NARUC Electrification and Load Forcasting

Low-Emissions Pathways & Buildings

June 1, 2023

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Agenda

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

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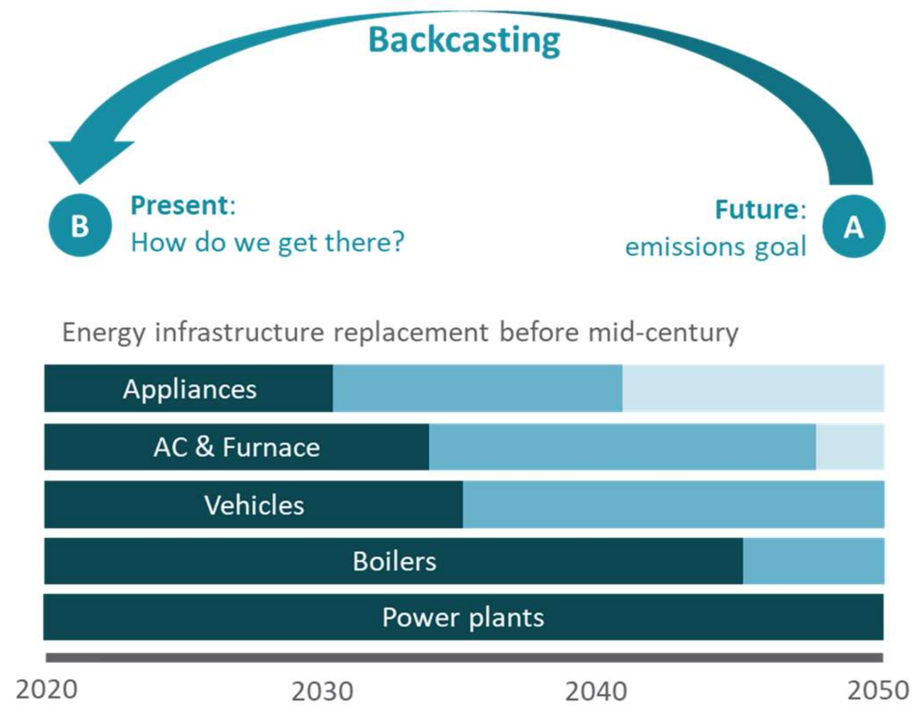
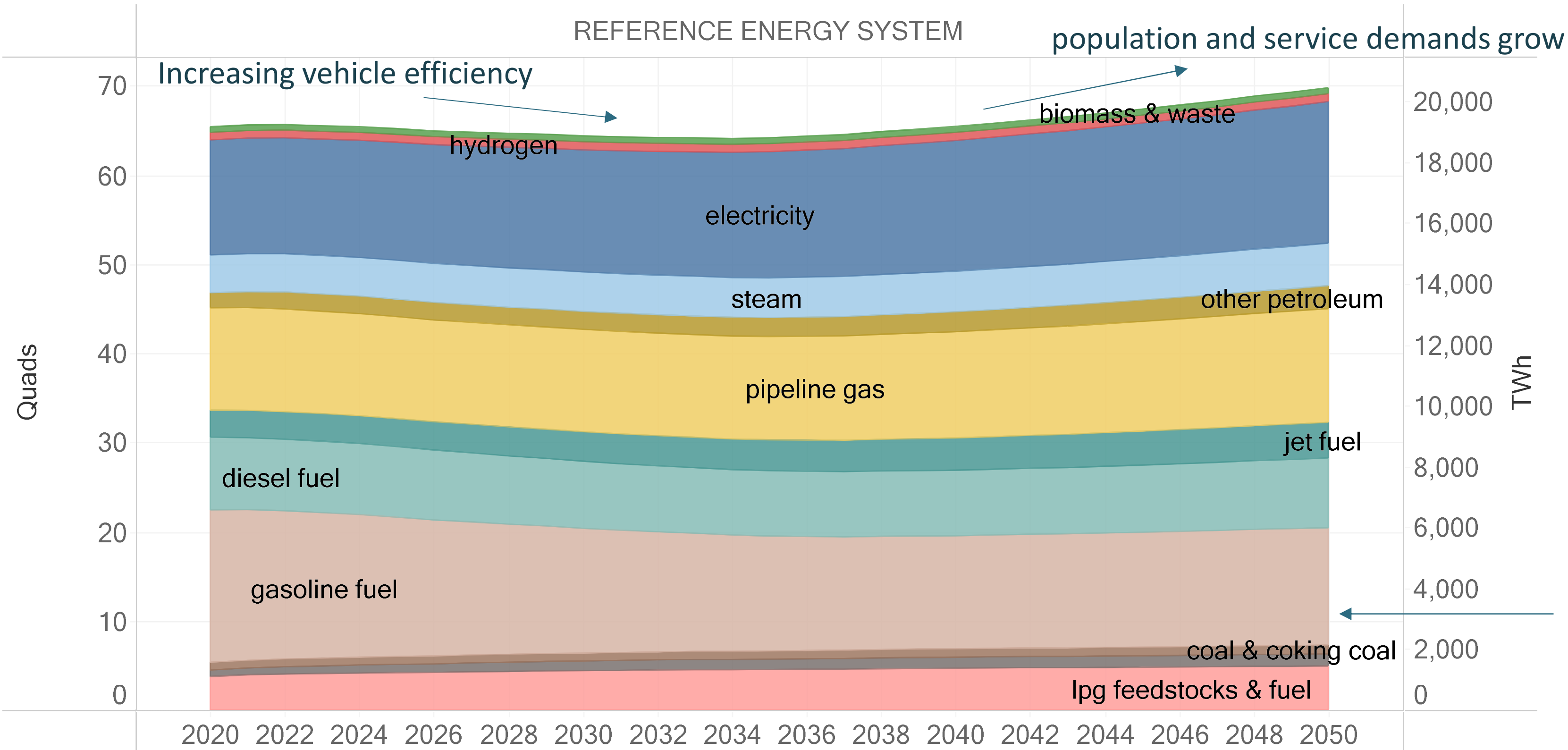
High Electrification Scenarios

