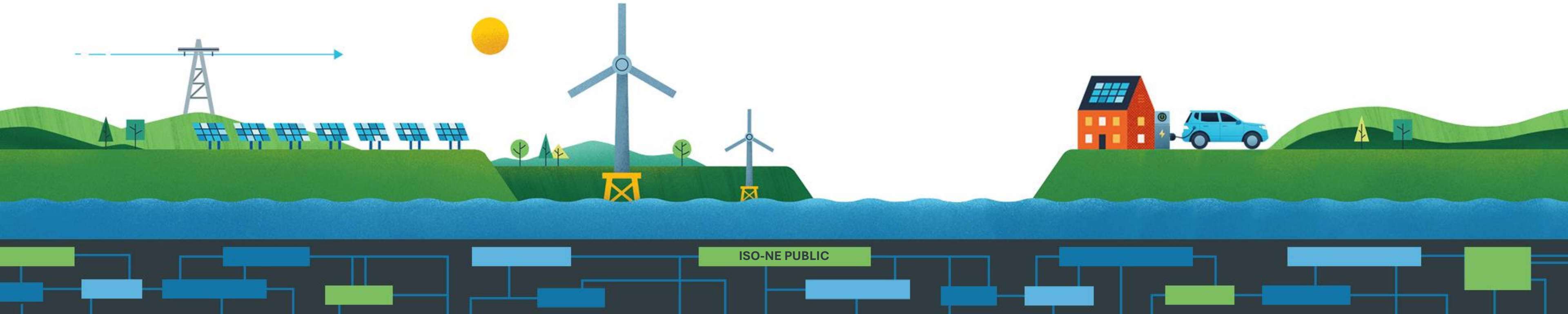
MAY 1, 2025

Final 2025 Heat Pump Forecast



Acronyms

AC	Air Conditioner	**ACS**	American Community Survey	**AHS**	American Housing Survey
ASHP	Air Source Heat Pump	**CBECS**	Commercial Building Energy Consumption Survey	**CELT**	Capacity, Energy, Loads, and Transmission
COP	Coefficient of Performance	**DOAS**	Dedicated Outdoor Air System	**DOE**	Department of Energy
EIA	Energy Information Administration	**GSHP**	Ground Source Heat Pump	**GWh**	Gigawatt Hour
HP	Heat Pump	**HPWH**	Heat Pump Water Heater	**HVAC**	Heating, Ventilation, Air Conditioning
MW	Megawatt	**NREL**	National Renewable Energy Laboratory	**PSZ**	Packaged Single Zone
PTAC	Packaged Terminal Air Conditioner	**PTHP**	Packaged Terminal Heat Pump	**PUMS**	Public Use Microdata Sample
PVAV	Packaged Variable Air Volume	**RECS**	Residential Energy Consumption Survey	**ROI**	Return On Investment
SF	Square Feet	**VAV**	Variable Air Volume	**VRF**	Variable Refrigerant Flow

Outline

- Introduction
- Final 2025 Adoption Forecast
- Final 2025 Energy Forecast
- Final 2025 Demand Forecast
- Appendices
  - Appendix I: Building Stock Characterization
  - Appendix II: Heating Electrification Pathways
  - Appendix III: Adoption Modeling Methodology
  - Appendix IV: State Space Heating Adoption
  - Appendix V: State Water Heating Adoption
  - Appendix VI: Hourly Demand modeling

Introduction

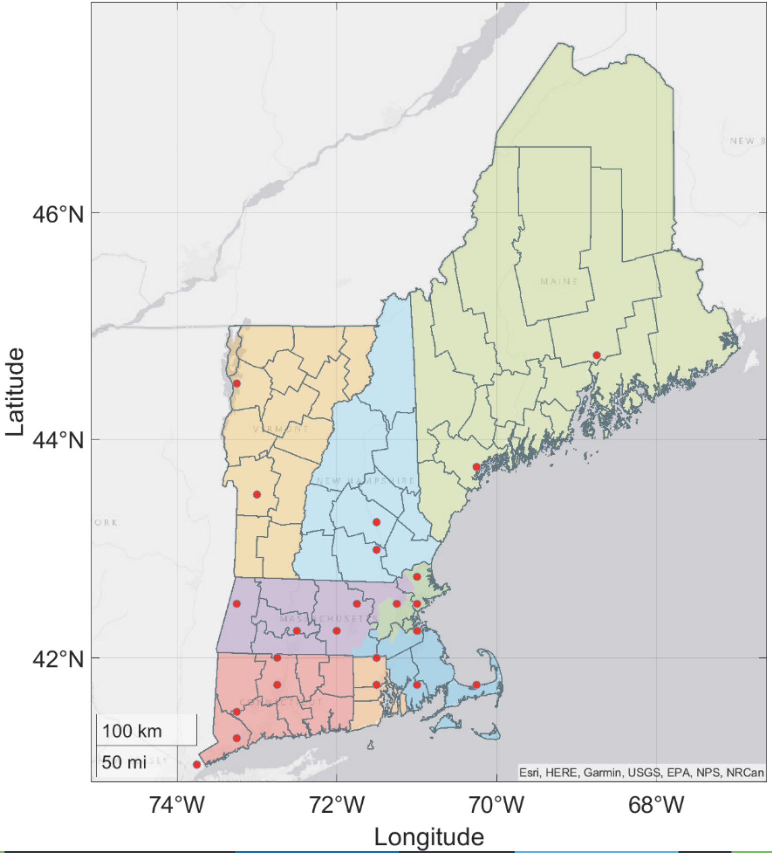
- Heating electrification is expected to play a pivotal role in the achievement of New England state greenhouse gas (GHG) reduction mandates and long-term decarbonization goals.
- Forecasted impacts of heating electrification on state and regional electric energy and demand are included as part of the 2025 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 of heat pumps (HP) to electrify space and water heating in residential and commercial buildings.

Introduction

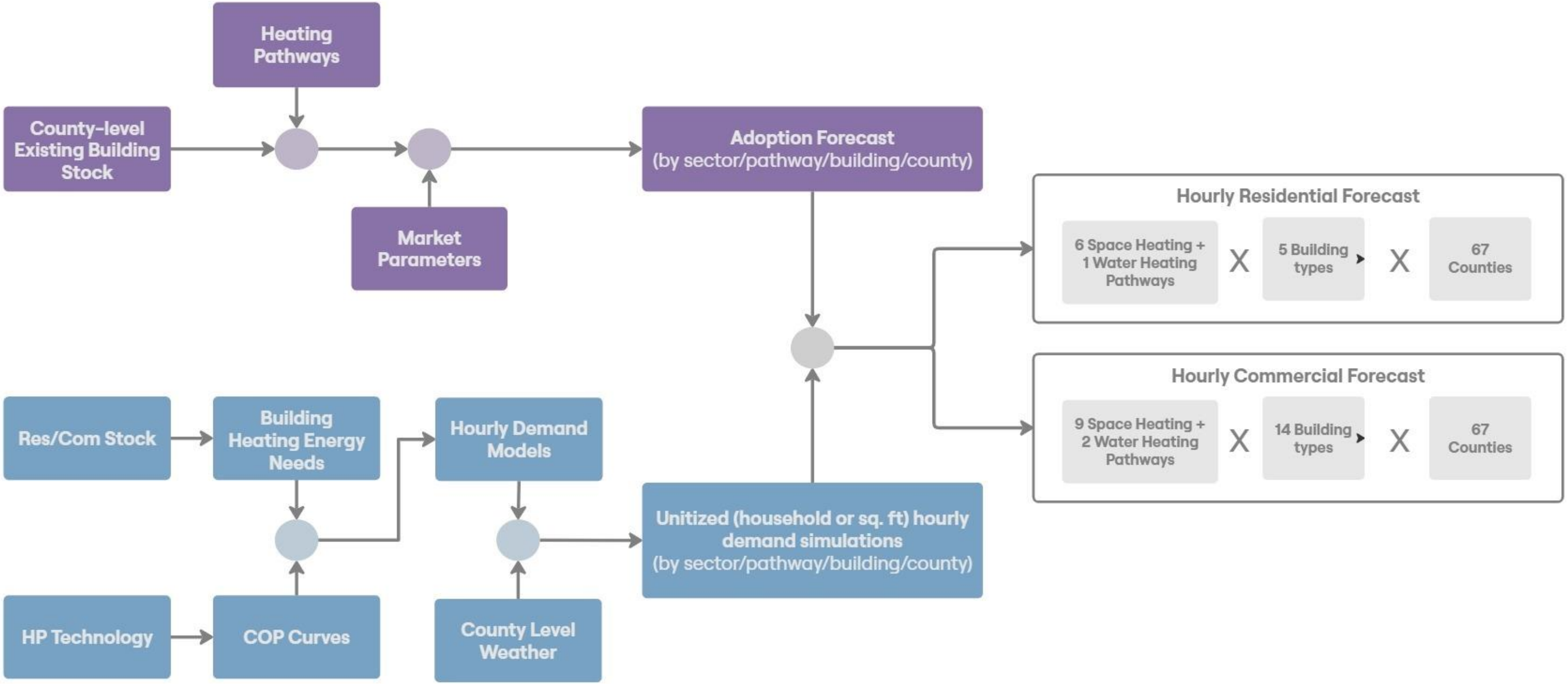
- The methodology used to model and forecast heating electrification impacts remains relatively unchanged from the prior forecast cycle
  - Prior to CELT 2025 the heating electrification forecast produced hourly results at the state level
  - Full set of hourly results could not be used prior to CELT 2025 since the gross load forecast only modeled daily peaks
  - Peak impacts were based on modeled HP demand during an assumed window of summer and winter peak hours
  - See the CELT 2024 Heating Electrification Forecast for further methodology details
- For CELT 2025 the heating electrification forecasts consists of hourly forecast simulations, at the county level, reflecting climate-adjusted weather
  - The climate-adjusted weather used is discussed on slide 8-12 of the Update to Forecast Data Sources presentation
  - HP peak demand impacts are determined based on a waterfall approach used while compiling the gross and net load forecasts
    - Refer to slides 10-12 of the 2025 Final Draft Energy and Seasonal Peak Forecast presentation
  - Development of the hourly simulations is further discussed on next slide

Heat Pump Forecast Improvements

- Development of HP forecasts
  - HP impacts are modeled hourly for the entire forecast horizon
  - All forecast components were simulated using the same 70 years of weather for each forecast year
- County-level forecast accounting
  - Plot shows county boundaries overlayed with load zones
    - Red dots indicate weather stations
    - County forecasts utilize weather at station closest to county center
  - County-level forecasts were aggregated to load zones before combining with the base load forecast



Heating Electrification Forecast Process

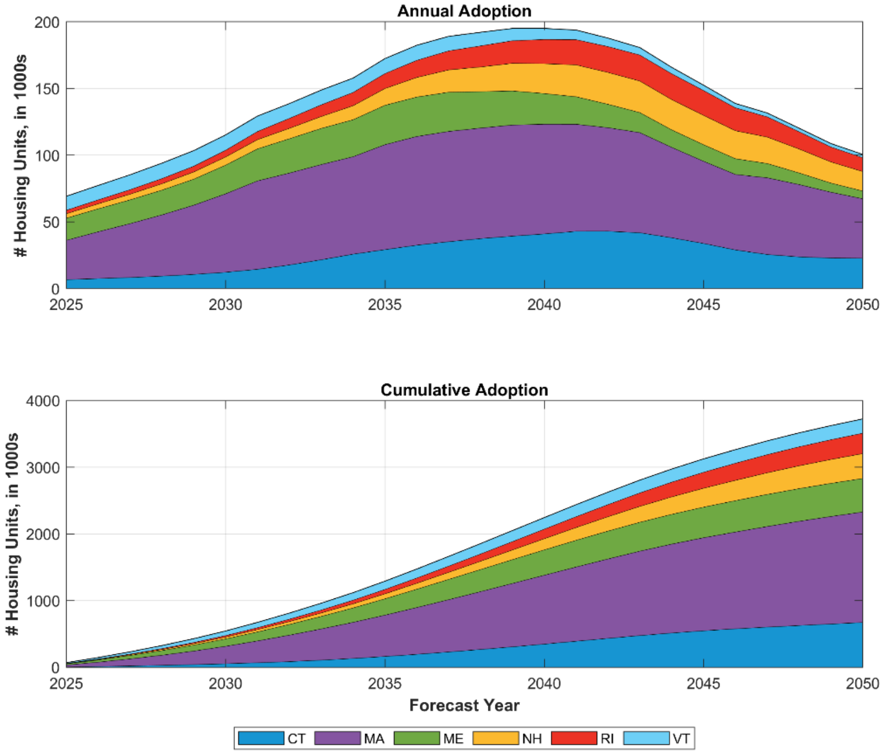


FINAL 2025 ADOPTION FORECAST

Transitional Slide Subtitle

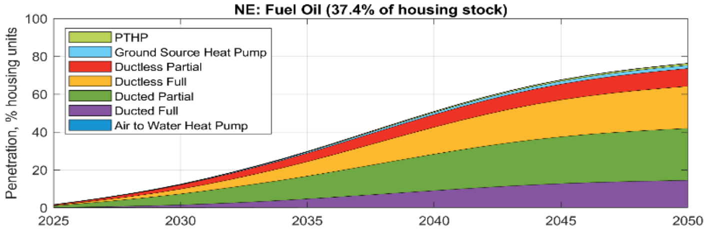
Residential Space Heating Adoption

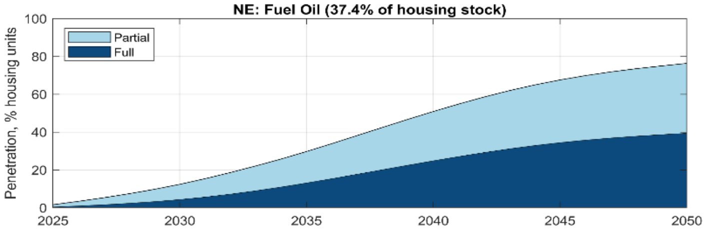
- Adoption forecast for residential space heating (full + partial) is shown to the right
  - Incremental adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes more than 3.7 million housing units with electrified space heating by 2050
  - ~58% of total housing stock
  - ~71% of fossil fueled 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 Append IV

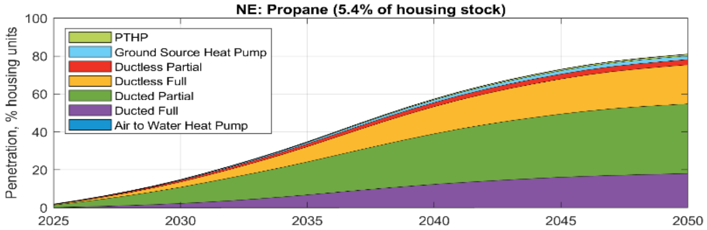


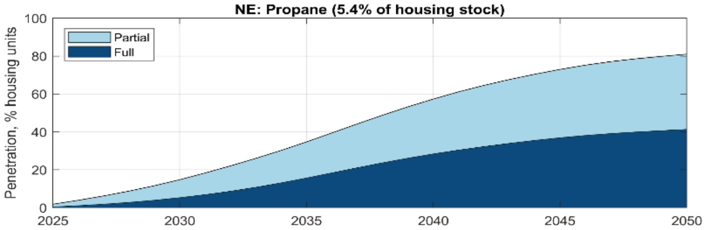
Adoption By Legacy Residential Space Heating Fuel

