End-Use Load Profiles for the U.S. Building Stock: Data Access and Use Cases

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December 14, 2022
Logistics

- We are recording the webinar.

- Because of the large number of participants, everyone is muted.

- Please use the Q&A box to send us questions at any time during the presentation.

- We will put the link to the slides in the Q&A box. We will send links to the recording and slides to everyone registered for the meeting a few days after the webinar.
Agenda and Speakers

- Opening remarks
- Project overview
- Options to access the End-Use Load Profile dataset
- Example #1: Scenarios to achieve state greenhouse gas reduction goals
- Example #2: Improving long-term load forecasting
- Q&A
Simulated Stock-Level End-Use Load Profiles: You’re Welcome!

Amir Roth, Ph.D.
US Department of Energy, Building Technologies Office
Decarbonizing the (Existing) Building Stock

“Natural” construction/replacement timelines are too slow
• Concerted effort on existing building stock

Interaction with grid and other demand sectors
• Intentional, planned, coordinated activity

How can states, cities, and utilities forecast and plan?
Whole-Building Physics-Based (Stock) Energy Modeling

Important tool for this type of analysis
• Can evaluate arbitrary technology upgrades in arbitrary combinations
• Under different assumptions (e.g., future weather)
• Can produce 8760 (or 36,440) “load shapes” \( \rightleftarrows \) for grid planning

Model every individual building? Possible, but ...
• Requires a significant amount of data to create models ...
• And computation to evaluate scenarios
• Useful for implementing programs (customer acquisition)

Alternative: prototypes and weighting/sampling
• Requires less data (still a lot though), e.g., RECS/CBECS
• More computationally efficient
• Good if you need a high-level plan

Credit: ORNL
Hand-Crafted Prototypes

Represent most common configurations of commercial and residential buildings

- 16 Commercial “Prototype” models – one set for each ASHRAE 90.1 and IECC code version
- 2 Residential “Prototype” models – one set for each IECC code version
- Each set contains one model for each building type in each ASHRAE climate zone

Leave much to be desired for building stock analysis ... especially for grid planning use

- Limited envelope and system types, only one envelope/system combo per building type/CZ
- No “mixed-vintage” buildings, e.g., old envelopes and newer HVAC/lighting systems
- Too little asset and operational diversity in general
- Makes it difficult to generate realistic aggregate load shapes and calibrate
ResStock and ComStock

Prototypes, but ...

• Not 16 commercial and 2 residential → 350k and 550k
• Not hand-made → sampled from RECS/CBECS+ACS+COSTAR ...
• Calibrated to utility load shapes
• All the stock diversity you want, and more

Most intensive, ambitious data collection, modeling, and calibration effort undertaken by BTO

• Underlying characteristic distributions and models
• End-use load shapes ... and (soon) “measure saving shapes”!
• Continually improved and updated, but already quite useful
  • DECARB pathways, BPS, envelope/HVAC typologies
  • Filter/mash data for your own analysis (energy, CO2)

Credit: NREL
End-Use Load Profiles for the U.S. Building Stock: Data Access and Use Cases

Natalie Mims Frick and Margaret Pigman, Berkeley Lab

December 14, 2022
End-Use Load Profiles for the U.S. Building Stock

- 900,000 building energy models statistically representing the U.S. building stock as it was in 2018, as nearly as possible
- Simulation results, building characteristics, energy models are available
End-Use Load Profile and Savings Shape Reports

Market Needs, Use Cases and Data Gaps

Methodology and Results of Model Calibration, Validation and Uncertainty Quantification

Practical Guidance on Accessing and Using the Data

End-Use Savings Shapes: Residential Round 1

Access all datasets on the project website https://www.nrel.gov/buildings/end-use-load-profiles.html
## Practical Guidance on Accessing and Using End-Use Load Profiles

