Utility and Grid Operator Resources for Future Power Systems Webinar Series

Advanced Load Forecasting

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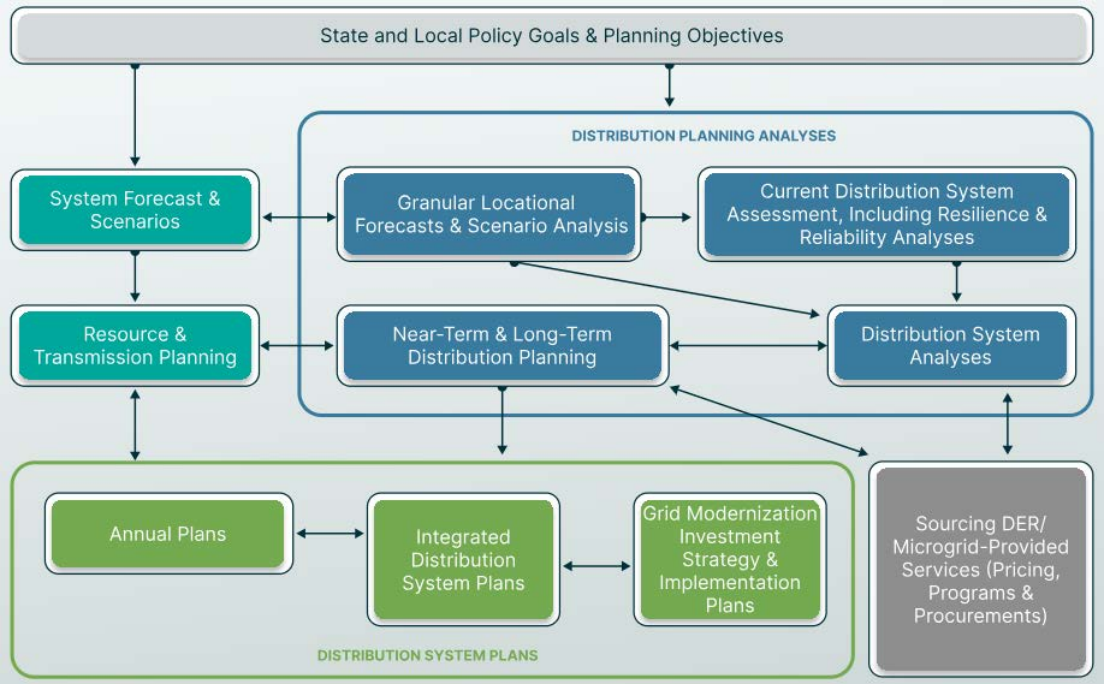
NREL Webinar Series
June 24, 2025

Overview

- Background
- Current State of the Industry
- Current Challenges and Interests
- NREL Tools and Capabilities
- Q&A and Discussion

Load Forecasting Is the Foundation of Planning

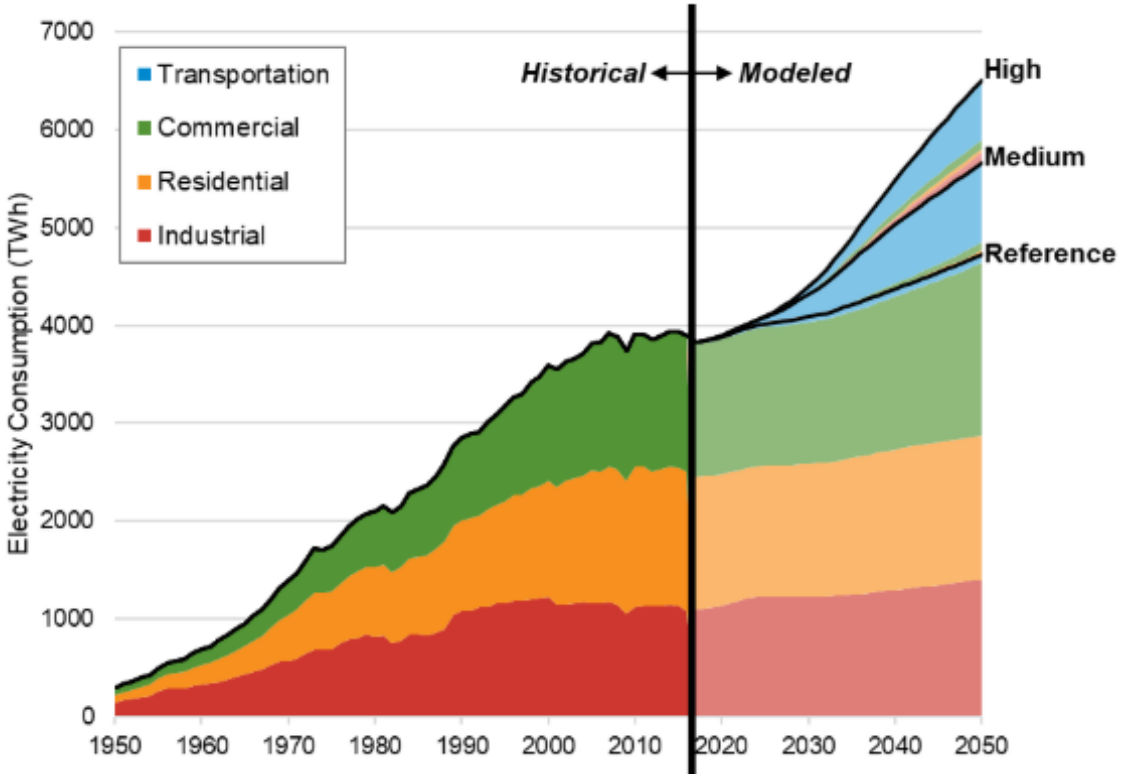
- Load forecasting is **fundamental to utility planning processes**
  - Integrated resource planning
  - Transmission planning
  - Distribution system planning
  - Rate design
  - Customer program design