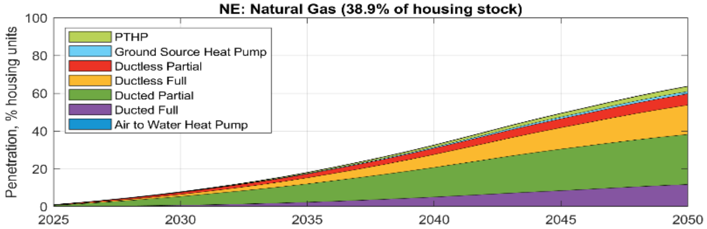
New England

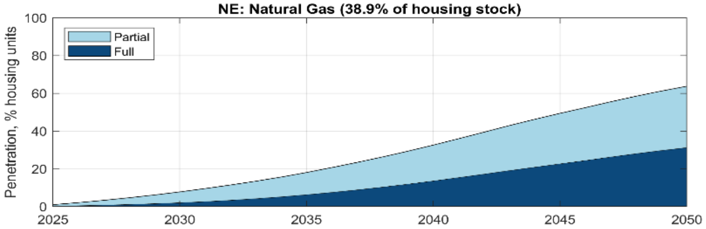






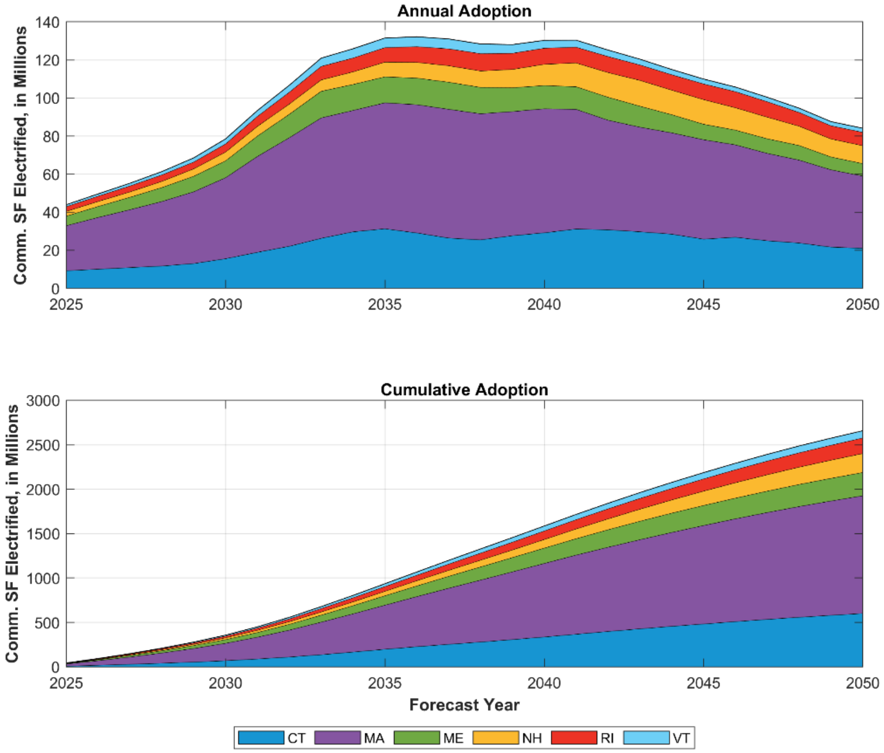






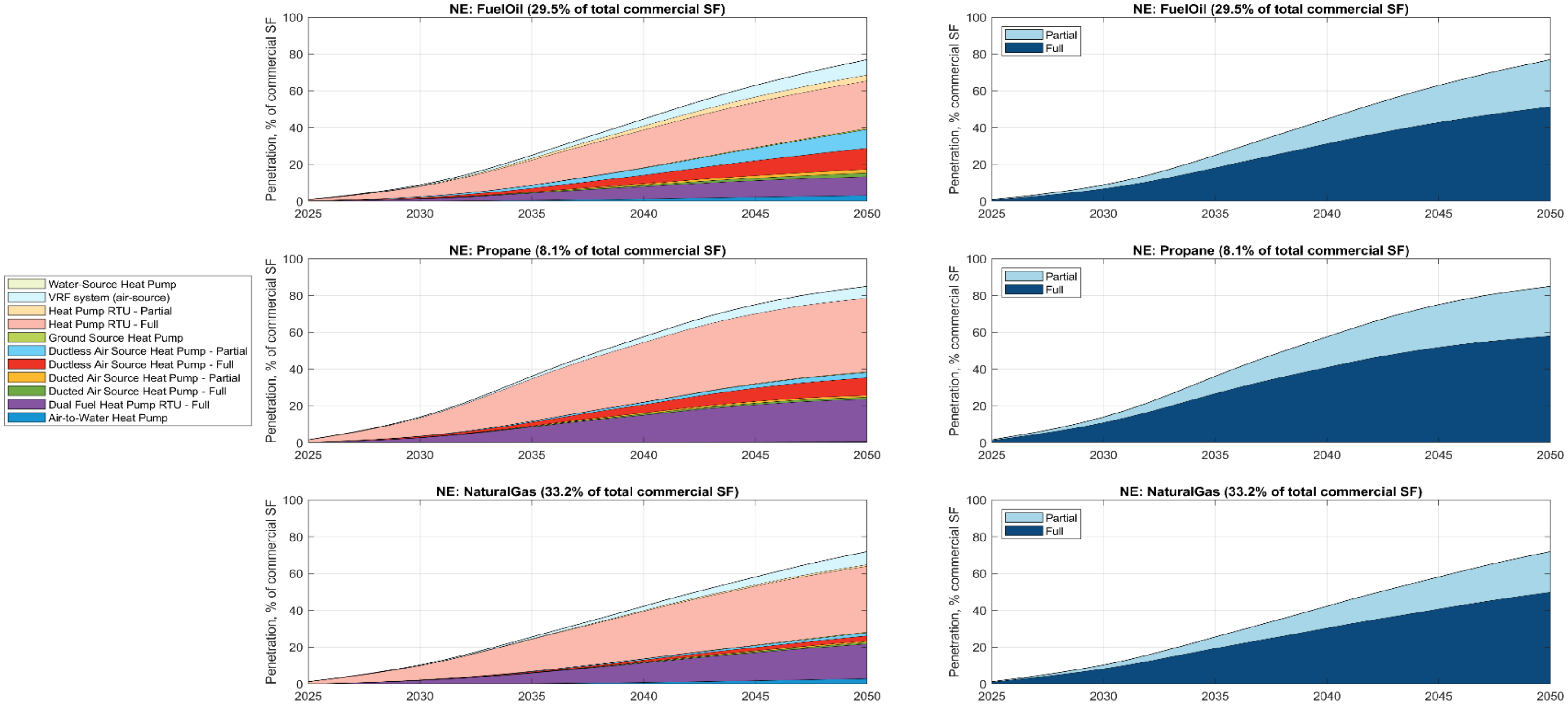
Commercial Space Heating Adoption

- Adoption forecast for commercial space heating (full + partial) is shown to the right
  - Incremental adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes more than 2.6 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 IV



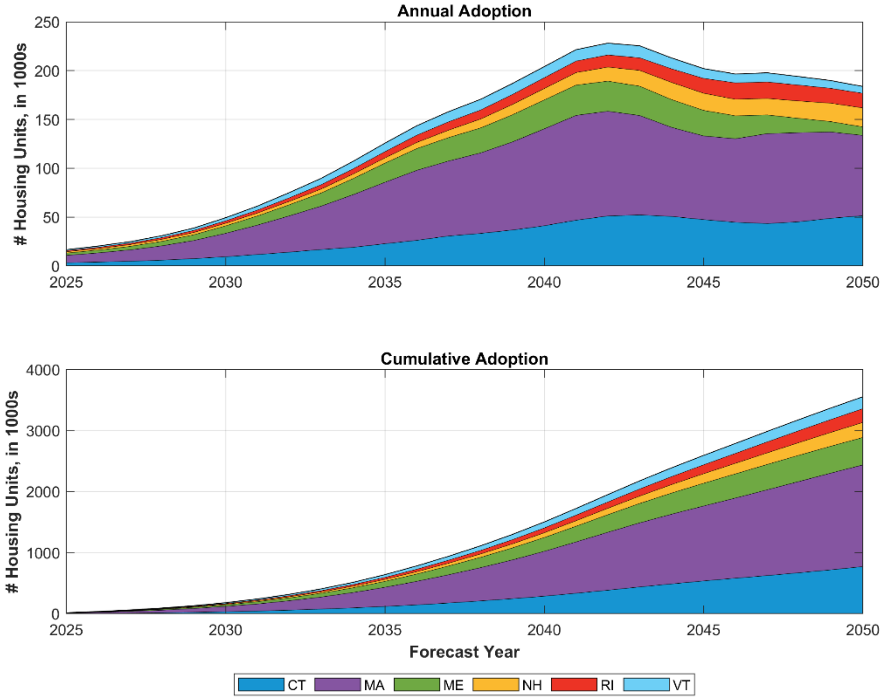
Adoption By Legacy Commercial Space Heating Fuel

New England



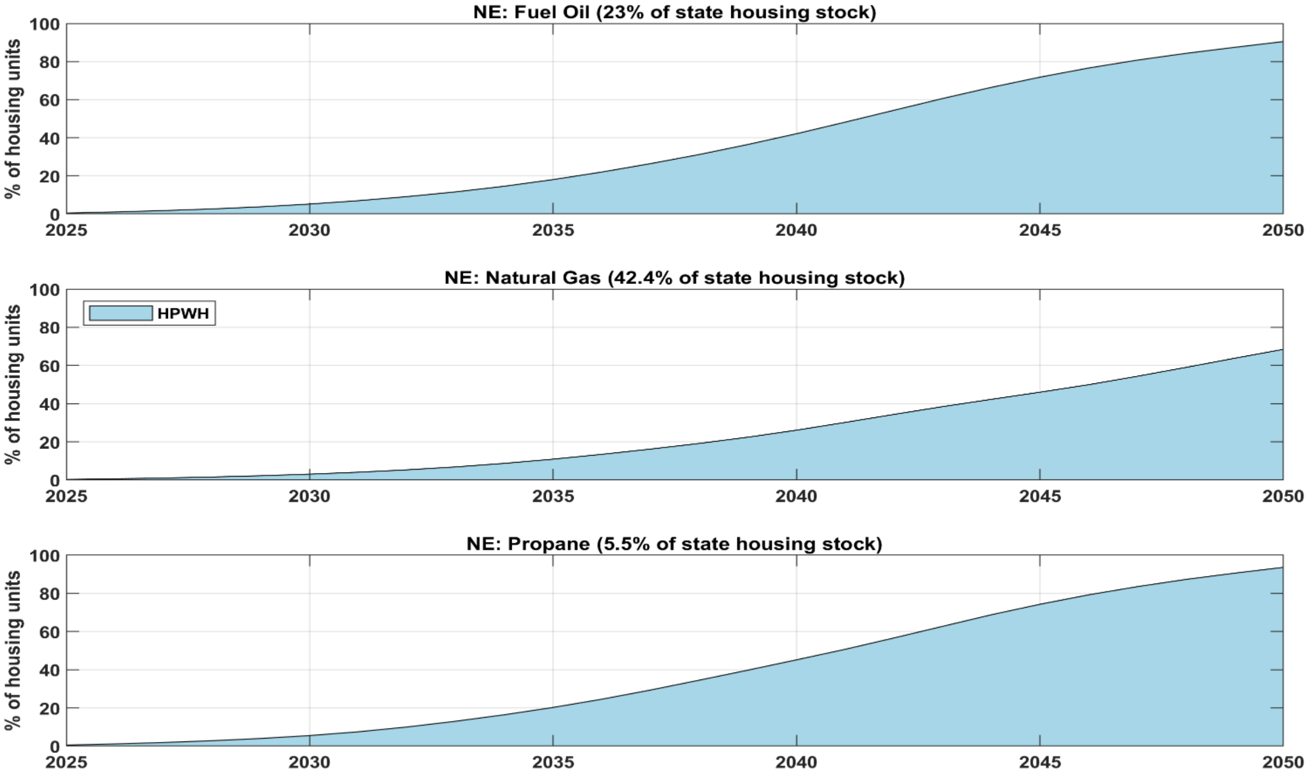
Residential Water Heating Adoption

- Adoption forecast for residential heat pump water heaters (HPWHs) is shown to the right
  - Incremental adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes more than 3.5 million housing units with electrified water heating by 2050
  - ~53% of total housing stock
  - ~76% 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 V



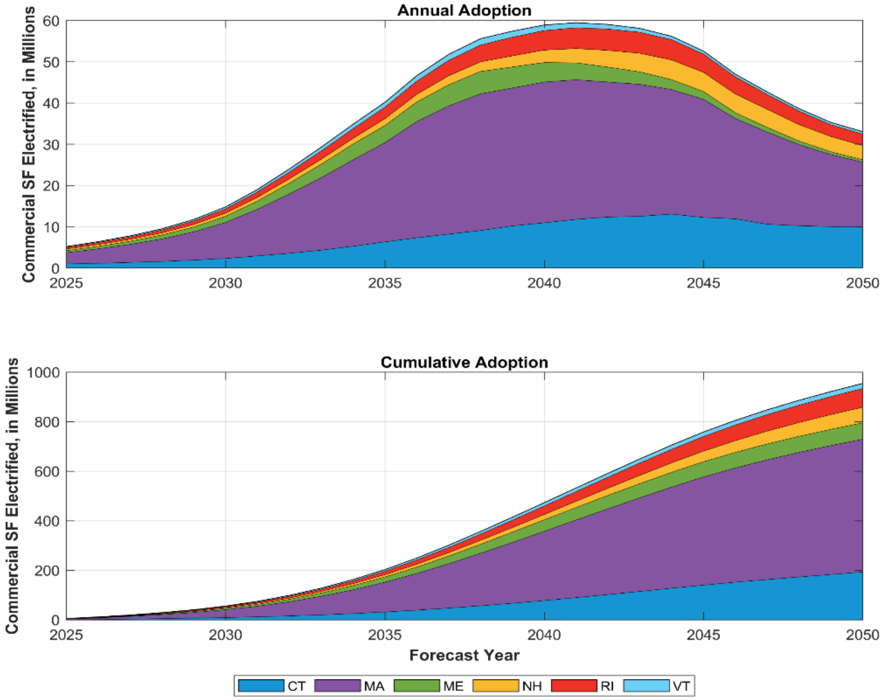
Adoption By Legacy Residential Water Heating Fuel

New England



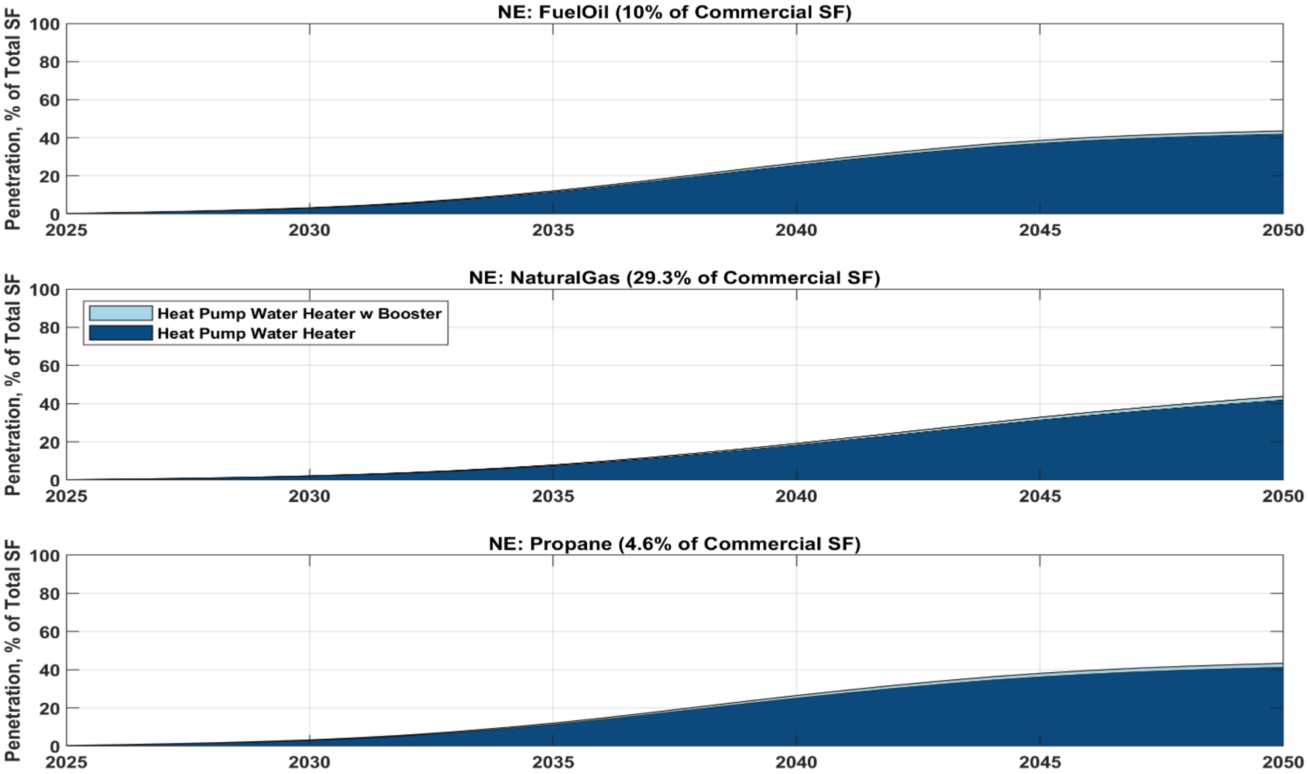
Commercial Water Heating Adoption

- Adoption forecast for commercial water heating is shown to the right
  - Incremental adoption (top)
  - Cumulative adoption (bottom)
- Forecast includes electrification of water heating serving almost a billion square feet 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 V



