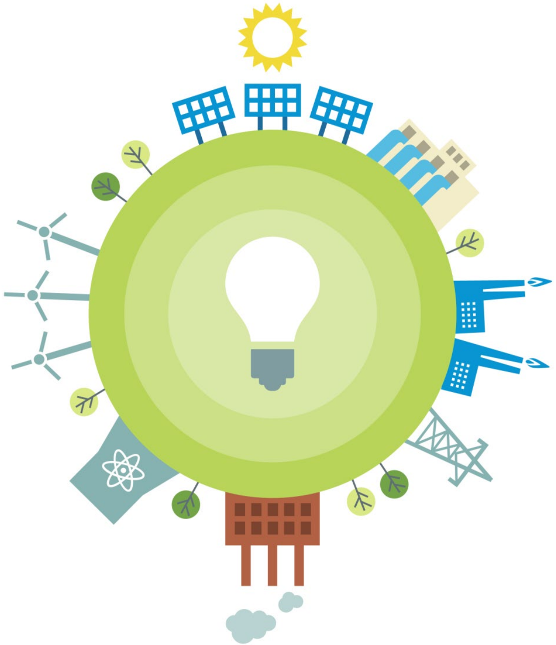
APRIL 28, 2023

# Final 2023 Heating Electrification Forecast

# Outline





# Introduction

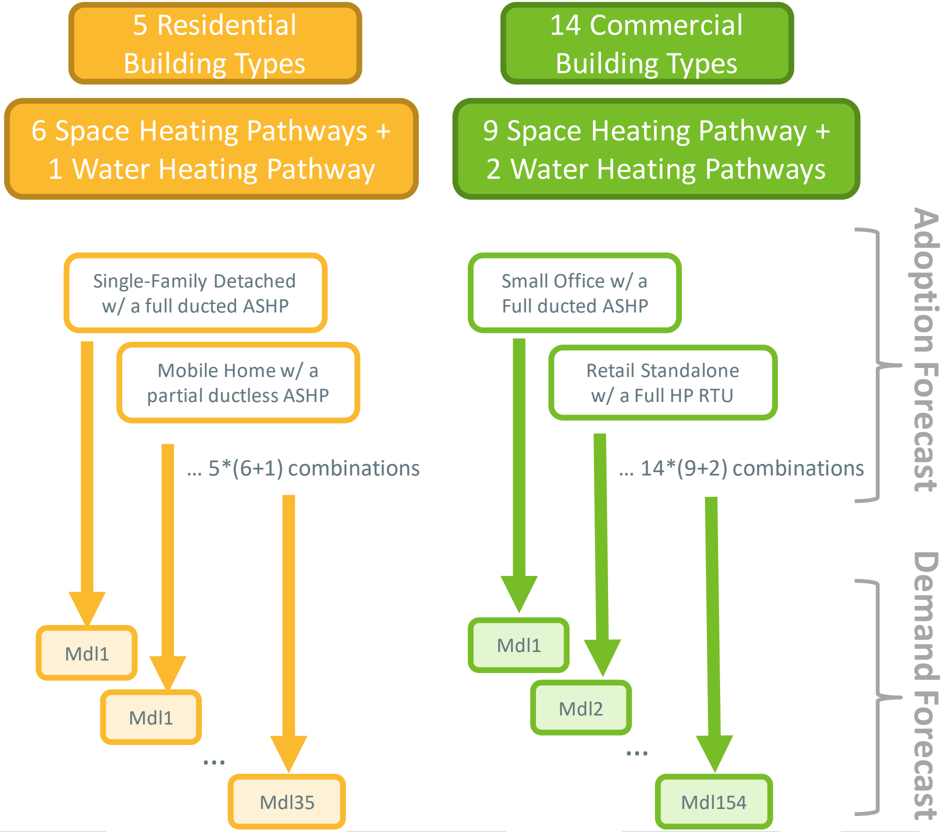
- Heating electrification is expected to play a pivotal role in the achievement of New England state greenhouse gas (GHG) reduction mandates and long-term decarbonization goals
- Forecasted impacts of heating electrification on state and regional electric energy and demand are included as part of the 2023 Capacity, Energy, Loads, and Transmission (CELT) forecast
- The ISO’s heating electrification forecast seeks to forecast the energy and demand impacts associated with the adoption of various forms of heat pumps to electrify the following:
  - Residential space and water heating
  - Commercial space and water heating

# Heating Electrification Forecast

*New Methodology for CELT 2023*

New methodology leverages the National Renewable Energy Laboratory's ResStock and ComStock datasets, and is based on four sequential tasks

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



# BUILDING STOCK CHARACTERIZATION

# Building Stock Characterization

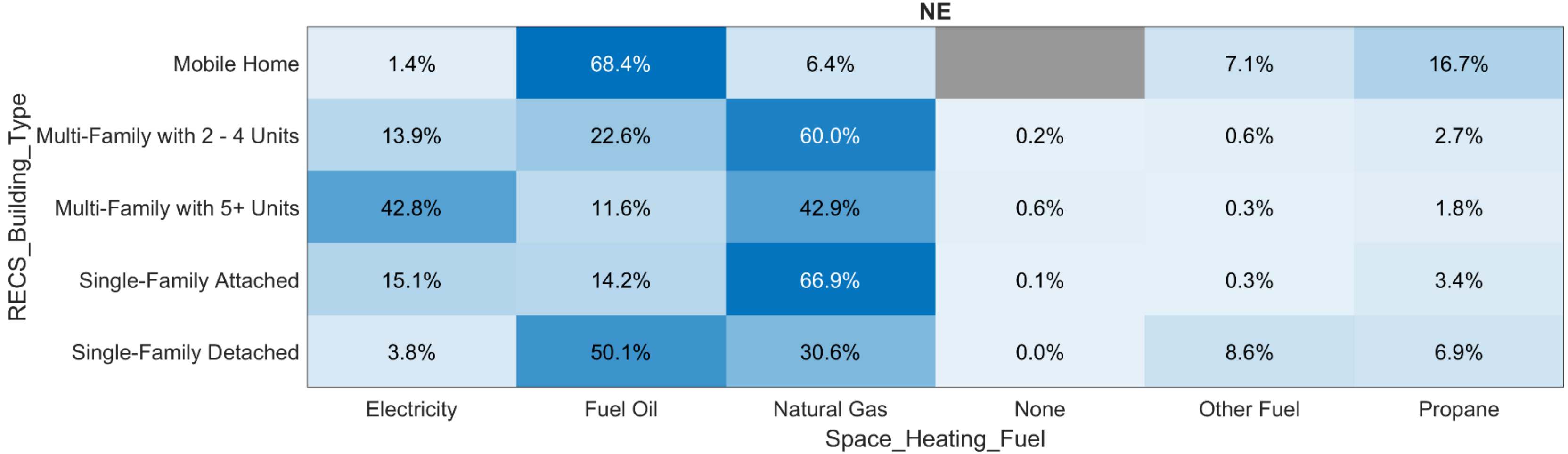
- Establishes a comprehensive picture of 2018 New England building stock
  - Building sector/types/uses
  - Building age
  - Heating fuel
  - Heating delivery system
  - Cooling delivery system
  - Location (state/county)
- Aggregation
  - Residential buildings are quantified in households
  - Commercial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

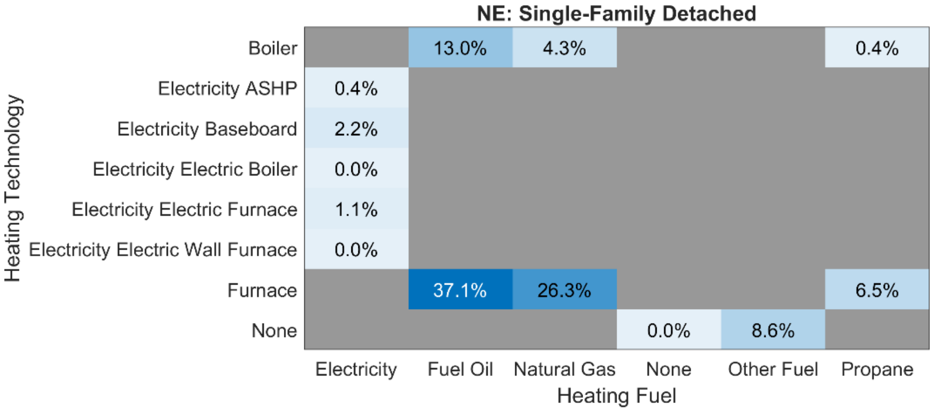
| State | Building Type | % of Households |
|---|---|---|
| NE | Single-Family Detached | 58% |
| NE | Multi-Family with 2 - 4 Units | 17% |
| NE | Multi-Family with 5+ Units | 17% |
| NE | Single-Family Attached | 5% |
| NE | Mobile Home | 3% |

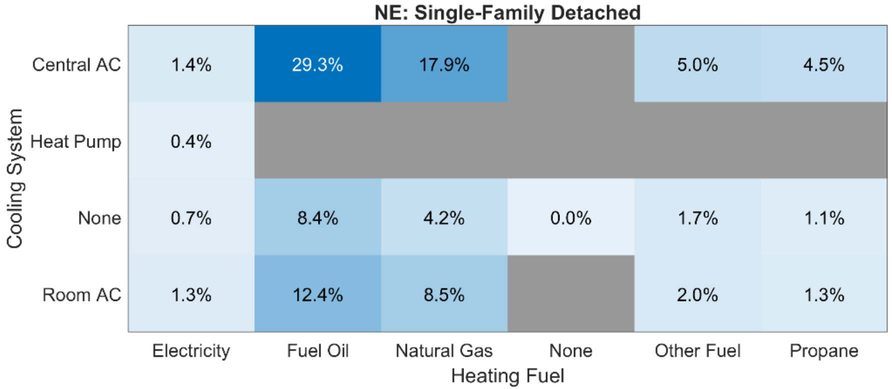
*Sum across each row = 100%*

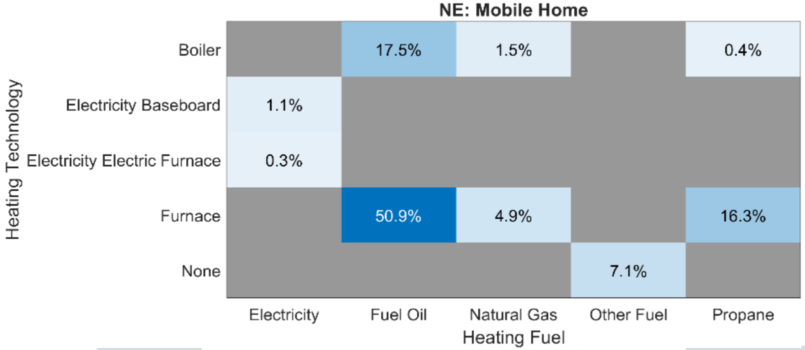


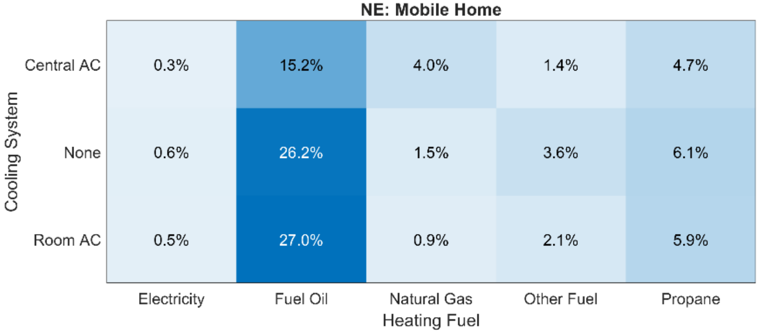
# Residential Buildings

*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 \ 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% | | | | |

# HEATING PATHWAYS

# Heating Electrification Pathways

*Residential Space Heating*

- CELT 2022 included only two residential space heating pathways, partial displacement ASHPs and full displacement ASHPs

**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 Space Heating*

- Electrification of commercial space heating was not included in CELT 2022 and is new this year

## 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

# Heating Electrification Pathways

*Residential Water Heating*

- Electrification of residential water heating was not included in CELT 2022 and is new this year

**Residential Water Heating Pathways**

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

# Heating Electrification Pathways

*Commercial Water Heating*

- Electrification of commercial water heating was not included in CELT 2022 and is new this year

**Commercial Water Heating Pathways**

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

# ADOPTION FORECASTING

*Modeling and Results*

# 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 full 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 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

# Residential Space Heating

*Existing Fuel Sources*

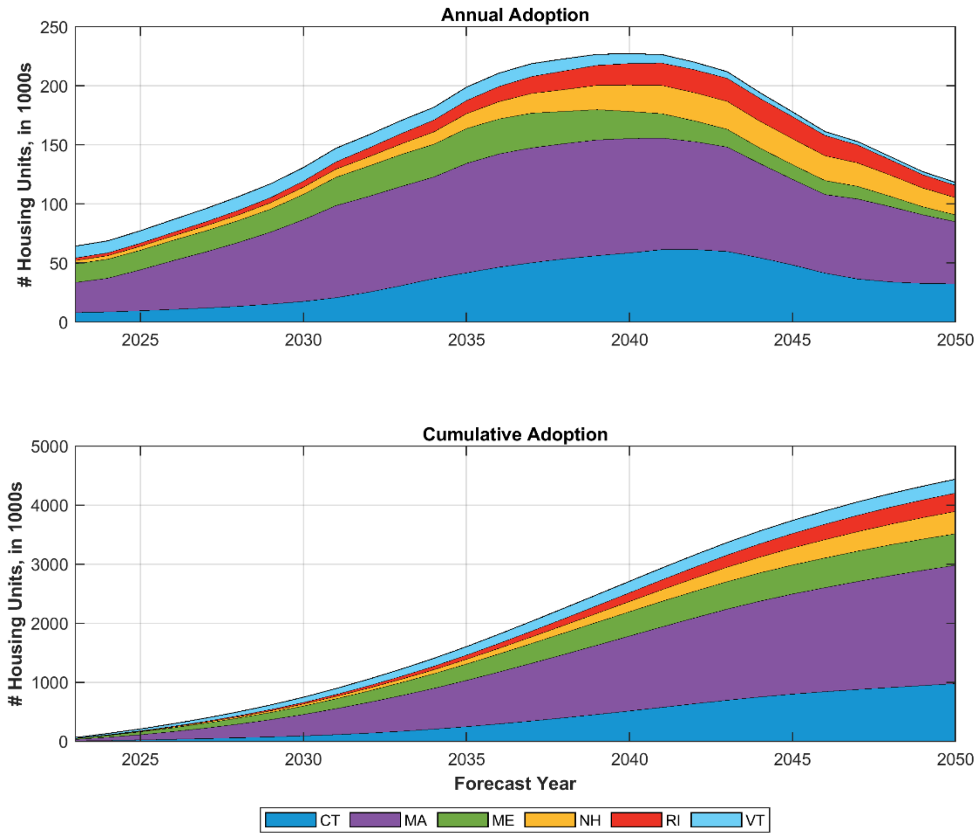
- Adoption modeling focuses exclusively on legacy fossil fueled space heating:
  - Fuel Oil
  - Propane
  - Natural Gas

