Low Carbon Pathways in Buildings

Energy Systems Integration Group (ESIG)

Session 5 – Building Electrification

June 15, 2023

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EVOLVED ENERGY RESEARCH

Agenda

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- High electrification scenarios – uncertainty and possibility
- Bottom-up load shape generation based on historical weather years
- Projecting building electrification impacts

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High Electrification Scenarios

Forecasting vs. backcasting

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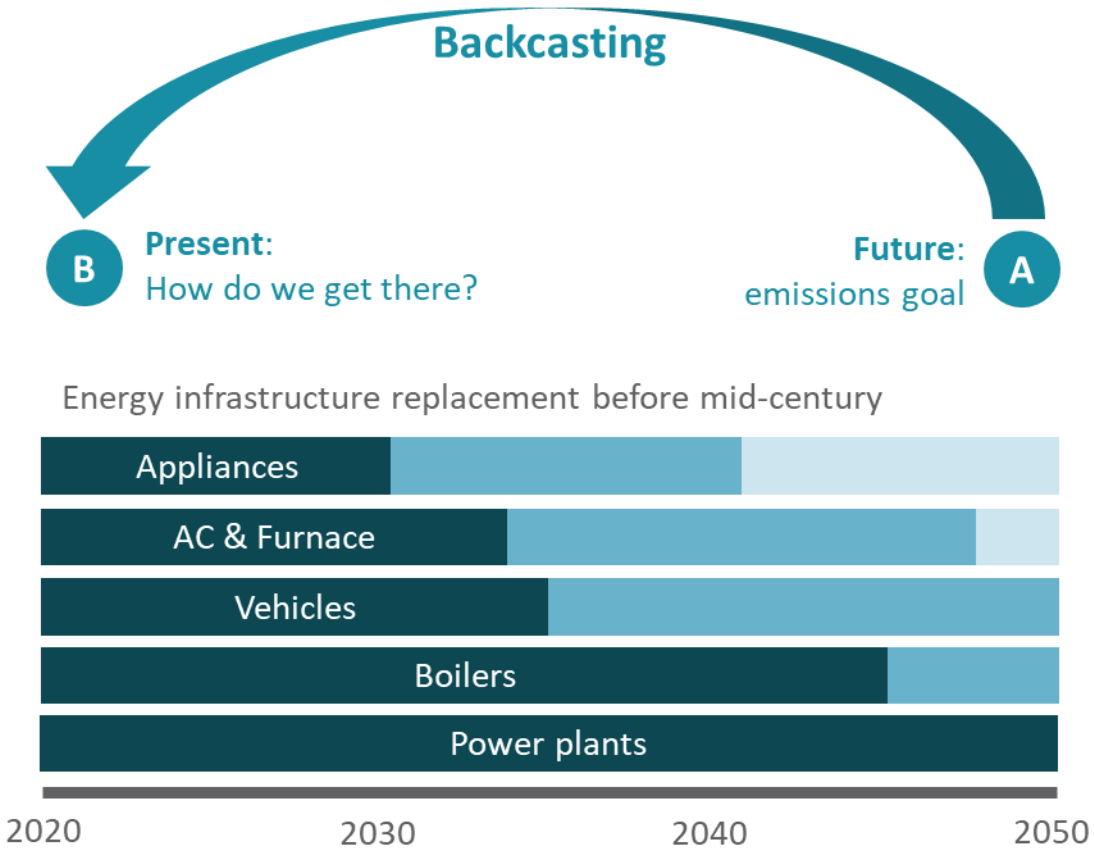
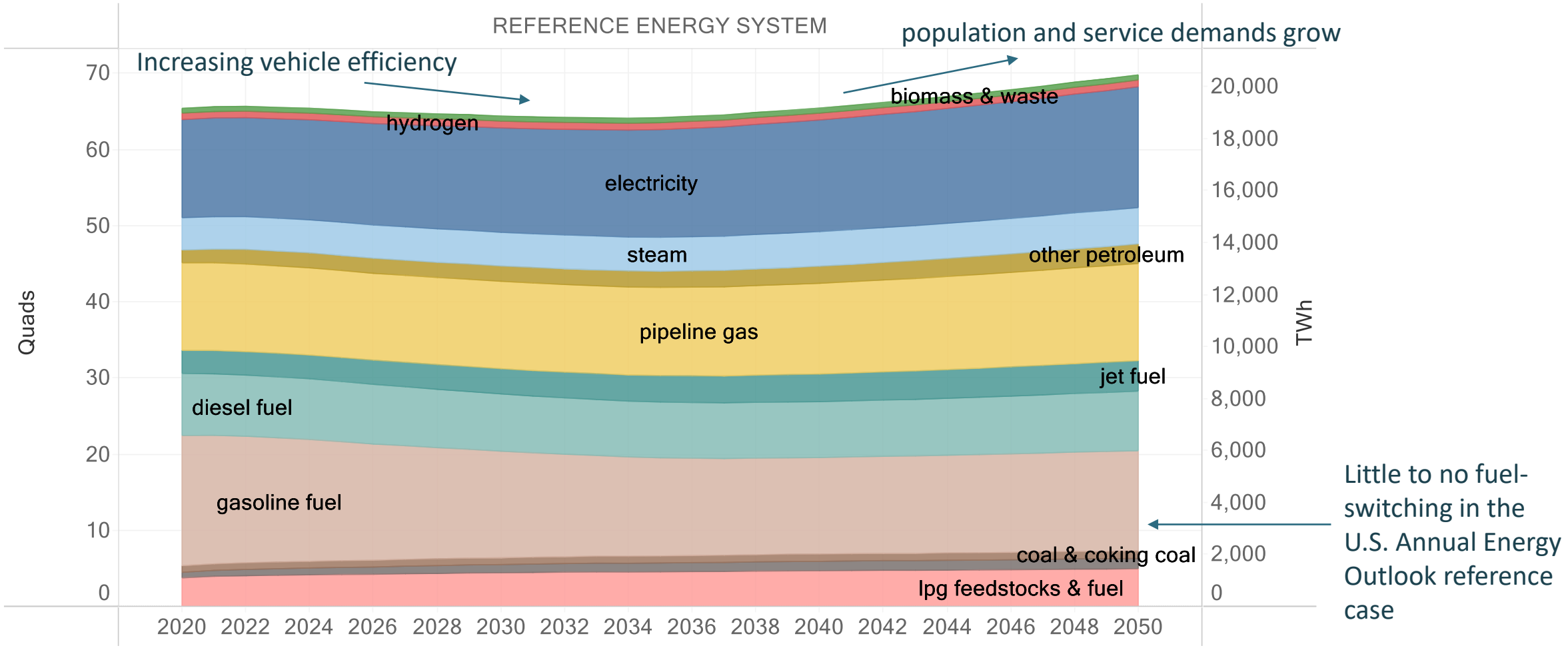
- **Forecasting**: project changes based on expected customer behavior given incentives/technology
- **Backcasting**: start with an end-point and work backwards to infer customer adoption over time