### Use Case

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Application of End-Use Load Profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated resource planning</td>
<td>Develop load forecast or energy efficiency supply curves</td>
</tr>
<tr>
<td>Long-term load forecasting</td>
<td>Analyze the impact of particular equipment adoption scenarios statewide, across a utility area, or a smaller geographic area; improve baseline building energy consumption assumptions</td>
</tr>
<tr>
<td>Transmission planning</td>
<td>Disaggregate the load into components that behave differently during and after a fault</td>
</tr>
<tr>
<td>Distribution system planning</td>
<td>Analyze the value of solar and wind as well as different types of energy efficiency based on the location and timing of the generation or savings</td>
</tr>
<tr>
<td>Electrification planning</td>
<td>Understand how electrification could affect annual electricity consumption and how the increase in consumption could be spread across hours of the year</td>
</tr>
<tr>
<td>Demand-side management</td>
<td>Use as an input to cost-benefit analysis to understand the time-value of energy efficiency; in potential assessments to understand the available amount and timing of energy efficiency (e.g., improving baseline building energy consumption assumptions); and in program design</td>
</tr>
<tr>
<td>Bill impacts and rate design</td>
<td>Estimate how electricity bills may increase or decrease with adoption of DERs or switching to a new time-based electricity rate for individual buildings with realistic load profiles, and aggregations of buildings</td>
</tr>
</tbody>
</table>

### Accessing the End-Use Load Profiles and Savings Shapes

### Considerations and Limitations

### Use Cases
Options to Access the End-Use Load Profiles
# Contents of the Dataset

<table>
<thead>
<tr>
<th></th>
<th>Commercial</th>
<th>Residential</th>
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<tr>
<td>Models Run</td>
<td>350,000 buildings</td>
<td>550,000 dwelling units</td>
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<tr>
<td>(per weather year and upgrade)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Representing</td>
<td>64% of U.S. commercial floor area per CBECs</td>
<td>137 million U.S. homes</td>
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<tr>
<td></td>
<td></td>
<td>Excludes AK, HI, territories</td>
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<td>5</td>
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<tr>
<td>End Uses</td>
<td>19</td>
<td>49</td>
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<tr>
<td>Upgrades</td>
<td>Coming soon</td>
<td>10 packages</td>
</tr>
<tr>
<td>Weather years</td>
<td>TMY (typical meteorological year), AMY 2018 (actual meteorological year)</td>
<td>TMY, AMY 2012, AMY 2018</td>
</tr>
</tbody>
</table>
Three Strengths of ResStock and ComStock End-use Load Profiles

**Building stock**

Residential heating systems in Virginia

- Shared Heating
- Other
- None
- Gas/Floor Furnace, 68% AFUE
- Gas/Floor Furnace, 80% AFUE
- Fuel Furnace, 92.5% AFUE
- Fuel Furnace, 80% AFUE
- Fuel Furnace, 76% AFUE
- Fuel Boiler, 90% AFUE
- Fuel Boiler, 80% AFUE
- Fuel Boiler, 76% AFUE
- Hydronic Well Furnace, 100% AFUE
- Electric Furnace, 100% AFUE
- Electric Boiler, 100% AFUE
- Baseboard, 100% Efficiency
- ASHP, SEER 15, 8.5 HSPF
- ASHP, SEER 13, 7.7 HSPF
- ASHP, SEER 10, 6.2 HSPF

**Geographic granularity**

Example of Public Use Microdata Area* (PUMA) resolution:
~200k people; ~2,400 in U.S.

* [https://www.census.gov/programs-surveys/geography/guidance/geo-areas/pumas.html](https://www.census.gov/programs-surveys/geography/guidance/geo-areas/pumas.html)

**Behavioral diversity**

Wilson et al. 2022 Figure 368 (subset)
Overview of the Access Options

**ResStock** and **ComStock**
- Web viewer
  - Annual and timeseries graphs
  - 15-minute end-use consumption for a custom set of buildings
  - Compare baseline and efficiency upgrades (ResStock only for now)

**OpenEI Data Lake**
- Aggregate files
  - 15-minute end-use consumption by building type and geography (e.g. state, county)

- Individual buildings
  - 15-minute end-use consumption for individual buildings and dwelling units
  - Building energy model files
**Flat Electricity Rate**

