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

Natalie Mims Frick and Margaret Pigman, Lawrence Berkeley National Laboratory

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Elaina Present, National Renewable Energy Laboratory (NREL)

December 14, 2022

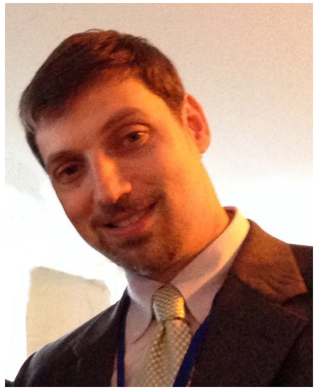
This work was funded by the Building Technologies Office of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy , under Contract No. DE-AC02-05CH11231.

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


Amir Roth, U.S. Department of Energy


Margaret Pigman, Berkeley Lab


Natalie Mims Frick, Berkeley Lab


Kenji Takahashi, Synapse


Arthur Maniaci, NYISO


Elaina Present, NREL

U.S. DEPARTMENT OF
ENERGY

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ENERGY EFFICIENCY &
RENEWABLE ENERGY

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” ← for grid planning

Model every individual building? Possible, but …

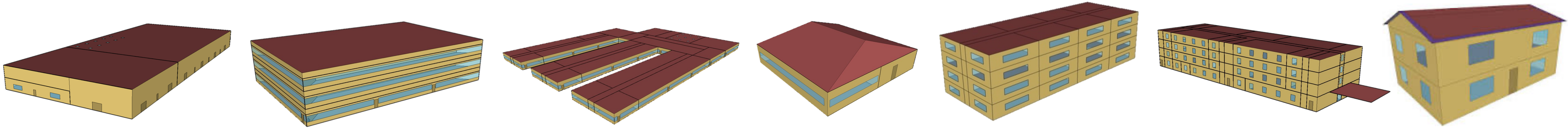
- Requires a significant amount of data to create models …
- And computation to evaluate scenarios
- Useful for implementing programs (customer acquisition)

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 "Reference" models – sets for "pre-1980", "1980-2007", "new construction"
- 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

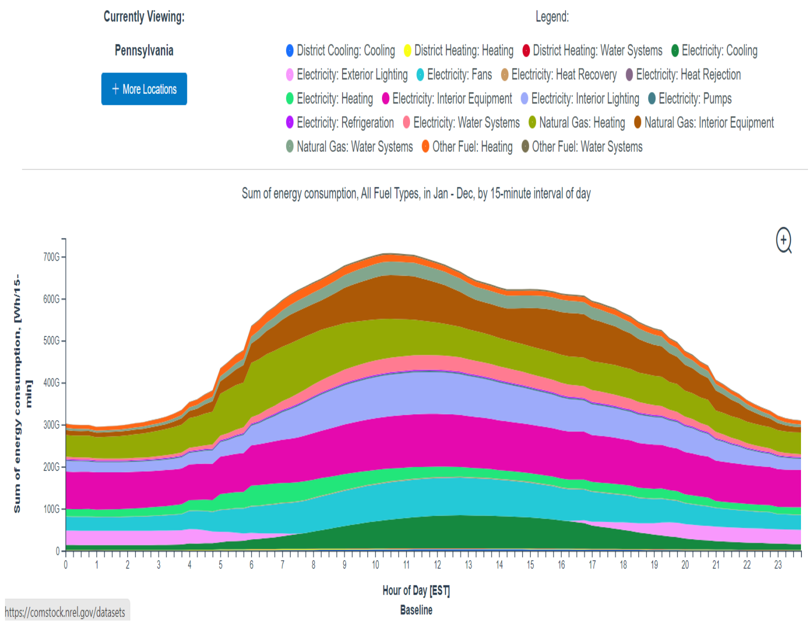
ResStock and ComStock

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, CO_2)



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

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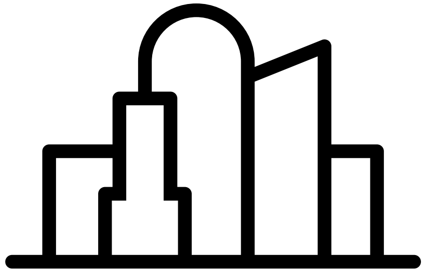
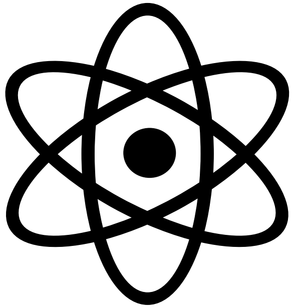
End-Use Load Profiles for the U.S. Building Stock

ComStock ResStock



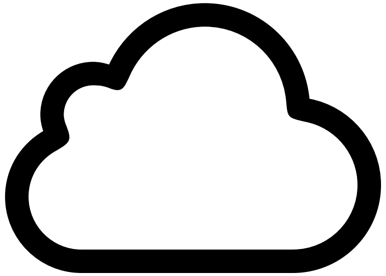
Building stock characteristics database

+



Physics-based computer modeling

+



High-performance computing

- 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

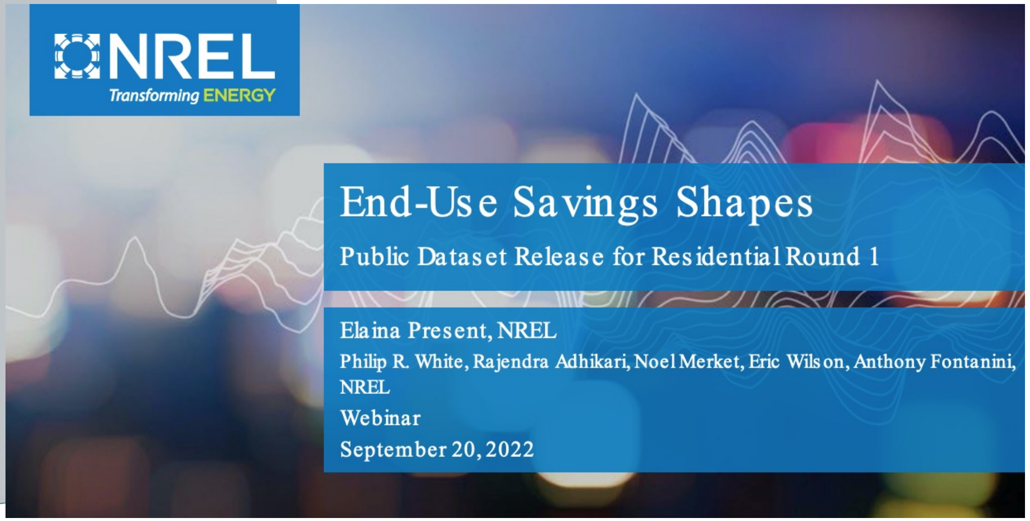
End-Use Load Profile and Savings Shape Reports

[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

- Accessing the End-Use Load Profiles and Savings Shapes
- Considerations and Limitations
- Use Cases

Use Case	Application of End-Use Load Profiles
Integrated resource planning	Develop load forecast or energy efficiency supply curves
Long-term load forecasting	Analyze the impact of particular equipment adoption scenarios statewide, across a utility area, or a smaller geographic area; improve baseline building energy consumption assumptions
Transmission planning	Disaggregate the load into components that behave differently during and after a fault
Distribution system planning	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
Electrification planning	Understand how electrification could affect annual electricity consumption and how the increase in consumption could be spread across hours of the year
Demand-side management	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
Bill impacts and rate design	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

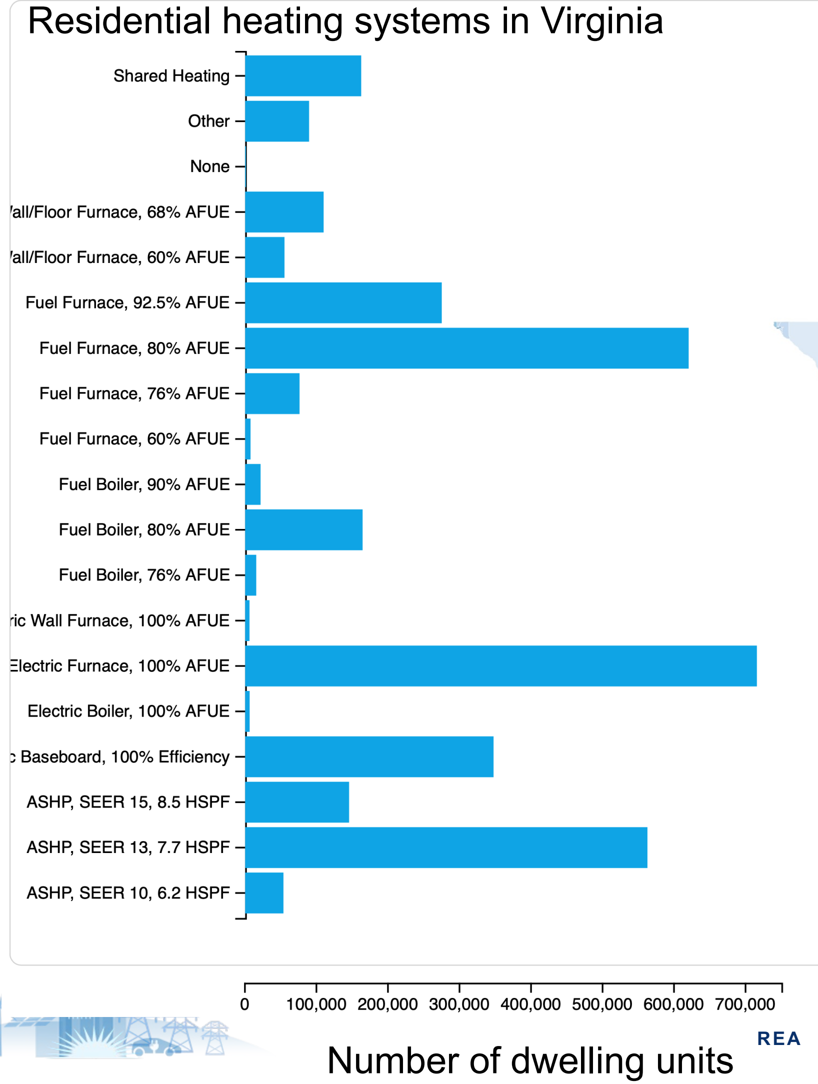
Options to Access the End-Use Load Profiles

Contents of the Dataset

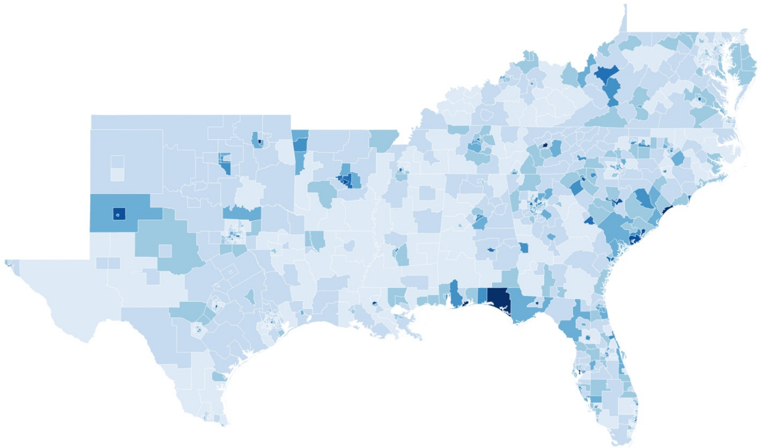
	Commercial	Residential
Models Run (per weather year and upgrade)	350,000 buildings	550,000 dwelling units
Representing	64% of U.S. commercial floor area per CBECS	137 million U.S. homes Excludes AK, HI, territories
Building Types	14	5
End Uses	19	49
Upgrades	Coming soon	10 packages
Weather years	TMY (typical meteorological year), AMY 2018 (actual meteorological year)	TMY, AMY 2012, AMY 2018