Adoption By Legacy Commercial Water Heating Fuel

New England



FINAL 2025 ENERGY FORECAST

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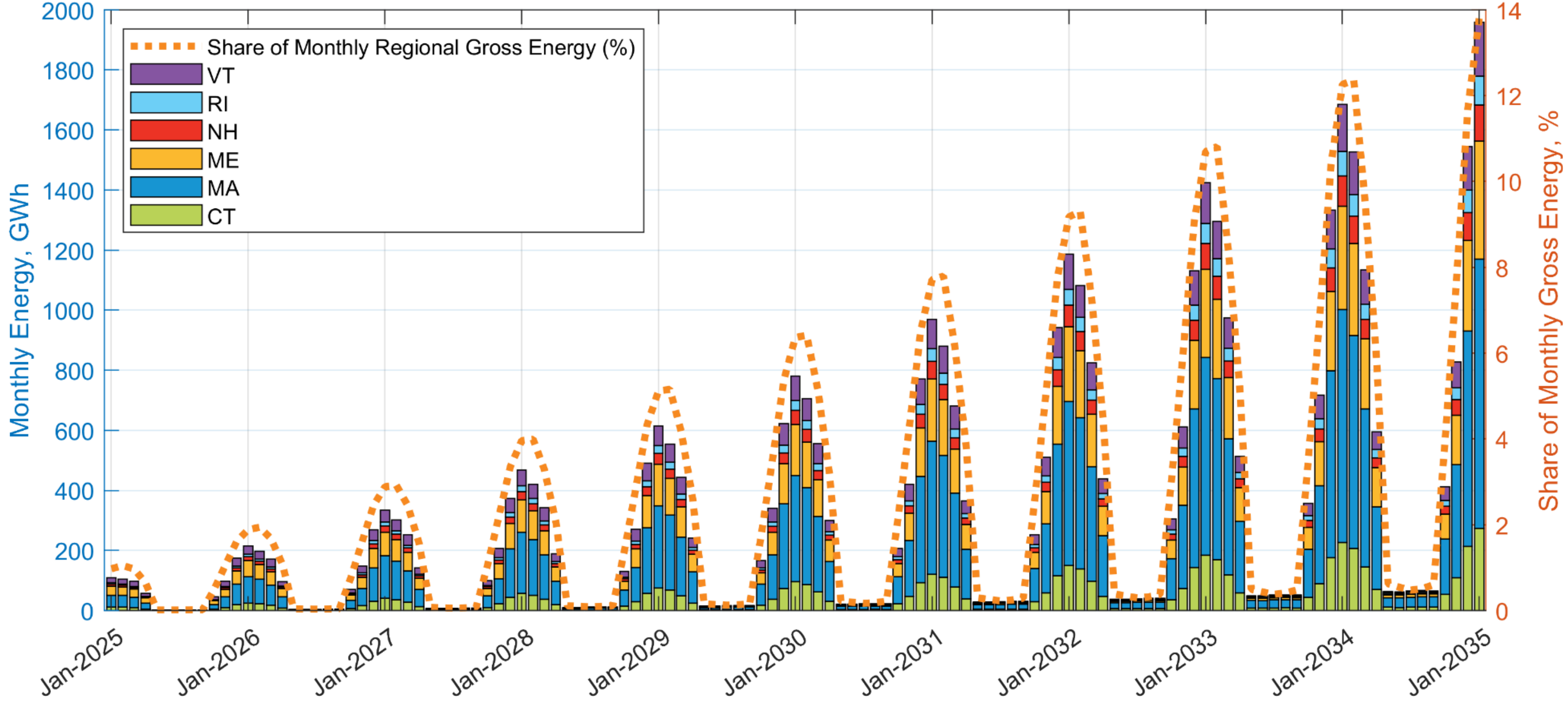
Estimating Energy Impacts of HP Adoption

- For each year of the forecast horizon, hourly HP profiles are simulated based on modeling described in Appendix VI and climate-adjusted weather
  - Climate-adjusted weather represents expected impacts of climate change on the weather spanning the historical period November 1, 1953 to October 31, 2023 (70 years)
  - The base load model and each of the component forecast models all use the same model estimation period
- Monthly HP energy forecasts are calculated as the average of the 70 resulting monthly HP energy (i.e., sum of all hours in each month) values
  - For example, the January 2030 HP energy forecast is the average HP energy value for all 70 Januarys simulated for that forecast year
- The annual HP energy is calculated as the sum of the 12 monthly energy values determined as described above

Final 2025 Heating Electrification Forecast

Monthly Energy, GWh



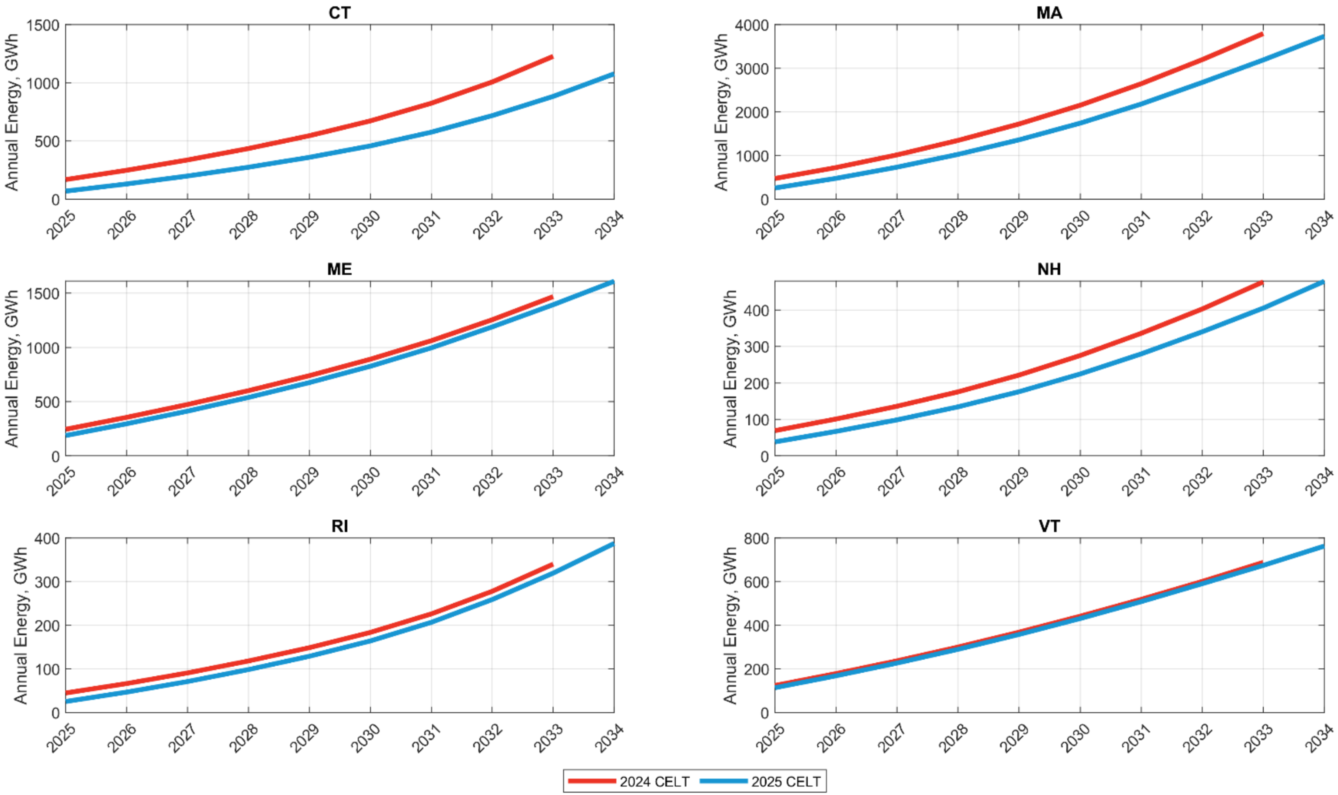
Final 2025 Heating Electrification Forecast

Annual Energy, GWh

	Annual Energy (GWh)									
Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Connecticut	70	131	199	275	360	458	576	719	884	1,077
Massachusetts	257	478	735	1,028	1,361	1,742	2,181	2,675	3,191	3,732
Maine	188	296	413	539	676	826	996	1,189	1,394	1,610
New Hampshire	38	67	99	134	176	225	280	340	405	479
Rhode Island	25	47	71	98	129	164	207	259	318	387
Vermont	114	168	227	290	358	431	508	590	674	763
Total	**692**	**1,188**	**1,743**	**2,365**	**3,060**	**3,846**	**4,748**	**5,773**	**6,867**	**8,049**

Annual Heating Electrification Energy

Final CELT 2025 vs. Final CELT 2024



FINAL 2025 DEMAND FORECAST

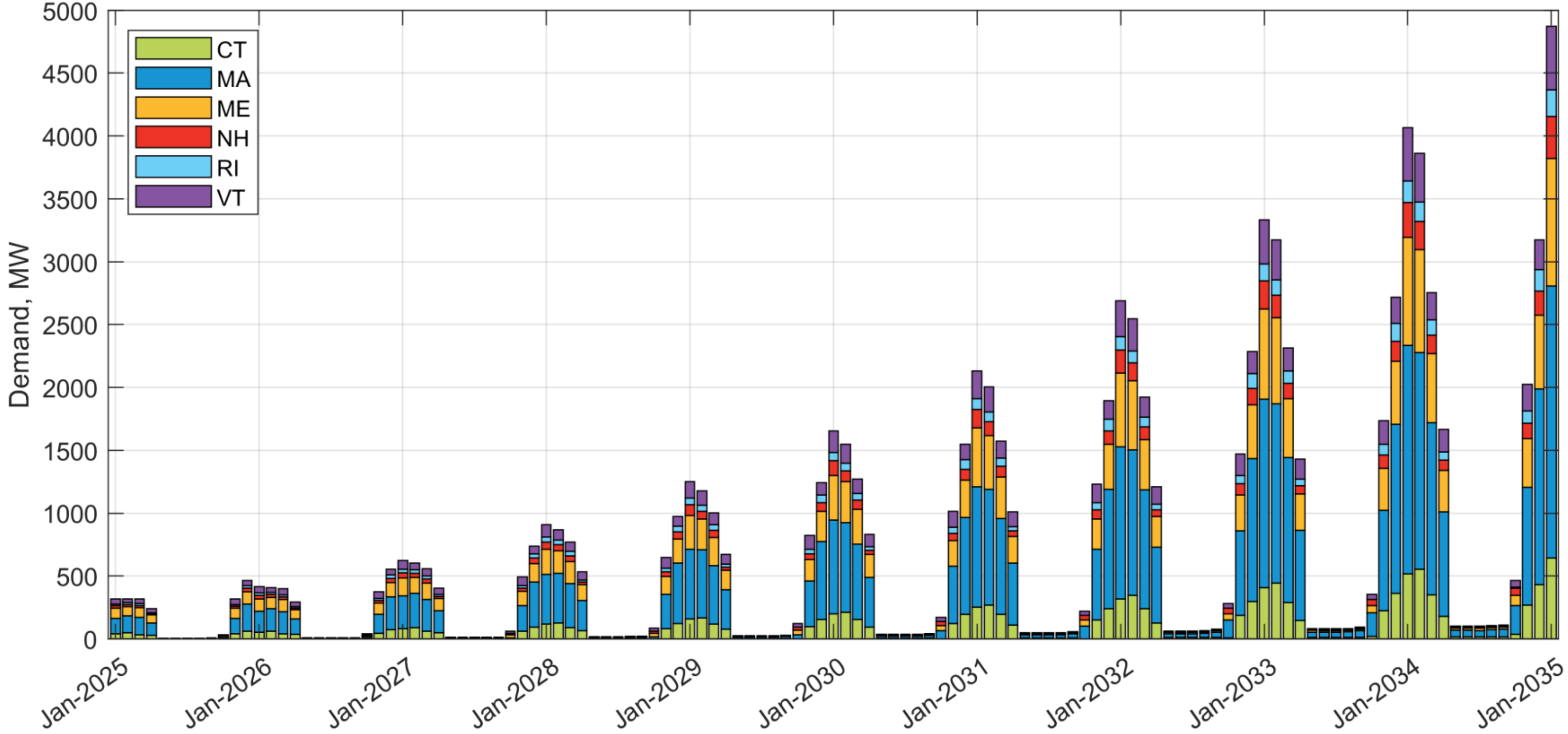
Transitional Slide Subtitle

Modeling Demand Impacts of HP Adoption

- For each year of the forecast horizon, hourly HP profiles are simulated using the demand modeling approach described in Appendix VI and climate-adjusted weather
  - Climate-adjusted weather represents expected impacts of climate change on the weather spanning the historical period November 1, 1953 to October 31, 2023 (70 years)
- Final HP demand forecasts are determined via a waterfall approach described in slides 10-12 of ISO's 2025 Final Draft Energy and Seasonal Peak Forecasts

Final 2025 Heating Electrification Forecast

Monthly Demand, 50/50



Final 2025 Heating Electrification Forecast

Winter (January) Demand, 50/50

	Winter Peak (MW)									
Year	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34	2034-35
Connecticut	29	70	108	140	191	236	324	366	454	588
Massachusetts	60	159	276	404	622	869	1,106	1,424	1,756	2,167
Maine	54	113	170	245	326	439	549	700	850	1,065
New Hampshire	11	29	51	65	90	124	160	194	247	292
Rhode Island	6	19	32	43	57	74	101	132	158	192
Vermont	25	45	69	95	136	186	232	306	372	464
Total	**186**	**435**	**707**	**992**	**1,421**	**1,927**	**2,472**	**3,123**	**3,837**	**4,765**

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 2025 Heating Electrification Forecast

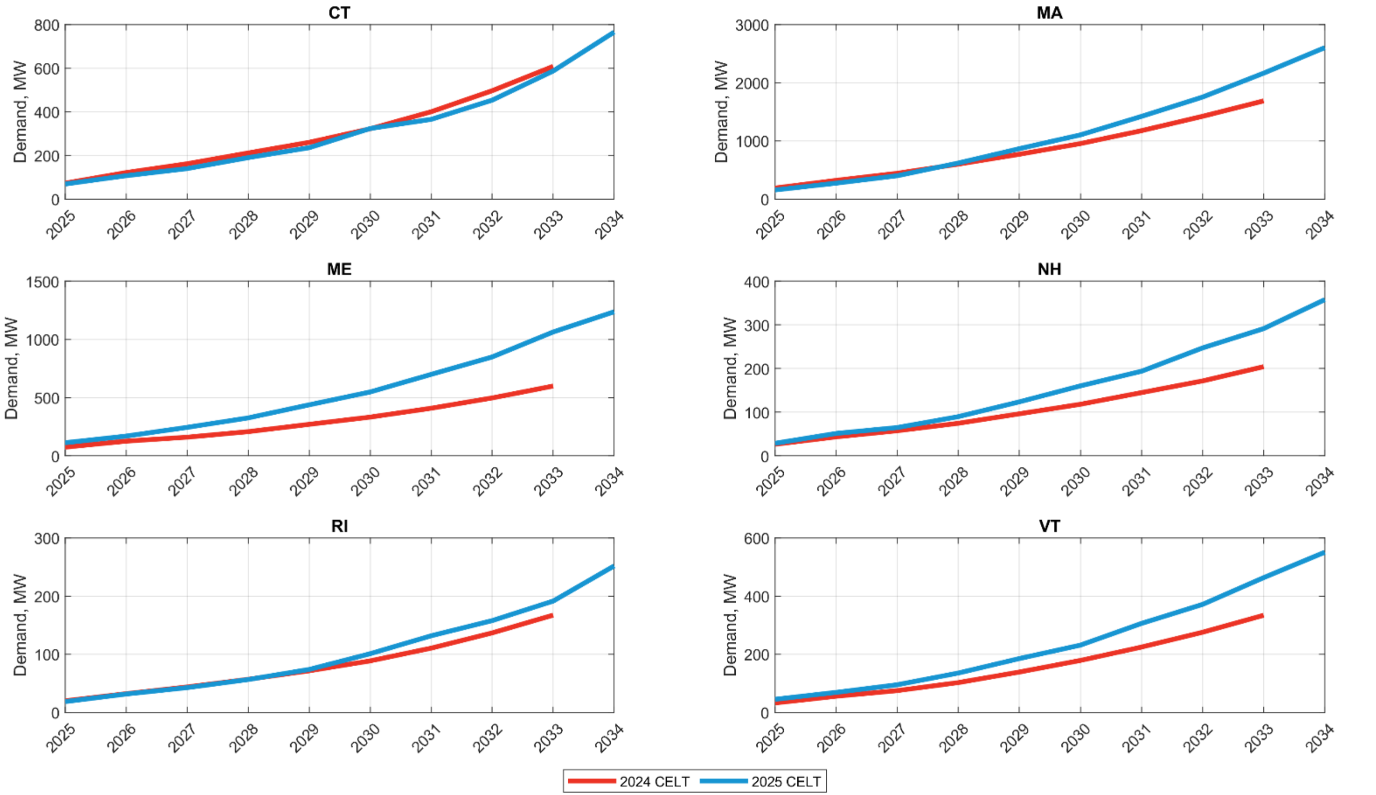
Winter (January) Demand, 90/10

	Winter Peak (MW)									
Year	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34	2034-35
Connecticut	41	81	125	173	250	340	477	613	764	938
Massachusetts	70	187	344	506	768	1,061	1,411	1,850	2,336	2,840
Maine	47	97	196	308	443	594	765	955	1,157	1,366
New Hampshire	22	42	63	86	111	140	183	232	293	355
Rhode Island	9	24	42	64	92	118	144	183	247	315
Vermont	32	53	80	115	158	212	273	347	435	524
Total	**221**	**484**	**850**	**1,252**	**1,822**	**2,464**	**3,253**	**4,180**	**5,233**	**6,337**