**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 |

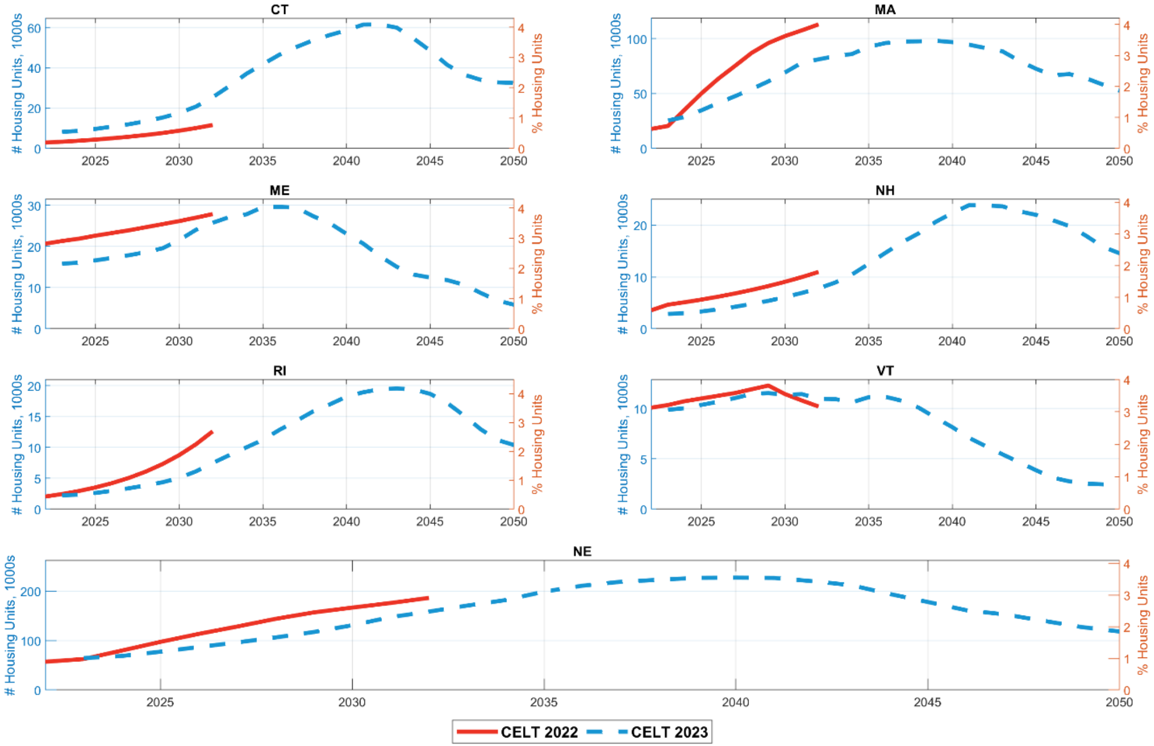
# Residential Space Heating Adoption

- 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 I



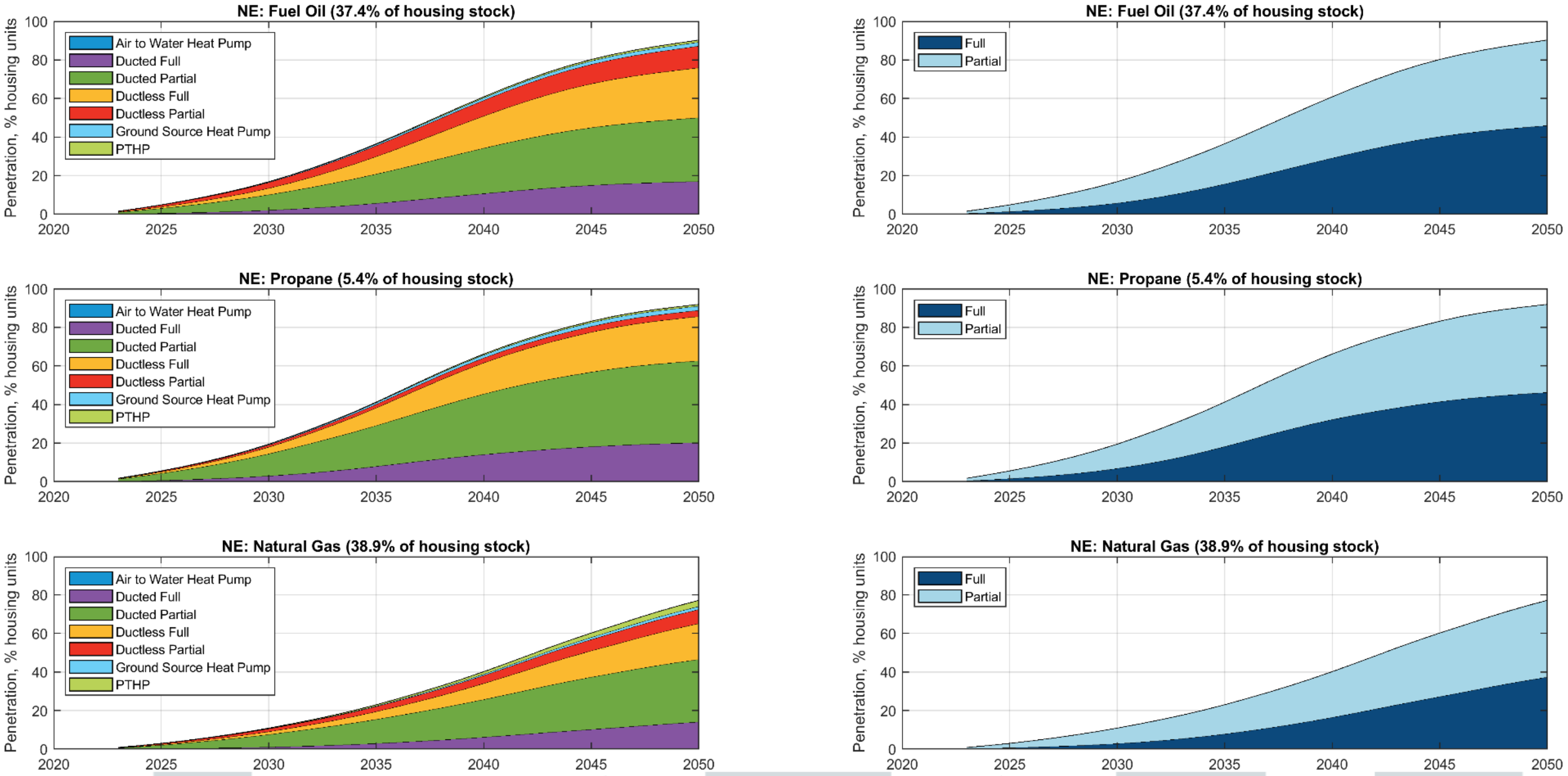
# Residential Space Heating Adoption

*CELT 2023 versus CELT 2022 Adoption Forecast*



# Adoption By Legacy Residential Space Heating Fuel

*New England*



# Commercial Space Heating

*Legacy Fuel Sources*

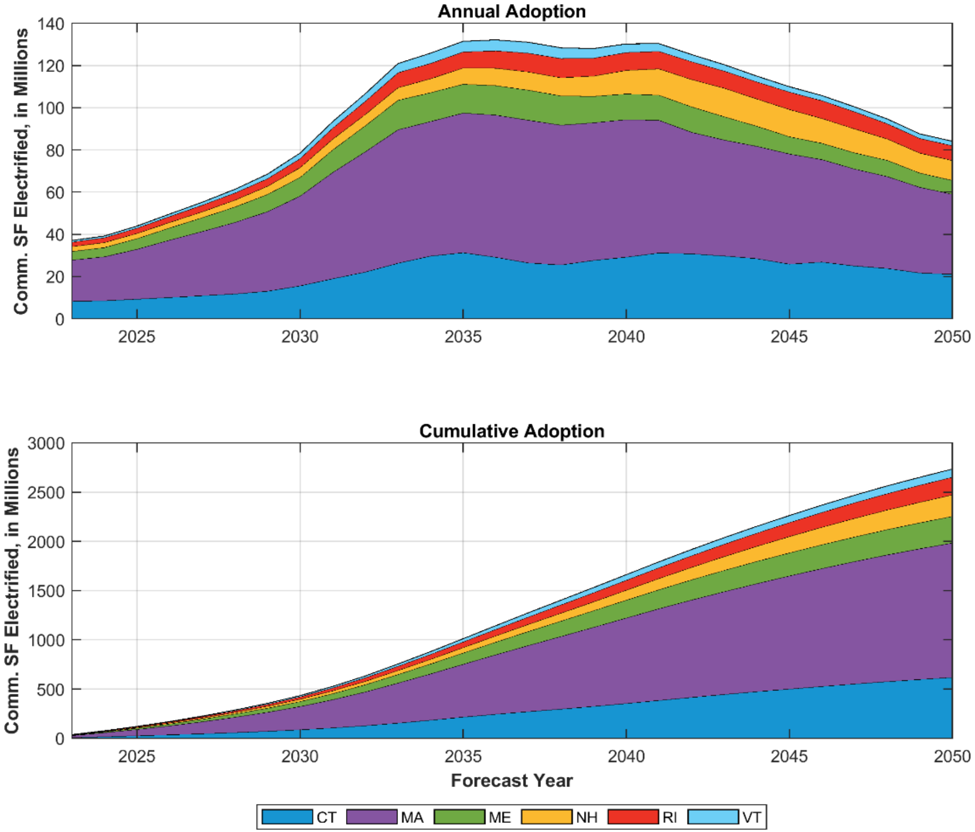
- Adoption modeling focuses exclusively on legacy fossil fueled space heating:
  - Fuel Oil
  - Propane
  - Natural Gas

**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 |

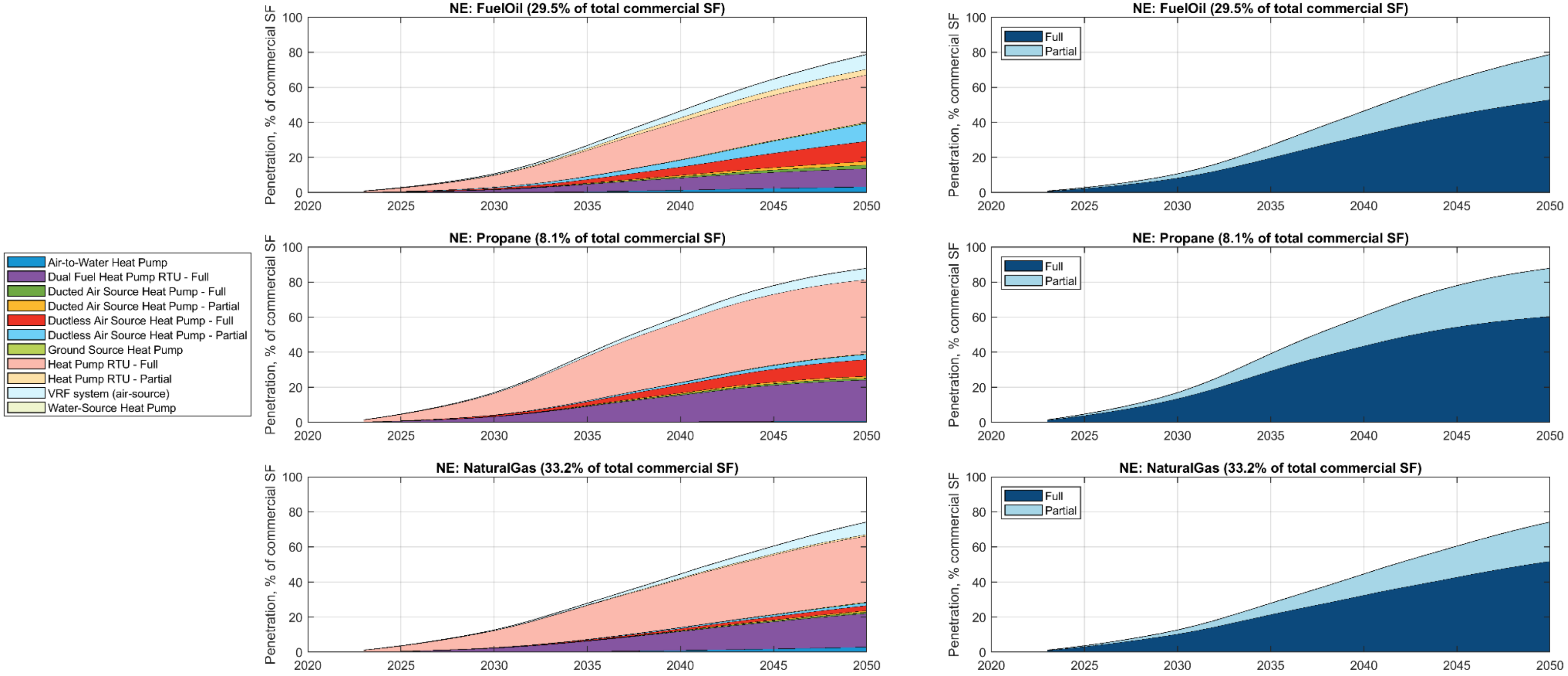
# Commercial Space Heating Adoption

- 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 II



# Adoption By Legacy Commercial Space Heating Fuel

*New England*



# Residential Water Heating

*Legacy Fuel Sources*

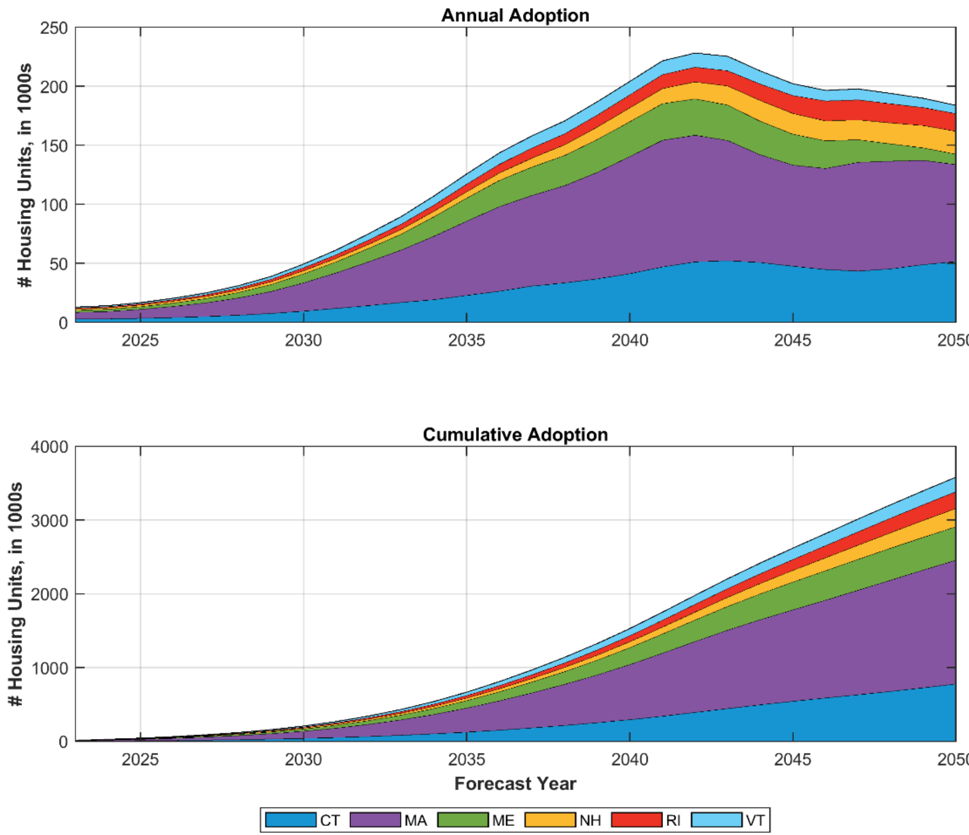
- Adoption modeling focuses exclusively on legacy fossil fueled water heating:
  - Fuel Oil
  - Propane
  - Natural Gas

