Appendix I

Heat Pump Analysis and Considerations

Appendix I
Heat Pump Analysis and Considerations

By Ian Burnes, Laura Martel, and Lauren Trapani
11-8-2021

Introduction

1. What is the purpose of this testimony?

This testimony describes the family of measures that the Efficiency Maine Trust (the Trust or EMT) refers to as "heat pumps" (HPs) and provides evidence about the quantity of HP installations that are achievable for incorporation into the Trust's Triennial Plan V.

2. Who is introducing this testimony?

The testimony is provided by Ian Burnes, Laura Martel, and Lauren Trapani. At EMT, Mr. Burnes is the Director of Strategic Initiatives, Ms. Martel is the Research and Evaluation Manager, and Lauren Trapani is a Research and Data Analyst.

3. Mr. Burnes, please state your name, title, and business addresses.

My name is Ian Burnes, and I am employed by EMT as the Director of Strategic Initiatives. My business address is 168 Capital Street, Suite 1, Augusta, ME 04330.

4. Please summarize your educational and professional experience.

I have a Bachelor of Arts Degree in Economics from Wesleyan College. I have been working at EMT since 2009. My responsibilities include the oversight of the strategic initiatives team that implements EMT's customer tracking database, maintains the Technical Reference Manuals, oversees the program evaluations, and manages the Trust's resource in ISO-NE's Forward Capacity Market. Before coming to EMT I worked at the Governor's Office of Energy Independence and Security.

5. Ms. Martel, please state your name, title, and business addresses.

My name is Laura Martel, and I am employed by EMT as the Research and Evaluation Manager. My business address is 168 Capital Street, Suite 1, Augusta, ME 04330**.**

6. Please summarize your educational and professional experience.

I have a Bachelor of Science Degree in Ocean Engineering from Florida Atlantic University and a Master of Engineering in Acoustics from Pennsylvania State University. I have over 21 years of technical leadership, project management, and research and evaluation experience. I was hired by EMT in 2014 to design and implement impact and process evaluations for energy efficiency programs. Prior to joining EMT, I was with Lockheed Martin in Manassas, Virginia, where I served in various engineering, management, and technical leadership roles of increasing responsibility.

7. Ms. Trapani, please state your name, title, and business addresses.

My name is Lauren Trapani, and I am employed by EMT as a Research and Data Analyst. My business address is 168 Capital Street, Suite 1, Augusta, ME 04330.

8. Please summarize your educational and professional experience.

I have a Bachelor of Science Degree in Environment and Natural Resources from the Ohio State University. Between my school studies and roles as a research assistant and teaching assistant, I have three years of experience in benefit-cost analysis, environmental valuation, sustainability education, and carbon emissions tracking. I was hired by the Trust in 2020 to support the Strategic Initiatives team.

Background

9. What is the measure that is the subject of this testimony?

EMT refers to this family of measures in general terms as heat pumps. The measures consist of space heating equipment that transfers heat in and out of buildings using ambient thermal energy as a heat reservoir.[1] Heat pumps extract thermal energy from outside a building and deliver it indoors using a refrigerant cycle and heat exchangers. In cooling mode, they reverse this process, extracting heat from indoor air and delivering it outdoors.

EMT's programs incentivize a wide range of high-efficiency HPs, including but not limited to ductless mini-splits, Variable Refrigerant Flow (VRF) systems, and Packaged Terminal Heat Pumps (PTHPs).

10. Does the Efficiency Maine Trust Act (the statute) provide any direction on EMT's heat pump activity specifically?

Several provisions of the statute have an impact on EMT's HP planning and budgeting. First, in some purchasing scenarios, HPs constitute a cost-effective electric efficiency measure. The statute directs EMT to "identify the maximum achievable cost-effective energy efficiency savings [MACE]… pursuant to sections 10110 and 10111 [of the Act]"[2] and to develop and implement programs to procure MACE efficiency resources.[3] To the extent HP installations are cost-effective as an electric efficiency measure, the Triennial Plan must develop programs to promote them, and they must be included in the Electric Efficiency Procurement budgets.

Second, the statute directs the Trust to design its Triennial Plan to advance certain enumerated goals. Most recently, in the 130th Maine Legislature, the statute was amended to set new, statewide heat pump goals. Specifically, the Act calls for the Triennial Plan to "promot[e] the purchase of high-efficiency

[1] EMT's programs recognize eligibility for a wide variety of heat pump applications. These include systems that use the ambient, outside air as a thermal reservoir ("air source" heat pumps), as well as those that use the ground or water as a thermal reservoir. They also include systems that distribute heat (or cooling) through a building using flexible lines (tubing) in a "ductless" distribution system, as well as those that use ducts. For purposes of this testimony, unless otherwise indicated, use of the term "heat pump" refers to air source systems using a ductless distribution system. This testimony does not address the application of heat pump technology for domestic water heating.

[2] 35-A MRS §10104(A).