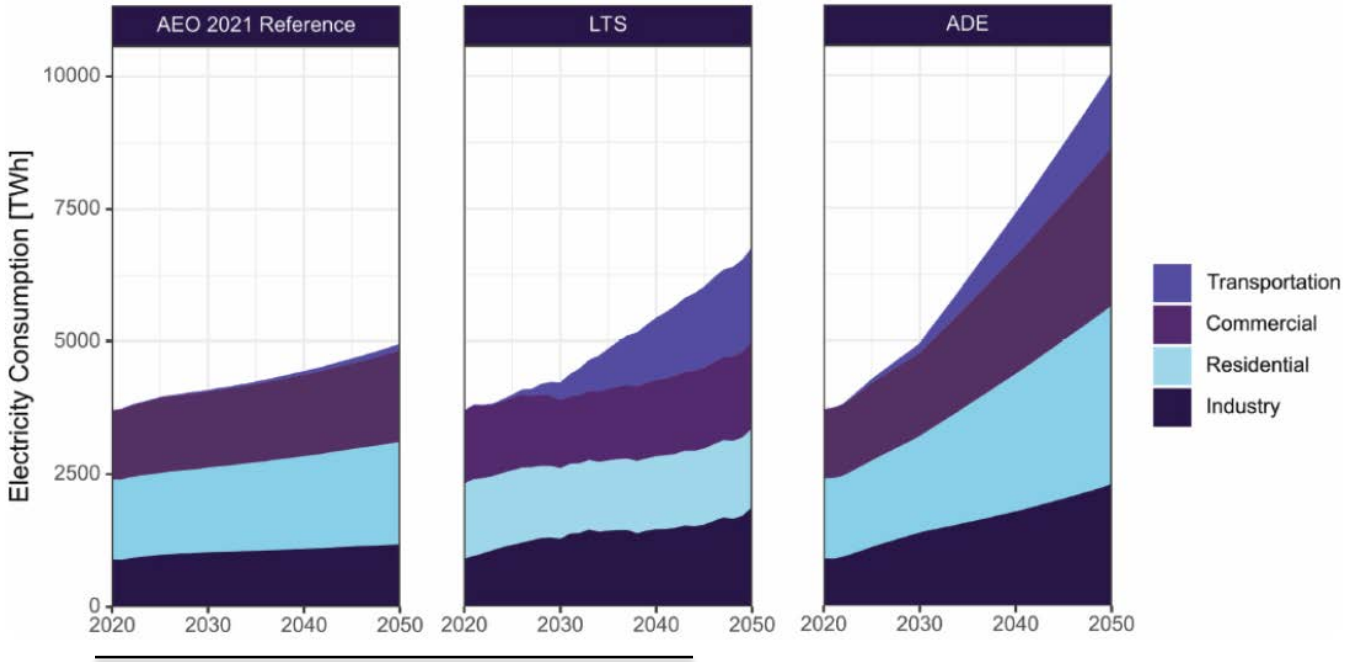
Lawrence Berkley National Laboratory. 2024. "Integrated Distribution System Planning." https://emp.lbl.gov/projects/integrated-distribution-system-planning