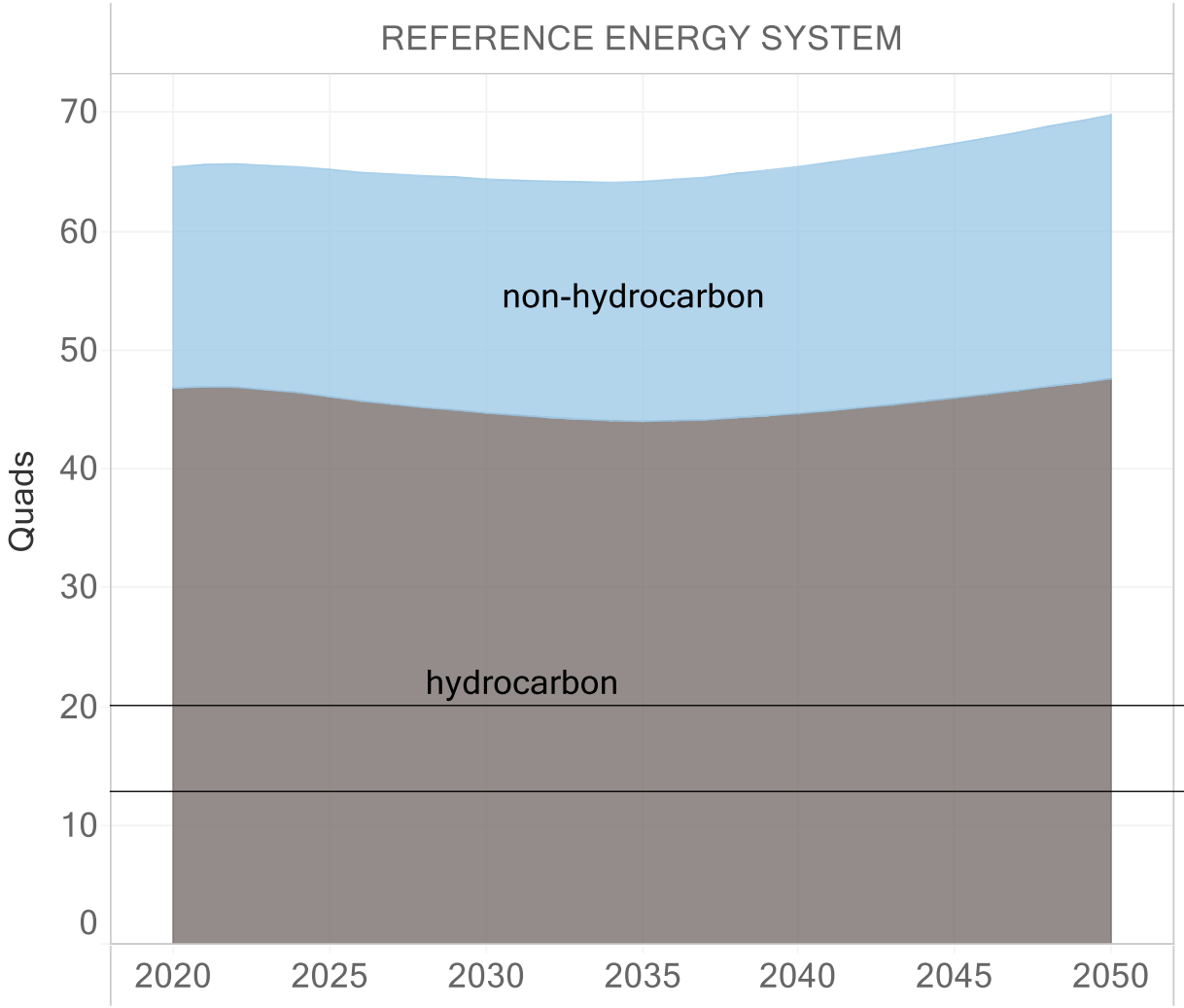


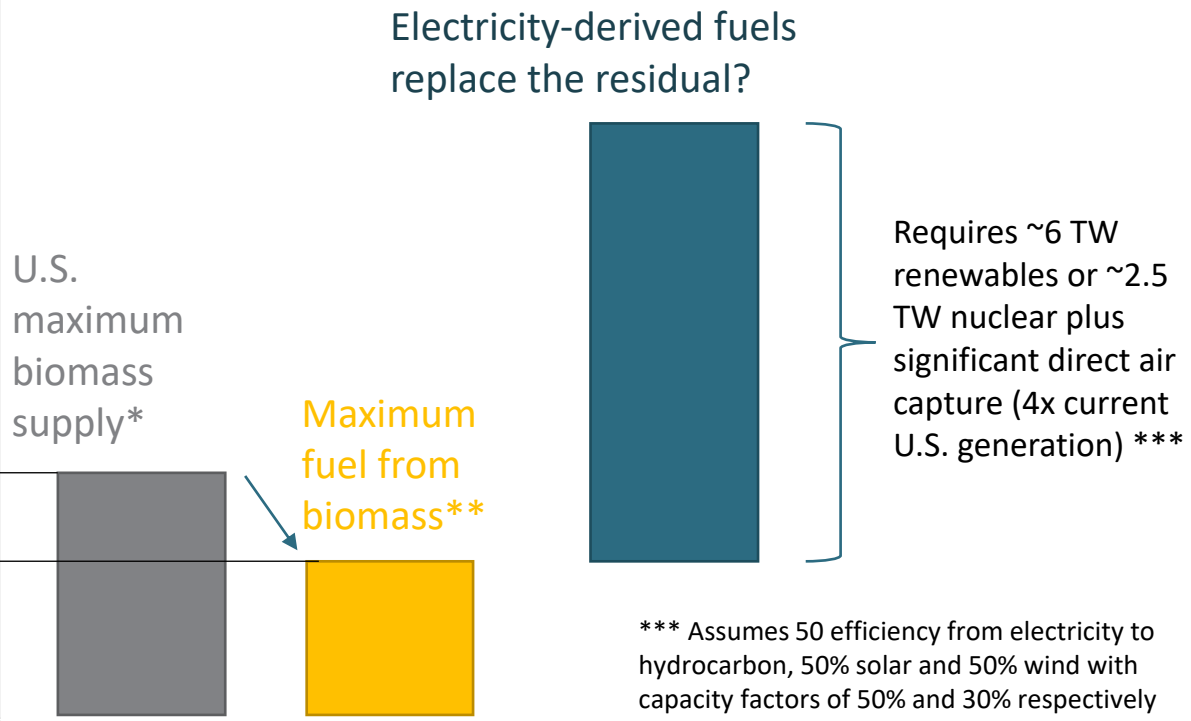
Final energy demand in the U.S. economy



Note: Excludes energy from fossil extraction and refining. Data from AEO2019.

Electrification is required in all low-carbon pathways



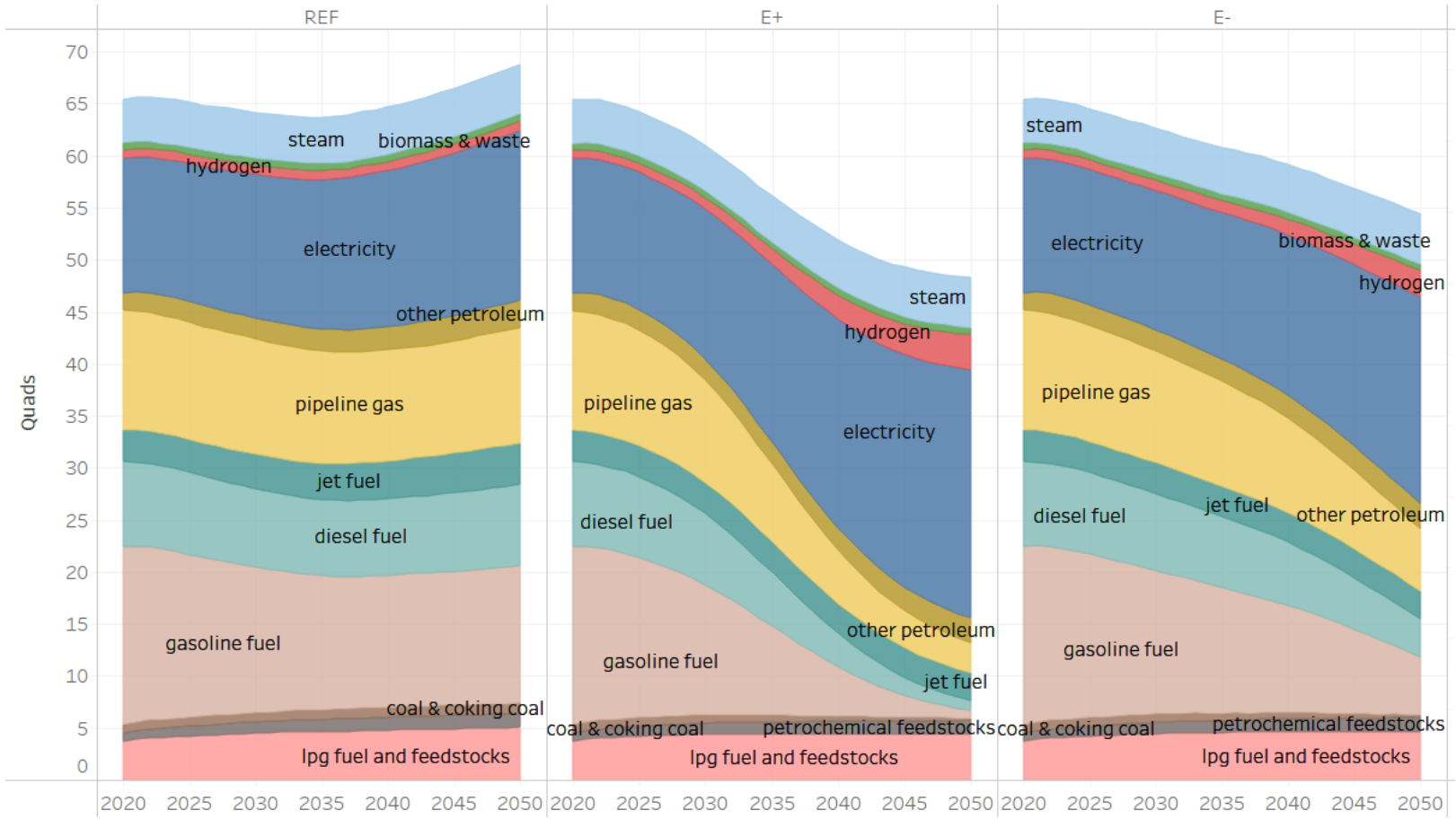


*** Assumes 50 efficiency from electricity to hydrocarbon, 50% solar and 50% wind with capacity factors of 50% and 30% respectively

*U.S. Billion Ton Study **Assumes 50-60% conversion efficiency

Final energy demand scenario examples

- Final energy demand in the reference scenario drops until 2035 due to vehicle fuel economy improvements and then starts to increase again over the following 15 years as service demand grows
- By contrast, the high electrification scenario (E+) shows sharp declines in all petroleum fuels and pipeline gas due to electrification of transportation and buildings, and to a lesser extent industry.