- Custom aggregation in the ResStock web viewer
- Annual bar charts

- **Illinois**
  - Natural gas heating in the baseline

- **Export data as csv**

- **High efficiency heat pump upgrade package**
Flat Electricity Rate

- Custom aggregation in the ResStock web viewer
- Annual bar charts

Illinois

High efficiency heat pump upgrade package

Export data as csv

Flat Electricity Rate

- Custom aggregation in the ResStock web viewer
- Annual bar charts

Illinois

High efficiency heat pump upgrade package

Export data as csv

Natural gas heating in the baseline
Time-of-Use Electricity Rate

- Custom aggregation in the ResStock web viewer
- Timeseries view

Natural gas heating in the baseline

Illinois

High efficiency heat pump upgrade package

Export data as csv

- Custom aggregation in the ResStock web viewer
- Timeseries view

Natural gas heating in the baseline

Export data as csv
### Time-of-Use Electricity Rate

- **Downloaded 15-min interval data**

<table>
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<tr>
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<th>CL</th>
<th>CP</th>
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</table>

- **Transition from peak to super peak price**

- **Convert to local time**

- **Fill in hourly rate**

- **Volumetric cost**
## Average Annual Savings

<table>
<thead>
<tr>
<th></th>
<th>Electricity - flat rate</th>
<th>Electricity - TOU rate</th>
<th>Gas</th>
<th>Total - flat rate</th>
<th>Total - TOU rate</th>
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</thead>
<tbody>
<tr>
<td><strong>Baseline - gas heating</strong></td>
<td>$485</td>
<td>$498</td>
<td>$775</td>
<td>$1,261</td>
<td>$1,274</td>
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<tr>
<td><strong>Upgrade - high efficiency heat pump</strong></td>
<td>$871</td>
<td>$862</td>
<td>$123</td>
<td>$995</td>
<td>$985</td>
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<tr>
<td><strong>Savings</strong></td>
<td>$(386)</td>
<td>$(363)</td>
<td>$652</td>
<td>$266</td>
<td>$289</td>
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</table>
## Distribution of Savings

- Building characteristics and annual end-use consumption (csv and parquet format)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
<th>P</th>
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<tbody>
<tr>
<td>bldg_id</td>
<td>in.county</td>
<td>in.sqft</td>
<td>in.bedrooms</td>
<td>in.geometry_building_type_acs</td>
<td>in.heating_fuel</td>
<td>in.heating_setpoint</td>
<td>in.heating_setpoint_has_offset</td>
<td>in.hot_water_fixtures</td>
<td>out.electricity</td>
<td>out.heating</td>
<td>out.electricity_heating_energy_consumption</td>
<td>out.electricity_heating_energy_consumption_intensity</td>
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<td>2</td>
<td>1 G5100230</td>
<td>1623</td>
<td>3</td>
<td>50 or more</td>
<td>L Natural Gas</td>
<td>68F</td>
<td>No</td>
<td>50% Usage</td>
<td>118.947854</td>
<td>0.07328888</td>
<td>32025.0873</td>
<td>19.7320316</td>
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<td>3</td>
<td>2 G5600250</td>
<td>617</td>
<td>1</td>
<td>3 or 4 Unit</td>
<td>Natural Gas</td>
<td>65F</td>
<td>No</td>
<td>100% Usage</td>
<td>104.603659</td>
<td>0.1695389</td>
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<td>4</td>
<td>3 G4801130</td>
<td>333</td>
<td>1</td>
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<td>L Natural Gas</td>
<td>65F</td>
<td>Yes</td>
<td>100% Usage</td>
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<td>0.00627557</td>
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<td>2 Unit</td>
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<td>6.41789098</td>
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<td>100% Usage</td>
<td>3863.58688</td>
<td>1.19209715</td>
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<td>50% Usage</td>
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<td>4.87990218</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Individual Buildings

Distribution of Savings

- Flat electricity rate; could do the same with TOU rate
- What are the characteristics of dwelling units with higher or lower savings?

![Annual Savings Graph](image-url)
What's Next?