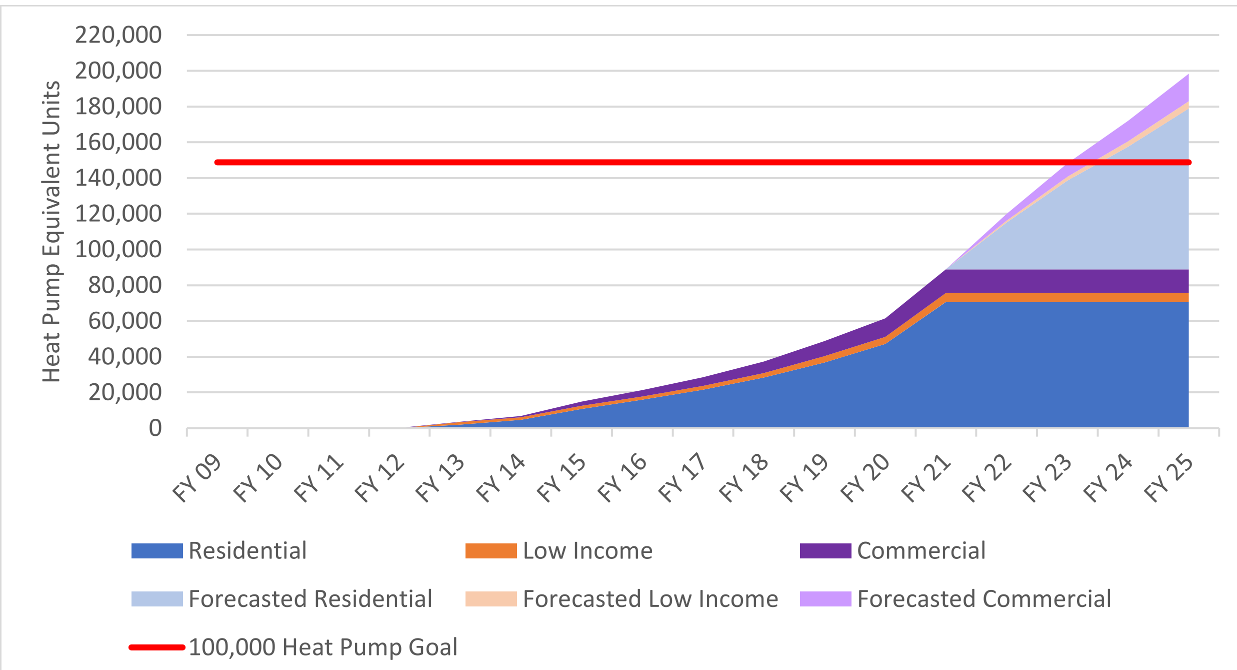
[3] 35-A MRS §10110(4-A).

heat pump systems to achieve by 2030 the goal of at least 115,000 households in the State wholly heated by heat pumps and an additional 130,000 households in the State partially heated by heat pumps."[4] Additionally, in 2019, the Legislature enacted LD 1766 to establish a statewide, five-year goal to install 100,000 high-performance heat pumps and, during the five-year period, to dedicate all EMT revenue from the Forward Capacity Market (FCM) to help fund the initiative.[5] The legislation specified that any funds derived from the FCM must be used to "supplement, but not supplant" the Trust's heat pump incentives funded by the Electric Efficiency Procurement.

11. Does Triennial Plan V put EMT on pace to meet the state goal of installing 100,000 heat pumps by the end of FY2025?

Yes. Triennial Plan V puts the Trust on track to meet the state goal by FY2024 (see Figure 1). Table 1 shows the budget breakdown by program and funding stream.

Figure 1: Cumulative Heat Pump Installations



Note: The counts of HP installations shown in this chart are based on "heat pump equivalents" to accommodate the diversity of systems installed. A "heat pump equivalent" is equal to 25.1 MMBtu heat provided per year. This is the amount of heat provided by the first single-zone, Tier 1 unit installed in a home as modeled by the Trust. Every HP measure is given an equivalence rating to convert it to heat pump equivalents based on the heat it is modeled to provide relative to an equivalent HP. As an example, a VRF unit that provides 250 MMBtu/year would be counted as 10 heat pump equivalents.

[4] 35-A MRS §10104(4)(F)(7).

[5] Public Law, Chapter 306, 129th Maine State Legislature, First Regular Session, LD 1766, An Act To Transform Maine's Heat Pump Market To Advance Economic Security and Climate Objectives, 2019.

Table 1: Heat Pump Budget by Sector and Program

Total Heat Pump Budgets with Delivery								
Program	CIP	CIP	CIP	SBI	HESP	HESP	LMI	LMI
Sector	Commercial	Commercial	Commercial	Commercial	Residential	Residential	Low Income	Low Income
Funding Source	*Procurement*	*RGGI*	*NECEC*	*RGGI*	*Procurement*	*FCM*	*FCM*	*NECEC*
FY2023	$3,082,474	$530,000	$633,000	$2,200,000	$6,415,928	$6,729,533	$1,330,667	$1,267,000
FY2024	$3,445,376	$530,000	$633,000	$2,200,000	$6,943,245	$3,654,433	$1,330,667	$1,267,000
FY2025	$3,808,610	$530,000	$633,000	$2,200,000	$7,470,561	$4,494,833	$1,330,667	$1,267,000
TPV Total	$10,336,460	$1,590,000	$1,899,000	$6,600,000	$20,829,734	$14,878,799	$3,992,001	$3,801,000
								$63,926,994

Two categories of measures are reflected in the budgets in Table 1: measures included in MACE that have an electric baseline, and those supported by FCM, Regional Greenhouse Gas Initiative (RGGI), and New England Clean Energy Connect (NECEC) settlement funds that have an unregulated fuel as a baseline.

In the C&I Prescriptive (CIP) Initiatives, the MACE measures include lost opportunity heat pumps and lost opportunity VRFs. They also include PTHP retrofits in circumstances where the baseline is an electric resistance heater. CIP Initiatives retrofit VRF measures and Small Business Initiative (SBI) mini-split retrofits are funded with RGGI and NECEC funds.