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 2025 vs. CELT 2024



Final 2025 Heating Electrification Forecast

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

	Summer Peak (MW)									
Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Connecticut	0	1	3	3	5	6	8	11	14	17
Massachusetts	1	3	8	9	12	17	22	29	39	54
Maine	0	1	2	3	4	5	7	9	12	15
New Hampshire	0	0	1	1	2	2	3	4	4	5
Rhode Island	0	1	1	2	2	3	4	5	6	8
Vermont	0	0	1	1	1	1	2	3	4	5
Total	**2**	**6**	**16**	**18**	**25**	**34**	**45**	**60**	**78**	**104**

Notes:

1. Summer demand values are due to electrified water heating

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%

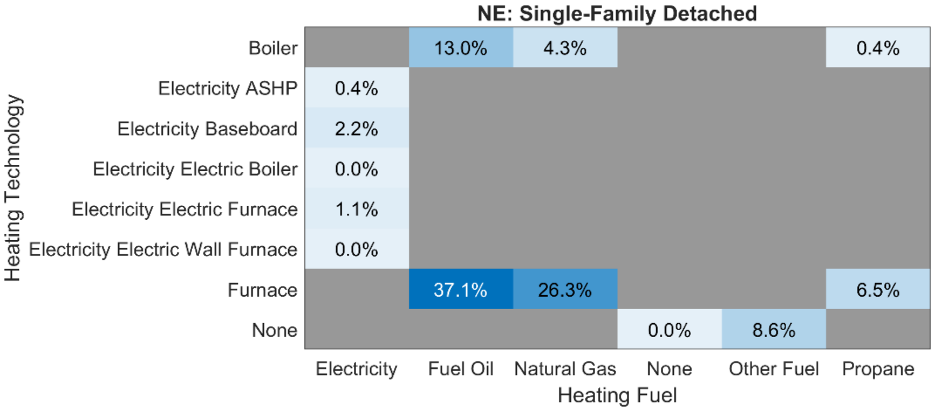
Sum across each row = 100%

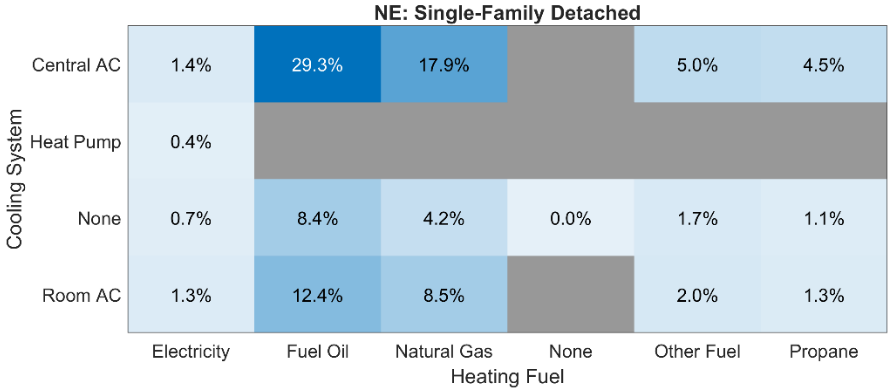
NE

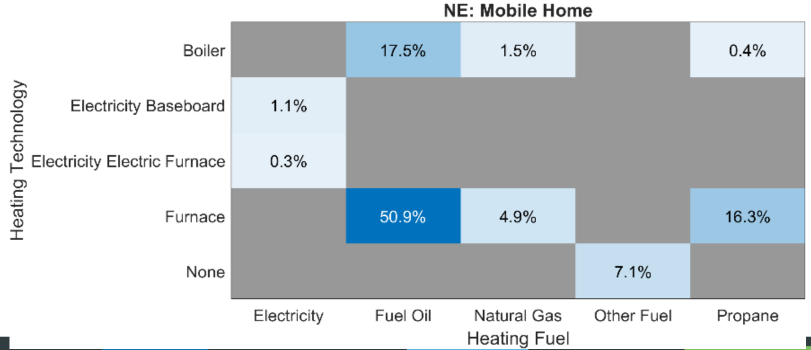
RECS_Building_Type \ Space_Heating_Fuel	Electricity	Fuel Oil	Natural Gas	None	Other Fuel	Propane
Mobile Home	1.4%	68.4%	6.4%		7.1%	16.7%
Multi-Family with 2 - 4 Units	13.9%	22.6%	60.0%	0.2%	0.6%	2.7%
Multi-Family with 5+ Units	42.8%	11.6%	42.9%	0.6%	0.3%	1.8%
Single-Family Attached	15.1%	14.2%	66.9%	0.1%	0.3%	3.4%
Single-Family Detached	3.8%	50.1%	30.6%	0.0%	8.6%	6.9%

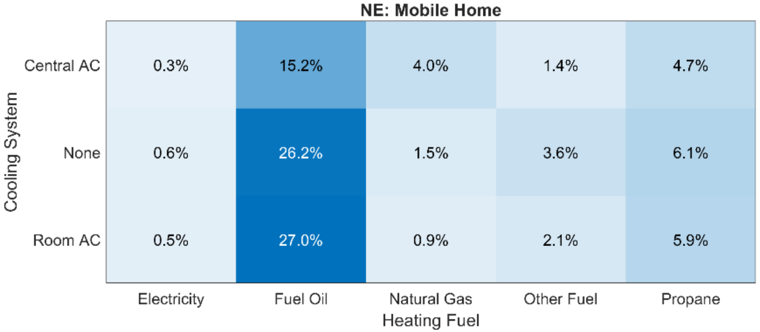
Residential Buildings

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 \ Heating_Fuel	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%

Commercial Buildings

Baseline HVAC Systems in New England, Medium Office Example

NE: MediumOffice

	DistrictHeating	Electricity	FuelOil	NaturalGas	NoHeating	Propane
DOAS with VRF		1.5%				
Fan coil air-cooled chiller with boiler				0.4%		
Fan coil chiller with boiler				2.0%		
Other				0.2%		
PSZ-AC with baseboard electric		0.8%				
PSZ-AC with baseboard gas boiler				2.0%		
PSZ-AC with district hot water	0.3%					
PSZ-AC with electric coil		1.4%				
PSZ-AC with gas boiler			28.5%	3.6%		3.3%
PSZ-AC with gas coil				21.3%		1.0%
PSZ-AC with gas unit heaters						1.9%
PSZ-AC with no heat					12.5%	
PSZ-HP		6.4%				
PTAC with baseboard gas boiler				0.1%		
PTAC with electric coil		1.4%				
PTAC with gas coil				1.4%		
PVAV with PFP boxes		1.9%				
PVAV with gas boiler reheat				1.0%		
PVAV with gas heat with electric reheat		0.2%				
Residential AC with baseboard electric		0.2%				
Residential AC with no heat					0.1%	
Residential AC with residential forced air furnace				2.3%		
VAV air-cooled chiller with gas boiler reheat				2.5%		
VAV chiller with gas boiler reheat				0.3%		
VAV district chilled water with district hot water reheat	0.2%					
Water source heat pumps with ground source heat pump		1.1%				

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 county 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 56 representing the greatest barrier to adoption
  - **Current Levels of Technology Saturation**
- Uncertainty in the evolution of ROI and policy impacts over the forecast are 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 Drive**
    - 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 system
    - 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 do not easily fit into the adoption modeling framework outlined above, are 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, %

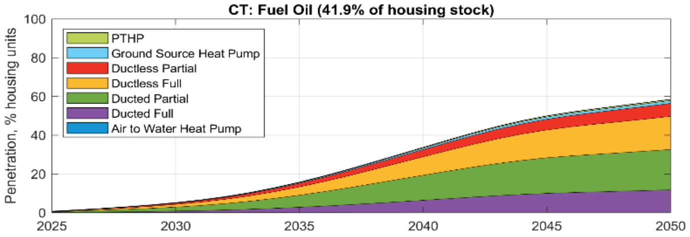
Water Heating Fuel	CT	MA	ME	NH	RI	VT	NE
DistrictHeating	1.1	1.2	0.7	1.1	0.9	1.5	1.1
Electricity	57.3	53	62.8	57.2	46.5	57.2	55
FuelOil	11.4	7.7	16.2	13.5	7.9	14.4	10
NaturalGas	26.2	34.9	11.4	18	42.1	19.8	29.3
Propane	4.1	3.2	8.9	10.3	2.6	7	4.6

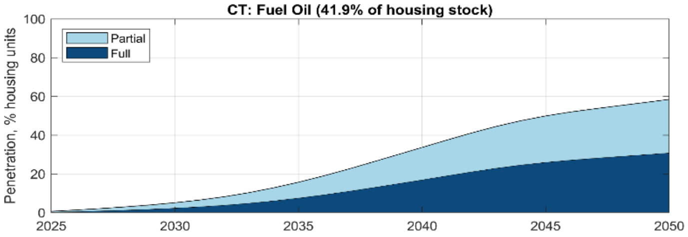
APPENDIX IV

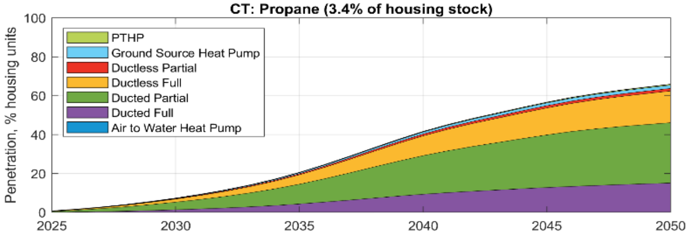
State Space Heating Adoption

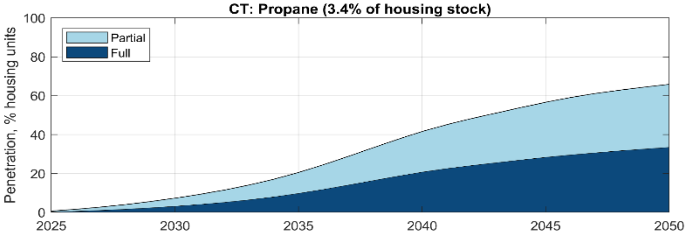
Adoption By Legacy Residential Space Heating Fuel

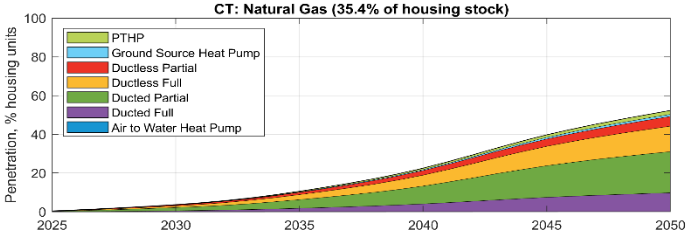
Connecticut

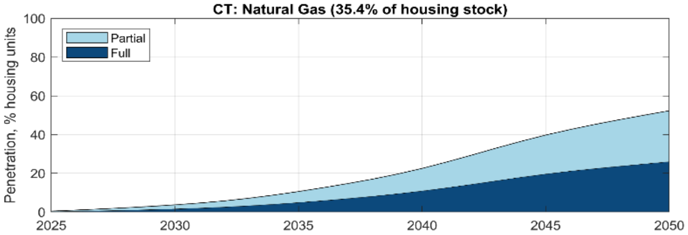






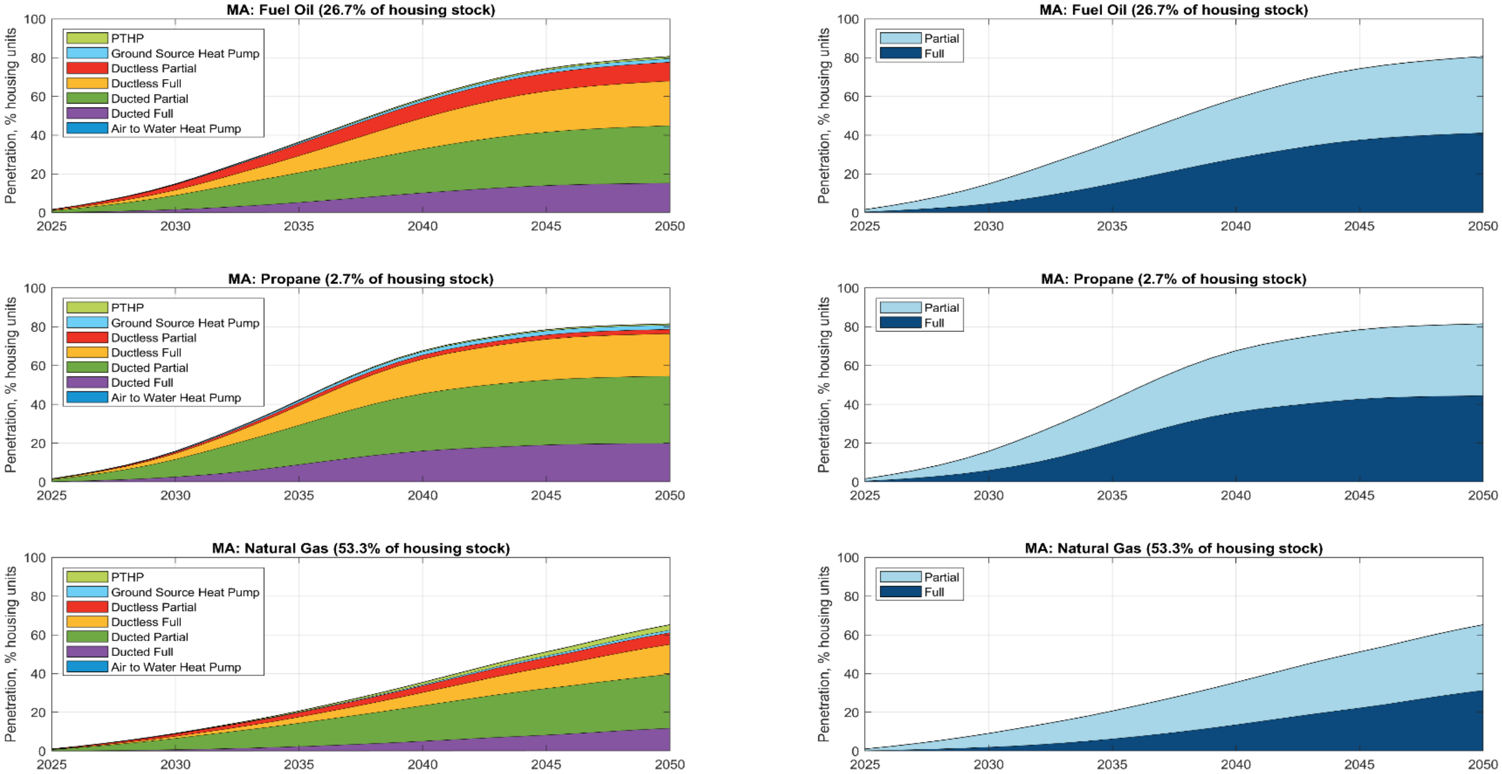






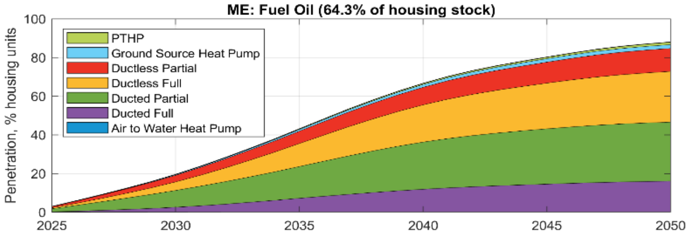
Adoption By Legacy Residential Space Heating Fuel

