APRIL 27, 2024

Final 2024 Heating Electrification Forecast

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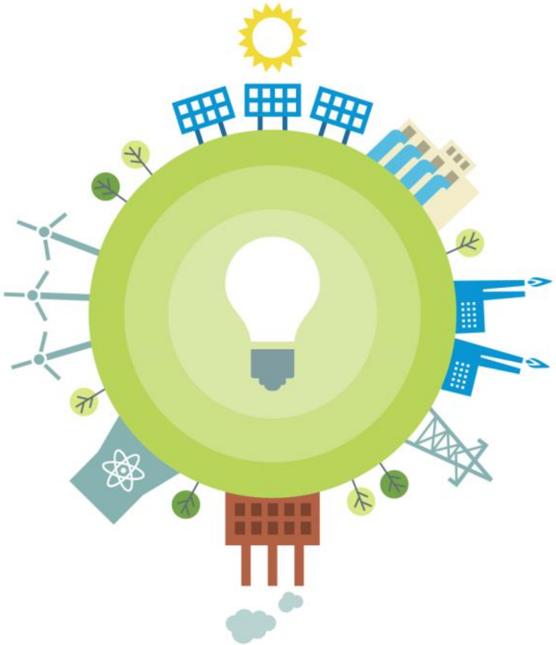


Introduction

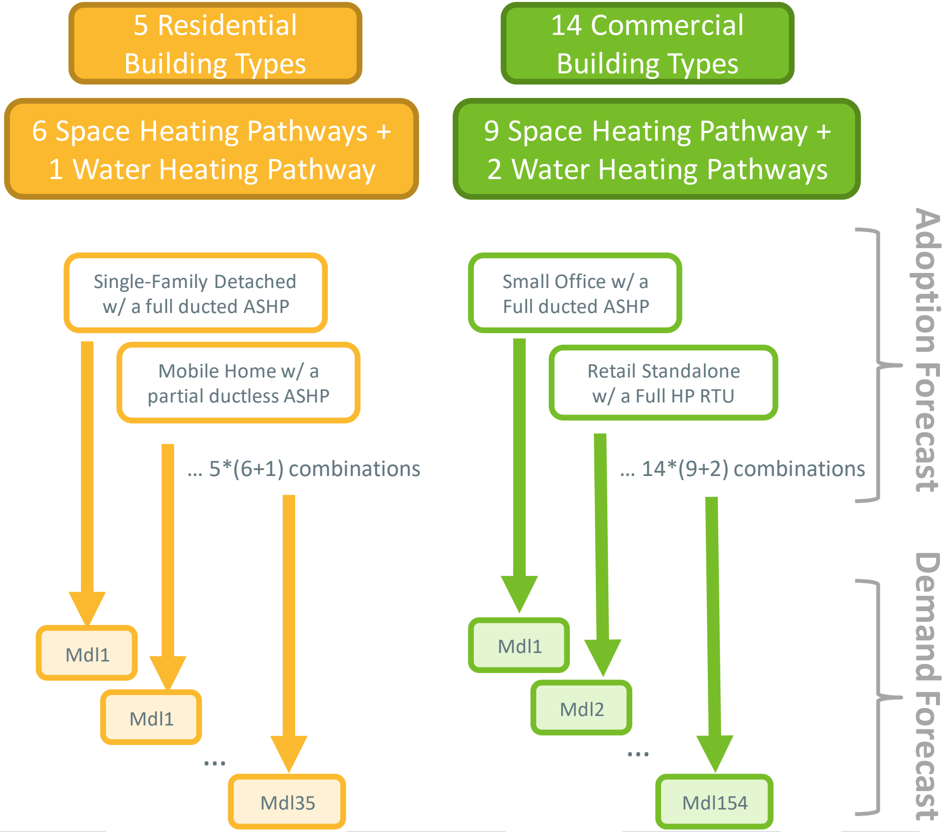
- Heating electrification is expected to play a pivotal role in the achievement of New England state greenhouse gas (GHG) reduction mandates and long-term decarbonization goals
- Forecasted impacts of heating electrification on state and regional electric energy and demand are included as part of the 2024 Capacity, Energy, Loads, and Transmission (CELT) forecast
- The ISO's heating electrification forecast reflects the anticipated energy and demand impacts of regional electricity customer adoption heat pumps to electrify space and water heating in the residential and commercial building sectors

Heating Electrification Forecast

Methodology for CELT 2024

The heating electrification forecast methodology leverages the National Renewable Energy Laboratory's ResStock and ComStock datasets, and has four components

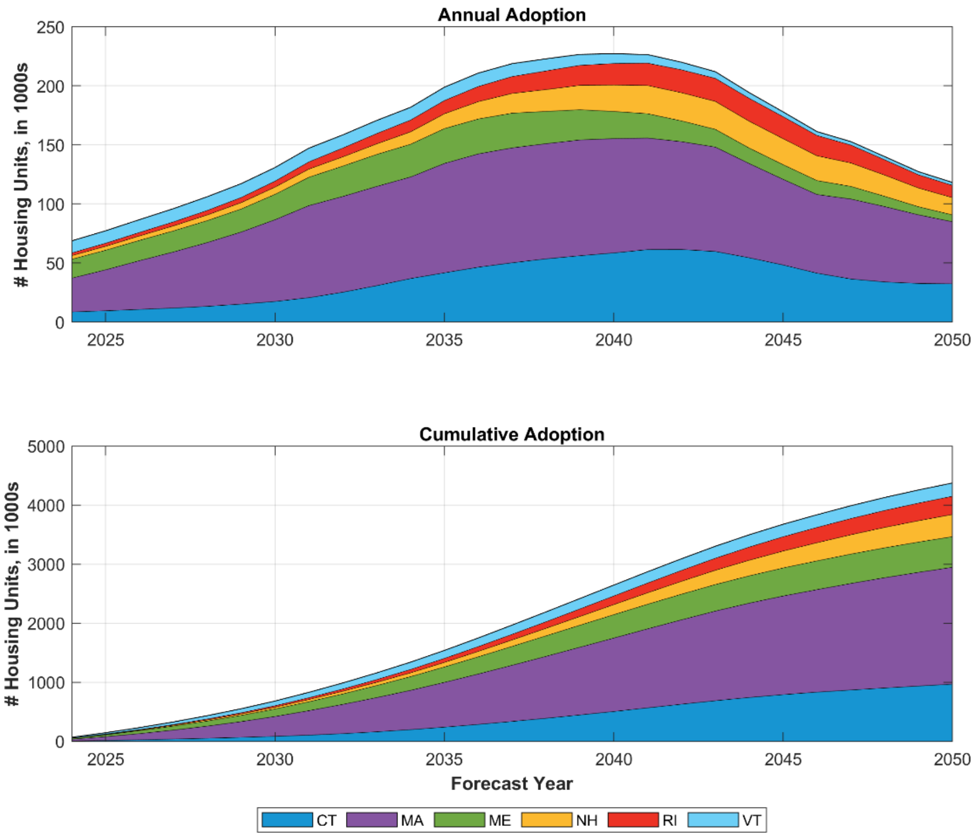
1. New England building stock characterization
   - Comprehensive characterization of the existing New England building stock
2. Development of "heating pathways"
   - Heating pathways specify a technology that could be used to either partially or fully electrify a given building's space or water heating needs
3. Adoption forecasting
   - Level of adoption of technologies along specified pathways for a variety of building types in the residential and commercial sectors
4. Hourly demand modeling
   - Captures the electric impacts of each adoption pathway for each building type in the residential and commercial sectors
   - CELT 2024 forecast incorporates improvements to the partial displacement demand modeling



FINAL 2024 ADOPTION FORECAST

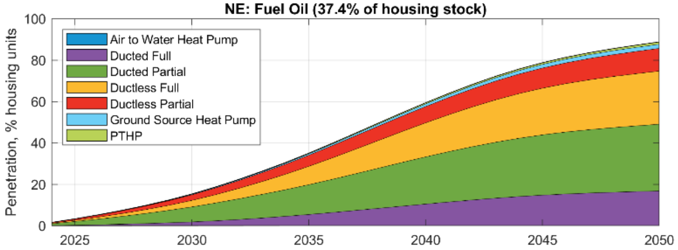
Residential Space Heating Adoption

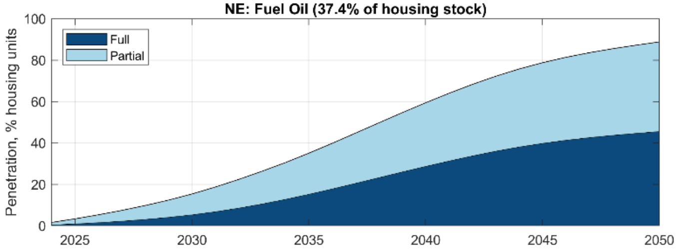
- Adoption forecast for residential space heating (full + partial) is shown to the right
  - Annual adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes more than 4.4 million housing units with electrified space heating electrified by 2050
  - ~69% of total housing stock
  - ~84% of fossil fueled heating
- The regional forecast penetration of electrified residential space heating according to legacy heating fuels is shown on the next slide, including a breakdown of full versus partial heating
  - Similar graphics for state forecast penetrations are included in Appendix IV

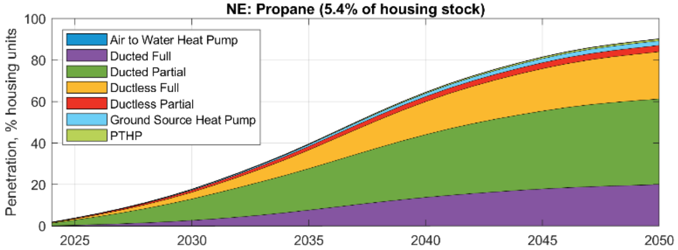


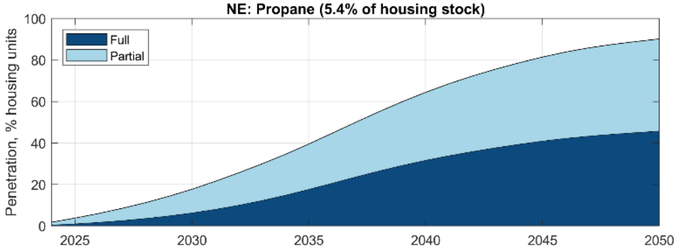
Adoption By Legacy Residential Space Heating Fuel

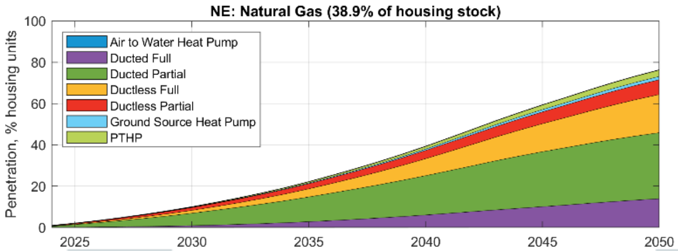
New England

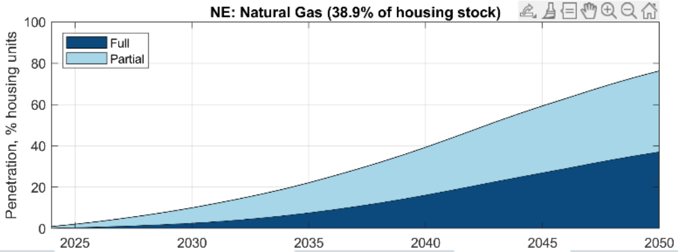






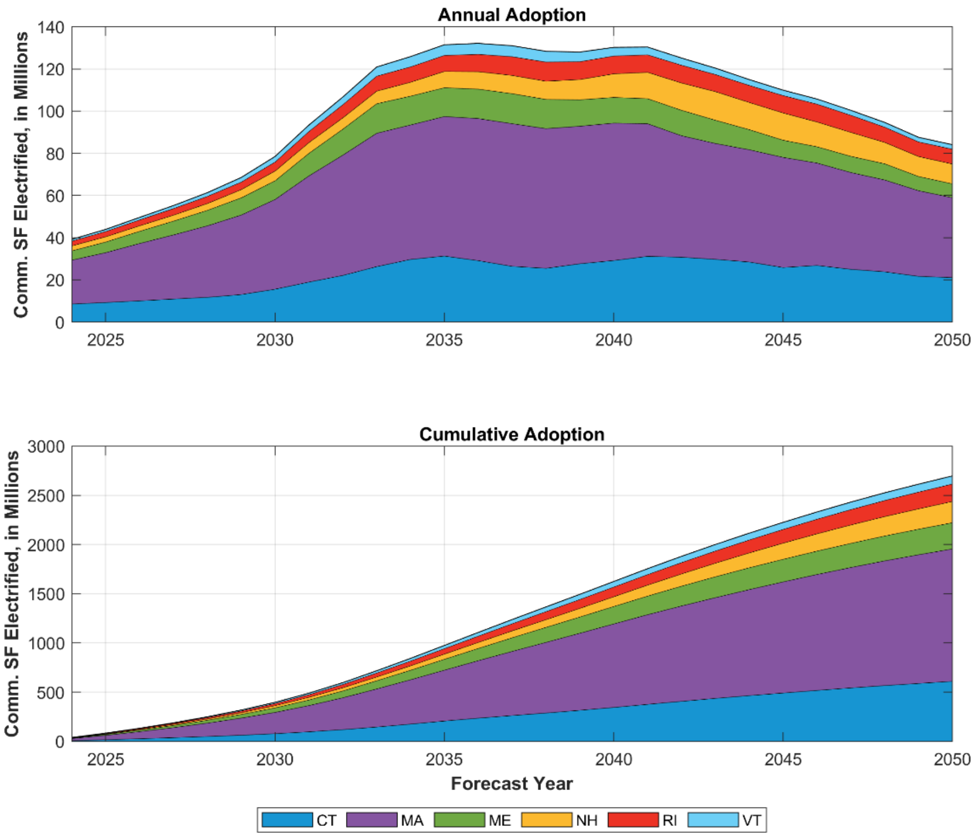






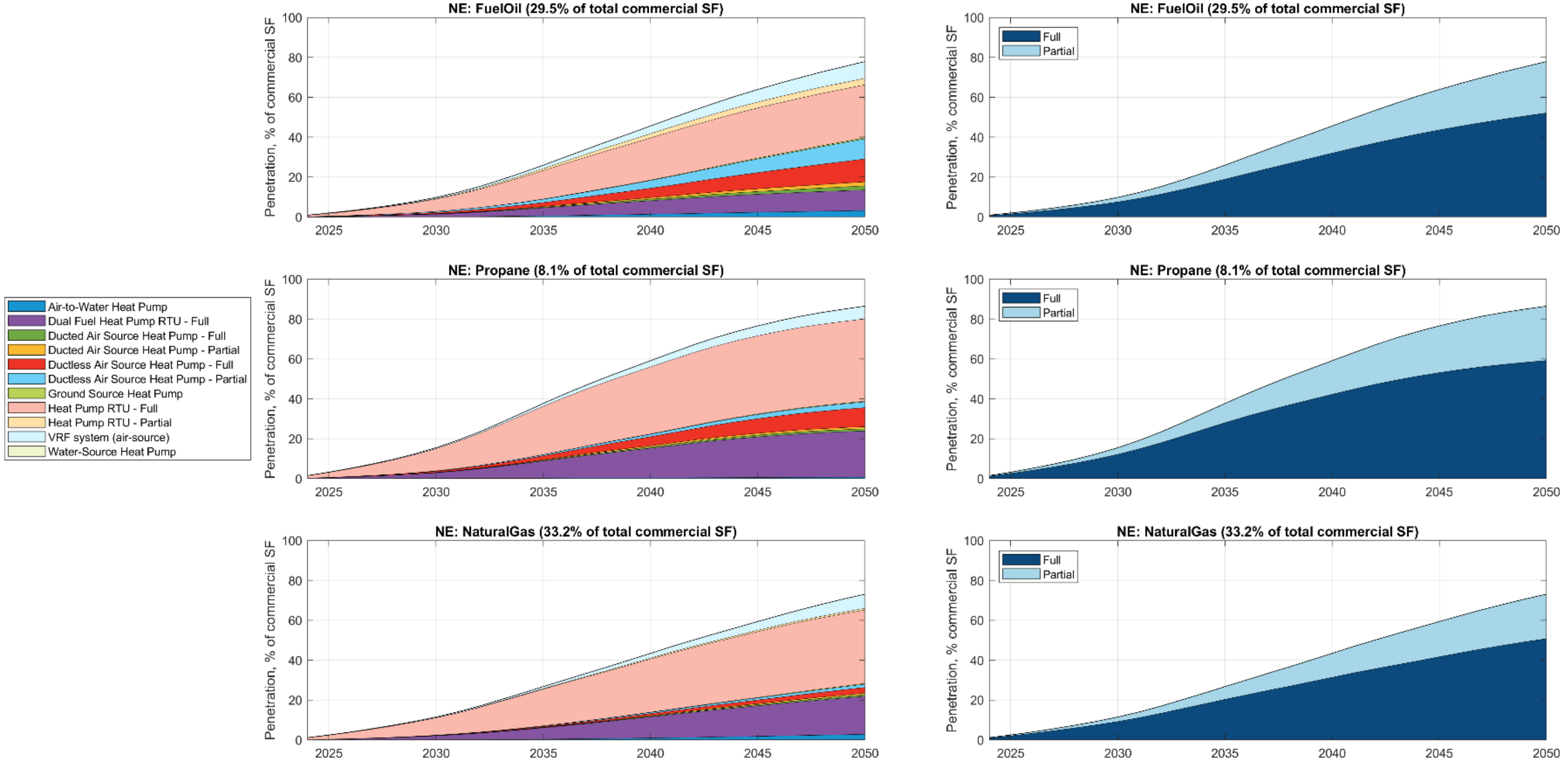
Commercial Space Heating Adoption

- Adoption forecast for commercial space heating (full + partial) is shown to the right
  - Annual adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes more than 2.7 billion square feet of commercial space heating electrified by 2050
- The regional forecast penetration of electrified commercial space heating according to legacy heating fuels is shown on the next slide, including a breakdown of full versus partial heating
  - Similar graphics for state forecast penetrations are included in Appendix V



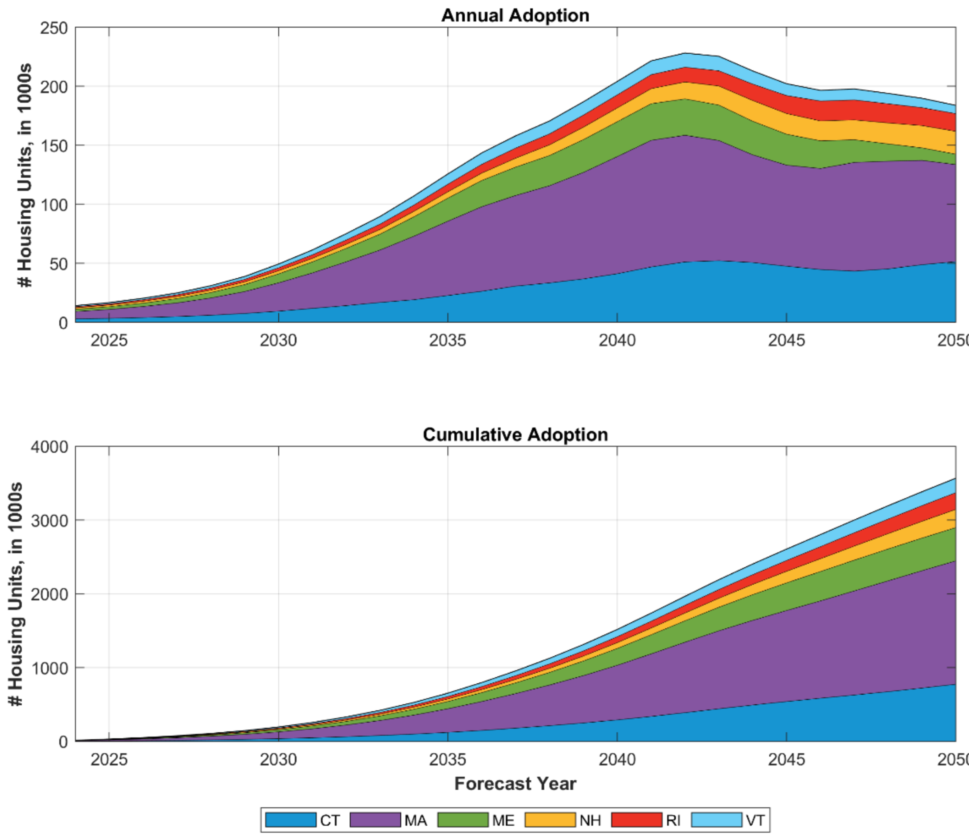
Adoption By Legacy Commercial Space Heating Fuel

