Testimony submitted by Raymond J. Albrecht LLC on behalf of the
Massachusetts Energy Marketers Association

2022-2024 Three-Year Energy Efficiency Plans, D.P.U. 21-120 through D.P.U. 21-129

INTRODUCTION

I am a consulting environmental engineer and have worked for over 40 years in the subject area of renewable fuels. My technical specialties include the use of solid and liquid renewable fuels in power generation and thermal applications. I perform work relating to equipment design, fuel utilization, regulatory permitting, emissions testing, and life-cycle analysis. I have worked for manufacturing companies, trade organizations and environmental agencies. I am a member of the ISO New England Planning Advisory Committee and active with the ISO New England Load Forecasting Committee. I spent 30 years as lead technical staff person for heating technology and fuels R&D at the New York State Energy Research and Development Authority (NYSERDA). During the past 14 years, I have been principal of Raymond J. Albrecht LLC.

I am a graduate of Cornell University with an undergraduate degree in engineering and a Master of Science degree in Theoretical and Applied Mechanics. I am a Life Member of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and am past chairman of ASHRAE Technical Committee 6.10 for Fuels and Combustion. I received the ASHRAE Distinguished Service Award in 2015. I am a licensed professional engineer (No. 056935) in New York. I served as a 1st Lt (Infantry) in the United States Army during 1970-80 (active plus reserve) and am a graduate of the US Army Infantry Officer School at Fort Benning, Georgia. I fulfilled my active reserve obligation in northeastern Kenya, near the Somali border.

REFERENCES USED IN PREPARATION OF TESTIMONY

As the first step in preparation of this testimony, I compiled and reviewed a list of key testing reports that have been published over the past six years relating to actual field performance of cold-climate heat pumps.

The listed reports below represent the most frequently cited literature that has been published on field performance of cold-climate heat pumps:

1) Commonwealth Edison Company (2020). Cold Climate Ductless Heat Pump Pilot Executive Summary. Chicago, IL. https://www.comedemergingtech.com/images/documents/ComEd-Emerging-Technologies-Cold-Climate-Ductless-Heat-Pump.pdf

2) ISO New England (2020), Final 2020 Heating Electrification Forecast. Holyoke, MA. https://www.iso-ne.com/static-assets/documents/2020/04/final_2020_heat_elec_forecast.pdf

3) The Levy Partnership/NYSERDA (2019). Downstate (NY) Air Source Heat Pump Demonstration. Albany,
NY. https://static1.squarespace.com/static/5a5518914c0dbf4226cd5a8e/t/5d963d39f515f87c7bafe3ff/1570127329734/TLP+ASHP+Demo+Presentation+9.26.19.pdf

4) slipstream/Michigan Electric Cooperative Association (2019). Dual Fuel Air-Source Heat Pump Monitoring Report. Grand Rapids, MI. https://slipstreaminc.org/sites/default/files/documents/research/dual-fuel-air-source-heat-pump-pilot.pdf

5) Center for Energy and Environment (2018). Case Study 1 – Field Test of Cold Climate Air Source Heat Pumps. St. Paul, MN. https://www.mncee.org/MNCEE/media/PDFs/ccashp-Study-1-Duplex.pdf

6) Center for Energy and Environment (2018). Case Study 2 – Field Test of Cold Climate Air Source Heat Pumps. Minneapolis, MN. https://www.mncee.org/MNCEE/media/PDFs/ccashp-Study-2-MPLS.pdf

7) Center for Energy and Environment/Minnesota Department of Commerce, Division of Energy Resources (2017). Cold Climate Air Source Heat Pump. Minneapolis, MN. https://www.mncee.org/MNCEE/media/PDFs/86417-Cold-Climate-Air-Source-Heat-Pump-(CARD-Final-Report-2018).pdf

8) The Cadmus Group/Vermont Public Service Department (2017). Evaluation of Cold Climate Heat Pumps in Vermont. Montpelier, VT. https://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/Reports/Evaluation%20of%20Cold%20Climate%20Heat%20Pumps%20in%20Vermont.pdf

9) The Cadmus Group/Massachusetts and Rhode Island Electric and Gas Program Administrators (2016). Ductless Mini-Split Heat Pump Impact Evaluation. MA and RI. http://www.ripuc.ri.gov/eventsactions/docket/4755-TRM-DMSHP%20Evaluation%20Report%2012-30-2016.pdf

10) Center for Energy and Environment/American Council for an Energy-Efficient Economy/Minnesota Department of Commerce, Division of Energy Resources (2016). *Field Assessment of Cold Climate Air Source Heat Pumps*. 2016 ACEEE Summer Study on Energy Efficiency in Buildings. https://www.aceee.org/files/proceedings/2016/data/papers/1_700.pdf

11) Steven Winter Associates, Inc./National Renewable Energy Laboratory (2015). Field Performance of inverter-Driven Heat Pumps in Cold Climates. VT and MA. https://www.nrel.gov/docs/fy15osti/63913.pdf

12) The Levy Partnership and CDH Energy Corp./NYSERDA (2014). Measured Performance of Four Passive Houses on Three Sites in New York State. Albany, NY. https://static1.squarespace.com/static/5a5518914c0dbf4226cd5a8e/t/5ab273db562fa758761512bd/1521644514205/Measured-Performance-of-three-Passive-Houses+%283%29.pdf

Additional field studies of cold-climate heat pump performance are known to be currently underway in Massachusetts and New York but no information has been published relating to their scope or interim results.

SUMMARY CONCLUSIONS - USE PATTERNS AND FIELD PERFORMANCE OF COLD CLIMATE HEAT PUMPS SIGNIFICANTLY IMPACT EMISSIONS REDUCTION ASSESSMENTS

Studies of cold climate heat pump field performance, combined with electric use data, indicate that renewable liquid fuel use in heating applications is a more effective pathway to earlier, greater greenhouse gas emissions reductions. The transition to renewable liquid fuels can be achieved at a near zero cost, compared to cold-climate heat pump installations. Further, heating with biofuel boilers and furnaces aligns well with consumer use patterns compared to heat pumps, which broadly experience low utilization in winter weather.

Understanding real world electrical loads, cold-climate heat pump field performance and customer use patterns using the most accurate science allows the accurate assessment of a broader range of solutions to drive the maximum environmental benefits possible. Emissions factors rooted as much as possible in real-world measurements, rather than assumptions, are much less prone to error.

NEED FOR USE OF MARGINAL EMISSION RATES IN EVALUATION OF ELECTRIFICATION MEASURES

A recent publication by the Rocky Mountain Institute (RMI) states that a growing number of environmental organizations, when evaluating the emissions impacts of changes to grid loads or power production, "have been mis-applying average emissions factors to estimate the impact of environmental decisions. To protect against this mistake, the correct way to measure the impact of environmental decisions is to use *marginal* emissions factors. Marginal emissions factors measure the actual environmental consequences of taking different potential actions on the power grid."

See additional details in the informative RMI document entitled, On the Importance of Marginal Emissions Factors for Policy Analysis, which is available at https://rmi.org/combating-climate-change-measuring-carbon-emissions-correctly/ and also attached as an appendix at the end of this document.

See also https://www.watttime.org/app/uploads/2019/03/Automated-Emissions-Reduction-Primer_RMI-Validation_June2017.pdf and https://www.watttime.org/marginal-emissions-methodology/ for multiple additional references on the use of marginal emission rates for energy analysis. WattTime is a new, not-for-profit organization, subsidiary to the Rocky Mountain Institute, that collects and disseminates hourly, real-world data on grid performance to enable environmentally responsible electricity choices by large customers.

The use of average grid mix figures has unfortunately become pervasive among electrification advocates in the Northeast. Average grid mix figures result in a severe underestimation of increases in CO2 emissions that would result from implementation of electrification measures. The Mass Save program should become science-based in its evaluation of electrification programs through the implementation of ISO New England Marginal Emission Rates (MERs) in analyses. We encourage Massachusetts to seize the opportunity to become the Northeast leader in the proper use of marginal emission rates for energy policymaking.

As an additional note, Boston University recently procured a substantial amount of wind power for its campus. The following link leads to a presentation which includes an emphasis by the school on marginal emission rates for guidance in their power purchase agreement with the wind power supplier:

https://www.bu.edu/sustainability/files/2021/05/18-10-24-Carlberg-GBC-Renewable-Energy-Workshop-v04.pdf This signifies that the use of marginal emission rates has already gained interest among a number of environmentally conscious organizations in New England.