The MACE measures in the Home Energy Savings Program (HESP) are all single-zone and multizone units considered lost opportunities. FCM funding is used to fund retrofit single-zone units. In the Trust's initiatives to add heat pumps in low- and moderate-income (LMI) households, the measures are considered retrofits and are funded through a combination of FCM and NECEC funds.

12. How did EMT arrive at the program participation projection included in Figure 1?

For all lost opportunity measures included in MACE, EMT looked at past program performance and year-over-year changes in program participation and projected the trend forward in time. As shown in Figure 1, the projected growth traces a smooth curve based on past performance, including a significant increase realized between FY2020 and FY2021 for residential heat pumps. Several factors converged in late FY2020 and early FY2021 that may have contributed to the sharp increase in program participation. Program incentives were modified during FY2020 to spur activity and encourage retrofit projects with the introduction of Tier 2 qualification criteria. The Governor's announcement of the newly enacted state goal of installing 100,000 heat pumps by the end of FY2025 received significant coverage in the press. Starting in Spring of 2020, many people found themselves spending more time at home due to COVID restrictions. Also, the summer of 2020 (beginning of FY2021) was the third warmest summer on record. With more than 50,000 HPs installed in Maine by the beginning of FY2021, there was a large network of satisfied customers who helped market the product through word-of-mouth. Surveys show very high satisfaction with the equipment, and most surveyed said they would recommend HPs to friends and family. Finally, most Mainers received stimulus money from the federal government, increasing their disposable income. The combination of these factors led to a significant jump in purchases of heat pumps.

For retrofit measures, the Trust used a top-down approach extrapolating program performance based on the availability of RGGI, FCM, and NECEC funds. In both retrofit and lost-opportunity cases, EMT also assumed that rebate levels remain constant or substantially the same as past rebate levels, that marketing efforts remain constant with recent years, and that the workforce grows at a sufficient rate to keep pace with the growth in demand reflected in this figure.

13. Please provide a high-level overview of EMT's approach for calculating the cost-effectiveness of a HP in Triennial Plan V and the resulting funding implications.

EMT's approach to calculating HP cost-effectiveness and the resulting funding implications depend largely on the relevant decision type for a HP purchase—"lost opportunity" or "retrofit." For a lost opportunity, EMT's incentive encourages a customer who is already considering a HP to purchase a high-efficiency model. For a retrofit, EMT's incentive encourages a customer to install a HP to offset or replace their existing, functional heating system.

In the lost opportunity context, EMT calculates the incremental costs and benefits of the high-efficiency HP compared to the standard HP.[6] For every unit of heating that the standard HP would have delivered, the high-efficiency HP does the same work using less electricity. Thus, the high-efficiency HP measure delivers electricity savings during all times that the standard HP would be delivering heat. An additional advantage of a high-efficiency HP is that it maintains higher heating capacity than the standard HP across a wide range of outdoor temperatures, especially at colder temperatures. Therefore, the high-efficiency HP provides more heat during the year than the standard HP.[7] In delivering that incremental, additional heat, the high-efficiency HP displaces considerably more of the fuel used by the building's central heating system compared to the standard HP. And in doing so, the high-efficiency HP also consumes additional electricity (more than the standard HP which, as noted above, experiences reduced heating capacity as outside temperatures decline compared to the high-efficiency HP). The end result is a net[8] savings of electricity and a net savings of fossil fuels compared to the standard HP, the value of which EMT factors into the benefits of the measure.[9]

---

[6] High-efficiency HPs are those that meet program qualification requirements (e.g., HSPF 12 for single-zone Tier 1 HPs). In modeling the energy savings, the Trust uses weighted average performance of the HP models that make up the top 80% of program participation. For modeling standard efficiency HP performance, the Trust selected eight representative HP models that are commercially available that do not qualify for its programs and weighted them to match the distribution of program participation by capacity. The Trust then adjusted the capacity of the standard efficiency HPs to match that provided by the high-efficiency HPs at 61°F.

[7] As an example, at 1°F, Tier 1 high-efficiency HPs can produce 2,200 Btu/hour more than the standard efficiency HPs on average.

[8] As used in this testimony, the term "net" is not referring to adjustments made to reflect free-ridership.

[9] The increased electricity use of the high-efficiency HP in providing additional heat beyond that provided by the standard efficiency HP is less than the electricity savings achieved by the high-efficiency HP when it is providing the same heat as the standard efficiency HP more efficiently, resulting in a net savings of electricity. It is important to note that this analysis for lost opportunity HPs does not count among the benefits the full fuel savings from a HP displacing heat from the building's central heating system (as it would in a retrofit scenario). Rather, with regard to

In a lost opportunity, the economic benefits from the incremental energy savings by a high-efficiency HP compared to the standard efficiency HP exceed the incremental cost. All lost opportunity HPs are part of the MACE electric opportunity.

In the retrofit context, the measure cost for a high-efficiency HP is calculated first by determining the total project cost, summing the costs of equipment, installation, and operation (notably, increased electricity consumption). Next the benefits are calculated, including the value of all energy savings experienced as a result of the operation of the HP.[10]

In a HP retrofit scenario, EMT assumes that absent the program's intervention there would have been no HP installed of any kind, and thus there is no incremental savings of electricity. Without significant electrical savings, the measure will not be funded from the Electric Efficiency Procurement. The benefits that make the retrofit HP cost-effective are derived from saving unregulated fuels. EMT uses non-procurement funds to support these retrofit incentives. During Triennial Plan V, these funds will include FCM, RGGI, and NECEC funds. They may potentially be supplemented by federal funds as well. By reserving FCM funds for the enhanced incentives EMT is offering on retrofit HPs, EMT satisfies the statutory requirement that those funds be used to "supplement but not supplant" the Trust's incentives funded by the Electric Efficiency Procurement (lost opportunity HP incentives).