Princeton Net-Zero America Project

Excludes fossil extraction and refining

General conclusions

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- Forecasting vs. backcasting electrification can result in very different long-term load forecasts
  - Forecast ‘reference’ case with 0.2% load growth
  - Back-cast ‘low carbon’ scenarios see periods with 2-3% load growth
  - Early 2020s may be seen, in retrospect, as a period of maximum load growth uncertainty
- Electrification is required for any feasible low-emissions pathway
  - Timing of electrification has more uncertainty than its long-term scale
- IRA is likely to accelerate electrification trends by 5-10 years but forecasts of impacts differ widely

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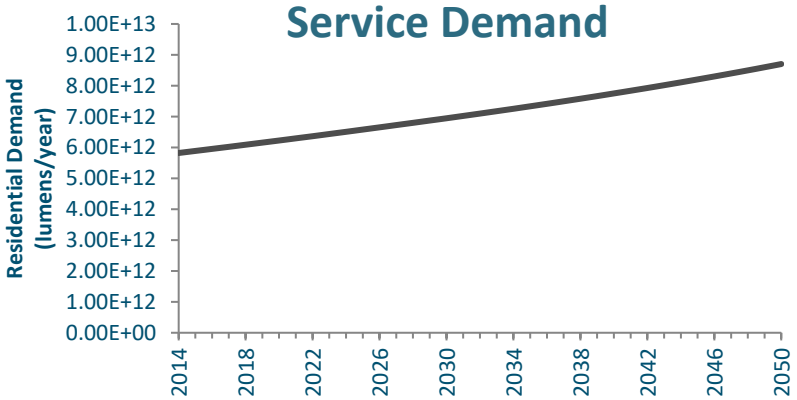
Projecting load bottom-up

Projecting energy demand from the “bottom-up”



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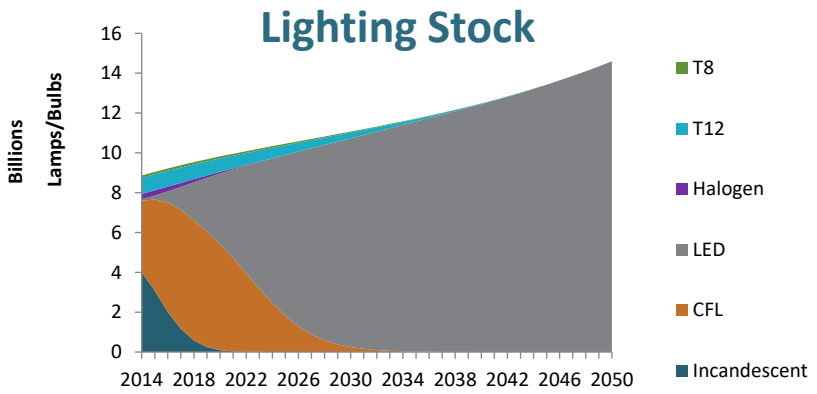

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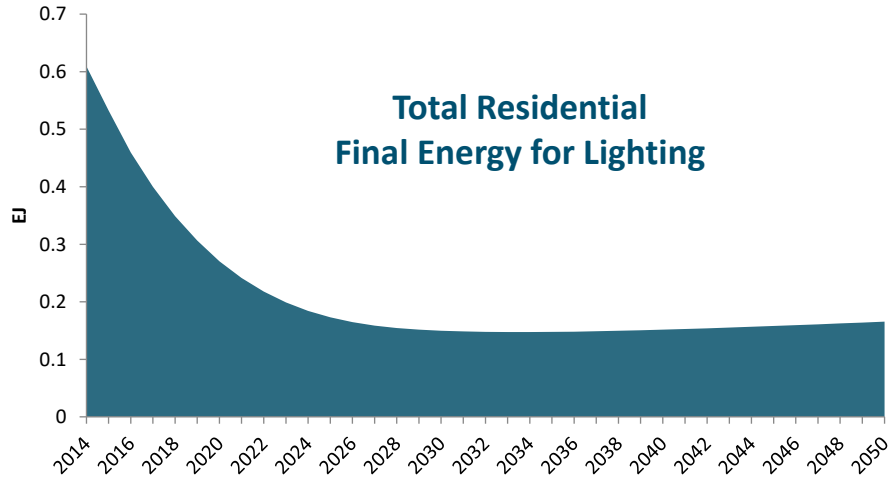
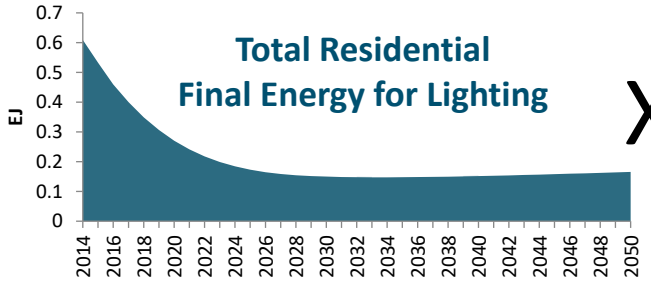


Infrastructure stock rollover model keeps track of “stuff” (i.e., number of light bulbs by type)

Scenario-based, bottom-up energy model (not optimization-based)

Creating hourly electricity load shapes



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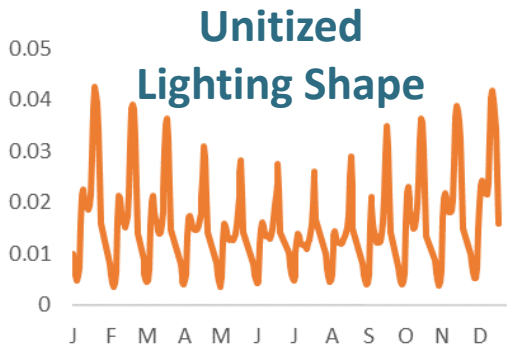

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Projected lighting shape

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Projected EV shape

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Projected heating shape

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Projected dryer shape

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Additional demand subsectors

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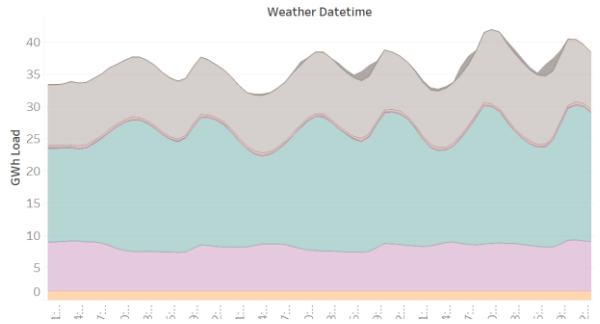
System Load



EnergyPATHWAYS projects future load shapes bottom-up. Annual energy is multiplied by a unitized service demand shape for each subsector and summed across each model region. In the first model year the bottom-up shape is benchmarked against a top-down shape from historical electric utility data. A series of hourly 'reconciliation factors' are created from this comparison that represent both bias and random noise not observed in the (often simulated) end-use data. These reconciliation factors are applied to future years.