NEED FOR USE OF LIFE-CYCLE ANALYSIS OF ENERGY RESOURCES

It is of critical importance to use life-cycle analysis for energy policymaking. Onsite-based emissions evaluations generally fail to address the real-world challenges of bringing renewable energy resources to the market.

Argonne National Laboratory has been the host administrator of the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model for many years. GREET is a highly respected tool for modeling the life-cycle characteristics of energy resources.

The United Nations Intergovernmental Panel on Climate Change (IPCC) has issued a series of updates to its comprehensive documentation relating to evaluation of energy resources.

Both GREET and IPCC provide clear guidance on the evaluation of upstream emissions of energy resources. Notably, both have recently addressed the problem of methane leakage in compounding the environmental impact of natural gas. Massachusetts energy agencies are strongly encouraged to join the international community in recognizing and quantifying the environmental impact of methane leakage.

EVALUATION OF RESULTS FROM FIELD TESTING OF COLD-CLIMATE HEAT PUMPS

The efficiency of cold climate heat pumps in the field has been documented as 20% to 30% below current manufacturer ratings. Based on the data included in the reports listed above, I have put together a series of graphs that illustrate heat pump performance and homeowner characteristics noted regarding utilization of their heat pumps.

The first graph below shows heat pump Coefficients of Performance (COPs) vs. outdoor temperature, as derived from the field testing studies. The graph includes average manufacturer ratings of heat pumps (red data curve) used in the various field studies listed above. The graph also shows actual field testing results published in the listed reports. The graph shows how heat pump COPs vary with outdoor temperature. It is also possible to see the trend of actual performance falling below manufacturer ratings for most studies.

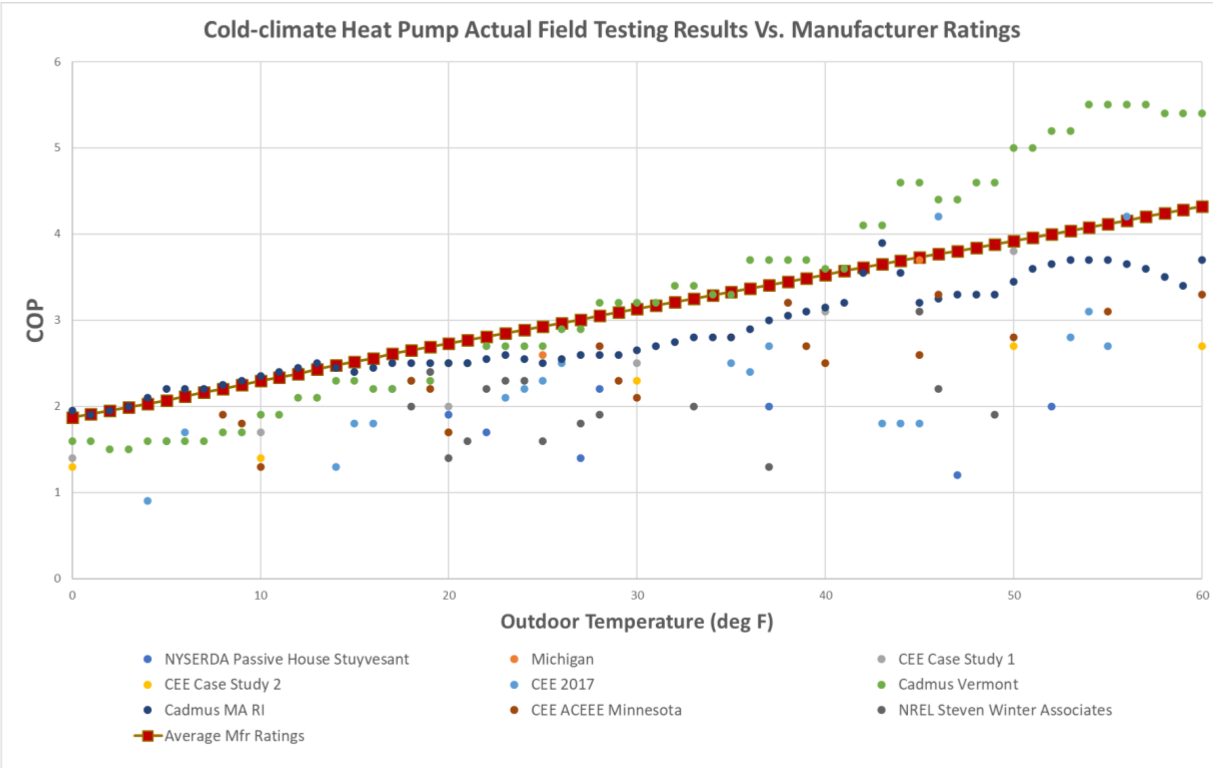

Figure 1. Cold-climate Heat Pump Actual Field Testing Results vs. Manufacturer Ratings

The next graph shows annual COPs measured by several of the field test studies. The graph shows manufacturer ratings for a representative sample of products used in the field testing studies (see gray bars). Actual cold-climate heat pump field testing results fall below manufacturer ratings. The green, yellow and red bars show measured COPs published in the reports, which noted that some results were skewed upward due to higher utilization during mild weather and lower utilization during cold weather. The two largest studies (Cadmus Vermont and Cadmus MA RI) noted particularly low utilization rates among the participating homeowners during the winter.

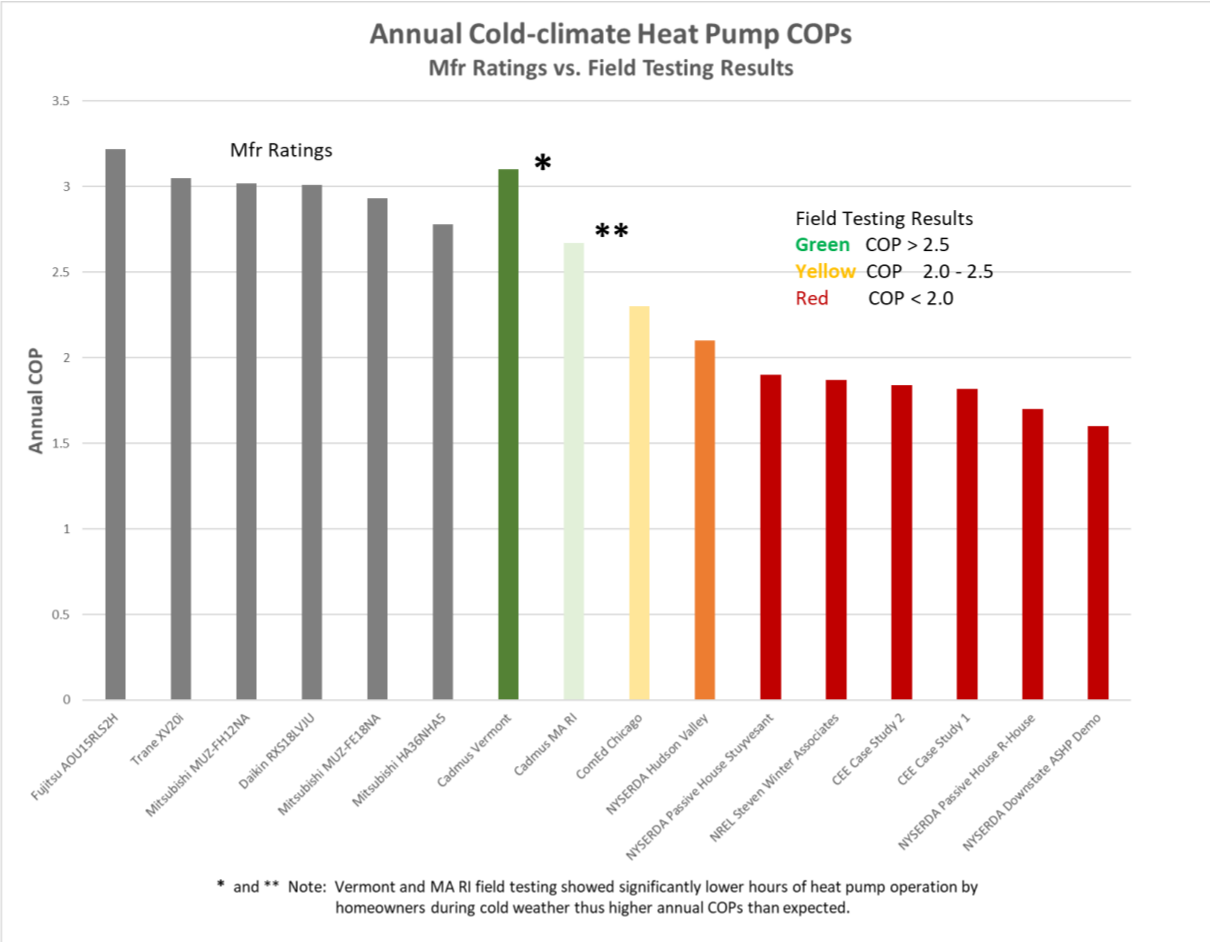

Figure 2. Annual Cold-climate Heat Pumps COPs

Annual cold-climate heat pump COPs indicate much lower field efficiency than manufacturer ratings. Higher reported field efficiency by VT and MA/RI field testing was due to low utilization in colder weather, not actual cold climate performance. Power demand graphs in the cited references indicate that the drop-out rate increased as the outdoor temperature went down. As noted again, such homeowner behavior resulted in artificially high measured, annual COP values since the performance data was skewed toward warmer temperatures. The remaining studies generally entailed, by design or mandate, a high utilization factor through the winter.