**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 |

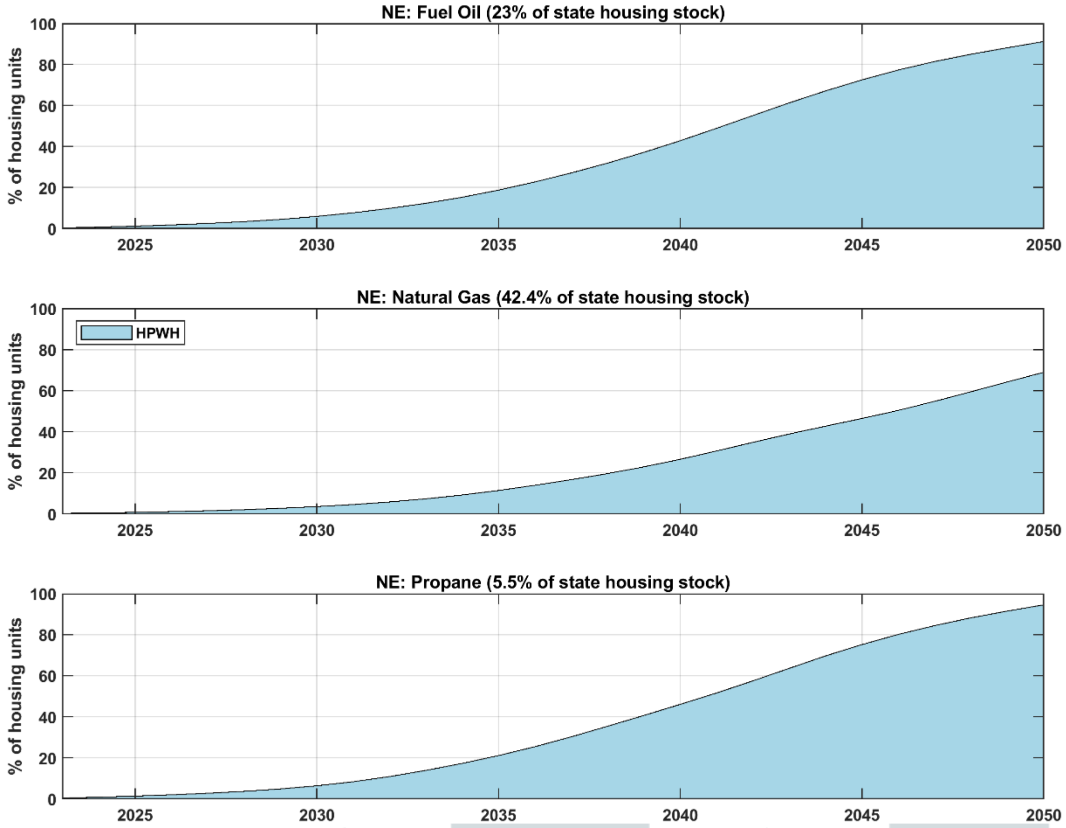
# Residential Water Heating Adoption

- 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 III



# Adoption By Legacy Residential Water Heating Fuel

*New England*



# Commercial Water Heating

*Legacy Fuel Sources*

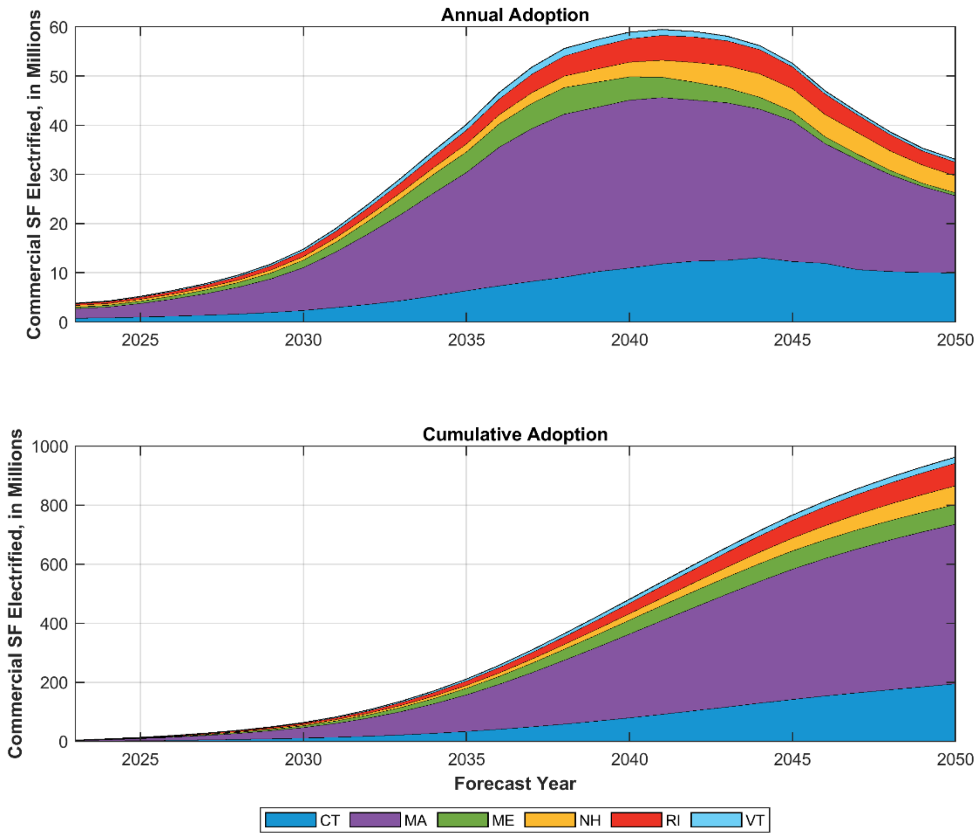
- Adoption modeling focuses exclusively on legacy fossil fueled water heating:
  - Fuel Oil
  - Propane
  - Natural Gas

**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 |

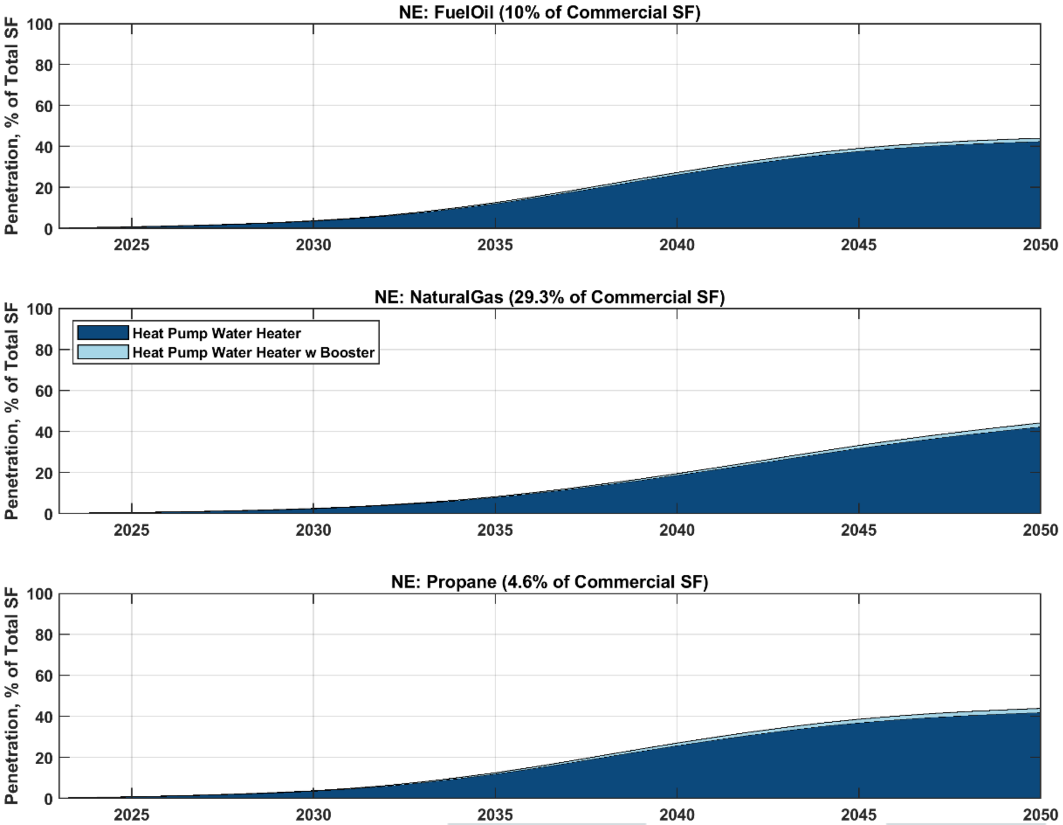
# Commercial Water Heating Adoption

- 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 IV



# Adoption By Legacy Commercial Water Heating Fuel

*New England*



# DEMAND MODELING

# Demand Modeling Methodology (1 of 2)

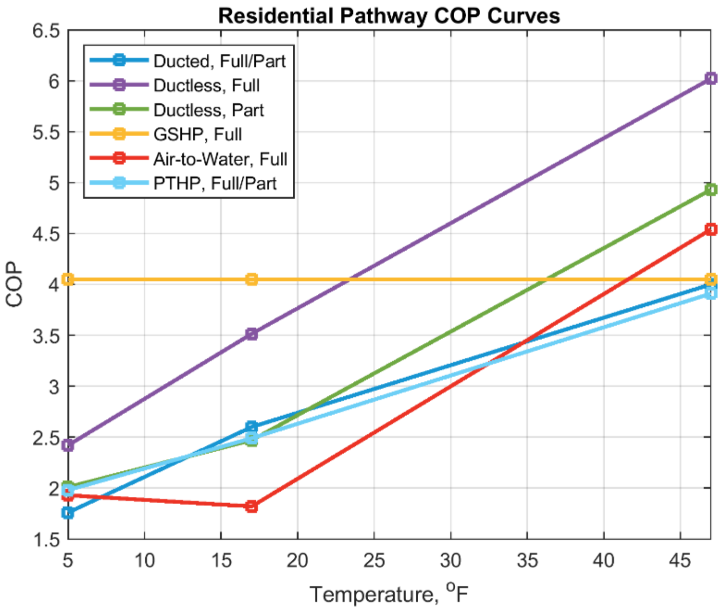
- Demand modeling methodology consists of three steps, which are described further below and on the next slide:
  1. Develop relationships between hourly heating usage and outdoor temperature for all residential and commercial building types
  2. Develop coefficient of performance (COP) curves for all 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 when temperatures are below 20$^{o}$F is provided by a supplemental, non-electric heating system
    - Hourly demand is zero for all temperatures 20 degrees F or lower
  - 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

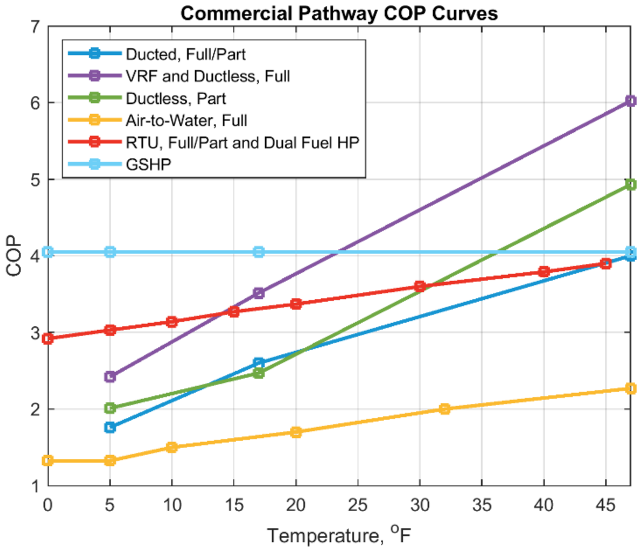
# Residential Space Heating Pathway Assumptions

| 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

# FINAL 2023 ENERGY FORECAST

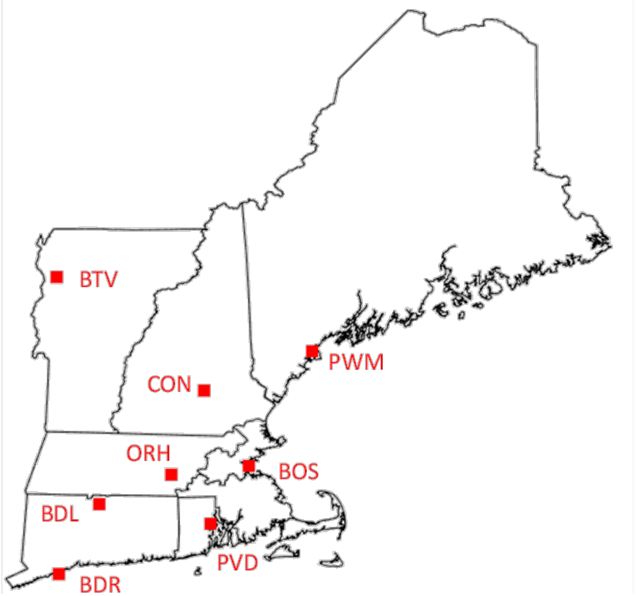
# Weather Used in HP Simulation Profiles

*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**

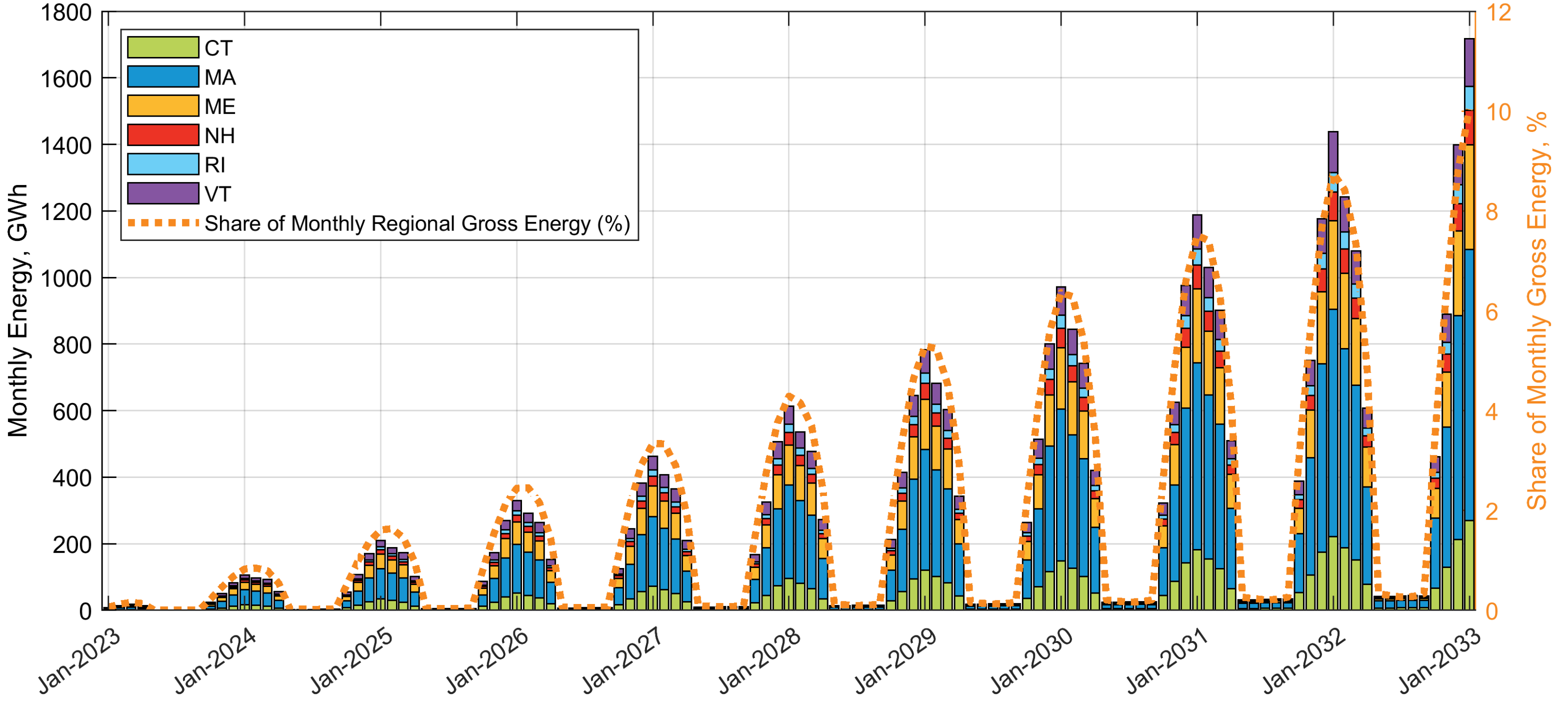


# Estimating Energy Impacts of HP Adoption

- Hourly HP profiles were simulated based on modeling described in slides 26-31 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 40
  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 41-45 of the ISO's Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross energy forecast