U.S. sectoral granularity based on EIA surveys

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Buildings

	Subsector		# Technologies
Commercial	commercial air conditioning	12 building types	22
	commercial cooking		4
	commercial lighting		26
	commercial other		N/A
	commercial refrigeration		18
	commercial space heating		18
	commercial unspecified		N/A
	commercial ventilation		4
	commercial water heating		7
	district services		N/A
	office equipment (non-p.c.)		N/A
	office equipment (p.c.)		N/A
Residential	residential air conditioning	3 building types	13
	residential clothes drying		3
	residential clothes washing		4
	residential computers and related		6
	residential cooking		3
	residential dishwashing		2
	residential freezing		4
	residential furnace fans		N/A
	residential lighting		39
	residential other uses		14
	residential refrigeration		6
	residential secondary heating		N/A
	residential space heating		18
	residential televisions and related		5
	residential water heating		6

Transportation

	Subsector	Sub-category	# Technologies
Transportation	aviation		N/A
	buses	3 duty cycles	5
	domestic shipping		N/A
	freight rail		N/A
	heavy duty trucks	2 duty cycles	6
	international shipping		N/A
	light duty autos		10
	light duty trucks	2 types	11
	lubricants		N/A
	medium duty trucks		6
	military use		N/A
	motorcycles		N/A
	passenger rail	3 types	N/A
	recreational boats		N/A

Industry

	Subsector	Sub-category
Industry	agriculture-crops	4 process types
	agriculture-other	4 process types
	aluminum industry	6 process types
	balance of manufacturing other	9 process types
	bulk chemicals	50 process types
	cement	8 process types
	coal mining	2 process types
	computer and electronic products	10 process types
	construction	3 process types
	electrical equip., appliances, and components	9 process types
	fabricated metal products	9 process types
	food and kindred products	9 process types
	glass and glass products	7 process types
	iron and steel	8 process types
	machinery	9 process types
	metal and other non-metallic mining	2 process types
	oil & gas mining	2 process types
	paper and allied products	7 process types
	petroleum refining	1 process type
	plastic and rubber products	9 process types
	transportation equipment	9 process types
	wood products	9 process types

*Electrolysis load is modeled as an energy supply technology

Sample load shapes for New York (high electrification)

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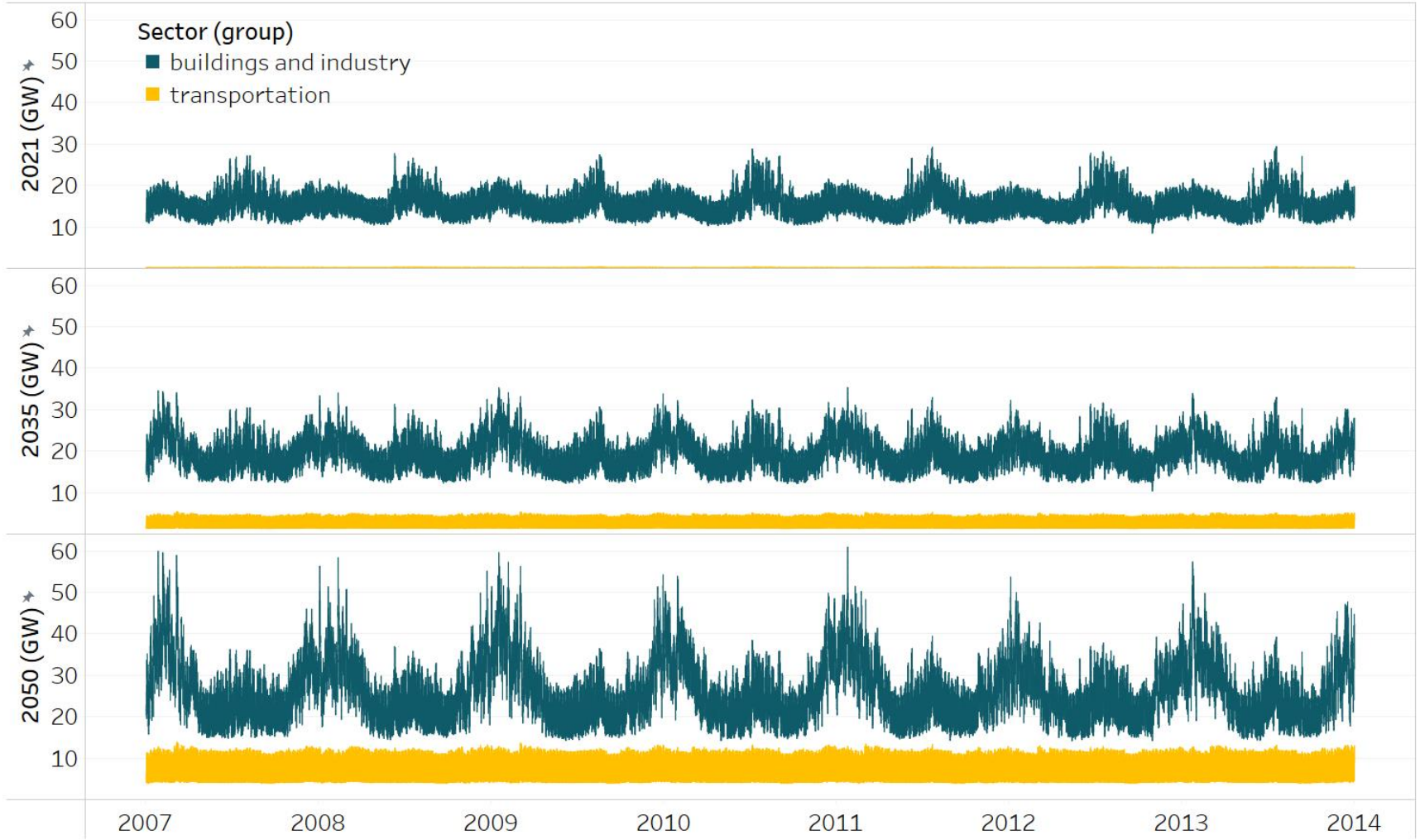
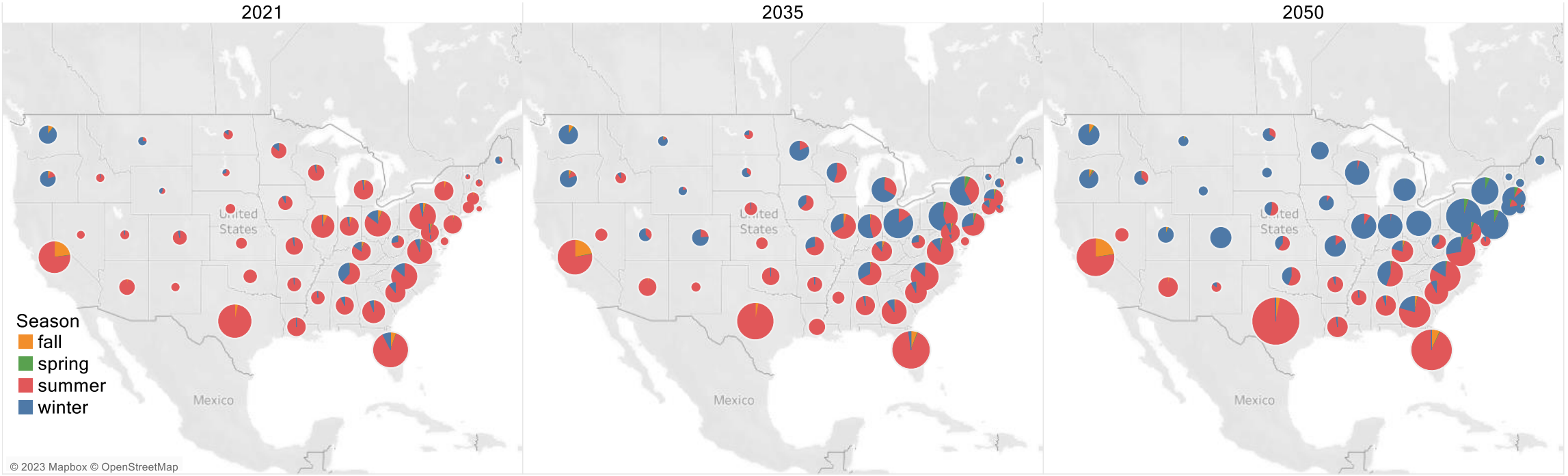