The manufacturer-rated seasonal COPs are generally around 3 or so, but the actual field testing results show values in the range of about 1.6 to 2.3 (see color coding of graph bars), which translates into a loss of about 20 to 30% from the manufacturer-rated values. The resulting conclusion is that, especially if the lower COP figures are combined with the use of marginal/non-baseload carbon intensity figures for power generation (instead of average grid mix figures), plus life-cycle analysis of natural gas used for power generation, the GHG savings of cold-climate heat pumps, compared to traditional oil-fired systems, are significantly diminished.

Low heat pump utilization by customers in winter weather is a near universal phenomenon. The next two graphs address further the subject of homeowner utilization of cold-climate heat pumps.

Three of the studies (Cadmus VT/Cadmus MA and RI/ISO New England) looked at power consumption among large populations of heat pumps. They showed that homeowners were, on average, using their heat pumps for less than half of the potential winter hours of operation. Some homeowners indeed used their heat pumps dutifully even during the coldest days of winter, but most dropped out at some point as the weather got colder, or never even turned on the systems at all for heating purposes.

This raises the thorny issue of homeowners taking advantage of heat pump incentive programs to purchase systems that are used substantially for cooling and only partially for heating, whether upfront incentives vs. pay-for-performance should be provided to homeowners, and whether ratepayer vs. utility shareholder funds should be used for heat pump incentive programs.

PERFORMANCE OF HEAT PUMPS IN NEW ENGLAND

The graph below shows average electrical demand vs. outdoor temperature within the heat pump populations of the three largest field studies. The graph shows a representative electric demand for a full-sized heat pump with capacity of 40,000 Btu/hr at 0 deg F, also for a partial-sized heat pump with a capacity of 15,000 Btu/hr at 0 deg F. The data curves for the three field studies show that actual electricity consumption was only a small fraction of what would be expected with full heat pump utilization. Note that the actual electrical demand curves are relatively flat below 30 deg F. This indicates very low heat pump utilization below 30°F. Since heat pump power demand increases dramatically as the outdoor temperature drops further, due to increasing heat load plus decreasing heat pump COP, this means further that the homeowner percentage drop-out rate is increasing as the temperature drops.

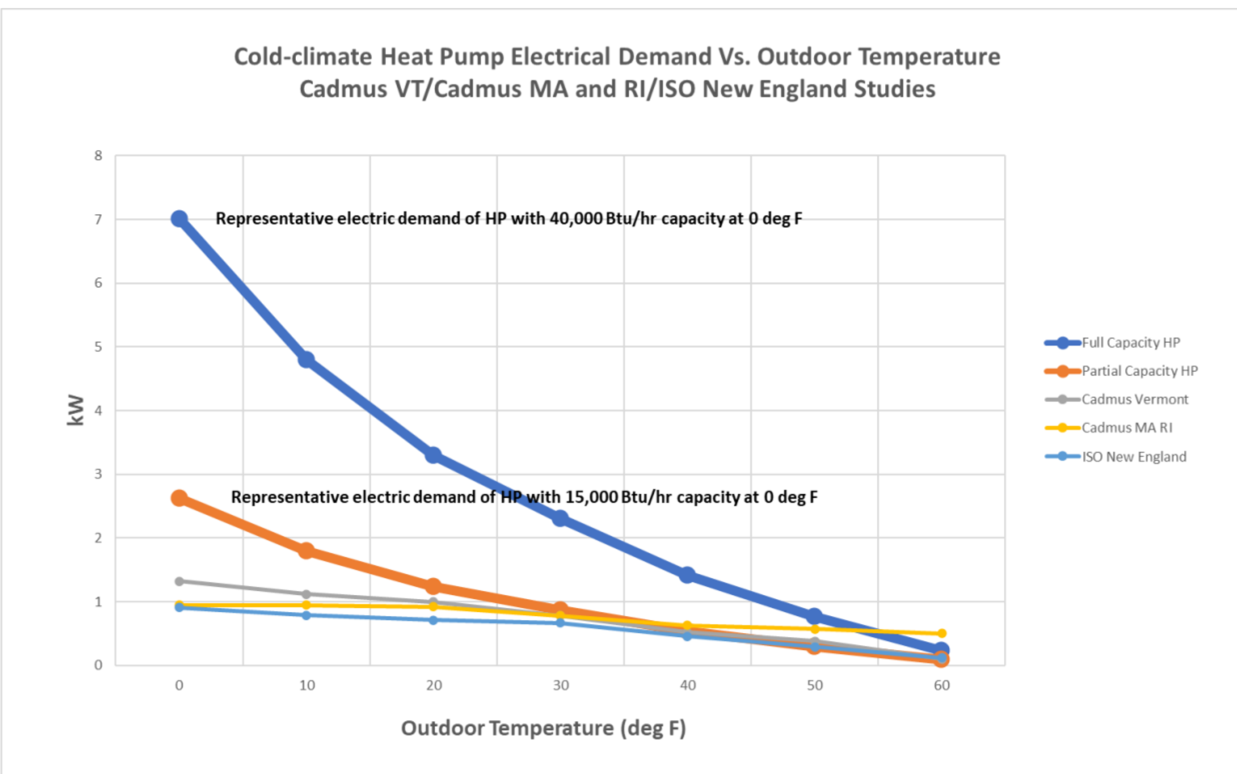

Figure 3. Cold-climate Heat Pump Electrical Demand vs. Outdoor Temperature

The bar graph below illustrates, in a different format, the same message re: low homeowner utilization of heat pumps during the winter. It is important to note that most of the test sites in the ISO New England and Cadmus MA RI studies were in Massachusetts. There is direct relevance of the heat pump utilization question to policymaking for incentive programs in Massachusetts.