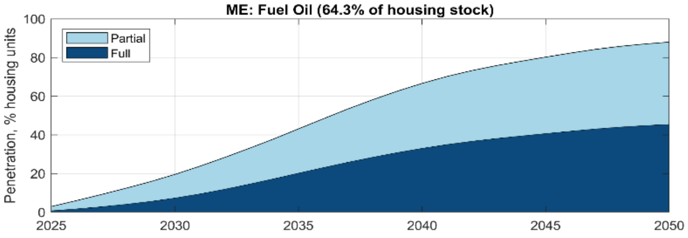
Massachusetts

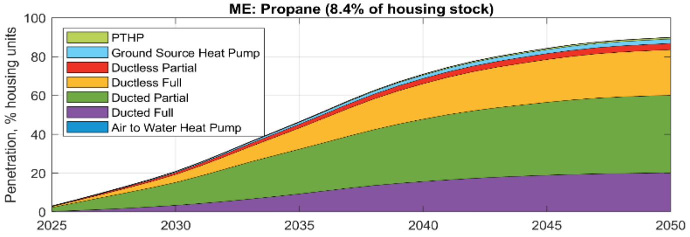


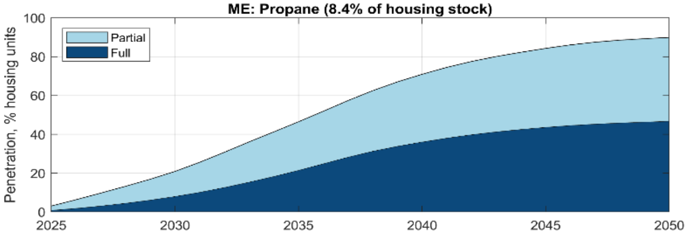
Adoption By Legacy Residential Space Heating Fuel

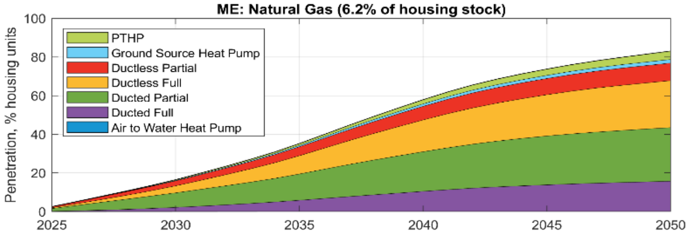
Maine

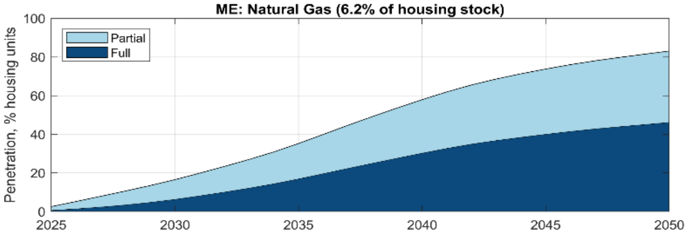






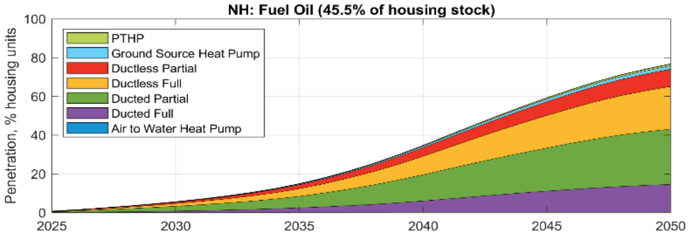


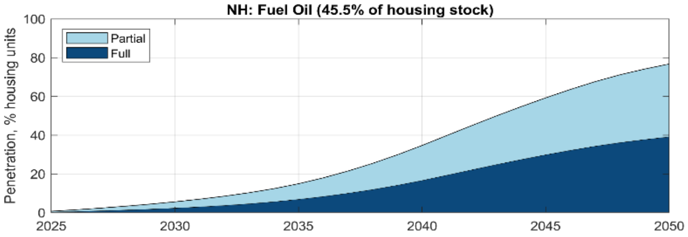


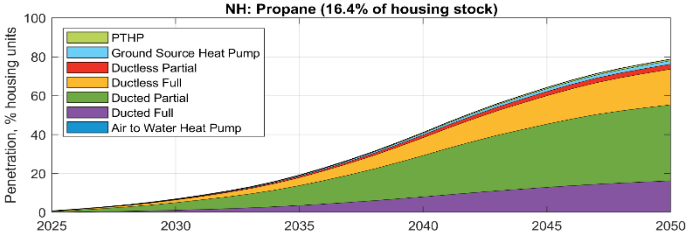


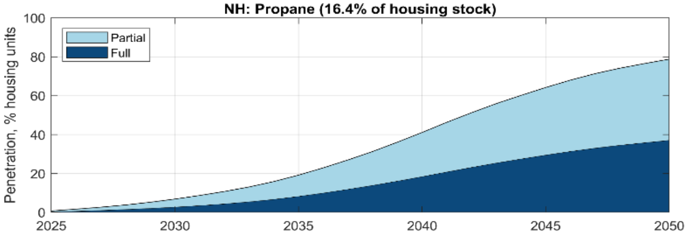
Adoption By Legacy Residential Space Heating Fuel

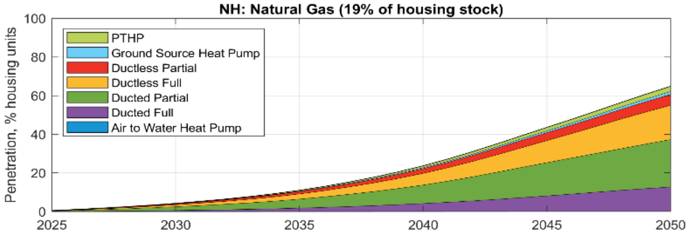
New Hampshire

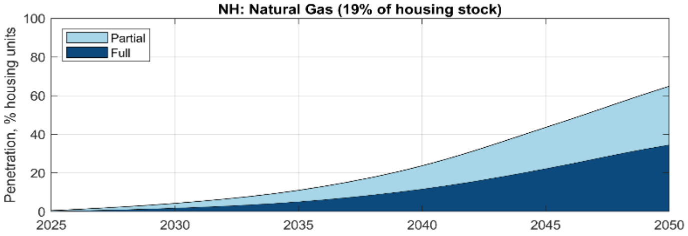






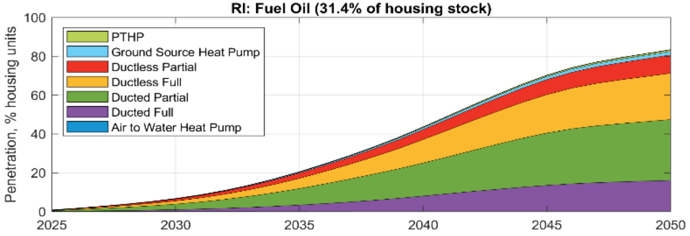


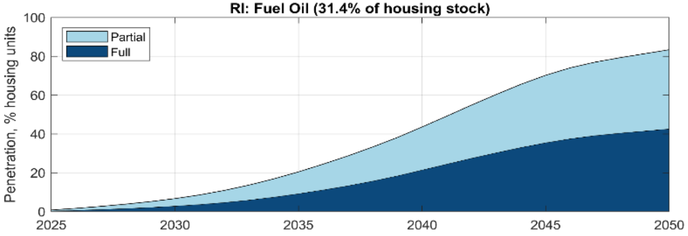


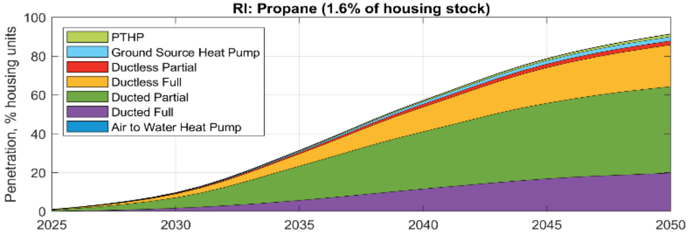


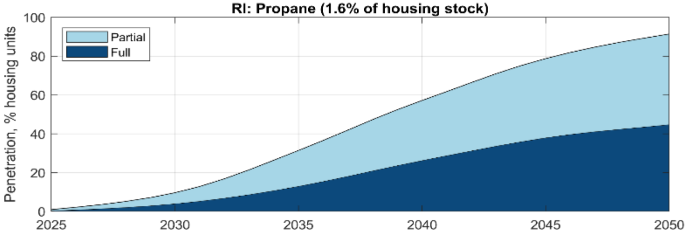
Adoption By Legacy Residential Space Heating Fuel

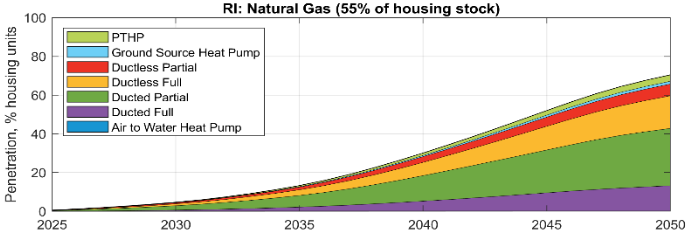
Rhode Island

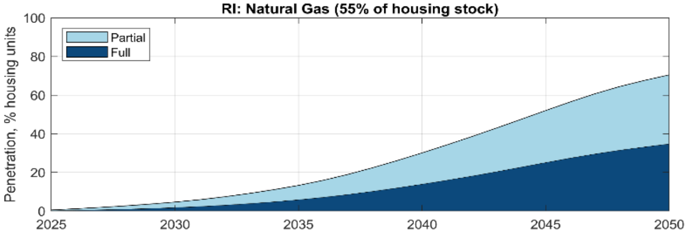






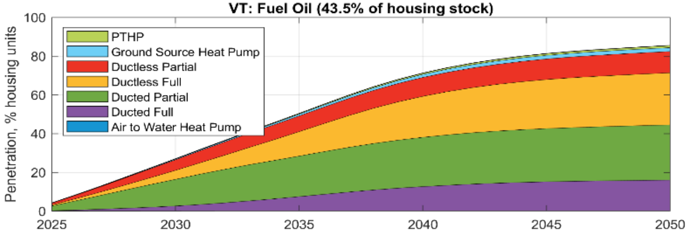


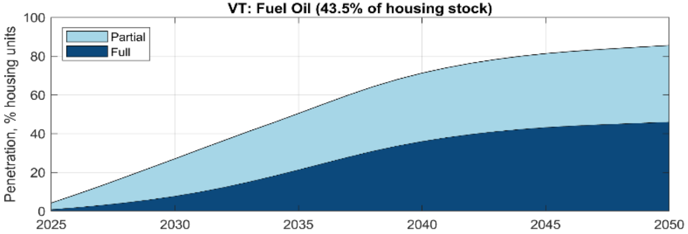


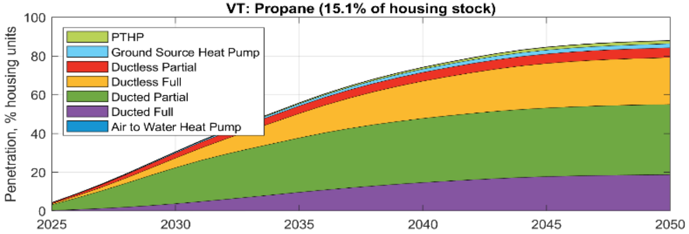


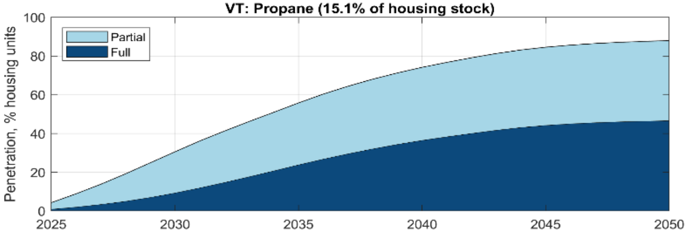
Adoption By Legacy Residential Space Heating Fuel