Three Strengths of ResStock and ComStock End-use Load Profiles

Building stock



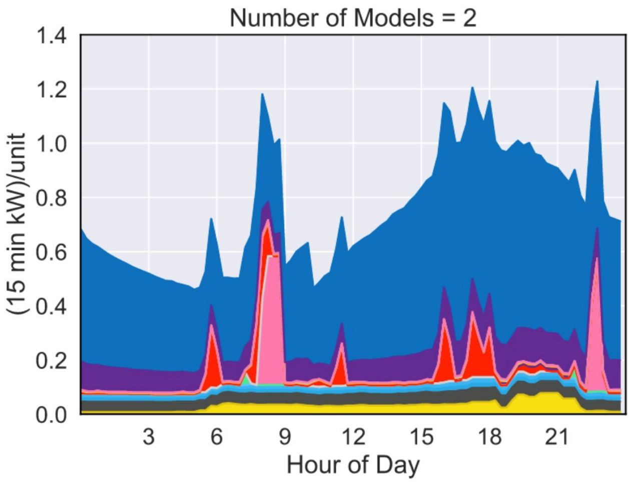
Geographic granularity

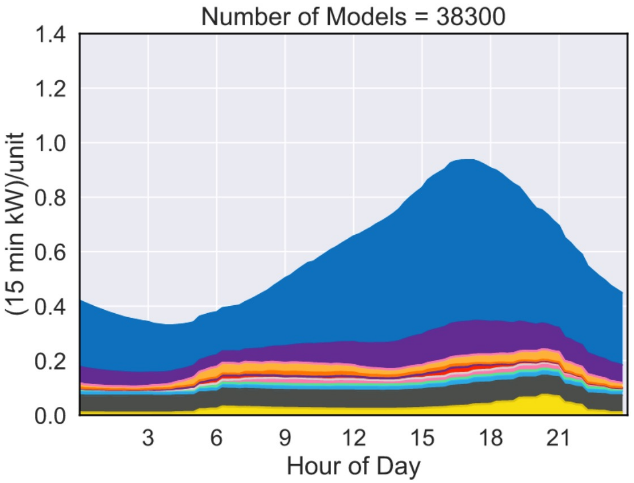


Example of Public Use Microdata Area* (PUMA) resolution:
~200k people; ~2,400 in U.S.

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

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

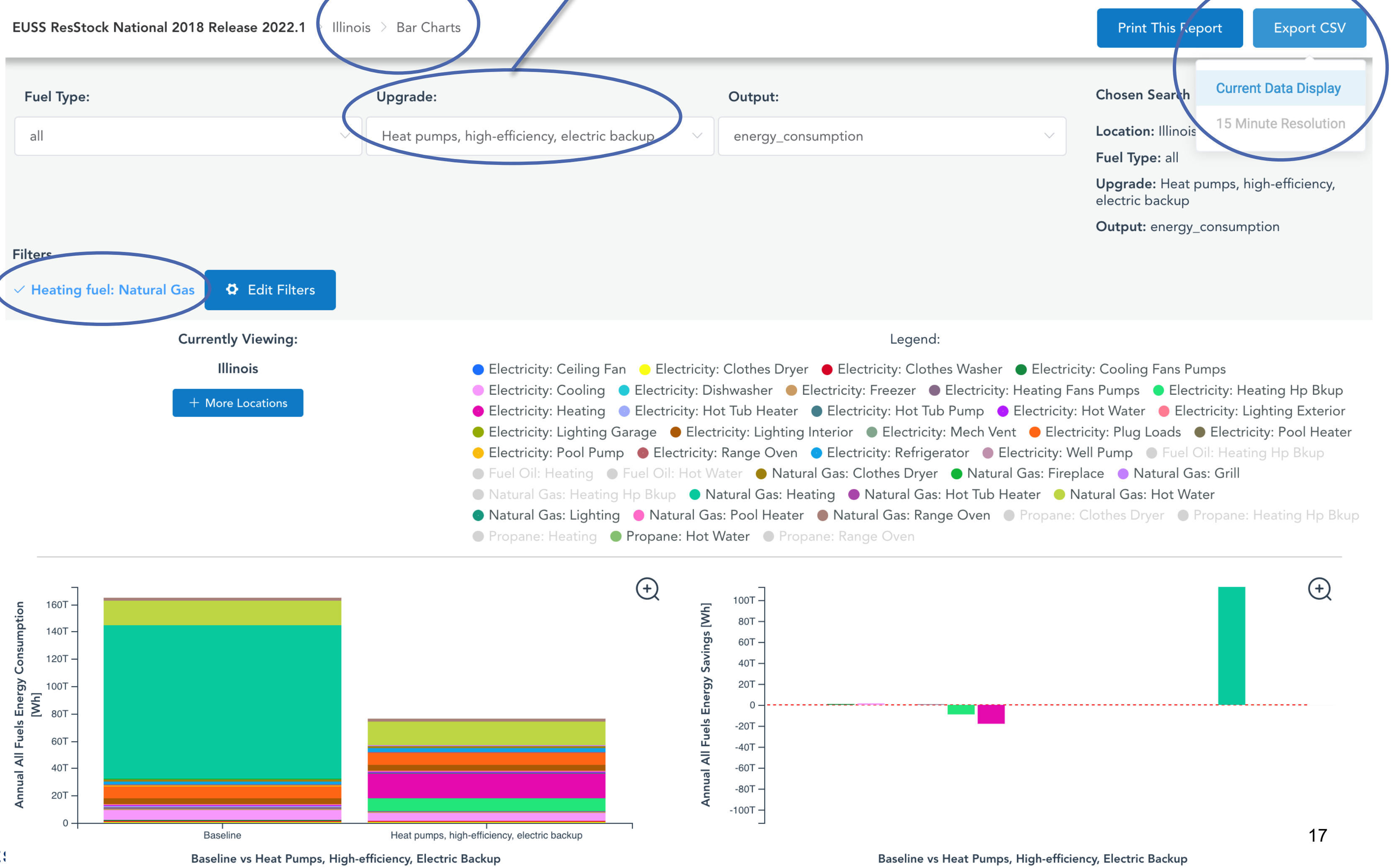
- Custom aggregation in the ResStock web viewer
- Annual bar charts

Illinois

High efficiency heat pump upgrade package

Export data as csv

Natural gas heating in the baseline



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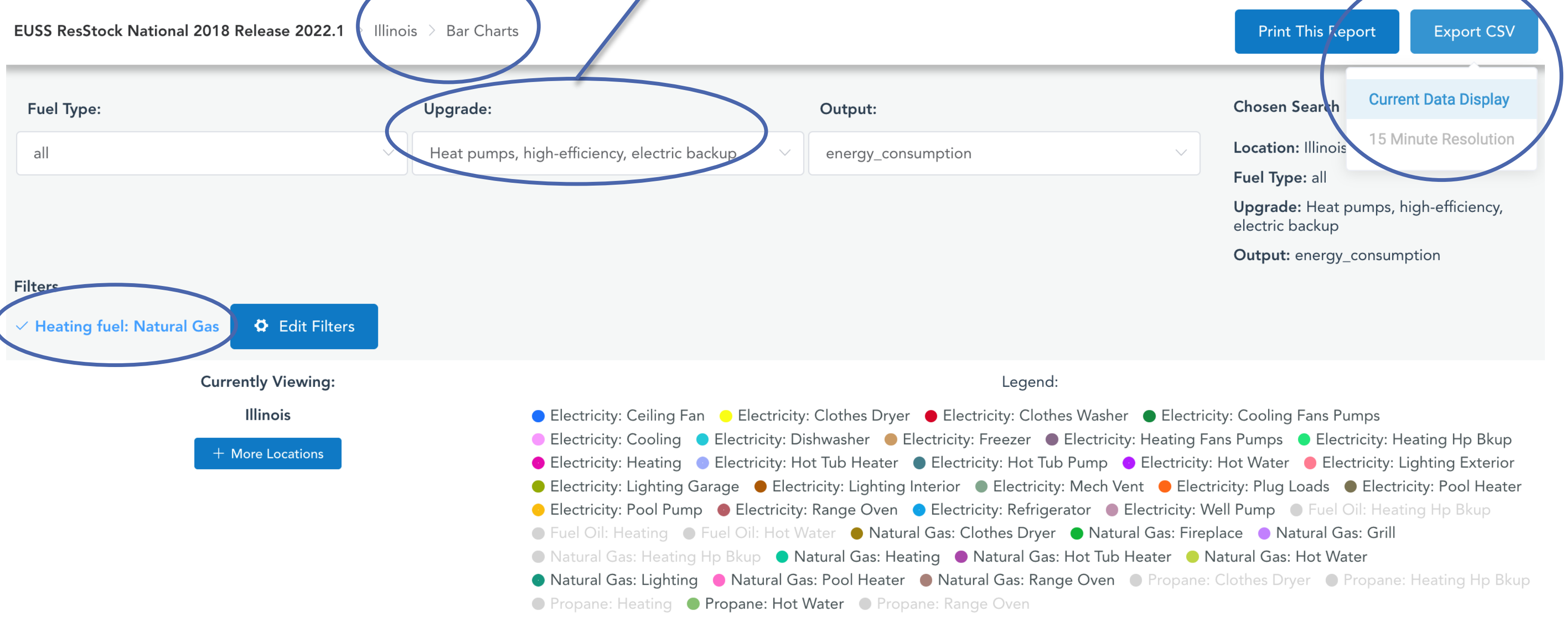
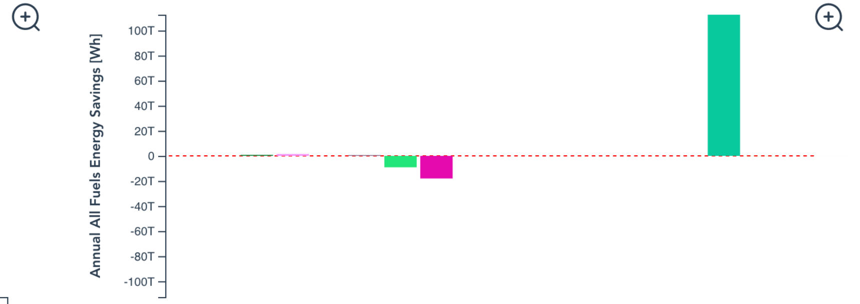


	A	B	C	D	I	J	K	AF
1	upgrade	electricity--ceiling-fan	electricity--clothes-dryer	electricity--clothes-washer	electricity--heating-fans-pumps	electricity--heating-hp-bkup	electricity--heating	natural-gas--heating
2	Baseline	183238733.6	837800691	91625185.7	1823576958	0	0	1.1258E+11
3	Heat pumps	183238733.6	837800691	91625185.7	1219898083	9112837148	1.803E+10	0
4	Savings	2.98E-08	-1.19E-07	0	603678875	-9.113E+09	-1.803E+10	1.1258E+11