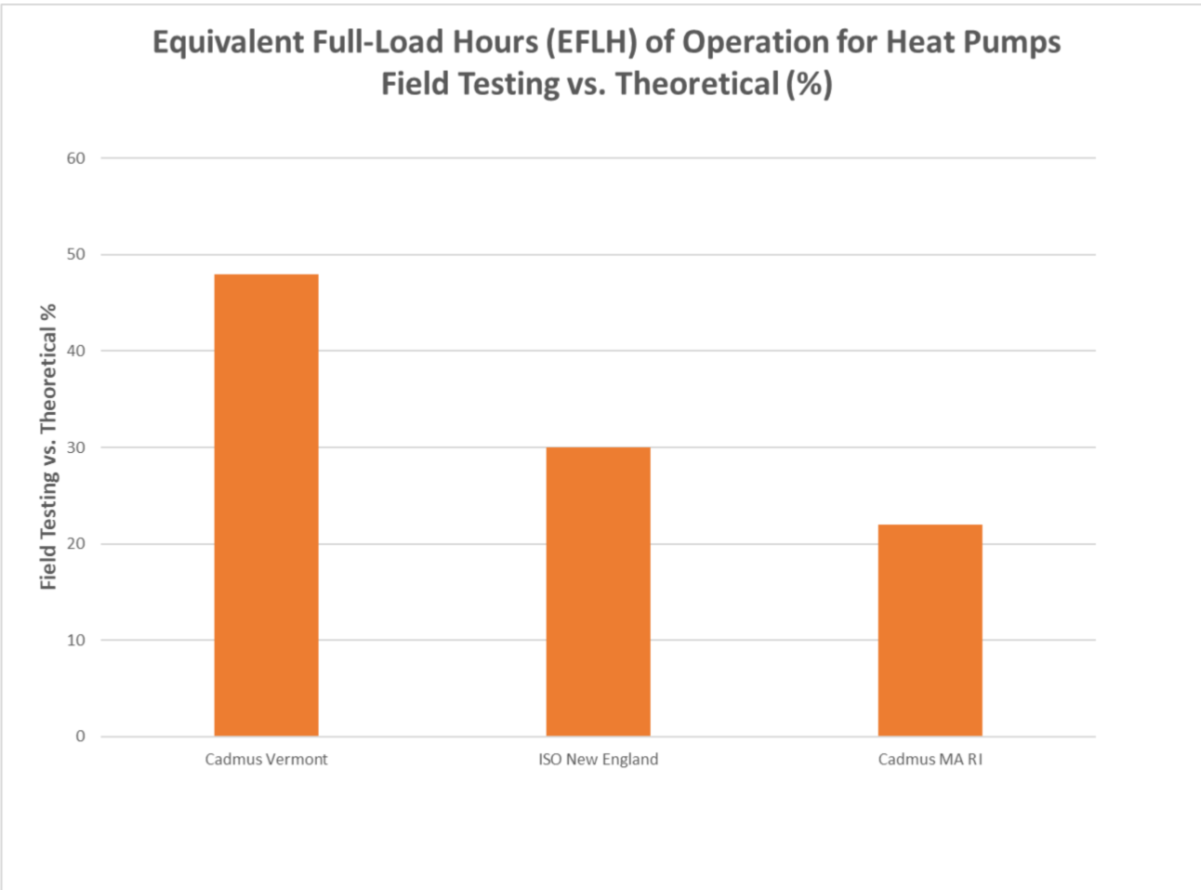

Figure 4. Equivalent Full-Load Hours of Operation for Heat Pumps

For preparation of this testimony, I used USEPA AVERT (AVoided Emissions and geneRation Tool) software to do an hourly analysis of ISO New England grid impacts from residential heat pumps. See https://www.epa.gov/avert and https://www.epa.gov/avert/avert-overview-0 for more information about the AVERT program.

USEPA's AVERT software performs deep analysis of which power plants would increase/decrease their output in response to grid load changes and what the corresponding changes in fuel use and emissions would occur. AVERT software uses the EPA national Air Markets database, which incorporates hourly efficiency and emissions performance data for all power plants in the United States over 25 MW capacity. There are over 100 such power plants in New England.

AVERT software can calculate the hourly, regional (e.g., New England), marginal impact of reductions in grid load due to energy efficiency measures, as well as increases in grid load due to intentional loadbuilding measures such as heat pumps and electric vehicles. AVERT software also can predict the hourly, marginal impact of renewable generation by resources such as solar PV and wind power, using actual weather data. AVERT also predicts local changes in power generation output levels by individual generating plants within a specified region.

The AVERT 3.1 software version released just this past October also incorporates direct linkage with USEPA Co-Benefits Risk Assessment (COBRA) public health and Sparse Matrix Operator Kernel Emissions (SMOKE) air quality input software packages. This allows for direct modeling of public health and air quality impacts (NOx/SOx/etc) of changes in load or generation output within a regional grid. This enables the evaluation of air quality deterioration in environmental justice communities located adjacent to fossil-fired power plants as grid loads increase due to electrification.

AVERT spreadsheets are somewhat bulky, with typically close to 9,000 rows in height and many columns wide, but are nevertheless relatively user-friendly. Ancillary spreadsheet analysis of grid loads, using digital, hourly (8760 hours per year) weather data and heat pump performance formulas, can be easily copied into AVERT spreadsheets to yield highly informative, power generation and emissions outputs. Massachusetts DPU/DOER staff are encouraged to use AVERT software if they are not already doing so.

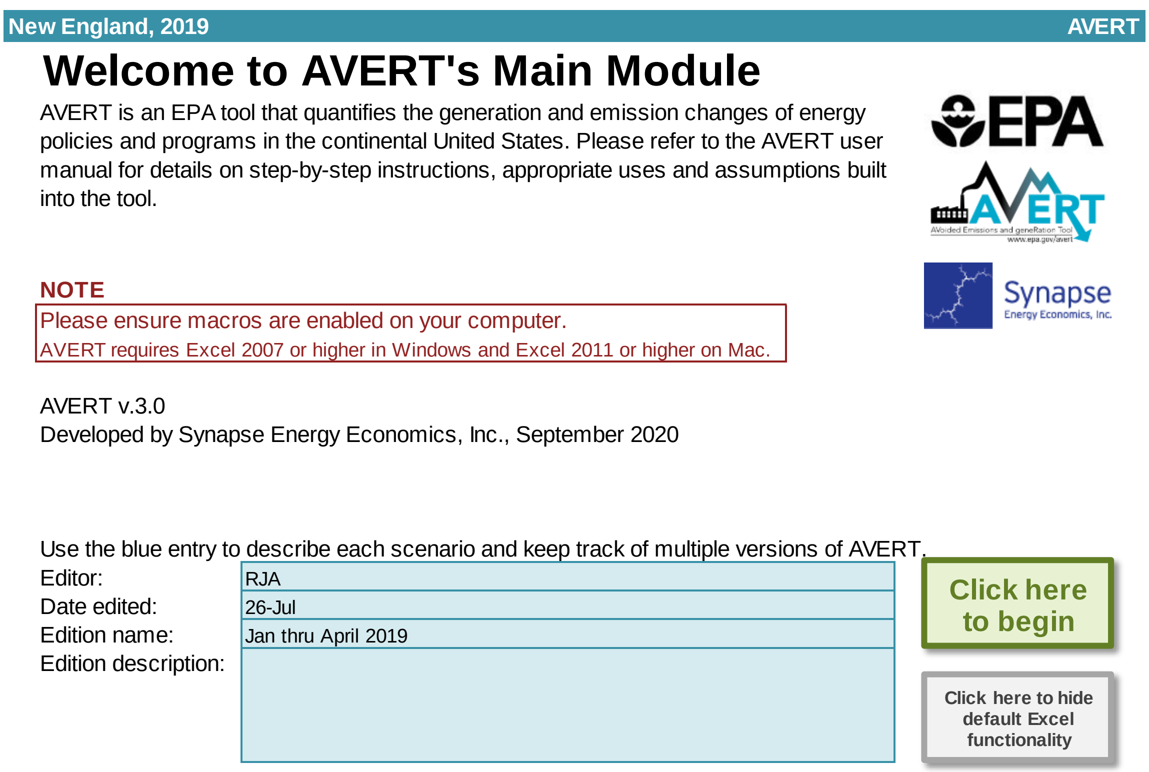

Figure 5. Homepage for USEPA AVERT Software

In the analysis referred to in this testimony, I used digital weather data for Worcester MA during the year 2019, which is the most recent year that could be modeled under the AVERT program. I used a peak design heating load of 32,000 Btu/hr for a single-family home, which corresponds to an annual fuel consumption of about 800 gallons of liquid fuel for space heating.

I used heat pump performance data from the literature referenced above, including two scenarios of 1) accept manufacturer ratings as published, and 2) conservative 10% deduction from manufacturer ratings to represent actual field performance in anticipation that current product development efforts will be successful in achieving improvements that could then be marketed within the next five years. To note, a deduction for field performance would be somewhat greater for currently marketed products, but I chose to be more forward looking.

The graphic below shows summary results from adding 100,000 heat pumps to the ISO New England grid. To note, the AVERT program automatically adds 8% to incremental end-user loads to account for transmission/distribution line losses between the points of power generation and end-use. **The results of the AVERT analysis of the installation of 100,000 cold climate heat pumps using field performance from the studies demonstrate a higher carbon intensity than traditional heating oil below 45°F(need to calculate), and a higher carbon intensity than B20 – a 20% blend of biodiesel in a gallon of heating oil – throughout the entire temperature range below 70°F.**

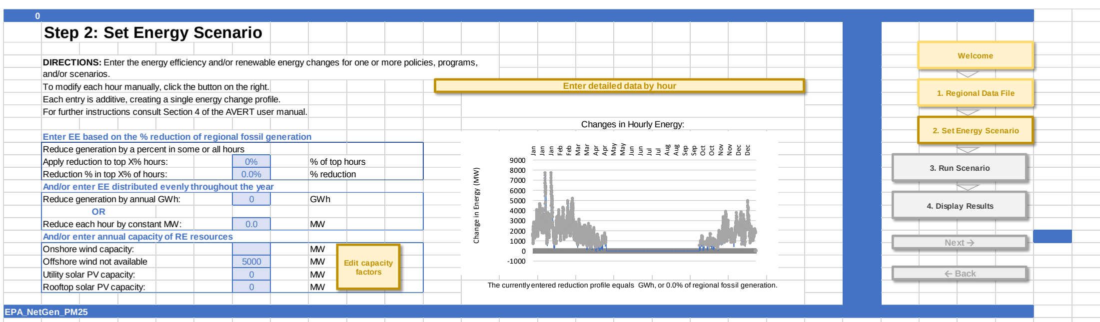

Figure 6. Screenshot of AVERT input page showing grid load input data.