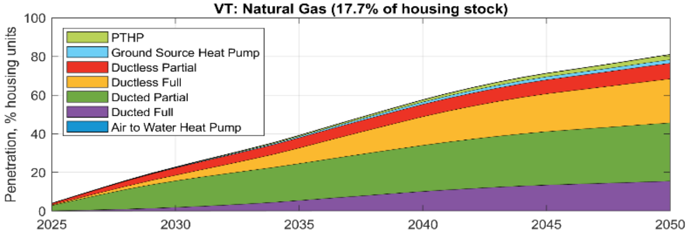
Vermont

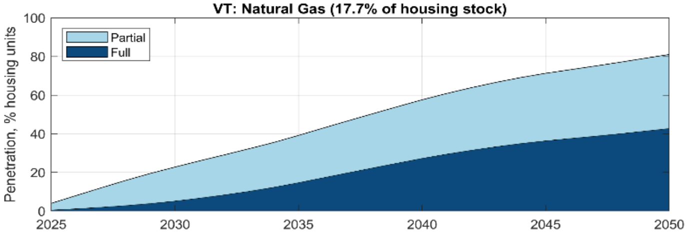






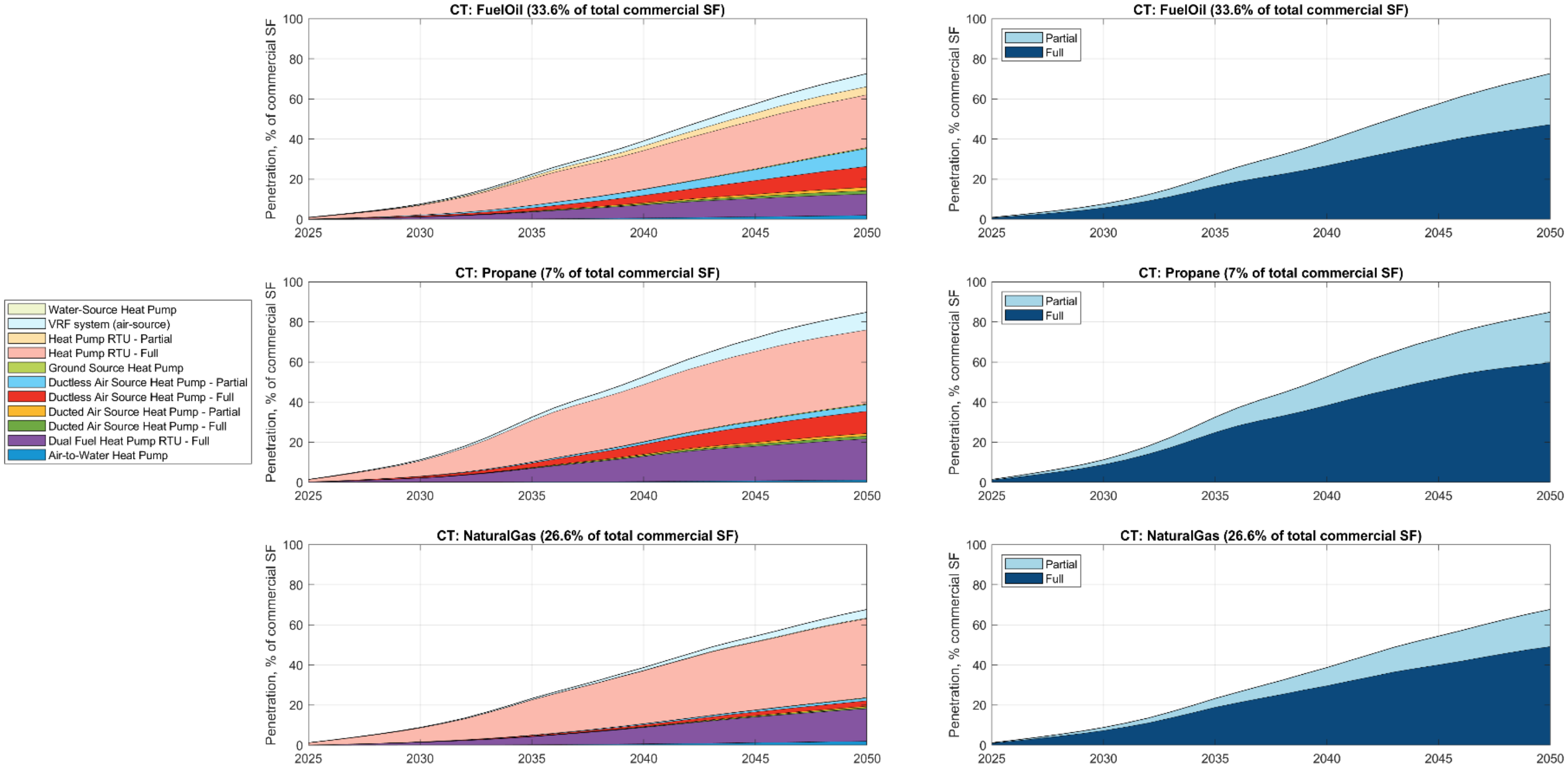






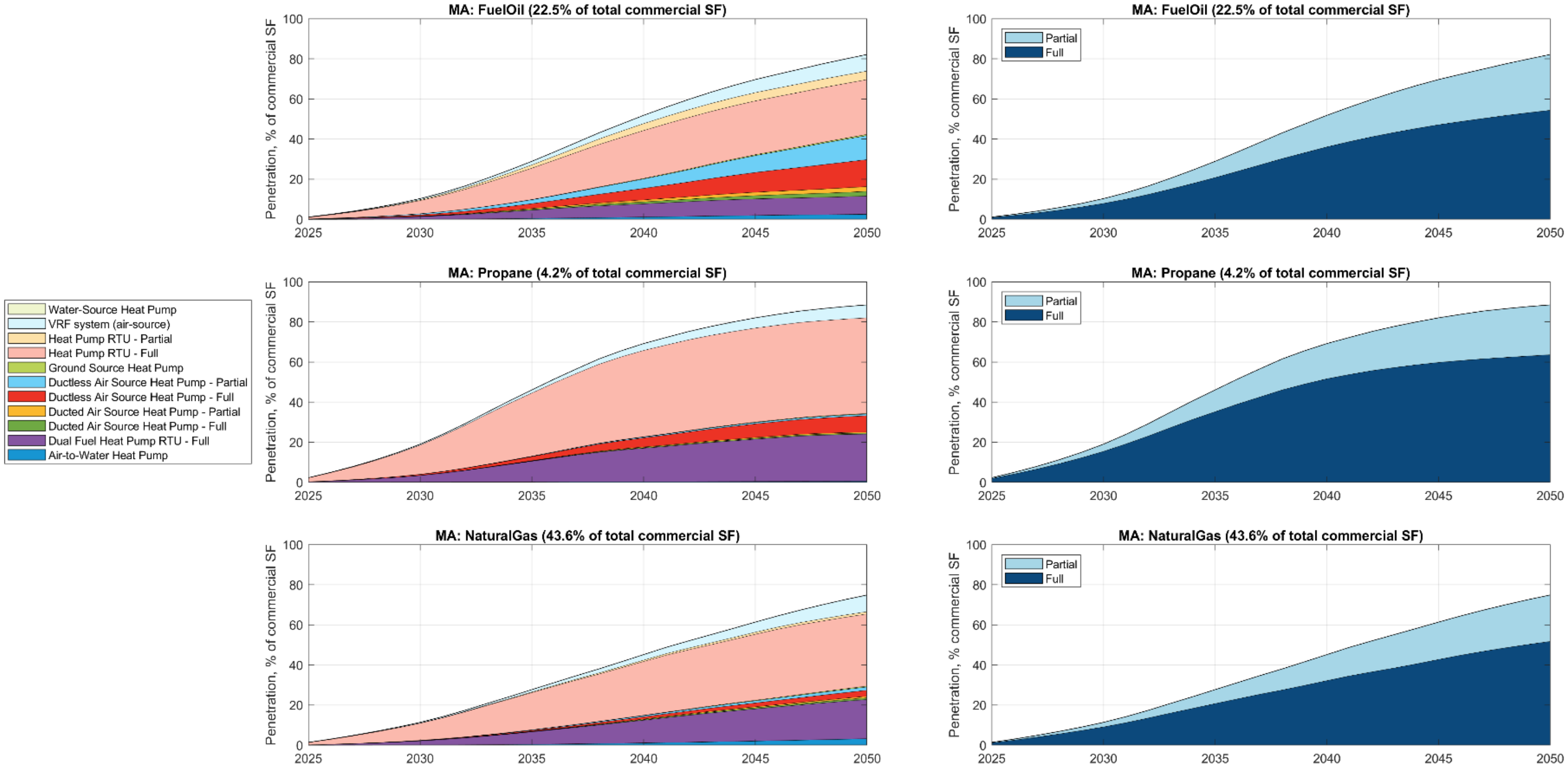
Adoption By Legacy Residential Space Heating Fuel

Connecticut



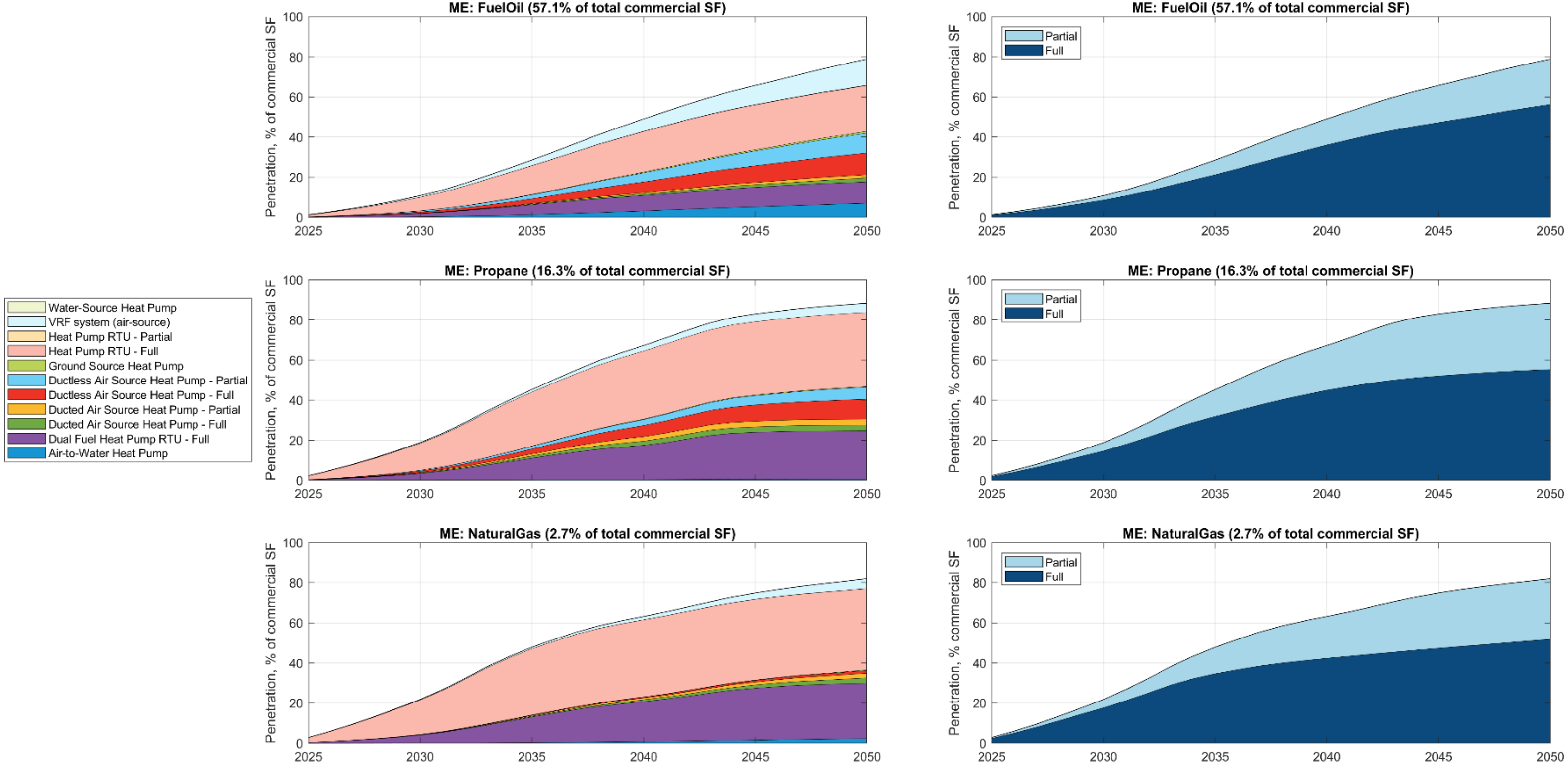
Adoption By Legacy Residential Space Heating Fuel

Massachusetts



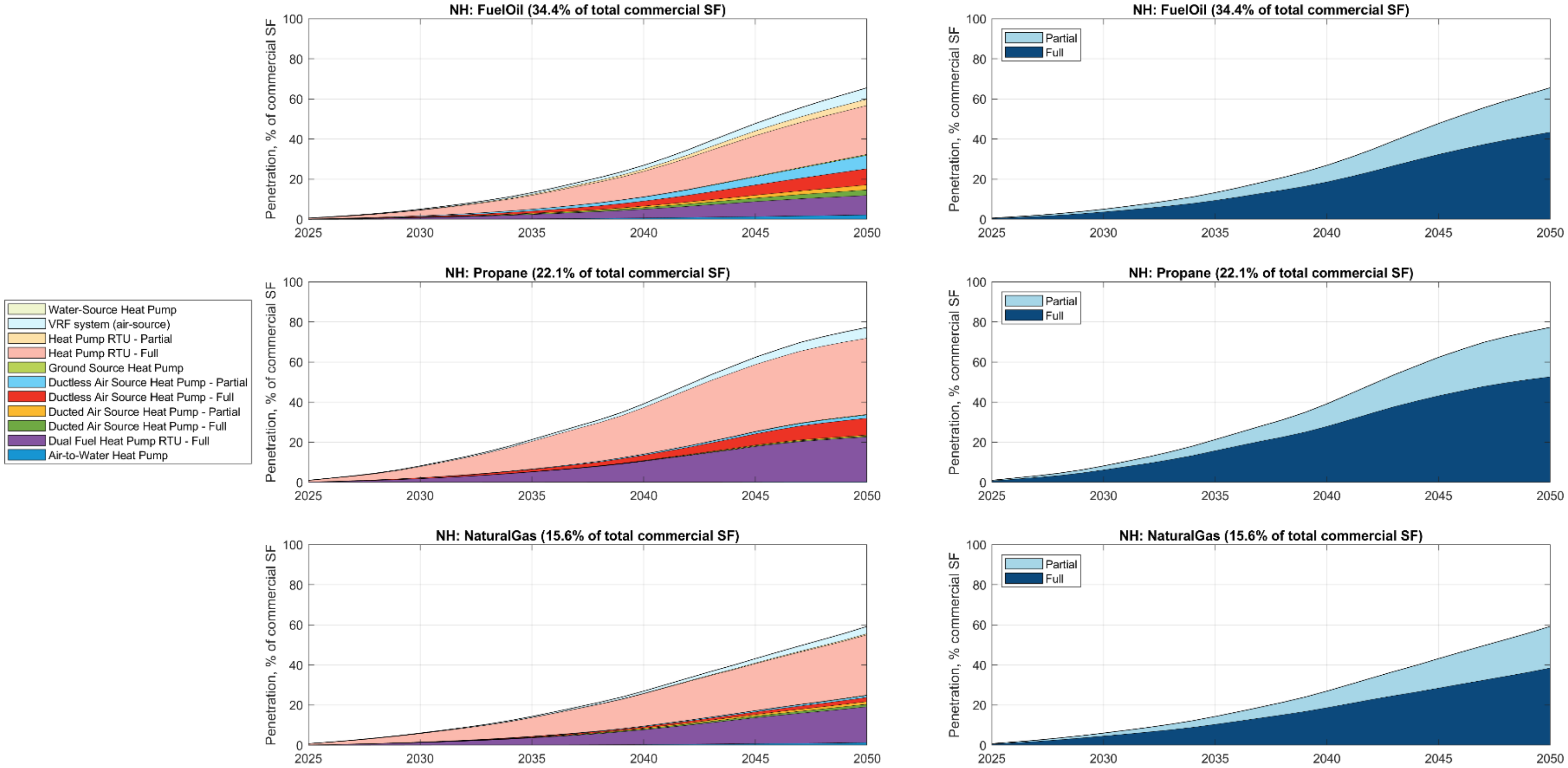
Adoption By Legacy Residential Space Heating Fuel

Maine



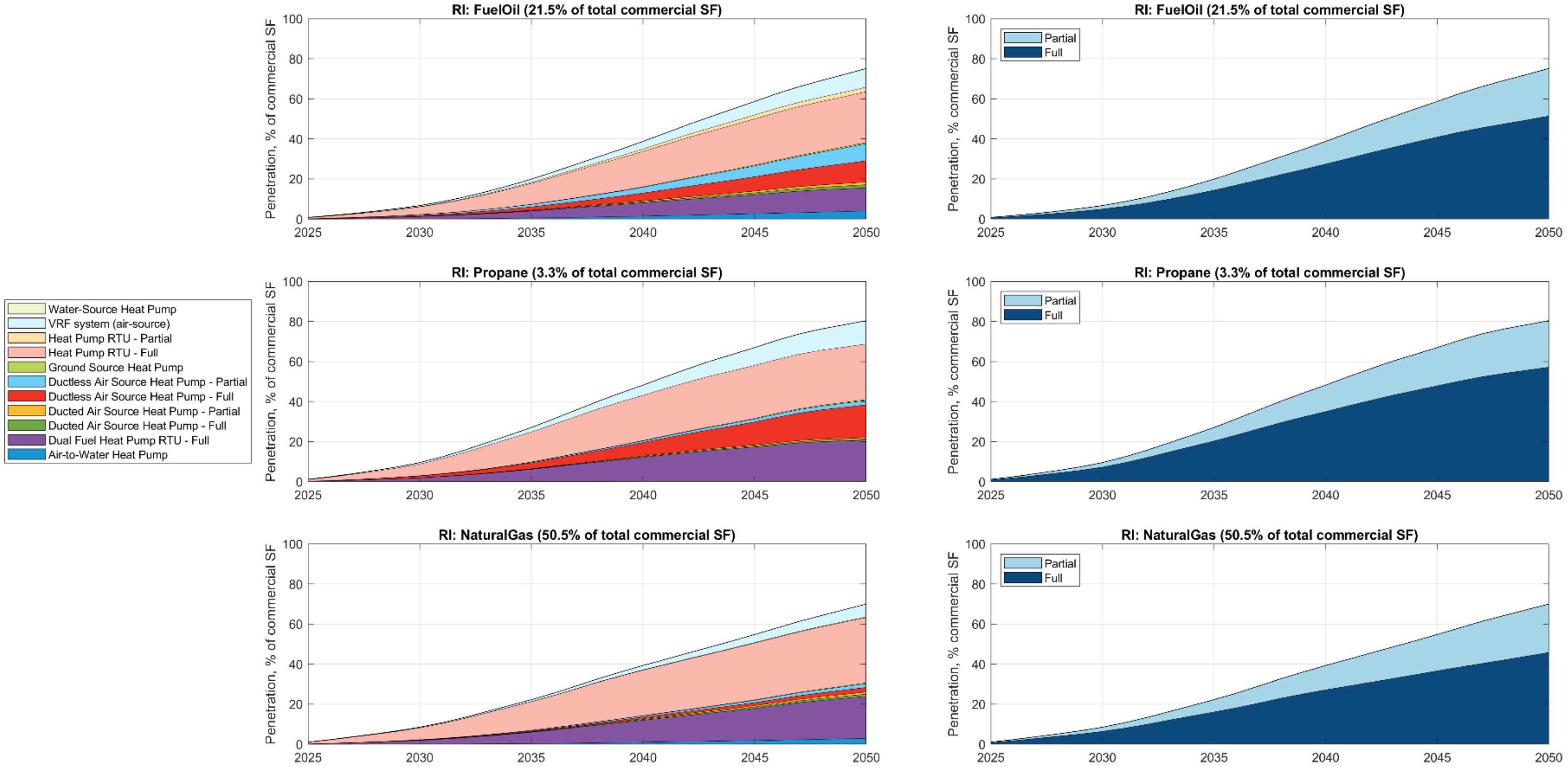
Adoption By Legacy Residential Space Heating Fuel