Electric Loads Are Changing

U.S. Annual Electricity Forecast (2016)



U.S. Annual Electricity Forecast (2022)



AEO: Annual Energy Outlook
LTS: Long-Term Strategy
ADE: Accelerated Demand Electrification

- National Renewable Energy Laboratory. Electrification Futures Study (EFS). https://www.nrel.gov/analysis/electrification-futures.html.
- 2023. "The Evolving Electricity System and the Potential Role of Advanced Nuclear Reactors." In *Laying the Foundation for New and Advanced Nuclear Reactors in the United States*. National Academies of Sciences, Engineering, and Medicine. Washington, DC: The National Academies Press. https://doi.org/10.17226/26630.

Predicting the Future Is … Hard.

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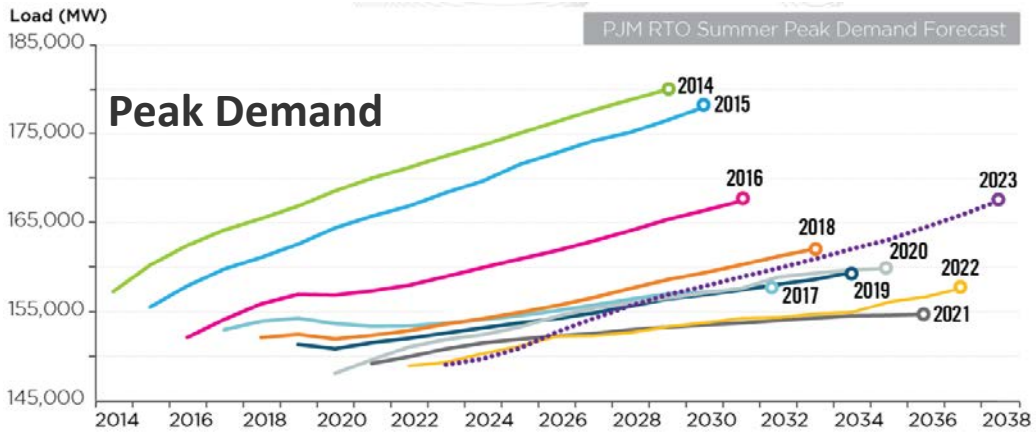

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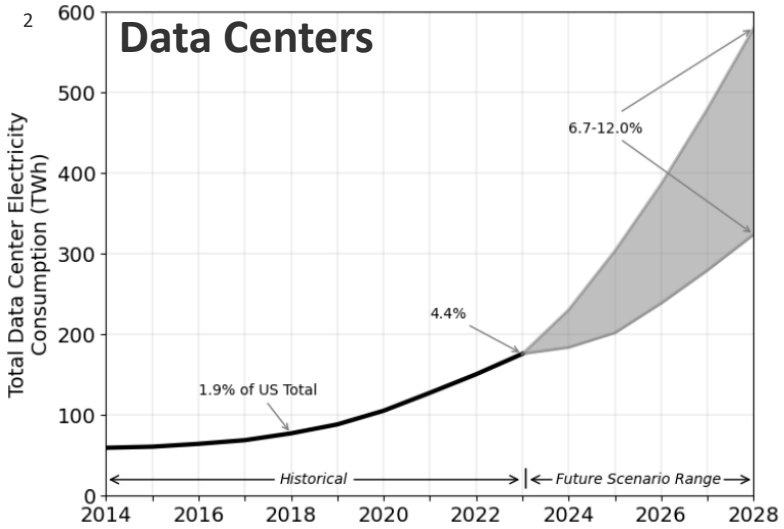
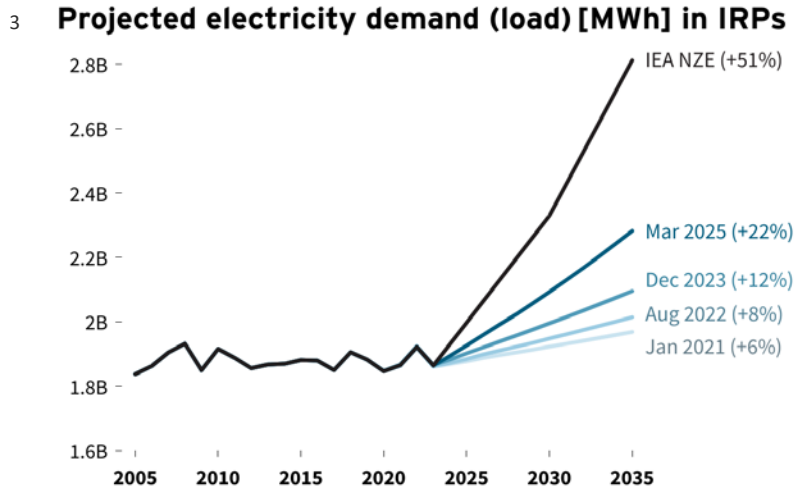