Baseline vs Heat Pumps, High-efficiency, Electric Backup



Baseline vs Heat Pumps, High-efficiency, Electric Backup

Time-of-Use Electricity Rate

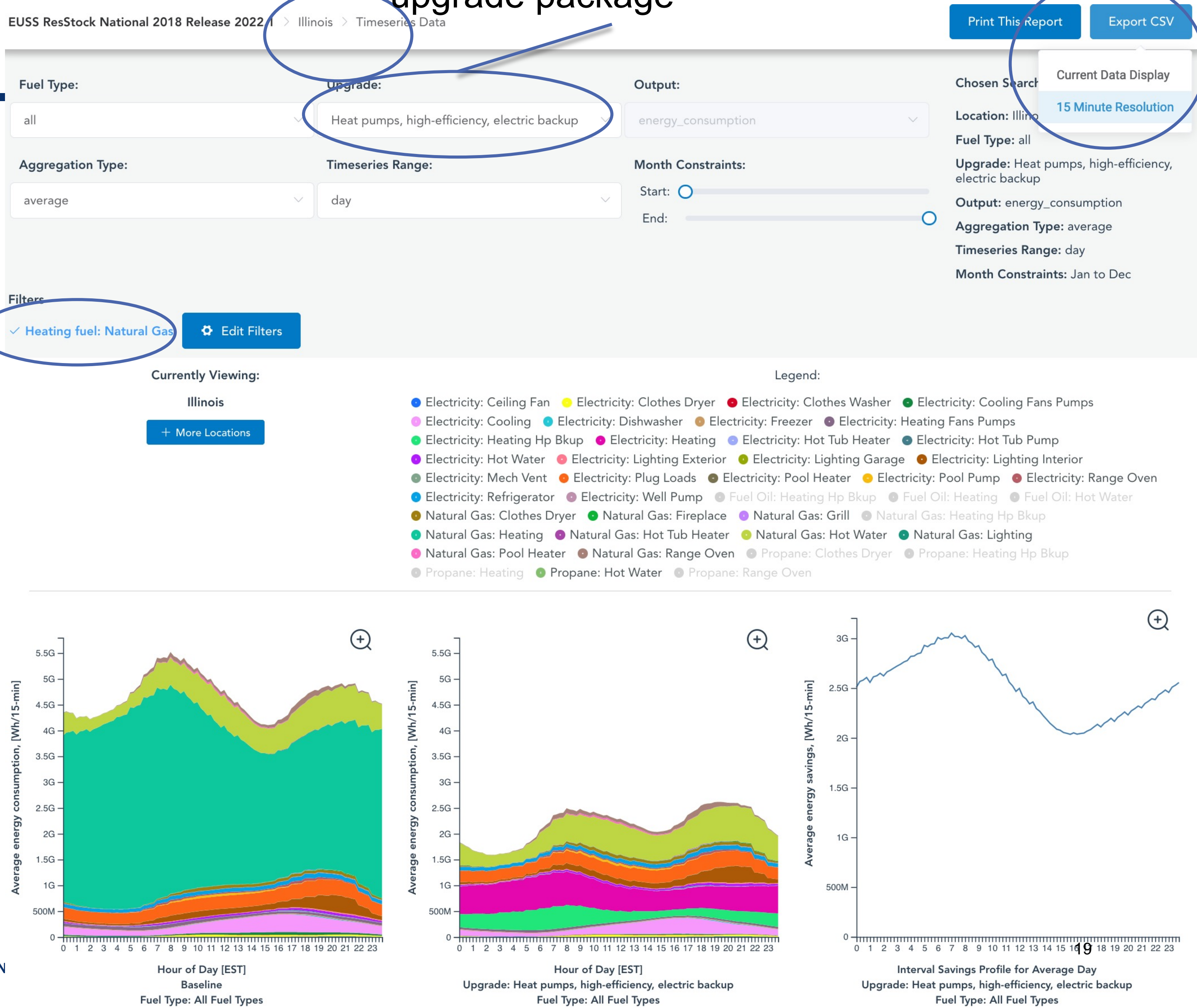
- Custom aggregation in the ResStock web viewer
- Timeseries view

Illinois

High efficiency heat pump upgrade package

Export data as csv

Natural gas heating in the baseline



Time-of-Use Electricity Rate

- Downloaded 15-min interval data

Convert to local time

Fill in hourly rate

Volumetric cost

Transition from peak to super peak price

	A	AR	CL	CP	CQ	CR	CS
1	Timestamp (EST)	baseline.out.electricity.total.energy_consumption.kwh	upgrade.out.electricity.total.energy_consumption.kwh	Local time (CST/CDT)	rate ($/kWh)	baseline electricity ($)	upgrade electricity ($)
56	2018-01-01 13:45:00-05:00	906634.638	7986468.45	12	0.08545	$ 77,471.93	$ 682,443.73
57	2018-01-01 14:00:00-05:00	898330.028	7818924.45	13	0.08545	$ 76,762.30	$ 668,127.09
58	2018-01-01 14:15:00-05:00	877458.335	7657893.28	13	0.08545	$ 74,978.81	$ 654,366.98
59	2018-01-01 14:30:00-05:00	875859.302	7541719.54	13	0.08545	$ 74,842.18	$ 644,439.94
60	2018-01-01 14:45:00-05:00	873704.094	7422615.78	13	0.08545	$ 74,658.01	$ 634,262.52
61	2018-01-01 15:00:00-05:00	870937.505	7322186.13	14	0.08545	$ 74,421.61	$ 625,680.81
62	2018-01-01 15:15:00-05:00	862350.086	7262278.81	14	0.08545	$ 73,687.81	$ 620,561.72
63	2018-01-01 15:30:00-05:00	864577.934	7213323.31	14	0.08545	$ 73,878.18	$ 616,378.48
64	2018-01-01 15:45:00-05:00	865263.164	7176855.95	14	0.08545	$ 73,936.74	$ 613,262.34
65	2018-01-01 16:00:00-05:00	873581.091	7158143.1	15	0.11451	$ 100,033.77	$ 819,678.97
66	2018-01-01 16:15:00-05:00	895583.778	7260022.15	15	0.11451	$ 102,553.30	$ 831,345.14
67	2018-01-01 16:30:00-05:00	903908.727	7280471.8	15	0.11451	$ 103,506.59	$ 833,686.83
68	2018-01-01 16:45:00-05:00	916390.823	7340300.68	15	0.11451	$ 104,935.91	$ 840,537.83
69	2018-01-01 17:00:00-05:00	933485.514	7413630.79	16	0.11451	$ 106,893.43	$ 848,934.86
70	2018-01-01 17:15:00-05:00	1007172.28	7725512.72	16	0.11451	$ 115,331.30	$ 884,648.46
71	2018-01-01 17:30:00-05:00	1021814.18	7924136.67	16	0.11451	$ 117,007.94	$ 907,392.89

Average Annual Savings

	Electricity - flat rate	Electricity - TOU rate	Gas		Total - flat rate	Total - TOU rate
Baseline - gas heating	$ 485	$ 498	$ 775		$ 1,261	$ 1,274
Upgrade - high efficiency heat pump	$ 871	$ 862	$ 123		$ 995	$ 985
Savings	$ (386)	$ (363)	$ 652		$ 266	$ 289

