO_{2e} to have the same impact on the competitiveness of RTTs in the analyzed customer segments as a 25 percent increase in fossil fuel prices.

6.4—Thermal Renewable Energy Certificates

The electric supply and distribution companies in Connecticut are mandated to meet a Renewable Portfolio Standard (RPS) requirement of 27 percent renewable electricity generation by 2020. The RPS generally does not create Renewable Energy Credits (RECs) for renewable thermal energy.

While a carbon price assigns a cost on the use of polluting technology, a REC awards the use of clean technologies and establishes an avoided cost of carbon. As of April 2016, 12 states have included renewable thermal technologies in their RPS, with variations over which technologies have been included, how performance is measured and monitored, how the thermal energy is valued, and how it is classified in the RPS.[76]

Regionally, New Hampshire has created a separate sub-category for RTTs in its RPS: TRECs. Electricity producers are now required to generate or acquire equivalent thermal RECs as part of their renewable energy portfolio. Massachusetts has created an Alternative Energy Portfolio Standard (APS) generating Alternative Energy Credits (AEC) for a range of RTTs. Massachusetts' APS is distinct from the RPS, but essentially acts as a separate tier.

76 http://www.cesa.org/assets/Uploads/Renewable-Thermal-in-State-RPS-April-2015.pdf

In our study we have included a TREC based on the experience of New Hampshire:

- One TREC is valued as the equivalent of 1 MWh. The drive energy of heat pumps is deducted in determining the TREC
- A TREC is priced at $25 per MWh[77]
- TRECs are given for a period of 15 years
- The TREC price escalates at an annual rate of 1 percent

Providing a monetary incentive under a state RPS requirement could influence the economics of RTTs and offer incentives to utilize resources across businesses.

Table 20 shows the implication for RTT competitiveness of a TREC, as described above.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							

77 The rate of TRECs in New Hampshire, as of 2016 is $25/MWh. http://www.puc.state.nh.us/sustainable%20energy/renewable_portfolio_standard_program.htm

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 20 | Sensitivity analysis for a TRECs alternative. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The influence on the competitiveness of RTTs depends on the value of the TREC, but it is undoubtedly a positive point of leverage to change the relative operational fuel costs in favor of low-emitting technologies. The impact on the competitiveness of RTTs of a TREC of $25 per MWh seems to be similar to a carbon price of $41 per metric ton CO_2e in our analysis.

Representing technologies that can be measured with some degree of certainty, TRECs not only can be an instrument to fund larger installations, such as thermal loops and industrial fuel switching, but smaller projects through aggregation. Including TRECs would equate renewable energy from thermal technologies with renewable energy from electricity generation, which would make private investors optimize between thermal and electrical energy.

6.5—Financial Terms

Financial terms can reduce barriers to RTTs such as high upfront costs, financing costs, awareness, and risk through trust in the technology. This can involve low interest rates, longer debt terms, and conditions to make the investment cash flow positive for the customer.

Table 21 shows the impact of a reduction of the debt interest rate by 25 percent, from 3.5 to 2.6 percent, in the residential sector, and from 4 to 3 percent for commercial customers (with a 15-year debt term). As a comparison, the current interest rate of a residential Smart-e loan is 2.99 percent over 10 years, and 5 percent over 10 years for commercial PACE.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 21 | Sensitivity analysis for a 25 percent reduction of debt interest rates. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

Table 22 shows the impact of an increase of debt term by 25 percent, limited by the economic life of the asset.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 22 | Sensitivity analysis for an increase of debt term. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

From a purely economic point of view, the implication of reducing the debt interest rate and increasing the debt term seems to be small. Reducing the debt interest rate makes biomass competitive in the residential sector and ASHPs with ductwork competitive in additional commercial segments.

Although not the most impactful parameters on NPV, financial terms matter to the customers for other reasons. Favorable financing terms through a recognized organization:

- reduce the risk for private lenders, and the project can achieve lower rates on other loans.
- give attention and credibility to the technology.
- qualify the technology as an environmentally friendly technology.

6.6—Sets of Simultaneous Changes

Larger market impact and probability for success can be achieved through intervention on several parameters at a time. The impact of sets of simultaneous changes has been analyzed for the following packages of measures and technologies.

PACKAGE 1:
INCREMENTAL INITIAL COSTS, FUEL COSTS, AND CARBON PRICE

- Incremental initial costs 25 percent lower
- Solar PV reduces electricity costs of heat pumps and SHW by 25 percent
- Pellets prices 25 percent lower
- Carbon price of $120 per tCO_2

PACKAGE 2:
INCREMENTAL INITIAL COSTS, SOLAR PV, AND INCREASED FOSSIL FUEL COSTS

- Incremental initial costs 25 percent lower
- Solar PV reduces electricity costs of heat pumps and SHW by 25 percent
- Fossil fuel costs 50 percent higher

Table 23 shows the impact of changing several variables at the same time: initial costs, solar PV, lower pellet prices, and a carbon price. Table 24 shows the impact of changing several variables at the same time: initial costs, solar PV, and increased fuel costs for the fossil fuels.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 23 | Sensitivity analysis for sets of simultaneous changes in initial costs, solar PV for heat pumps, and carbon price. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 24 | Sensitivity analysis for sets of simultaneous changes in initial costs, solar PV for heat pumps, and increased fuel costs incumbent case. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

- Combinations of market interventions are necessary to make heat pumps competitive against fuel oil.
- Natural gas is persistently the most economically favorable alternative for space and water heating.

6.7—Implications for Cash Flow

Net present value, payback, and internal return will indicate to what extent a project is economically favorable. As the future is uncertain, the implications on cash flow may be more interesting for the customer than NPV: How much money will I have to pay "net out of pocket" annually with this alternative compared to that? This can be illustrated with the single-family home category replacing conventional electric technologies with GSHPs for space heating and cooling, as shown by Figure 32. The cash flow over the lifetime of the project (20 years) is shown for 4 cumulative steps:

1. The base case analysis for the single-family home installing a GSHP for space heating and cooling instead of conventional electric heating and traditional air conditioning shows a positive NPV of $5,600. However, due to a 70 percent loan ratio, the customer has an initial cash payment of around $14,000 that has to come from his or her savings.

2. If, however, the initial incremental installation costs had been 25 percent lower, e.g. as a consequence of a grant, a "Thermalize" campaign, combinations of both, etc., the project would be economically more favorable and the initial cash payment would be $3,500 lower than for the base case. The customer would need 25 percent less savings to quality for a loan requiring 30 percent equity.

3. If, in addition to the 25 percent lower initial incremental installation costs, the customer had leased a solar PV installation at a rate 25 percent lower than the electricity prices from the electric grid, the GSHP would be considerably more economically favorable. The customer would be able to benefit from lower operational costs without increasing the need for raising capital upfront.

4. All prior steps imply that the customer has to raise capital upfront as the project is funded at a 70 percent debt ratio. Not all customers are able or willing to invest large amounts upfront, e.g. because they do not have the capital, they prefer constant and predictable payments, or they do not know how long they will stay in the house. The design of financial products, such as leasing, EPC, PACE, and on-bill financing, can overcome these barriers. As can be seen from the 100 percent debt ratio case, the cash-flow has shifted to positive for all years. The annual net benefit is somewhat lower for case 4 than case 3, but still favorable with a positive NPV.