PJM: Pennsylvania-New Jersey-Maryland
IRP: Integrated Resource Planning
dPV: Distributed Photovoltaics

3



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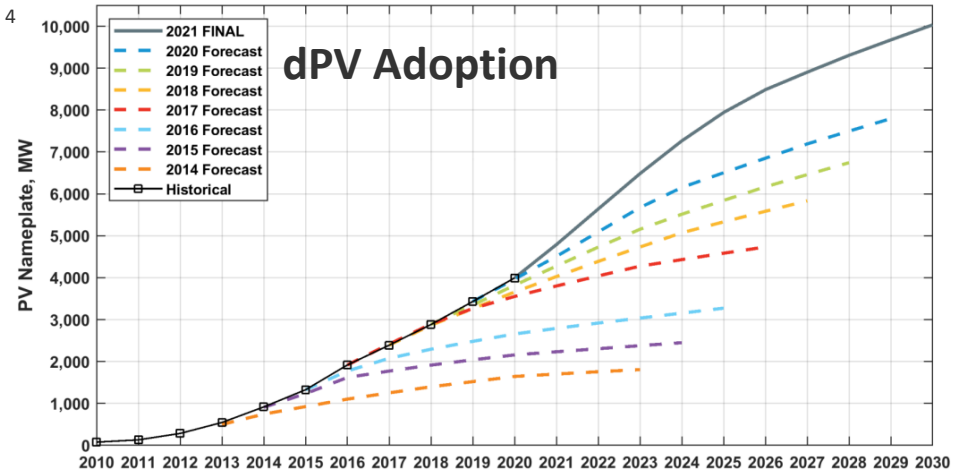


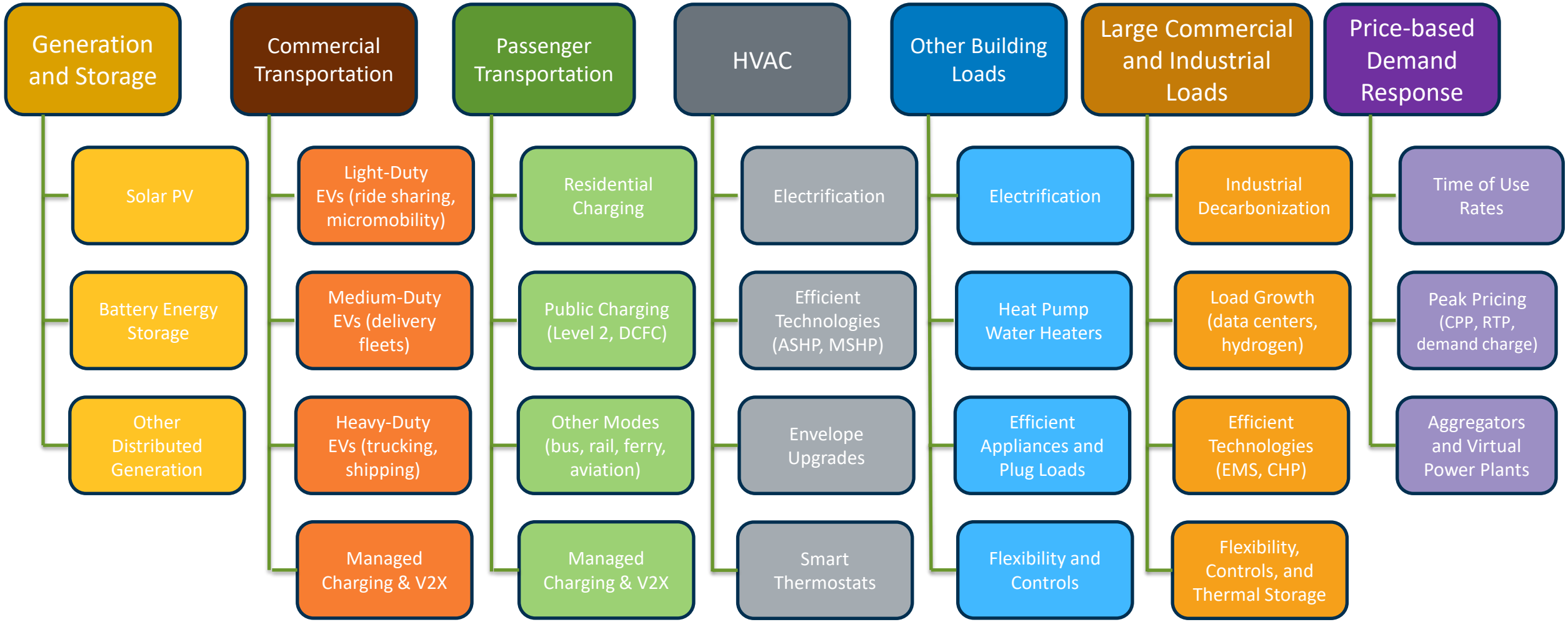
[1]PJM. 2023. 2022 Tennessee Infrastructure Report. https://www.pjm.com/-/media/library/reports-notices/state-specific-reports/2022/2022-tennessee-state-infrastructure-report.ashx