AVERT software produces an array of output tables and graphs ranging from hourly to annual figures. The information can then be further processed to evaluate the environmental characteristics of changes to grid loads or generation outputs.

New England, 2019 **AVERT**

Output: Annual Regional Results

Click here to return to Step 4: Display Outputs

	Original	Post Change	Change
Generation (MWh)	41,709,790	42,632,450	922,650
Total Emissions from Fossil Generation Fleet			
SO_2 (lbs)	1,605,630	1,694,870	89,240
NO_x (lbs)	6,991,920	7,159,330	167,410
CO_2 (tons)	22,265,850	22,742,700	476,850
$PM_{2.5}$ (lbs)	1,219,700	1,244,170	24,470
Fossil Generation Fleet Emission Rates			
SO_2 (lbs/MWh)	0.038	0.040	
NO_x (lbs/MWh)	0.168	0.168	
CO_2 (tons/MWh)	0.534	0.533	
$PM_{2.5}$ (lbs/MWh)	0.029	0.029	

Negative numbers indicate displaced generation and emissions.

All results are rounded to the nearest ten. A dash ("—") indicates a result greater than zero, but lower than the level of reportable significance.

Figure 7. Screenshot of AVERT annual regional output and emissions data for 100,000 heat pumps in New England

Figure 7 shows that total generation would have to increase by 922,660 MWH per year, which represents additional, onsite electricity usage of approximately 8,000 kWh per home. There would be an increase of 476,850 tons of CO2 emissions associated with the increase in grid load. The corresponding Marginal Emission Rate (MER) for the 100,000 heat pump scenario would be approximately 0.52 tons/MWh (compared to the corresponding average grid mix figure of less than half of the MER) which reflects that the primary sources of marginal electricity generation would entail the use of natural gas, oil and coal. AVERT software is correctly based on the use of marginal analysis, rather than average, annual grid mix figures as often, and incorrectly, espoused by heat pump advocates. One important note, however, the AVERT software incorporates onsite power generation emissions, as reported to the USEPA air markets program. AVERT software does not reflect, however, life-cycle analysis of fuels used for power generation, as has been the case with Argonne National Laboratory GREET software and United National Intergovernmental Panel on Climate Change (IPCC) evaluation guidelines.

The table below is a very small sample of the output of the AVERT model. The model shows which power plants will increase/decrease their output and emissions, based on changes in grid load. Again, AVERT model also connects directly to the EPA COBRA (health effects) and SMOKE (air quality forecasting) computer models, which can then identify environmental justice communities that would suffer from increased power plant emissions.

Generation (MW) New England (NE)

Click here to return to Step 4: Display Output

									ORSPL	58054	1595	55126	55126	55317	55149	56047	54907
									UNITID	ST01	4	CT01	CT02	11	LRG2	1	1
Hour	Year	Month	Regional L	Energy Ch	Load after Energy Ch	Timestamp	Orig Gen (	Post Chan	Sum: All U	Burgess Bic	Kendall Gr	Milford Pov	Milford Pov	Fore River	Lake Road (	CPV Towa	MIT Centr
1	2019	1	2259	1,652	3910.919	01/01/2019 00:00	2,252	3,932	1680.086	1.177	15.183	31.805	30.373	48.671	13.685	16.786	-0.897
2	2019	1	2288	1,652	3939.919	01/01/2019 01:00	2,281	3,953	1671.784	1.107	12.635	32.832	32.017	50.472	9.373	13.88	-1.166
3	2019	1	1944	1,498	3441.726	01/01/2019 02:00	1,938	3,445	1506.605	0.259	27.161	39.047	30.049	14.466	23.499	42.516	-2.135
4	2019	1	1879	1,448	3327.018	01/01/2019 03:00	1,874	3,320	1445.271	-1.702	30.659	34.215	35.429	5.892	28.018	47.653	-3.517
5	2019	1	1781	1,244	3024.919	01/01/2019 04:00	1,778	3,012	1233.478	-2.359	26.666	33.931	29.331	-14.675	35.82	51.917	-4.344
6	2019	1	1917	1,059	2976.402	01/01/2019 05:00	1,912	2,972	1059.843	-2.27	24.343	26.449	24.19	-6.853	26.897	38.558	-3.049
7	2019	1	2119	840	2959.374	01/01/2019 06:00	2,110	2,957	847.649	-2.337	16.266	19.244	14.552	-4.965	18.784	23.098	-1.841
8	2019	1	2201	812	3013.08	01/01/2019 07:00	2,193	3,002	809.47	-1.802	9.568	20.659	8.062	-6.425	19.769	22.993	-1.993
9	2019	1	2471	762	3232.892	01/01/2019 08:00	2,469	3,221	751.425	-2.262	12.232	17.54	11.142	23.524	9.864	17.605	-1.835
10	2019	1	2585	696	3281.418	01/01/2019 09:00	2,587	3,269	681.7	-4.347	8.473	16.756	8.087	11.175	13.911	19.563	-3.569
11	2019	1	2535	691	3226.034	01/01/2019 10:00	2,535	3,214	678.841	-3.715	10.385	17.41	11.112	14.819	12.411	16.443	-2.711
12	2019	1	2402	696	3098.418	01/01/2019 11:00	2,398	3,088	690.057	-0.462	10.929	17.98	8.341	24.219	8.756	12.084	-0.582
13	2019	1	2422	863	3285.225	01/01/2019 12:00	2,419	3,273	854.16	-0.596	13.278	17.522	8.945	32.854	7.434	20.611	-1.208

Figure 8. Partial screenshot of AVERT output table

COMPARISON OF HEAT PUMPS WITH RENEWABLE LIQUID FUELS

The next graph shows hourly data points for carbon intensity (lbs per MMBTU of delivered heat), as a function of outdoor temperature, for biodiesel blends vs. heat pump manufacturer ratings close to published marketing figures. The blue data points represent heat pumps with varying time-of-day characteristics and Marginal Emission Rates (MERs) for the ISO New England grid, which are strongly influenced by diurnal peak/off-peak periods.

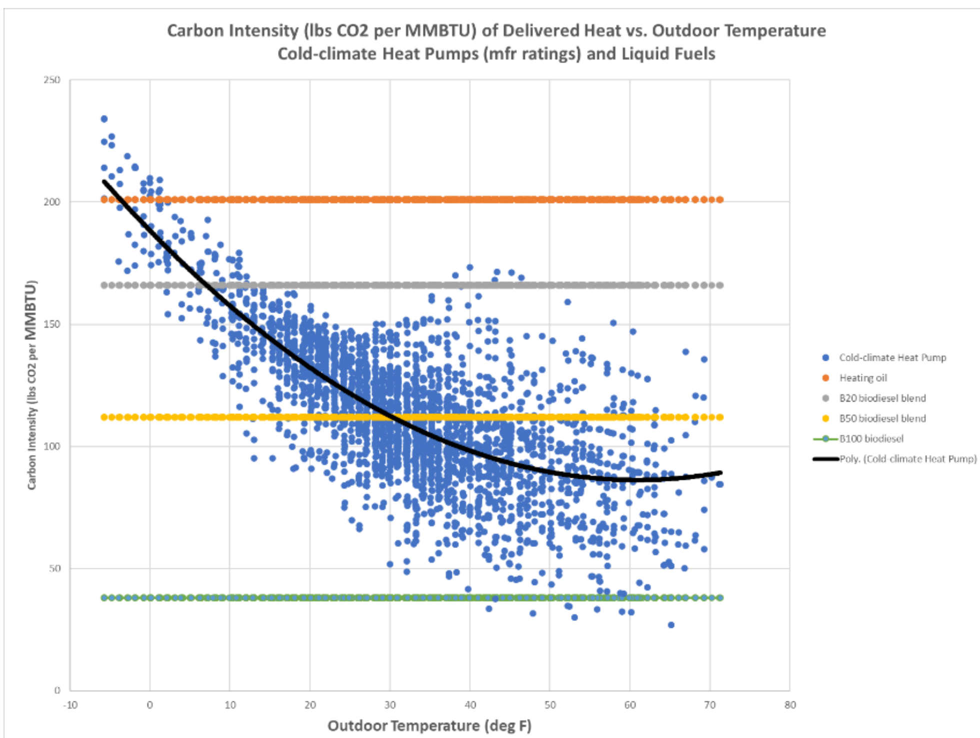

Figure 9. Carbon Intensity of Delivered Heat vs. Outdoor Temperature

In the above graph, the black curve is a second order polynomial fit to the heat pump data. The graph shows that, if close to manufacturer ratings (which are significantly higher than field studies indicate) are used, and if life-cycle analysis is not used for natural gas input for power generation, heat pumps would have lower carbon intensity than a B50 biodiesel blend (yellow line) at temperatures above 30 degrees F, and higher carbon intensities than B50 at temperatures below 30 deg F. B100 (green line) would be the lowest carbon choice, however, during nearly all temperature-grid-MER combinations.