HP Cost-Effectiveness Details

14. Please explain the Plan's approach to determining what decision type is applicable for HP purchases, by program, and the corresponding funding source.

For residential HP rebates administered through HESP, EMT instituted a tiered incentive system in January 2020 following passage of LD 1766. This approach enabled HESP to continue its support of lost opportunity HPs by maintaining the program's well-established minimum efficiency standard and rebate amounts and to introduce a new retrofit measure. The incentive for a "retrofit" HP is enhanced; in HESP during fiscal years 2020 and 2021, the incentive for this measure was worth double the amount of the incentive for a "lost opportunity" HP. The enhanced incentive was deemed necessary to accelerate market demand for high-efficiency HPs beyond the status quo to meet the statutory goal of adding 100,000 heat pumps by 2025 per the terms of LD 1766.

EMT considered the incremental market demand for HPs, that which exceeded the established growth rates of HP participation of the status quo, to be retrofits. Consistent with the practice begun in the most recent triennial plan, the Trust will continue to treat HPs purchased under the lost opportunity decision type as part of MACE and fund this measure with Electric Efficiency Procurement funds. All HPs purchased as retrofits are excluded from MACE. EMT will use FCM funds to pay for these retrofit incentives.

---

the fuel savings from the building's central heating system, the lost opportunity approach only counts the *incremental* savings achieved by the improved capacity of the high-efficiency HP compared to the standard HP and adds these to the net electrical savings.

[10] Energy benefits are calculated using the marginal cost of energy and demand, including non-imbedded costs of carbon, for electricity energy and demand savings, and all fuel savings.

For Low Income Initiatives, all HP installations are assumed to be retrofit scenarios. EMT allocates a combination of FCM and NECEC funds to pay for these incentives.

For HPs deployed in commercial and multifamily applications, EMT has several incentive offerings within its CIP Initiatives. It provides a base-level incentive for ductless and mini-ducted HPs, modeled as lost opportunity and funded with Electric Efficiency Procurement funds. It provides enhanced incentives to encourage retrofits in the Small Business Initiative, funded by RGGI. Packaged Terminal Heat Pump (PTHP) retrofits replacing Packaged Terminal Air Conditioners (PTACs) that use electric resistance heat are funded by Electric Efficiency Procurement funds. Variable Refrigerant Flow (VRF) systems replacing operational fossil-fuel-fired heating systems are funded by RGGI.

15. Can you explain in more detail the key assumptions and methods used in the HP savings modeling?

EMT contracted Bruce Harley Energy Consulting, LLC to improve the in-house HP modeling being performed at EMT. In making the model improvements for the EMT, Mr. Harley leveraged experience he had gained working with the Canadian Standards Association (CSA) to establish a new Dynamic [Heat Pump] Test Procedure. The modeling uses typical meteorological year 3 (TMY3) temperature bins with a behavioral model developed for the CSA Dynamic Test Procedure applied to avoid brief off-season periods of heating and cooling. This results in a heating and cooling temperature bin profile that models how heating and cooling is performed throughout a typical year. At each temperature, the capacity and coefficient of performance (COP)[11] was calculated using temperature-dependent performance of a representative program-eligible HP and a representative non-eligible HP. Key assumptions in the model include:

- Program-eligible HP performance used in the modeling is a weighted average of program-eligible models, in proportion to actual program participation, using engineering data adjusted by achieved performance determined from metered use under the HESP Impact Evaluation.[12]
- For non-eligible units, a weighted average performance was calculated using corresponding non-program eligible unit engineering data in comparable proportions and adjusted proportionally for achieved performance.
- The actual heat delivered by the HPs for any given temperature is a function of the heat load of the building, the capacity of the HP, and the interaction between the HP and the central heating system.
- A factor (termed "Load Factor") was introduced to model the interaction between the HP and the central heating system. This factor is used to adjust the point at which the HP cannot fully meet the heat loss of the area being served and triggers the addition of heat generated by the

[11] COP is a ratio of useful heating or cooling provided (output) to energy consumed (input) where input and output are measured in the same units. Higher COPs equate to higher efficiency, lower energy consumption, and thus lower operating costs.

[12] West Hill Energy and Computing, Efficiency Maine Trust Home Energy Savings Program Impact Evaluation - Program Years 2014-2016, August 23, 2019.

central system. Since the heat called for at any given temperature is fixed, any heat provided by the central system is heat that cannot be provided by the HP even if it has the capacity to do so. The portion of the heat provided by the HP, when both the HP and central system are providing heat, is directly proportional to the capacity ratio between the HP and the central system. The capacity of the central system was set to 1.5 times the design capacity of the HP, and the "Load Factor" was set to 3.5 for the first residential HP. This results in the central system contributing a significant portion of the heat needed when the capacity of the HP falls below 3.5 times the heat loss. Ideal interaction between the central system and HP would have a load factor of 1. A load factor of 3.5 was selected because it represents a realistic operation strategy as observed in the HESP Impact Evaluation metering results.[13]

- A second factor (termed "Sizing Factor") was introduced to model the ratio of the HP's capacity at the design temperature to the heat loss at the design temperature. A sizing factor of 1 indicates that the HP capacity at the design temperature is perfectly matched to the heat loss of the area it serves. Inversely, the area served by the HP is matched to the HP's capacity at the design temperature. A sizing factor greater than 1 indicates that the HP is oversized for the area it serves. This would represent a scenario where the HP is installed in a less-than-ideal location where it is serving a space smaller than its capacity could support. A sizing factor of 1 was selected for the first residential HP with the assumption that the first HP installed in a home or business is located where it can heat the largest space possible given its capacity. A sizing factor of 2.5 was selected for the second HP, representing a less ideal location where the HP is serving a space smaller than its capacity would allow. For multifamily buildings, where the heat load of the home is generally smaller, a sizing factor of 2 was selected. The load and size factors used for each HP use case are defined in the Technical Reference Manuals.