New Hampshire



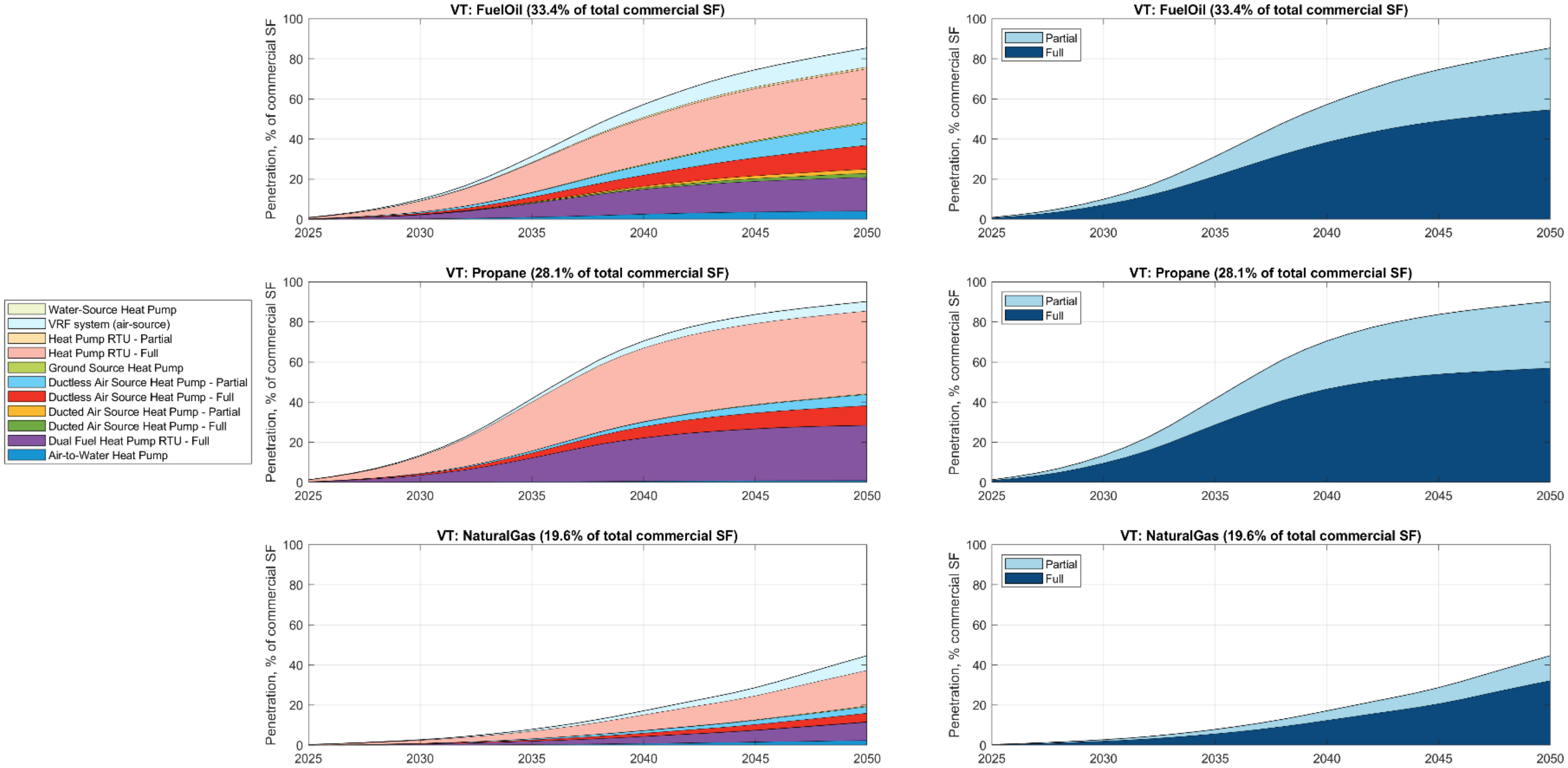
Adoption By Legacy Residential Space Heating Fuel

Rhode Island



Adoption By Legacy Residential Space Heating Fuel

Vermont

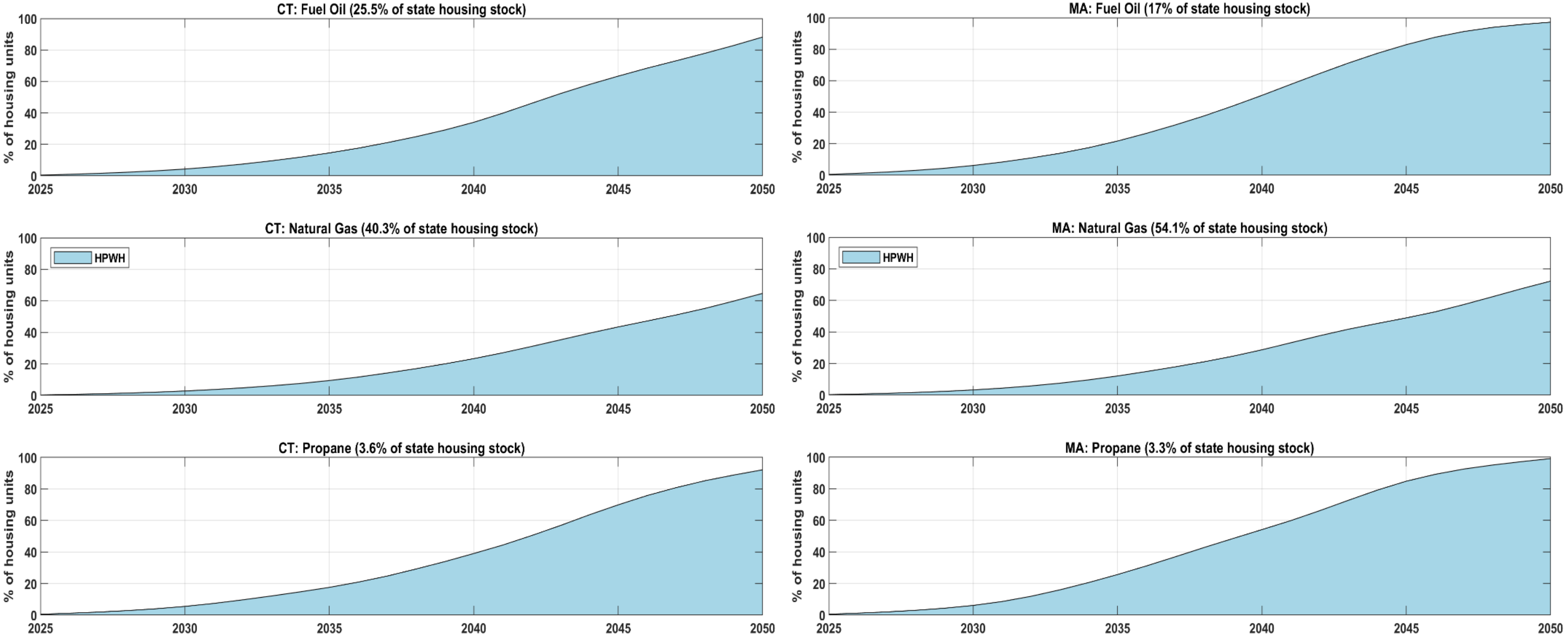


APPENDIX V

State Water Heating Adoption

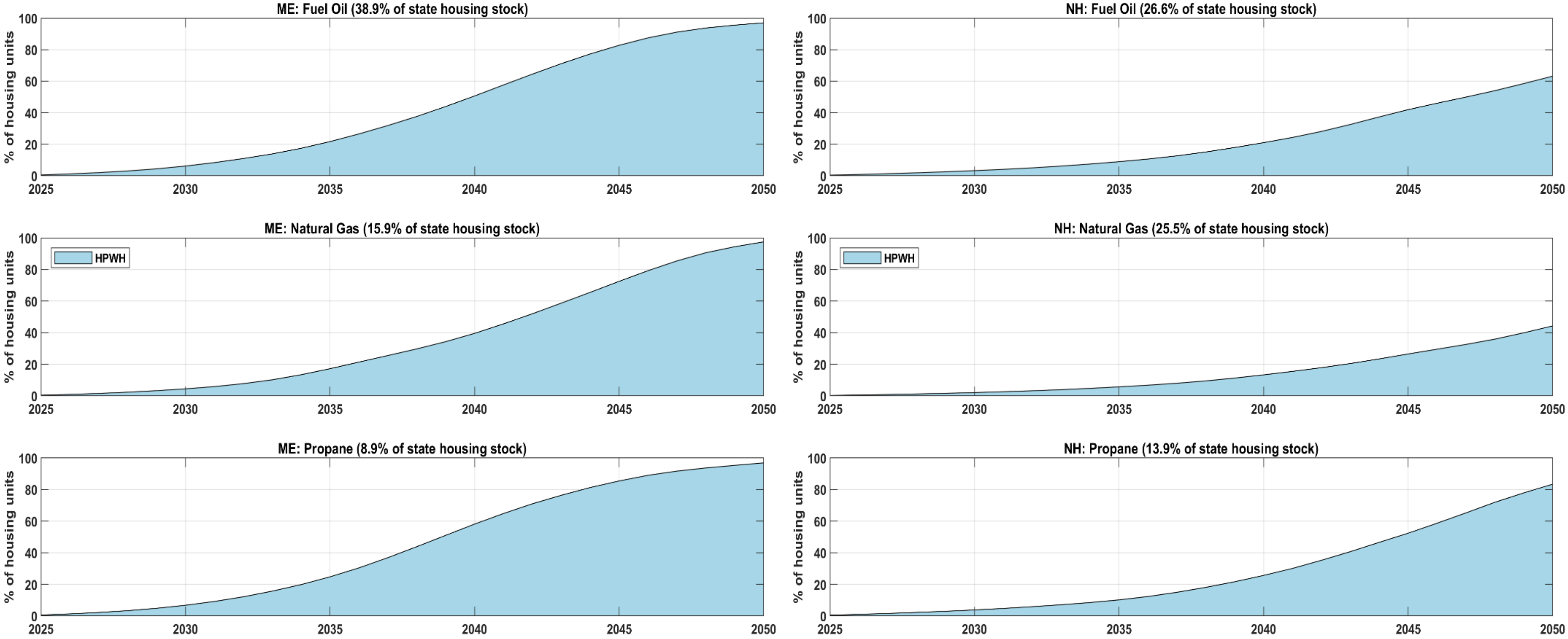
Adoption By Legacy Residential Space Heating Fuel

Connecticut (left) and Massachusetts (right)



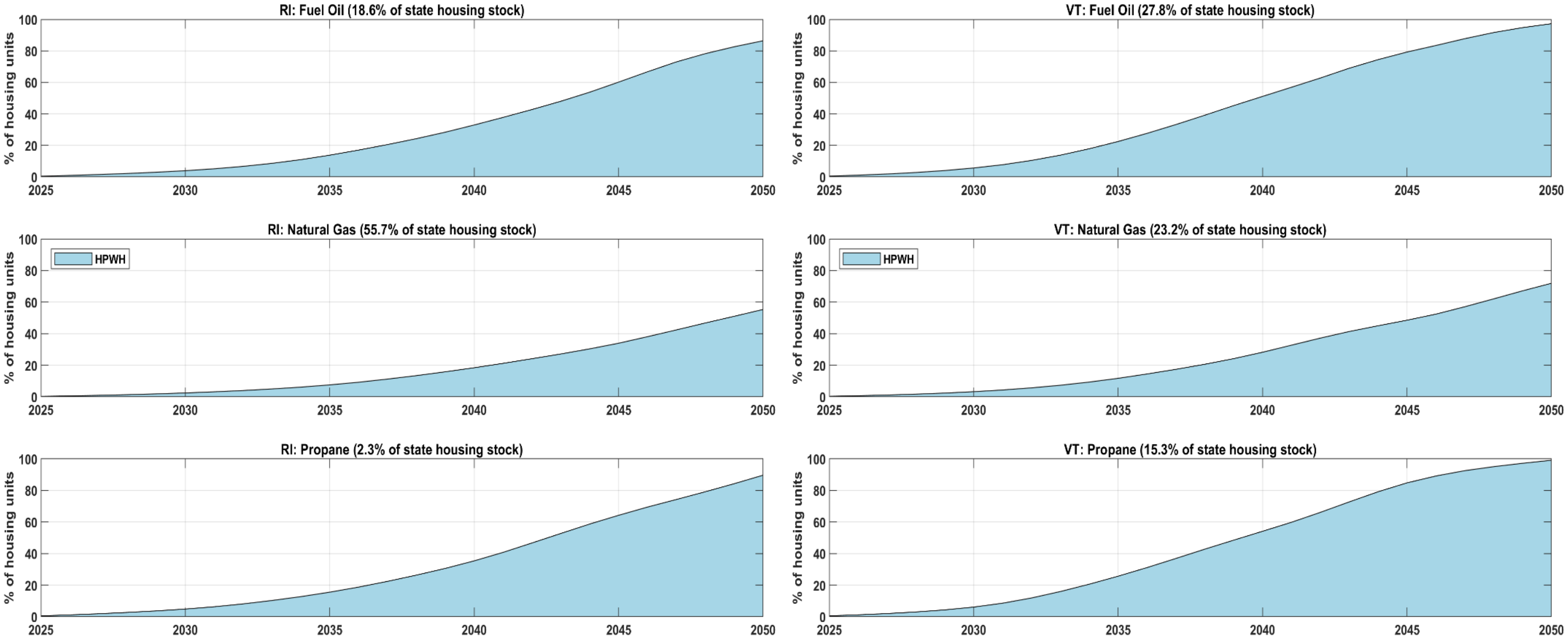
Adoption By Legacy Residential Space Heating Fuel

Maine (left) and New Hampshire (right)



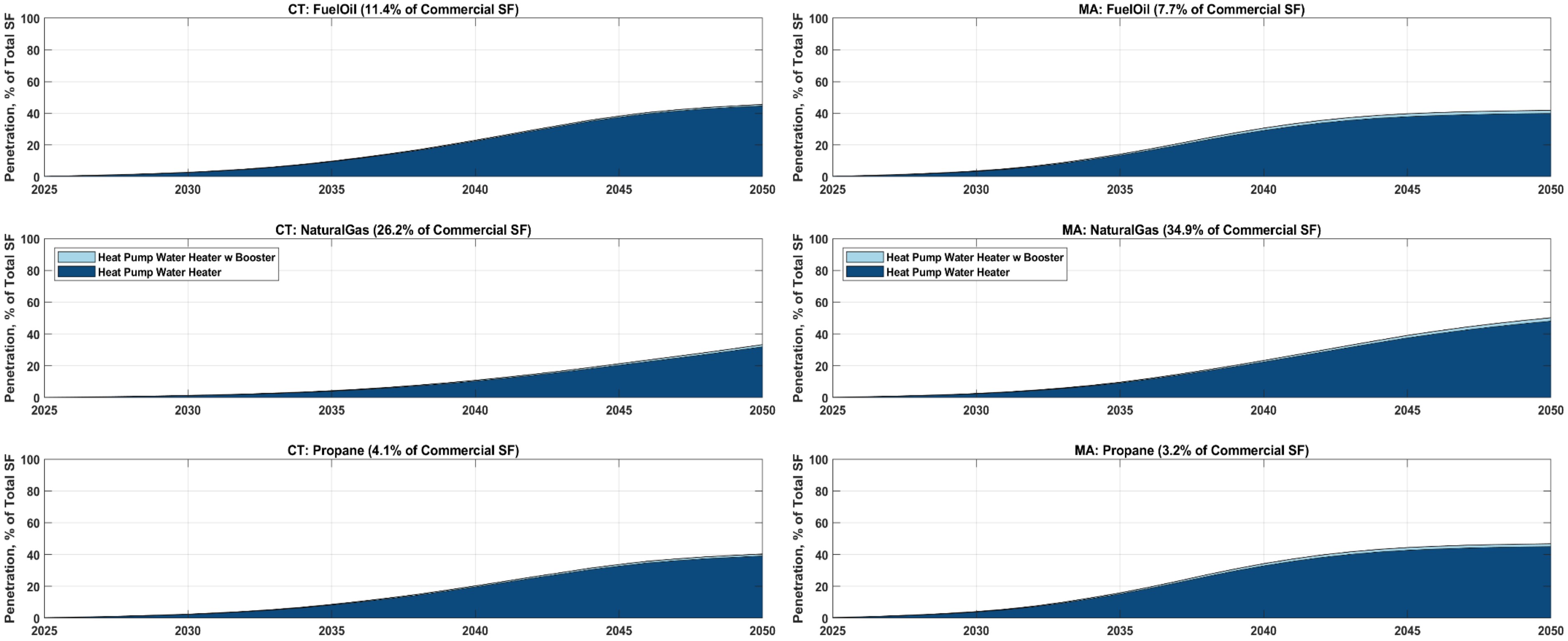
Adoption By Legacy Residential Space Heating Fuel