# Final 2023 Heating Electrification Forecast

*Monthly Energy, GWh*



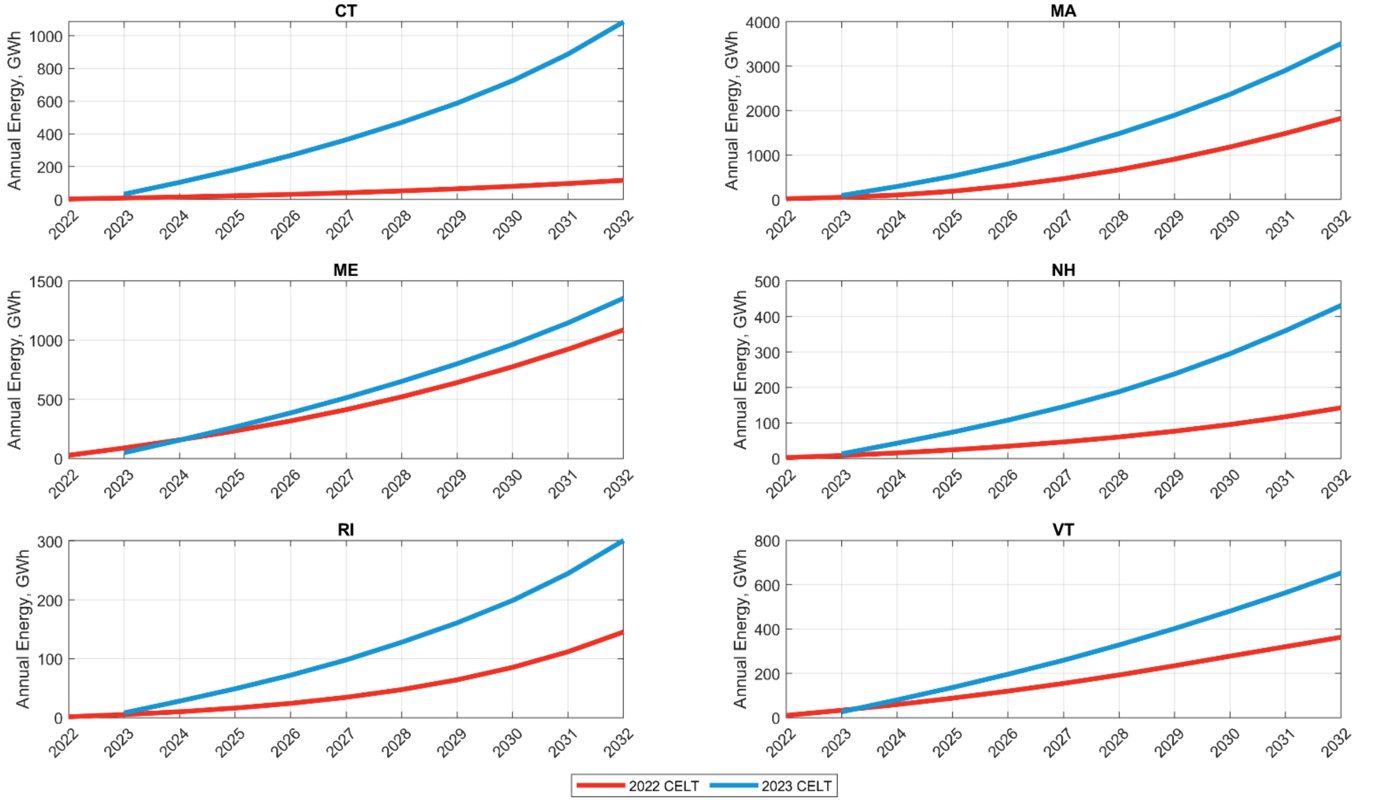
# Final 2023 Heating Electrification Forecast

*Annual Energy, GWh*

| | Annual Energy (GWh) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
| Connecticut | 32 | 104 | 182 | 268 | 364 | 470 | 588 | 725 | 888 | 1,085 |
| Massachusetts | 87 | 290 | 522 | 798 | 1,117 | 1,482 | 1,896 | 2,367 | 2,907 | 3,510 |
| Maine | 49 | 155 | 266 | 385 | 513 | 651 | 800 | 963 | 1,146 | 1,354 |
| New Hampshire | 13 | 43 | 74 | 108 | 146 | 188 | 238 | 295 | 360 | 431 |
| Rhode Island | 8 | 28 | 49 | 72 | 98 | 128 | 161 | 199 | 245 | 301 |
| Vermont | 26 | 80 | 136 | 196 | 259 | 328 | 402 | 481 | 564 | 653 |
| **Total** | **215** | **699** | **1,229** | **1,827** | **2,498** | **3,247** | **4,085** | **5,030** | **6,111** | **7,334** |

# Annual Heating Electrification Energy

*Final CELT 2023 vs. Final CELT 2022*



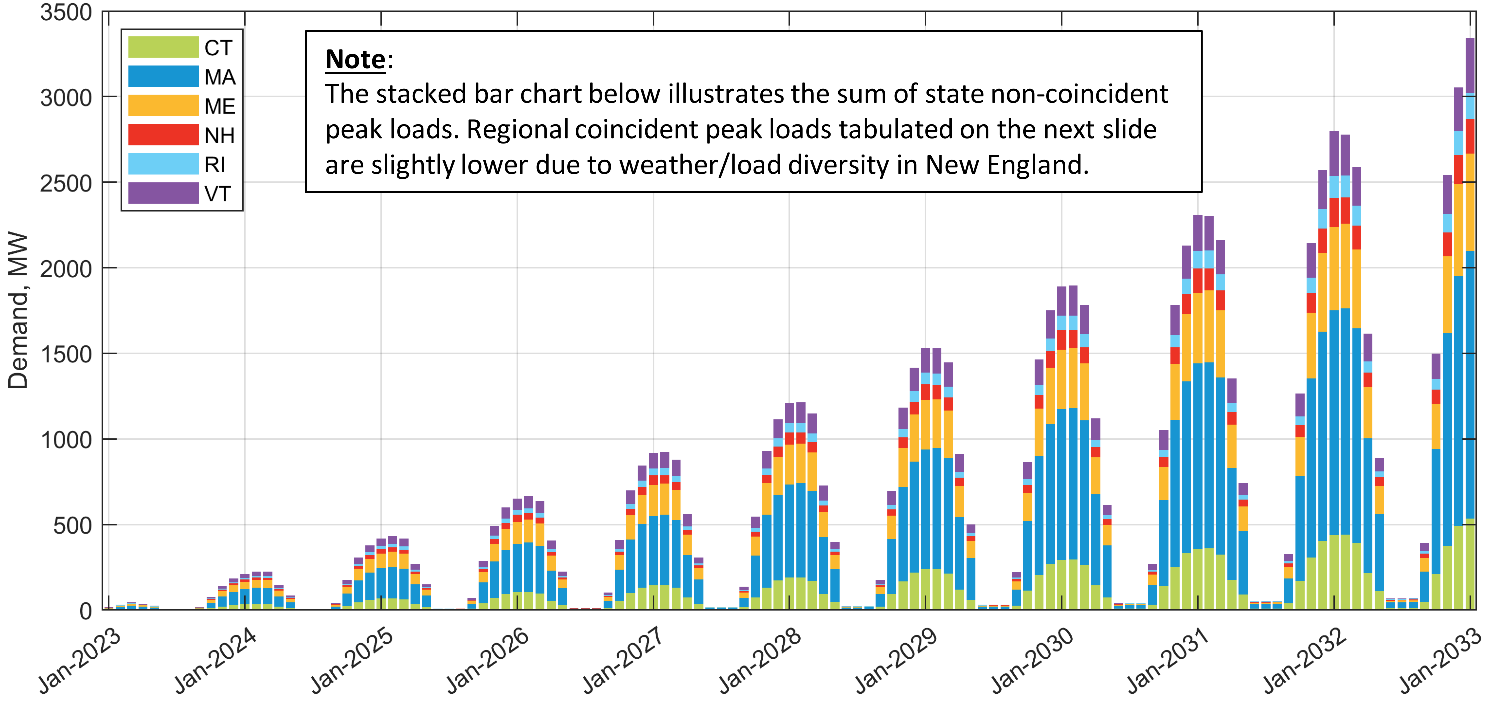
# FINAL 2023 DEMAND FORECAST

# 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 46-50 of the ISO's Long-Term Load Forecast Methodology Overview for background information on the methodology used for the gross demand forecast

# Final 2023 Heating Electrification Forecast

*Monthly Demand, 50/50*



# Final 2023 Heating Electrification Forecast

*Winter (January) Demand, 50/50*

| | Winter Peak (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2023-24 | 2024-25 | 2025-26 | 2026-27 | 2027-28 | 2028-29 | 2029-30 | 2030-31 | 2031-32 | 2032-33 |
| Connecticut | 34 | 71 | 111 | 155 | 184 | 224 | 277 | 332 | 415 | 485 |
| Massachusetts | 72 | 148 | 254 | 364 | 438 | 586 | 742 | 945 | 1,149 | 1,366 |
| Maine | 34 | 73 | 111 | 156 | 201 | 248 | 306 | 367 | 446 | 513 |
| New Hampshire | 13 | 28 | 43 | 59 | 72 | 88 | 112 | 130 | 156 | 178 |
| Rhode Island | 8 | 18 | 28 | 37 | 47 | 60 | 70 | 86 | 104 | 128 |
| Vermont | 15 | 33 | 54 | 76 | 99 | 126 | 166 | 203 | 251 | 294 |
| **Total** | 175 | 370 | 601 | 848 | 1,040 | 1,333 | 1,673 | 2,063 | 2,521 | 2,965 |

**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 2023 Heating Electrification Forecast

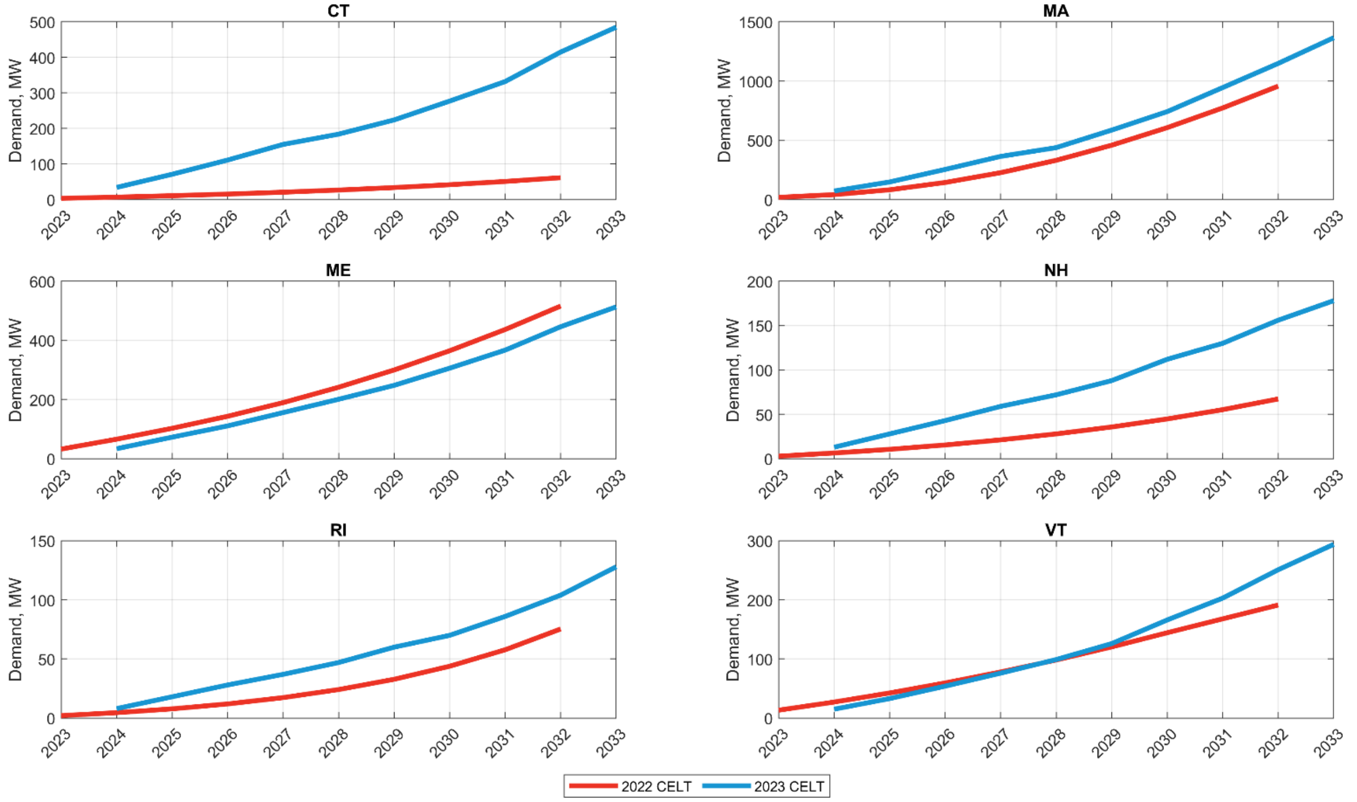
*Winter (January) Demand, 90/10*

| | Winter Peak (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2023-24 | 2024-25 | 2025-26 | 2026-27 | 2027-28 | 2028-29 | 2029-30 | 2030-31 | 2031-32 | 2032-33 |
| Connecticut | 41 | 85 | 133 | 183 | 240 | 302 | 372 | 463 | 566 | 690 |
| Massachusetts | 94 | 195 | 299 | 423 | 565 | 725 | 907 | 1,131 | 1,380 | 1,664 |
| Maine | 44 | 92 | 147 | 207 | 277 | 356 | 446 | 553 | 673 | 809 |
| New Hampshire | 16 | 32 | 50 | 73 | 94 | 120 | 151 | 189 | 228 | 271 |
| Rhode Island | 10 | 20 | 32 | 45 | 56 | 71 | 87 | 108 | 133 | 163 |
| Vermont | 20 | 42 | 67 | 96 | 132 | 174 | 225 | 287 | 357 | 435 |
| **Total** | 225 | 466 | 728 | 1,026 | 1,365 | 1,749 | 2,188 | 2,732 | 3,337 | 4,033 |