New England



Residential Water Heating Adoption

- Adoption forecast for residential HPWHs is shown to the right
  - Annual adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes almost 3.6 million homes with electrified water heating by 2050
  - ~55% of total housing stock
  - ~78% of fossil fueled heating
- Regional forecast penetration of HPWHs according to legacy water heating fuels is shown on the next slide
  - Similar graphics for state forecast penetrations are included in [Appendix VI]



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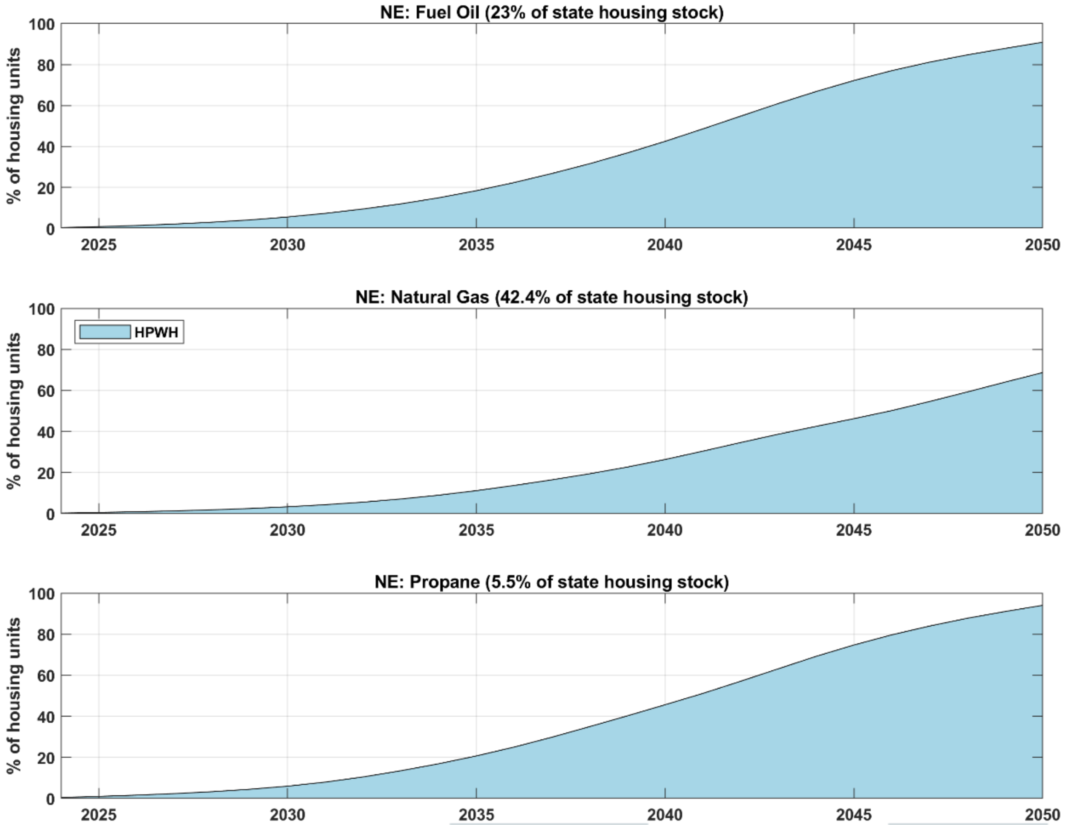
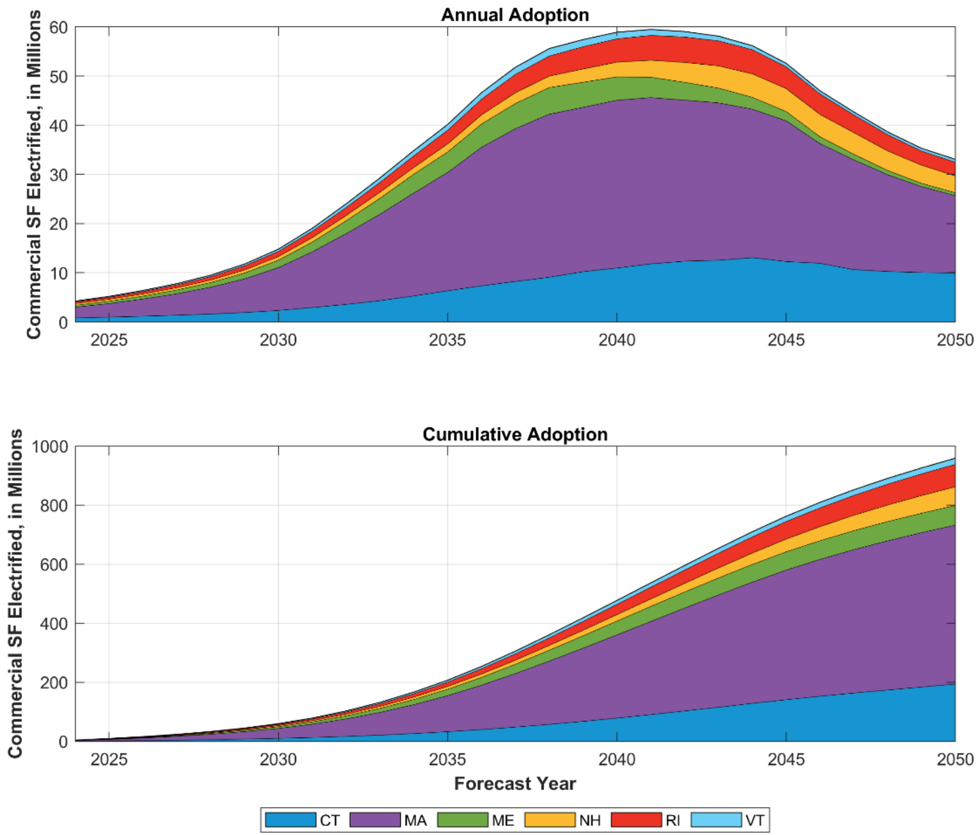
Adoption By Legacy Residential Water Heating Fuel

New England



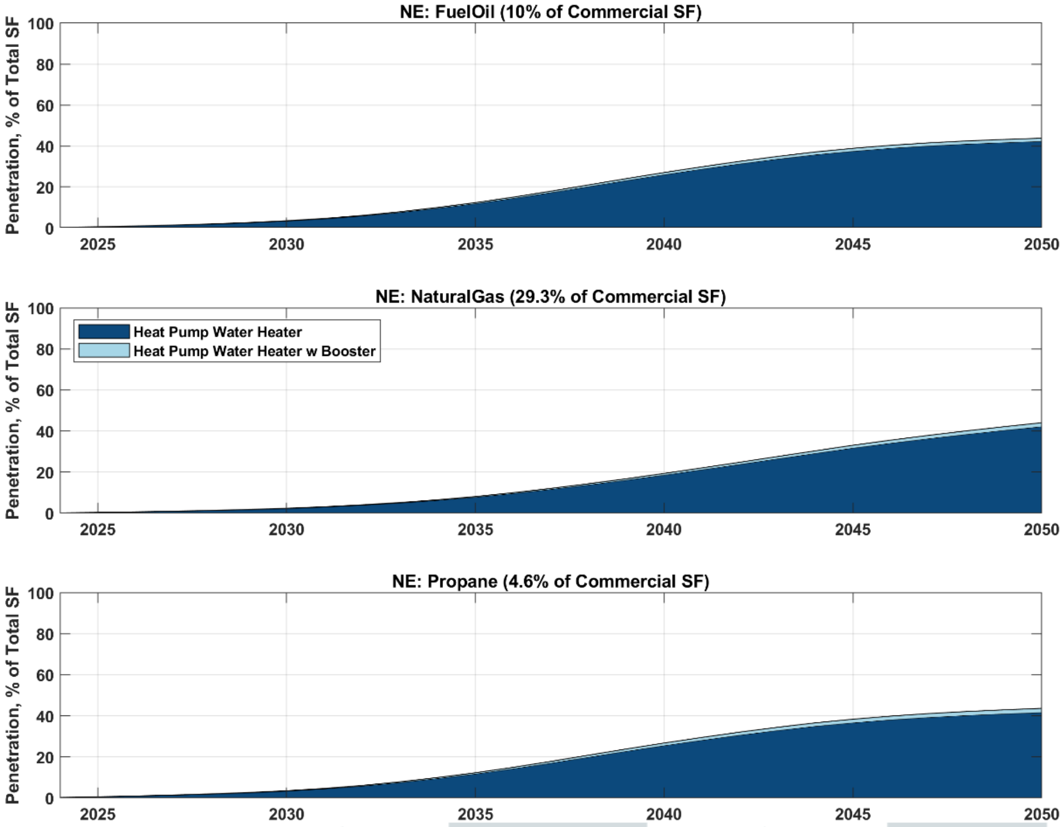
Commercial Water Heating Adoption

- Adoption forecast for commercial water heating is shown to the right
  - Annual adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes electrification of water heating serving almost a billion SF of commercial space by 2050
- Regional forecast penetration of HPWHs according to legacy water heating fuels is shown on the next slide
  - Similar graphics for state forecast penetrations are included in [Appendix VII]



Adoption By Legacy Commercial Water Heating Fuel

New England



FINAL 2024 ENERGY FORECAST

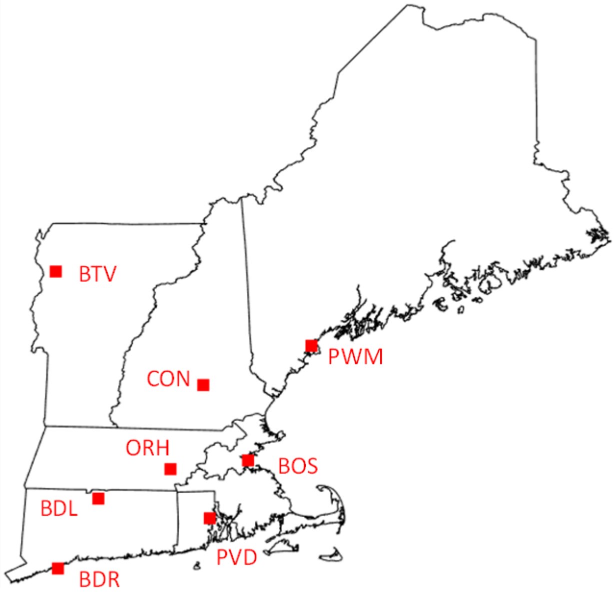
Weather Used in HP Simulation Profiles

Station Weights Used for Each State

State weather used in HP simulations is calculated using station weights below

Weather Station (City, State)	Weather Station	CT	MA	ME	NH	RI	VT
Boston, MA	BOS	-	0.44	-	-	-	-
Bridgeport, CT	BDR	0.17	-	-	-	-	-
Burlington, VT	BTV	-	-	-	-	-	1.00
Concord, NH	CON	-	-	-	1.00	-	-
Portland, ME	PWM	-	-	1.00	-	-	-
Providence, RI	PVD	-	0.27	-	-	1.00	-
Windsor Locks, CT	BDL	0.83	0.16	-	-	-	-
Worcester, MA	ORH	-	0.13	-	-	-	-

Locations of weather stations

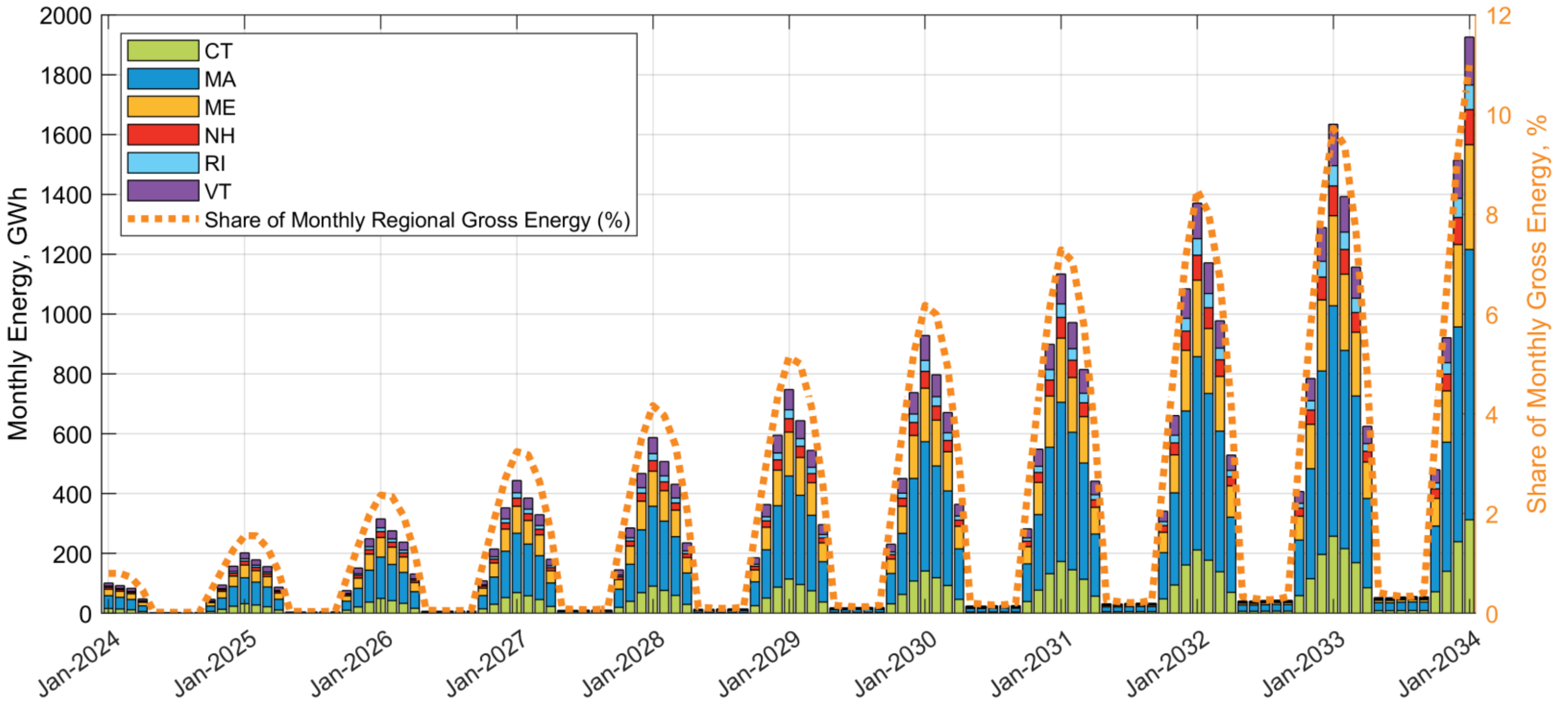


Estimating Energy Impacts of HP Adoption

- Hourly HP profiles were simulated based on modeling described in Appendix IV and weather over the period 1991-2020 (30 years)
  - Corresponds to the "weather normal" period used for gross energy modeling
- The process for estimating monthly energy impacts for each state is as follows:
  1. Calculate the mean monthly energy value for the hourly demand simulations generated for each combination of heating pathway/building type based on state weather
     a) Station-level weather is converted to state weather using weights tabulated on slide 15
  2. Multiply mean monthly energy values from step 1 by the appropriate monthly HP adoption values for each combination of heating pathway/building type
  3. Sum resulting energy values for all HP types for each state
     a) Regional energy is the sum of all state energy values
  4. Gross up all energy values by 6% to account for assumed transmission and distribution losses, consistent with other forecast processes
- Refer to slides 23-25 of the ISO's Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross energy forecast

Final 2024 Heating Electrification Forecast

Monthly Energy, GWh



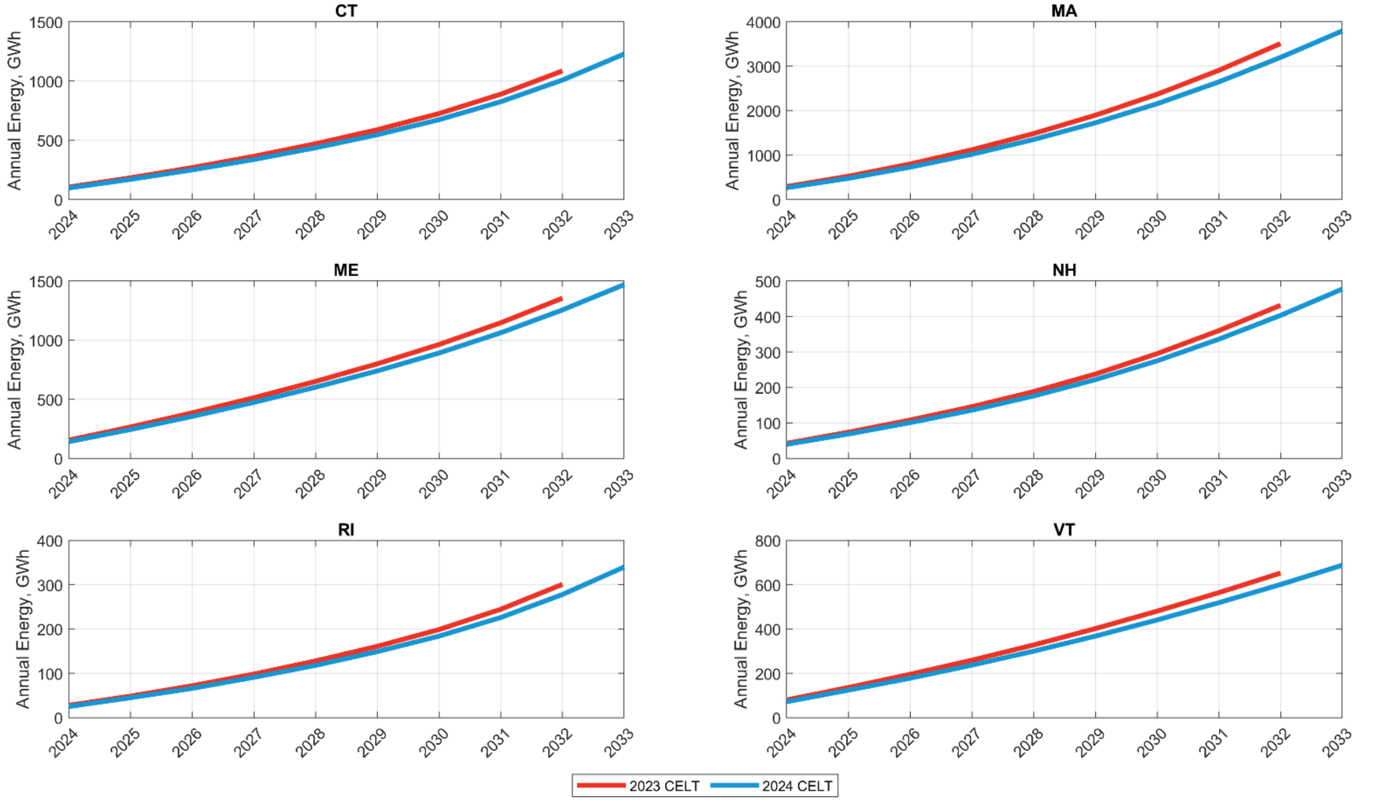
Final 2024 Heating Electrification Forecast