[2]Shehabi, Arman, Sarah Smith, Alex Hubbard, Alex Newkirk, Nuoa Lei, Md Abu Bakar Siddik, Billie Holecek, Jonathan Koomey, Eric Masanet, and Dale Sartor. 2024. *2024 United States Data Center Energy Usage Report*. Berkeley, California: Lawrence Berkeley National Laboratory. LBNL-2001637. https://eta-publications.lbl.gov/sites/default/files/2024-12/lbnl-2024-united-states-data-center-energy-usage-report.pdf.

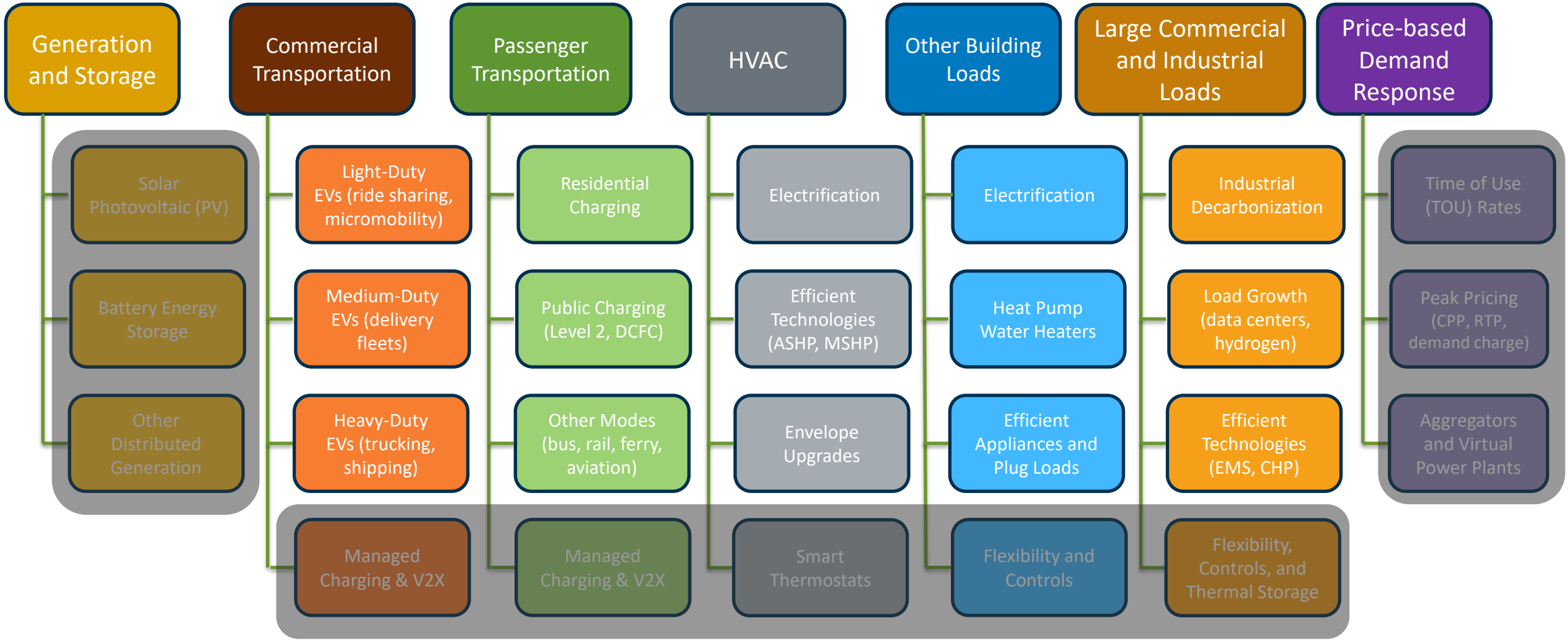
[3]Rea, Jon, and Ryan Foelske. 2025. "The State of Utility Planning, 2025, Q1." RMI. https://rmi.org/the-state-of-utility-planning-2025-q1/.