- Additional End-Use Savings Shapes
  - The first release of commercial results are expected in March 2023
  - Gathering stakeholder requests for measures for future rounds
    https://forms.office.com/g/wrGeAEwZh7

- Step-by-step examples of accessing the data
  - Detailed walkthroughs of using the data, including code snippets

  - Gathering stakeholder feedback on the current version in preparation for updating it

Keep up-to-date on the project website, sign up for mailing list

Contacts

Margaret Pigman: mpigman@lbl.gov
Natalie Mims Frick: nfrick@lbl.gov

For more information

Download publications from the Electricity Markets & Policy: https://emp.lbl.gov/publications
Sign up for our email list: https://emp.lbl.gov/mailing-list
Follow the Electricity Markets & Policy on Twitter: @BerkeleyLabEMP

Acknowledgements

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Lawrence Berkeley National Laboratory Webinar: End-Use Load Profiles for the U.S. Building Stock: Data Access and Use Cases

December 14, 2022

Kenji Takahashi
Synapse Energy Economics

• Founded in 1996 by CEO Bruce Biewald

• Leader for public interest and government clients in providing rigorous analysis of the electric power, natural gas, and transportation sectors

• Staff of 40+ includes experts in energy, economic, and environmental topics
Scope of the study

• **Background:** Oregon Governor’s Executive Order No. 20-04 (EO 20-40) on GHG emissions reduction mandates:
  • At least 45 percent below 1990 emissions levels by 2035
  • At least 80 percent below 1990 emissions levels by 2050

• **Overview:** On behalf of Sierra Club, Synapse assessed the potential impact of two future scenarios in which Oregon meets its 2035 and 2050 goals by incorporating aggressive efficient building electrification initiatives

Scope of the study (continued)

• Scenarios:
  • Scenario 1: No fossil fuel equipment sales post 2030: accelerates adoption of electrification measures towards 100-percent market share by 2030
  • Scenario 2: No fossil fuel equipment sales post 2025: accelerates adoption of electrification measures towards 100-percent market share by 2025

• End-uses:
  • Space heating, water heating, cooking, and clothes drying
Scope of the study (continued)

• Analysis:
  • Incorporated technology switching from inefficient electric resistance space and water heating systems to efficient electric heat pumps to reduce winter electric peak demand
  • Projected energy and emissions impacts of electrification measure adoption using Synapse’ Building Decarbonization Calculator (BDC)
  • Estimated electric peak load impacts using NREL’s EULP data and the associated economic impacts on electric and gas system operations and investments
  • Estimated bill impacts and customer payback of residential electrification in two cities in Oregon
Statewide electricity consumption by end-use and scenario

Scenario 1: No fossil fuel equipment sales post 2030

Scenario 2: No fossil fuel equipment sales post 2025

Source: Takahashi et al. 2022. Figure 16.
# High level summary of two building electrification scenarios

<table>
<thead>
<tr>
<th></th>
<th>2030 Sales Target Scenario</th>
<th>2025 Sales Target Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Executive Order 20-40</strong></td>
<td>2035: 45 percent</td>
<td>2035: 45 percent</td>
</tr>
<tr>
<td></td>
<td>2050: 80 percent</td>
<td>2050: 80 percent</td>
</tr>
<tr>
<td><strong>CO₂e emissions reductions relative to 1990</strong></td>
<td>2035: 3.3 million metric tons (47%)</td>
<td>2035: 3.9 million metric tons (56%)</td>
</tr>
<tr>
<td></td>
<td>2050: 6.8 million metric tons (97%)</td>
<td>2050: 6.9 million metric tons (98%)</td>
</tr>
<tr>
<td><strong>2050 energy consumption reductions relative to 2019</strong></td>
<td>57.8. Tbtu (61%)</td>
<td>58.5 Tbtu (61%)</td>
</tr>
<tr>
<td><strong>Electricity consumption increase relative to 2019</strong></td>
<td>2030: 1,340 GWh (10%)</td>
<td>2030: 1,580 GWh (12%)</td>
</tr>
<tr>
<td></td>
<td>2050: 1,720 GWh (13%)</td>
<td>2050: 1,700 GWh (13%)</td>
</tr>
</tbody>
</table>

*Source: Takahashi et al. 2022. Table ES-1.*
Projections of winter peak loads by end-use category

Scenario 1: No fossil fuel equipment sales post 2030

Scenario 2: No fossil fuel equipment sales post 2025

Note: COM stands for commercial, and RES stands for residential.

Source: Takahashi et al. 2022. Figure 29.
Projected changes in hourly loads by end use – Scenario 1

Source: Takahashi et al. 2022. Figure 30.
Projections of electricity and gas system cost impacts

Source: Takahashi et al. 2022. Table 9.