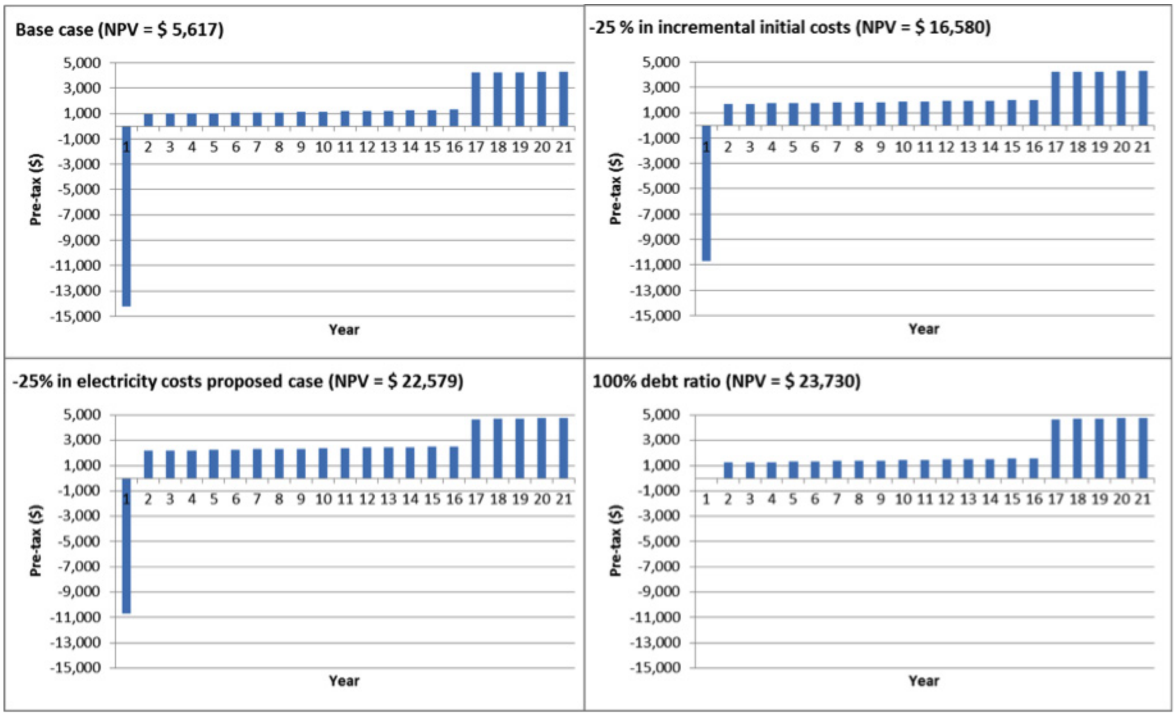


Figure 32 | Cash flow analysis. Single-family home replacing electricity with GSHP for space heating and cooling.

This example shows how combinations of marketing campaigns, financial products, and energy technologies can contribute to the attractiveness of RTTs.

CHAPTER 7
Recommendations

The market potential for RTTs remains considerable through 2050, and a high RTT deployment rate is needed to achieve the 2050 GHG emission targets. Several RTTs are currently challenged by unfavorable economics and non-economic barriers. To bring the market for RTTs to a scale capable of providing major contributions to reducing GHG emissions, a bundle of measures is needed.

While the companion field study[78] recommends a wide range of strategies and measures to break down barriers and build up drivers, the following recommendations focus specifically on market interventions directly targeting the technical potential and financial competitiveness of RTTs.

1. **Reduce upfront costs.** Initial installation costs have large impacts on RTT economics and how much capital the customer has to raise upfront. Initial installation costs are higher for RTTs than for the alternatives, and lower initial installation costs would considerably enhance favorability. The following market strategies would contribute to reducing the barrier of high upfront costs:
    - Cost reduction campaigns à la Solarize[79] that make RTTs more competitive with conventional thermal technologies, as shown in 6.2.1.
    - Partial-load strategies: using RTTs to displace most of the thermal demand for space heating but not requiring them to cover 100 percent of the capacity needed for the peak demand generally improves the financial evaluation, as shown in 6.2.2.
    - New business and financing models removing upfront costs and securing 100 percent financing: loans, leases, and property assessed clean energy (PACE) financing. This is illustrated by the cash-flow analysis in 6.7, where the need to raise money up front is leveled out.

2. **Implement market interventions to improve the operational cash flow.** The analysis shows that fuel costs have a large impact on the financial feasibility of RTTs. Strategies to reduce the operational costs of RTTs relative to the alternatives using fossil fuels would favor the cleaner technologies; so would strategies to establish revenue streams:
    - Packaging RTTs with solar PV and deep renovation may improve the economics, as shown solar PV in 6.1.4.
    - Favorable financing—interest rates and debt term—that reduces risk for private lenders, gives credibility to the technology, and qualifies it as environmentally friendly. This has been discussed in 6.5.

78 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

79 Solarize CT is a community-based program that leverages social interaction to promote the adoption of solar through a group-pricing scheme to reduce soft costs.

- Carbon pricing, as discussed in 6.3, would provide leverage for changing the relative operational fuel costs in favor of RTTs.
- Thermal Renewable Energy Certificates (TRECs), discussed in 6.4, reward the use of clean technologies much as a carbon price would.
- Explore rate mechanisms that recognize the value of RTTs in reducing demand for natural gas and electricity.

3. **Enhance awareness of—and trust in—RTTs through marketing efforts, trusted messengers, and proven installations.** Strategies include:
   - Performance verification through metering and monitoring to show that the technologies deliver as promised. Over- or underperformance would have implications similar to those illustrated by the fuel cost sensitivities discussed in 6.1. Performance verification would facilitate new revenue streams and business models, such as Thermal Renewable Energy Certificates, third-party ownership, green bonds, and Energy Performance Contracts. The level of required accuracy would influence the additional cost. We recommend evaluating the cost-benefits of various methods for performance verification with respect to the purpose it will serve, differentiated by customer segments.
   - Green Bank involvement, which enhances credibility, as discussed in 6.5.
   - Declining block grants[80] enhance the competitiveness of RTTs through a reduction of the incremental initial costs, as shown by Chapter 6.2.1.

4. **Use the building code and building standards to establish a predictable minimum market for RTTs.** In addition to stricter requirements for the building envelope (see Chapter 4), which eventually will favor low-temperature solutions such as heat pumps, the code can signal clearly which energy systems to install and which to avoid in new buildings. This will help attain the GHG emission targets as discussed in 5.3, and we recommend evaluating the possibilities of using the building code to:
   - Avoid oil boilers in new construction.
   - Establish a minimum efficiency level for fossil fuel boilers.
   - Require a share of renewable heating and cooling in new construction.

This market potential study has not evaluated the feasibility of district energy. District energy and thermal grids may represent opportunities for cheap and clean thermal energy, exploiting waste energy from electricity generation and industrial processes. The field study on barriers and drivers does provide some recommendations to promote thermal grids.

80 Declining block grants are grants and rebates that decrease over a certain time period according to a pre-determined profile.

This study has revealed some areas where further research could be valuable:

- An evaluation of where limited bioenergy resources would bring the highest value: transportation, electricity generation, or heating buildings and processes.
- A quantification of GHG emission factors across all energy sources specific for Connecticut or New England.
- Demand and generation profiles of different energy technologies and their interaction with the electricity and natural gas grids.

Appendices

APPENDIX A
Assumptions for the Competition Analysis

Building Size and Efficiency

		RESIDENTIAL		COMMERCIAL				
		SINGLE FAMILY	APARTMENT	HOTEL	OFFICE	HOSPITAL	EDUCATION	FOOD SERVICES
Building size (sq ft)[1]		2000	29063	119479	48438	201554	38750	5651
Energy Use Intensities (MBTU/ year/ sq ft)[2]	**Space heating**	46.4	58.5	25.8	33.4	112.7	61.5	58.9
	Space cooling	1.4	1.7	1.7	7.1	10.4	3.1	3.5
	Hot water	5.6	7.3	31.7	3.3	39.6	7.2	31.1
Peak load (kW)[3]	**Space heating**	15	328	637	363	4383	427	83
	Space cooling	1	20	82	126	468	59	7
	Hot water	4	86	841	30	1489	80	48
Annual demand (MMBTUs)[4]	**Space heating**	79	1701	3081	1618	22722	2385	333
	Space cooling	3	49	199	344	2086	120	20
	Hot water	11	213	3787	162	7978	280	176

Table 25 | Building Size and Efficiency

1. The average building size of different categories have been informed by the Connecticut Program Savings Document for 2016, RECS 2009, and CBECS 2003.
2. The Energy Use Intensities have been informed by the Connecticut Program Savings Document for 2016, RECS 2009, and CBECS 2003 (adjusted for the energy efficiency rate from the reference case of the Annual Energy Outlook 2015).
3. The peak load has been elaborated based on the estimated annual thermal demand and hours of utilization time from the Connecticut Program Savings Document for 2016.
4. The annual demand has been estimated based on the building size and the EUIs.

The following dimensioning rules have been applied to the case studies:

- For technologies delivering both space heating and hot water, the peak load for space heating has generally defined the installed capacity. The installation costs for the largest users of hot water—Food Service, Health Care, and Hotel—have been increased by 50 % of the needed capacity to capture hot water.
- For technologies delivering both space heating and cooling, the peak load for space heating has defined the installed capacity.