[4]Fontaine, Mike. 2021. “Solar Power Growth in New England.” ISO New England. https://www.energy.gov/sites/default/files/2021-06/DOE%20Solar%20Forecasting%20Workshop%20-%20Day%201%20-%20ISO%20Panel%20-%20ISO-NE.pdf

The Technology Landscape Is Massive

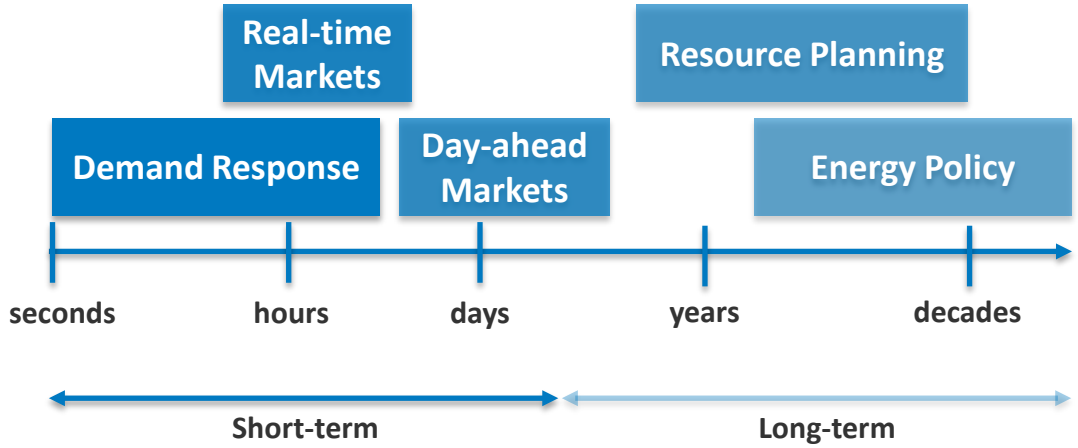


What's Included in Load Forecasting?



Forecasting Definitions

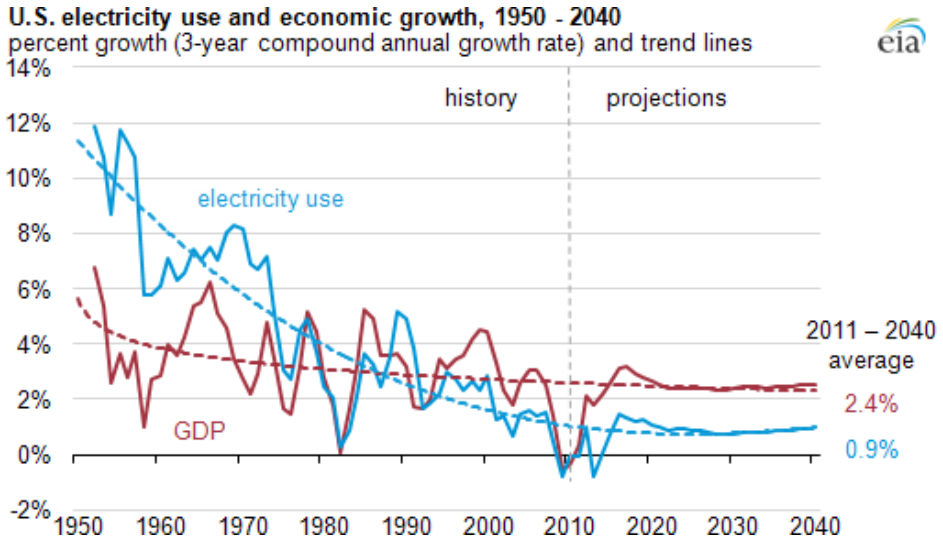
- Short vs. long term
  - Short term: hours-to-weeks, weather-based
  - Long term: months-to-decades