If the AVERT modeling is modified to incorporate life-cycle analysis of natural gas used for power generation, however, the carbon intensity results shift significantly. Many analyses performed by electrification advocates have incorporated just onsite, direct CO2 emissions for power generation, while also wrongly using average annual grid, rather than marginal, emissions figures, while nevertheless charging a full life-cycle analysis burden against liquid fuels.

As previously noted, two major reference sources, including the Argonne National Lab GREET 2021 model, as well as the recent United Nations Intergovernmental Panel on Climate Change (IPCC) 2019 Update Report, have correctly addressed the environmental characteristics of natural gas used for power generation.

Both the GREET and IPCC references incorporate a methane leakage rate of approximately 0.7% of the volume of natural gas used for power generation. This accounts for methane loss during natural gas production and high-pressure transmission to power plants (but not through any local distribution piping).

If a 100-year timeframe is used for analysis (GHG factor for NG = 25 compared to CO2), the 0.7% methane leakage rate results in about a 9 percent increase in the carbon intensity of natural gas that reaches the power plant. If a 20-year timeframe is used, however, for analysis (GHG factor for NG = 84 compared to CO2), the 0.7% methane leakage rate results in about a 25 to 30 percent increase in the carbon intensity. There is growing support for the use of 20-year greenhouse gas analysis since that reflects the timeframe that is now perceived as necessary for addressing climate change.

The graph shown in Figure 9 above was then modified to reflect the life-cycle analysis of natural gas used for power generation. See figure 10 following below.

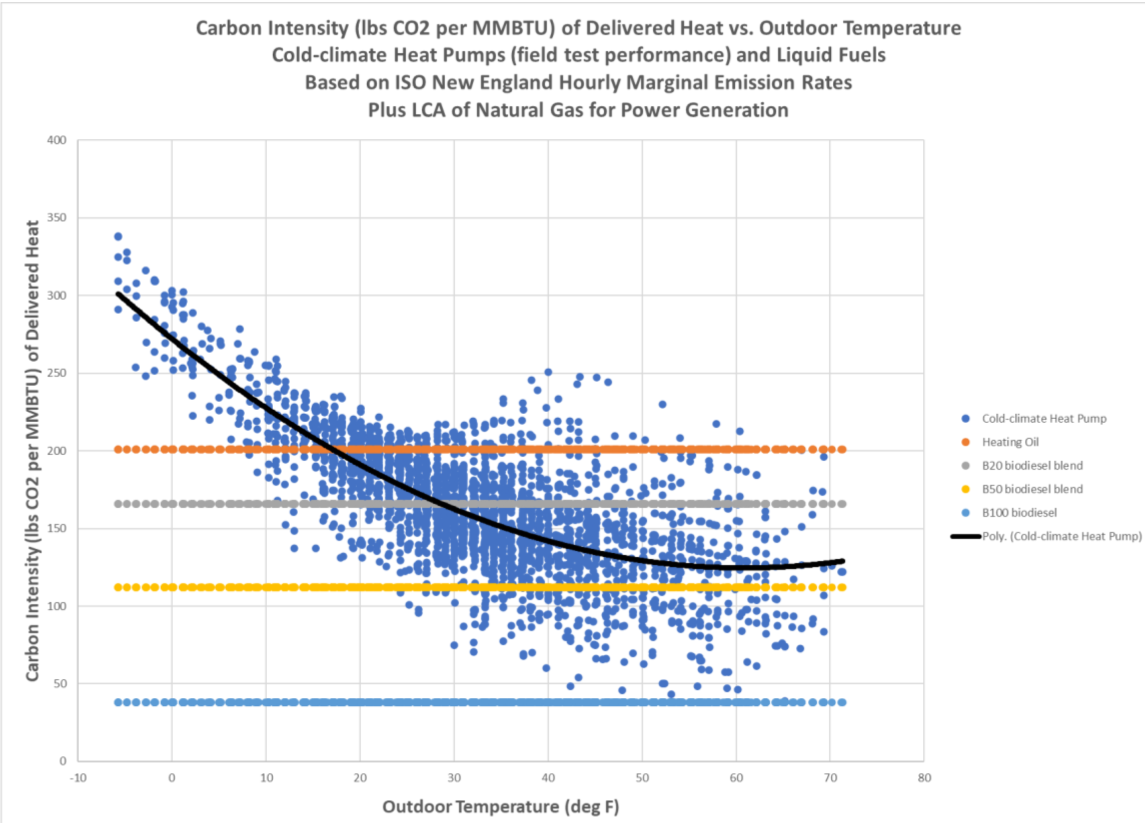

Figure 10. Carbon Intensity of Delivered Heat vs. Outdoor Temperature Based on Life-cycle Analysis of Natural Gas for Power Generation

The revised graph above now shows that B50 (yellow line) has lower carbon intensity than cold-climate heat pumps (black curve) throughout the entire temperature range below 70 deg F.

The next bar graph shows that actual carbon savings for heat pumps will be only about 15 percent compared to traditional oil, rather than the 40+ percent savings that are usually claimed by electrification advocates. The results also indicate that B20 has lower carbon intensity that cold-climate heat pumps.

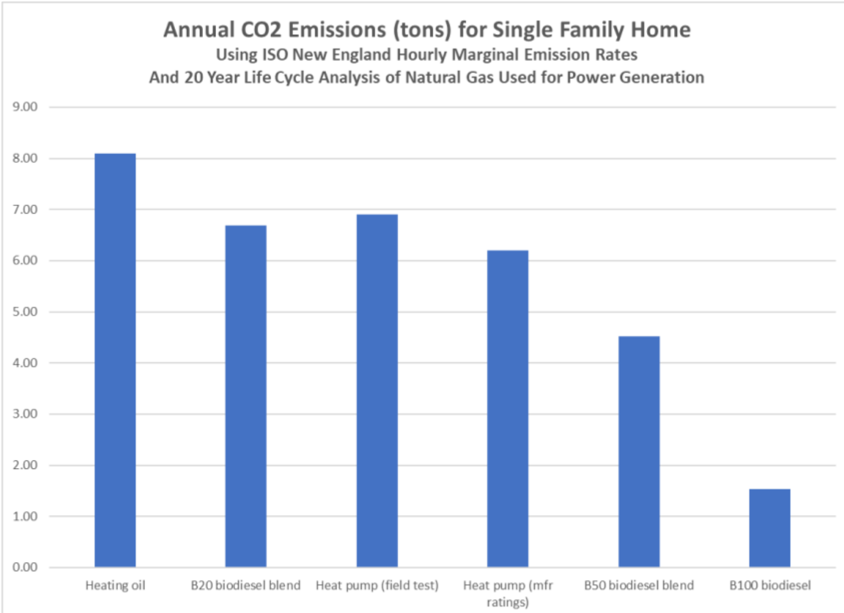

Figure 11. Annual CO_2 Emissions (tons) for Single Family Home

IMPACT ON GRID LOADS IN NEW ENGLAND

The next graph shows the expected ISO New England grid load growth that would occur if heat pumps were to be installed in 1 million homes. The 1 million heat pump figure represents the approximate total goal for heat pump installation by 2030 in the six New England states. **Installing 1,000,000 heat pumps by 2030 in New England would require an additional 8000 MW of generation capacity, with about 4000 MW additional generation required to service commercial buildings converted to heat pumps at the same market penetration rate, and even more for electric vehicles. The wind projects planned for the next 10 years off Martha's Vineyard, even if fully developed, will be just barely sufficient to start eliminating fossil generation for present grid loads, without accounting for heat pumps or transportation growth.**