**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 2023 vs. CELT 2022*




ISO-NE PUBLIC

# Final 2023 Heating Electrification Forecast

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

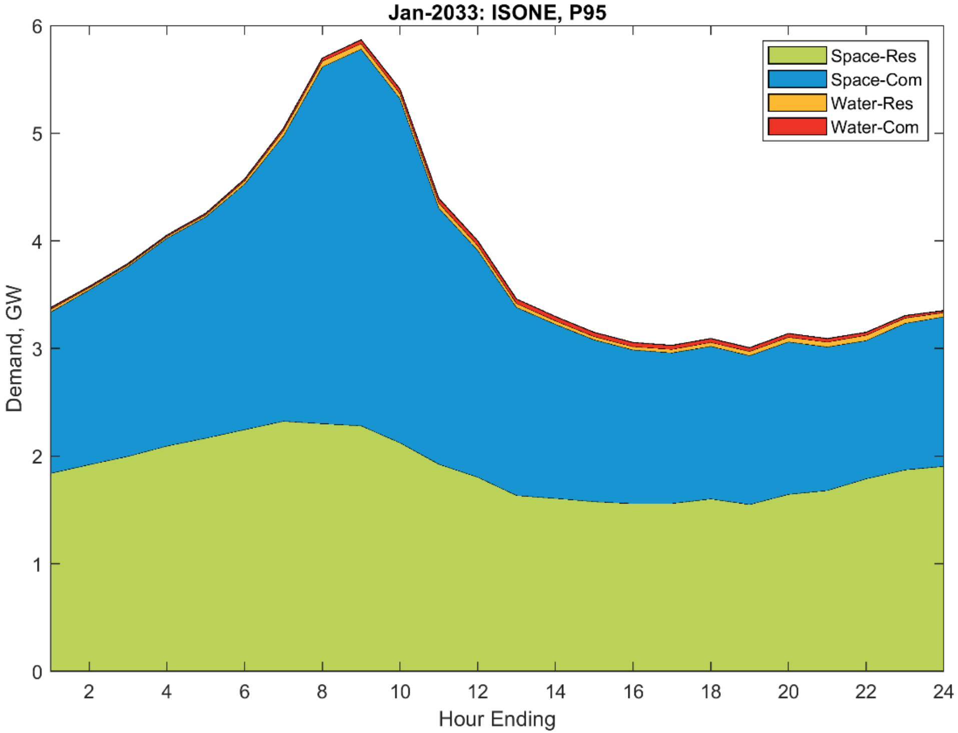
| | Summer Peak (MW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
| Connecticut | 0 | 1 | 2 | 2 | 3 | 4 | 6 | 7 | 9 | 12 |
| Massachusetts | 1 | 2 | 4 | 6 | 8 | 11 | 15 | 20 | 26 | 35 |
| Maine | 0 | 1 | 1 | 2 | 2 | 3 | 4 | 6 | 7 | 10 |
| New Hampshire | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 4 |
| Rhode Island | 0 | 0 | 1 | 1 | 1 | 2 | 3 | 3 | 4 | 5 |
| Vermont | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 3 |
| **Total** | **2** | **5** | **8** | **12** | **17** | **23** | **31** | **41** | **53** | **69** |

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

# 50/50 Winter Peak Composition

*January 2033*

- Plot shows the forecast composition of hourly winter 50/50 peak demand impacts of heating electrification in January 2033
  - 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

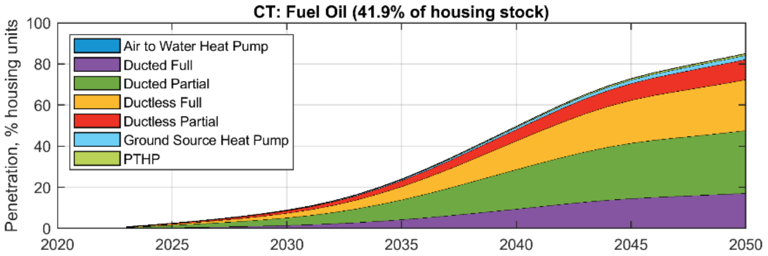


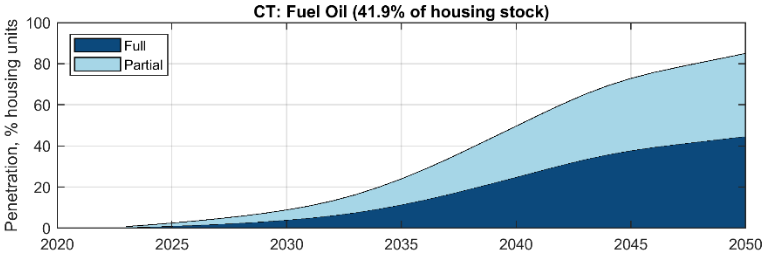
# APPENDIX I

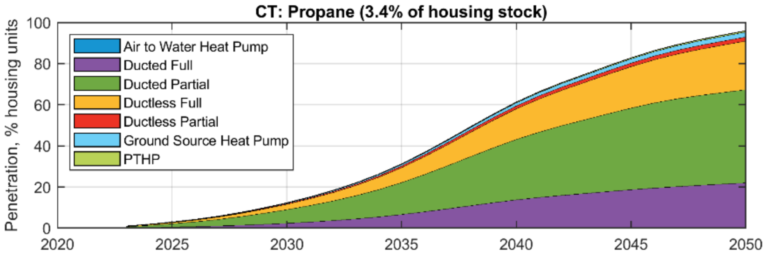
*State Adoption Plots – Residential Space Heating*

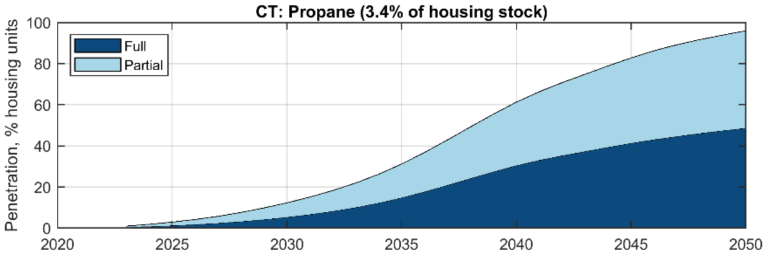
# Adoption By Legacy Residential Space Heating Fuel

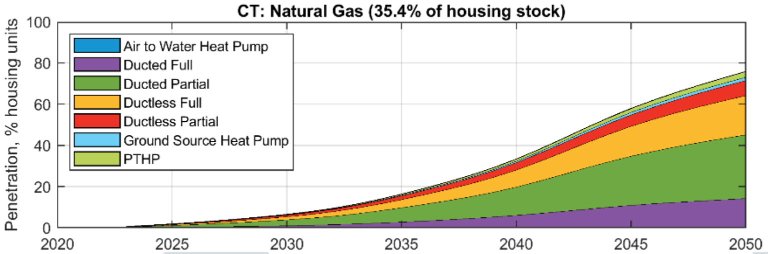
*Connecticut*

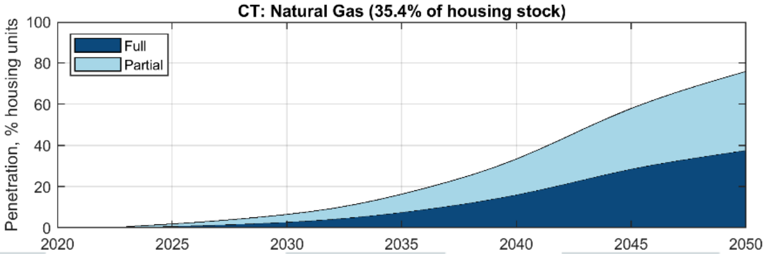


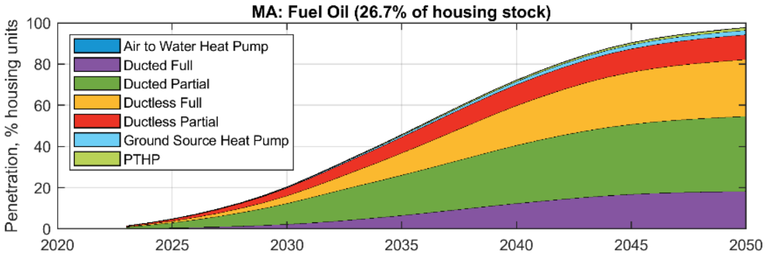



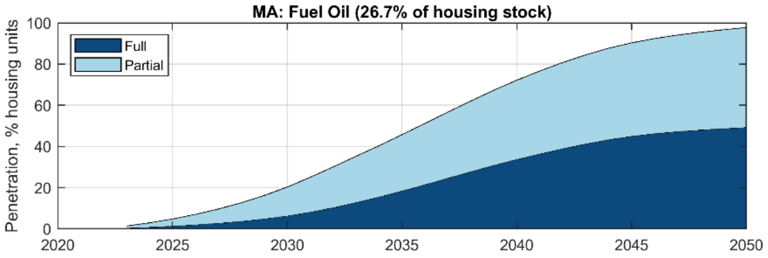



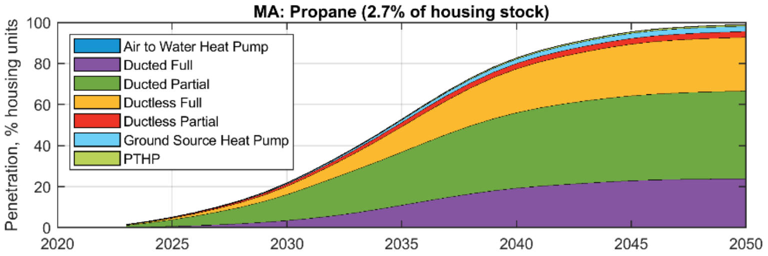



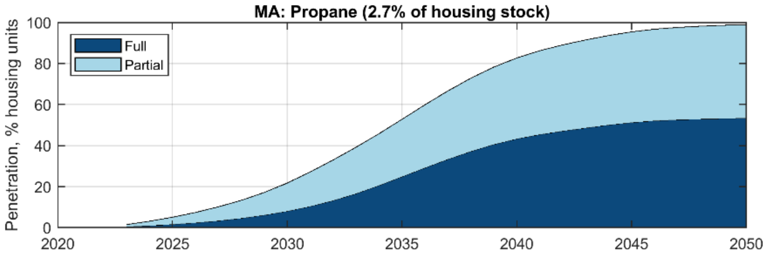
# Adoption By Legacy Residential Space Heating Fuel

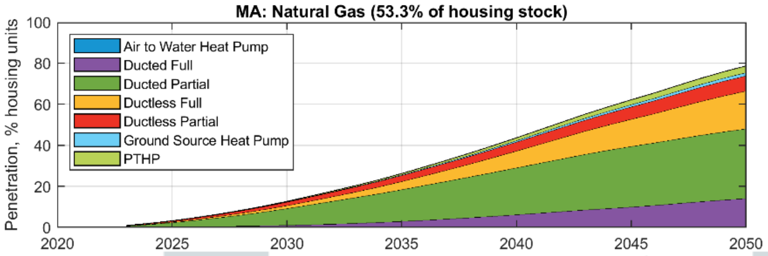
*Massachusetts*

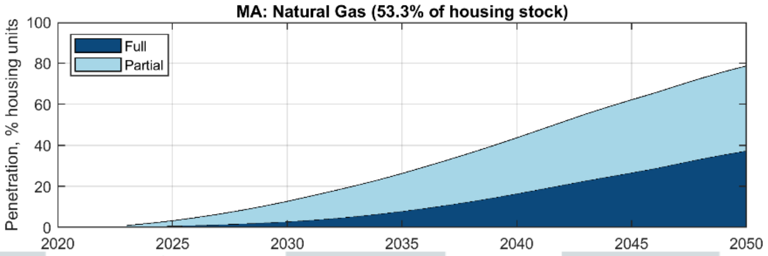


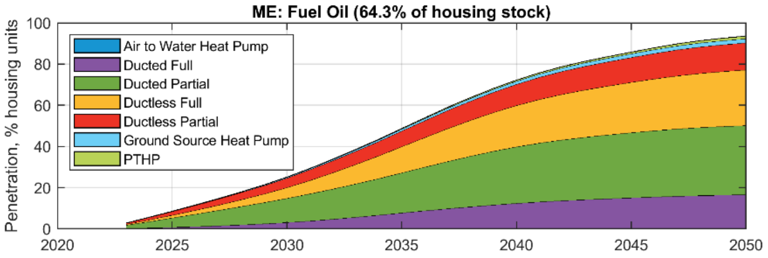



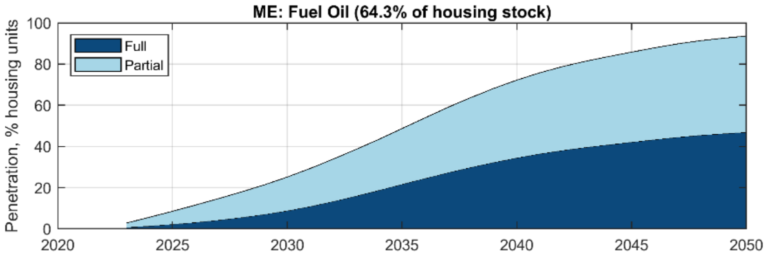



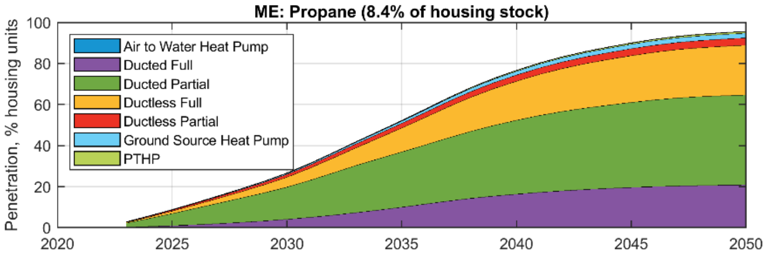



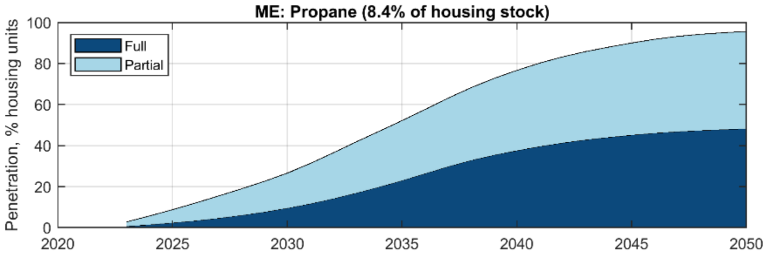
# Adoption By Legacy Residential Space Heating Fuel