Forecasting vs. backcasting

- **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



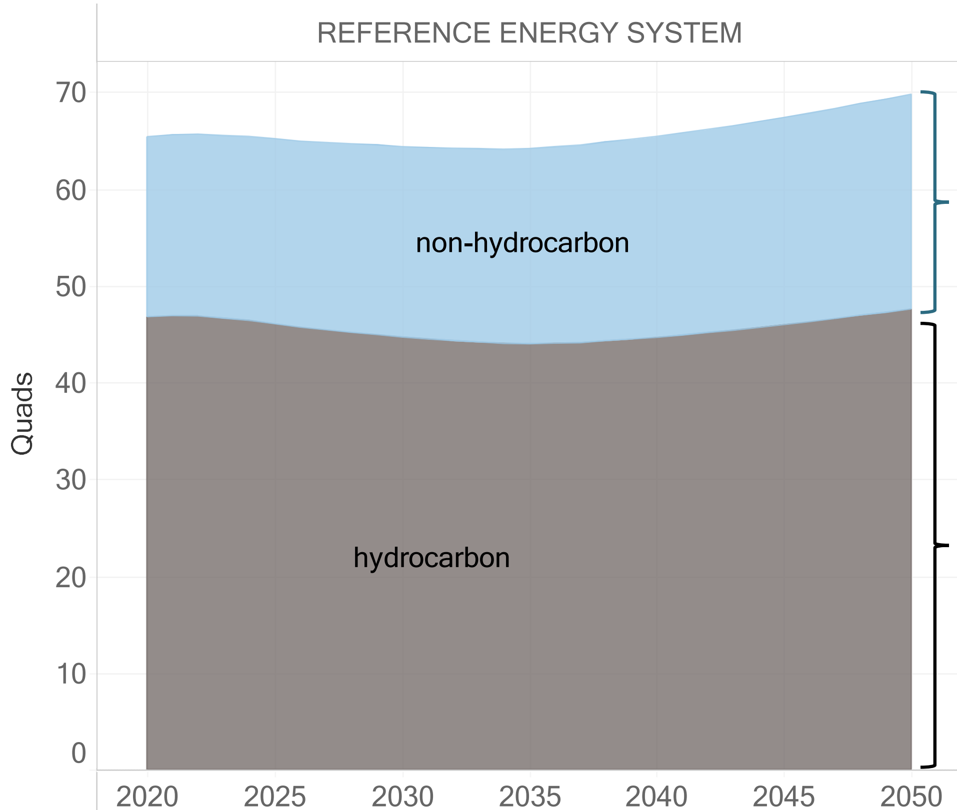
Final energy demand in the U.S. economy



Little to no fuel-switching in the U.S. Annual Energy Outlook reference case

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

Visualizing demand for hydrocarbon fuels

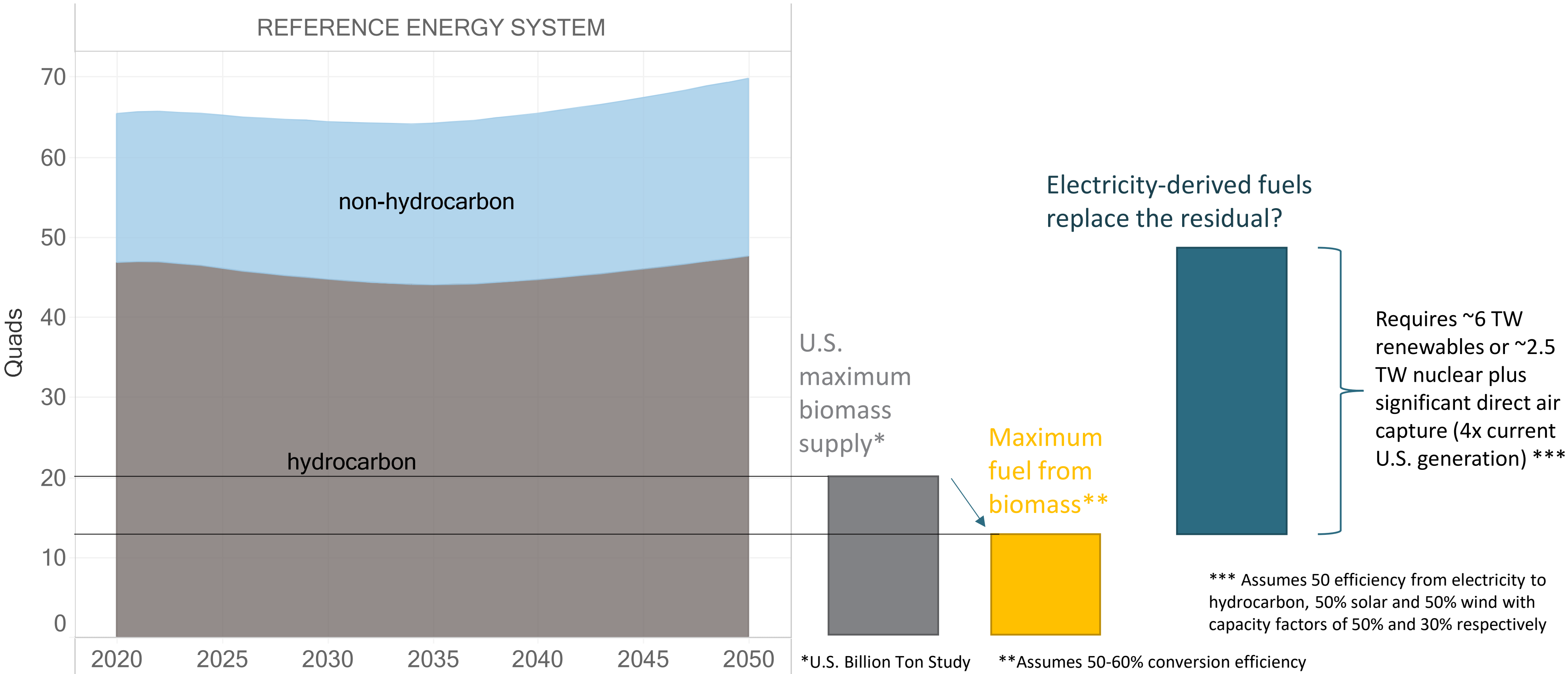


22 quads of non-hydrocarbon final energy demands could be satisfied with zero carbon electricity