Cost and Efficiency Assumptions

TECHNOLOGY	SECTOR	INSTALLED COST PER KW ($/KW)[1]	EFFICIENCY[2]	FUEL BTU CONTENT[3]	FUEL COSTS[4]	FUEL COST ESCALATOR[5]	PROJECT LIFE[6]	COMMENT
Natural gas (standard)	Residential	255	82%	1028 Btu/ft3	11.82 $/ thousand ft3	1.6%	20	
	Commercial	255	82%		8.18 $/ thousand ft3	1.6%	30	
Natural gas (highly efficient)	Residential	470	95%		11.82 $/ thousand ft3	1.6%	As proposed case	
	Commercial	470	95%		8.18 $/ thousand ft3	1.6%		
Ductwork[7]	Residential	560						
	Commercial	660						
Electric water heater	Residential	500 $/unit	0.71 energy factor	3412 Btu/kWh	0.209 $/kWh	0.6%	10	
	Commercial							
Electric cooling	Residential	320	SEER 13	3412 Btu/kWh	0.209 $/kWh	0.6%	As proposed case	
	Commercial	320	EER 11		0.1595 $/kWh	0.6%		
Fuel oil	Residential	255	84%	0.1371 mmBtu/gal	1.96 $/gal	0.7%		
	Commercial	255	84%		1.96 $/gal	0.7%		
ASHP	Residential	1100	200% for heating. 18 SEER	3412 Btu/kWh	0.209 $/kWh	0.6%	18	
	Commercial	1100	200% for heating. 18 SEER		0.1595 $/kWh	0.6%	18	
ASHP water heater	Residential	1100 $/unit	2.0 energy factor		0.209 $/kWh	0.6%	10	
	Commercial					N/A	N/A	
GSHP	Residential	2110	300% for heating / cooling 15.1 EER (22.61 SEER)	3412 Btu/kWh	0.209 $/kWh	0.6%	20	
	Commercial	2010	300 % for heating / cooling 15.1 EER (22.61 SEER)		0.1595 $/kWh	0.6%	25	
Biomass pellets	Residential	920	80%	7750 Btu/lb	$260 / ton	260	20	Storage included
	Commercial	790	85%		$230 / ton	230	25	
SHW	Residential	960 $/ m2 aperture	2.5 SEF	0.35 kWh/ ft2/day	0.209 $/kWh	0.6%	20	
	Commercial	1440 $/m2 aperture	2.5 SEF		0.1595 $/kWh	0.6%	20	

Table 26 | Installation costs, efficiency, fuel BTU content, fuel prices, and project life per technology

1. The installation costs have been informed by regional project data provided by the CT Green Bank, Massachusetts Clean Energy Center, New Hampshire Public Utilities Commission, Vermont Public Services Department, and the Northern Forest Center. In addition, we have consulted the RETScreen cost database, the report "Massachusetts renewable heating and cooling opportunities and impacts study" (Meister Consulting Group 2012), and the report "Research on the costs and performance of heating and cooling technologies" (Sweett, 2013). See Appendix C.
2. The efficiencies of different technologies have been informed by the CT Program Savings Document, the RETScreen database, Massachusetts Clean Energy Center central biomass program, and Energize CT.
3. The fuel BTU content is from the Annual Energy Outlook 2015.
4. The fuel costs have been informed by the Energy Information Agency SEDS and the regional project portfolio.
5. The fuel costs escalators have been derived from the reference case of the Annual Energy Outlook 2015.
6. The project life of different technologies has been informed by the CT Program Savings Document 2016 and the Annual Energy Outlook 2015. The project life for the incumbent technology follows the project life of the proposed technology in our financial calculations.
7. The term "Ductwork" is used for all necessary retrofit of thermal infrastructure.

TECHNOLOGY	SECTOR	INCREMENTAL COST OVER INCUMBENT ALTERNATIVE ($/KW) OR ($/M2 APERTURE)			
		NATURAL GAS	ELECTRIC	FUEL OIL	AC
Natural gas (highly efficient)	Residential	215	1030	215	
	Commercial	215	1030	215	
ASHP no ductwork	Residential	1100	1100	1100	-320
	Commercial	1100	1100	1100	-320
ASHP ductwork	Residential	1660	1660	1660	-320
	Commercial	1760	1760	1760	-320
ASHP water heater	Residential	600 /unit	600 /unit	600 /unit	
	Commercial				
GSHP	Residential	2415	2670	2415	-320
	Commercial	2415	2670	2415	-320
Biomass pellets	Residential	665	1480	665	
	Commercial	535	1450	535	
SHW	Residential	960	960	960	
	Commercial	1440	1440	1440	

Table 27 | Incremental installation costs per installed kW, unit or aperture

PROPOSED TECHNOLOGY	BASE TECHNOLOGY	RESIDENTIAL ($PER UNIT)		COMMERCIAL ($PER UNIT)				
		SINGLE FAMILY	APARTMENT	HOTEL	OFFICE	HOSPITAL	EDUCATION	FOOD SERVICES
Natural gas (highly efficient)	Electricity	18,437	337,903	719,484	410,082	4,952,593	482,277	94,108
	Natural gas	3,849	70,533	136,893	78,024	942,308	91,761	17,905
	Fuel oil	3,849	70,533	136,893	78,024	942,308	91,761	17,905
ASHP no ductwork	Electricity	19,333	359,660	674,065	358,777	4,671,453	450,465	89,391
	Natural gas	19,333	359,660	674,065	358,777	4,671,453	450,465	89,391
	Fuel oil	19,333	359,660	674,065	358,777	4,671,453	450,465	89,391
ASHP ductwork	Electricity	29,357	543,375	1,094,294	598,294	7,564,119	732,149	144,356
	Natural gas	29,357	543,375	1,094,294	598,294	7,564,119	732,149	144,356
	Fuel oil	29,357	543,375	1,094,294	598,294	7,564,119	732,149	144,356
ASHP water heater	Electricity	600						
	Natural gas							
	Fuel oil							
GSHP	Electricity	47,794	875,923	1,700,019	968,955	11,702,146	1,139,538	222,361
	Natural gas	42,871	791,061	1,511,340	835,996	10,434,870	1,011,698	198,906
	Fuel oil	42,871	791,061	1,511,340	835,996	10,434,870	1,011,698	198,906
Biomass pellets	Electricity	26,492	485,530	923,231	526,211	6,355,098	618,850	120,758
	Natural gas	11,904	218,161	340,641	194,154	2,344,812	228,334	44,555
	Fuel oil	11,904	218,161	340,641	194,154	2,344,812	228,334	44,555
SHW	Electricity	5,135	117,642	1,732,342	65,578	3,065,587	169,409	99,101
	Natural gas	5,135	117,642	1,732,342	65,578	3,065,587	169,409	99,101
	Fuel oil	5,135	117,642	1,732,342	65,578	3,065,587	169,409	99,101

Table 28 | Incremental installation costs per installed system

	END USES	DUCTWORK NECESSARY	STATUS OF TECHNOLOGY	DISPLACES EXISTING TECHNOLOGY
Natural gas (highly efficient)	Space heating; Hot water	No	Primary	Yes
ASHP no ductwork	Space heating; Space cooling	No	Supplementary	Incumbent as back up
ASHP ductwork	Space heating; Space cooling	Yes	Supplementary	Incumbent as back up
ASHP water heater	Hot water	No	Primary	Yes
GSHP	Space heating; Space cooling	Yes	Primary	Yes
Biomass pellets	Space heating; Hot water	No	Primary	Yes
SHW	Hot water	No	Primary	Yes

Table 29 | Summary of assumptions determining incremental installation costs

	RESIDENTIAL		COMMERCIAL					IND
	SINGLE FAMILY	APARTMENT	HOTEL	OFFICE	HOSPITAL	EDUCATION	FOOD SERVICES	BAKERIES
Depreciation rate[1]	5.2%	5.2%	4.9%	5.8%	4.6%	5.4%	4.5%	4.7%
Debt interest rate[1]	3.5%	3.5%	3.5%	3.5%	3.5%	4.0%	3.5%	3.5%
Debt ratio	70%	70%	70%	70%	70%	70%	70%	70%
Inflation	2%	2%	2%	2%	2%	2%	2%	2%
Debt term	15 years	15 years	15 years	15 years	15 years	15 years	15 years	15 years