Rhode Island (left) and Vermont (right)



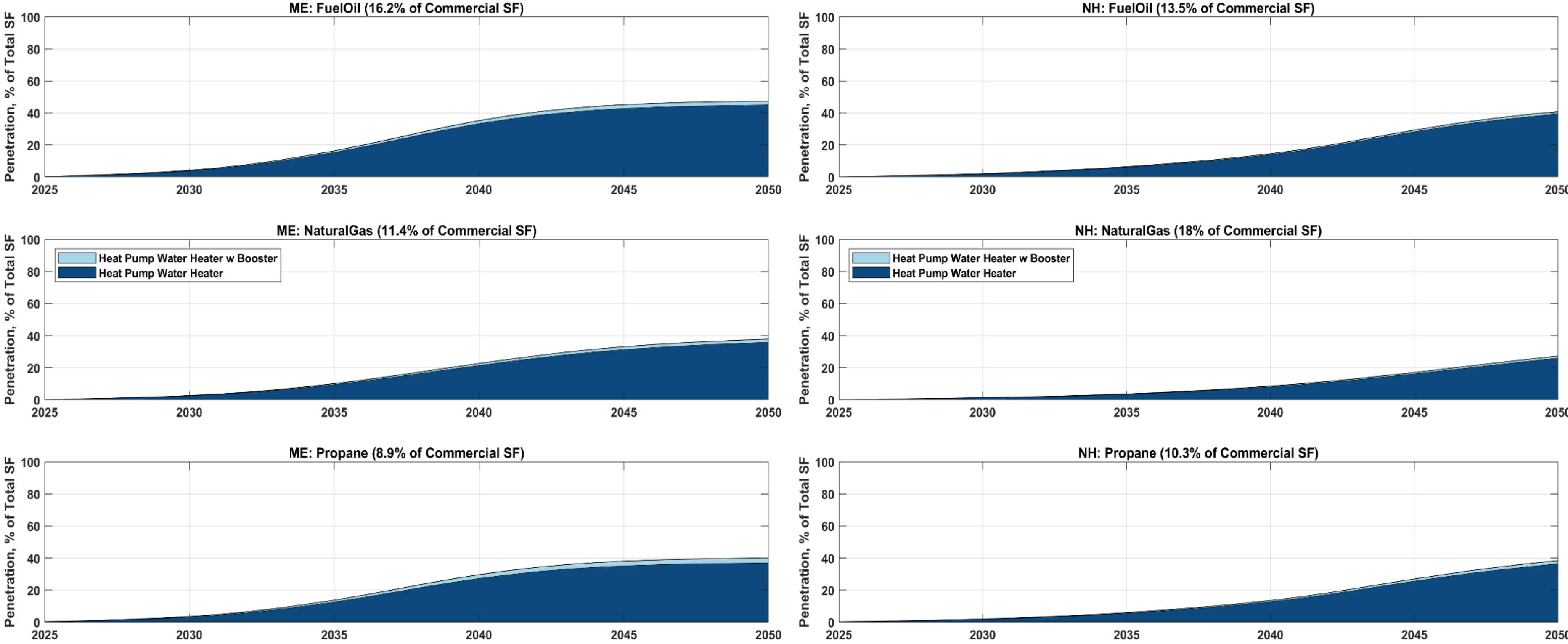
Adoption By Legacy Residential Space Heating Fuel

Connecticut (left) and Massachusetts (right)



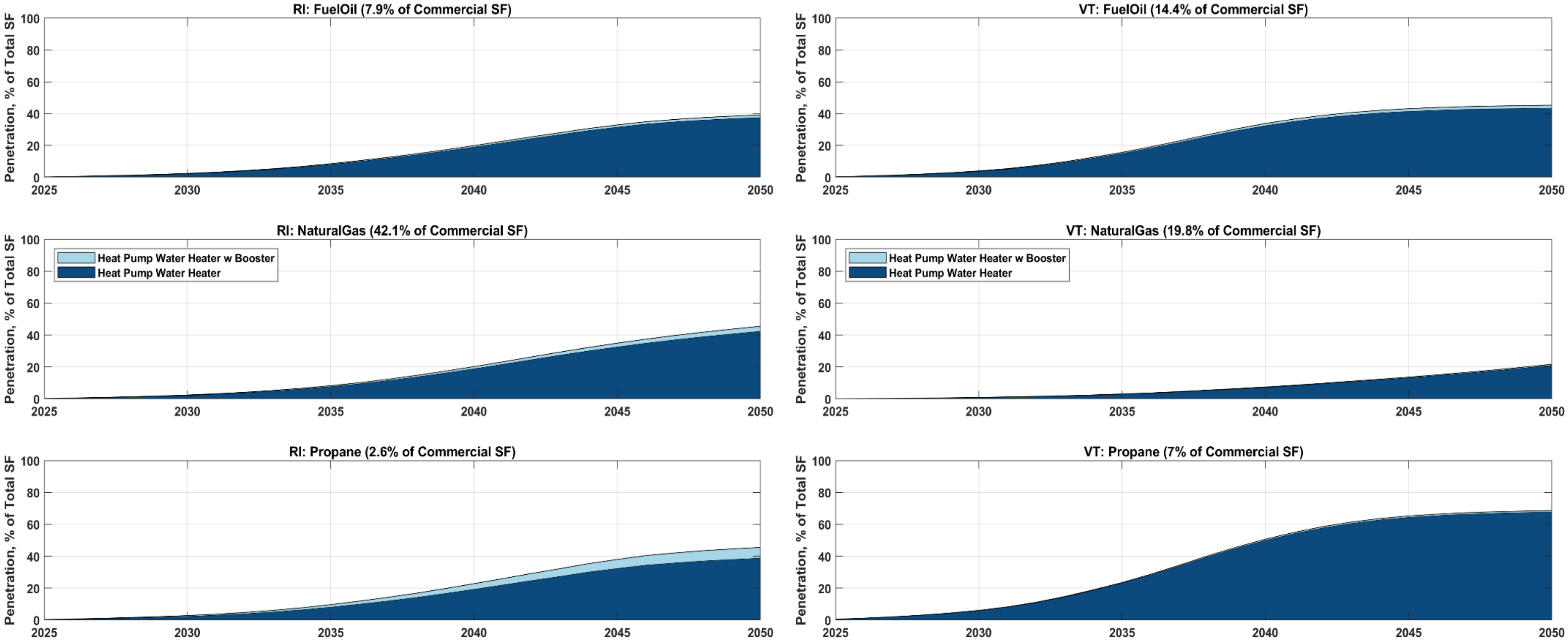
Adoption By Legacy Residential Space Heating Fuel

Maine (left) and New Hampshire (right)



Adoption By Legacy Residential Space Heating Fuel

Rhode Island (left) and Vermont (right)



APPENDIX VI

Demand Modeling

Demand Modeling Methodology (1 of 2)

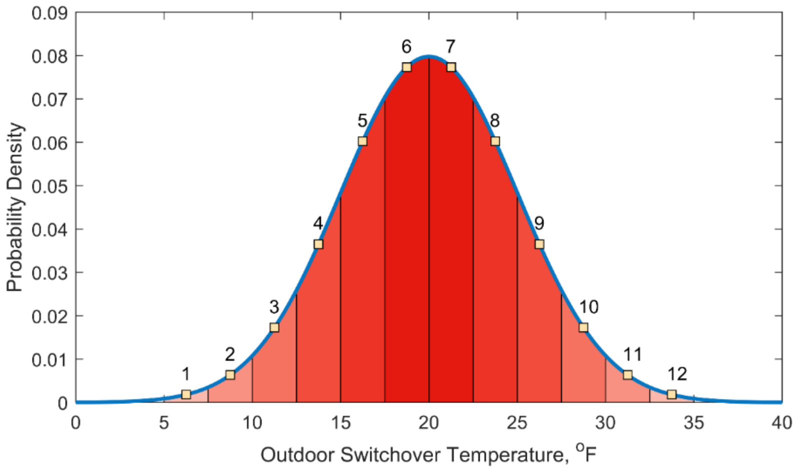
- Demand modeling methodology consist of three steps, which are described further below and on the next slide:
  - Develop relationships between hourly heating usage and outdoor temperature for all residential and commercial building types
  - Develop coefficient of performance curves for all heating pathways
  - 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, use the associated reference make/model heat pump's coefficient of performance ($COP = \frac{Heat\ Output}{Input\ Power}$) 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°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, as described on the following slide
  - 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 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

Blended Demand Profiles

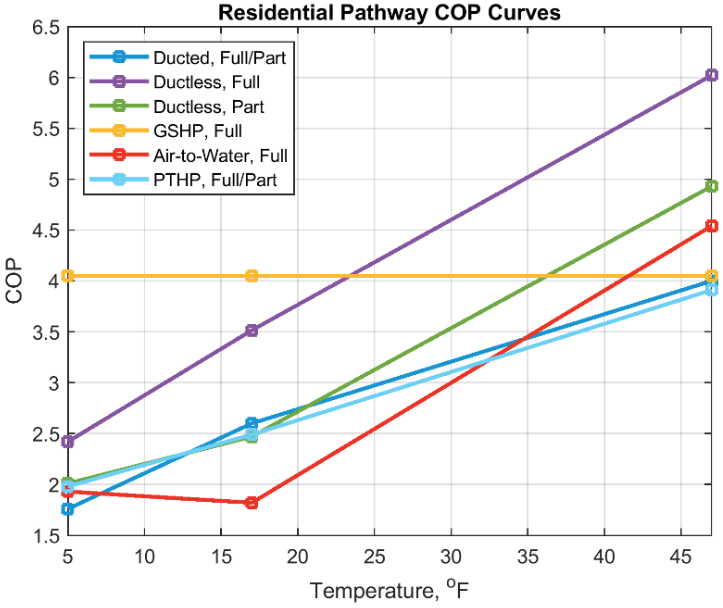
- ISO Created a blended demand profile for each partial space heating pathway that reflects a range of switchover temperatures
- Assumes a normal distribution with mean of 20ºF and a standard deviation of 5ºF
  - Divide normal distribution into 12 switchover temperatures and probabilities as plotted 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, ^{o}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

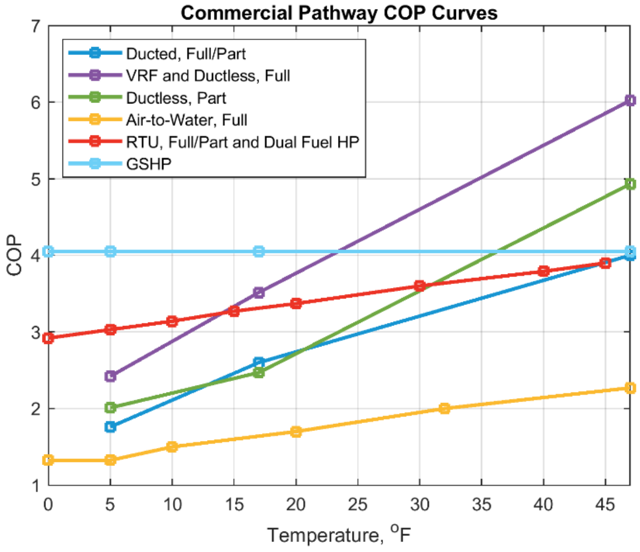
Residential Space Heating Pathway Assumptions

Pathway	Share of Adoption (%)		Min. Operating Temp (F)	Approx. Seasonal Heating Supplied (%)	Reference HP
	2034	2050			
Air-to-Water	0.2	0.2	-5	100	Taco Comfort System M
Ducted Full	14.5	18.9	5	100	Lennox Central Heat Pump
Ducted Partial	47.2	39.1	5	63-74	
Ductless Full	21.9	26.8	-13	100	Mitsubishi M-Series
Ductless Partial	13.2	10.3	-13	65-76	Daikin DZ6VS
Ground Source Heat Pump (GSHP)	1.7	2.2	-20	100	Energy Star rated models
Packaged Terminal Heat Pump (PTHP)	1.2	2.5	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	1.7	3.7	0	100	Trane ACX
Dual Fuel Heat Pump Rooftop Unit (RTU)	19.2	20.8	0	81	Rheem Renaissance Packaged Heat Pump
Ducted Full	0.8	1.8	5	100	Lennox Central Heat Pump
Ducted Partial	0.8	1.8	5	61-74	
Ductless Full	4.4	9.5	-13	100	Mitsubishi M-Series
Ductless Partial	2.9	7.0	5	63-76	Daikin DZ6VS
Ground Source Heat Pump	0.3	0.6	-20	100	Energy Star rated models
Rooftop Unit (RTU) – Full	63.6	42.6	0	100	Rheem Renaissance Packaged Heat Pump
RTU - Partial	1.8	2.3	0	81	
Variable Refrigerant Flow (VRF)	4.5	9.9	-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 weekends/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

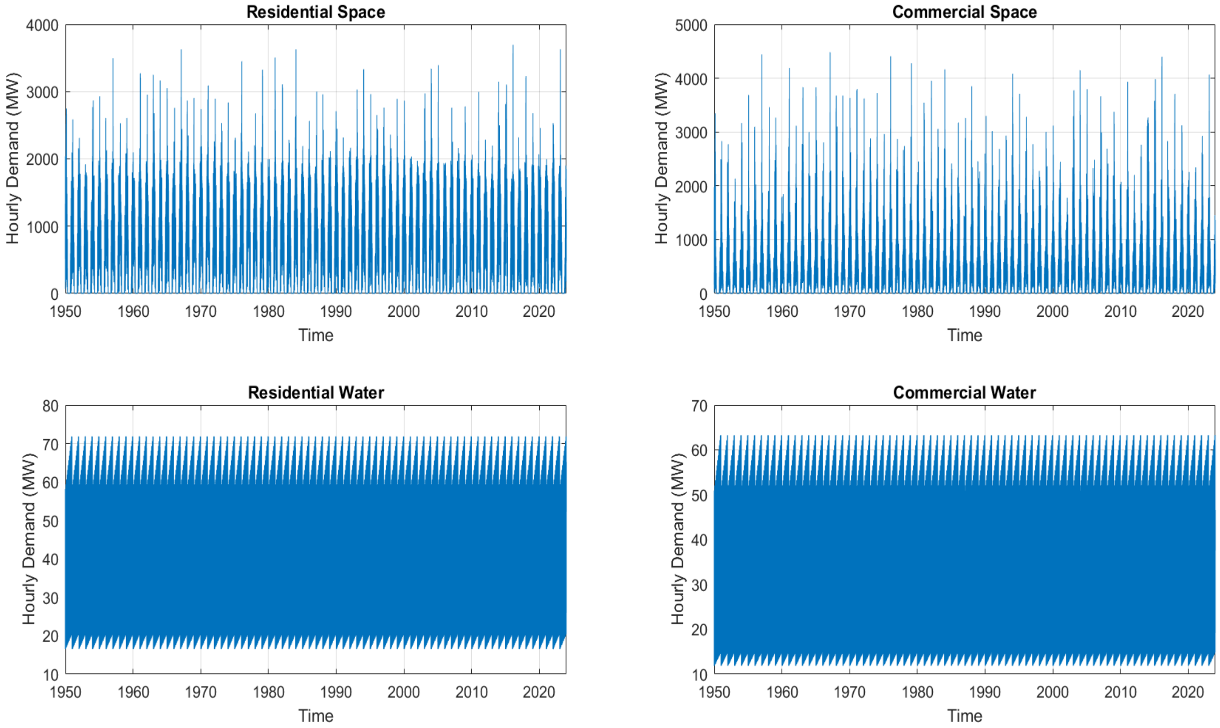
Hourly Demand Modeling

- More than 64,000 hourly residential demand models:
  - 8 pathways (7 space and 1 water)
  - 5 building types
  - 67 counties
  - 24 hours

- More than 247,000 hourly commercial demand models
  - 11 pathways (9 space and 2 water)
  - 14 building types
  - 67 counties
  - 24 hours

- Hourly models applied to 70 years of weather data

- Figures to the right illustrate regional hourly demand profiles for forecast year 2034 for the entire model period



Hourly Demand Modeling

- Figure to the right shows regional hourly demand results for each component of the heating electrification forecast for a particularly cold winter day in 2034