48 quads demand for hydrocarbons with the following solutions:

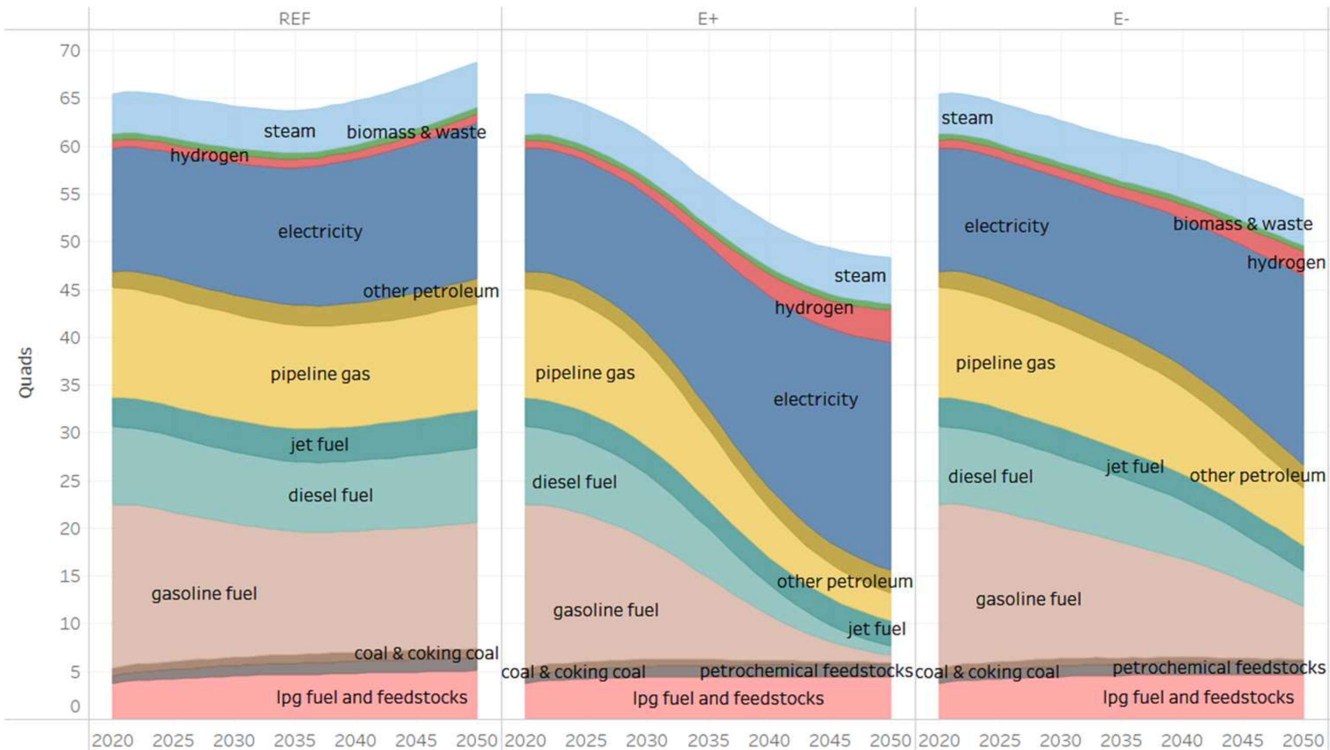
1. **Drop-in fuel replacements**
2. **Efficiency, mode shifting, conservation**
3. **Emissions offsetting**
4. **Electrification**

Electrification is required in all low-carbon pathways



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

- 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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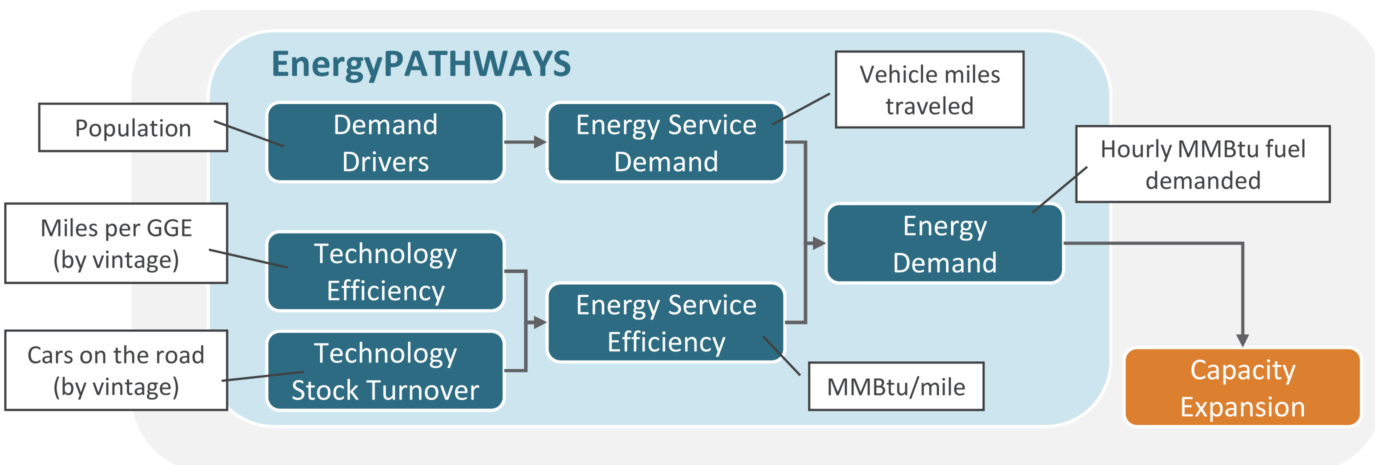
Projecting load bottom-up