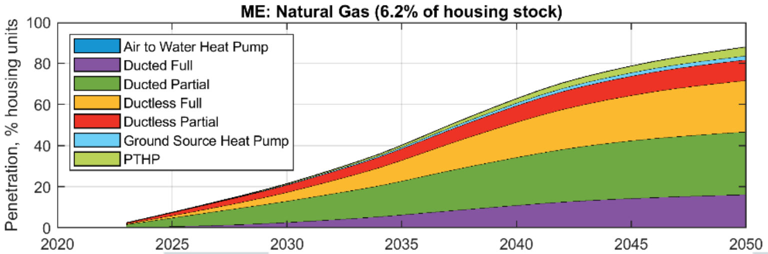
*Maine*

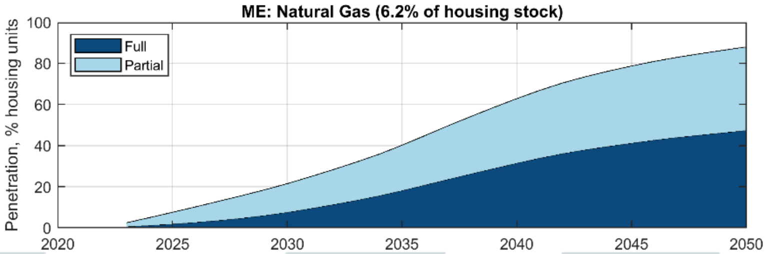


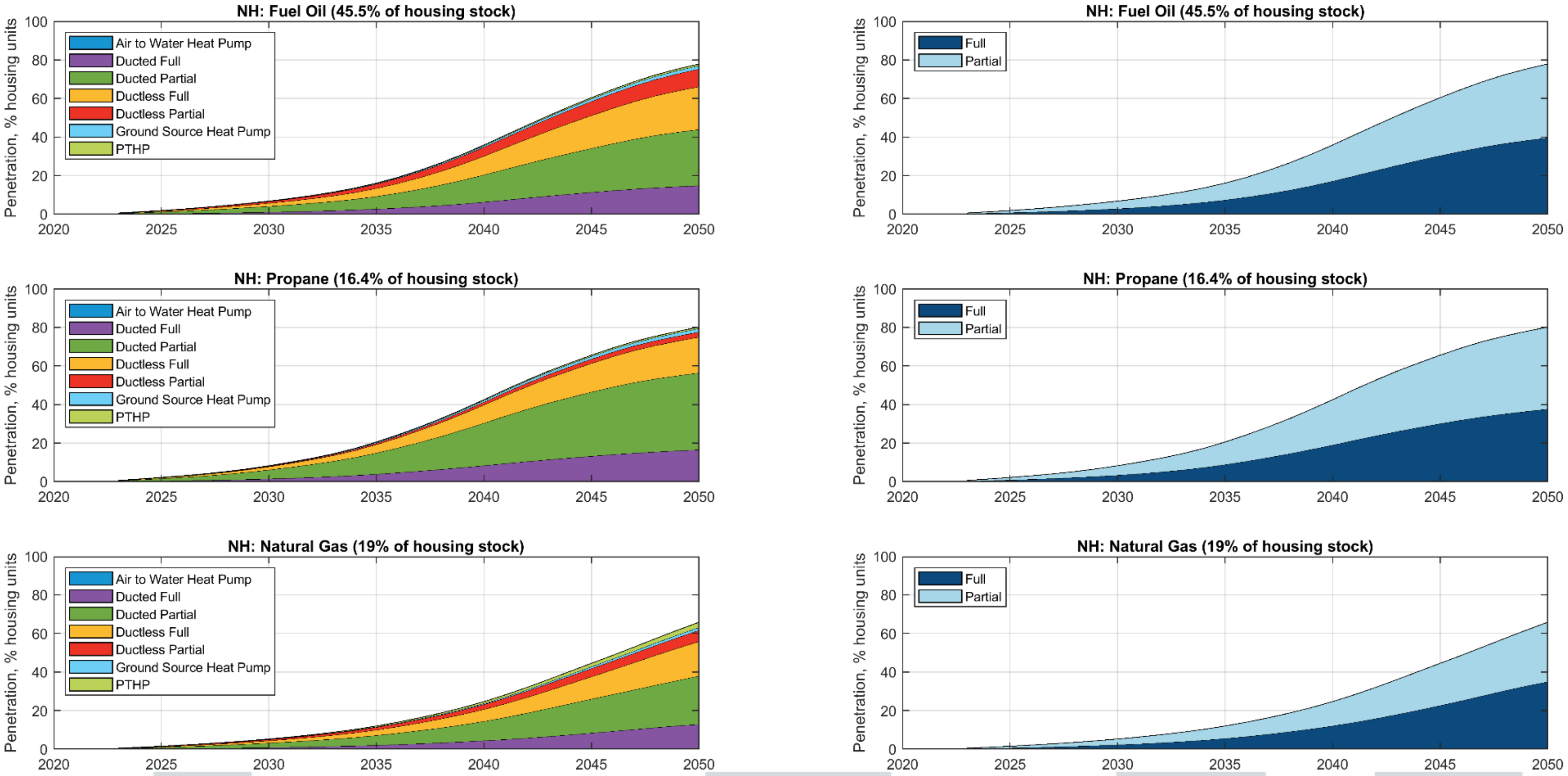



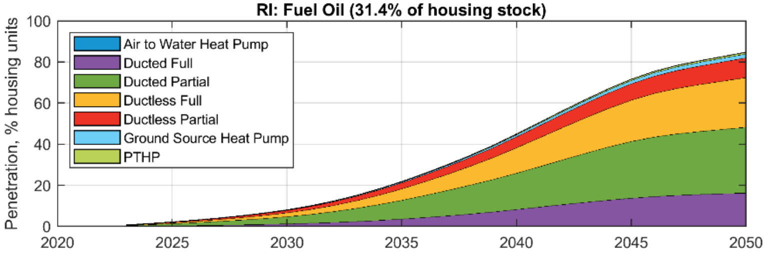
# Adoption By Legacy Residential Space Heating Fuel

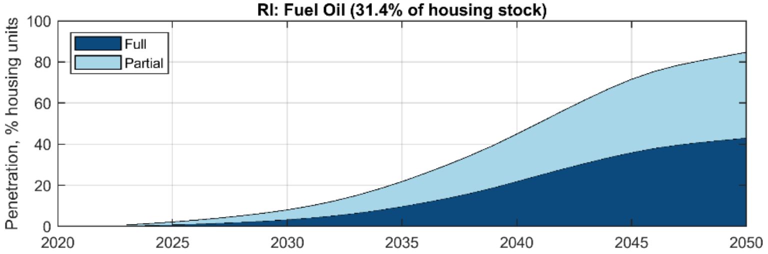
*New Hampshire*

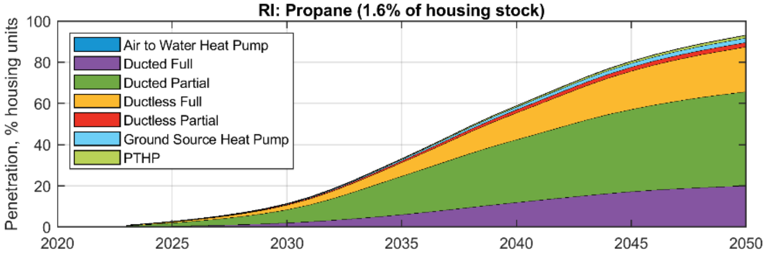


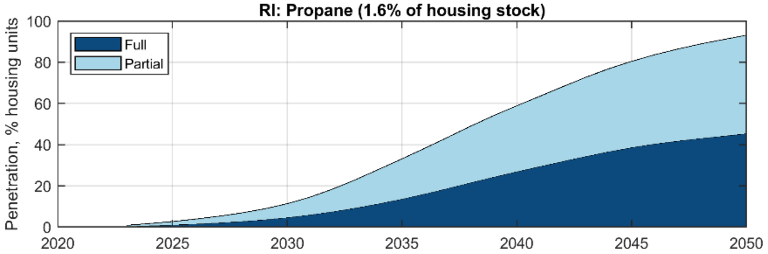
# Adoption By Legacy Residential Space Heating Fuel

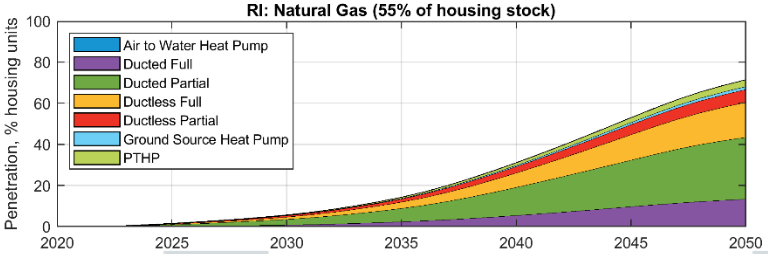
*Rhode Island*

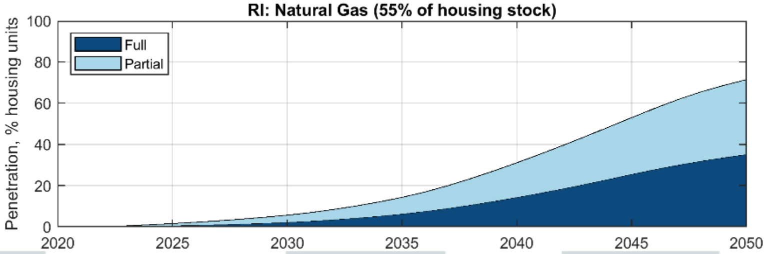


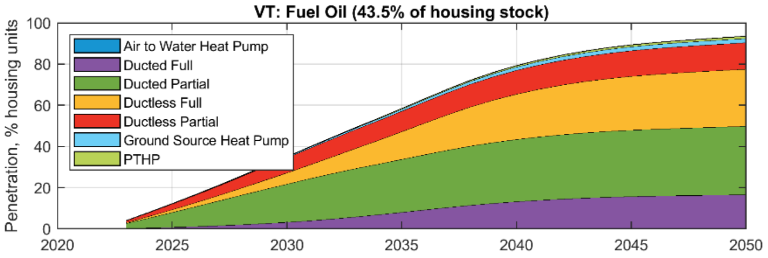



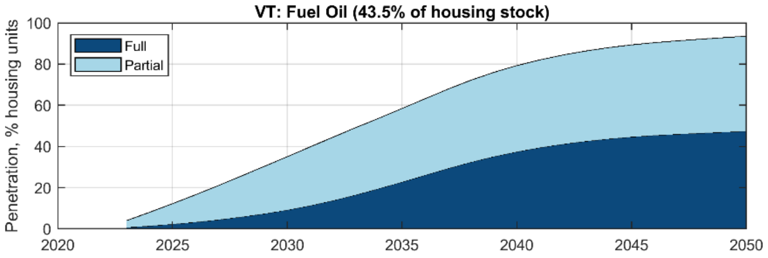



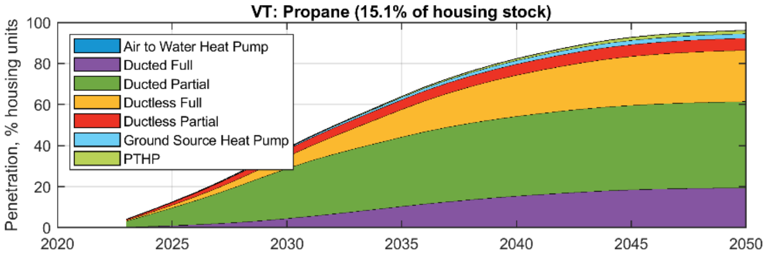



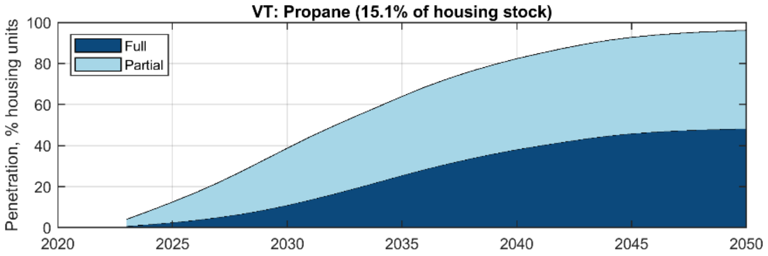
# Adoption By Legacy Residential Space Heating Fuel

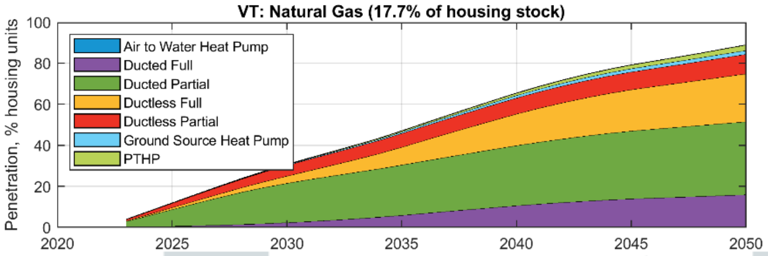
*Vermont*

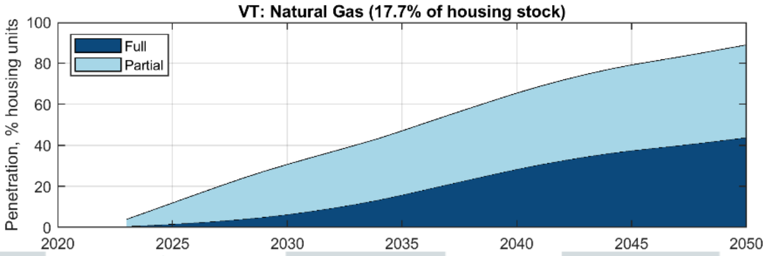


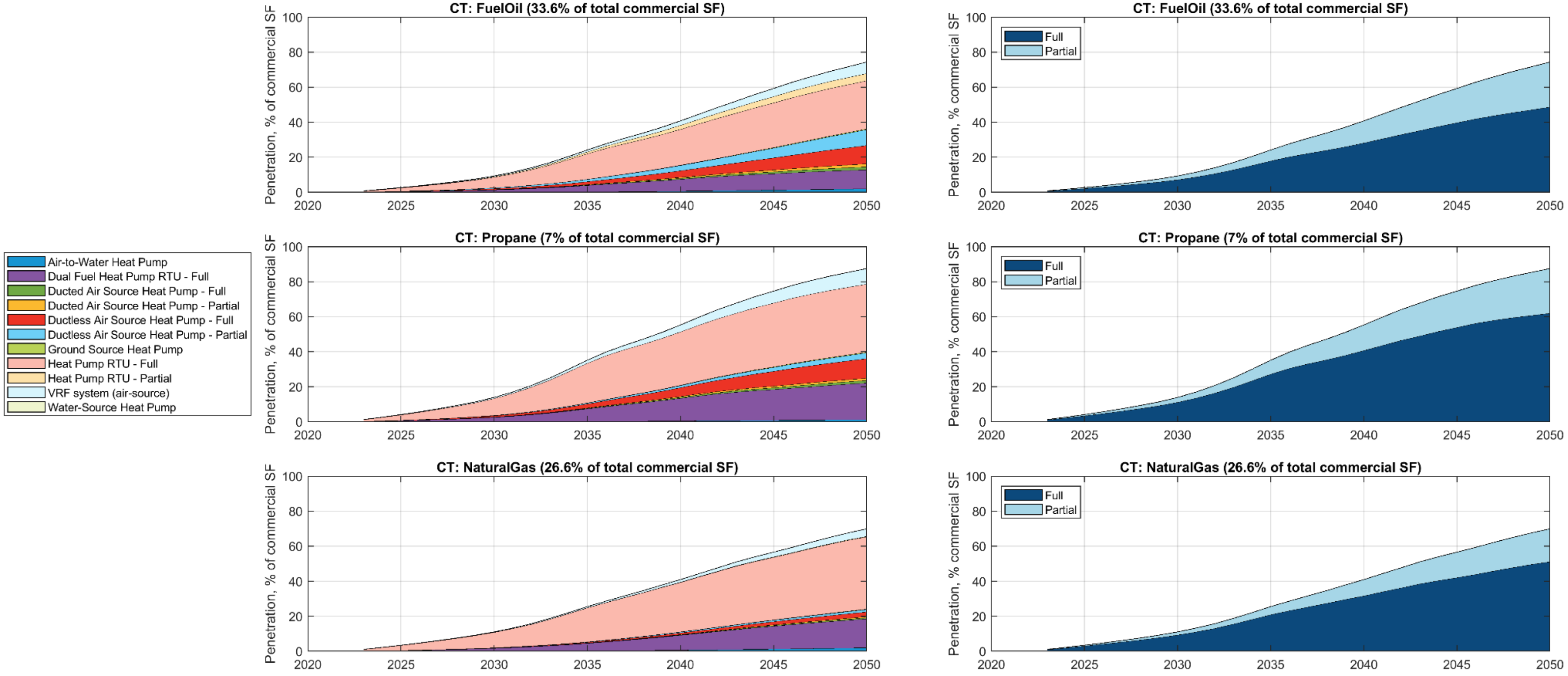



# APPENDIX II

*State Adoption Plots – Commercial Space Heating*

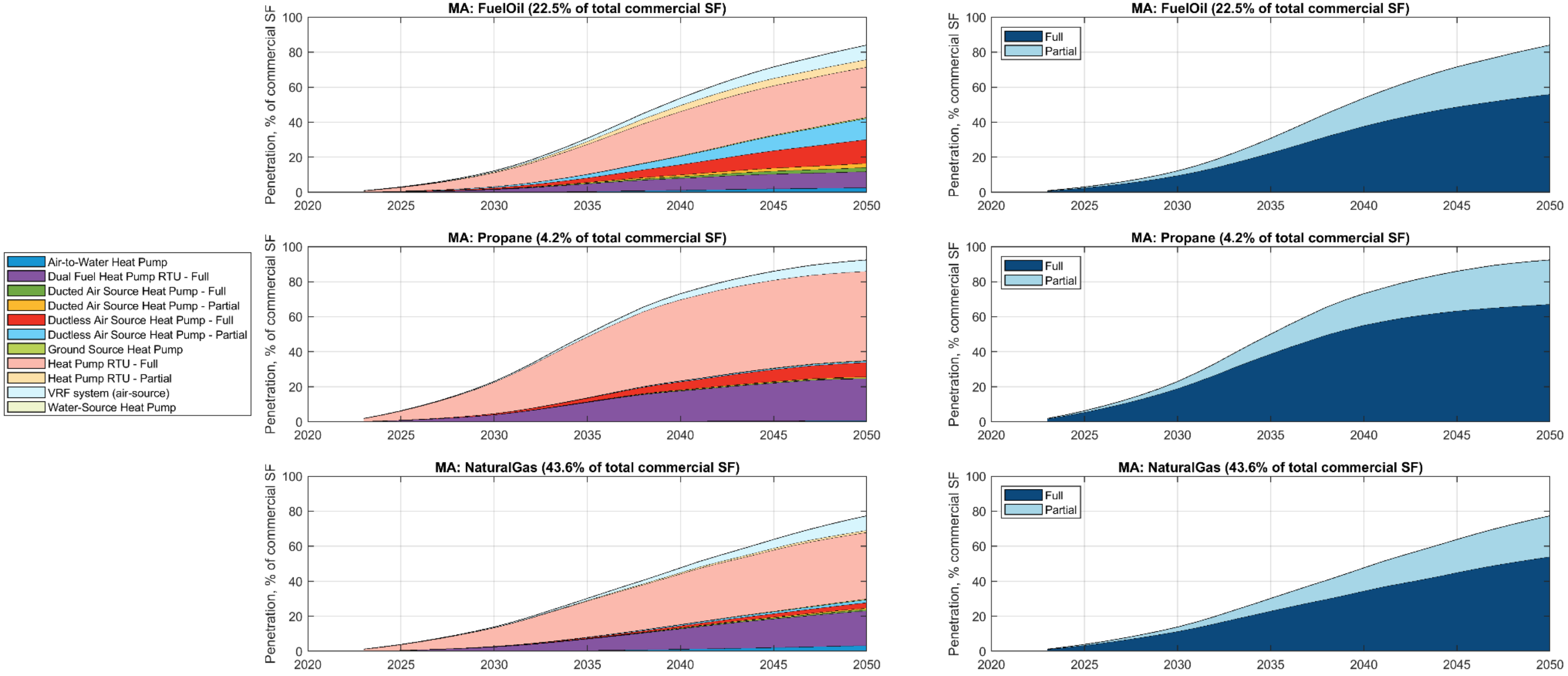
# Adoption By Legacy Commercial Space Heating Fuel