Annual Energy, GWh

	Annual Energy (GWh)									
Year	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Connecticut	96	169	249	337	436	546	673	825	1,008	1,228
Massachusetts	263	475	726	1,016	1,348	1,725	2,154	2,646	3,198	3,794
Maine	142	245	355	474	602	740	891	1,062	1,255	1,469
New Hampshire	40	69	101	136	176	222	275	336	403	477
Rhode Island	25	45	66	91	118	149	184	226	278	340
Vermont	72	124	178	237	300	368	441	519	601	688
Total	**640**	**1,127**	**1,676**	**2,292**	**2,979**	**3,749**	**4,618**	**5,614**	**6,742**	**7,996**

Annual Heating Electrification Energy

Final CELT 2024 vs. Final CELT 2023



FINAL 2024 DEMAND FORECAST

Estimating Demand Impacts of HP Adoption

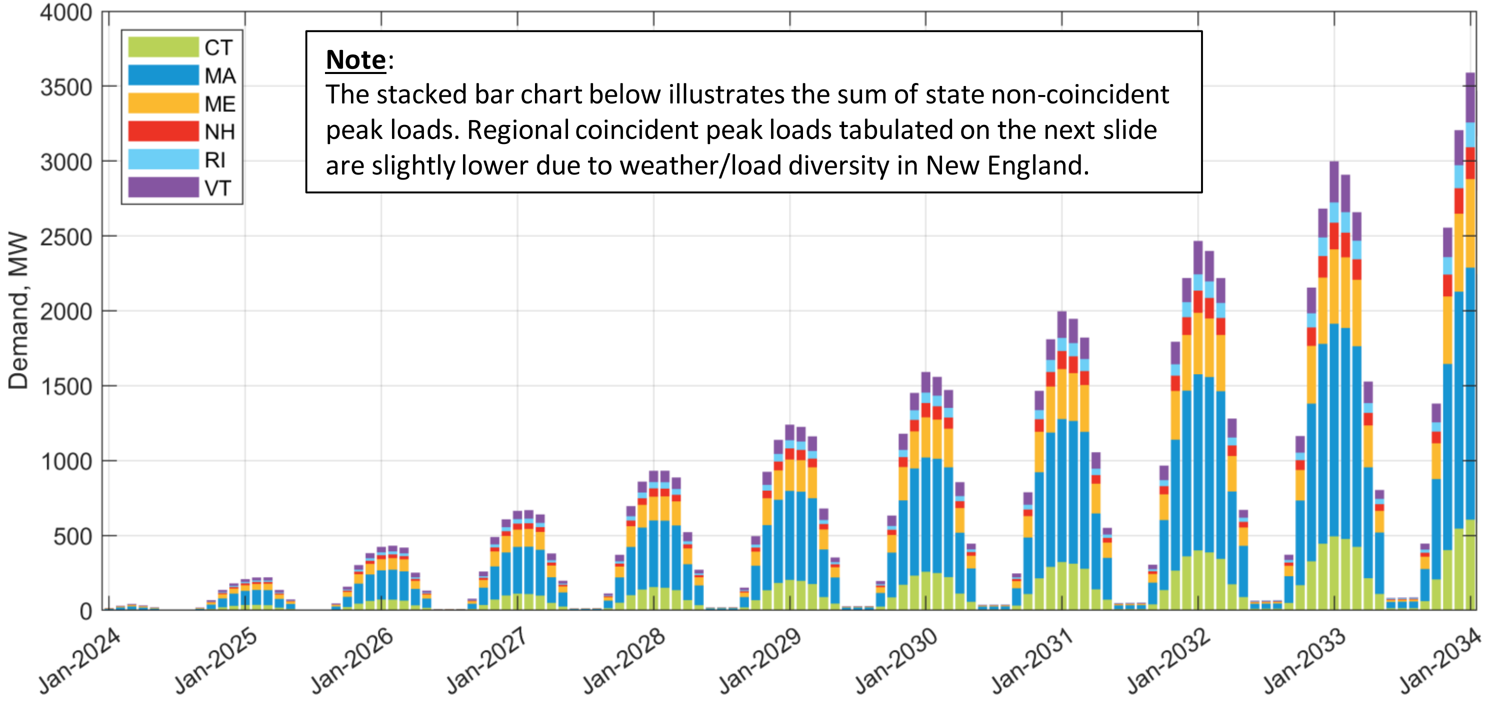
- The weekly weather distributions used to generate weekly gross load forecast distributions are used to estimate monthly HP demand impacts for each state as follows:
  1. Input weekly state weather distributions (for each week in a given month) to the hour ending 18 demand model for each combination of heating pathway/building type
  2. Multiply resulting per HP demand value by the appropriate monthly HP adoption values for each combination of heating pathway/building type
  3. Sum resulting demand values for all combinations of heating pathway/building types
  4. Calculate the “50/50” (i.e., “P95”) and “90/10” (i.e., “P99”) values for each week of the forecast; maximum 50/50 and 90/10 values in each month are monthly demand forecasts
     - Aligns with the percentiles used in the gross load forecast
  5. Gross up by 8% to account for assumed transmission and distribution losses, consistent with other forecast processes

- Regional HP demand is the sum of the resulting “weather coincident” state HP demand values
  – Steps 4 and 5 above are then performed uniquely for regional sums of HP demand

- Refer to slides 26-34 of the ISO’s Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross demand forecast

Final 2024 Heating Electrification Forecast

Monthly Demand, 50/50



Final 2024 Heating Electrification Forecast

Winter (January) Demand, 50/50

	Winter Peak (MW)									
Year	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34
Connecticut	37	74	122	163	212	261	323	401	497	609
Massachusetts	92	192	324	446	603	773	956	1,178	1,425	1,689
Maine	39	75	127	161	208	271	333	409	498	600
New Hampshire	13	27	44	58	75	96	118	145	172	204
Rhode Island	9	20	32	44	57	72	89	111	137	167
Vermont	15	33	56	75	103	139	179	225	276	334
Total	**206**	**421**	**705**	**946**	**1,258**	**1,612**	**1,998**	**2,469**	**3,005**	**3,604**

Notes:
1. State values are at the time of New England coincident peak loads.
2. State values may not sum to the total region values due to rounding.

Final 2024 Heating Electrification Forecast

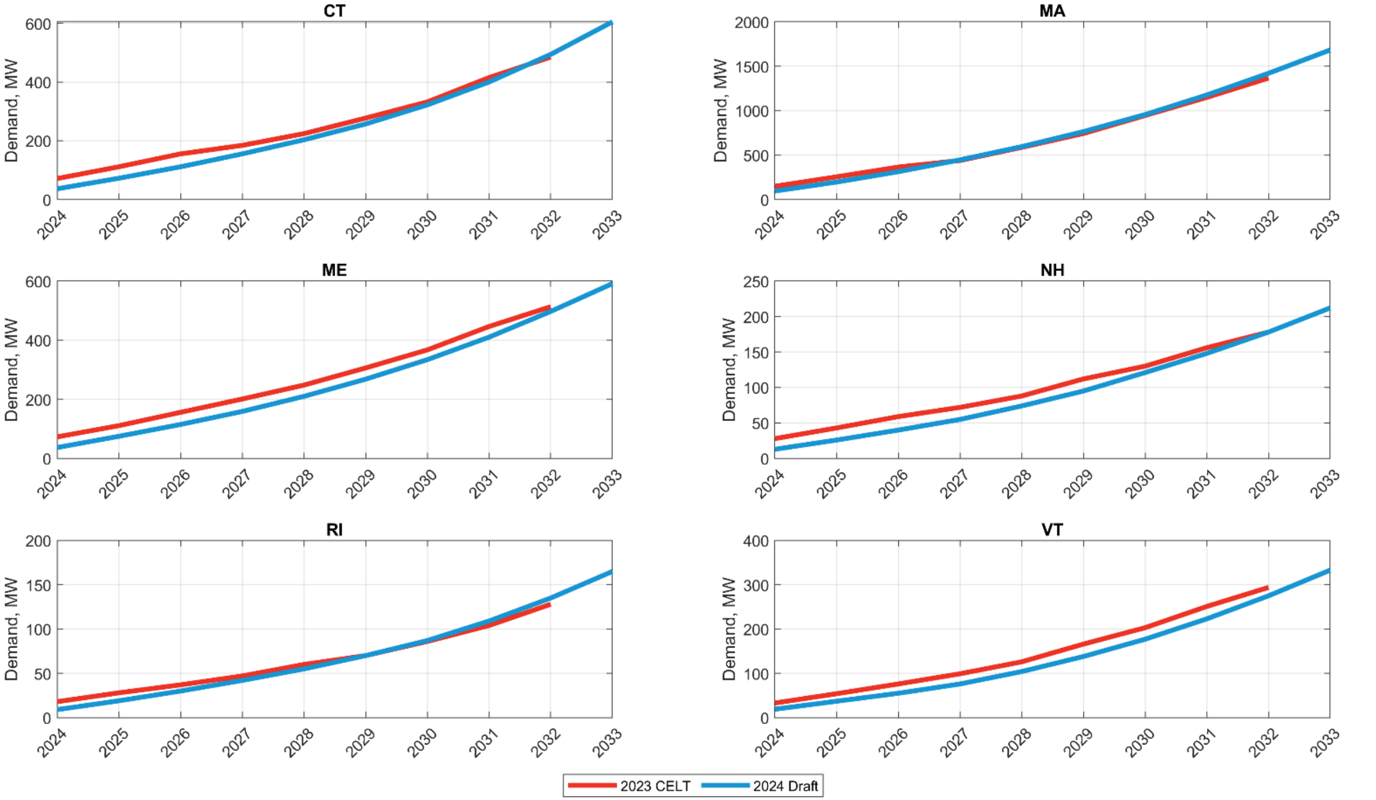
Winter (January) Demand, 90/10

	Winter Peak (MW)									
Year	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34
Connecticut	43	87	135	189	250	316	402	499	615	758
Massachusetts	104	215	340	473	628	807	1,023	1,262	1,533	1,829
Maine	47	96	151	220	292	375	474	583	706	840
New Hampshire	16	32	52	73	96	125	160	196	236	281
Rhode Island	11	22	34	48	63	76	97	120	150	183
Vermont	21	44	70	104	143	190	248	311	383	464
Total	**242**	**495**	**782**	**1,106**	**1,472**	**1,889**	**2,402**	**2,971**	**3,623**	**4,356**

Notes:
1. State values are at the time of New England coincident peak loads.
2. State values may not sum to the total region values due to rounding.

Winter Heating Electrification Peak Demand, 50/50

CELT 2024 vs. CELT 2023



Final 2024 Heating Electrification Forecast

Summer (July) Demand, 50/50 and 90/10

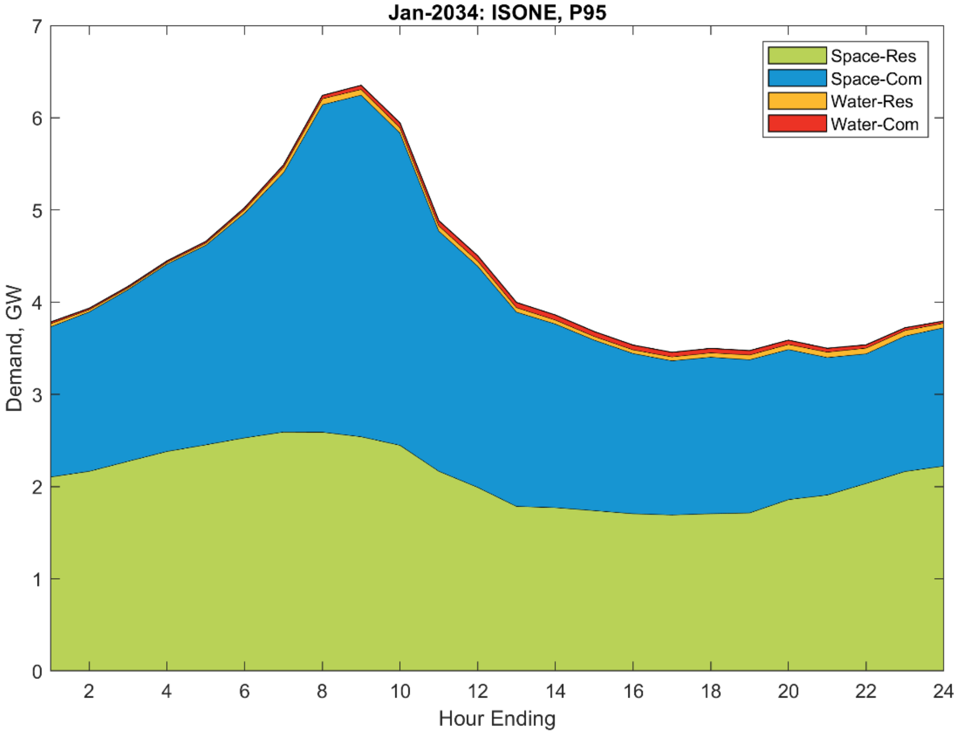
	Summer Peak (MW)									
Year	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Connecticut	0	1	2	3	4	5	7	9	11	14
Massachusetts	1	2	4	7	10	14	19	25	33	43
Maine	0	1	1	2	3	4	5	7	9	12
New Hampshire	0	0	1	1	2	2	3	3	4	5
Rhode Island	0	0	1	1	2	2	3	4	5	6
Vermont	0	0	0	1	1	1	2	2	3	4
Total	**2**	**5**	**9**	**14**	**21**	**28**	**38**	**50**	**66**	**85**

Notes:
1. Summer demand values are due to electrified water heating

50/50 Winter Peak Composition

January 2034

- Plot shows the forecast composition of hourly winter 50/50 peak demand impacts of heating electrification in January 2034
  - Residential space heating (“Space-Res”)
  - Commercial space heating (“Space-Com”)
  - Residential water heating (“Water-Res”)
  - Commercial water heating (“Water-Com”)
- Demand during morning peak hours is significantly higher than during typical ISO-NE coincident winter peak hour(s) (hours 18-19) that exist today
- ISO will continue to investigate the outlook for potential load shape impacts such as these as part of its electrification forecasting efforts



APPENDIX I

Building Stock Characterization

Building Stock Characterization

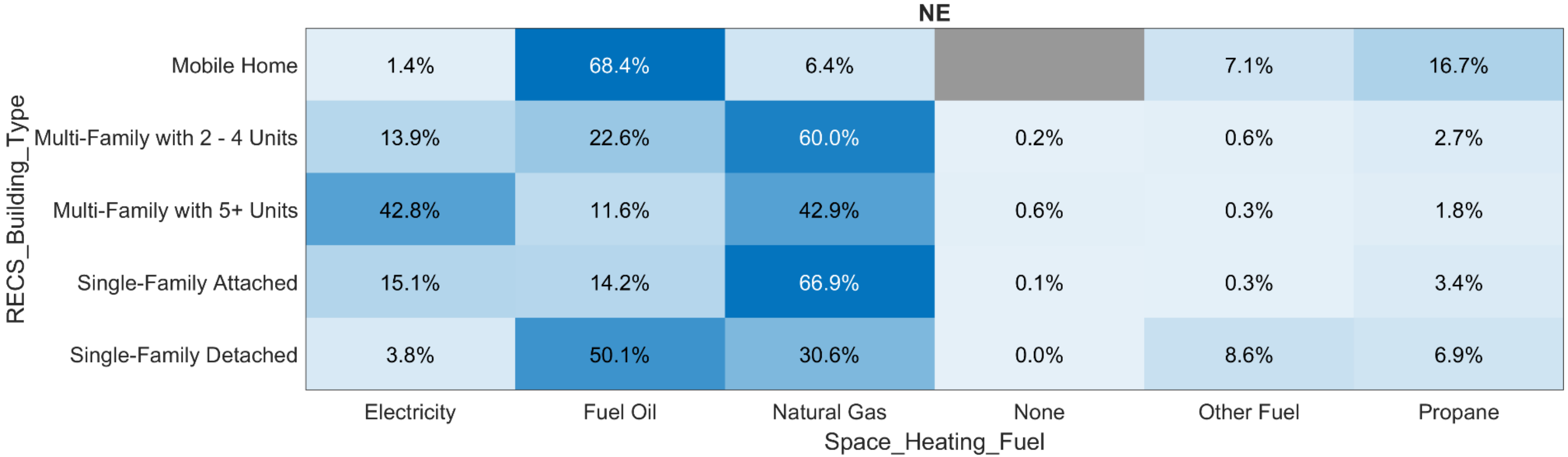
- Establishes a comprehensive picture of 2018 New England building stock
  - Building sector/types/uses
  - Building age
  - Heating fuel
  - Heating delivery system
  - Cooling delivery system
  - Location (state/county)
- Aggregation
  - Residential buildings are quantified in households
  - Commercial buildings are quantified in square-feet

- Based on NREL ResStock and ComStock datasets, which utilizes a wide variety of data sources, surveys, studies, and reports including:
  - EIA Residential Energy Consumption Survey (RECS)
  - EIA Commercial Building Energy Consumption Survey (CBECS)
  - American Community Survey (ACS) Public Use Microdata Sample (PUMS)
  - American Housing Survey (AHS)
  - DOE Commercial Prototype Buildings
  - Many other studies and reports along with commercially purchased and proprietary end-use data

Residential Buildings

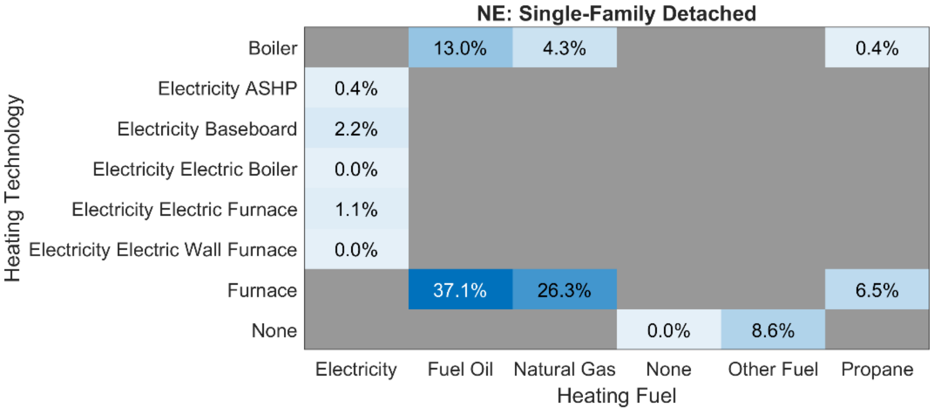
State	Building Type	% of Households
NE	Single-Family Detached	58%
NE	Multi-Family with 2 - 4 Units	17%
NE	Multi-Family with 5+ Units	17%
NE	Single-Family Attached	5%
NE	Mobile Home	3%