Table 30 | Summary of assumptions determining incremental installation costs

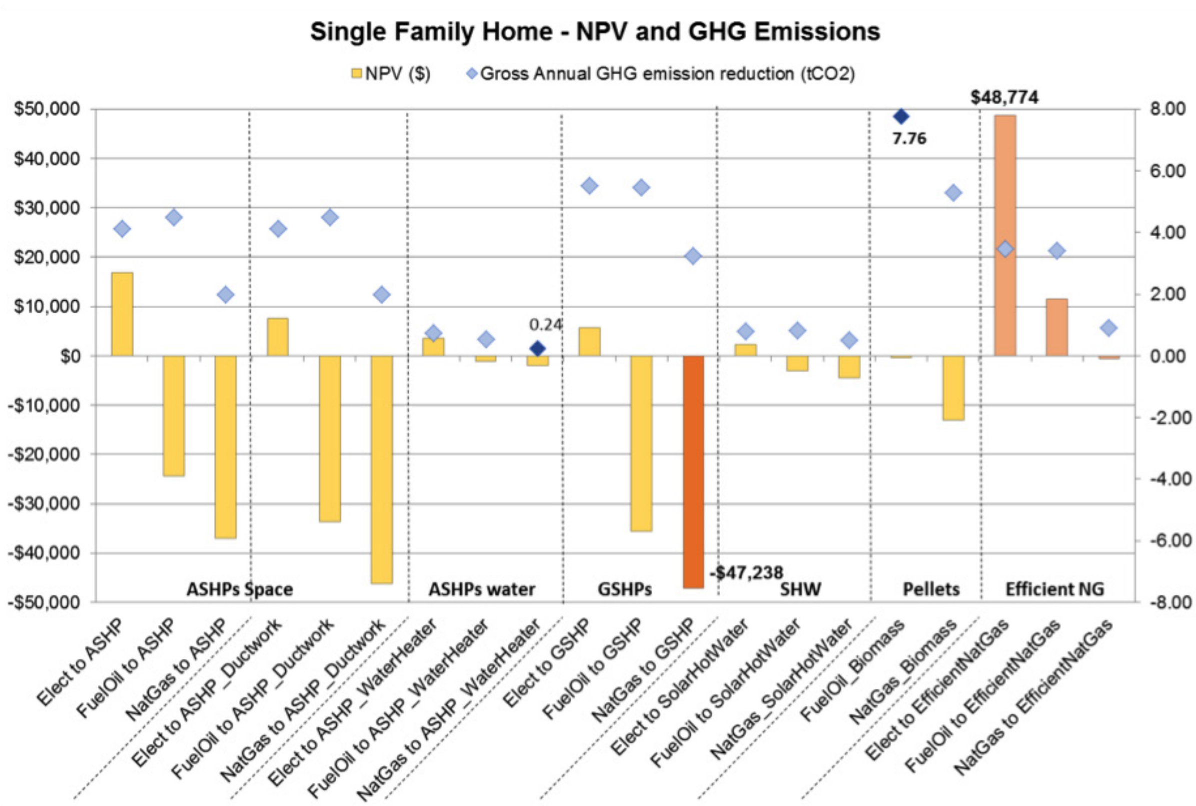
1. Informed by http://people.stern.nyu.edu/adamodar/New_Home_Page/datafile/wacc.htm.
The depreciation rate is the weighted average of the debt interest rate and the equity interest rate.

APPENDIX B
RETScreen Calculation Archetypes

Single Family Home (SFH)

MAIN FINDINGS

- All cases replacing electricity with ASHPs, SHW, or efficient natural gas boilers have a positive NPV
- The case with the highest NPV for SFH is replacing electricity with Efficient Natural Gas
- The case with the lowest NPV for SFH is replacing natural gas with GSHP
- The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
- The lowest GHG emission reductions result from replacing a standard natural gas boiler with an ASHP water heater



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 2,000 sq. ft.

2. Capacity needed for installation (kW):
   - 17.9 for proposed cases including space heating
   - 3.77 for proposed cases including water heating
   - 1.12 for proposed cases including cooling

3. Operating hours:
   - 1,519 hours per year for heating
   - 708 hours per year for cooling

4. Hot water:
   - 54.4 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency

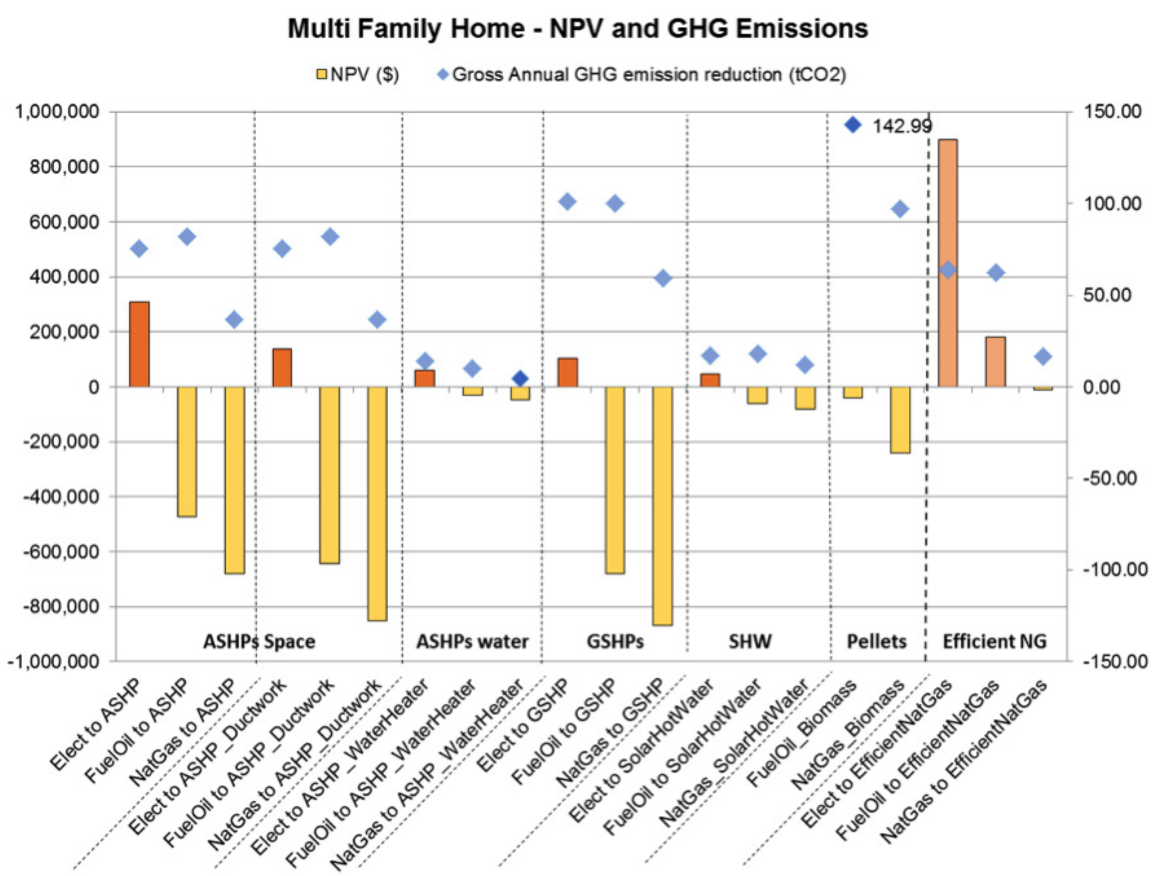
5. Annual demand (MMBTUs):
   - Space Heating: 92.8
   - Space Cooling: 2.7
   - Domestic Hot Water: 11.1

6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $19,332
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $29,356
   - Electricity, Fuel oil or Natural Gas to ASHP Water Heater: $600
   - Electricity to GSHP: $47,435
   - Fuel oil or Natural Gas to GSHP: $42,870
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $5,135
   - Fuel oil or Natural Gas to Biomass: $11,904
   - Electricity to Efficient Natural Gas: $18,437
   - Fuel oil or Natural Gas to Efficient Natural Gas: $3,849

Apartment—Multi Family Home (MFH)

MAIN FINDINGS

- Replacing electricity with heat pumps, SHW, or efficient natural gas boilers has a positive NPV
- The case with the highest NPV for SFH is replacing electricity with Efficient Natural Gas
- The case with the lowest NPV for MFH is replacing natural gas with GSHP
- The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
- The lowest GHG emission reductions result from replacing a standard natural gas boiler with an ASHP water heater