Seasonal loads across the U.S.



- Size based on 1-in-2 peak load
- Seasonal split based on the top 100 load hours per year

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Building electrification impacts

Heating electrification includes many uncertain factors with non-linear impacts on peak load

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- Rates of electrification
- Building mass / insulation improvements
- Heat-pumps
  - Sizing
  - Low-temperature performance (cutout)
  - Back-up heating
  - Technology improvement projections
- Spatial diversity factors
- Future climate changes
- Customer behavior (thermostat set-points, flexible load participation)

Assumptions can be synthesized/summarized by estimating the heating equipment utility factor

Building space heating equipment utility factors

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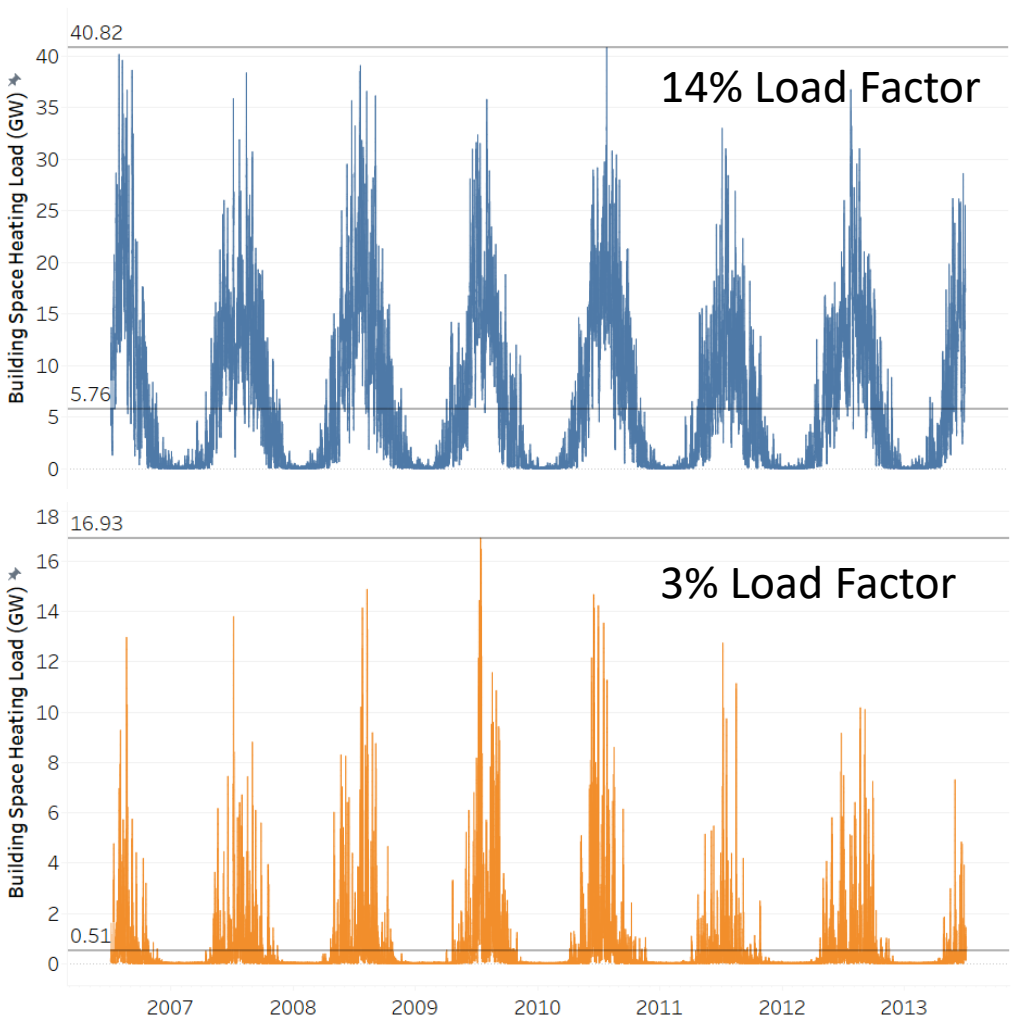
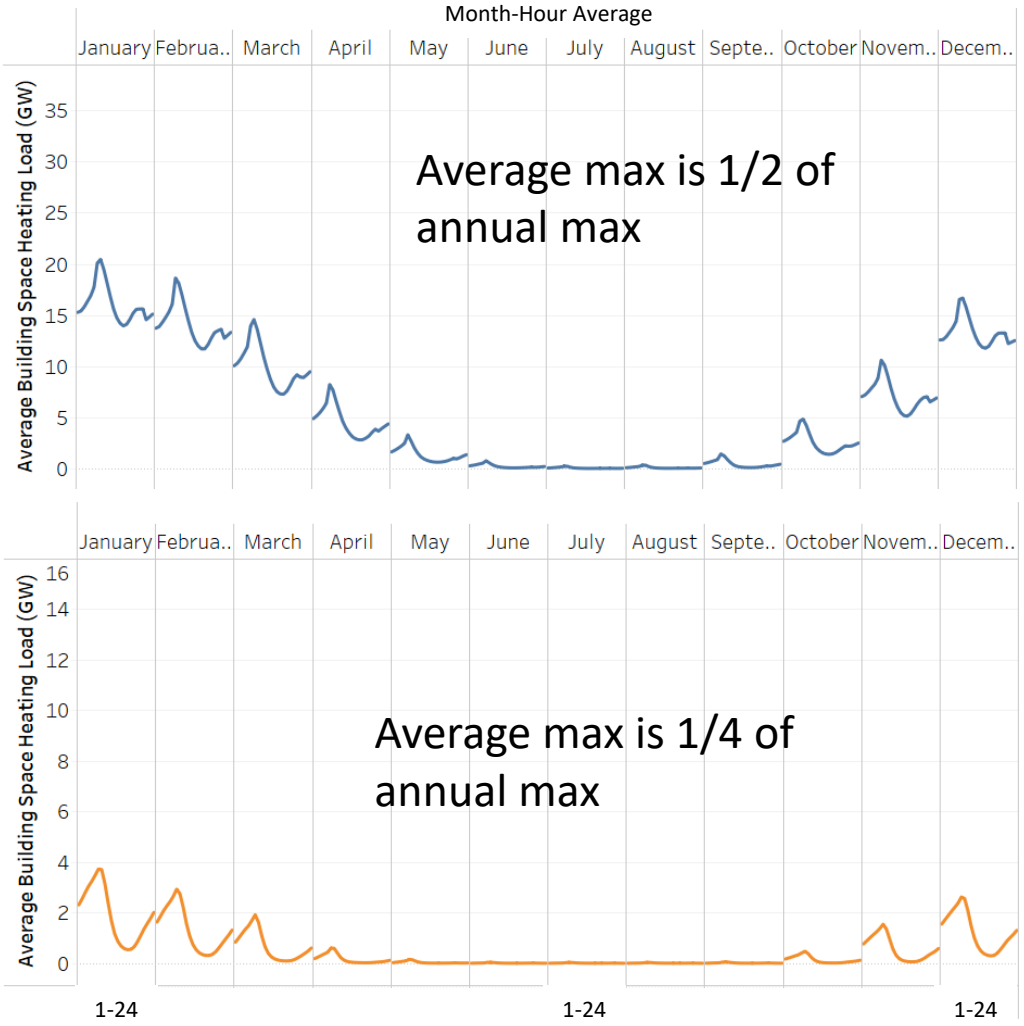
- Utility factor defined as average consumption divided by peak
  - 3-10% -- Possible warm climates. In cold climates, this represents a worst-case scenario. It sometimes means underlying assumptions need to be revisited
  - 10-15% -- Our current best guess for utility factors of populations of heat pumps in temperate climates
  - 16%+ -- Likely too high with a strong possibility of underestimating peak load

Electrification profile examples (2050)