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>Total (net present value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>-8</td>
<td>-145</td>
<td>-282</td>
<td>-1,088</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>-55</td>
<td>-177</td>
<td>-290</td>
<td>-1,661</td>
</tr>
</tbody>
</table>

Source: Takahashi et al. 2022. Figure 33.
Summary

1. Under Scenarios 1 and 2, Oregon’s building sector can reduce significant GHG emissions by 47-56% by 2035 and 97-98% by 2050—well beyond the state’s GHG reduction targets for 2050.

2. Building electrification will increase electric loads, but the expected growth rate is similar to the historical levels (0.5-0.6% per year).
   • Switching from electric resistance heating to heat pumps can play a critical role in keeping load growths down and reducing electrical system investments in Oregon.

3. The building electrification scenarios can save $1 to $1.6 billion of energy system investments in Oregon by avoiding a substantial amount of gas system operating costs and fuel costs.

4. NREL’s end-use load profile (EULP) database was critical for estimating peak load impacts from building electrification in our study.
Contact info

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ktakahashi@synapse-energy.com
Applications of End-Use Load Profiles to Long-Term Forecasting

Arthur Maniaci
Principal Forecaster

Lawrence Berkely National Laboratory Webinar: End-Use Load Profiles for the U.S. Building Stock: Data Access and Use Cases

December 14, 2022
Roles of the NYISO

- Reliable operation of the bulk electricity grid
  - Managing the flow of power on 11,000 circuit-miles of transmission lines from hundreds of generating units

- Administration of open and competitive wholesale electricity markets
  - Bringing together buyers and sellers of energy and related products and services

- Planning for New York’s energy future
  - Assessing needs over a 10-year horizon and evaluating projects proposed to meet those needs

- Advancing the technological infrastructure of the electric system
  - Developing and deploying information technology and tools to make the grid smarter
1. **Statistically Adjusted End-Use (SAE) models**  
These produce monthly energy and peak forecasts for each utility service territory in NY. Major forecast drivers are historical load growth, population and employment trends, end-use or appliance saturations, efficiency improvement trends in appliances and building shells, and trended weather normals to account for impacts due to climate change.

2a) **Exogenous load reducing modifiers:**  
- Additional energy efficiency gains  
- BTM solar impacts  
- BTM distributed generation impacts  
- BTM storage peak reductions

2b) **Exogenous load increasing modifiers:**  
- Electric vehicle impacts  
- Heating and base load electrification  
- Energy storage net energy usage  
- Interconnecting large loads

3. **Hourly forecast models are then produced for every forecast component**  
- Standardized daily weather patterns ensure that weather sensitive loads for different end-uses and technologies for all rise and fall in unison  
- Final system hourly loads accounts for very dissimilar hourly load patterns of load modifiers  
- Reports provide both coincident system peak impact and non-coincident peak impact of each component of the forecast.  
- End-use load profiles are a key driver for producing accurate hourly load forecasts for the bulk power system.
Typical values are shown for a specific year. In practice, each of these end-use values vary over time due to changes in household trends, efficiencies and adoption rates. Hourly end-use load profiles are often grouped into heating-sensitive, cooling sensitive and non-weather-sensitive.
NREL heating & cooling load profiles were used in NYISO’s 2022 Metrix LT Long-term forecast to determine building electrification impacts.
2052 – Winter Peaking & High Impact of Electrification
Green – Before Electrification
Blue – After Electrification

Source: Itron MetrixLT Hourly Load software.
Summary

- End-use forecasting methodology is best practice for determining Long-term impacts (10 to 30 years ahead) of new technologies, energy policy, and climate trends. Econometric and time series methods may be more appropriate for shorter forecast horizons (1 to 3 years ahead).
- Forecasting system peaks using static hourly load profiles cannot properly capture impacts of emerging technologies such as heat pumps, solar PV systems and electric vehicles.
- Instead, it is more appropriate to first forecast the annual energy and hourly loads of individual technologies and then determine the resulting monthly and seasonal peaks.
- This will enable the long-term forecast to more accurately reflect changes in the hour of the peak and gradual shifts from one season to another.
- An accurate ensemble of hourly end-use load profiles such as ComStock and ResStock now makes more detailed hourly load forecasting a reality.
Our Mission & Vision