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

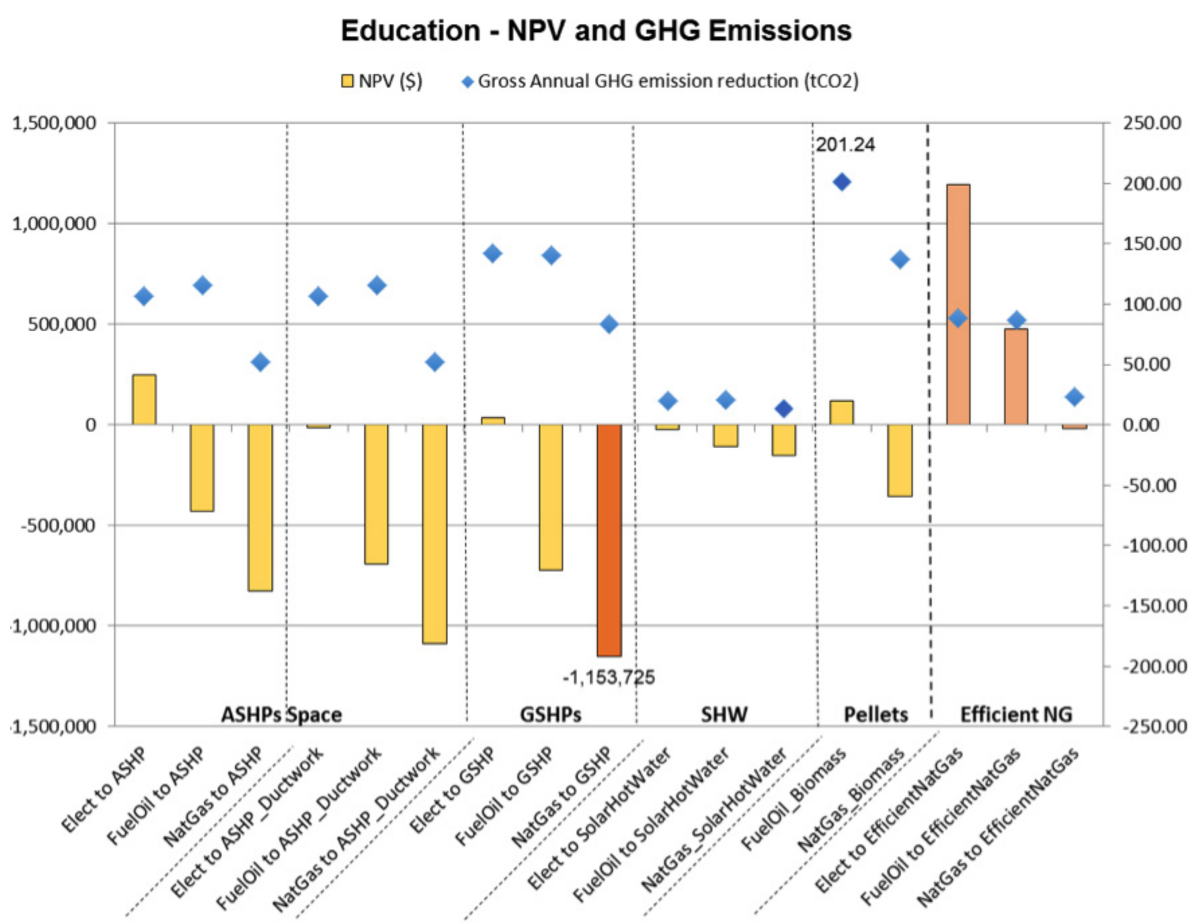
MAIN ASSUMPTIONS

1. Building size: 29,063 sq. ft.
2. Units: 33
3. Capacity needed for installation (kW):
   - 328 for proposed cases including space heating
   - 86 for proposed cases including water heating
   - 20 for proposed cases including cooling
4. Operating hours:
   - 1,519 hours per year for heating
   - 708 hours per year for cooling
5. Hot water:
   - 1,046 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency
6. Annual demand (MMBTUs):
   - Space Heating: 1,700
   - Space Cooling: 48.3
   - Domestic Hot Water: 213
7. Incremental initial costs:
   - Electricity, Fuel oil or natural gas to ASHP: $354,294
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $538,080
   - Electricity, Fuel oil or Natural Gas to ASHP Water Heater: $19,800
   - Electricity to GSHP: $869,254
   - Fuel oil or Natural Gas to GSHP: $785,759
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $117,642
   - Fuel oil or Natural Gas to Biomass: $218,160
   - Electricity to Efficient Natural Gas: $337,840
   - Fuel oil or Natural Gas to Efficient Natural Gas: $70,520

Education

MAIN FINDINGS

1. The cases with a positive NPV include:
   - Electricity to GSHP
   - Fuel Oil to Biomass
   - Electricity to ASHP
   - Electricity or fuel oil to efficient natural gas (highest NPV)
2. The case with the lowest NPV for education is replacing natural gas with GSHP
3. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
4. The lowest GHG emission reductions result from replacing a standard natural gas boiler with solar hot water



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

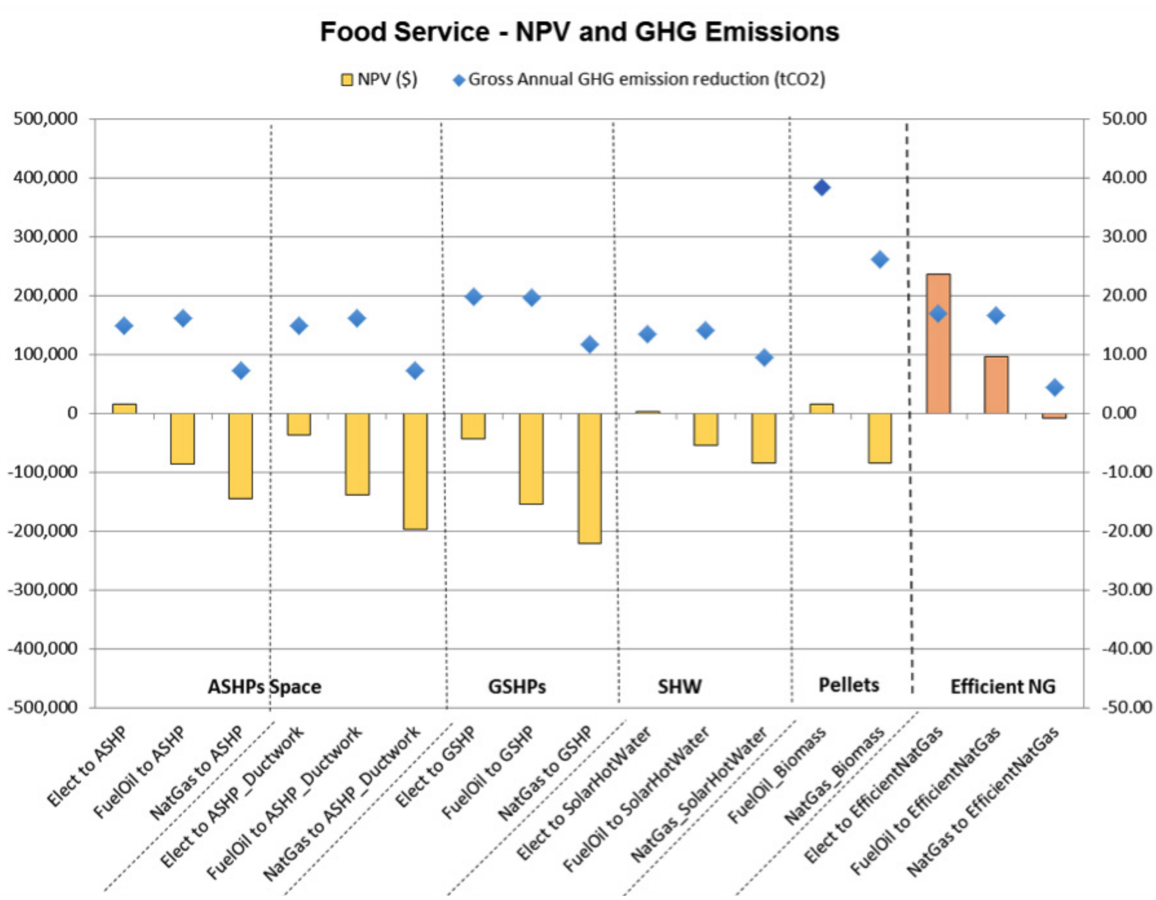
MAIN ASSUMPTIONS

1. Building size: 38,750 sq. ft.
2. Capacity needed for installation (kW):
    - 427 for proposed cases including space heating
    - 80 for proposed cases including water heating
    - 59 for proposed cases including cooling
3. Operating hours per year:
    - 1,637 hours per year for heating
    - 594 hours per year for cooling
4. Hot water:
    - 1,373 gallons per day used
    - 126 °F
    - 10% heat recovery efficiency
5. Annual demand (MMBTUs):
    - Space Heating: 2,384.5
    - Space Cooling: 120.42
    - Domestic Hot Water: 279.98
6. Incremental initial costs:
    - Electricity, Fuel oil or Natural Gas to ASHP: $450,820
    - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $732,640
    - Electricity to GSHP: $1,121,210
    - Fuel oil or Natural Gas to GSHP: $1,012,325
    - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $169,409
    - Fuel oil or Natural Gas to Biomass: $228,445
    - Electricity to Efficient Natural Gas: $439,810
    - Fuel oil or Natural Gas to Efficient Natural Gas: $91,805