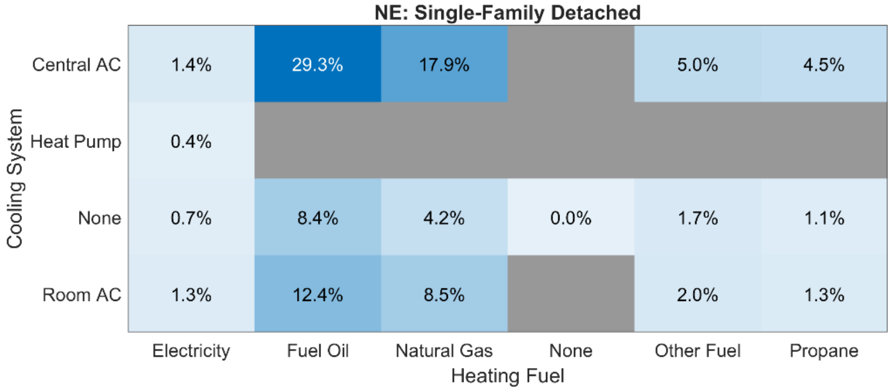
Sum across each row = 100%

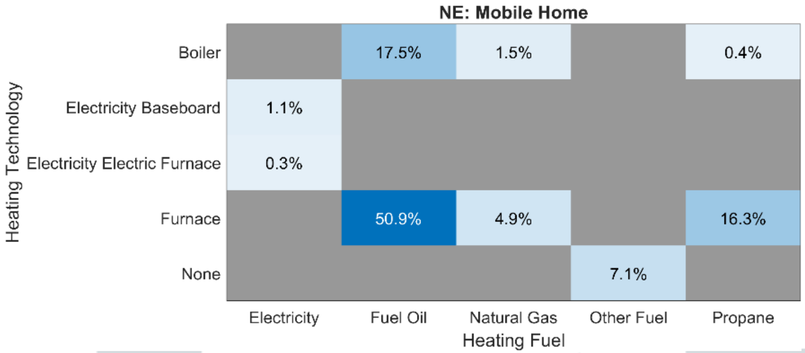


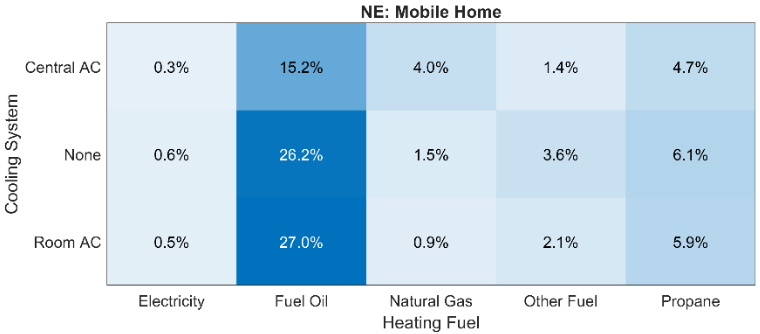
Residential Buildings

Examples of Space Conditioning Fuel Sources & Delivery Systems in New England









Commercial Buildings

State	Building Type	% Square Ft.
NE	Warehouse	31.1
NE	Industrial_Warehouse*	12.1
NE	MediumOffice	6.7
NE	SmallOffice	6.5
NE	RetailStripmall	6.3
NE	LargeOffice	5.6
NE	RetailStandalone	5.5
NE	SecondarySchool	5.2
NE	PrimarySchool	5.0
NE	Hospital	4.8
NE	SmallHotel	3.3
NE	Outpatient	3.0
NE	FullServiceRestaurant	1.8
NE	LargeHotel	1.7
NE	Industrial_MediumOffice*	1.3
NE	QuickServiceRestaurant	0.2

* Categories represent conditioned portions of industrial building types

Sum across each row = 100%

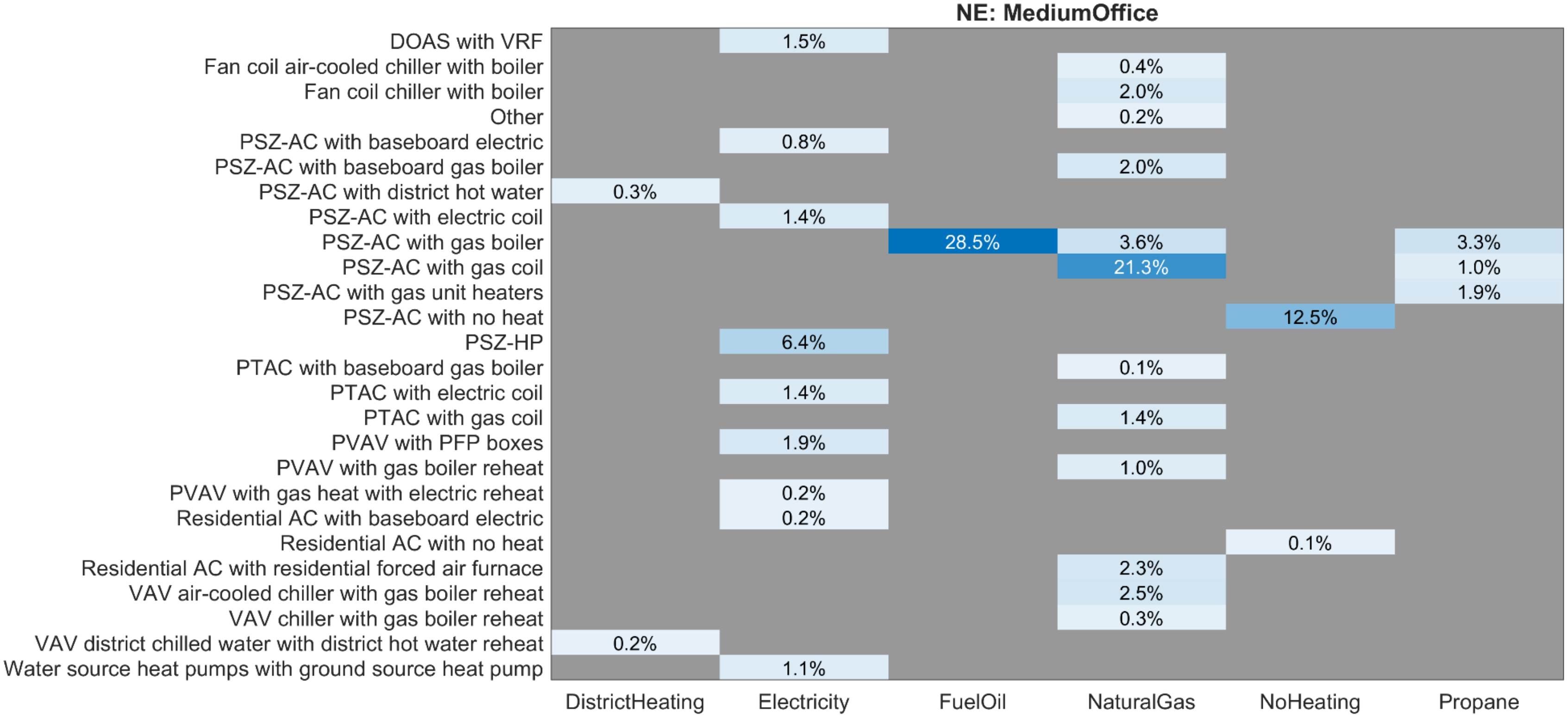
NE

Building_Type	DistrictHeating	Electricity	FuelOil	NaturalGas	NoHeating	Propane
FullServiceRestaurant	1.8%	15.6%	26.9%	33.7%	13.7%	8.3%
Hospital		7.2%	33.1%	29.0%	20.6%	10.0%
Industrial MediumOffice	0.7%	14.3%	31.6%	33.0%	12.8%	7.6%
Industrial Warehouse	2.7%	14.0%	30.1%	31.4%	12.2%	9.5%
LargeHotel	3.2%	19.2%	18.2%	38.8%	13.5%	7.1%
LargeOffice	4.1%	2.9%	28.2%	45.3%	14.6%	4.8%
MediumOffice	0.5%	14.9%	28.5%	37.3%	12.6%	6.2%
Outpatient	1.2%	17.6%	20.3%	41.5%	14.5%	4.9%
PrimarySchool	2.0%	14.2%	32.4%	27.9%	13.9%	9.7%
QuickServiceRestaurant	3.4%	9.4%	34.7%	30.5%	11.6%	10.4%
RetailStandalone	1.8%	14.9%	31.5%	30.3%	12.8%	8.8%
RetailStripmall	2.3%	14.5%	30.2%	33.2%	11.7%	8.2%
SecondarySchool	2.7%	15.6%	30.0%	28.3%	15.0%	8.5%
SmallHotel	1.3%	14.9%	31.6%	28.7%	14.4%	9.1%
SmallOffice	1.9%	14.0%	33.2%	29.2%	12.7%	8.9%
Warehouse	2.7%	14.3%	28.6%	34.0%	12.5%	7.8%

Heating_Fuel

Commercial Buildings

Baseline HVAC Systems in New England, Medium Office Example



APPENDIX II

Heating Electrification Pathways

Heating Electrification Pathways

Commercial and Residential Space Heating

Commercial Space Heating Pathways

Heating Type	Technology Type	Heating Displacement
Space Heating	District Heating via Geothermal Heat Pump	Full
	Dual Fuel Heat Pump RTU	Partial
	Heat Pump RTU	Full/Partial
	VRF system (air-source)	Full
	Air-to-Water Heat Pump	Full
	Ducted Air Source Heat Pump	Full
	Ducted Air Source Heat Pump	Partial
	Ductless Air Source Heat Pump	Full
	Ductless Air Source Heat Pump	Partial

RTU = Rooftop Unit; VRF = Variable Refrigerant Flow

Residential Space Heating Pathways

Heating Type	Technology Type	Heating Displacement
Space Heating	Ducted ASHP - Full	Full
	Ducted ASHP - Partial	Partial
	Ductless ASHP - Full	Full
	Ductless ASHP - Partial	Partial
	Ground Source Heat Pump	Full
	Air to Water Heat Pump	Full
	Packaged Terminal Heat Pump	Partial

ASHP = Air Source Heat Pump

Heating Electrification Pathways

Commercial and Residential Water Heating

Commercial Water Heating Pathways

Heating Type	Technology Type	Heating Displacement
Water Heating	Heat Pump Water Heater	Full
	Heat Pump Water Heater with Booster	Partial

Residential Water Heating Pathways

Heating Type	Technology Type	Heating Displacement
Water Heating	Heat Pump Water Heater	Full

APPENDIX III

Adoption Modeling Methodology

Adoption Modeling

- Adoption methodology considers potential pathways to space and water heating electrification based on existing building stock characteristics as well as state policy and economic considerations including:
  - Building type and sector
  - Existing heating fuels
  - Existing heating and cooling delivery systems (e.g. ducted, non-ducted)
  - Payback period for heating technology conversion
  - Level of state policy support, incentives, and goals regarding heating electrification
- Pathway adoption modeling is performed at the state level for both the residential and commercial sectors

Adoption Modeling Methodology

Framework

- Adoption along each pathway is based on a Bass diffusion model with input parameters guided by the following quantities:
  - **Return on Investment (ROI)**
    - Favorable ROI can drive maximum adoption, while any electrification technology pathway with low or negative ROI will only capture a small percentage of the maximum adoption
  - **Policy indicator**
    - State-level policy can significantly influence how quickly a given electrification technology will transition from innovators to mass adoption
    - This is a qualitative parameter ranging from 1 to 5, with 5 being the most aggressive level of policy supporting the adoption of electrified heating technologies
  - **Barrier indicator**
    - Reflects technical barrier to adoption and is separate from any financial barriers
    - Is defined for each pathway and held steady over the forecast horizon
    - This is a qualitative parameter ranging from 1 to 5, with 5 representing the greatest barrier to adoption
  - **Current levels of technology saturation**
- Uncertainty in the evolution of ROI and policy impacts over the forecast horizon is reflected via a Monte Carlo simulation

Adoption Modeling Methodology

Market Segmentation

- Existing building electrification market is segmented into two different avenues of participation, each reflecting differing economic and market size assumptions
  - **Market driven**
    - Customer’s previous heating system is at or near the point of failure and needs to be replaced
    - ROI is higher since the cost is determined by the incremental difference between the heat pump and the replacement cost of the existing system.
  - **Retrofit**
    - Customer electrifies despite fully functioning existing HVAC systems
    - Market size is the total number of existing homes and businesses, and the incremental cost of electrification is determined by the full cost of the heat pump

- Interactive effects between retrofit and market-driven adoption are also considered
  - Market-driven measures reduce the available market for retrofits
  - Retrofits reduce the amount of new electrification available for market-driven once the existing equipment would have failed and needed replacement

- Adoption of “niche” pathways (ground source heat pumps and air-to-water systems), which does not easily fit into the adoption modeling framework outlined above, is established by converting a small, fixed percentage of other pathways
  - Important for these to be included in the demand modeling

Space Heating

Legacy Fuel Sources

- Adoption modeling focuses exclusively on legacy fossil fueled space heating
  - Fuel oil, propane, and natural gas

Residential

Starting Share of Housing Units, %

Space Heating Fuel	CT	MA	ME	NH	RI	VT	NE
Electricity	16.5	14.9	5.7	8.3	9.9	5.8	12.8
Fuel Oil	41.9	26.7	64.3	45.5	31.4	43.5	37.4
Natural Gas	35.4	53.3	6.2	19	55	17.7	38.9
None	0	0.2	0.1	0.5	0	0	0.1
Other Fuel	2.8	2.2	15.3	10.3	2.1	18	5.4
Propane	3.4	2.7	8.4	16.4	1.6	15.1	5.4

Commercial

Starting Share of Commercial SF, %

Space Heating Fuel	CT	MA	ME	NH	RI	VT	NE
DistrictHeating	2.3	2.2	1.4	3.5	2.2	1.9	2.2
Electricity	17.7	13	10.8	11.9	10.2	8.3	13.6
FuelOil	33.6	22.5	57.1	34.4	21.5	33.4	29.5
NaturalGas	26.6	43.6	2.7	15.6	50.5	19.6	33.2
NoHeating	12.8	14.4	11.6	12.5	12.4	8.8	13.3
Propane	7	4.2	16.3	22.1	3.3	28.1	8.1

Water Heating

Legacy Fuel Sources

- Adoption modeling focuses exclusively on legacy fossil fueled space heating
  - Fuel oil, propane, and natural gas

Residential

Starting Share of Housing Units, %

Water Heating Fuel	CT	MA	ME	NH	RI	VT	NE
Electricity	30.6	25.5	35.7	33.9	23.4	33.2	28.9
Fuel Oil	25.5	17	38.9	26.6	18.6	27.8	23
Natural Gas	40.3	54.1	15.9	25.5	55.7	23.2	42.4
Other Fuel	0	0.1	0.5	0.1	0.1	0.5	0.2
Propane	3.6	3.3	8.9	13.9	2.3	15.3	5.5

Commercial

Starting Share of Commercial SF, %

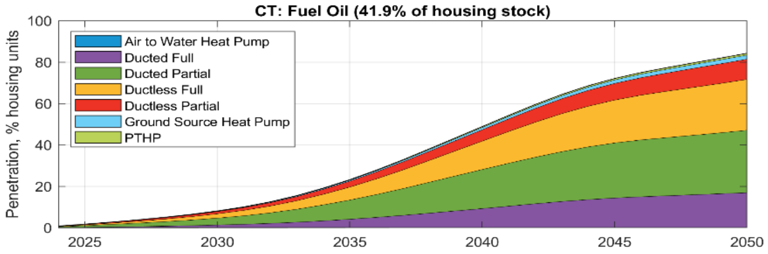
Water Heating Fuel	CT	MA	ME	NH	RI	VT	NE
DistrictHeating	1.1	1.2	0.7	1.1	0.9	1.5	1.1
Electricity	57.3	53	62.8	57.2	46.5	57.2	55
FuelOil	11.4	7.7	16.2	13.5	7.9	14.4	10
NaturalGas	26.2	34.9	11.4	18	42.1	19.8	29.3
Propane	4.1	3.2	8.9	10.3	2.6	7	4.6

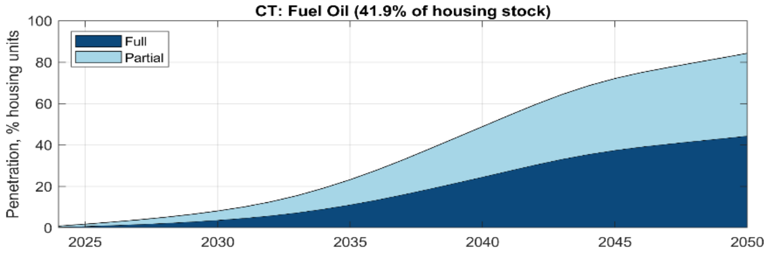
APPENDIX IV

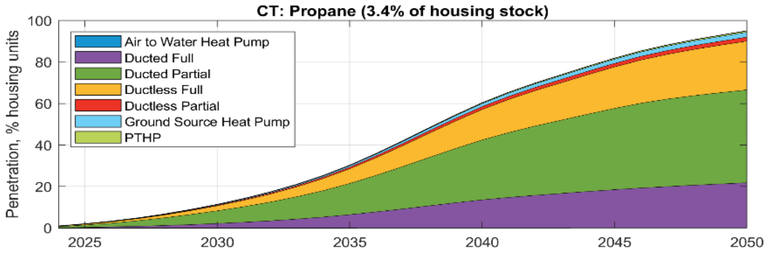
State Space Heating Adoption

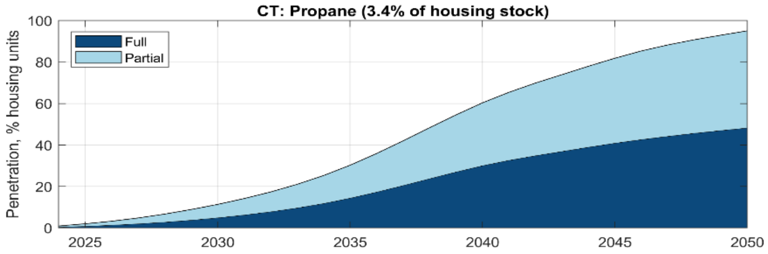
Adoption By Legacy Residential Space Heating Fuel

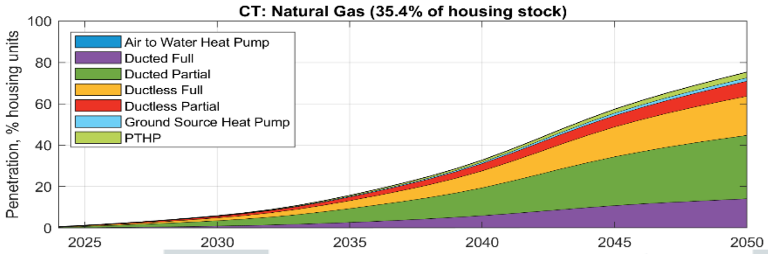
Connecticut

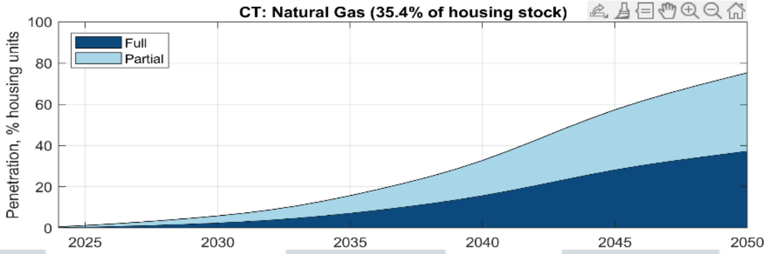






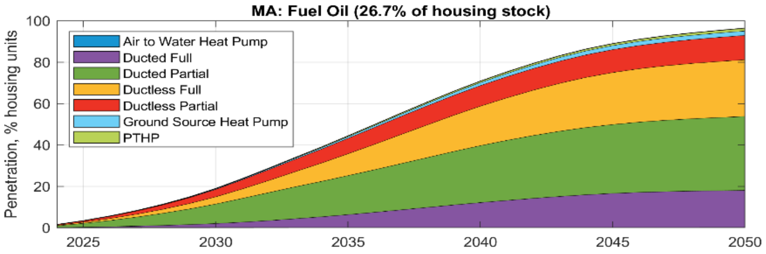


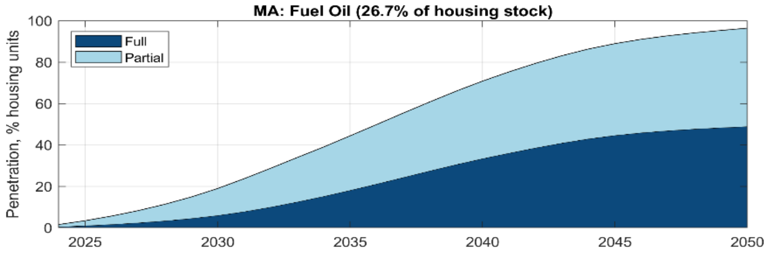


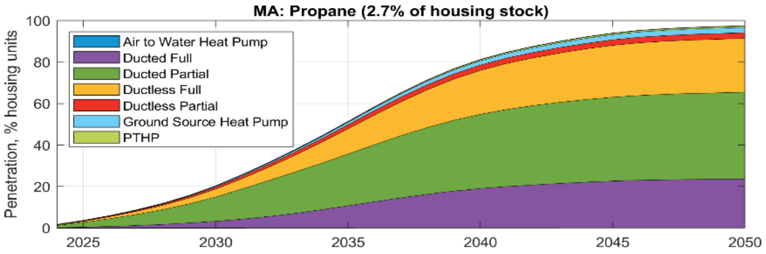


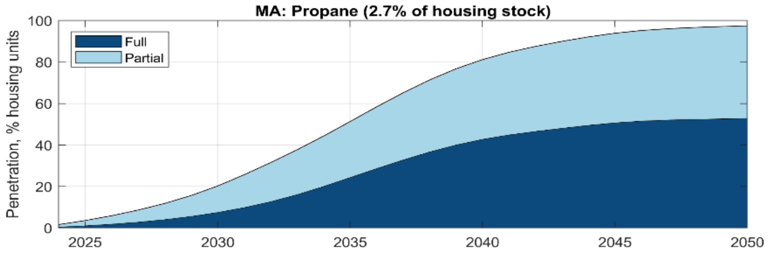
Adoption By Legacy Residential Space Heating Fuel