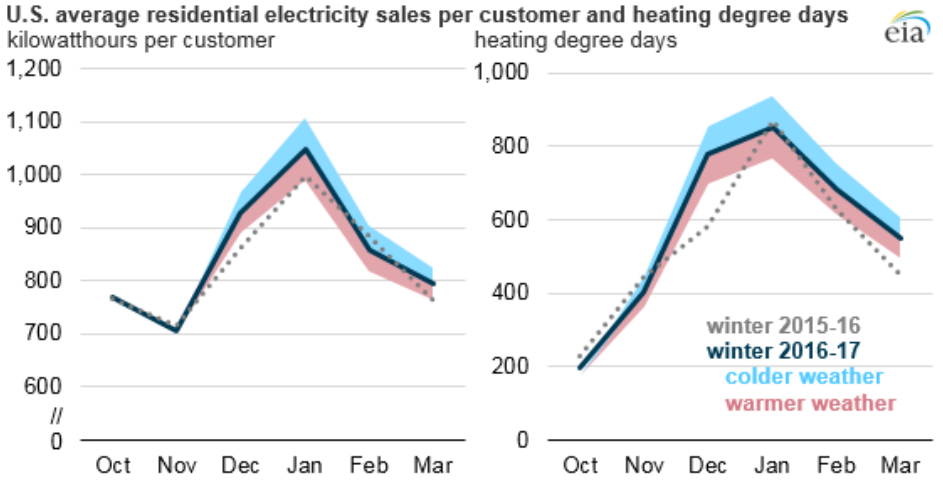


- Top-down vs. bottom-up
  - Top-down: econometric methods
  - Bottom-up: end-use methods

Econometric Methods (Top-down)

- Combines economic theory and statistical techniques
- Estimates relationships between energy consumption and:
  - Population growth
  - Business and industrial growth
  - Income and employment
  - Weather and climate
  - Electricity prices
- Pros:
  - Limited data requirements
  - Data is often available or requires few assumptions
  - Enables higher spatial resolution forecasts
- Cons:
  - Does not incorporate technology-specific trends or policies
  - Rarely considers sector-specific relationships





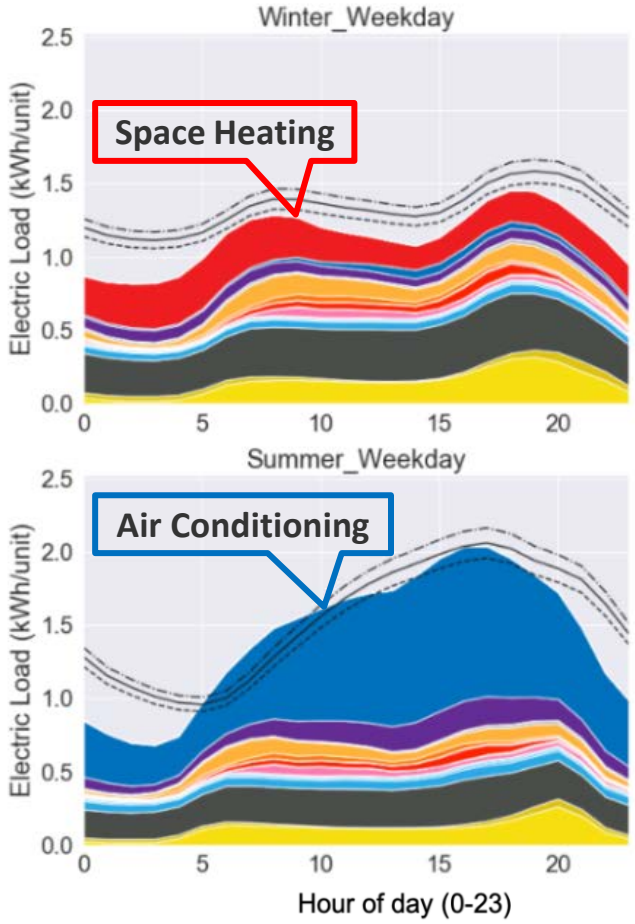
- 2013. "U.S. economy and electricity demand growth are linked, but relationship is changing." March 22, 2013. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=10491
- 2016. "Winter residential electricity consumption expected to increase from last winter." December 12, 2016. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=29112