New York



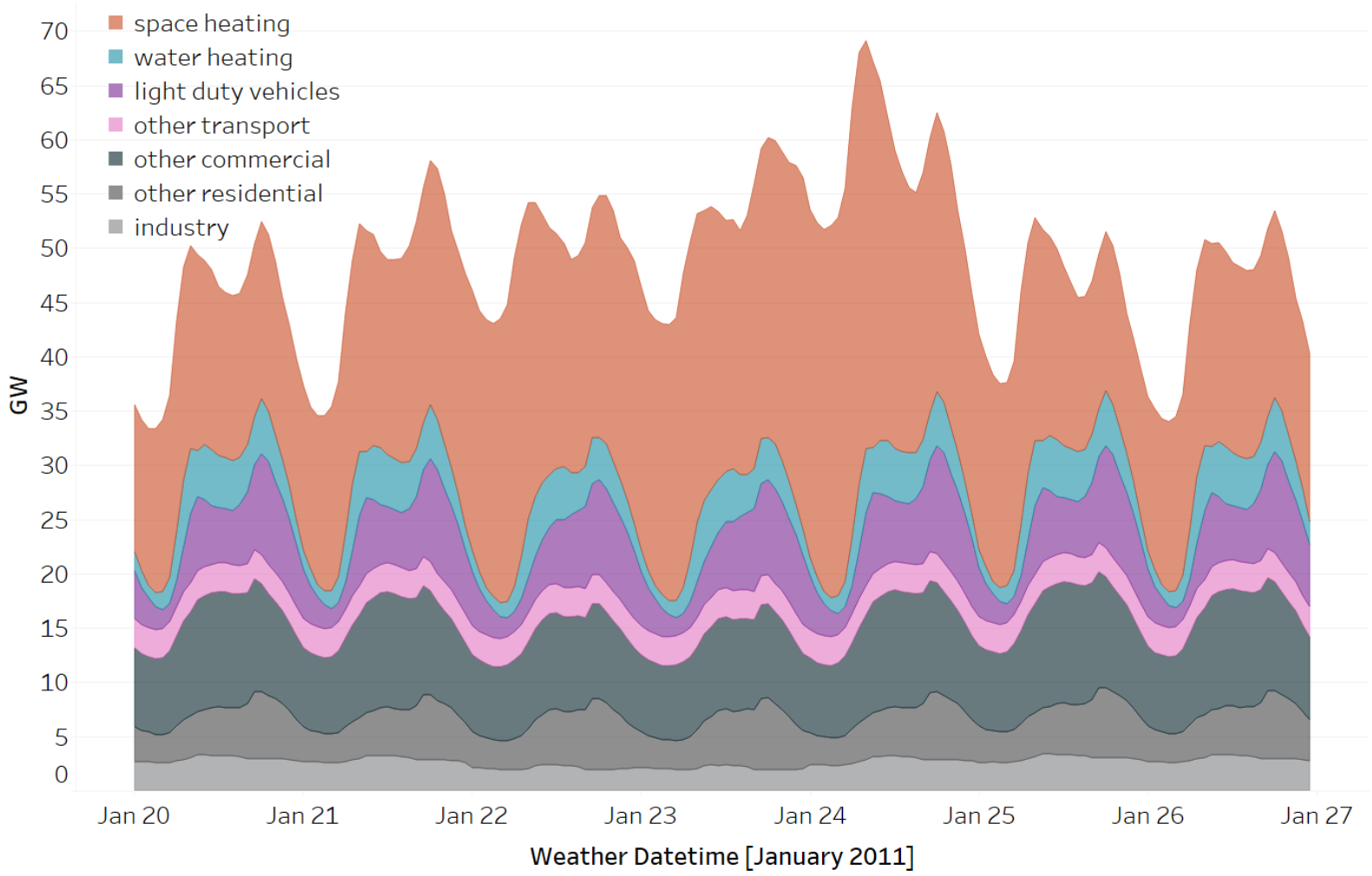
Florida



Shapes are the output of regressions based RESTOCK and COMSTOCK models scaled to annual demand from EP

Flexible load opportunities

- 2050 high electrification example for NY with a peak load on January 24th, 2011 at 8 am
- Loads with built-in thermal or chemical storage 53 GW
- Other loads are 16 GW



THANK YOU