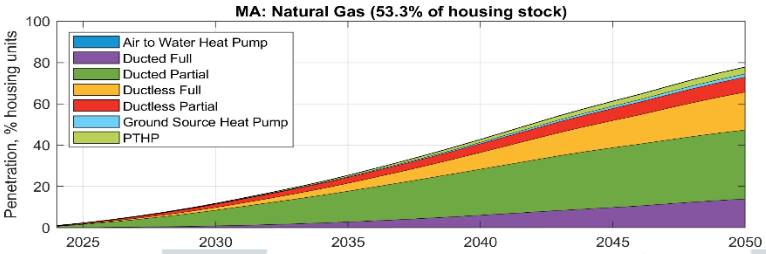
Massachusetts

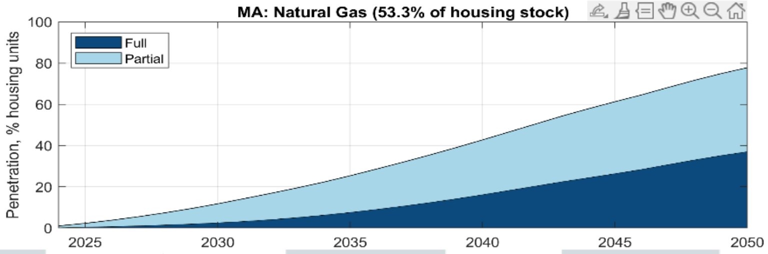






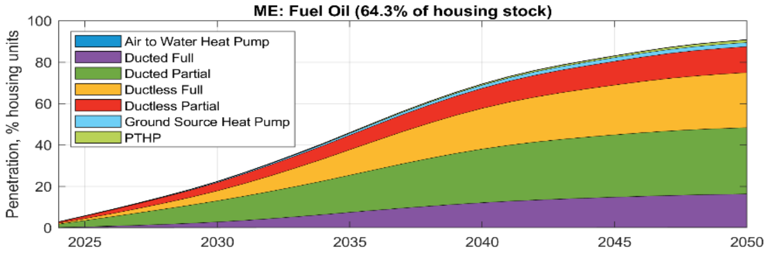


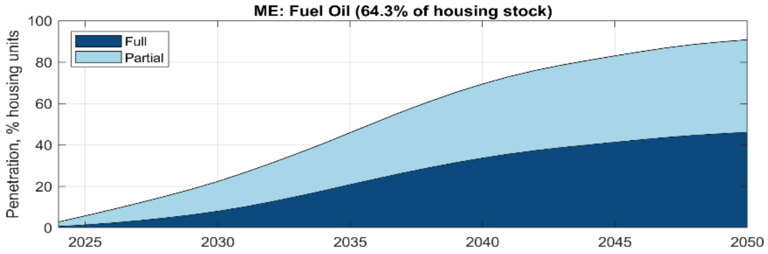


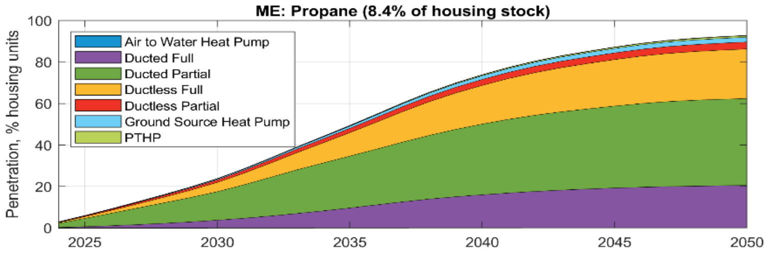


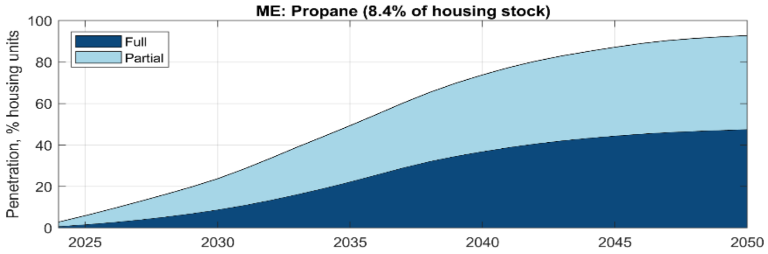
Adoption By Legacy Residential Space Heating Fuel

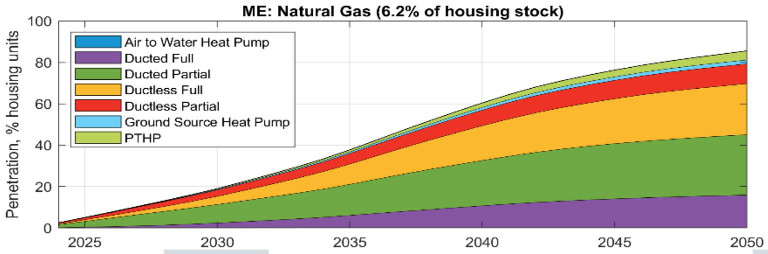
Maine

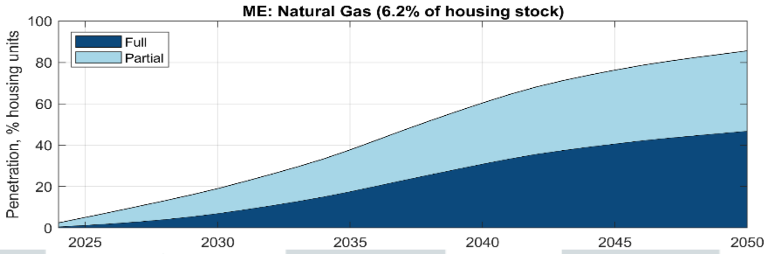






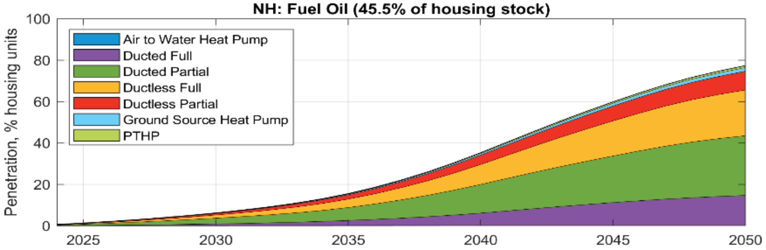


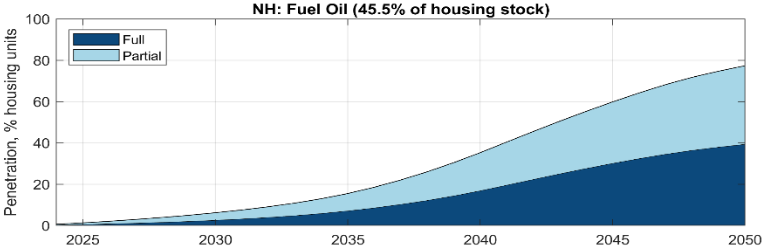


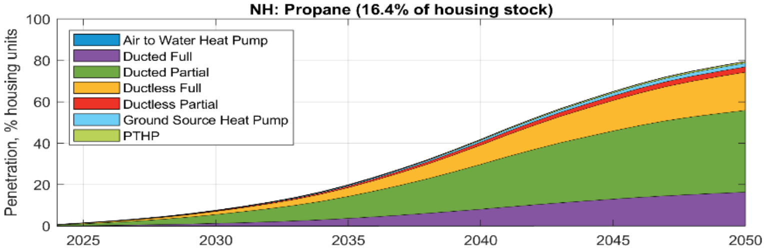


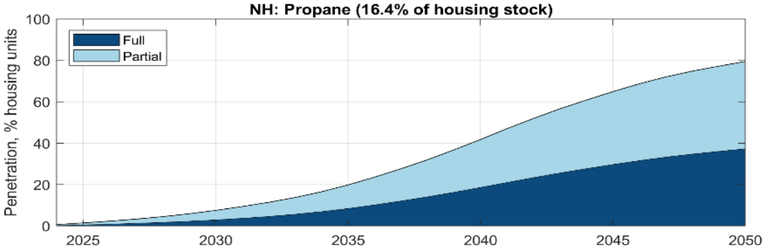
Adoption By Legacy Residential Space Heating Fuel

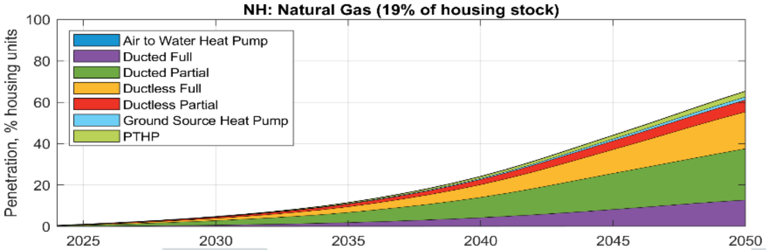
New Hampshire

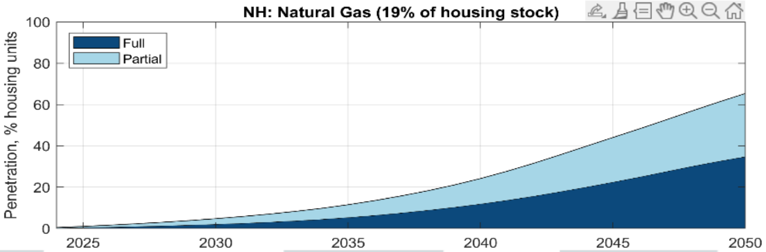






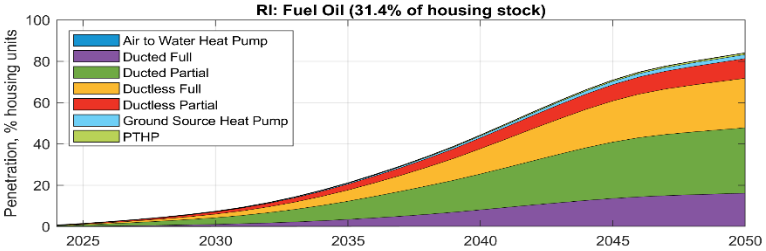


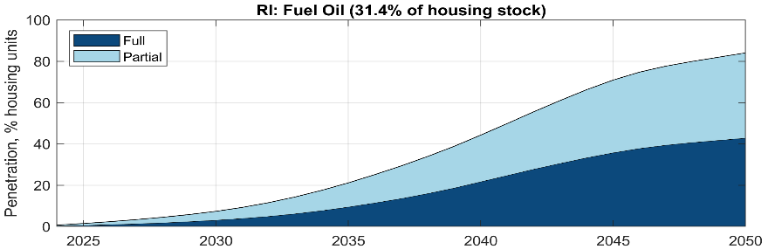


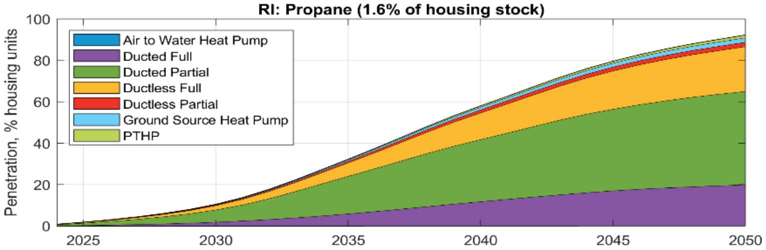


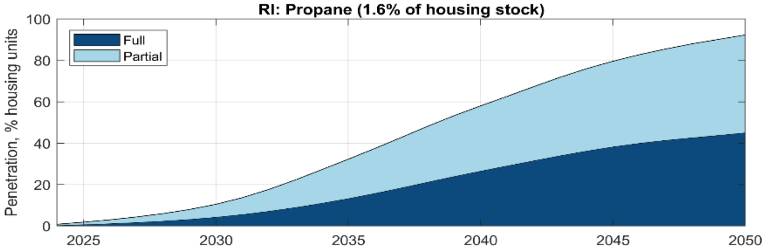
Adoption By Legacy Residential Space Heating Fuel

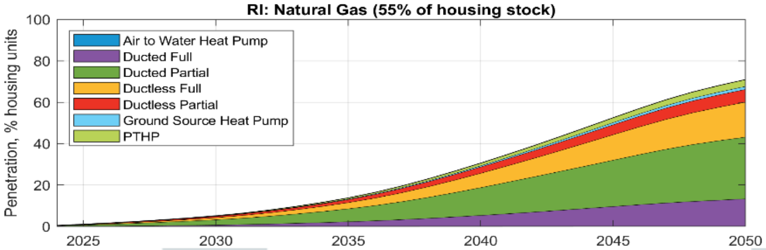
Rhode Island

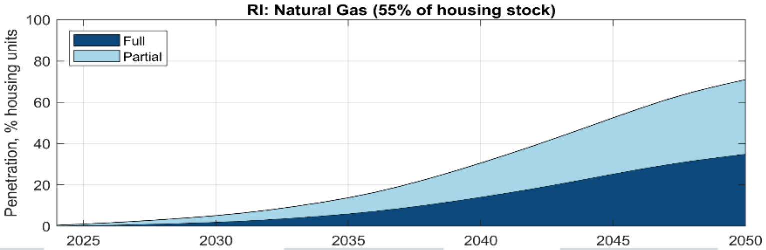






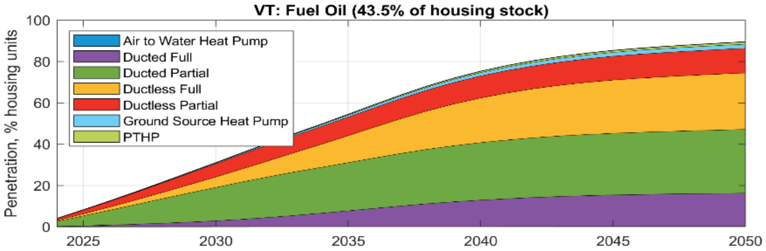


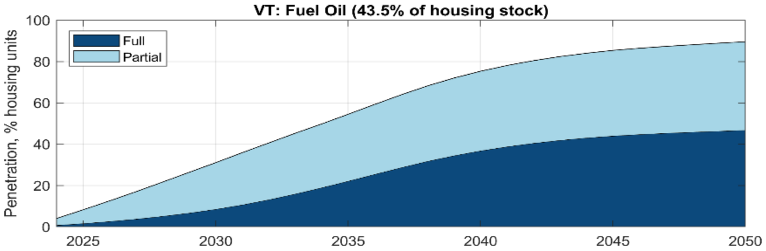


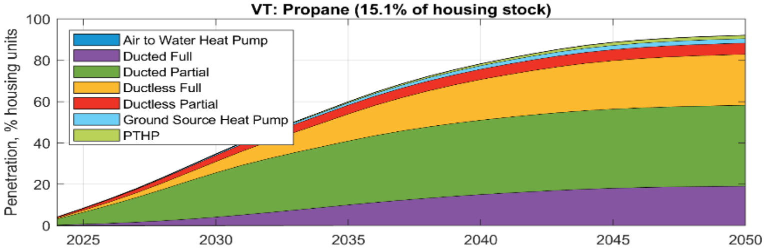


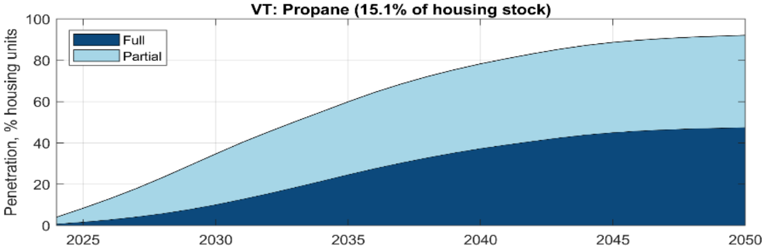
Adoption By Legacy Residential Space Heating Fuel