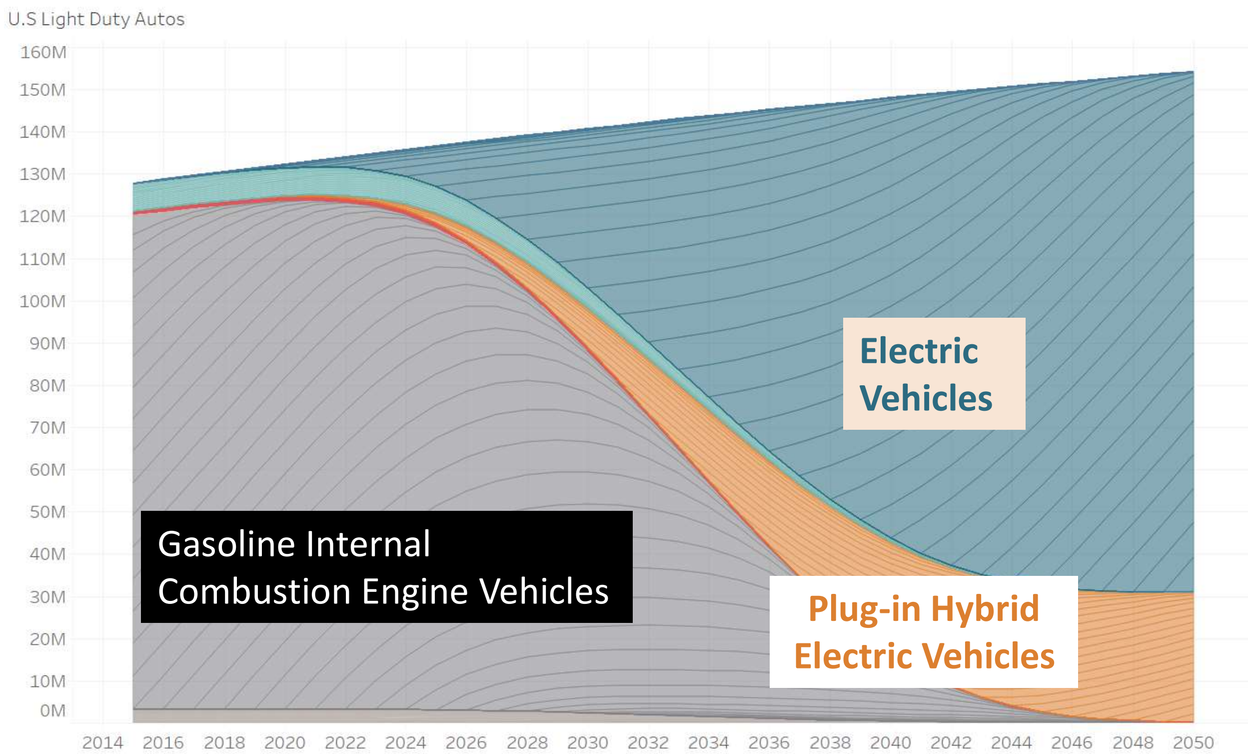
Bottom-up stock turnover models

- EER uses a model called EnergyPATHWAYS, a bottom-up stock accounting model
- The model tracks explicit user decisions about technology adoption and produces final-energy demand and hourly profiles for future years



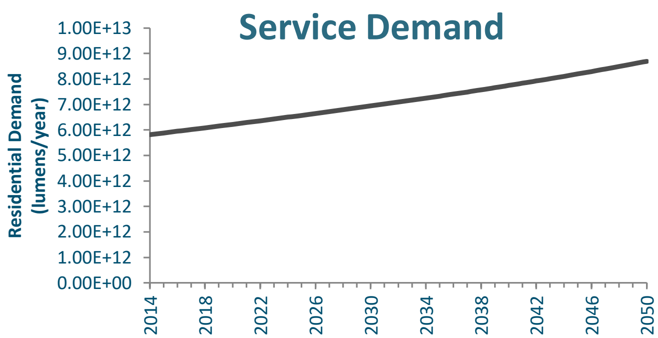
*GGE – Gallon of gas equivalent

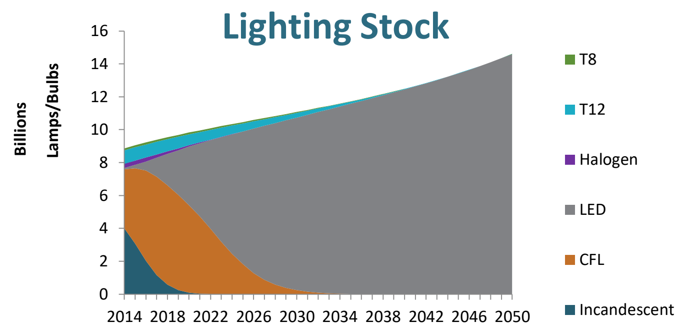
Example stock-rollover for Light Duty Automobiles