Food Service

MAIN FINDINGS

1. The cases with a positive NPV include:
   - Electricity to Solar Hot Water
   - Electricity to ASHP
   - Fuel Oil to Biomass
   - Electricity or fuel oil to efficient natural gas (highest NPV)
2. The case with the lowest NPV for food service is replacing natural gas with GSHP
3. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
4. The lowest GHG emission reductions result from replacing a standard natural gas boiler with an efficient natural gas boiler



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

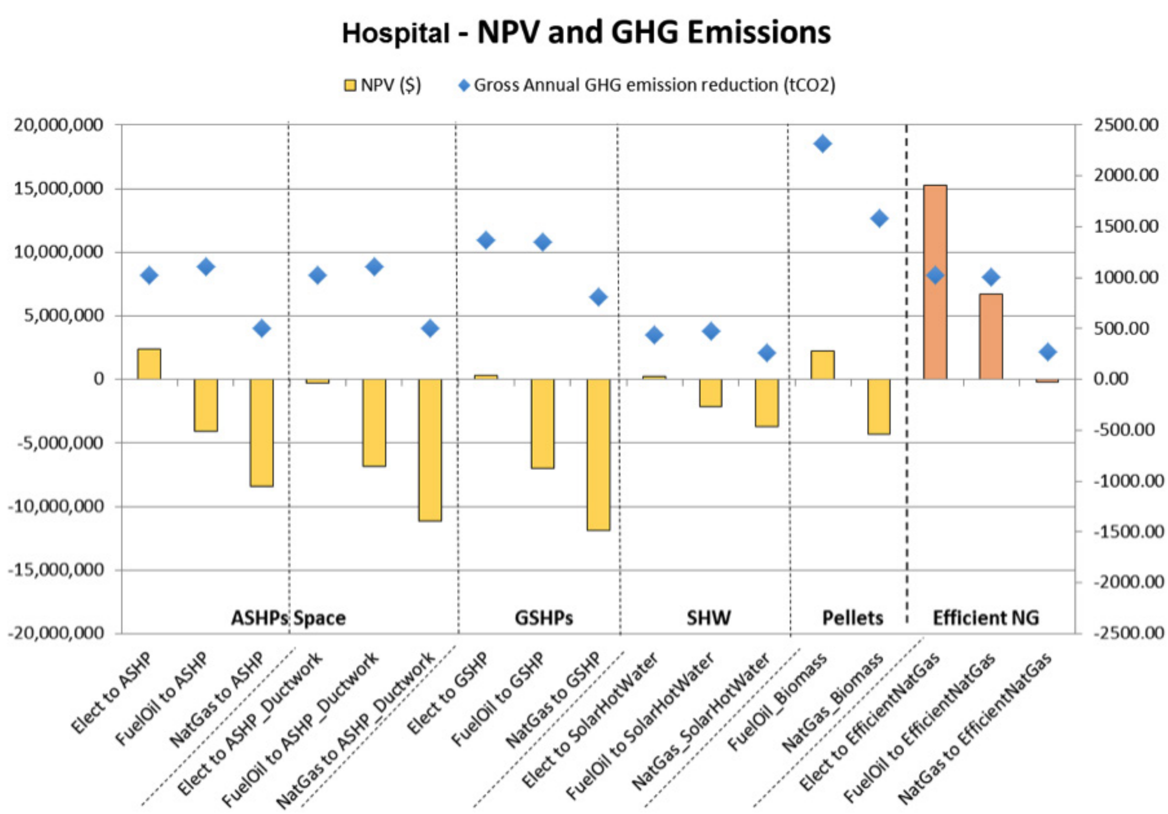
1. Building size: 5,651 sq. ft.
2. Capacity needed for installation (kW):
   - 83.28 for proposed cases including space heating
   - 48 for proposed cases including water heating
   - 7 for proposed cases including cooling
3. Operating hours per year:
   - 1,172 hours per year for heating
   - 837 hours per year for cooling
4. Hot water:
   - 862 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency
5. Annual demand (MMBTUs):
   - Space Heating: 333.12
   - Space Cooling: 19.8
   - Domestic Hot Water: 175.75
6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $89,368
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $144,333
   - Electricity to GSHP: $220,118
   - Fuel oil or Natural Gas to GSHP: $198,881
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $99,101
   - Fuel oil or Natural Gas to Biomass: $44,555
   - Electricity to Efficient Natural Gas: $85,778
   - Fuel oil or Natural Gas to Efficient Natural Gas: $17,905

Hospital

MAIN FINDINGS

1. The cases with a positive NPV include:
    - Electricity to Solar Hot Water
    - Electricity to GSHP
    - Electricity to ASHP
    - Fuel Oil to Biomass
    - Fuel oil or electricity to efficient natural gas (highest NPV)

2. The case with the lowest NPV for hospital is replacing natural gas with GSHP
3. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
4. The lowest GHG emission reductions result from replacing a standard natural gas boiler with solar hot water



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO_2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 201,554 sq. ft.

2. Capacity needed for installation (kW):
   - 4,383 for proposed cases including space heating
   - 1,489 for proposed cases including water heating
   - 468 for proposed cases including cooling

3. Operating hours per year:
   - 1,519 hours per year for heating
   - 1,307 hours per year for cooling

4. Hot water:
   - 38,476 gallons per day used (for the cases from electricity, fuel oil or natural gas to solar hot water, natural gas to biomass, and natural gas to efficient natural gas)
   - 39,112 gallons per day used (for the cases from fuel oil to biomass and from electricity or fuel oil to efficient natural gas)
   - 126 °F
   - 10% heat recovery efficiency

5. Annual demand (MMBTUs):
   - Space Heating: 22,721.88
   - Space Cooling: 2,086.17
   - Domestic Hot Water: 7,977.92

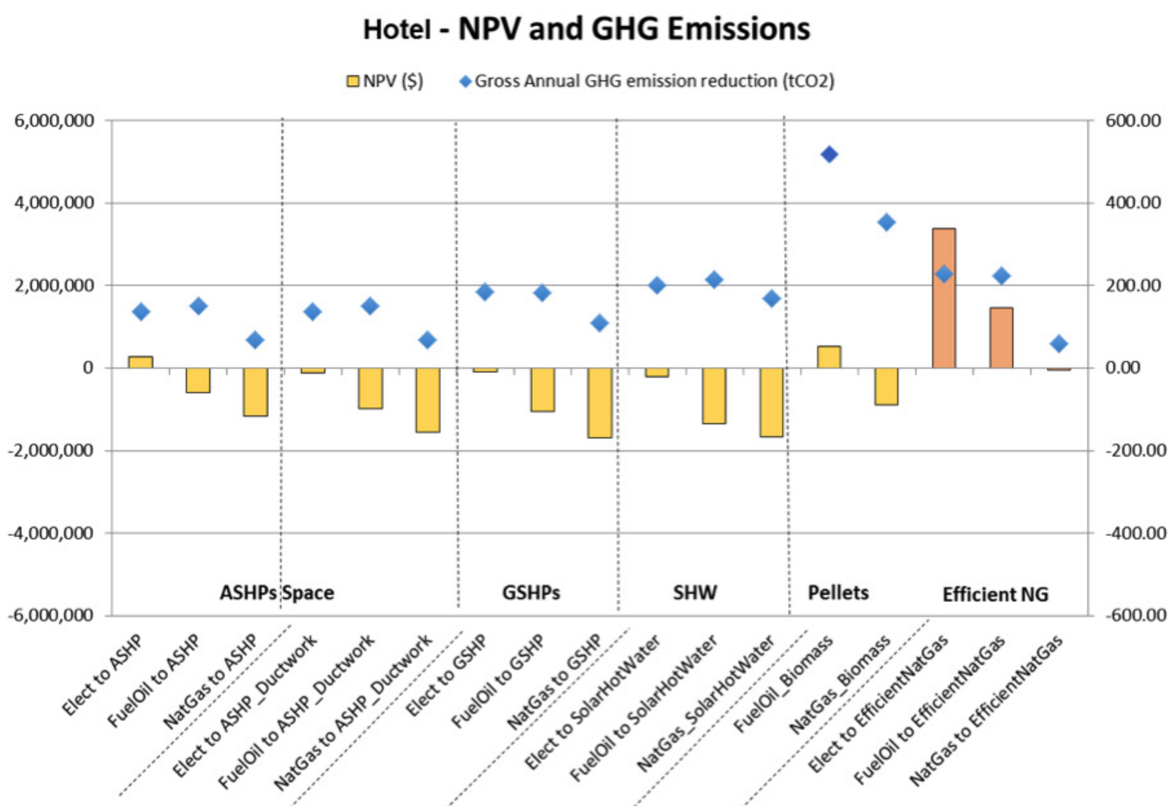
6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $4,671,540
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $7,564,320
   - Electricity to GSHP: $11,552,850
   - Fuel oil or Natural Gas to GSHP: $10,435,185
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $3,065,587
   - Fuel oil or Natural Gas to Biomass: $2,344,905
   - Electricity to Efficient Natural Gas: $4,514,490
   - Fuel oil or Natural Gas to Efficient Natural Gas: $942,345

Hotel

MAIN FINDINGS

1. The cases with a positive NPV include:
   - Electricity to ASHP
   - Fuel Oil to Biomass
   - Electricity, fuel oil or natural gas to efficient natural gas

2. The case with the highest NPV for hotel is replacing electricity with efficient natural gas
3. The case with the lowest NPV is replacing natural gas with GSHP
4. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
5. The lowest GHG emission reductions result from replacing a standard natural gas boiler with an efficient natural gas boiler



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 119,479 sq. ft.