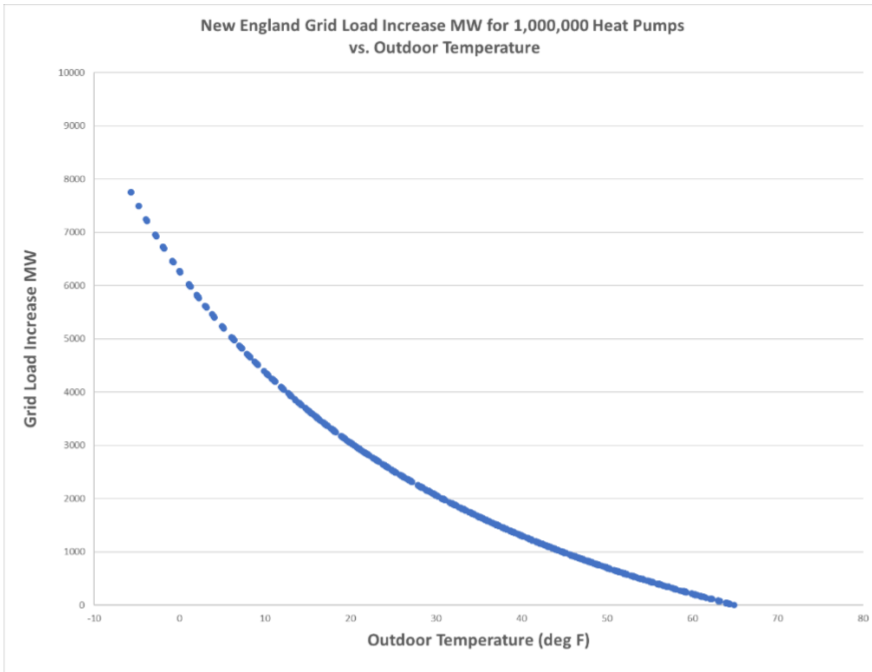

Figure 12. New England Grid Load Increase for 1,000,000 Heat Pumps vs. Outdoor Temperature

The next graph shows the grid load growth if 5 million residential heat pumps (roughly 90 percent market penetration) were to be installed in New England. The corresponding load growth, by approximately 40,000 MW, would take us into completely uncharted territory. **Adding 5 million cold-climate heat pumps to the grid would triple the ISO New England winter grid load, before accounting for commercial buildings or electric vehicles.**

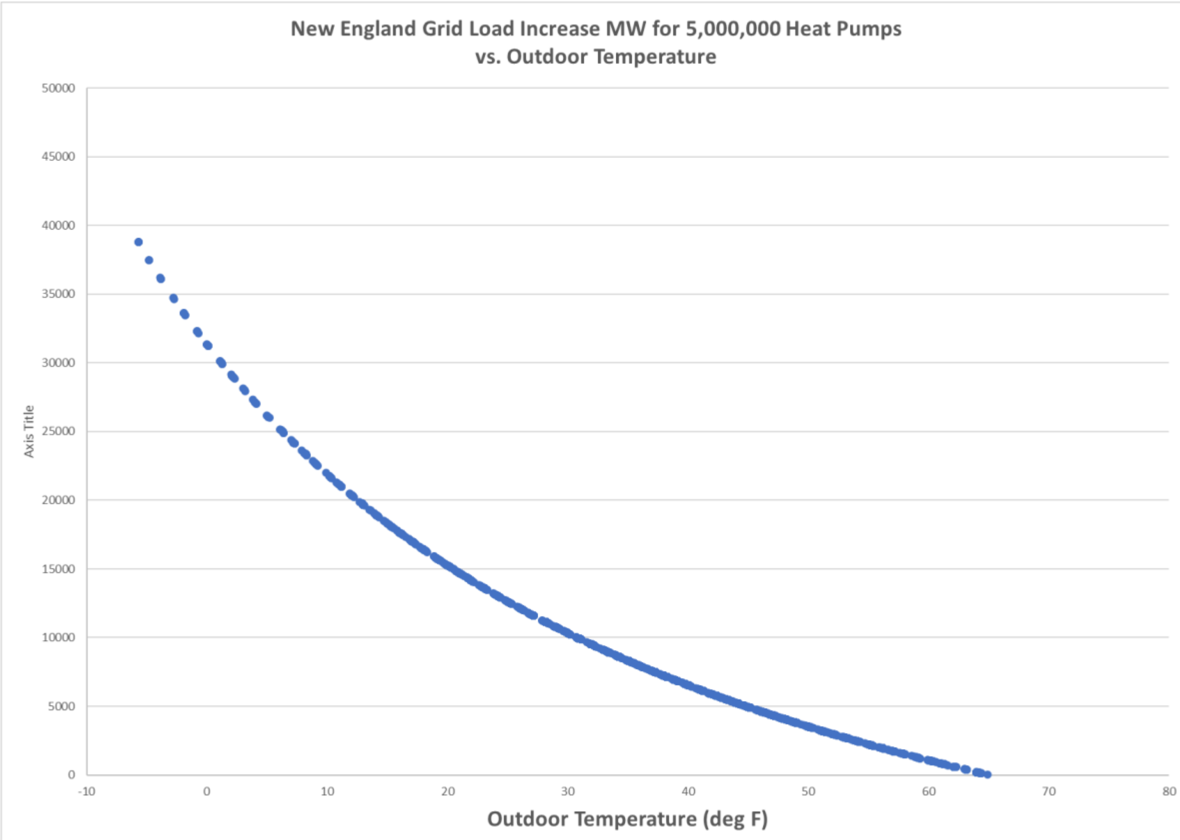

Figure 13. New England grid load increase (MW) for 5,000,000 heat pumps

NEED FOR HIGHER LEVELS OF RENEWABLE POWER GENERATION BEFORE ELECTRIFICATION CAN ACHIEVE ENVIRONMENTAL BENEFITS

The next graph shows the offshore wind capacity that would be required to meet the winter heating loads of 5 million cold-climate heat pumps. The blue bars represent the monthly peak MW loads resulting from 5 million residential heat pumps. Again, for energy analysis of commercial buildings, we would normally add about 50% of the residential load. Energy policymakers should consider the fact that 5 million residential heat pumps would approximately triple the ISO New England winter grid load, before accounting for commercial buildings or electric vehicles. The orange bars represent the nameplate capacity of offshore wind that would be required, assuming that battery storage is also installed with a full 3-day capability to ride through combined peak heating load and low wind output conditions, which can occur in New England. For a home with a 7-kW peak electrical demand for heating, the required worst-case, 3 day storage could require as much as 500 kWh capacity. If utility-scale battery storage were to cost $200 per kWh (or $200,000 per MWh), the cost of storage would be approximately $100,000 per home.

To counter the popular argument that the grid is becoming cleaner, so not to worry about power generation emissions due to heat pumps installed now, the next (and final) graph below shows the results of the AVERT program relating to the year 2030 scenario in which 1 million residential heat pumps and 5,000 MW nameplate capacity of offshore wind have been installed in New England.

The fundamental problem is that 5,000 MW nameplate capacity of offshore wind eliminates the need for fossil-based power generation, to meet our present grid loads, on only a handful of days during the year. The orange slivers on top of the blue bars show the relative extent of wind energy that would be available for operating heat pumps. Any incremental loads such as heat pumps and electric vehicles over the next ten years will continue to simply increase fossil generation loads.