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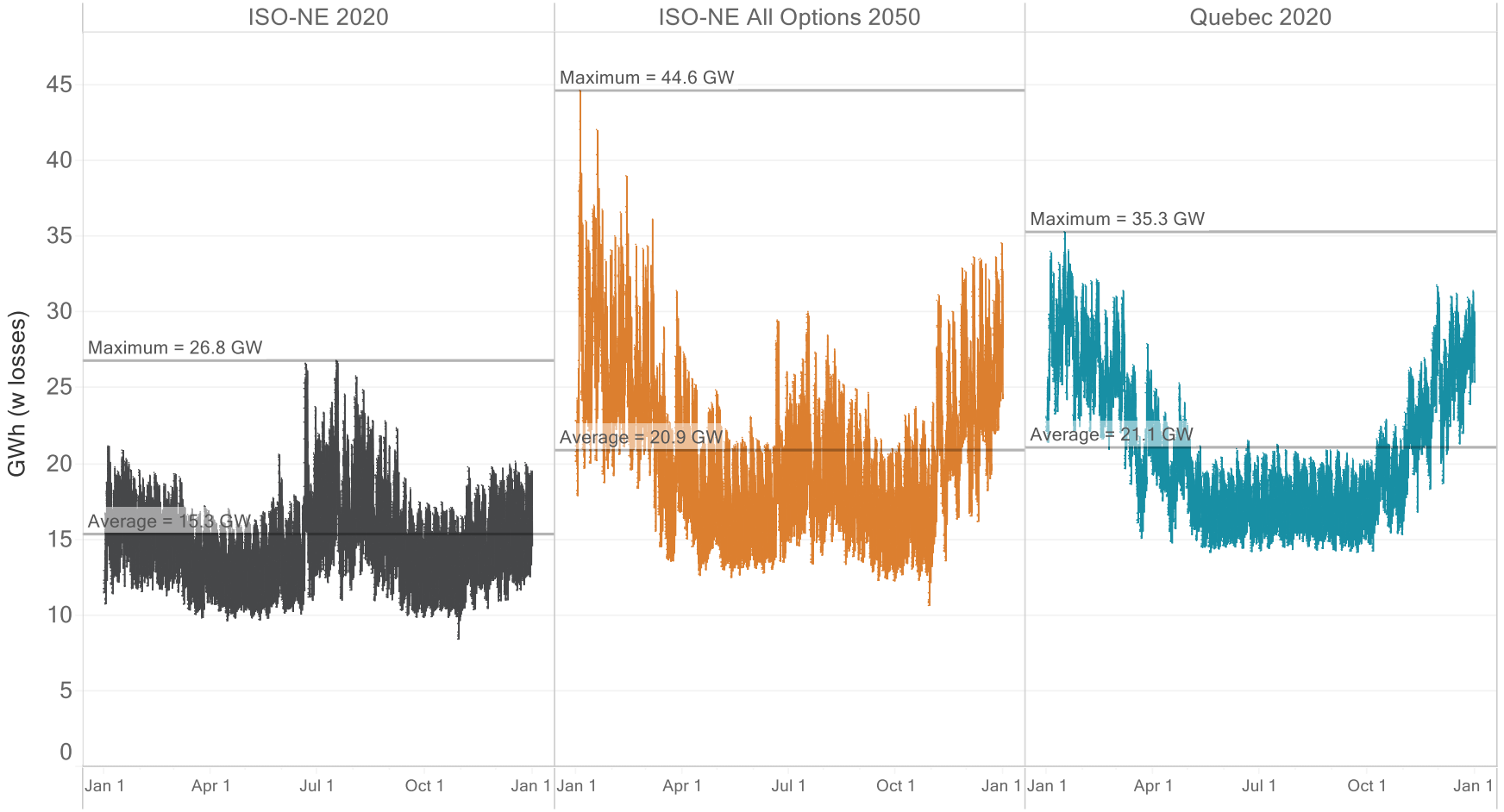
Comparing Net England with Quebec

- Quebec residential customers heat primarily with electric resistance
- Higher industrial loads in Quebec made 1-to-1 comparisons difficult, however, the Quebec experience suggests electric heating is possible if the right steps are taken



Massachusetts Roadmap Study: https://www.evolved.energy/post/ma-decarbonization-roadmap