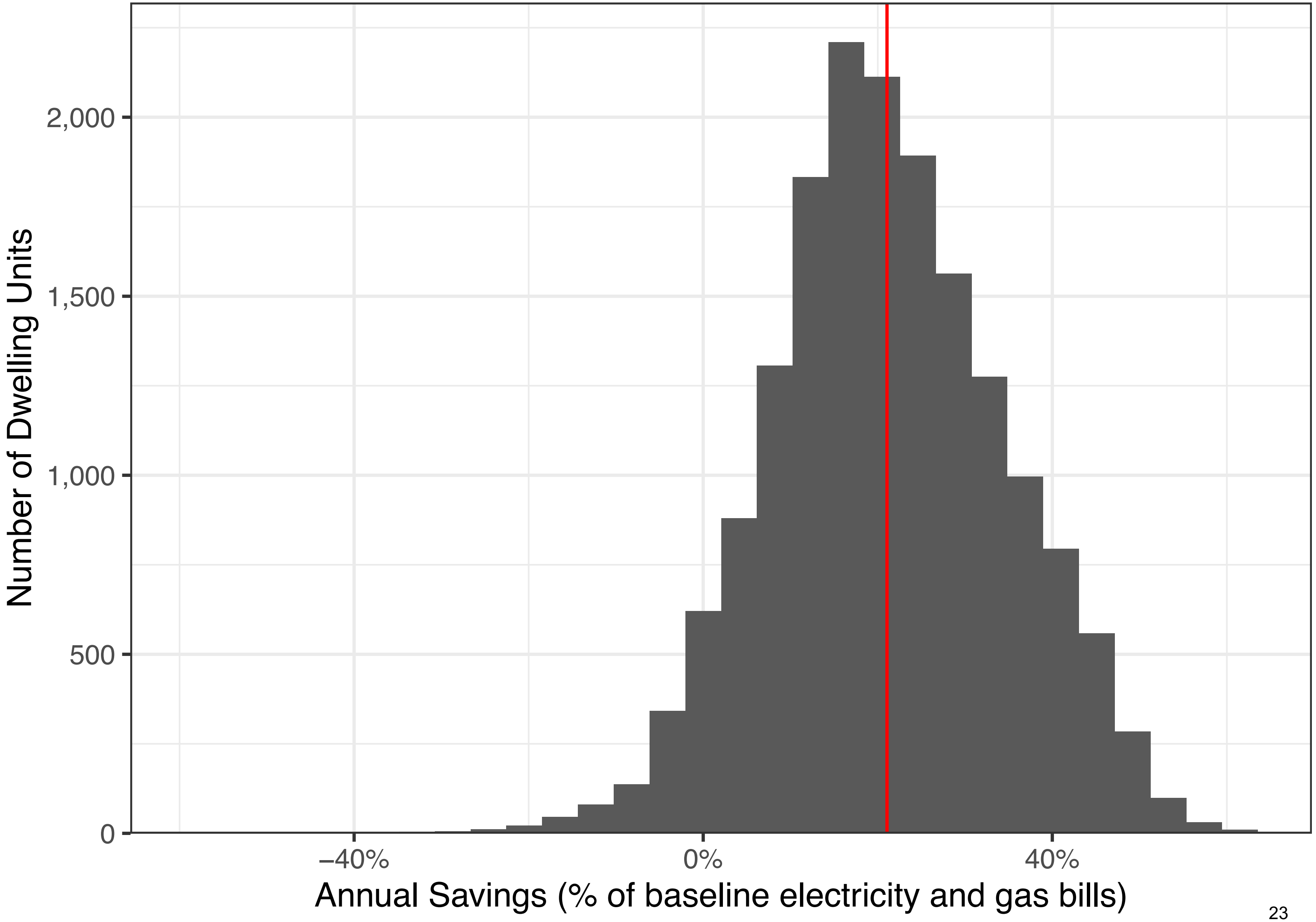
Distribution of Savings

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

	A	B	I	M	AO	BB	BC	BD	BI	FL	FM	ID	IE
1	bldg_id	in.county	in.sqft	in.bedrooms	in.geometry_building_type_acs	in.heating_fuel	in.heating_setpoint	in.heating_setpoint_has_offset	in.hot_water_fixtures	out.electricity.heating.energy_consumption	out.electricity.heating.energy_consumption_intensity	out.natural_gas.total.energy_consumption	out.natural_gas.total.energy_consumption_intensity
2	1	G5100230	1623	3	50 or more U	Natural Gas	68F	No	50% Usage	118.947854	0.07328888	32025.0873	19.7320316
3	2	G5600250	617	1	3 or 4 Unit	Natural Gas	65F	No	100% Usage	104.606059	0.1695398	21319.8167	34.5539979
4	3	G4801130	333	1	50 or more U	Natural Gas	65F	Yes	100% Usage	2.08976334	0.00627557	3743.20977	11.2408702
5	4	G2200190	617	2	2 Unit	Electricity	80F	No	50% Usage	3959.83874	6.41789098	0	0
6	5	G2901690	3241	3	Single-Famil	Electricity	70F	Yes	100% Usage	3863.58688	1.19209715	0	0
7	6	G1200990	2663	3	Single-Famil	Electricity	68F	No	200% Usage	122.863241	0.04613715	0	0
8	7	G0600730	1690	3	Single-Famil	Natural Gas	67F	Yes	200% Usage	9.26892312	0.00548457	3421.29707	2.02443614
9	8	G3101090	1690	3	Single-Famil	Electricity	70F	Yes	100% Usage	15556.5001	9.20502962	0	0
10	9	G1600550	1690	3	Single-Famil	Electricity	70F	No	100% Usage	29071.1186	17.2018453	0	0
11	10	G3600550	1690	4	Single-Famil	Electricity	65F	No	50% Usage	8247.03468	4.87990218	0	0

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?



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
- Time-Sensitive Value (TSV) Calculator https://emp.lbl.gov/publications/time-sensitive-value-calculator
  - Gathering stakeholder feedback on the current version in preparation for updating it

The Time Sensitive Value of Energy Efficiency Calculator

Copyright 2020 Lawrence Berkeley National Laboratory
Version: 1.7, January 2022
Authors: Natalie Mims Frick, Juan Pablo Carvallo, and Margaret Pigman

The Time Sensitive Value of Energy Efficiency Calculator (Calculator) is a publicly-available, free tool that estimates the value of up to six energy efficiency measures using hourly electricity system cost estimates for six value streams.

Content

C1 - Param input	Model-wide parameter inputs (year, discount rate, deflation rate); select measures and value streams for simulation; assign value to annual risk mitigation adder
C2 - Cost data user	Hourly cost data in $/MWh for each value stream in all simulation years.
C3 - Shape data user	Hourly measure shapes (savings or end use) for each measure.
C4 - Load data user	Hourly electricity system load at the busbar level for each simulation year.
C5 - Measure data	Measure names, descriptions, and lifetimes.

Additional auxiliary file

File: Auxiliary workbook	Creating hourly costs from annual values and the system load shape. Creating hourly CO2 costs from a flat cost and hourly emissions. Normalizing hourly values to one. Converting 15 minute data to hourly.

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

https://www.nrel.gov/buildings/end-use-load-profiles.html

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For more information

Download publications from the Electricity Markets & Policy: https://emp.lbl.gov/publications
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Acknowledgements

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Toward Net Zero Emissions from Oregon Buildings – Emissions and Cost Analysis of Efficient Electrification

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
- **Reference**: Takahashi et al. 2022. *Toward Net Zero Emissions from Oregon Buildings - Emissions and Cost Analysis of Efficient Electrification Scenarios*. Synapse Energy Economics, Inc. for Sierra Club. Available at: https://www.synapse-energy.com/net-zero-emissions-oregon-buildings.

Scope of the study (continued)

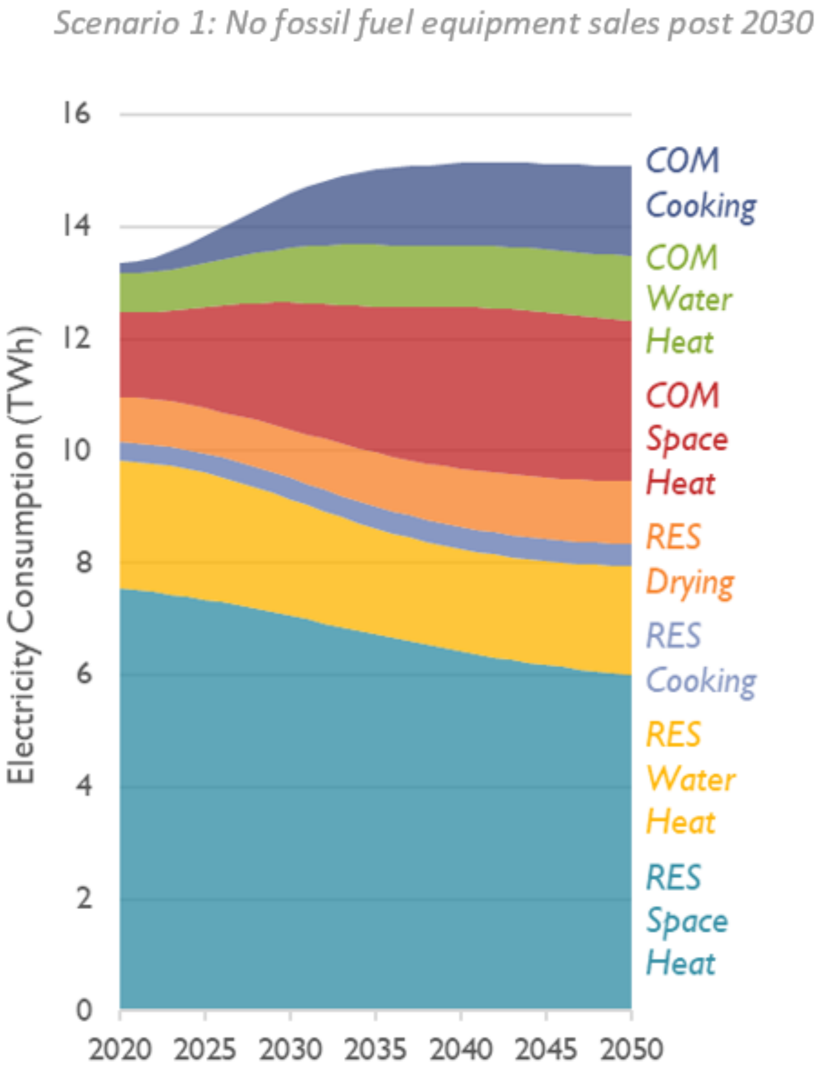
- **Scenarios**:
  - Scenario 1: No fossil fuel equipment sales post 2030: accelerates adoption of electrification measures towards 100-percent market share by 2030
  - Scenario 2: No fossil fuel equipment sales post 2025: accelerates adoption of electrification measures towards 100-percent market share by 2025
- **End-uses**:
  - Space heating, water heating, cooking, and clothes drying

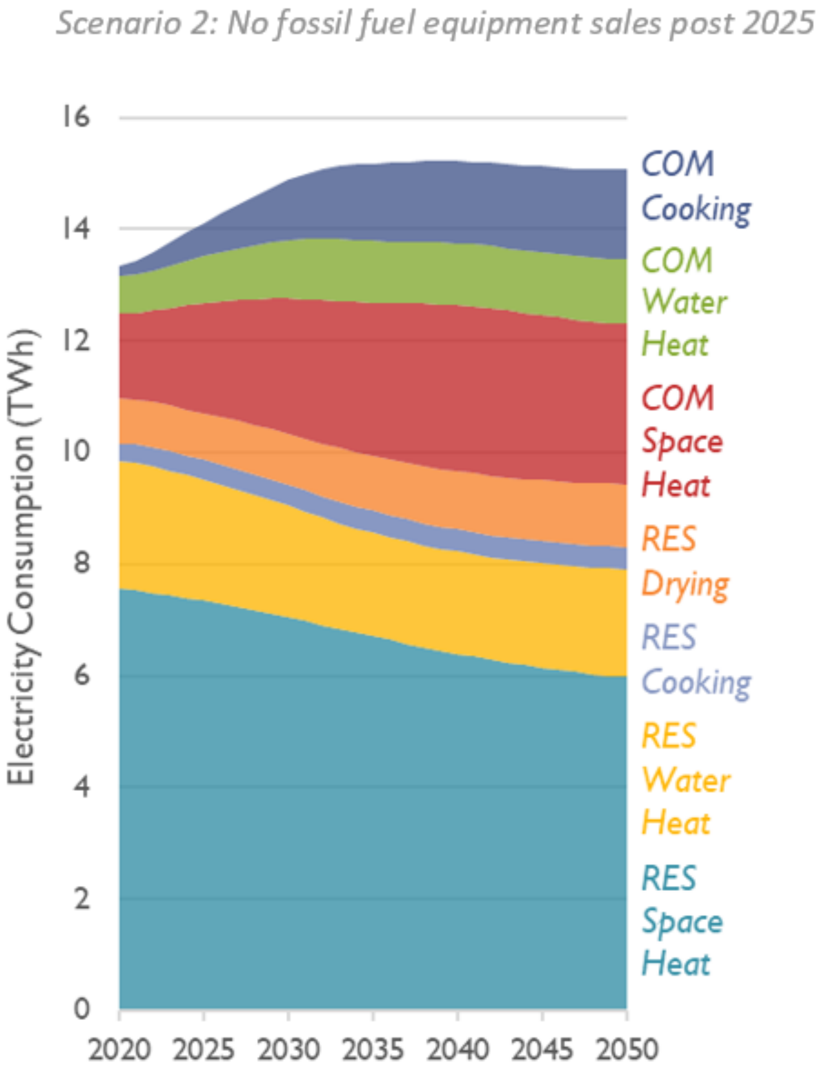
 |

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





Source: Takahashi et al. 2022. Figure 16.