2. Capacity needed for installation (kW):
    - 637 for proposed cases including space heating
    - 841 for proposed cases including water heating
    - 82 for proposed cases including cooling

3. Operating hours per year:
    - 1,418 hours per year for heating
    - 708 hours per year for cooling

4. Hot water:
    - 18,264 gallons per day used (for the cases from electricity, fuel oil, or natural gas to solar hot water)
    - 18,566 gallons per day used (for the cases from fuel oil or natural gas to biomass and from electricity, fuel oil, or natural gas to efficient natural gas)
    - 126 °F
    - 10% heat recovery efficiency

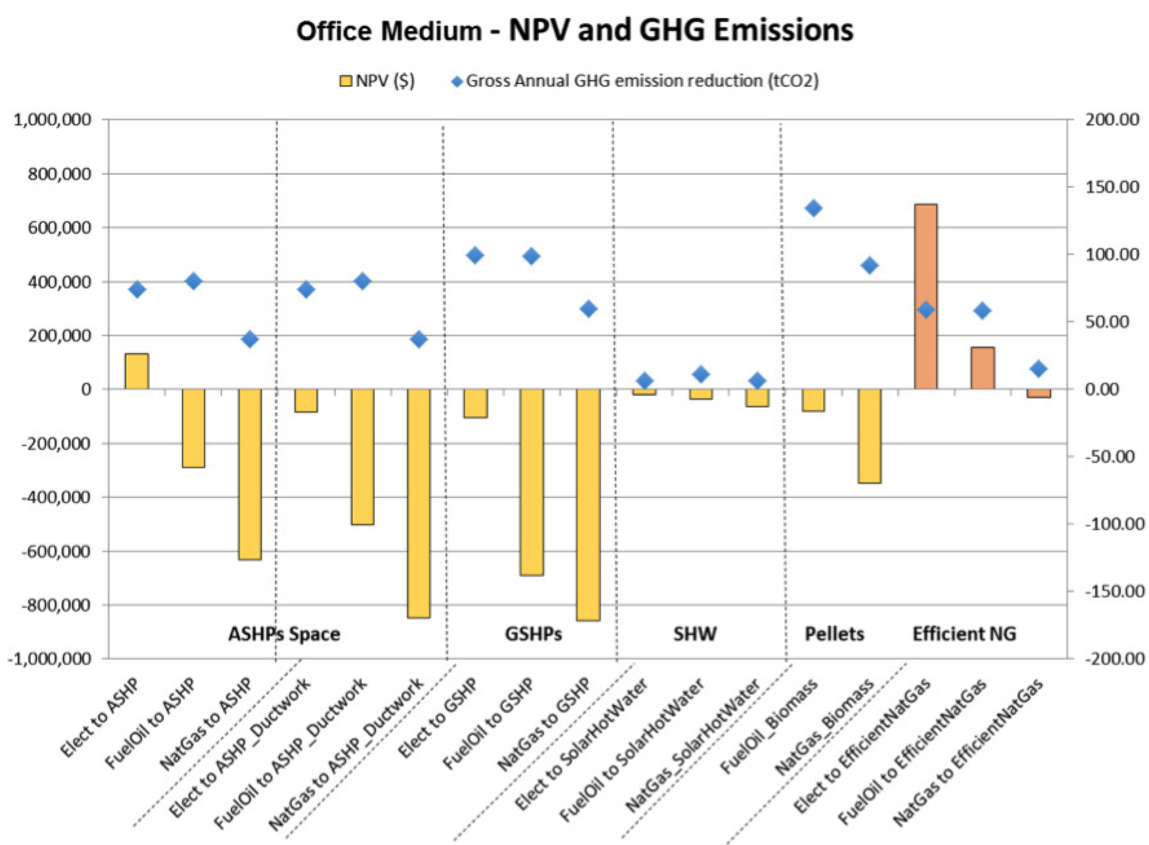
5. Annual demand (MMBTUs):
    - Space Heating: 3,081.42
    - Space Cooling: 198.73
    - Domestic Hot Water: 3,787

6. Incremental initial costs:
    - Electricity, Fuel oil or Natural Gas to ASHP: $674,460
    - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $1,094,880
    - Electricity to GSHP: $1,674,550
    - Fuel oil or Natural Gas to GSHP: $1,512,115
    - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $1,732,342
    - Fuel oil or Natural Gas to Biomass: $340,795
    - Electricity to Efficient Natural Gas: $656,110
    - Fuel oil or Natural Gas to Efficient Natural Gas: $136,955

Office Medium

MAIN FINDINGS

1. The cases with a positive NPV include:
    - Electricity to ASHP
    - Electricity or fuel oil to efficient natural gas
2. The case with the highest NPV for office medium is replacing electricity with efficient natural gas
3. The case with the lowest NPV is replacing natural gas with GSHP
4. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
5. The lowest GHG emission reductions result from replacing electricity with solar hot water



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 48,438 sq. ft.
2. Capacity needed for installation (kW):
   - 363 for proposed cases including space heating
   - 30 for proposed cases including water heating
   - 126 for proposed cases including cooling
3. Operating hours per year:
   - 1,306 hours per year for heating
   - 797 hours per year for cooling
4. Hot water:
   - 793 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency
5. Annual demand (MMBTUs):
   - Space Heating: 1,617.6
   - Space Cooling: 343.6
   - Domestic Hot Water: 161.7
6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $358,980
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $598,560
   - Electricity to GSHP: $928,890
   - Fuel oil or Natural Gas to GSHP: $836,325
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $65,578
   - Fuel oil or Natural Gas to Biomass: $194,205
   - Electricity to Efficient Natural Gas: $373,890
   - Fuel oil or Natural Gas to Efficient Natural Gas: $78,045

APPENDIX C
Cost Analysis

Project-specific installation costs for different RTTs have been provided by different program administrators across New England, as shown by Table 31.

TECHNOLOGY	YEARS OF DATA POINTS	MASSACHUSETTS	VERMONT	CONNECTICUT	NEW HAMPSHIRE
GSHP	**2010–2015**	Hard costs / Soft costs / Abnormal costs		Total costs / Abnormal costs	
ASHP	**2015**	Total costs			
Biomass	**2010–2015**	Hard costs / Soft costs / Abnormal costs	Total costs		Hard costs / Soft costs / Abnormal costs
Solar Thermal	**2009–2015**	Total costs	Total costs	Total costs	
Efficient Oil Boilers	**N/A**			Total costs	

Table 31 | Project-specific data available for the project

The resolution of the installation costs varies across states and technologies. Table 31 shows the available resolution of the costs. To the extent possible we differentiate between

- Hard costs—the costs of the equipment. Hard costs include equipment such as the central heater or cooler, collectors, drilling, bulk, and thermal storage.
- Soft costs—the costs of the installation work.
- Abnormal costs—the costs of necessary adaptations of the existing building and HVAC system. Examples of costs included in this category are upgrading distribution and ductwork.
- Total costs indicate that no differentiation has been made by type of costs.

The costs have been adjusted for inflation and are nominated by 2015 values. The cumulative rate of inflation was found through the US Inflation Calculator:[81]

- 2009–2015 10.5 %
- 2010–2015 8.7 %
- 2011–2015 5.4 %
- 2012–2015 3.2 %
- 2013–2015 1.7 %
- 2014–2015 0.1 %

The average installation costs per kW are shown by Table 32.