16. How does the performance of the high-efficiency HP compare to the standard efficiency HP?

As noted previously, over the course of a heating season, program-eligible HPs provide heat more efficiently than non-eligible HPs and provide cooling more efficiently over the cooling season. Additionally, the high-efficiency HP models have more heating capacity, with higher efficiency, at lower outdoor temperatures than non-eligible models. This means that the point at which the central system is needed to provide heat to supplement the HP(s) occurs at a warmer outdoor temperature for non-eligible HPs. Therefore, the savings realized in the lost opportunity case include both electricity savings from more efficient heating and cooling plus an incremental fuel savings (and increased electricity use) from the high-efficiency HP providing more of the home's total annual heat load.

17. For a retrofit scenario, how does the high-efficiency HP compare to a typical central heating system furnace or boiler?

The high-efficiency HP offers efficiency advantages in two ways. First, it uses source energy to deliver useful heat more efficiently than a typical central heating system. At peak performance, the high-

[13] West Hill Energy and Computing, Efficiency Maine Trust Home Energy Savings Program Impact Evaluation - Program Years 2014-2016, August 23, 2019.

efficiency HP is delivering heat at a COP above 3.0. The “seasonal COP” in Maine’s climate is the average COP of a HP over the course of an entire heating season, which is arrived at by taking the total heat delivered during the season divided by the total energy consumed. The seasonal COP of eligible HPs in EMT’s residential programs ranges from 2.43 to 2.75 depending on how the HP is used and interacts with the central system. That is equivalent to an efficiency ranging between 243% to 275%, which is more than three times the efficiency of an average oil boiler in Maine. Even when the losses from the power generator and line losses across the grid are factored in, the high-efficiency HP is still significantly more efficient than a fossil-fired furnace or boiler. Moreover, the HP delivers heat directly into a room, avoiding some of the losses that a central heating system typically incurs from ductwork (in furnaces) or from the pipes leading to the radiators (from boilers) of the distribution system. Because the modern, highest efficiency HP models can efficiently produce heat even at very low outdoor temperatures, it is appropriate, from a cost-effectiveness perspective, for users to run the HP so that it continues to deliver heat throughout the entirety of the heating season.

One exception to this would be in a space where the central heating system runs on natural gas. In a natural gas-heated space, a retrofit HP would not be cost-effective under current avoided costs.

18. What is the outside temperature at which a high-efficiency cold climate HP will no longer deliver heat into the home or business?

Manufacturer reported performance is that the cold climate, high-efficiency HPs promoted by EMT’s programs effectively deliver heat at temperatures below -10°F. One of the most popular models purchased in Maine reports an operating range down to -15°F.

19. Does the eligible HP switch over to a resistance coil heat element during the defrost cycle?

No. It is a misconception that the modern, high-efficiency models automatically switch to resistance heating in order to periodically defrost the outdoor unit to melt any build-up of ice. In fact, during the defrost cycle, the HP models that are eligible for EMT programs simply divert the heat produced by the HP’s normal process for making heat to the outdoor unit instead of transferring it into the lines for distribution into the home or business. This is a logical and far more efficient strategy than using resistance heating, since the defrost process is typically needed when the outside temperature is very close to “freezing” (i.e., 32°F). This is a temperature at which the HP is highly efficient and effective at producing heat.[14]

20. What is the impact of low outside temperatures on the economics of HPs as a supplemental heating system? Does it make economic sense to shut off a HP when outside temperatures sink below a certain level?

The Trust modeled the performance of a typical HP and a typical oil-fired central system used as backup. It assumed $2.75/gallon of heating oil, a central furnace or boiler having a system efficiency of 80.5%, and a HP with Heating Seasonal Performance Factor (HSPF) of 12 providing supplemental space heat with electricity at $0.16/kWh. The analysis showed that during the period of time when the outside

[14] Some program qualifying units use small electric resistance pan heaters that turn on during the defrost cycle to prevent condensate from freezing in the drain pan.

temperature is below -1° F., it would be less expensive for the consumer to heat the space with the oil-fired central heating system than the high-efficiency HP.

EMT applied this modeling to a typical home in Caribou, Maine, and found that if the home switched off its HP during periods when the outside temperature was below -1°F, and then turned it back on any time the outside temperature rose above -1°F, the customer could save less than $4 per year compared to just letting the HP run all winter. The analysis also shows that there are relatively few hours of the year when outside temperatures in Maine are below -1°F, these hours do not typically persist for extended periods, and they are relatively spread out across the winter months. Because HPs are most efficient when they operate in a steady state (as opposed to being ramped up and down), and because customers are unlikely to perfectly time switching the HP on and off whenever the outdoor temperature passes the -1° mark, EMT generally recommends that customers purchase the cold climate, high-efficiency HP (instead of the standard efficiency HP) and leave it on during all hours of the heating season.

An important point to understand about HP economics is that due to their high efficiency in cold climates, the models promoted by EMT—the cold climate, high-efficiency HPs—are able to make more heat than the lower-efficiency models when the outside temperature falls, and they are able to do so more economically.