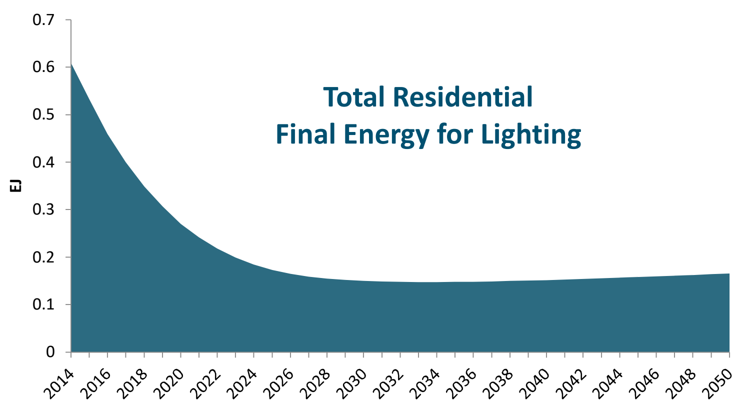


- Lines denote the vintage of the vehicle stock (i.e., when it's placed in service)
- Vintage impacts technology attributes (efficiency and cost) that can change over time
- Many technologies also have service demand that differs by age (new vehicles are driven more than old vehicles)

Projecting energy demand from the “bottom-up”



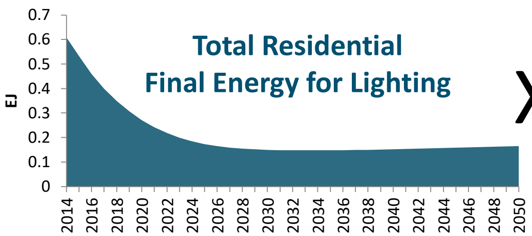




Infrastructure stock rollover model keeps track of “stuff” (i.e., number of light bulbs by type)

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

Creating hourly electricity load shapes



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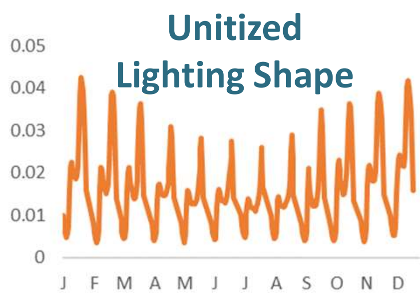

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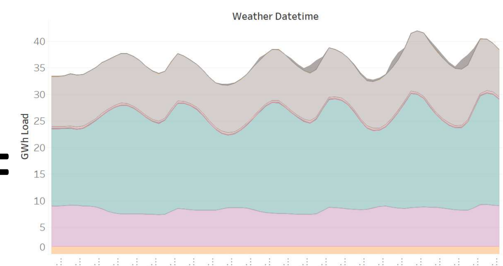
Projected lighting shape
+
Projected EV shape
+
Projected heating shape
+
Projected dryer shape
+
Additional demand subsectors
=

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

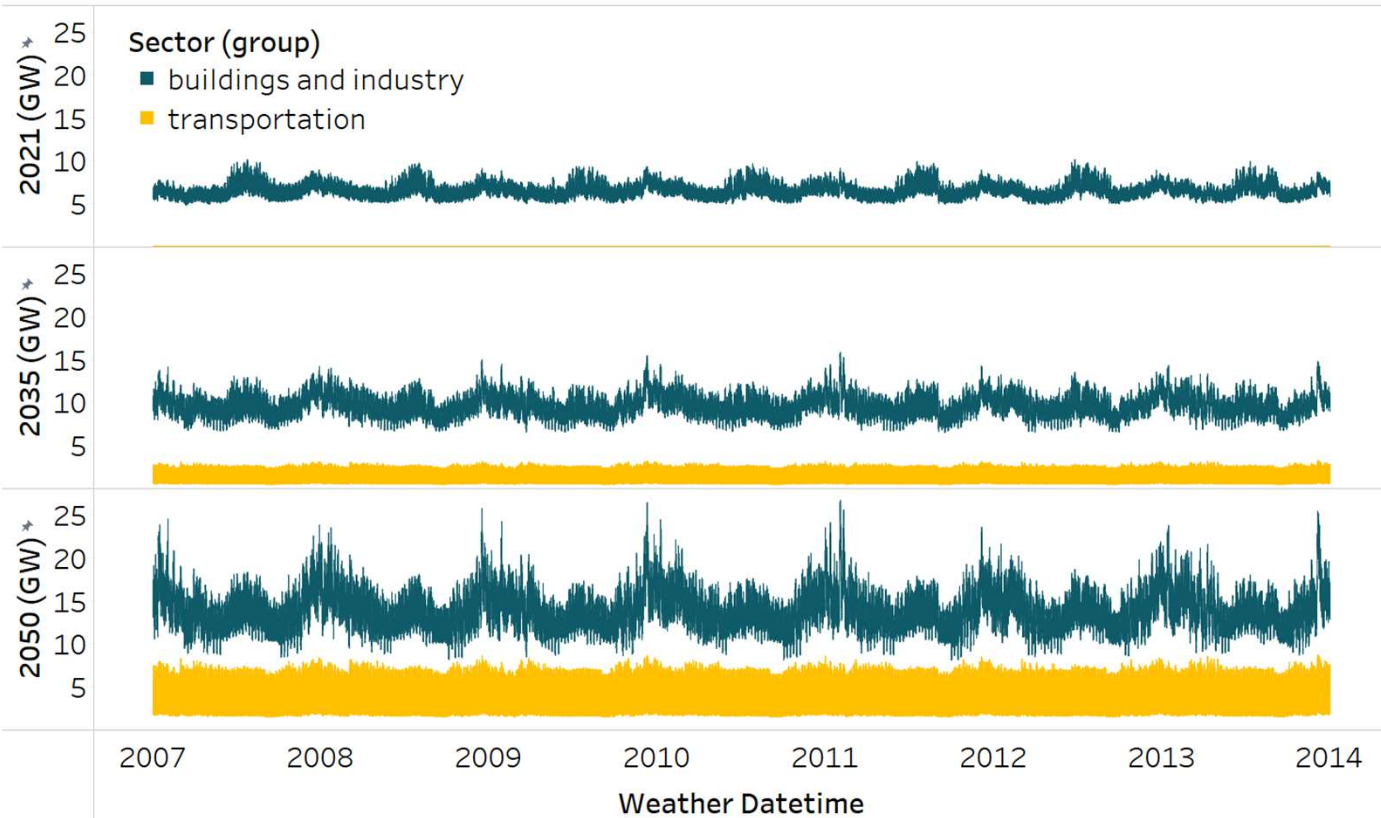
	Subsector	Sub-category	# Technologies
Transportation	aviation		N/A
	buses	3 duty cycles	5
	domestic shipping		N/A
	freight rail		N/A
	heavy duty trucks	2 duty cycles	6
	international shipping		N/A
	light duty autos		10
	light duty trucks	2 types	11
	lubricants		N/A
	medium duty trucks		6
	military use		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 Colorado (high electrification)