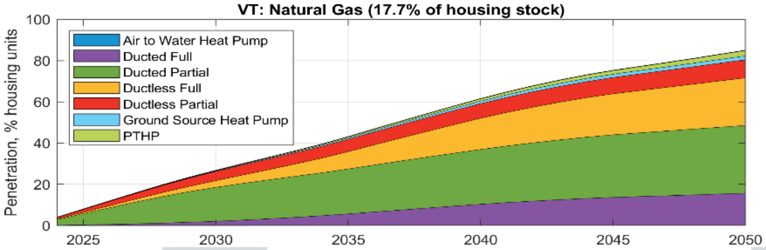
Vermont

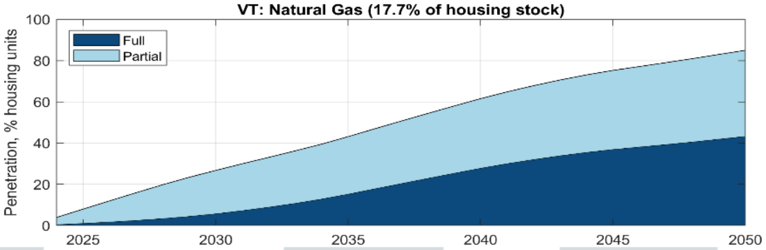






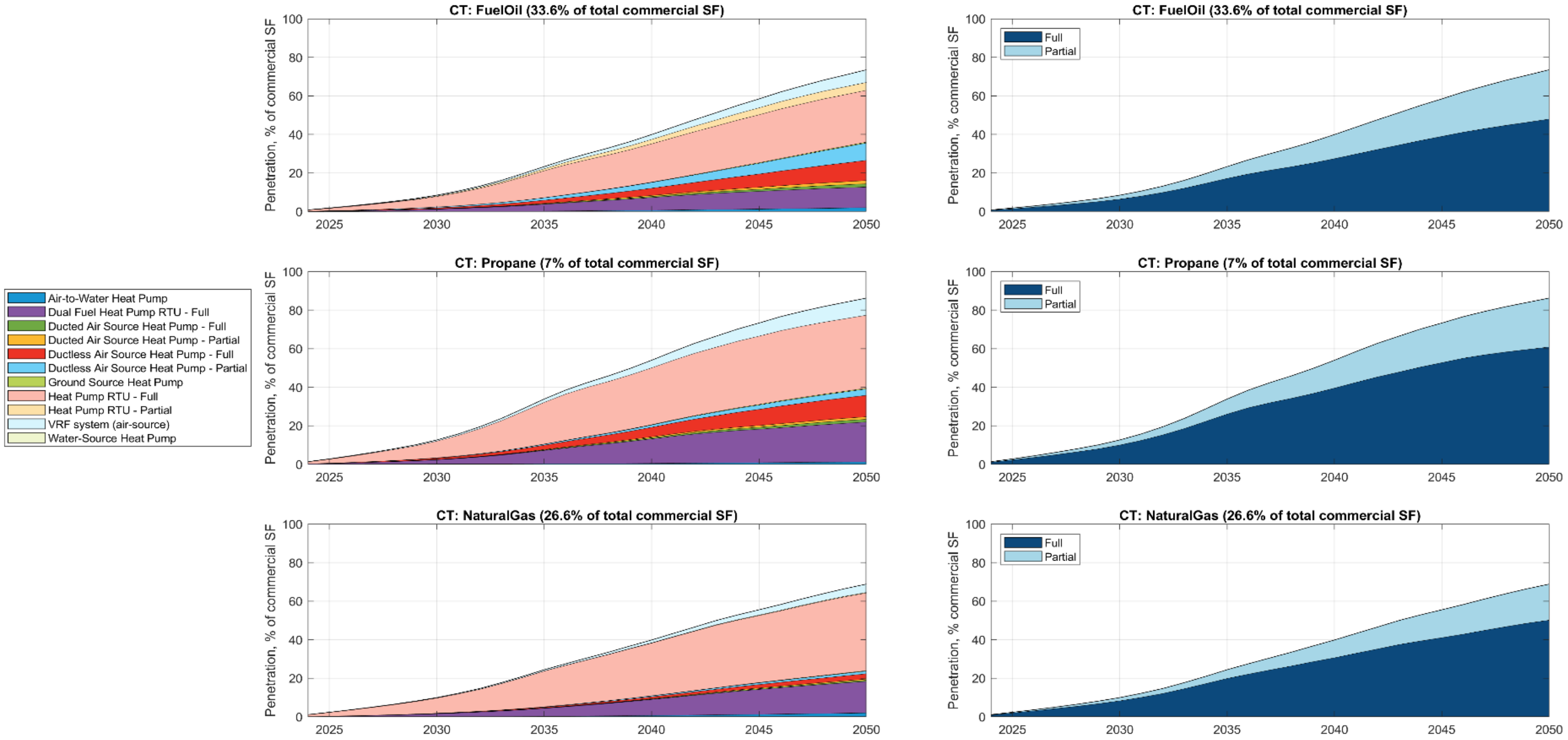






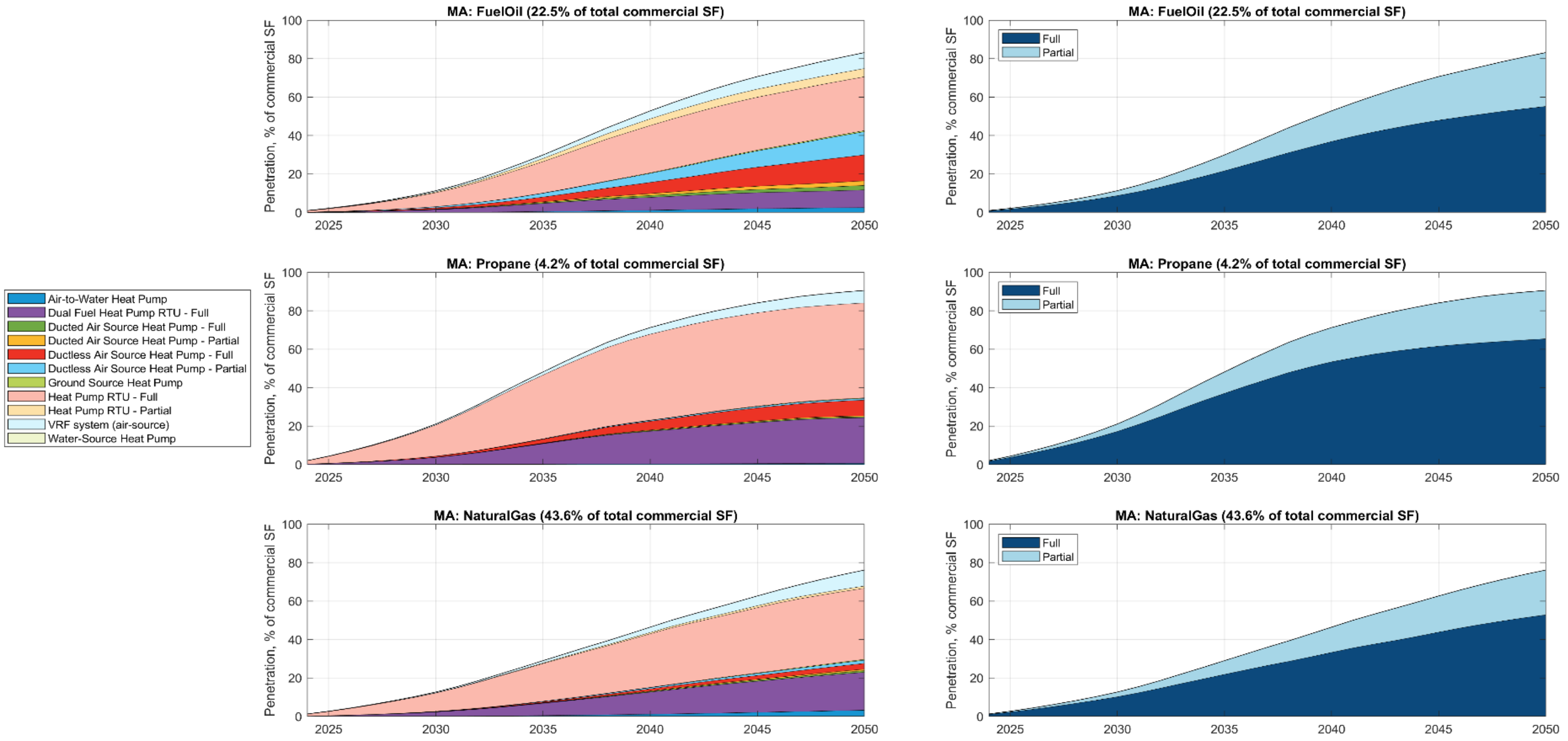
Adoption By Legacy Commercial Space Heating Fuel

Connecticut



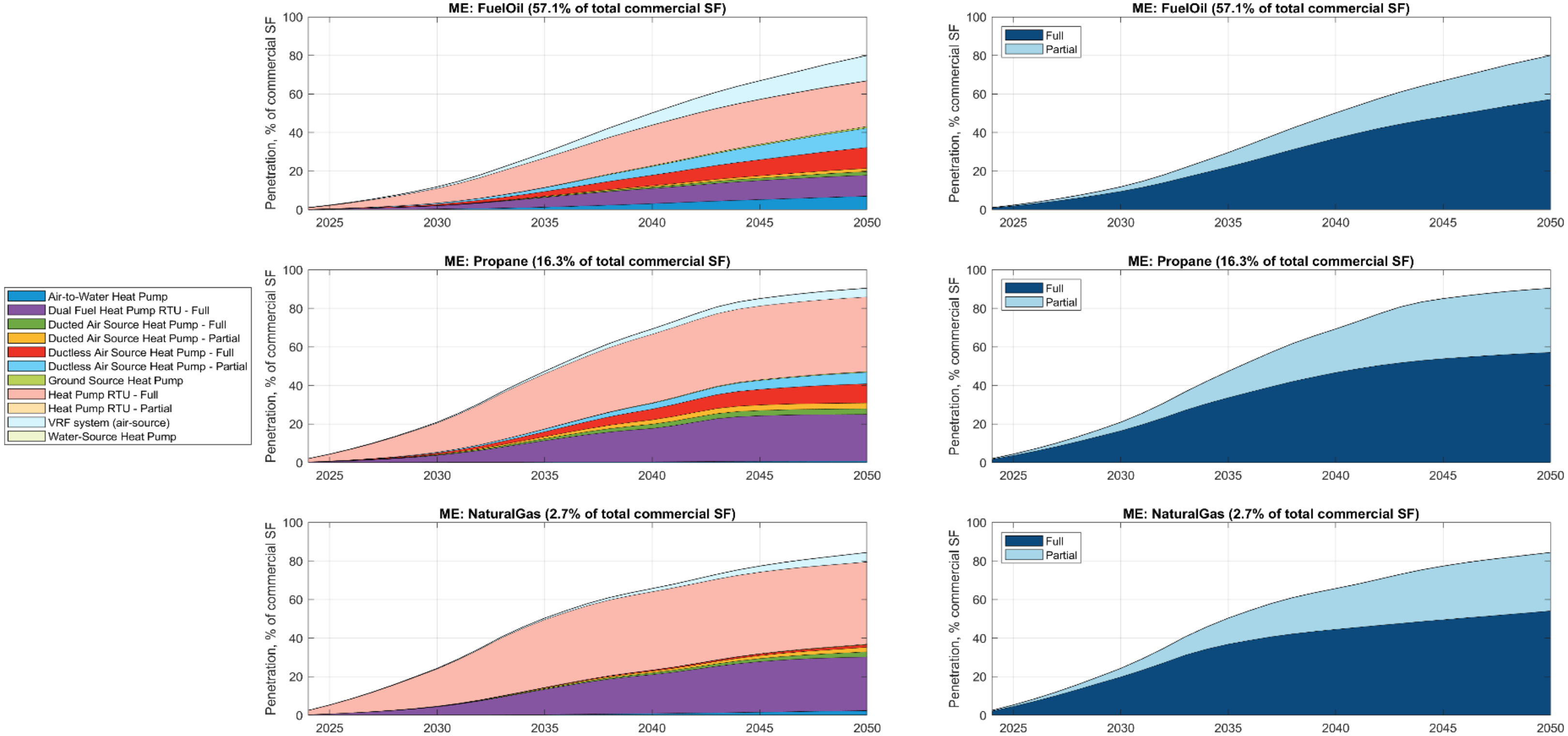
Adoption By Legacy Commercial Space Heating Fuel

Massachusetts



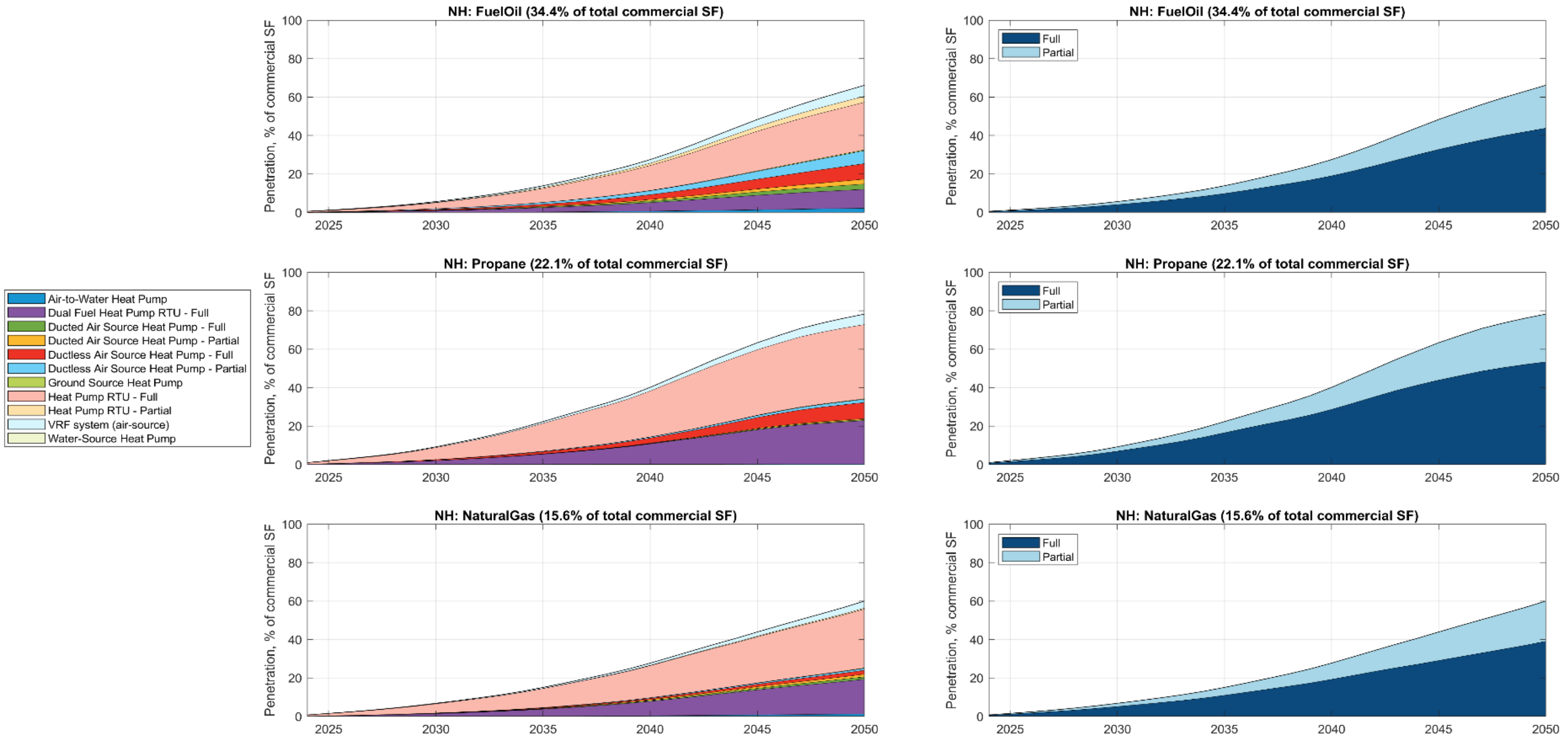
Adoption By Legacy Commercial Space Heating Fuel

Maine



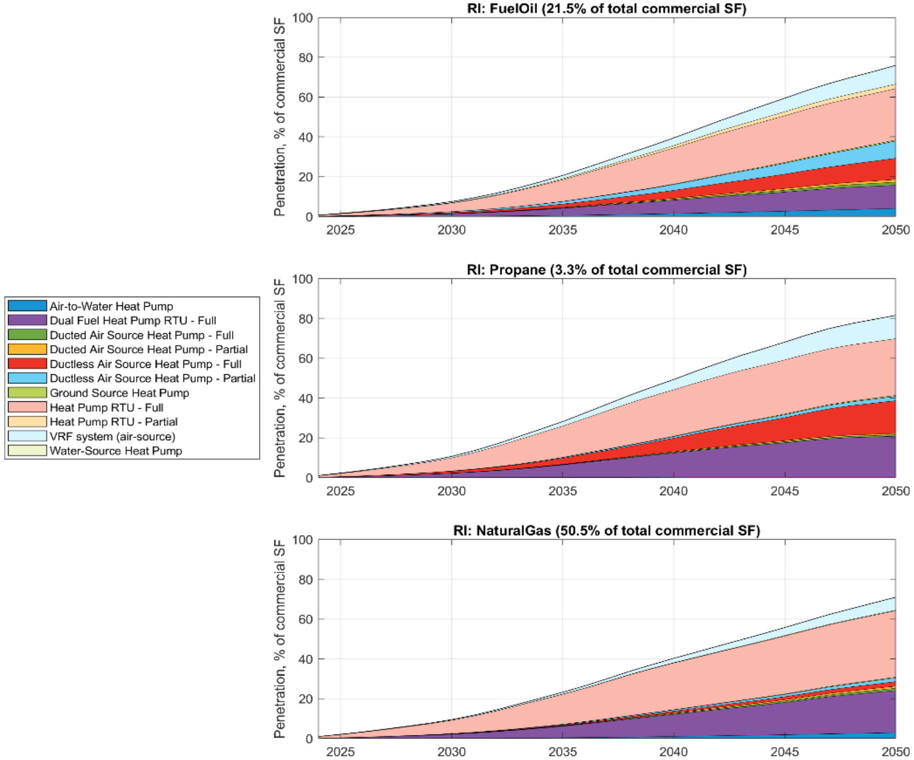
Adoption By Legacy Commercial Space Heating Fuel