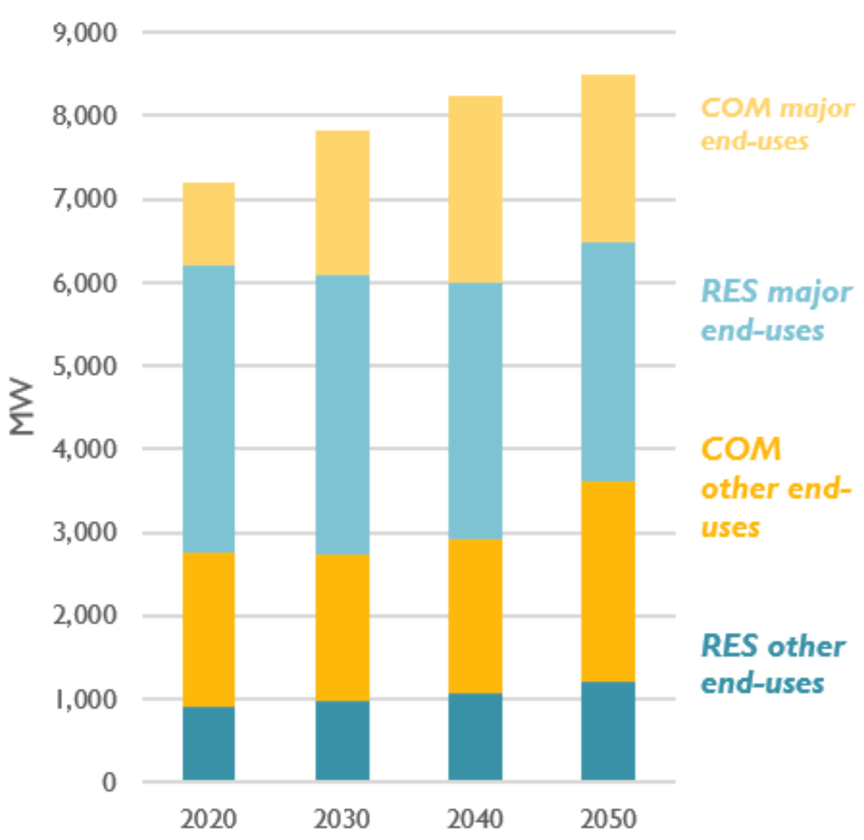
High level summary of two building electrification scenarios

	2030 Sales Target Scenario	2025 Sales Target Scenario
Executive Order 20-40	2035: 45 percent 2050: 80 percent	
CO_2e emissions reductions relative to 1990	2035: 3.3 million metric tons (47%) 2050: 6.8 million metric tons (97%)	2035: 3.9 million metric tons (56%) 2050: 6.9 million metric tons (98%)
2050 energy consumption reductions relative to 2019	57.8. Tbtu (61%)	58.5 Tbtu (61%)
Electricity consumption increase relative to 2019	2030: 1,340 GWh (10%) 2050: 1,720 GWh (13%)	2030: 1,580 GWh (12%) 2050: 1,700 GWh (13%)

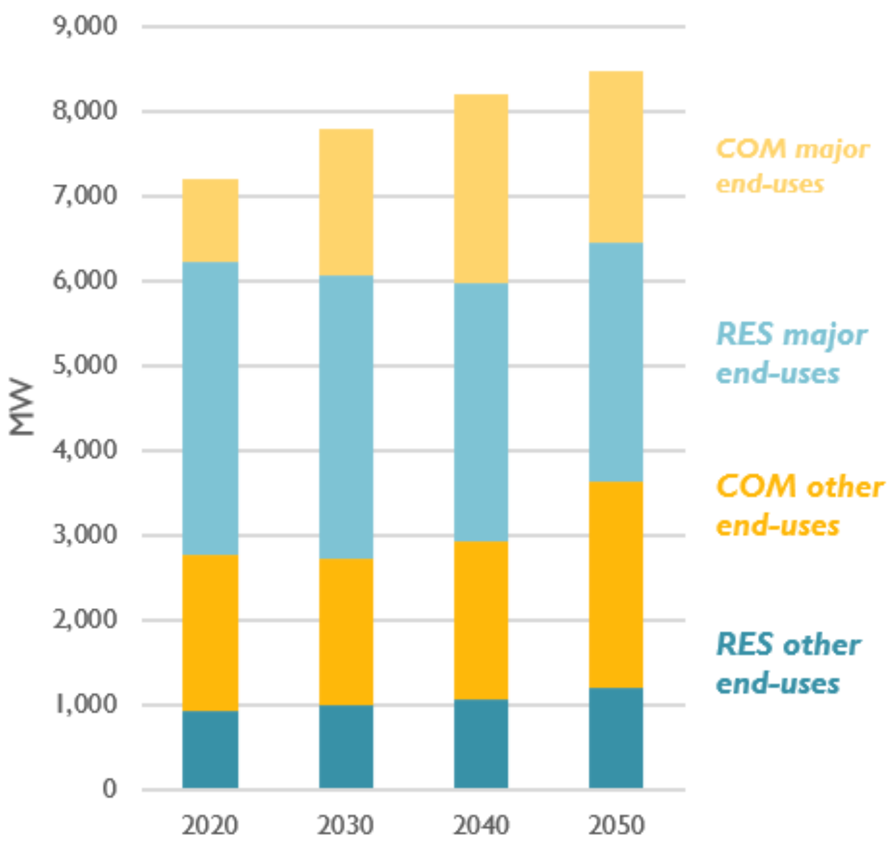
Source: Takahashi et al. 2022. Table ES-1.

Projections of winter peak loads by end-use category

Scenario 1: No fossil fuel equipment sales post 2030



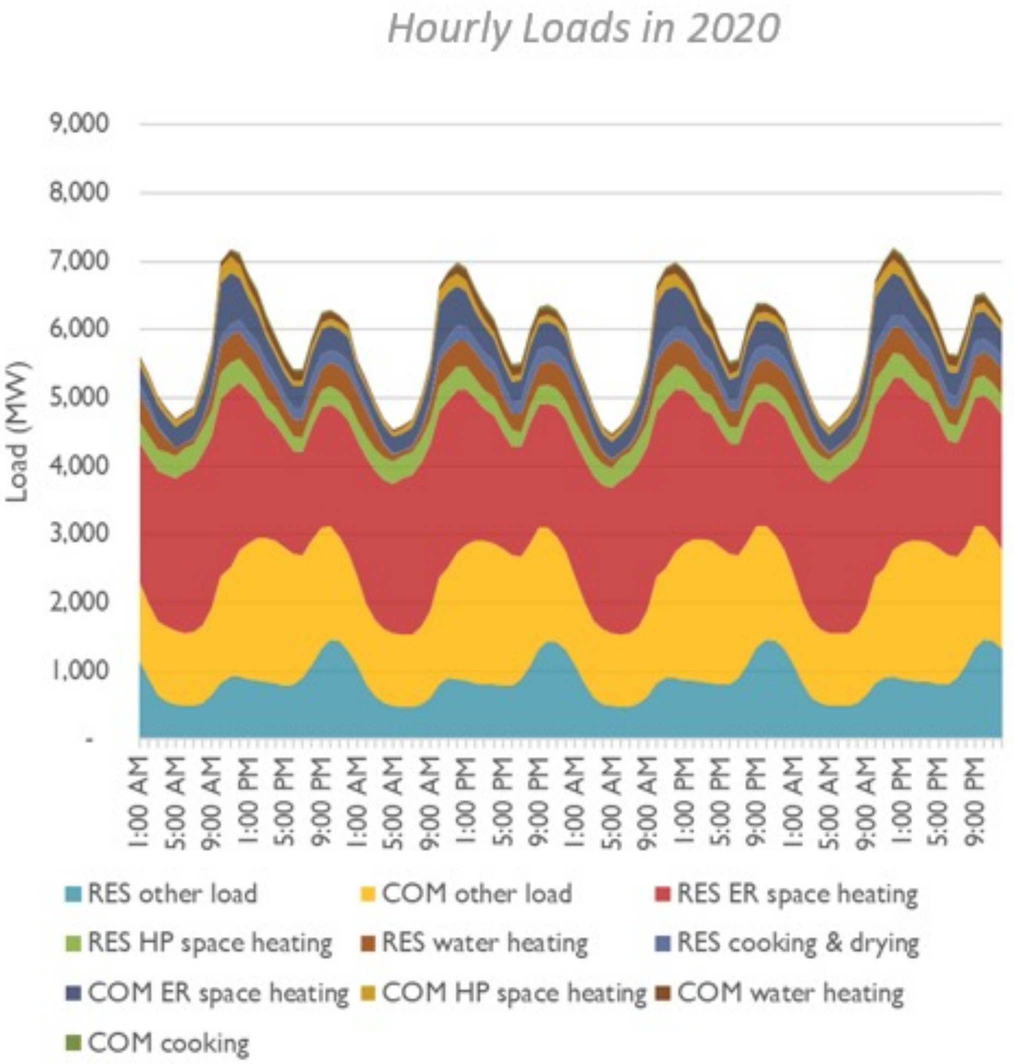
Scenario 2: No fossil fuel equipment sales post 2025

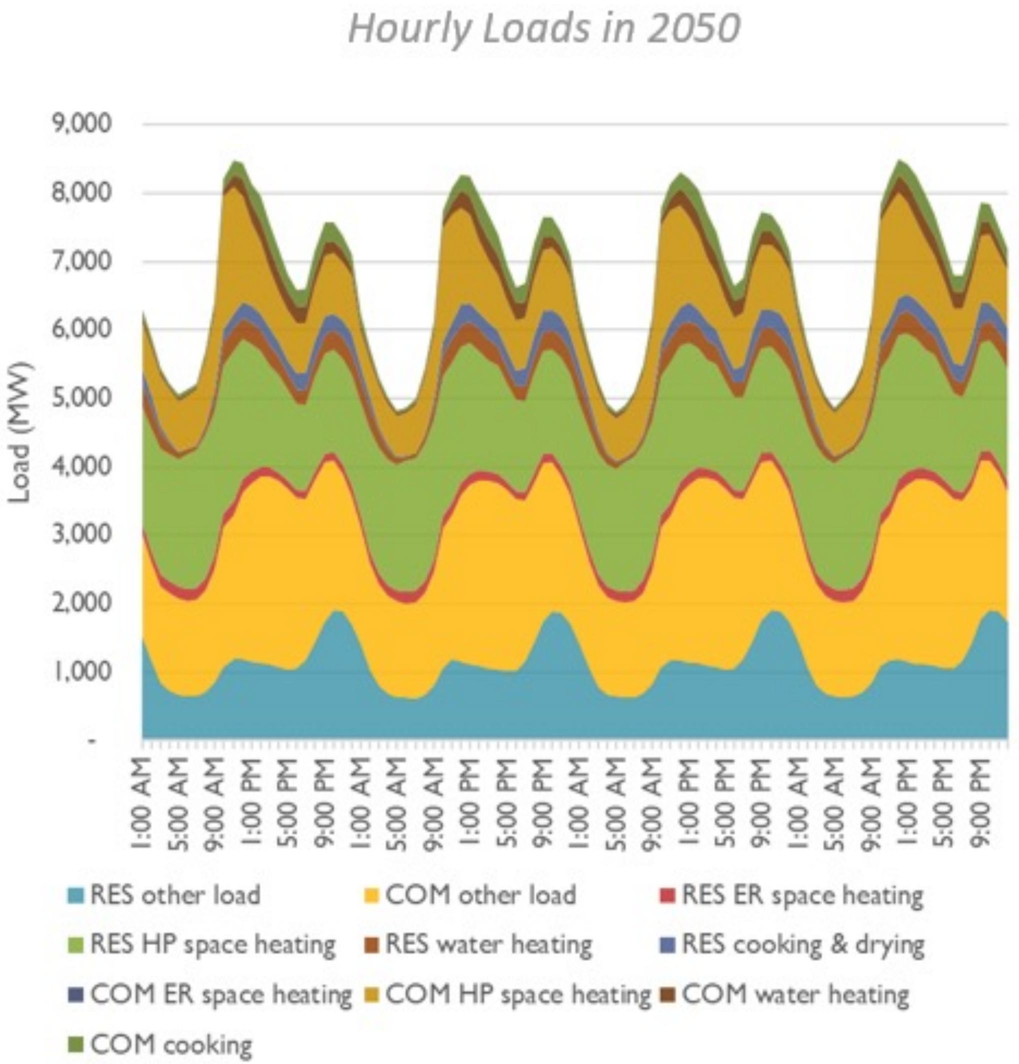


Note: COM stands for commercial, and RES stands for residential.

Source: Takahashi et al. 2022. Figure 29.