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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

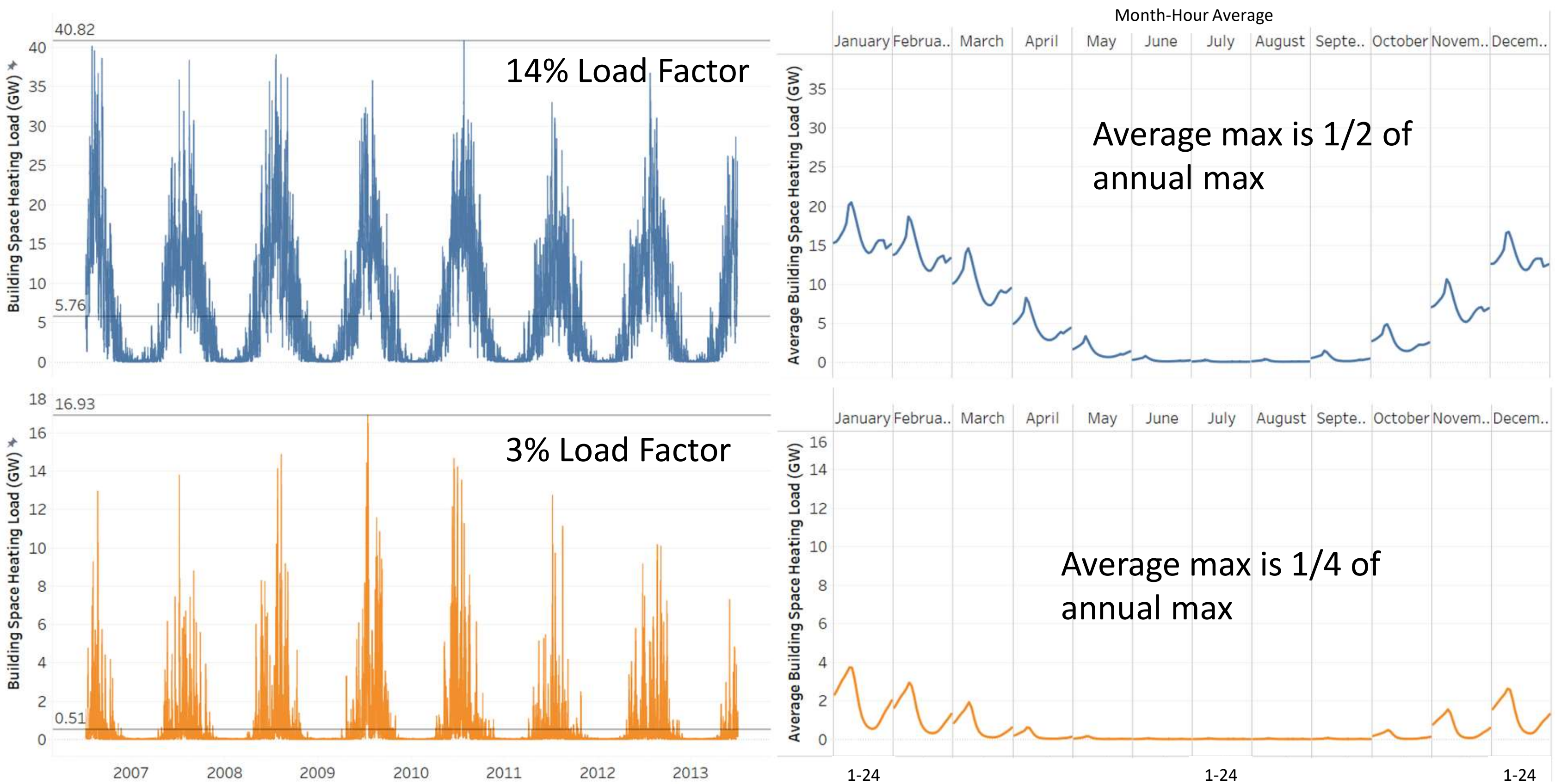
Building space heating equipment utility factors

- 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

New York

Florida



Benchmarking peak heating demand

Category	Heating Peak Analysis	Unit
Total number of households	1,970,000	
Annual heating demand per customer 2020	63	MMBtu
Total heating demand 2020	124,934,000	MMBtu
Building shell efficiency improvement to 2050 + HDD trend	17%	
Total heating demand 2050	104,070,022	MMBtu
Average heating demand per customer 2050	53	MMBtu
Number of customers with electric heat	1,700,000	
Heating demand in 2050 for electric customers	89,806,618	MMBtu
Average coefficient of performance assumed on the worst day	1.85	COP
Per customer heat demand on the coldest day	0.44	MMBtu
Heating demand for electric customers on the coldest day	740,451	MMBtu
% of annual heating allocated to the coldest day	0.82%	
System electricity consumed on the worst day	117	GWh
Customer electricity consumption on the coldest day	69	kWh
Peak / average heating profile	1.42	
Space heating peak demand	6,926	MW