21. How does EMT account for air conditioning costs and benefits in its HP cost-effectiveness calculations?

EMT's lost opportunity HP calculation accounts for fact that program-eligible HPs provide more efficient cooling than the baseline standard model HPs (i.e., it accounts for the incremental energy savings for cooling).

EMT's retrofit HP calculation accounts for cooling savings based on the following mix of assumptions regarding the cooling baseline:[15]

- 40% of homes have existing cooling capacity equivalent to that provided by the HP. This generates positive electricity savings due to more efficient cooling with a HP.
- 21% of homes have no existing AC at all. Adding a retrofit HP generates negative savings due to the added HP electric load.

[15] These cooling assumptions were derived from a collection of studies: the 2008 Central Maine Power (CMP) residential survey; NMR Group, Inc., Maine Single-Family Residential Baseline Study, September 14, 2015; West Hill Energy and Computing, Efficiency Maine Trust Home Energy Savings Program Impact Evaluation - Program Years 2014-2016, August 23, 2019; and engineering judgment. The 2015 Residential Baseline Study found 32% of Maine homes had cooling equipment installed at the time of the study, which occurred in the spring, before seasonal window A/C units are typically installed. The 2019 Home Energy Savings Impact Evaluation found 64% of surveyed homes reported having cooling equipment before installing a HP, and 64% of surveyed homes reported installing a HP to add air conditioning. The commercial assumptions were adjusted higher than the residential assumptions to account for more cooling typically found in commercial settings.

- 39% of homes have partial cooling capacity that is less than that provided by the HP. This has no energy impact; the HP provides more cooling load but does so more efficiently, resulting in neither an increase nor a decrease in energy use on average.
- For commercial applications, 60% of businesses have existing cooling capacity equivalent to that provided by the HP, 21% have no existing cooling capacity, and 19% have partial cooling.

22. Since EMT started incentivizing HPs, to what extent have EMT programs promoted messages, education, or training that would tend to help customers and installers understand operational practices that will improve the cost-effectiveness of HPs?

Prior to FY2019, the extent of EMT's education and training for HPs was minimal. It involved establishing appropriate HP specifications and minimum requirements for proper installation and maintenance and providing scholarships for HP installer training at community colleges. However, EMT did not deploy any significant education and awareness campaign regarding best practices for maximizing savings.

Around FY2019, it became clear to EMT that there was a lack of consumer awareness about how best to operate a HP efficiently, and that there were notable public misconceptions about modern HPs' technical capabilities. EMT's HESP Program Impact Evaluation found that a significant portion of HP users were underutilizing their HPs, thereby failing to capture the measure's full benefit.[16] EMT also learned that many heating technicians and homeowners were under the mistaken belief that it is better to turn off HPs in the winter months and rely entirely on central fossil-fuel fired systems. At the time, this message was being conveyed by fuel dealers across the state.[17]

In light of this information, EMT commenced a comprehensive education and training initiative for HPs starting in FY2019. This effort focused on sharing strategies for maximizing the benefit of a HP and debunking performance myths. First, EMT developed and published a set of HP "User Tips." EMT requires that HP installers provide each program participant with a copy of these User Tips upon completing a job. EMT also follows up with program participants after installation, emailing the User Tips and mailing a Heat Pump Tip Kit. EMT also makes the User Tips available on its website, along with other helpful videos and links. It leverages Google and Facebook ads to drive customers toward this information. Finally, it further disseminates this information through energy fairs, at presentations, and at other events across the state.

Second, EMT significantly expanded its outreach and training efforts with Maine's HP installer community. It developed the "Efficiency Maine Annual Heat Pump Basics Module," a webinar that highlights best practices, reviews system siting and selection considerations, and dispels common myths. EMT now requires that all qualifying third-party HP installation trainings for its Registered Vendors include this module. Additionally, at least one installer on every residential HP job crew must have proof that they have watched the module in the past year.

---

[16] West Hill Energy and Computing, Efficiency Maine Trust Home Energy Savings Program Impact Evaluation - Program Years 2014-2016, August 23, 2019, p. 5-5.
[17] "Heat pumps in Maine: Set it and forget it? Or turn it off in the winter?" *Portland Press Herald,* October 28, 2018.