TECHNOLOGY	RESIDENTIAL			COMMERCIAL		
	Hard Costs ($/kW)	Soft Costs ($/kW)	Total Costs w/o ductwork ($/kW)	Hard Costs ($/kW)	Soft Costs ($/kW)	Total Costs w/o ductwork ($/kW)
GSHP	1,358	753	2,111	N/A	N/A	2,003
ASHP	N/A	N/A	1,089	N/A	N/A	N/A
Biomass	759	165	924	626	161	786
Solar Thermal	1,703	1,118	2,821	1,971	1,264	3,235
Efficient boilers	N/A	N/A	470	N/A	N/A	N/A
Ductwork	N/A	N/A	558	N/A	N/A	664

Table 32 | Average installation costs ($/kW) Renewable Thermal Technology projects in New England

- The installation costs for GSHPs in residential buildings are for retrofit projects. Due to a small selection, the installation costs for GSHPs in commercial buildings are for retrofit projects and new buildings.
- The installation costs for GSHPs include equipment and installation work related to drilling loops. Costs related to upgrading distribution systems and ducts are not included.
- The installation costs for Biomass include storage. The cost category “Miscellaneous” has been excluded.
- The installation costs for SHW exclude the cost category “Miscellaneous.”
- The installation costs for each RTT do not include costs related to upgrading the distribution system/ductwork. Costs related to upgrading the distribution system / ductwork have been calculated separately.
- The installation costs for Ductwork in residential buildings are for GSHP retrofit projects.
- The installation costs for Ductwork in commercial buildings are for GSHP retrofit and new construction projects.

81 http://www.usinflationcalculator.com/

The number of projects included in the statistics of New England projects is shown by Table 33.

	RESIDENTIAL	COMMERCIAL
GSHP	321	25
ASHP	1,913	
Biomass	385	47
Solar Thermal	1,832	189
Efficient boiler	96	
Ductwork	285	18

Table 33 | Number of samples in the New England average installation costs.

For some technologies, particularly for the commercial sector, the extent of the data is limited. We have therefore compared the New England cost data to other sources, as shown by Table 34.[82, 83, 84]

TECHNOLOGY ($/KW)		RETSCREEN AVERAGE		NEW ENGLAND PROJECTS AVERAGE		MEISTER CONSULTING GROUP		SWEETT	
		RES	COM	RES	COM	RES	COM	RES	COM
ASHP		1300		1089	N/A	N/A		820–1590	1981
GSHP	Equipment & Installation	1236		2111	2003	2131	2841	2770–3360	1640–2410
	Horizontal Loop Total	1996							
	Vertical Loop Total	3156							
Biomass Pellets		306		924	786	800 to 1700	400 to 600	1323	290 to 800
Biomass chips		N/A		N/A		N/A	491 to 600	N/A	
Solar Thermal		Glazed: 480–960 $/aperture Evacuated: 840–1440 $/aperture		2821	3235	2000 to 2500	1412 to 2763	1440 to 2880	N/A
Gas Boiler	Standard	182	182	N/A		8450 to 9100 $/unit	24000 to 28000 $/unit	N/A	
	Highly efficient	N/A		470	N/A	N/A		N/A	
Fuel oil boiler		182	182	N/A		8450 to 9100 $/unit	24000 to 28000 $/unit	N/A	
ASHP water heater		N/A		1000 to 1200 $/unit (50 gallon)		N/A		N/A	
Electric water heater		N/A		450 to 500 $/unit (50 gallon)		N/A		N/A	
Ductwork		N/A		558	664	N/A		N/A	
Air-conditioning		320		N/A		N/A		N/A	

Table 34 | Comparison of different sources of RTT cost data.

The average New England installation costs have been used in the RETScreen calculations where these data seem reasonable compared to the references: ASHPs, GSHPs, biomass pellets, and highly efficient gas boilers. For other proposed and base case technologies, RETScreen values have been used. With the exception of solar hot water, the average RETScreen installation costs have been applied. The New England cost analysis suggests that the costs for solar hot water installations per aperture are on the higher end.

82 http://www.nrcan.gc.ca/energy/software-tools/7465

83 Meisters Consultants Group (2012): Massachusetts renewable heating and cooling opportunities and impacts study. March 2012

84 Sweett (2013): Department of Energy and Climate Change. Research on the costs and performance of heating and cooling technologies. February 2013

APPENDIX D
RETScreen Expert

The RETScreen International Clean Energy Project Analysis Software (www.retscreen.net) is a clean energy decision-making tool specifically aimed at facilitating pre-feasibility and feasibility analysis of clean energy technologies as well as ongoing energy performance analysis. RETScreen empowers professionals and decision-makers to identify, assess, and optimize the technical and financial viability of potential clean energy projects. This decision intelligence software platform also allows managers to measure and verify the actual performance of their facilities and helps find additional energy savings and production opportunities.

RETScreen Expert has been developed by Natural Resources Canada (NRCan), a department of the Government of Canada.

The software can be used worldwide to evaluate the energy production, lifecycle costs, greenhouse gas emission reductions, financial viability, and risk for various types of proposed energy efficient and renewable energy technologies, as well as cogeneration projects.[85]

RETScreen Expert (available in 36 languages from September 2016) leverages a global database of project inputs including:

- A climate database of 6,700 ground-station locations around the globe and incorporation of the improved NASA Surface Meteorology and Solar Energy Dataset for populated areas. (These are input directly into the RETScreen software).
- A product database consisting of technical features of energy technologies and cost ranges.
- An emission factor database representing, among other things, the national or state specific electricity generation mix.

All clean energy technology models in the RETScreen Software have a common look and follow a standard approach to facilitate decision-making with reliable results. Each model also includes integrated product, cost, and weather databases and a detailed online user manual, all of which help to dramatically reduce the time and cost associated with preparing pre-feasibility studies.

85 Clean Energy Project Analysis, RETScreen® Engineering & Cases Textbook https://web.archive.org/web/20150711130124/http://www.retscreen.net/ang/d_t_info.php

The standard analysis in the RETScreen Software consists of several steps:

1. Choose location for the climate data
2. Define the facility, including benchmark analysis and the performance of the building envelope and industrial processes
3. Define the energy demand and equipment, both for base case and proposed case
4. Pursue cost analysis, including incremental installation costs, fuel costs, and escalation rates
5. Emission reduction analysis at different levels of detail
6. Financial analysis including net present value, internal rate of return, and cash flows
7. Sensitivity and risk analysis on financial variables such as fuel costs, installation costs, debt ratio, interest rates, and carbon price

The RETScreen Software facilitates project implementation by providing a common evaluation and development platform for the various stakeholders involved in a project. The tool can be used for zzmarket studies; policy analysis; information dissemination; training; sales of products and/or services; project development & management; and product development/R&D.[86]

Thus the analysis of RET Screen provides output for a constructive dialogue between funders and lenders; regulators and policy makers; consultants and product suppliers; developers and owners.

The vast capabilities of RETScreen enrich the depth of the analysis although this translates into high levels of complexity and require some specialized training and familiarization with the tool.

Overall, the RETScreen Software is increasing and improving access to clean energy technologies, building awareness and capacity, and helping to identify opportunities that facilitate the implementation of energy projects that save money, while reducing greenhouse gas emissions.

More information: www.retscreen.net

86 Clean Energy Project Analysis, RETScreen® Engineering & Cases Textbook

APPENDIX E
Tax Credits, Rebates and Other Incentives

TECHNOLOGY	SECTOR	INCENTIVE			
		ITC	OTHER TAXES	REBATES	LOANS
Natural gas boilers (highly efficient)	Residential		6.35%[4]	\$300	2.99% / 10 years[3]
	Commercial		6.35%[4]	\$8/unit MBH	5% / 10 years[5]
ASHP	Residential		6.35%[4]	\$500	2.99% / 10 years[3]
	Commercial		6.35%[4]	\$5000 and up[2]	5% / 10 years[5]
ASHP water heater	Residential			\$400[7]	2.99% / 10 years[3]
	Commercial				
GSHP	Residential		6.35%[4]	\$500—\$1500	2.99% / 10 years[3]
	Commercial		6.35%[4]	\$5000 and up[2]	5% / 10 years[5]
Biomass pellets boilers	Residential				2.99% / 10 years[3]
	Commercial				5% / 10 years[5]
SHW	Residential	30%[1]	6.35%[4]		2.99% / 10 years[3]
	Commercial	30%[1]	6.35%[4]		5% / 10 years[5]

Table 35 | Tax credits, rebates and other incentives

1. 30% for facilities put under construction prior to December 31, 2019. Thereafter phase out by end of 2022. For commercial facilities there will be continued tax credits of 10% after 2022.
2. Eligibility in the service areas of Eversource and United Illuminating, Cool Choice program.
3. The interest rate and loan term is for Smart-e bundles implying that the customer has to bundle several measures.
4. Sales tax incentive through Connecticut Department of Revenue Services.
5. The interest rate is the lowest C-PACE rate, which starts at 5% for 10-year and goes up by 10 basis points for each year. Loan term is for C-PACE.
6. Eligibility in the service areas of Eversource and United Illuminating. Energy Star Heat Pump Water Heater program.