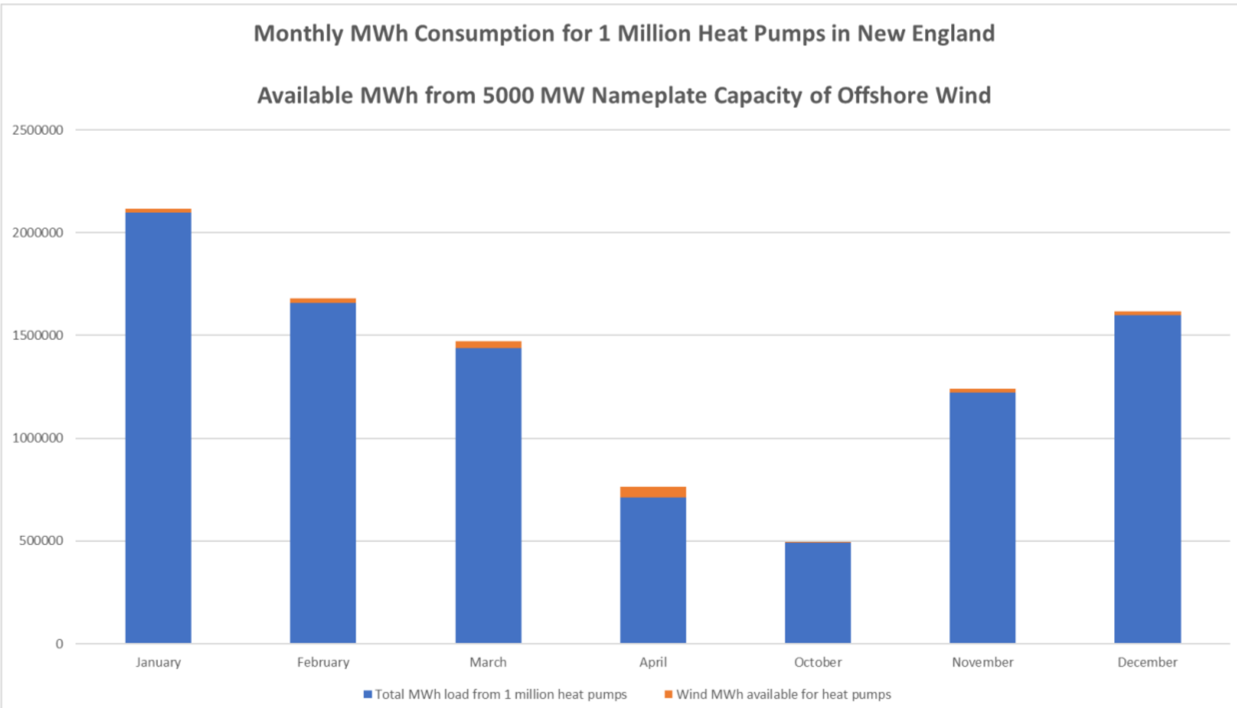

Figure 14. Month MWh consumption for 1 million heat pumps in New England with 5000 MW Offshore Wind

The Vineyard/Revolution/Deepwater/Mayflower offshore wind projects planned for the Martha's Vineyard coastal area are jockeying for a limited availability of transmission interconnection at the West Barnstable substation. Recent ISO New England Planning Advisory Committee deliberations have been consumed by the technical challenges of integrating offshore wind into the southeast Massachusetts grid. Even if transmission limitations are resolved, the wind projects planned for the next 10 years, even if fully developed, will be insufficient to eliminate fossil generation, except during a very few hours. Thus, any intentional grid load additions for heat pumps or electric vehicles will have to be met with fossil generation.

The result will be that most heat pumps installed today, if fully utilized for heating thus dealing with a service life of just 10 years or so, will not achieve a single molecule of CO_2 reduction compared to B50 or even B20.

APPENDIX

On the Importance of Marginal Emissions Factors for Policy Analysis

Environmental nonprofits WattTime and Rocky Mountain Institute recommend marginal rather than average emissions factors be used for analysis of policies whose goal is to reduce carbon emissions. This primer explains why.

The purpose of average emissions factors is to apportion environmental responsibility.

A common technique in environmental analysis is to divide responsibility for cleaning up pollution equally between the different actors in a power grid on the basis of their relative power consumption. For example, if a given city consumes 5% of all the electricity produced in a given power grid, it is simple and intuitive to call it responsible for 5% of all the emissions in that grid.

The virtue of this technique is its simplicity. Each city or company on a power grid can simply calculate the average emissions per each kilowatt-hour on its local power grid; measure its own kilowatt-hours consumed; and multiply to determine its "share" of a given grid's pollution.[1]

Average emissions factors should *not* be used to measure environmental impact.

Historically, average emissions rates have been a convenient way to apportion "ownership" of different organizations' responsibility for emissions. Unfortunately, as momentum builds for institutions to more actively manage emissions, a worrisome trend is the growing number of organizations mis-applying average emissions factors to estimate the impact of environmental decisions. Yet this approach does not accurately measure environmental consequences. Returning to the previous example, it's entirely possible that the exact 5% of the grid's electricity that city is consuming comes predominantly from aging natural gas power plants, which would mean comparatively high emissions.

The correct way to measure environmental impact is using marginal emissions factors.

To protect against this mistake, the correct way to measure the impact of environmental decisions is to use *marginal* emissions factors.[2] Marginal emissions factors measure the actual environmental consequences of taking different potential actions on the power grid.

If the example city is evaluating an energy efficiency measure to conserve one megawatt-hour of electricity consumption, this program will reduce local emissions by reducing output at one or more power plants. But *which* power plants? Many sources of power, for example most solar panels, are designed to send all the energy they can to the power grid no matter the level of energy demand. Thus, they will be completely unaffected.

[1] See, e.g. the GHG Protocol Corporate Standard.

[2] See, e.g. the GHG Protocol for Grid-Connected Electricity Projects.

Conserving energy only affects some power plants: those which can scale up or down in response, known as the "marginal" power plants. Marginal emissions measure the emissions per kilowatt-hour only from these power plants, thus accurately measuring real-world results.

Why using average emissions can lead to incorrect policy conclusions.

When a power grid experiences a change in energy demand—for example, adding electric vehicles, or installing new clean power—that changes the emissions from local power plants. But some power plants are completely unaffected, for example, most solar panels and nuclear plants.

Using average emissions factors to measure the effect of environmental decisions implicitly assumes that energy policy-making affects all power plants equally. This overestimates the effects on these unaffected plants, and underestimates the effects on the marginal plants which actually do change in response to policy. If these plants have different emissions rates, this can lead to incorrect measurement of policies.

This is a growing problem because the more "always-on" clean energy a region installs, the more inaccurate any analyses using average emissions factors become. For example, on Friday May 3rd, 2019 at 1:30 PM, the CAISO website reported the following data regarding real-time energy supply and emissions. CAISO was delivering 23, 690 MW of power at an emissions rate of 3,042 $mTCO_2$/hour. Nearly 50% of the total supply (12,086 MW), was from renewable sources. Using an approach of average emissions, one would say that the current emissions rate was 283lbs CO_2/MWh.[3]

However, the marginal emissions rate for the same time was much higher, at 927 lbs CO_2/MWh. Despite the high penetration of midday solar, if 1 MWh of load was added to the grid at this time, the solar plants would likely not be the type of fuel responding to the increased load. It is more likely that an inefficient gas generator would ramp to meet the increased load, thus creating an emissions impact of 927 lbs of CO_2.[4]

As seen here, true emissions rates can be up to four times higher than average emissions-based estimates would imply, with major consequences for policy evaluation.

If policymakers were to only allow technologies that were below the average emissions levels, they might inadvertently allow existing, inefficient generators to operate more than they intend. The result would be restricting projects are that good for the environment, instead of encouraging them.

[3] California ISO real-time energy data.
[4] WattTime marginal emissions data.

Common situations in which marginal emissions is most important.

Marginal emission factors should nearly always be used in environmental impact analysis. Leading researchers apply them when measuring everything from renewable energy, to electric vehicles, to energy storage.[5] But they have particular importance for public policy whenever a policy measure is comparing different options, for example:

- *Comparing what times are best to use or store energy*. Marginal emissions should be used to select which times are cleanest, such as for energy storage.[6]
- *Comparing where is best to site a new energy asset*. Marginal emission rates should be used to measure the impact of new renewable energy, particularly in selecting locations.[7]
- *Evaluating electrification*. Marginal emissions rates should be used when evaluating the environmental impact of electrifying fossil fuel technologies such as vehicles, water heaters, and appliances. For example, in some coal-heavy regions, switching from a gasoline-powered car to an electric vehicle can actually increase, not decrease emissions.
- *Evaluating low-emissions energy sources*. Marginal emissions rates should be used to evaluate the environmental impact of low-pollution electricity generation technologies such as fuel cells and biomass. These technologies are sometimes mistakenly thought to increase emissions if they emit more than the local average emissions rate. But in reality they reduce emissions anywhere they less than the local marginal emissions rate.

For more information about average vs. marginal emissions, see this joint WattTime-RMI post.

How to properly design policy based on data-driven marginal emissions rates

Several large, influential public agencies (the CPUC), and private customers are committed to accurately reducing carbon emissions by using marginal emissions analysis. In December of 2018, the CPUC staff released a draft regulation directing the commission to require entities utilizing public incentives in the Self Generation Incentive Program (SGIP) to use marginal emissions rates to determine the net GHG impact of their project.[8]

Creating effective regulations and policy, as the CPUC has done, requires thorough data analysis and stakeholder engagement. As an independent, third-party non-profit, WattTime was founded to guide policy makers and regulators through this process to ensure that their efforts accurately reduce greenhouse gas emissions.

[5] See, e.g. Hittinger and Azevedo (2015), Callaway et al (2017) or Fares and Weber (2017).
[6] E.g. the California Public Utilities Commission's decision to use marginal emissions in real time for energy storage.
[7] See, e.g. Boston University's recent decision to buy renewable energy outside Boston using marginal emissions.