- Spreadsheet bottom-up estimates can be used to test building simulation modeling outputs
- High/low bias across input assumptions can change peak load estimates by a wide margin

THANK YOU

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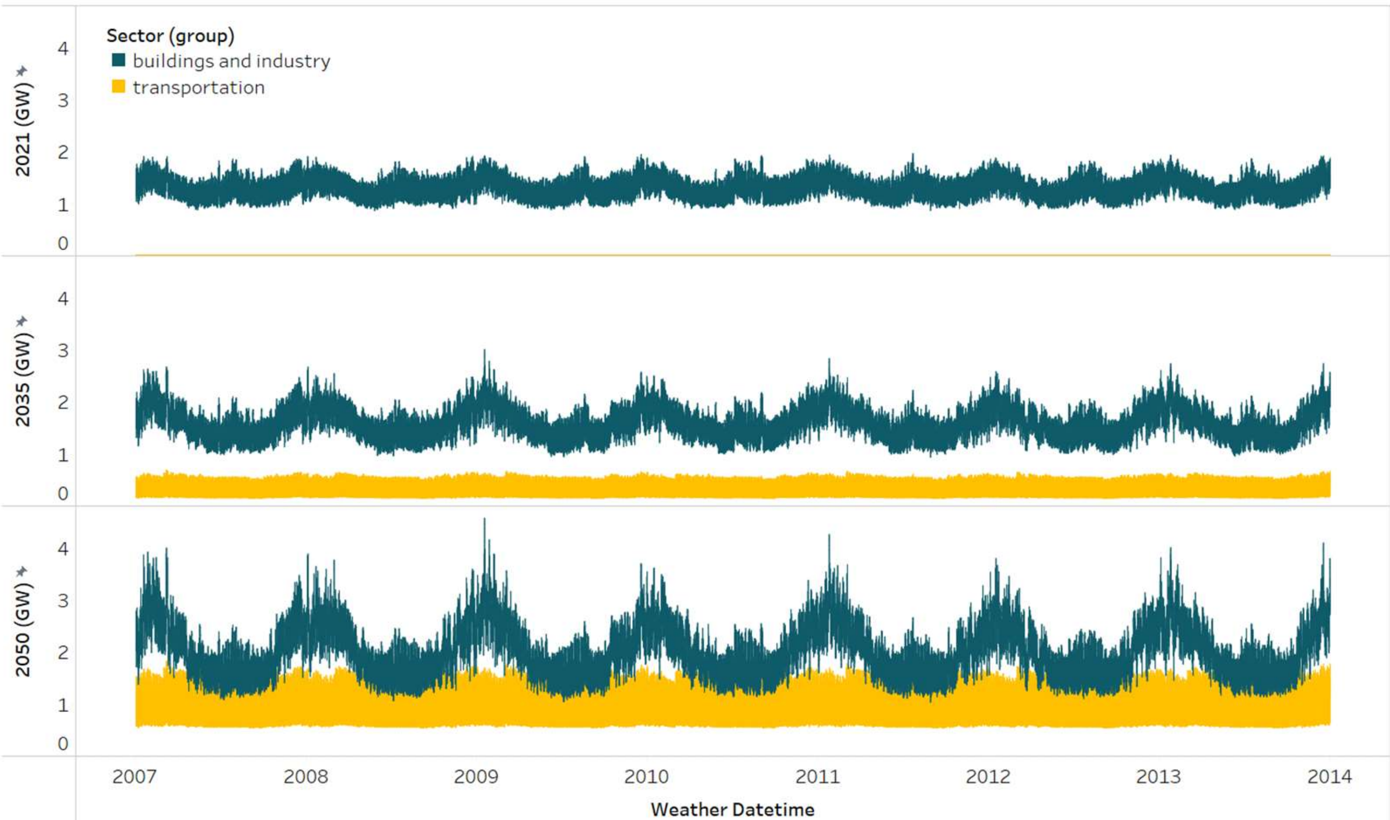
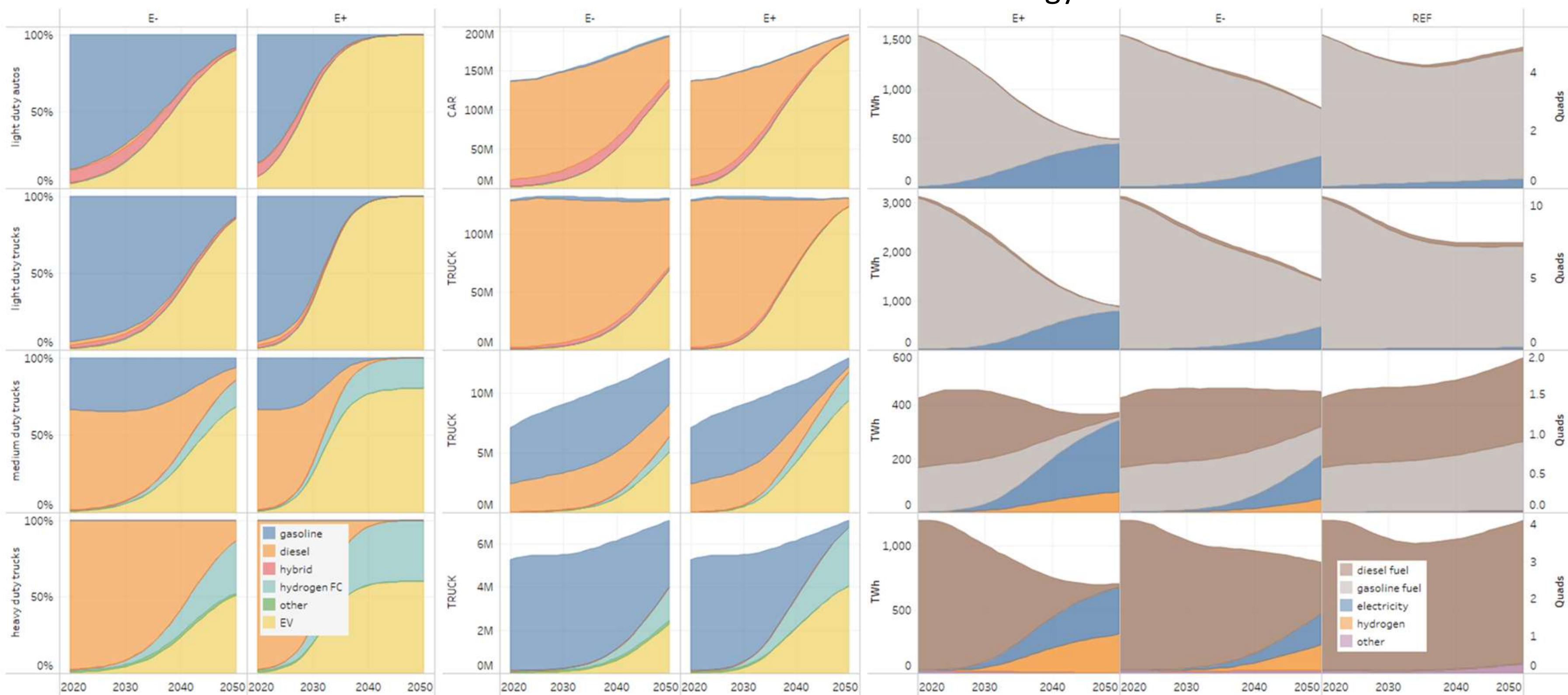
Sample load shapes for Maine (high electrification)