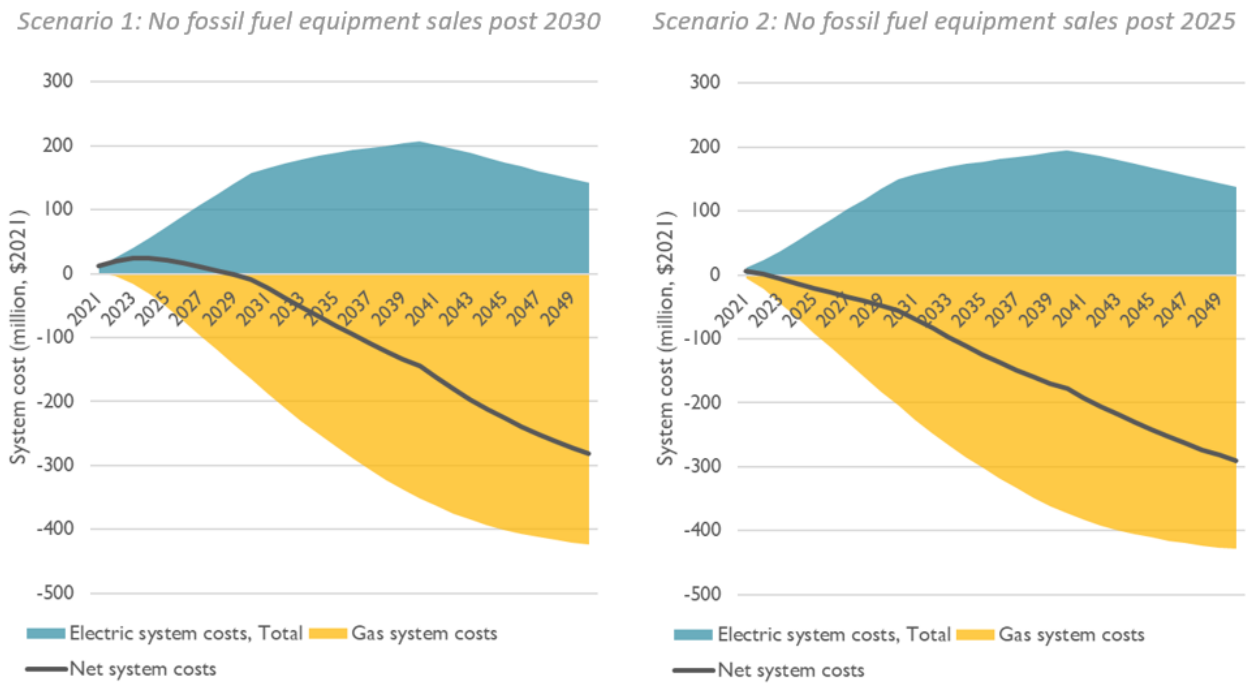
Projected changes in hourly loads by end use – Scenario 1





Source: Takahashi et al. 2022. Figure 30.

Projections of electricity and gas system cost impacts



Source: Takahashi et al. 2022. Figure 33.

	2030	2040	2050	Total (net present value)
Scenario 1	-8	-145	-282	-1,088
Scenario 2	-55	-177	-290	-1,661

Source: Takahashi et al. 2022. Table 9.

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.

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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

New York ISO

Long-Term Forecast Methodology

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.

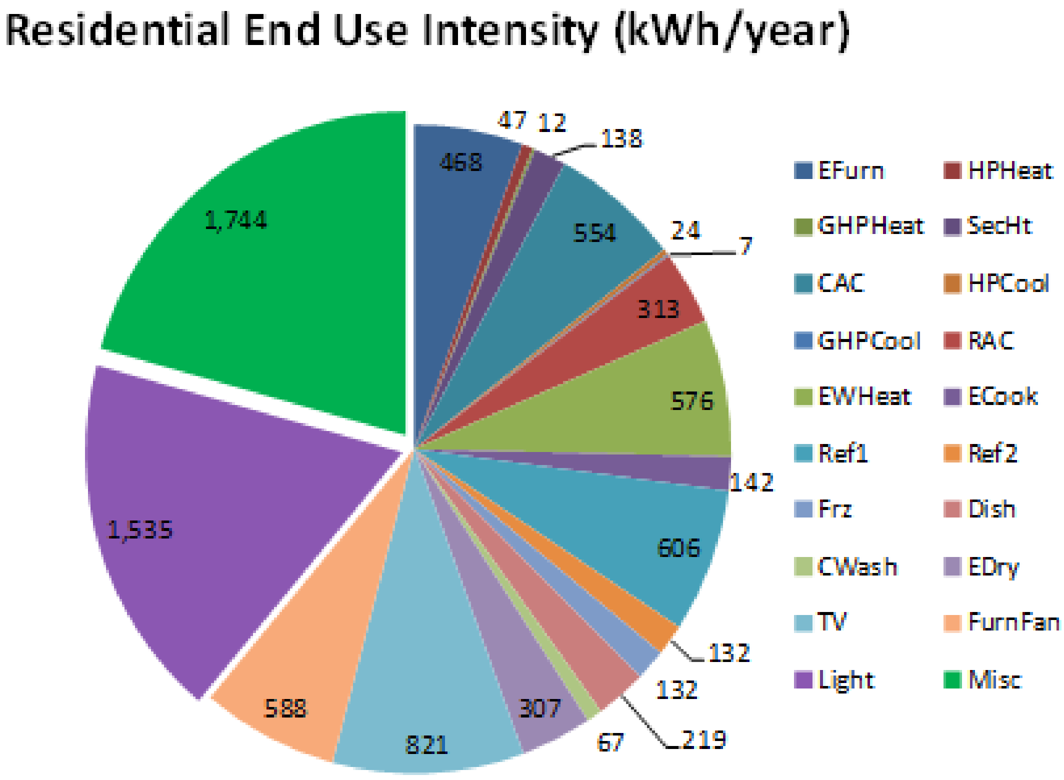
2a) **Exogenous load reducing modifiers:**
- Additional energy efficiency gains
- BTM solar impacts
- BTM distributed generation impacts
- BTM storage peak reductions

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.