HP Refrigerant Leakage

23. Please explain the concern regarding HP refrigerant leakage. What is the worst-case scenario?

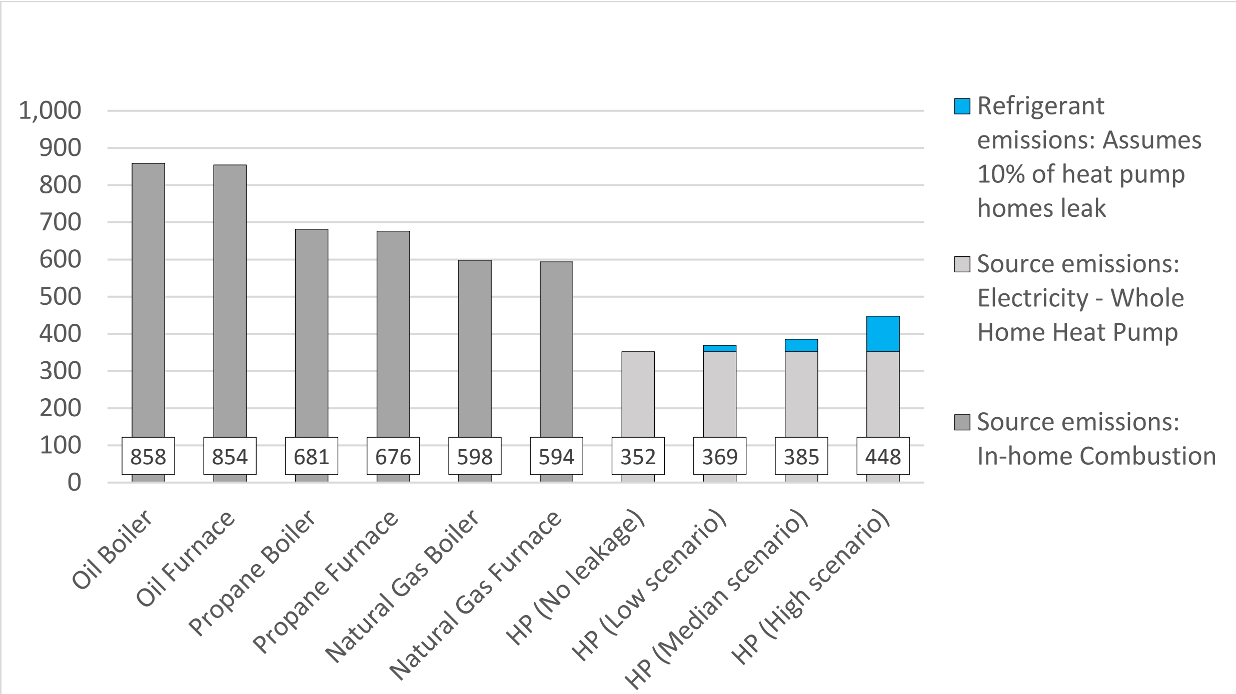
Most HPs today use a non-flammable and non-ozone-depleting refrigerant known as R-410A, which has a climatic effect 2,088 times more potent than carbon dioxide. In the vast majority of residential HP systems, this refrigerant is remains contained within the units and piping. However, in a small proportion of systems, R-410A can escape into the atmosphere through imperfections in pipe fittings.

There is very little primary research on refrigerant leakage in HPs. To determine the worst-case scenario, EMT relies on a 2014 study performed in the United Kingdom by Eunomia Research and Consulting. This study found that about 10% of residential HPs leaked to some degree. Of the HPs that did leak, interquartile leak rates ranged from 18% (low scenario) to 100% (high scenario) annually.[18] The City of Seattle also used this study as the basis of its in-depth refrigerant emissions analysis.[19]

Figure 2 illustrates potential emissions if homes were heated with whole home HP systems and 10% of whole home HPs leak. In the worst-case (high) scenario, 100% of the refrigerant charge leaks annually in 10 out of 100 homes with whole home HPs. In this case, approximately 91.88 pounds out of 918.75 pounds across 100 homes leak into the atmosphere each year, equating to 96 short tons of carbon dioxide equivalent (CO_2e) released into the atmosphere. The low and median scenarios represent 18% and 35% annual leakage in 10% of homes, respectively. Including both refrigerant leakage and carbon emissions from the electricity to power the HPs, annual emissions for 100 homes with whole home HPs are 43% (low scenario), 45% (median scenario), and 52% (high scenario) of would-be emissions if those homes were heated by high-efficiency, oil-fired equipment (87.7% AFUE).[20]

[18] Eunomia Research & Consulting Ltd and the Centre for Air Conditioning and Refrigeration Research, Impacts of Leakage from Refrigerants in Heat Pumps, United Kingdom: Department of Energy & Climate Change, March 2014.
[19] PAE Engineers, City of Seattle Refrigerant Emissions Analysis: GHG Emissions Calculations Methodologies, May 5, 2020.
[20] AFUE is the Annual Fuel Utilization Efficiency and is a measure of the total fuel consumed over a heating system compared to the useful heat provided into the space being heated. An AFUE of 100% would indicate that 100% of the BTU content of the fuel consumed was converted into useful heat.

Figure 2: Annual Emissions to Heat 100 Homes (short tons CO_2e) [21]



24. What indications of refrigerant leakage have been seen in Maine?

In a customer survey sent out to more than 16,000 Maine HP users in April 2021, 47 of 2,395 responses, or just under 2% of users, indicated a definite or probable refrigerant leak within their HP system. This likely means that the proportion of residential systems that leak is significantly less than the 10% found in the 2014 UK study. However, there has been no primary research on HP refrigerant leakage in Maine to date.

25. How does EMT work with HP installers to mitigate refrigerant leaks?

All of Efficiency Maine's Residential Registered Vendors (RRVs) are required to follow the HP installation checklist for installations rebated through the residential and low-income programs. This checklist requires a pressure test, the process used to identify leaks in a HP system during installation, as well as tightening of all flare connections to the manufacturer's torque specifications. Additionally, all RRVs installing HPs are required to obtain a minimum of two certifications that cover refrigerant management and testing, including the manufacturer's training for pressure testing (the process to identify leaks) and the U.S. Environmental Protection Agency's (USEPA's) Section 608 Refrigerant Handling Certificate. In addition, each RRV must complete the Efficiency Maine Trust's Heat Pump Basics Training.

For installers participating in Efficiency Maine Trust commercial and industrial programs, installers (called Qualified Partners) are required to follow all manufacturer installation procedures for heat pump and Variable Refrigerant Flow (VRF) systems. This includes testing for refrigerant leaks and ensuring that

[21] Does not account for natural gas leakage.

all piping connections are optimally tightened. VRF systems are first tested for leaks with dry nitrogen (elemental N_2 gas) over a 24-hour period before the system gets charged with refrigerant. This verifies the integrity of the pipe fittings through which leakage can occur. ZoomLock fittings have become a popular and effective connection fitting, and installers are encouraged to use them. Additionally, all Qualified Partners installing heat pumps or VRF systems are required to complete the manufacturer's product training and obtain the USEPA Section 608 Refrigerant Handling Certificate.