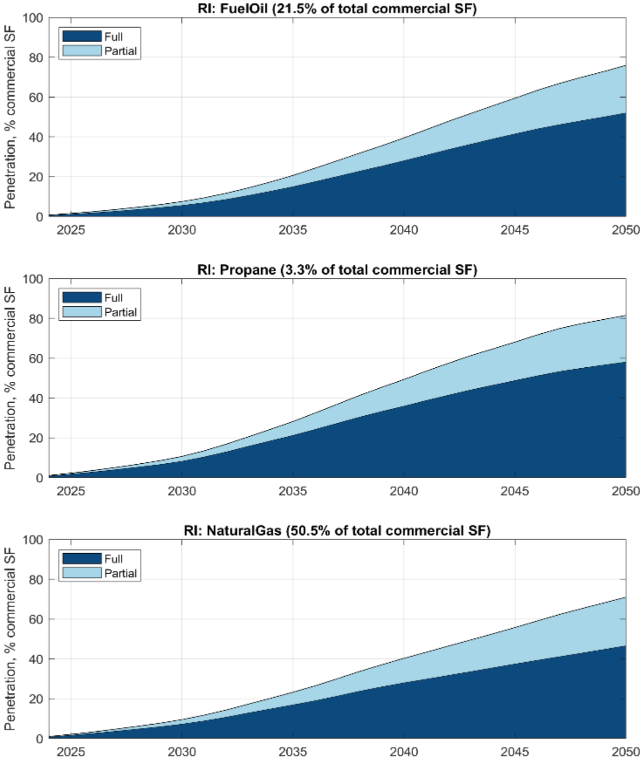
New Hampshire



Adoption By Legacy Commercial Space Heating Fuel

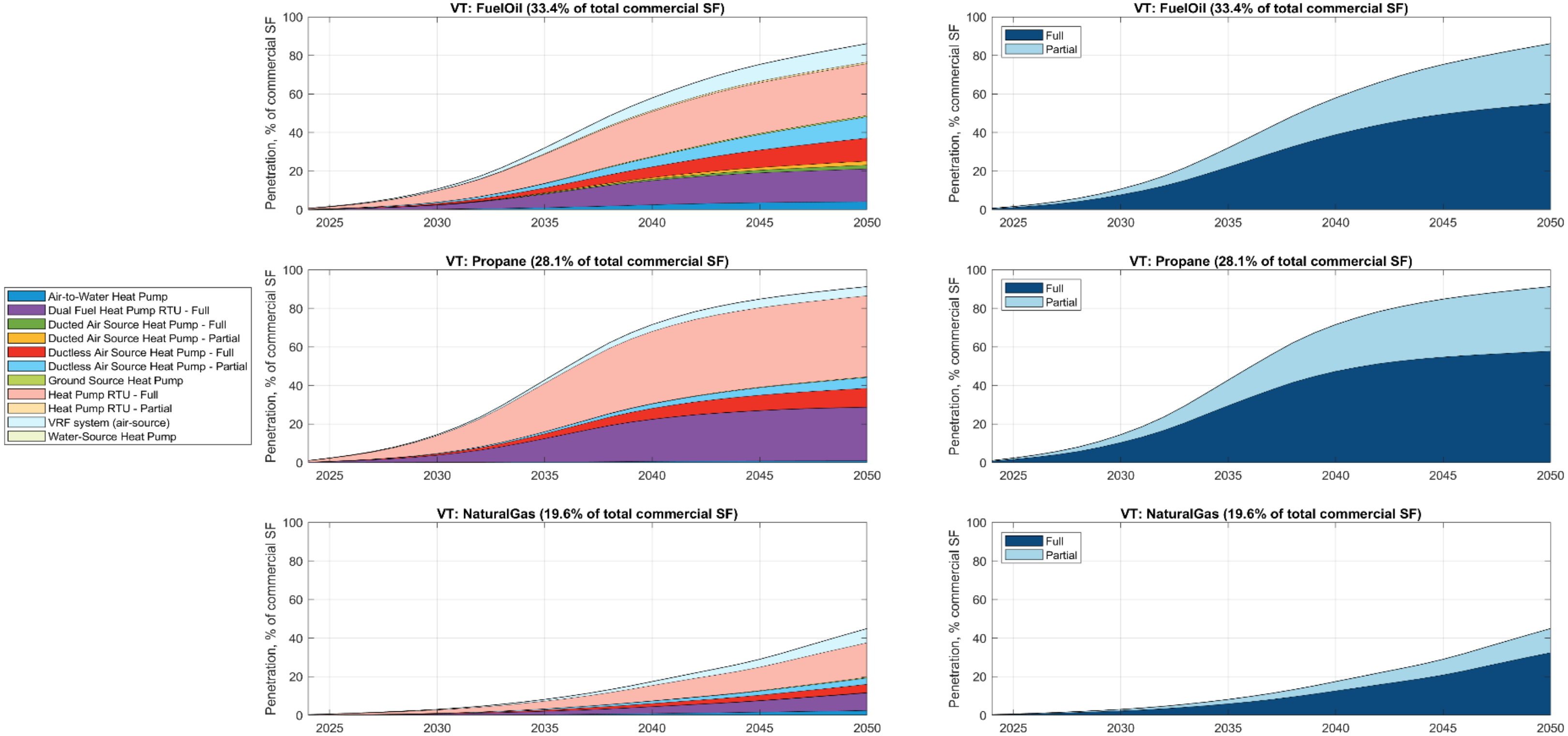
Rhode Island





Adoption By Legacy Commercial Space Heating Fuel

Vermont

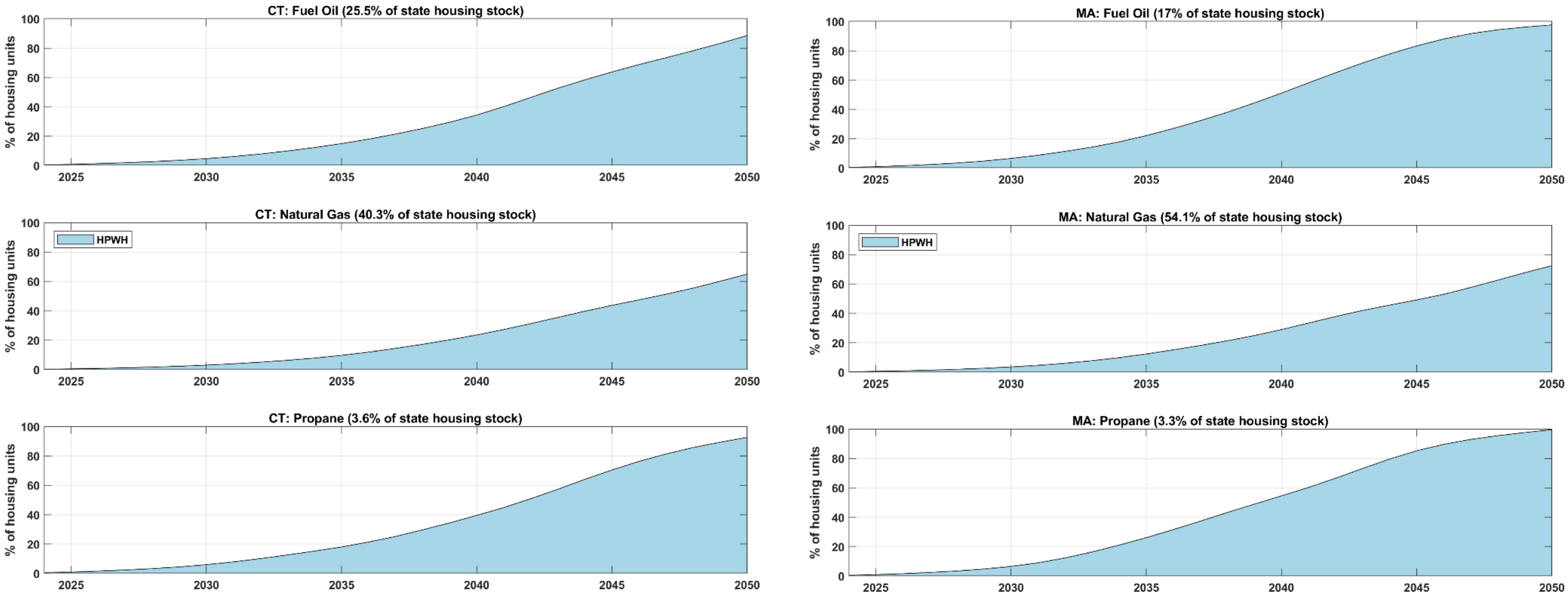


APPENDIX V

State Water Heating Adoption

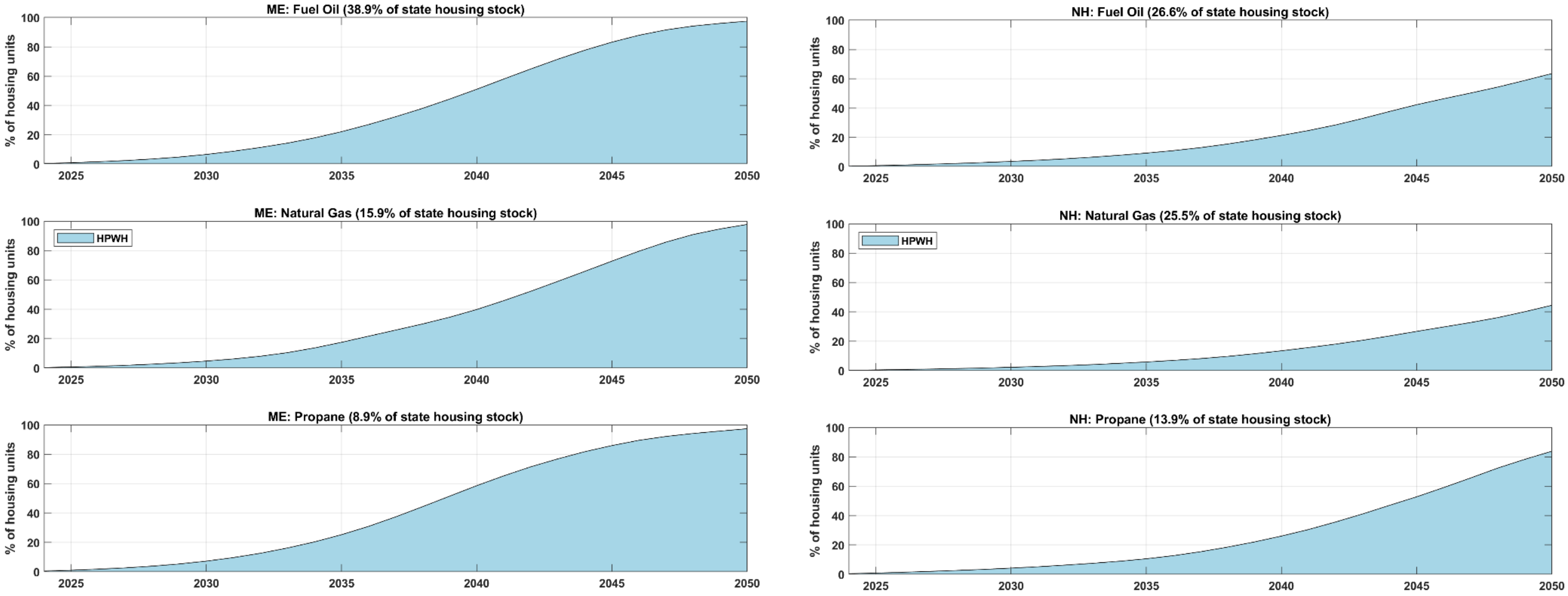
Adoption By Legacy Residential Water Heating Fuel

Connecticut (left) and Massachusetts (right)



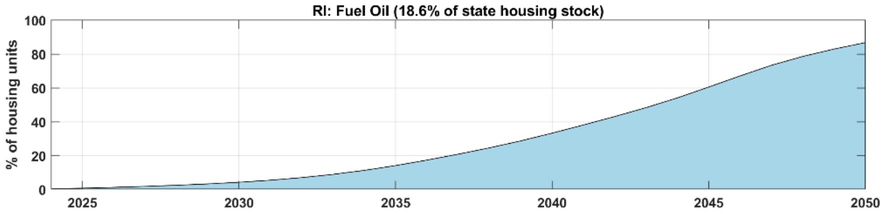
Adoption By Legacy Residential Water Heating Fuel

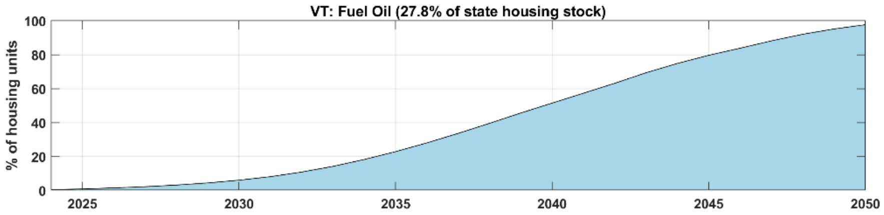
Maine (left) and New Hampshire (right)

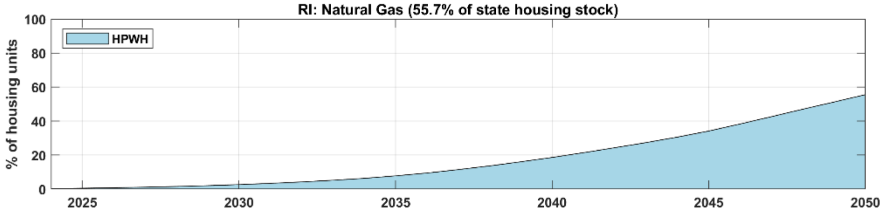


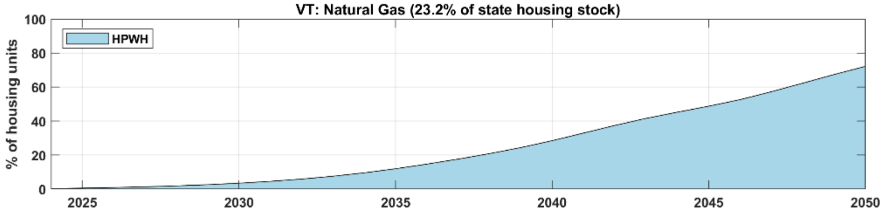
Adoption By Legacy Residential Water Heating Fuel

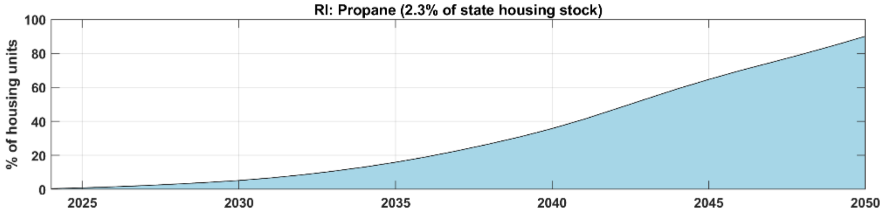
Rhode Island (left) and Vermont (right)

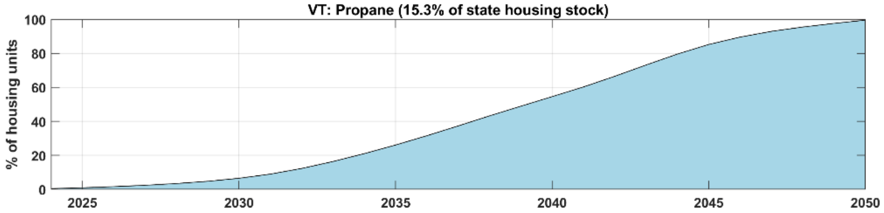






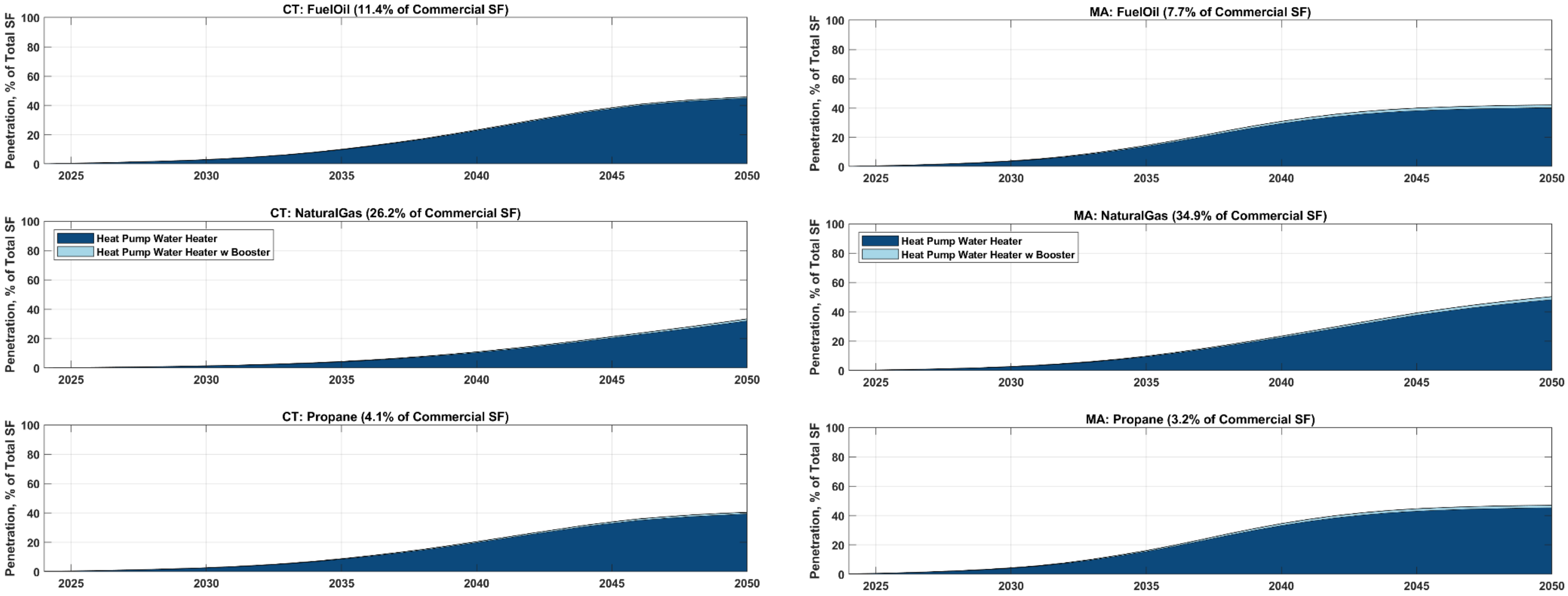






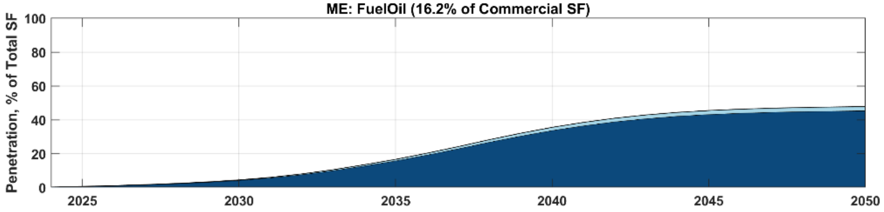
Adoption By Legacy Commercial Water Heating Fuel

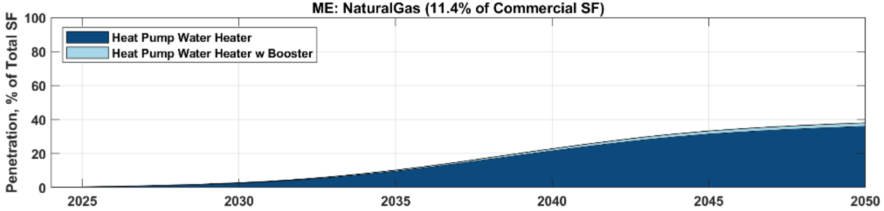
Connecticut (left) and Massachusetts (right)

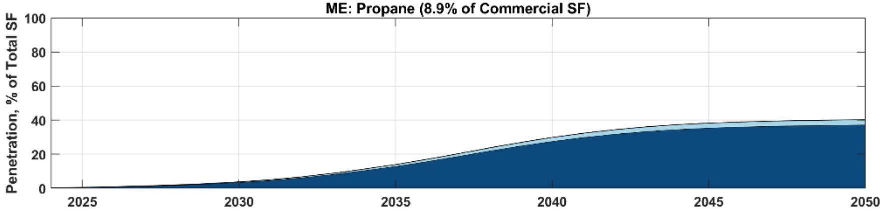


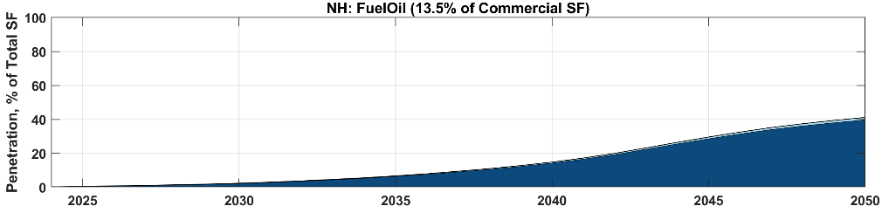
Adoption By Legacy Commercial Water Heating Fuel

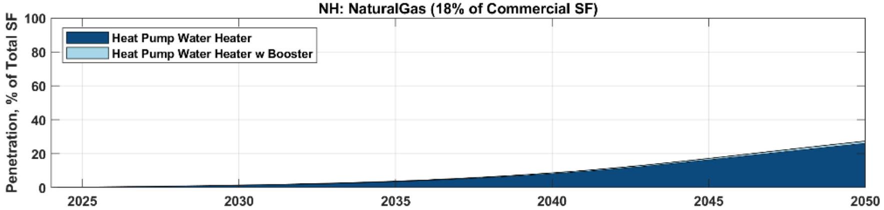
Maine (left) and New Hampshire (right)

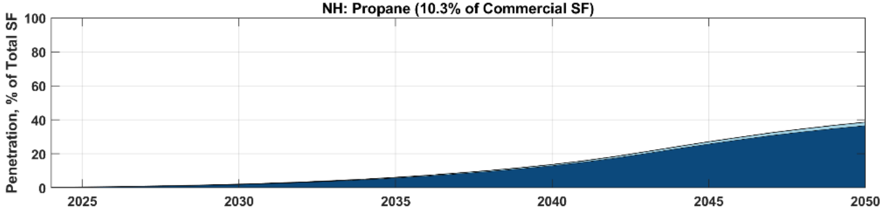






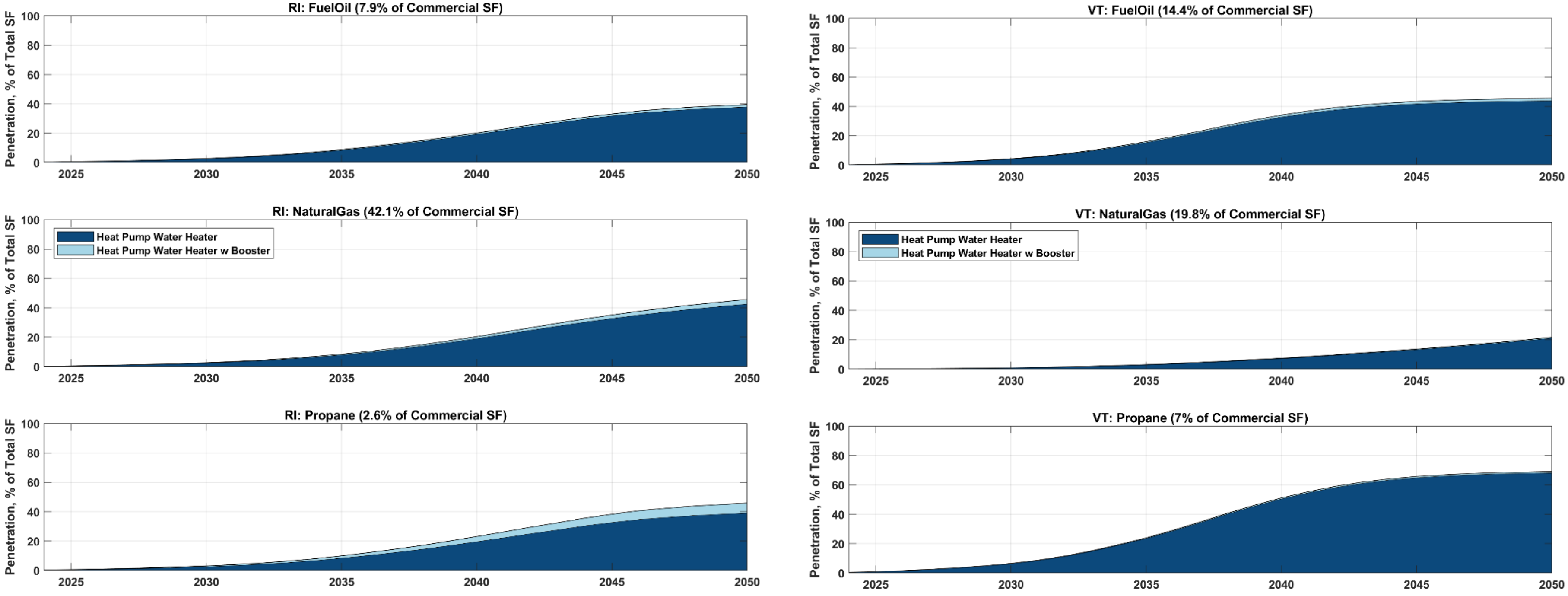






Adoption By Legacy Commercial Water Heating Fuel

Rhode Island (left) and Vermont (right)