New York ISO

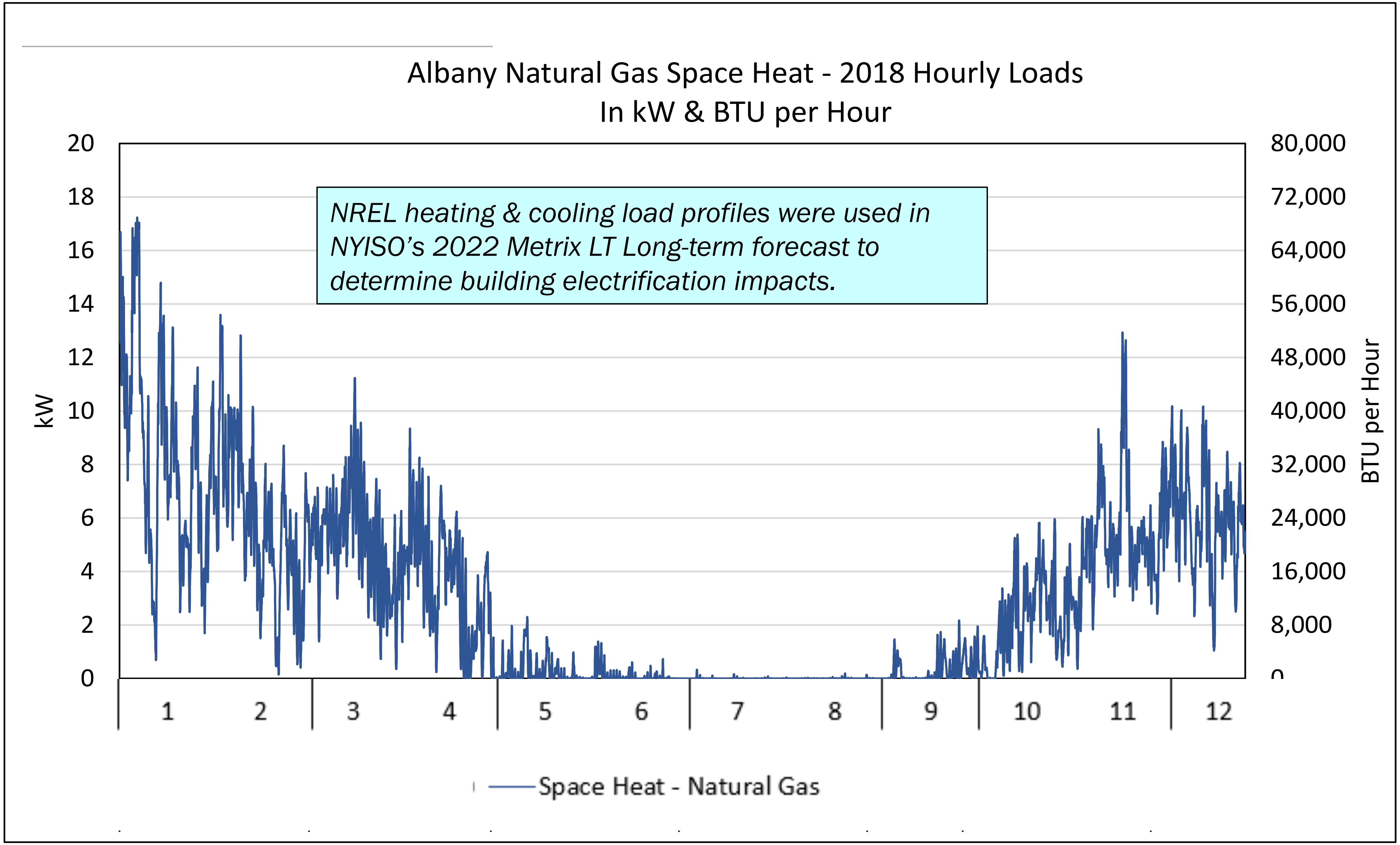
Residential End Uses



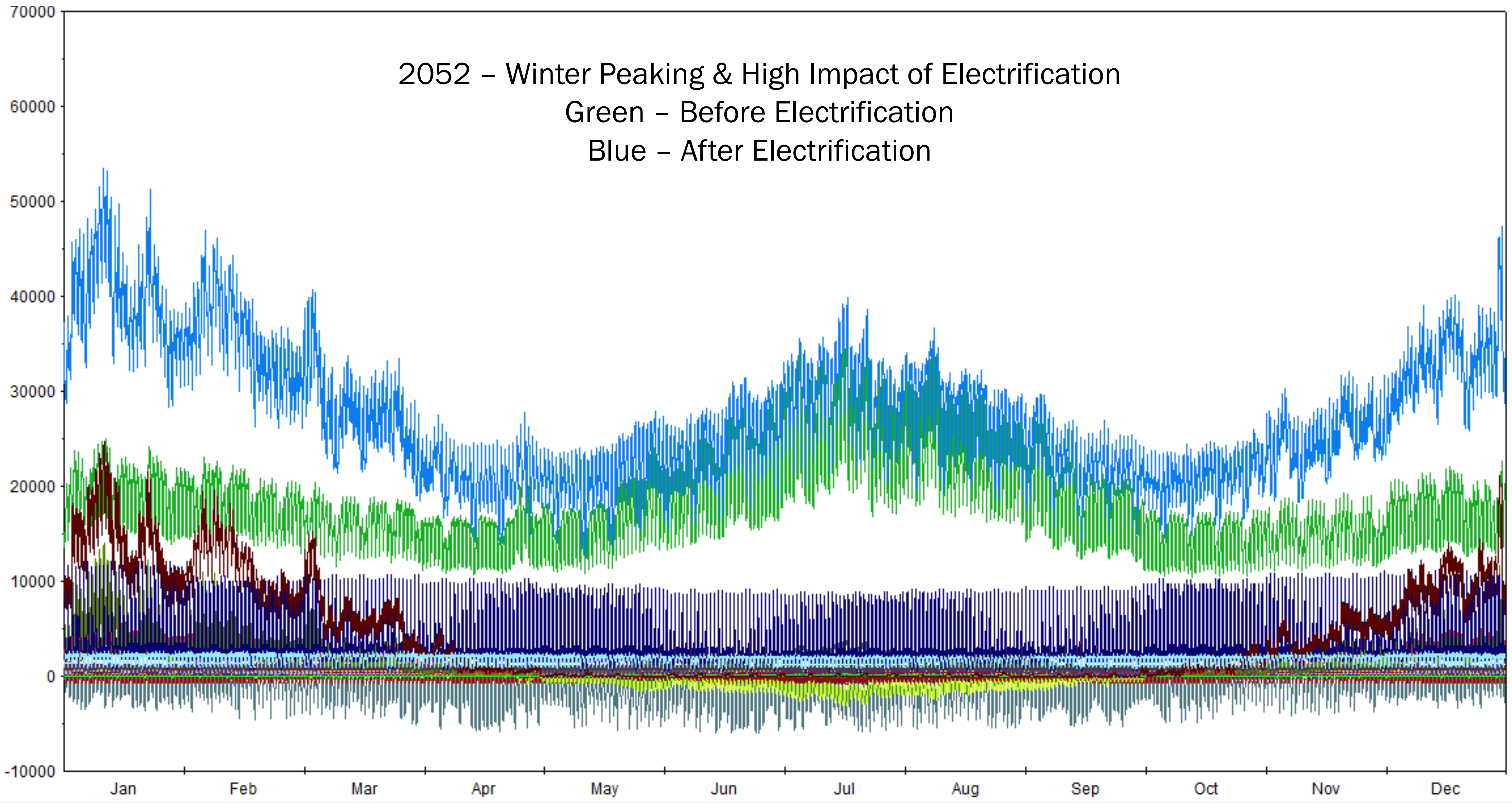
End Use & Equipment Definitions	
EFurn	Electric furnace and resistant room space heaters
HPHeat	Heat pump: space heating
GHPHeat	Ground-source heat pump space: heating
SecHt	Secondary heating
CAC	Central air conditioning
HPCool	Heat pump: space cooling
GHPCool	Ground-source heat pump: space cooling
RAC	Room air conditioners
EWHeat	Electric water heating
ECook	Electric cooking
Ref1	Refrigerator
Ref2	Second refrigerator
Frz	Freezer
Dish	Dishwasher
CWash	Electric clothes washer
EDry	Electric clothes dryer
TV	TV sets
FurnFan	Furnace fans
Light	Lighting
Misc	Miscellaneous electric appliances

Source: End-use chart and list from Itron

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.



Source: NREL ResStock database



Source: Itron MetrixLT Hourly Load software.

New York ISO

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.

New York ISO

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

New York ISO

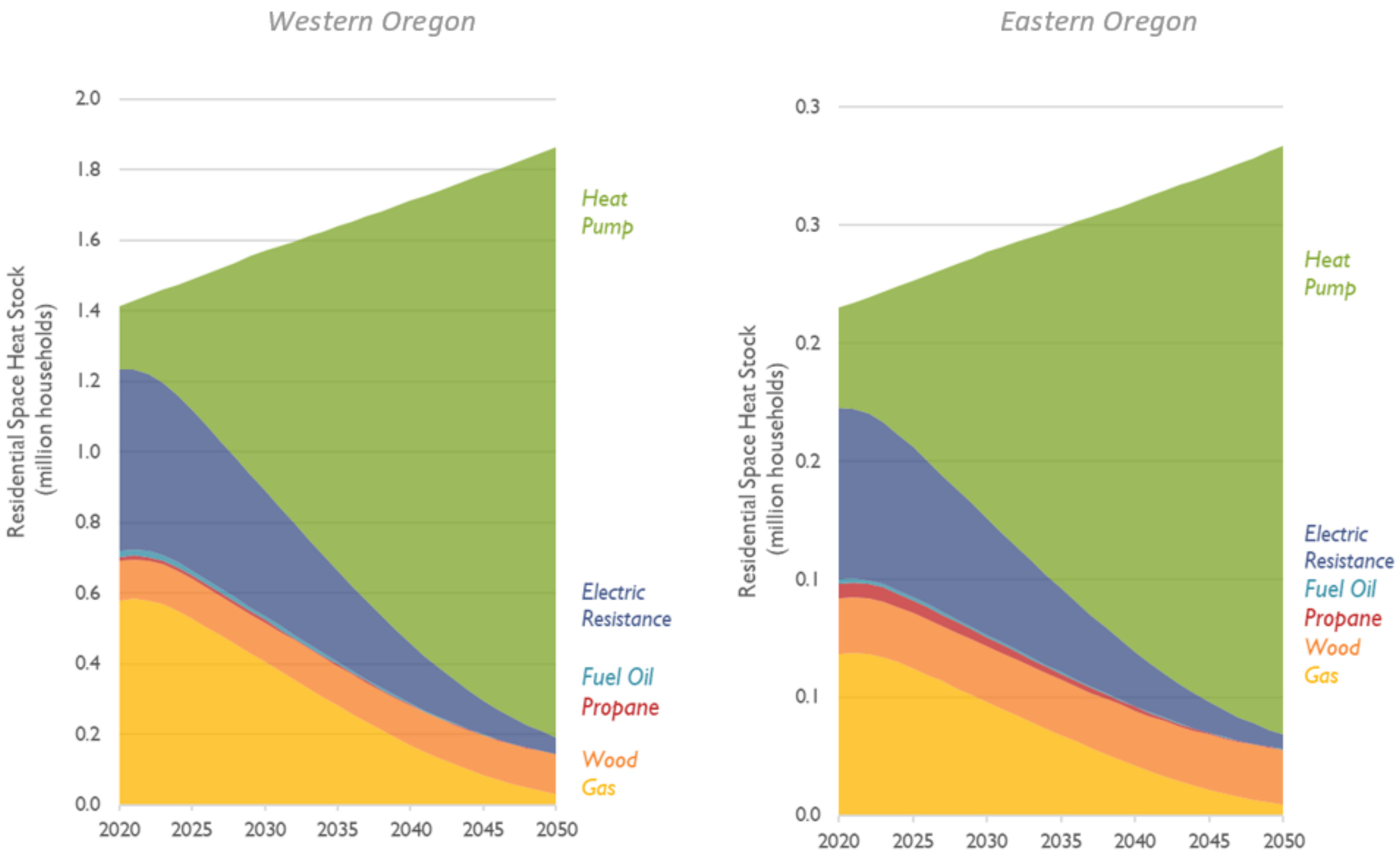
Questions?

Appendix

End-use Load Profile Use Cases Discussed in the Report

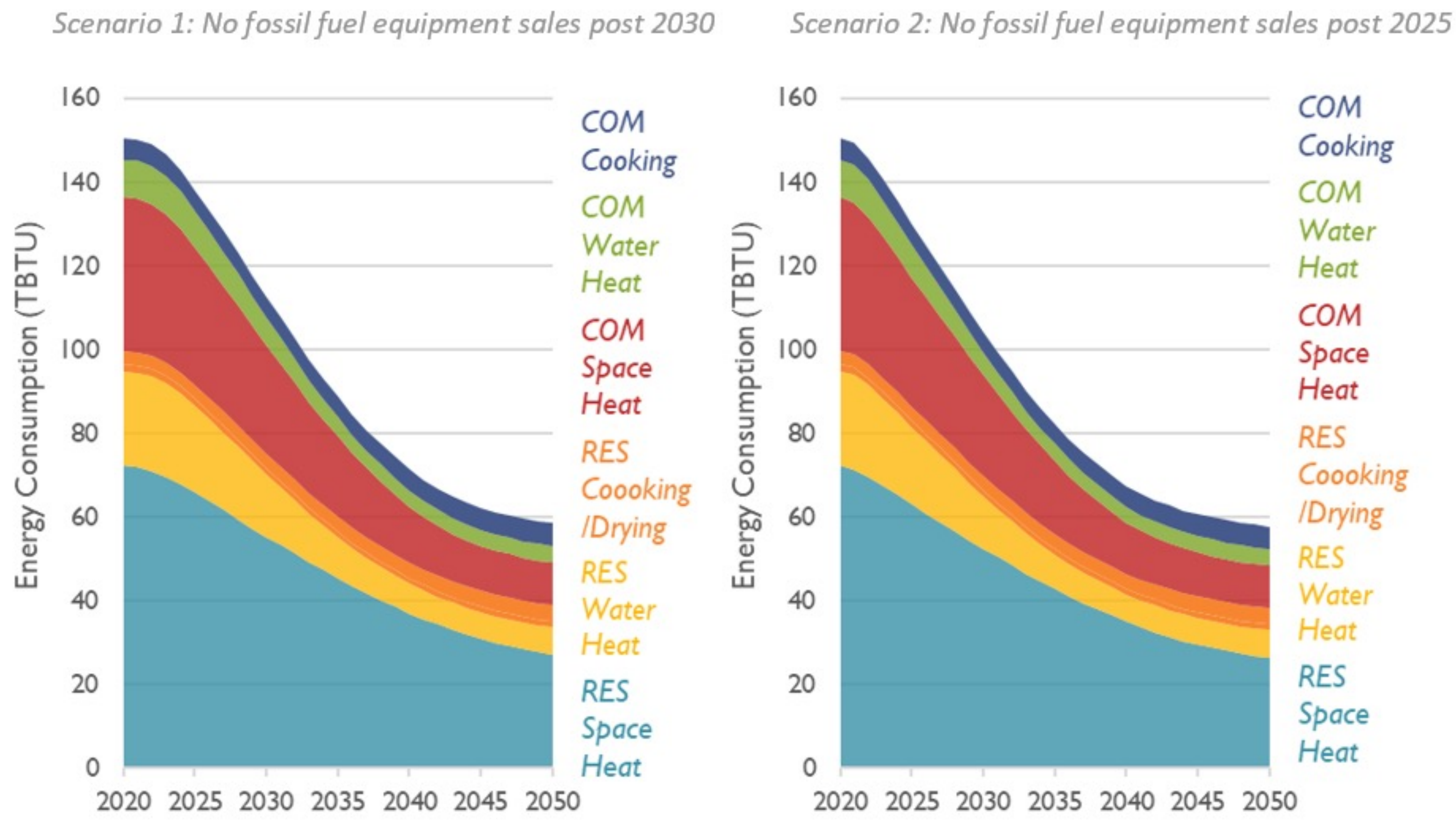
Use Case	Application of End-Use Load Profiles
Integrated resource planning	Develop load forecast or energy efficiency supply curves
Long-term load forecasting	Analyze the impact of particular equipment adoption scenarios statewide, across a utility area, or a smaller geographic area; improve baseline building energy consumption assumptions
Transmission planning	Disaggregate the load into components that behave differently during and after a fault
Distribution system planning	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
Electrification planning	Understand how electrification could affect annual electricity consumption and how the increase in consumption could be spread across hours of the year
Demand-side management	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
Bill impacts and rate design	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

Residential space heating stock by region – Scenario 1



Source: Takahashi et al. 2022. Figure 19.