26. What is the proper way to dispose of R410-A? What does the USEPA Section 608 license require?

According to the Refrigeration Service Engineers Society, due to the high vapor pressures of R-410A, the refrigerant must be evacuated from a heat pump using recovery cylinders rated for 400 psi or higher prior to disposal, while following all other manufacturer specifications.[22] All refrigerants must be sent to a certified general reclaimer or to the refrigerant manufacturer for proper disposal.

The USEPA Section 608 license requires technicians involved in maintenance, service, repair, and disposal of heat pump equipment to pass a written test on the following topics:[23]

- Environmental impacts of chlorofluorocarbon (CHC), hydrochlorofluorocarbon (HCFC), and hydrofluorocarbon (HFC) refrigerants
- Clean Air Act Section 608 regulations and the Montreal Protocol
- Refrigerant states, gauges, and leak detection
- Refrigerant recovery techniques and requirements
- Safety guidelines and requirements

This test must be administered by a certification program approved by the USEPA.

27. What does federal law require, and what is happening with the USEPA's Significant New Alternatives Policy (SNAP) Program (Section 612 of the Clean Air Act) in relation to refrigerants?

The purpose of the federal SNAP Program is to evaluate alternative refrigerants for commercialized end-use based on the following criteria: atmospheric impacts, exposure assessments, toxicity, flammability, and other environmental impacts including ecotoxicity and air quality. Based on these criteria, the SNAP Program designates alternative substances into the following categories: Acceptable, Acceptable subject to use conditions, Acceptable subject to narrowed use limits, and Unacceptable.[24]

On May 6, 2021, the USEPA enacted SNAP Program Final Rule 23, which went into effect on June 7th, 2021.[25] This rule designated the refrigerant R-32 (global warming potential [GWP] 675) for use in residential and light commercial split systems as Acceptable subject to use conditions. It also approved as acceptable subject to use conditions R-452B (GWP 700), R454A (GWP 240), R-454B (GWP 470),

---

[22] Frank Prah, *Refrigerant 410A*, Des Plaines, Illinois: Refrigeration Service Engineers Society, Service Application Manual, Form #620-108, 2001.
[23] USEPA (website), "Section 608 Technician Certification Test Topics," October 7, 2020.
[24] USEPA (website), "Overview of SNAP," October 7, 2020.
[25] Protection of Stratospheric Ozone: Listing of Substitutes Under the Significant New Alternatives Policy Program, 86 Fed. Reg. 24444 (May 6, 2021) (to be codified at 40 C.F.R. Part 82).

R-454C (GWP 150), and R-457A (GWP 140) as substitutes in the same application. All six of these refrigerants are non-ozone depleting substances and fall into the American Society of Heating, Refrigeration and Air Conditioning Engineers' (ASHRAE's) A2L safety group classification, indicating low flammability and low toxicity. R-410A achieves a higher safety classification (A1: no flammability and low toxicity); however, its GWP is 2,088—over three times more climatically damaging than R-32, the newest major alternative.

The following use conditions are required to reduce the (low) flammability risk of the newly accepted A2L refrigerants (R-32, R-452B, R-454A, R-454B, R-454C, and R-457A):

- The UL Standard Requirements 60335-2-40 regarding testing, charge sizes, ventilation, usage space, and hazard warnings and markers must be followed.
- The newly-approved refrigerants are approved only for use in new equipment, and cannot be retrofitted into existing equipment, with the exception of existing tubing if properly inspected and found to be suitable for use.
- All flammability warning labels must follow the specifications delineated in the Final Rule.
- All equipment must be properly marked to indicate flammable content. This includes, but is not limited to, red-colored hoses and marked refrigerant circuit ports.

Regarding the risk of leaks and fires, the Air Conditioning, Heating, and Refrigeration Institute (AHRI) has explained the low risk of flame propagation for A2L refrigerants as follows, ''[f]or almost all applications, air circulation will be sufficient to dilute the refrigerant concentration in the event of a catastrophic leak to below 25% of the LFL [Lower Flammability Limit]."[26] Since 2012, A2L refrigerants have been safely used in tens of millions of split systems in more than 90 countries. Multiple heat pump manufacturers, including Daikin, have endorsed replacing R-410A with R-32.

28. What does Maine State law require regarding refrigerants?

In June 2021, the 130th Maine Legislature passed LD 226, An Act To Limit the Use of Hydrofluorocarbons (HFCs) To Fight Climate Change. This new law provides for the phaseout of the use of the most environmentally damaging HFCs with high GWP in certain products and equipment for specified air conditioning, refrigeration, foam, or aerosol propellant end uses. The bill explicitly exempts heat pumps from the prohibitions in the law.[27]

On June 2, 2021, the Legislature's Joint Standing Committee on Environmental and Natural Resources sent a letter to EMT's Executive Director noting that, although not addressed in LD 226, they remain concerned about the issues posed by refrigerant leakage. They highlighted the possibility of imposing a fee upon refrigerants to fund a new program, potentially administered by EMT, focused on supporting the proper installation, repair, or servicing of products or equipment that have the potential to leak refrigerants. The Committee asked the Trust to conduct a review of leakage issues and the options for

[26] *Id*, p. 24462.
[27] Public Law, Chapter 192, 130th Maine State Legislature, First Regular Session, LD 226, An Act To Limit the Use of Hydrofluorocarbons To Fight Climate Change, 2021.

addressing those issues, including but not limited to the fee solution described above, and report back in early 2022 regarding any findings or recommendations from that review.

29. Does this conclude your testimony?

Yes.