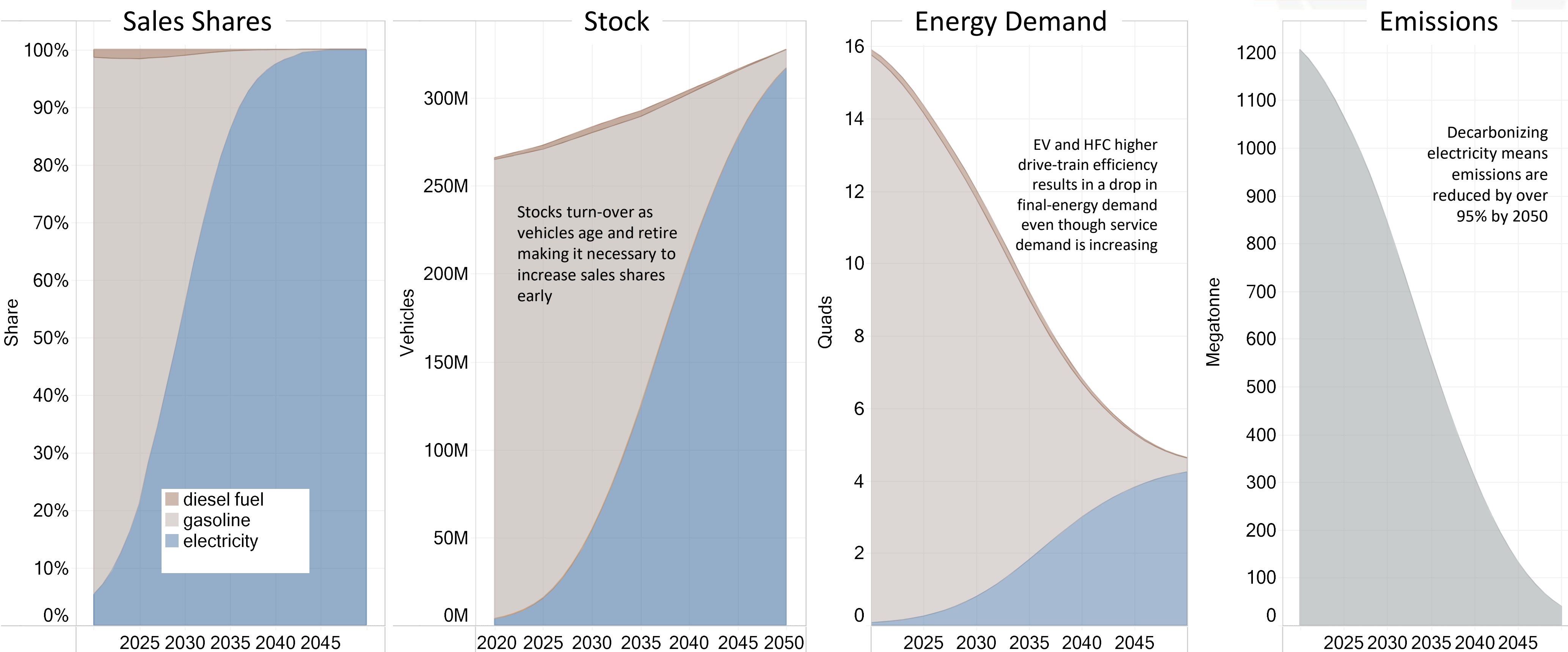


EnergyPATHWAYS sales & stock example

Sales Stock Final Energy



Infrastructure transition example: light-duty vehicles



Slower electrification under an emissions constraint results in more electricity demand

- Load is shifted from buildings and transportation to industrial loads associated with fuels production
- Literature is in general agreement that slower electrification pathways increase costs