**Mission**
Ensure power system reliability and competitive markets for New York in a clean energy future

**Vision**
Working together with stakeholders to build the cleanest, most reliable electric system in the nation
Questions?
Appendix
## End-use Load Profile Use Cases Discussed in the Report

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Application of End-Use Load Profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated resource planning</td>
<td>Develop load forecast or energy efficiency supply curves</td>
</tr>
<tr>
<td>Long-term load forecasting</td>
<td>Analyze the impact of particular equipment adoption scenarios statewide, across a utility area, or a smaller geographic area; improve baseline building energy consumption assumptions</td>
</tr>
<tr>
<td>Transmission planning</td>
<td>Disaggregate the load into components that behave differently during and after a fault</td>
</tr>
<tr>
<td>Distribution system planning</td>
<td>Analyze the value of solar and wind as well as different types of energy efficiency based on the location and timing of the generation or savings</td>
</tr>
<tr>
<td>Electrification planning</td>
<td>Understand how electrification could affect annual electricity consumption and how the increase in consumption could be spread across hours of the year</td>
</tr>
<tr>
<td>Demand-side management</td>
<td>Use as an input to cost-benefit analysis to understand the time-value of energy efficiency; in potential assessments to understand the available amount and timing of energy efficiency (e.g., improving baseline building energy consumption assumptions); and in program design</td>
</tr>
<tr>
<td>Bill impacts and rate design</td>
<td>Estimate how electricity bills may increase or decrease with adoption of DERs or switching to a new time-based electricity rate for individual buildings with realistic load profiles, and aggregations of buildings</td>
</tr>
</tbody>
</table>
Residential space heating stock by region – Scenario 1

Source: Takahashi et al. 2022. Figure 19.
Statewide energy consumption by end-use and scenario

Source: Takahashi et al. 2022. Figure 17.
Space and water heating by fuel type in Oregon

- **Residential:**
  - Approximately 50% of energy usage for space and water heating is met by electricity
  - The rest is mainly met by utility gas

- **Commercial:**
  - Approximately 75% or more of usage for space and water heating is met by utility gas
  - The rest is met by electricity

Annual bill impact summary across three cases in Portland and Bend

Source: Takahashi et al. 2022. Figure 35.
Payback analysis of heat pumps and HWPH relative to the Mixed-Fuel Base Case

<table>
<thead>
<tr>
<th></th>
<th>Portland</th>
<th>Bend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat pump for space heating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual average bill savings</td>
<td>$42</td>
<td>$82</td>
</tr>
<tr>
<td>Average incremental cost</td>
<td>same or less</td>
<td>same or less</td>
</tr>
<tr>
<td>Payback (years)</td>
<td>Immediately</td>
<td>Immediately</td>
</tr>
<tr>
<td><strong>HPWH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual bill savings</td>
<td>$51</td>
<td>$70</td>
</tr>
<tr>
<td>Average incremental cost</td>
<td>$640</td>
<td>$640</td>
</tr>
<tr>
<td>Payback (years)</td>
<td>12.7</td>
<td>9.2</td>
</tr>
</tbody>
</table>

*Source: Takahashi et al. 2022. Table 19.*
## Payback analysis of heat pumps and HWPH relative to the ER Base Case

<table>
<thead>
<tr>
<th></th>
<th>Portland</th>
<th>Bend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat pump</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual bill savings</td>
<td>($1,067)</td>
<td>($1,318)</td>
</tr>
<tr>
<td>Average incremental cost</td>
<td>$2,339</td>
<td>$2,339</td>
</tr>
<tr>
<td>Payback (years)</td>
<td>2.2</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>HPWH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual bill savings</td>
<td>($218)</td>
<td>($197)</td>
</tr>
<tr>
<td>Average incremental cost</td>
<td>$640</td>
<td>$640</td>
</tr>
<tr>
<td>Payback (years)</td>
<td>2.9</td>
<td>3.2</td>
</tr>
</tbody>
</table>

*Source: Takahashi et al. 2022. Table 21.*
Distribution of Savings

- Flat electricity rate; could do the same with TOU rate
- What are the characteristics of dwelling units with higher or lower savings?
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