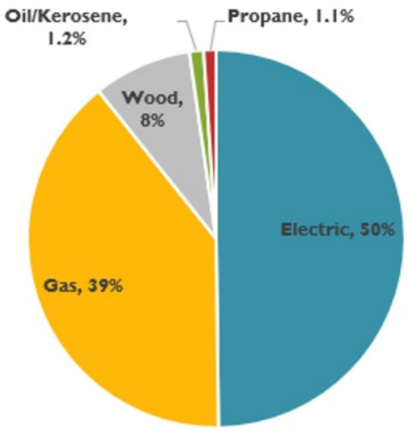
Statewide energy consumption by end-use and scenario



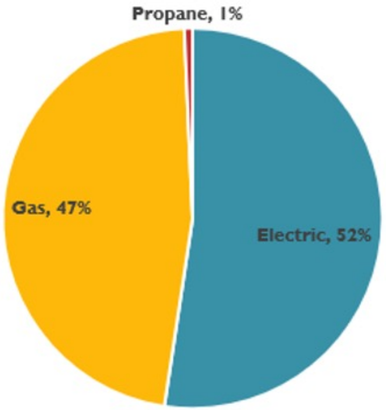
Source: Takahashi et al. 2022. Figure 17.

Space and water heating by fuel type in Oregon

Residential space and water heating

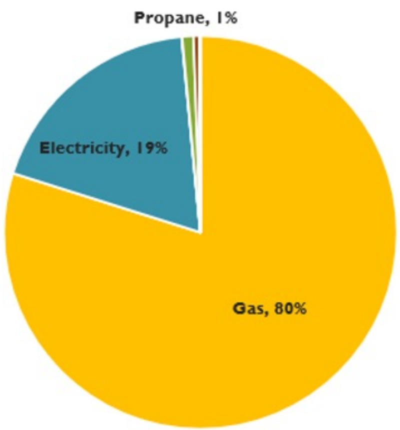


Space heating

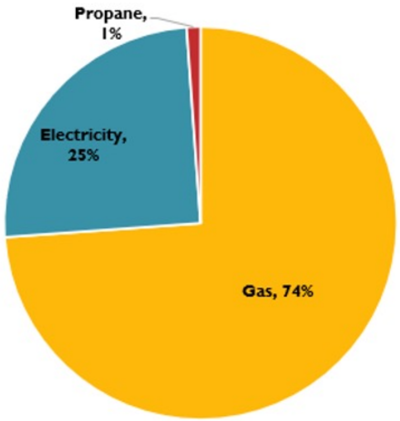


Water heating

Commercial space and water heating



Space Heat

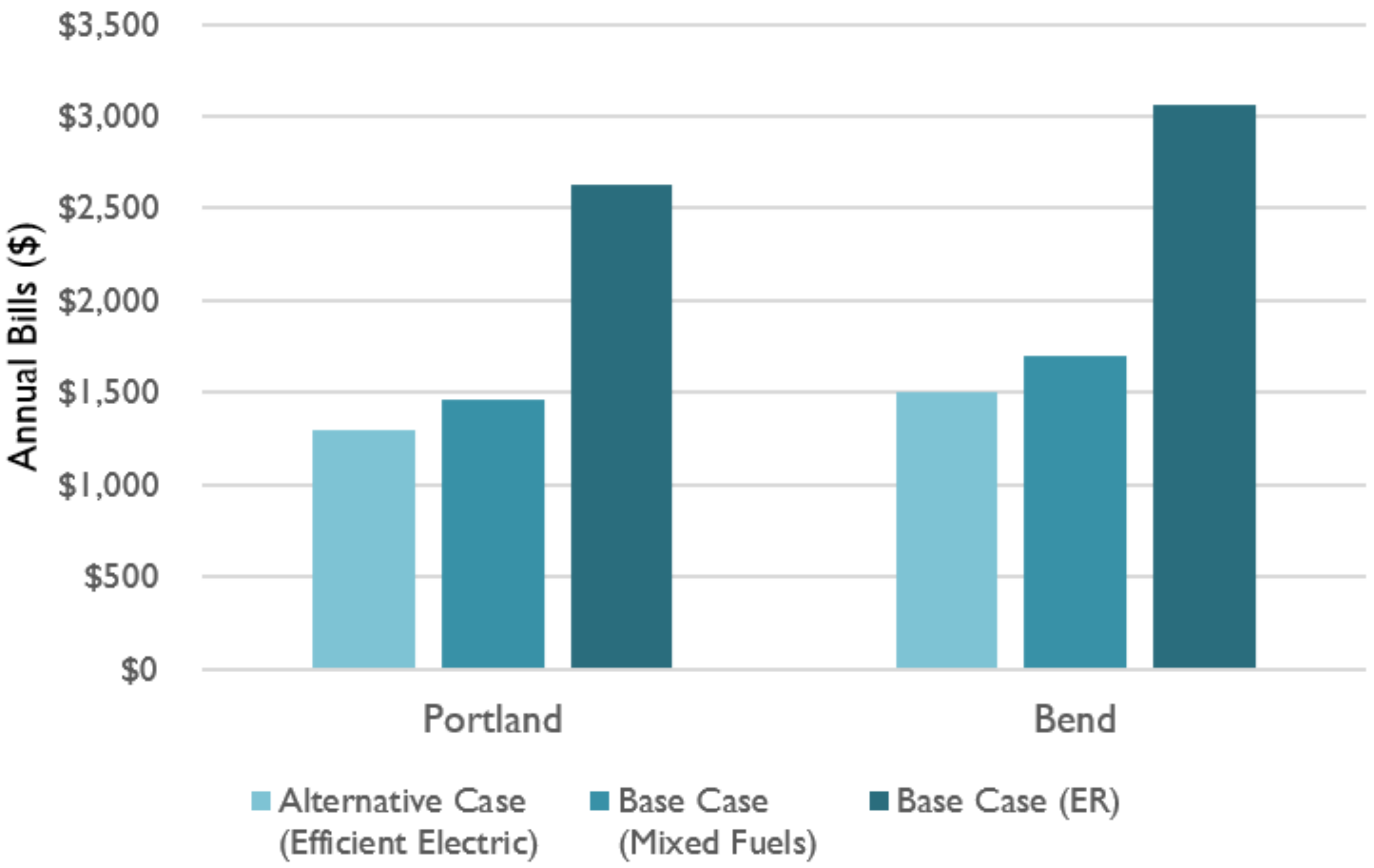


Water Heat

- 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

Source: Takahashi et al. 2022. Figures 3 and 8.

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

	Portland	Bend
Heat pump for space heating		
Annual average bill savings	$42	$82
Average incremental cost	same or less	same or less
Payback (years)	Immediately	Immediately
HPWH		
Annual bill savings	$51	$70
Average incremental cost	$640	$640
Payback (years)	12.7	9.2

Source: Takahashi et al. 2022. Table 19.

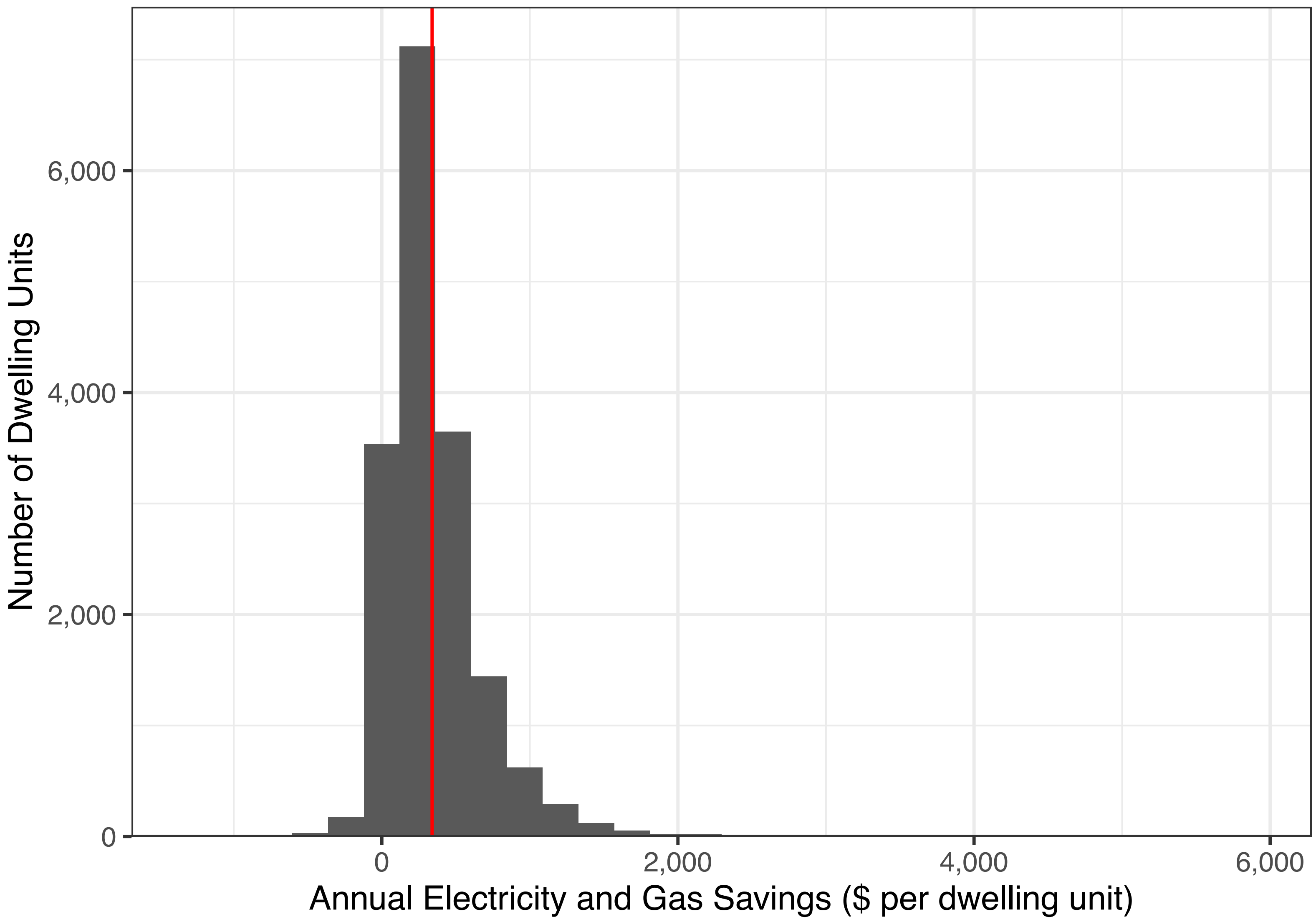
Payback analysis of heat pumps and HWPH relative to the ER Base Case

	Portland	Bend
Heat pump		
Annual bill savings	($1,067)	($1,318)
Average incremental cost	$2,339	$2,339
Payback (years)	2.2	1.8
HPWH		
Annual bill savings	($218)	($197)
Average incremental cost	$640	$640
Payback (years)	2.9	3.2

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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