APPENDIX VI

Demand Modeling

Demand Modeling Methodology (1 of 2)

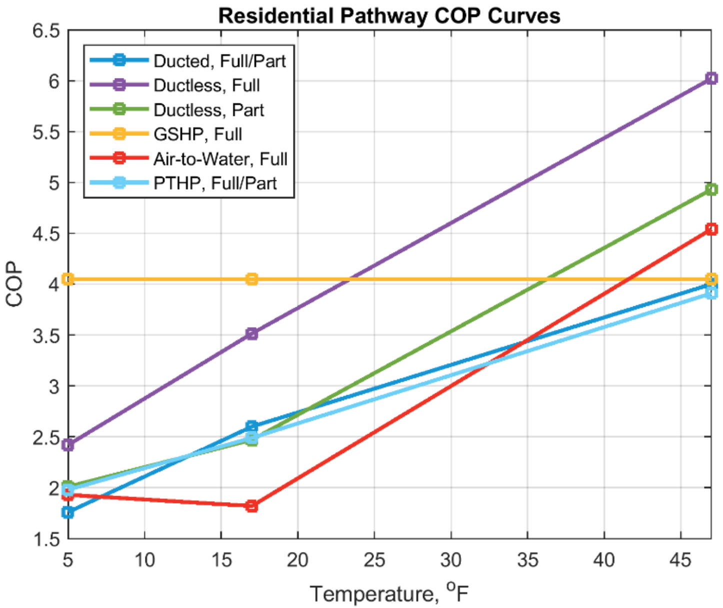
- Demand modeling methodology consists of three steps, which are described further below and on the next slide:
  1. Develop relationships between hourly heating usage and outdoor temperature for all residential and commercial building types
  2. Develop coefficient of performance (COP) curves for all heating pathways
  3. Develop models for HP electrical demand
- Step 1: Development of hourly heating load relationships to outdoor temperature for all building types was based on heating usage profiles within NREL's ResStock and ComStock databases that break out energy usage by end use
  - Heating usage was converted to heating load by assuming a boiler/furnace efficiency of 80%

Demand Modeling Methodology (2 of 2)

- Step 2: For each pathway, a reference make/model heat pump was selected, and its coefficient of performance ($COP = \frac{Heat\ Output}{Input\ Power}$) was used to convert hourly heating required to electricity demand
  - High performing HPs are used as reference under the assumption that performance will continue to improve over the forecast horizon
  - All COP curves and reference HP systems are detailed on the next two slides
- Step 3: Development of models for HP electricity demand assumed:
  - Space heating demand is initiated when outside temperatures are below 62^{o}F
  - For partial heating pathways, all heating load needed at temperatures below the HP's switchover temperature is provided by a supplemental, non-electric heating system
    - Partial heating demand profiles are blends of demand profiles resulting from a range of normally distributed switchover temperatures
  - For full heating pathways, electric resistance heat is assumed to be used to meet any load unable to be met by the HP (e.g., when temperatures are lower than the HP's minimum HP operating temperatures)
  - Resulting models for all combinations of building types and heating pathways include separate hourly parameters for both non-holiday weekdays and holidays/weekend days

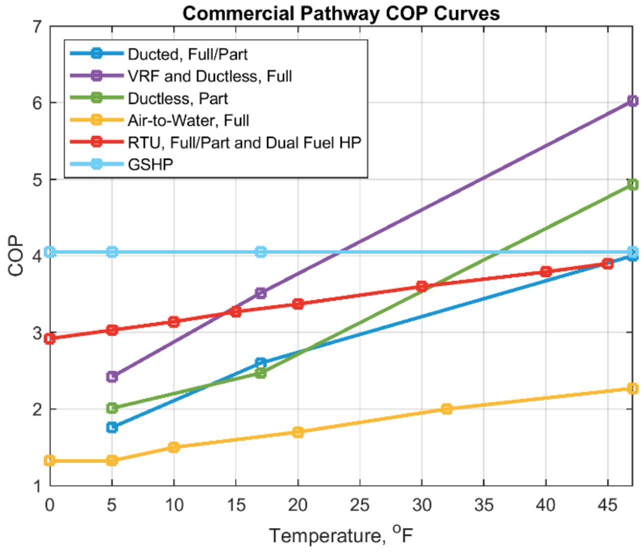
Residential Space Heating Pathway Assumptions

Pathway	Share of Adoption (%)		Min. Operating Temp (F)	Approx. Seasonal Heating Supplied (%)	Reference HP
	2032	2050			
Air-to-Water	0.2	0.2	-5	100	Taco Comfort System M
Ducted Full	12.6	18.6	5	100	Lennox Central Heat Pump
Ducted Partial	50.9	39.7	5	63-74	
Ductless Full	19.2	26.4	-13	100	Mitsubishi M-Series
Ductless Partial	14.5	10.5	-13	65-76	Daikin DZ6VS
Ground Source Heat Pump (GSHP)	1.5	2.1	-20	100	Energy Star rated models
Packaged Terminal Heat Pump (PTHP)	1.1	2.4	5	81	ICE-AIR HP



Commercial Space Heating Pathway Assumptions

Pathway	Share of Adoption (%)		Min. Operating Temp. (F)	Approx. Seasonal Heating Supplied (%)	Reference HP
	2032	2050			
Air-to-Water	1.4	3.7	0	100	Trane ACX
Dual Fuel Heat Pump Rooftop Unit (RTU)	17.4	20.6	0	81	Rheem Renaissance Packaged Heat Pump
Ducted Full	0.7	1.8	5	100	Lennox Central Heat Pump
Ducted Partial	0.7	1.7	5	61-74	
Ductless Full	3.8	9.3	-13	100	Mitsubishi M-Series
Ductless Partial	2.5	6.8	5	63-76	Daikin DZ6VS
Ground Source Heat Pump	0.2	0.6	-20	100	Energy Star rated models
Rooftop Unit (RTU) – Full	68.0	43.5	0	100	Rheem Renaissance Packaged Heat Pump
RTU - Partial	1.5	2.3	0	81	
Variable Refrigerant Flow (VRF)	3.8	9.7	-13	100	Mitsubishi M-Series



Water Heating Modeling Assumptions

- Assumed location of all HPWH installations is a conditioned or semi-conditioned area such that significant changes in COP do not occur as outdoor temperature decreases
  - Specific HP profiles are constant year-round for each building type and only vary to reflect different usage for non-holiday weekdays versus weekend/holidays
    - HPWH profiles reflect hourly average usage throughout the year
  - To reflect a degree of increased space heating load due to HPWH operation, modeling of all residential space heating pathways assumed a minor load increase of 1.2%
  - HPWHs in commercial buildings are assumed to be located in areas that do not meaningfully contribute to space heating loads
- For commercial buildings that have significant hot water loads that may need booster heat, 15% of the total water heating load is assumed to come from an electric booster, with a COP of 1.0
  - The weighted average COP of boosted/non-boosted heating is used

APPENDIX VII

Partial Heating Modeling Improvements

Background

- For CELT 2024, the ISO improved its modeling of partial space heating
  - Partial heating pathways are those for which a heat pump only provides a portion of a building's heating demand, with the remainder assumed to be provided by a non-electric heating source
  - For CELT 2023, partial heating comprised more than half of residential space heating adoption, and roughly 30% of commercial space heating adoption

- Two possible operational schemes exist for HPs supplying partial heating
  1. Integrated controls, with switchover temperature at which HP turns off and non-electric backup heat turns on → ***Implemented as part of CELT 2023***
  2. The HP keeps running at low temperatures and supplies part of building's heating load, with a backup heating source providing remainder of needed heat → ***ISO is still researching***

- The CELT 2023 incorporation of integrated controls modeling used simplified assumptions that resulted in unrealistic load volatility that will be described in subsequent slides

- Note that data on specific operation of HPs remains scarce, so using a fully "data-driven" method of modeling is not yet possible
  - Goal is to represent a range of HP operation scenarios that can be refined as more data are made available

Heating Electrification Pathways

Commercial and Residential Space Heating

Partial heating pathways are identified in **bold red** *below*

Commercial Space Heating Pathways

Heating Type	Technology Type	Heating Displacement
Space Heating	District Heating via Geothermal Heat Pump	Full
	Dual Fuel Heat Pump RTU	**Partial**
	Heat Pump RTU	Full/**Partial**
	VRF system (air-source)	Full
	Air-to-Water Heat Pump	Full
	Ducted Air Source Heat Pump	Full
	Ducted Air Source Heat Pump	**Partial**
	Ductless Air Source Heat Pump	Full
	Ductless Air Source Heat Pump	**Partial**

RTU = Rooftop Unit; VRF = Variable Refrigerant Flow

Residential Space Heating Pathways

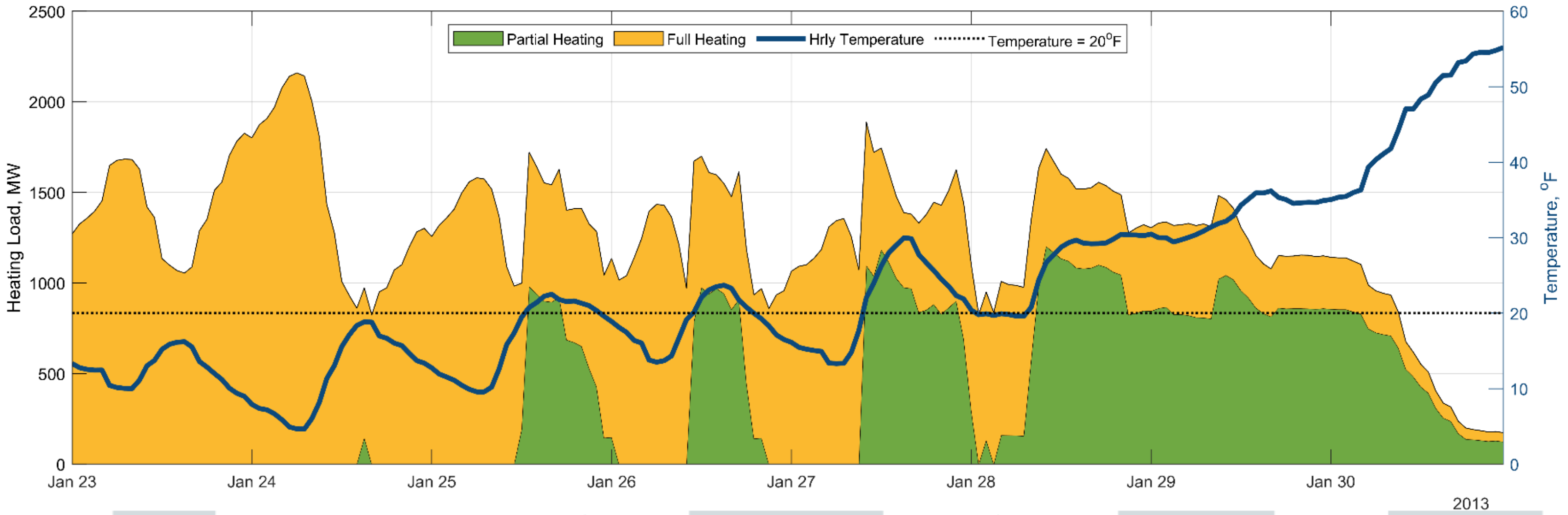
Heating Type	Technology Type	Heating Displacement
Space Heating	Ducted ASHP - Full	Full
	Ducted ASHP - Partial	**Partial**
	Ductless ASHP - Full	Full
	Ductless ASHP - Partial	**Partial**
	Ground Source Heat Pump	Full
	Air to Water Heat Pump	Full
	Packaged Terminal Heat Pump	**Partial**

ASHP = Air Source Heat Pump

CELT 2023 Example of Partial Heating Demand Issue

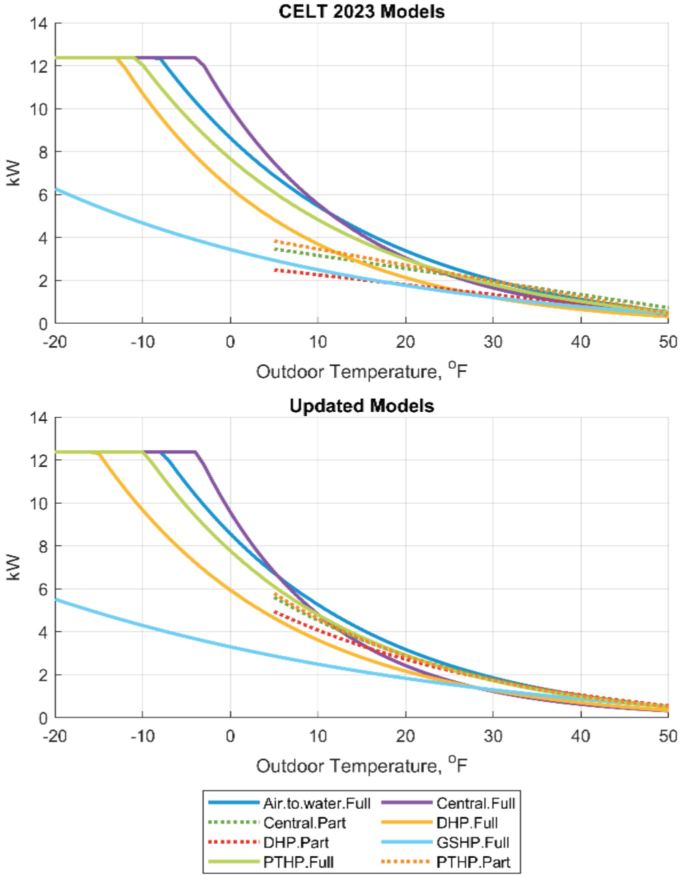
MA Residential Space Heating, January 2032 Adoption, January 2013 Weather

- The plot below shows the results of the CELT 2023 modeling for residential space heating in MA
  - Plot reflects CELT 2023 adoption forecast for January 2032, and January 2013 weather
- Plot illustrates the consequence of existing partial heating HP modeling
  - All partial heating (in green) switching on/off at the same temperature (20°F) yields significant load volatility
  - In reality, heat pumps in partial heating applications are expected to be used in a range of switchover temperatures



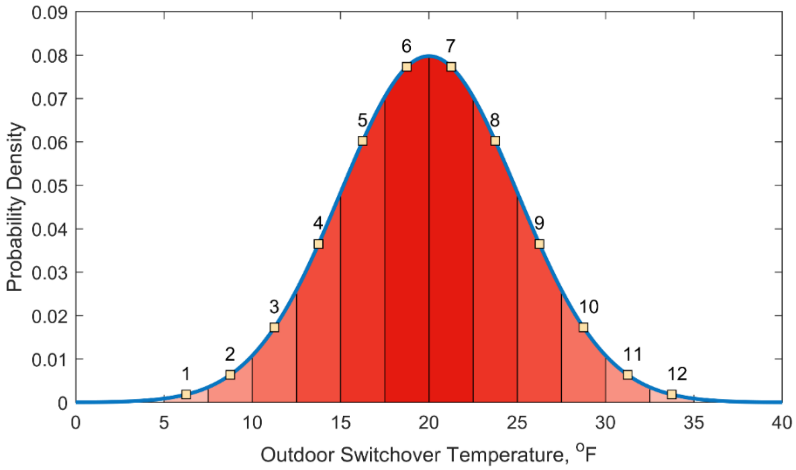
Demand Modeling Refinements

- The ISO and its consultant to refined the demand modeling developed and used for CELT 2023
  - Work included a recalibration of the modeled coefficient of performance (COP) curves to those observed in more recent metering studies
- Plots to the right show examples of the changes in the modeling
  - Demand curves are for single-family detached buildings, weekdays, hour 8
  - Very minor adjustments to the full heating pathways (solid lines in plots)
  - Significant changes to partial heating pathways (dashed lines in plots)



Blended Demand Profiles

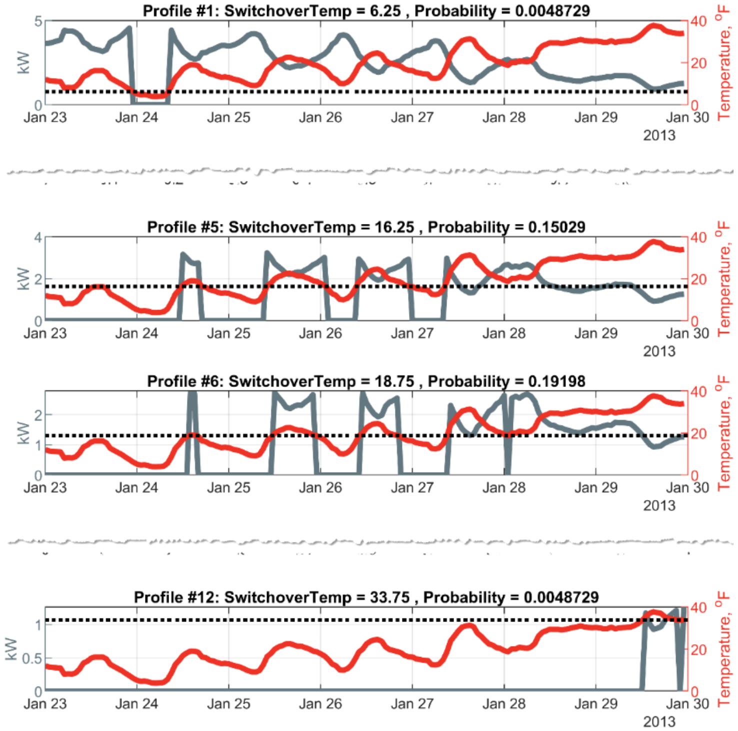
- ISO Created a blended demand profile for each partial space heating pathway that reflects a range of switchover temperatures
- Assumes a normal distribution with mean of 20°F and a standard deviation of 5°F
  - Divide normal distribution into 12 switchover temperatures and probabilities as plotted and tabulated
  - Based on each switchover temperature and probability, model a weighted average demand profile reflecting a composite of all 12 resulting demand profiles



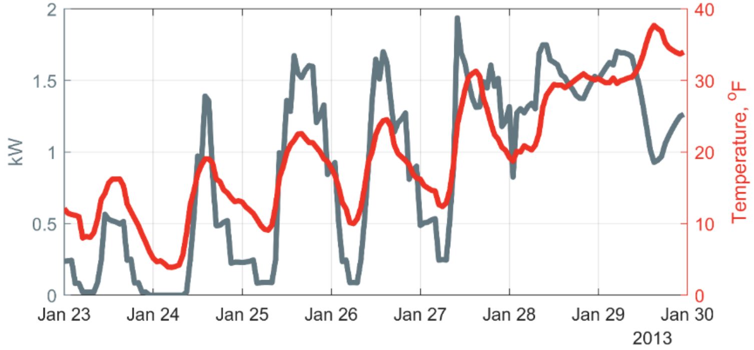
Segment	Temperature, °F	Probability
1	6.25	0.0049
2	8.75	0.0166
3	11.25	0.0442
4	13.75	0.0921
5	16.25	0.1503
6	18.75	0.1920
7	21.25	0.1920
8	23.75	0.1503
9	26.25	0.0921
10	28.75	0.0442
11	31.25	0.0166
12	33.75	0.0049

Raw and Blended Partial Heating Profiles

12 Raw Profiles



Blended Profile



CELT 2023 Example – Results of Updated Modeling

MA Residential Space Heating, January 2032 Adoption, January 2013 Weather

- The plot below shows the results of the CELT 2024 modeling for residential space heating in MA
  - Plot reflects CELT 2023 adoption forecast for January 2032, and January 2013 weather
- Plot illustrates the significant improvements to the partial heating HP modeling
  - All partial heating (in green) now switches on/off at a diversity of temperatures in the range of ~6^{o}F-34^{o}F, and yields dramatically less load volatility