*Connecticut*



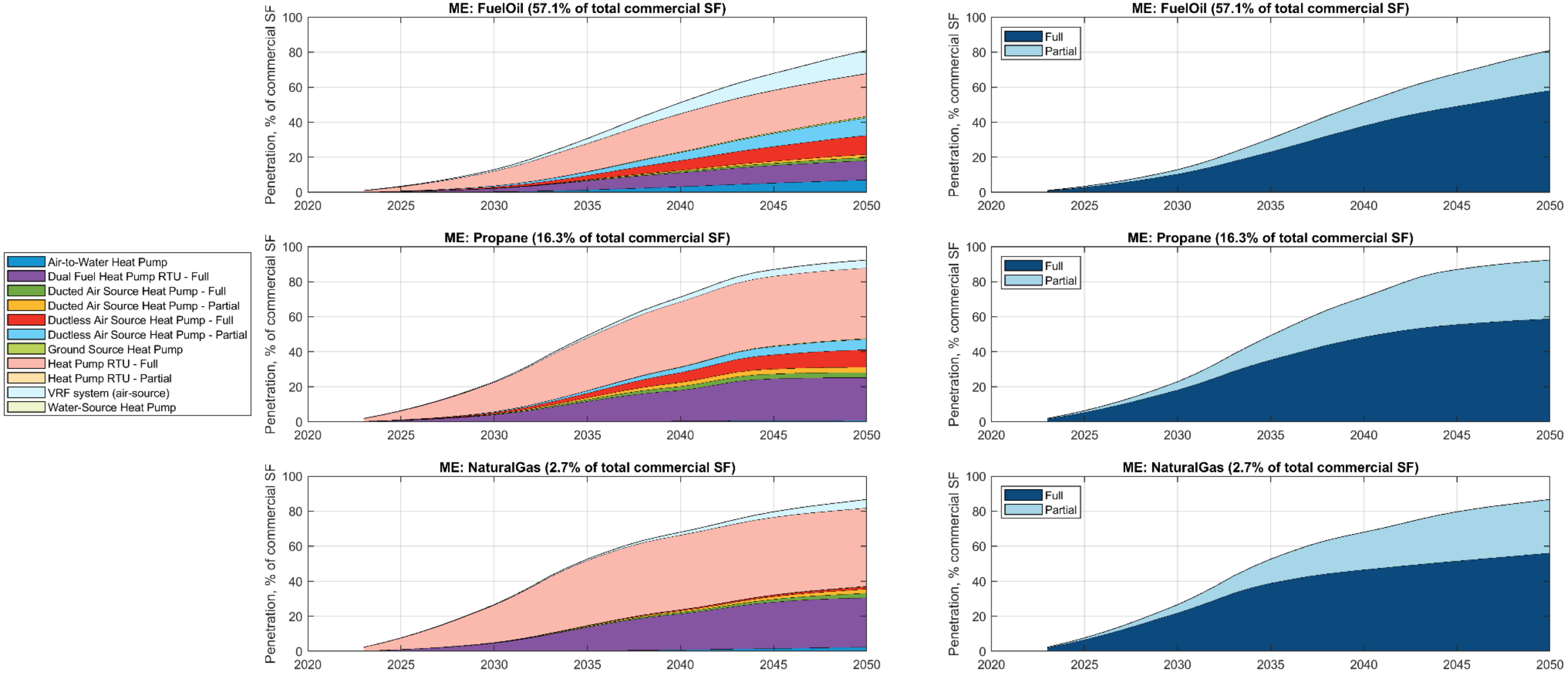
# Adoption By Legacy Commercial Space Heating Fuel

*Massachusetts*



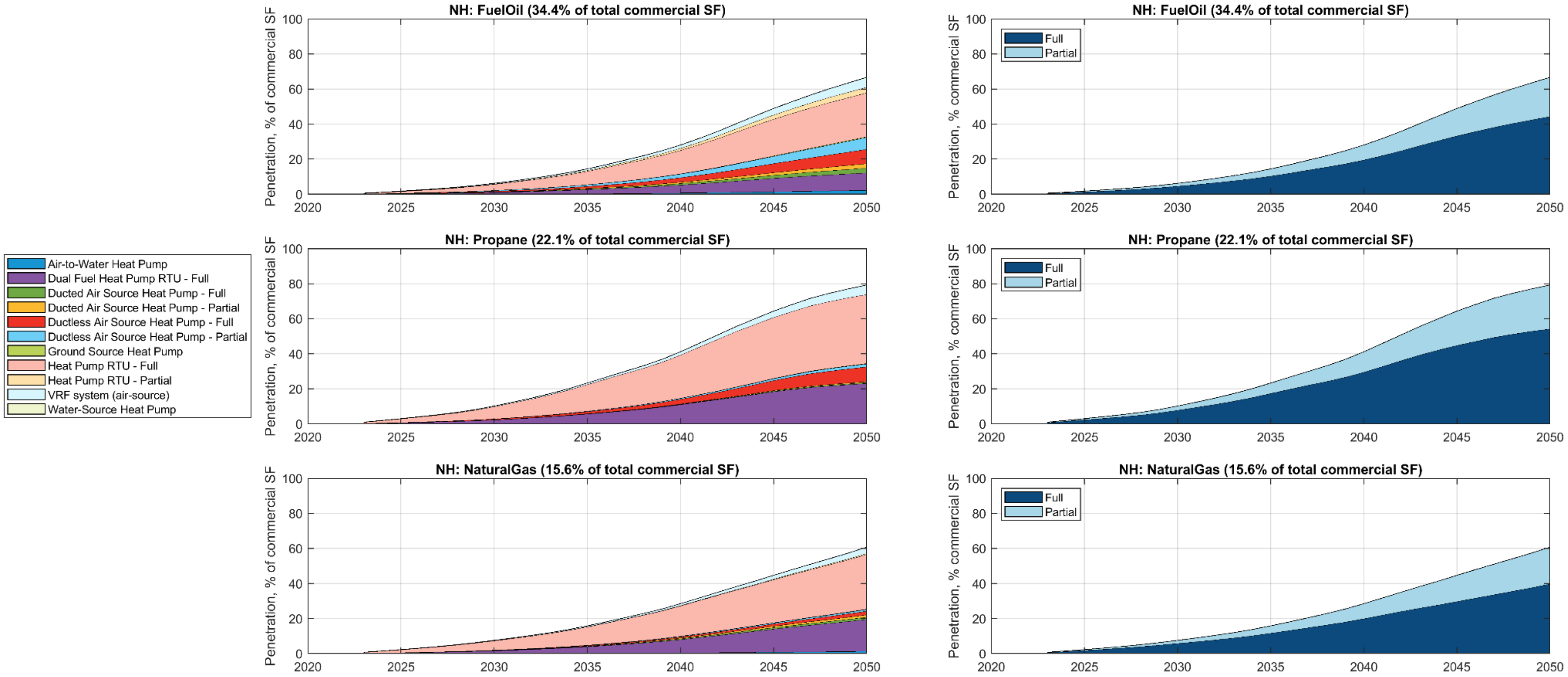
# Adoption By Legacy Commercial Space Heating Fuel

*Maine*



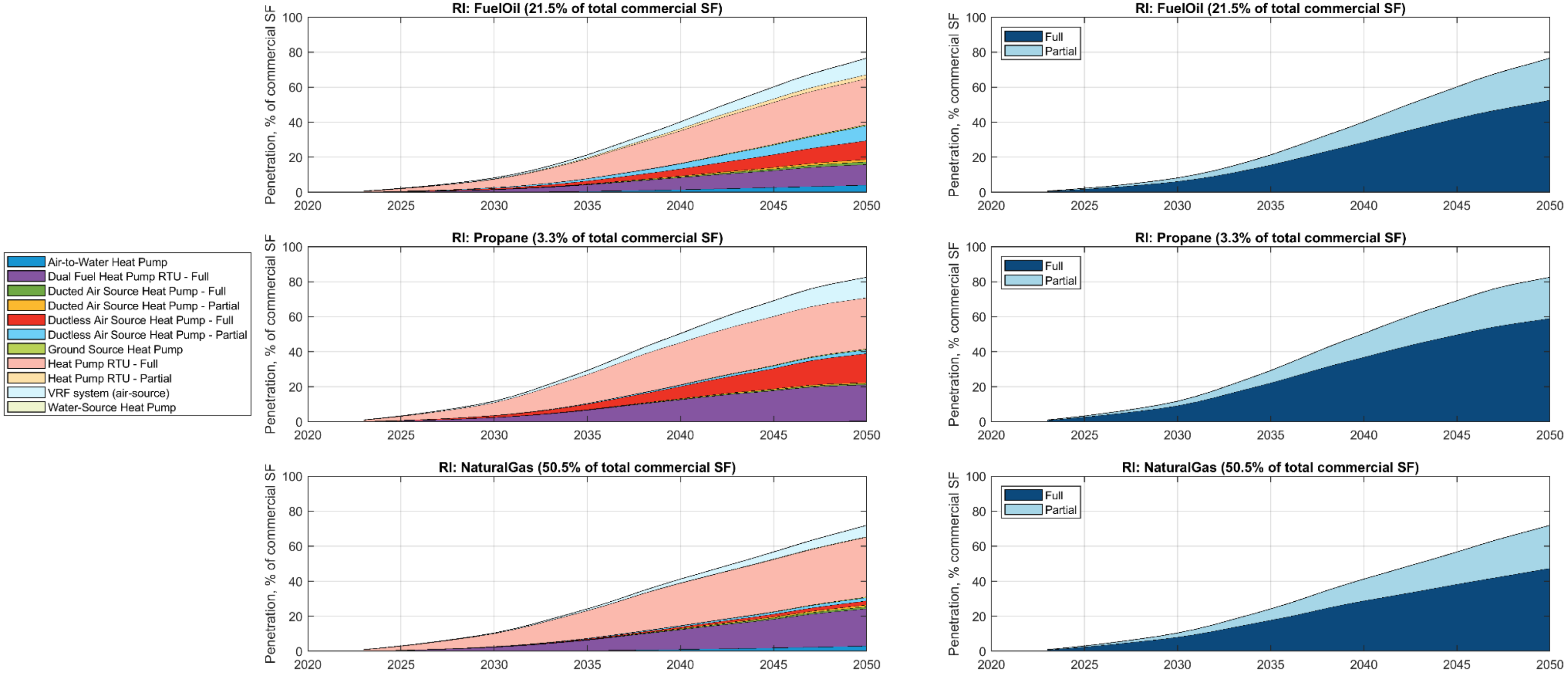
# Adoption By Legacy Commercial Space Heating Fuel

*New Hampshire*



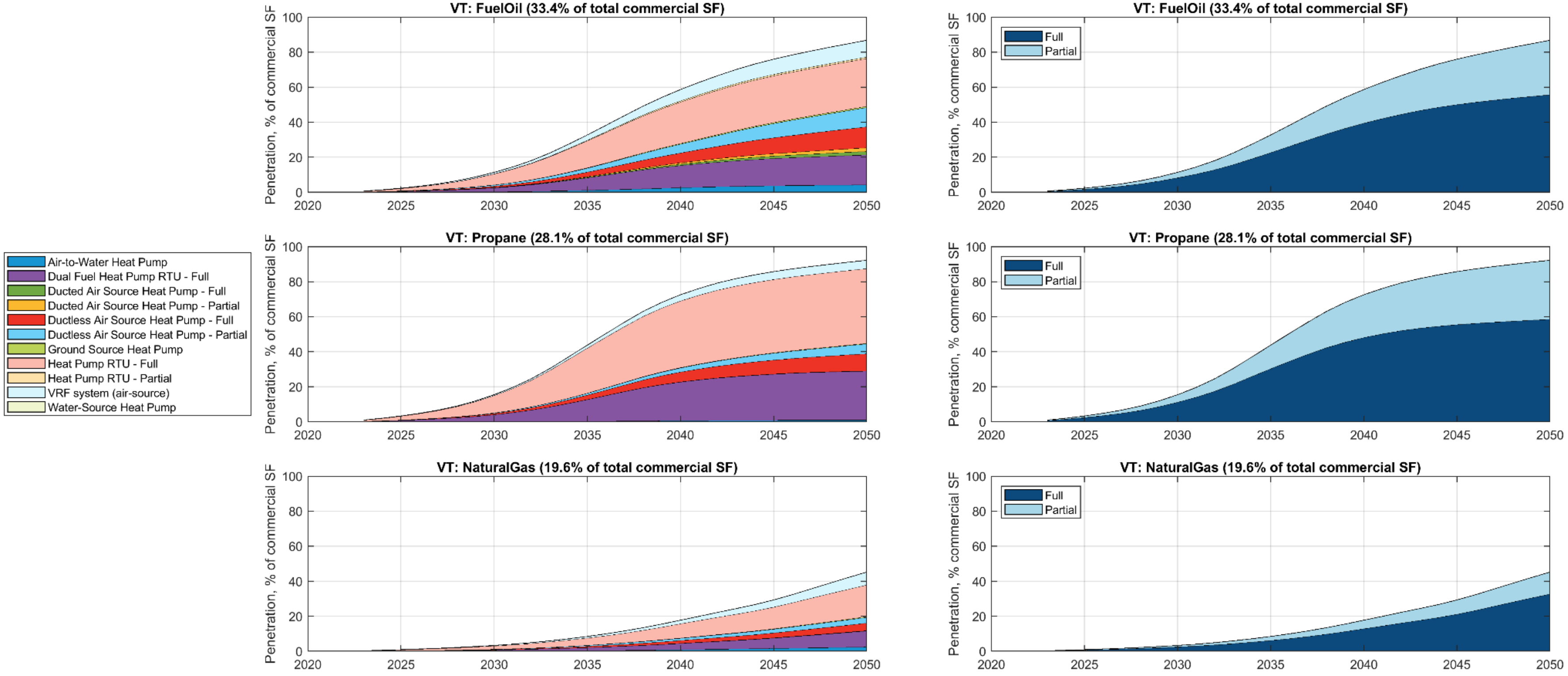
# Adoption By Legacy Commercial Space Heating Fuel

*Rhode Island*



# Adoption By Legacy Commercial Space Heating Fuel

*Vermont*

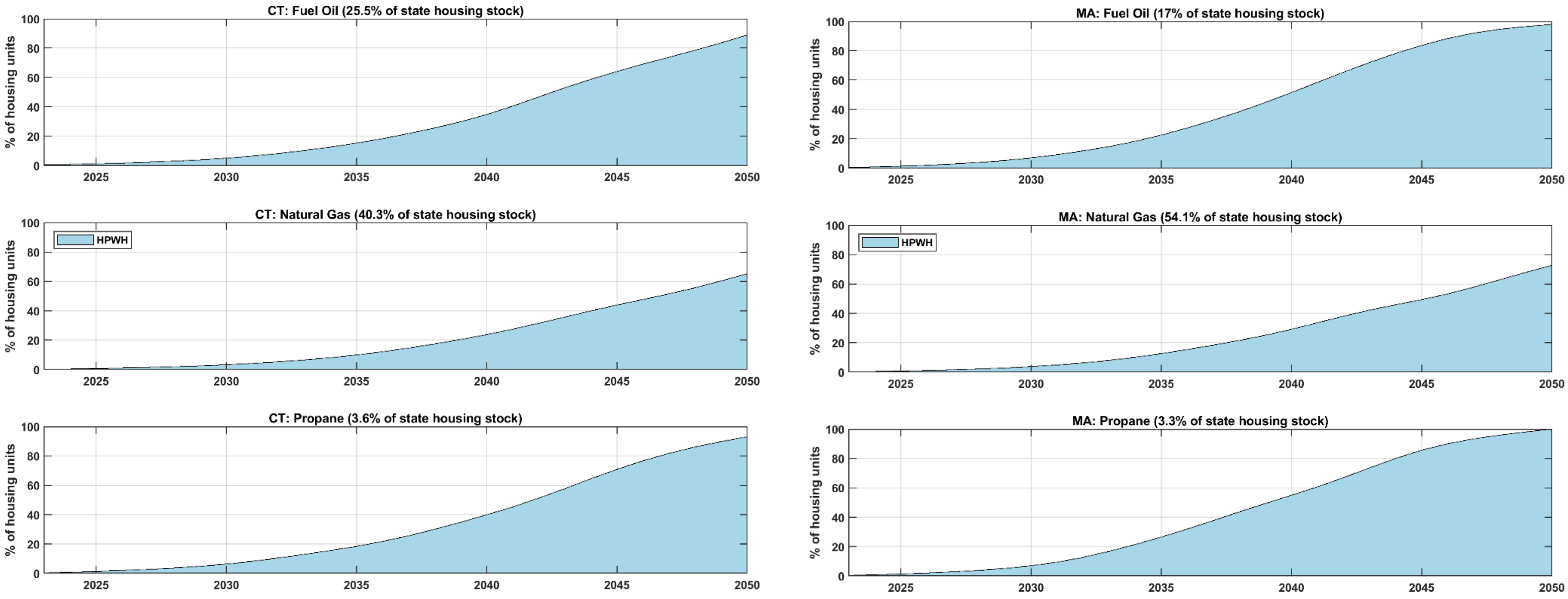


# APPENDIX III

*State Adoption Plots – Residential Water Heating*

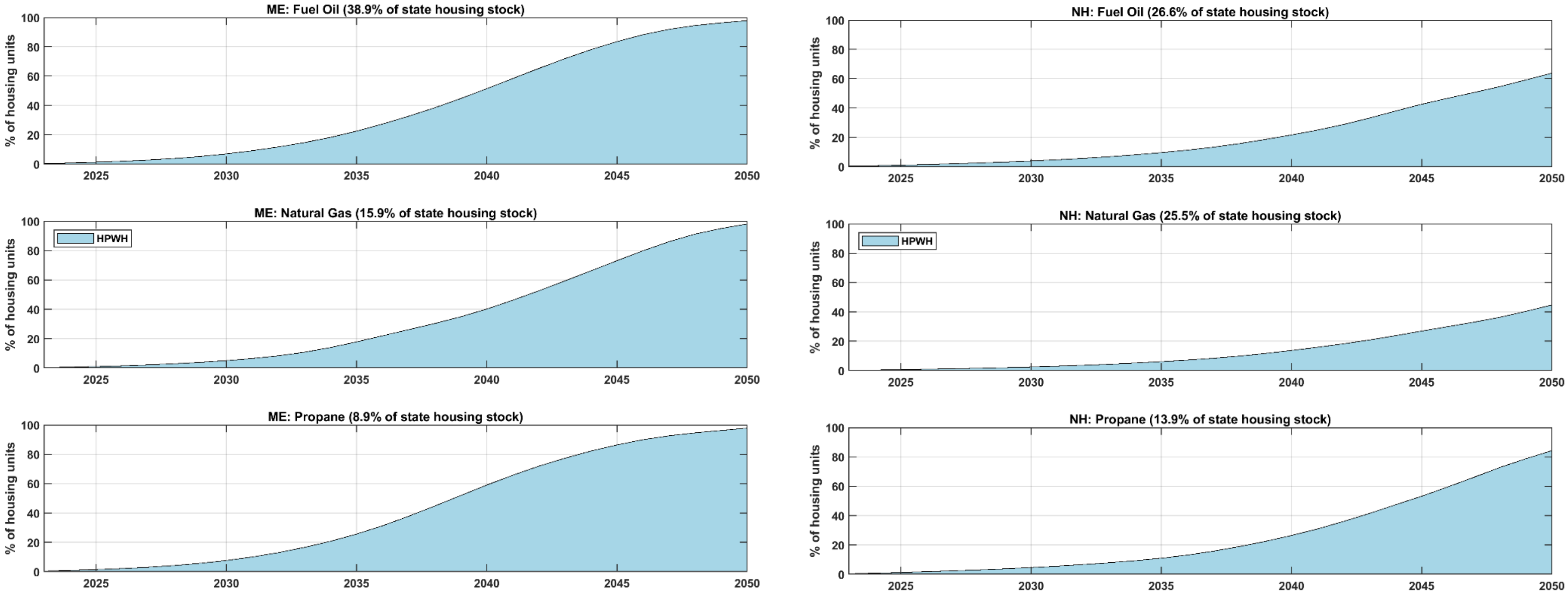
# Adoption By Legacy Residential Water Heating Fuel

*Connecticut (left) and Massachusetts (right)*



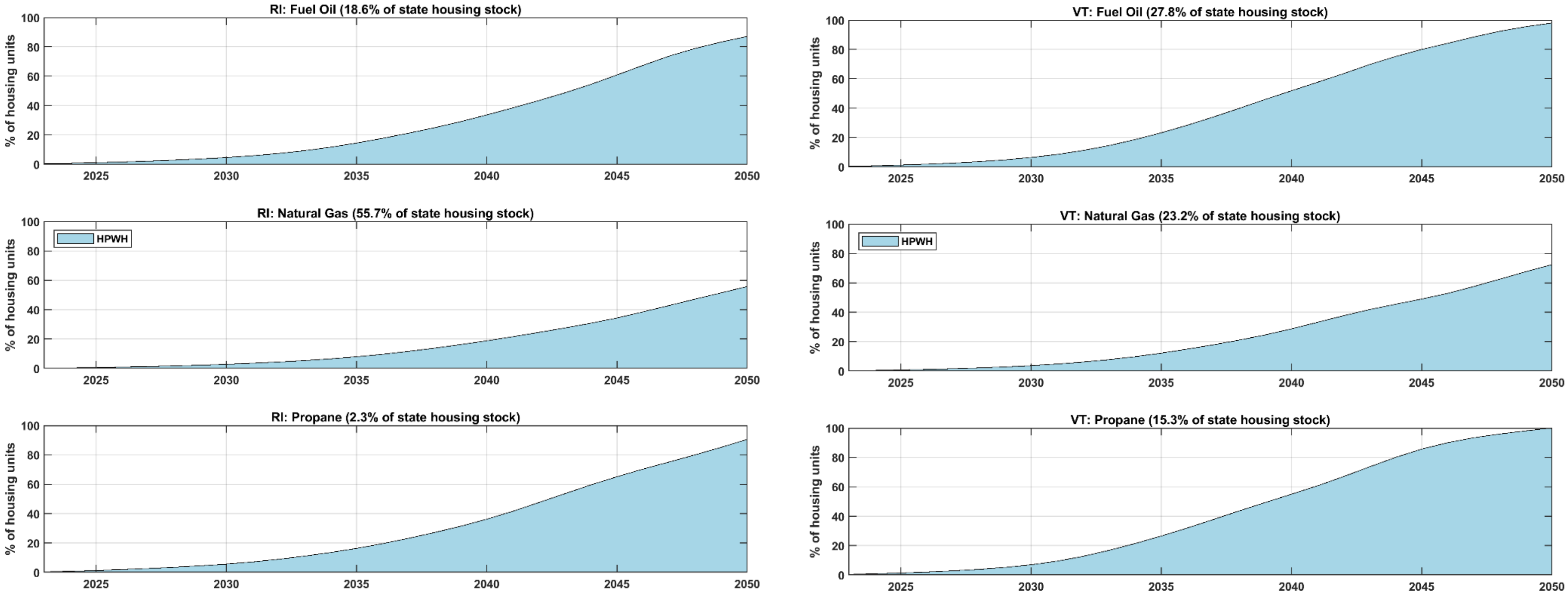
# Adoption By Legacy Residential Water Heating Fuel

*Maine (left) and New Hampshire (right)*



# Adoption By Legacy Residential Water Heating Fuel

*Rhode Island (left) and Vermont (right)*

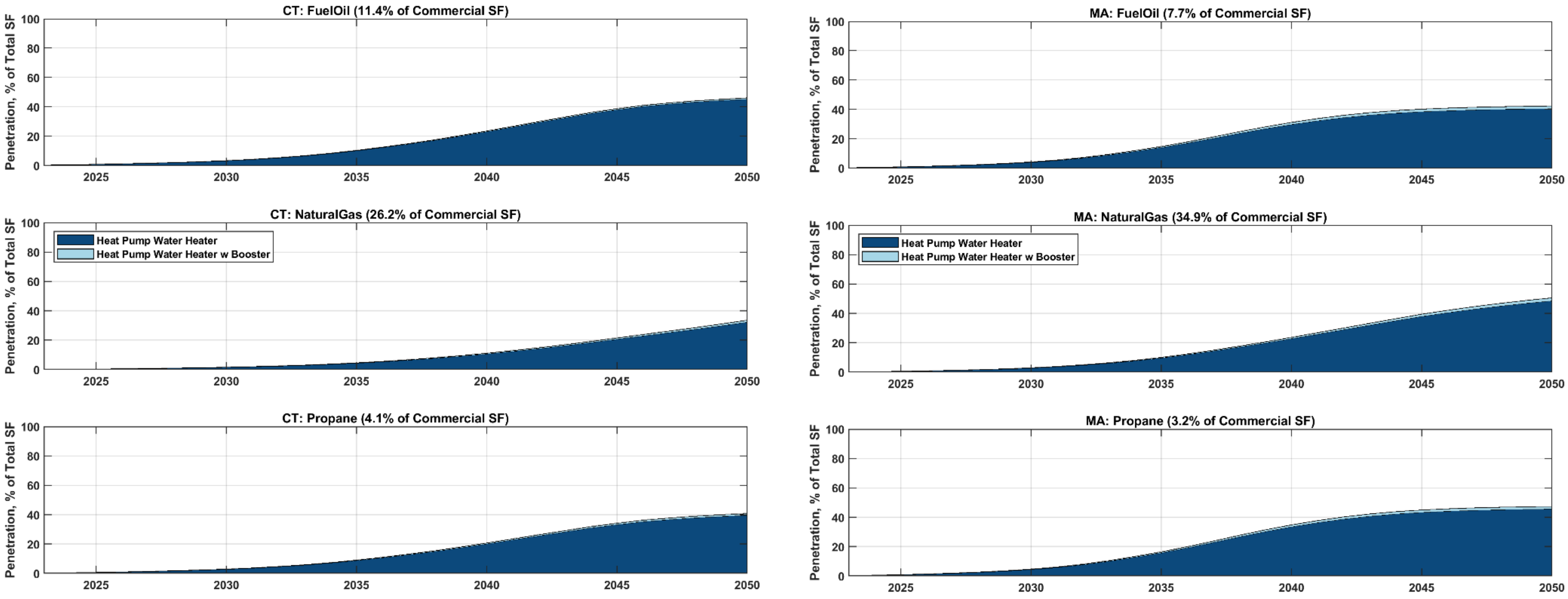


# APPENDIX IV

*State Adoption Plots – Commerical Water Heating*

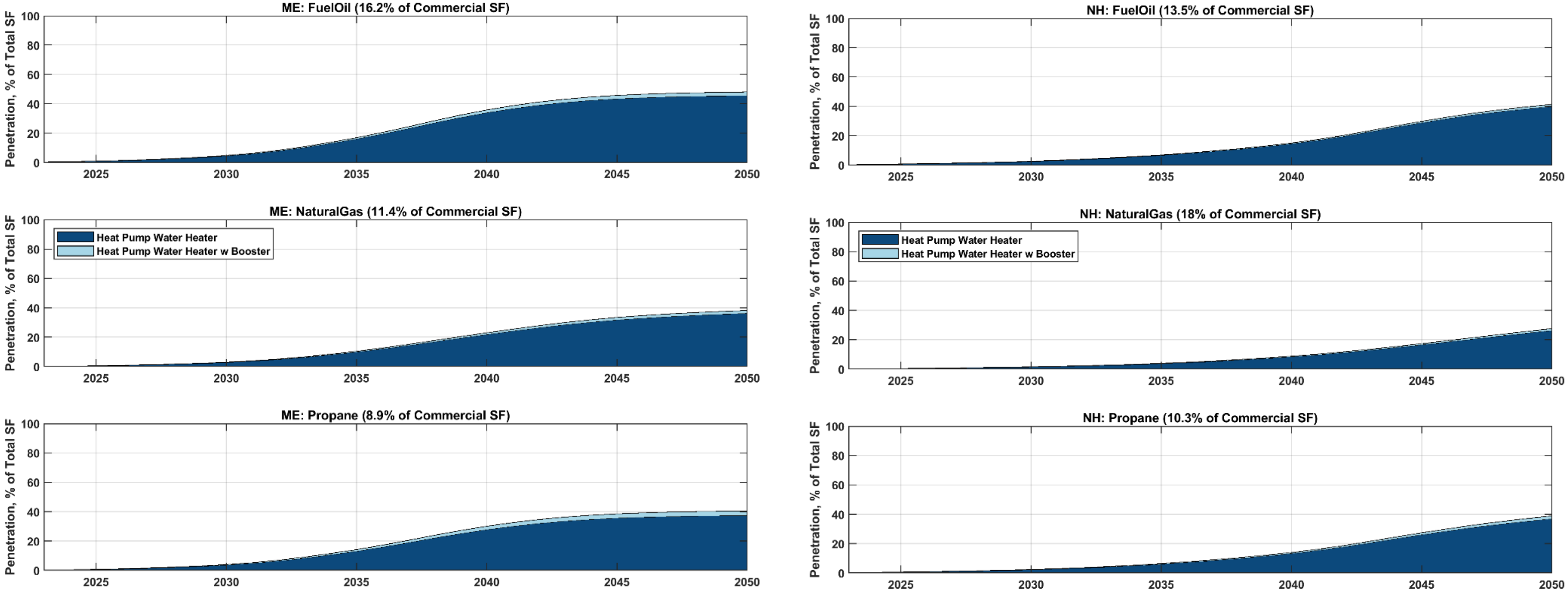
# Adoption By Legacy Commercial Water Heating Fuel

*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)*