End-use Methods (Bottom-up)

- Aggregates load forecasts across multiple end uses and/or customer sectors
- Often a two-step process:
  - Technology adoption modeling
    - Considers historical adoption, technoeconomic factors, stock turnover, etc.
    - Determines the customer adoption rate and/or nameplate capacity
  - Energy modeling
    - Considers weather, customer behavior, historical load shapes
    - Generates peak demand levels and/or load profiles

- Pros:
  - Often done for key technologies and combined with top-down forecasts
  - Can require less historical data
  - More feasible with disaggregated load data
- Cons:
  - Can require large amounts of technology-specific data
  - Difficult to reconcile with load data streams (e.g., Advanced Metering Infrastructure, Supervisory Control and Data Acquisition)

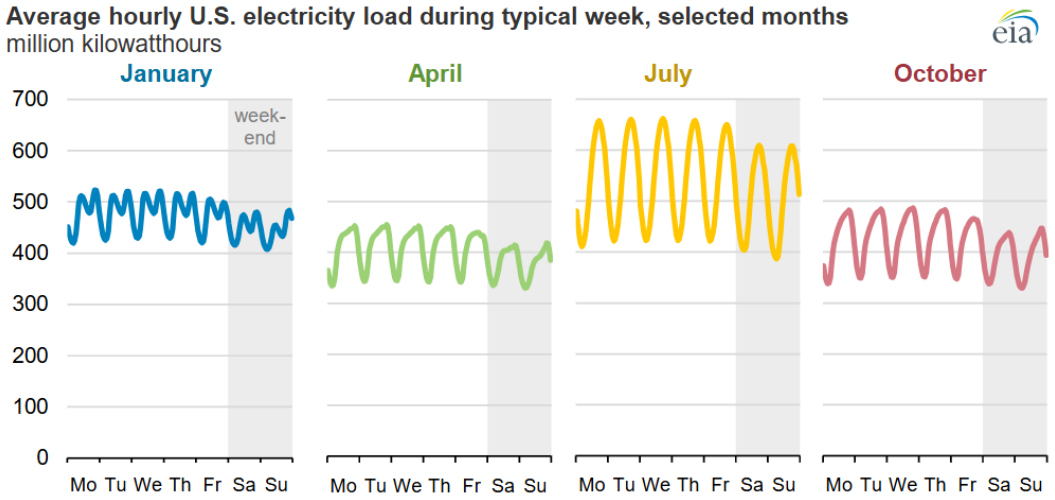
Residential End Use Load Profiles

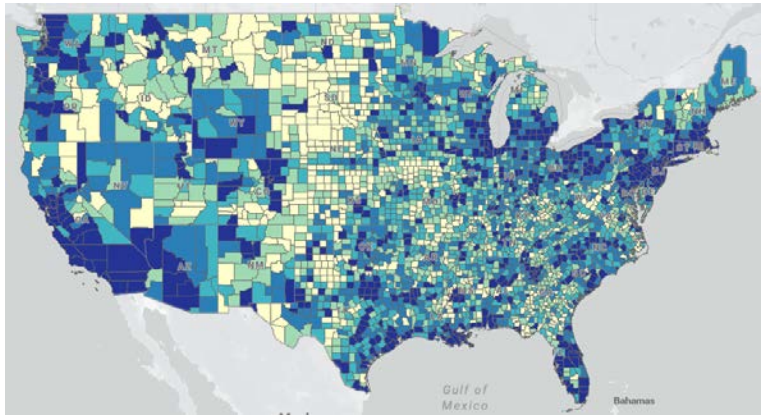


National Renewable Energy Laboratory. "End-Use Load Profiles for the U.S. Building Stock." https://www.nrel.gov/buildings/end-use-load-profiles.html

Forecast Granularity

- Temporal:
  - Annual
  - Seasonal/diurnal
  - Time series (e.g., hourly)
- Spatial (geographic):
  - System-wide
  - Zonal/nodal
  - Asset-based (e.g., feeder)





- 2020. “Hourly electricity consumption varies throughout the day and across seasons.” U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=42915
- National Renewable Energy Laboratory. "Net Electricity and Natural Gas Consumption." Accessed 4/23/2025, https://maps.nrel.gov/slope

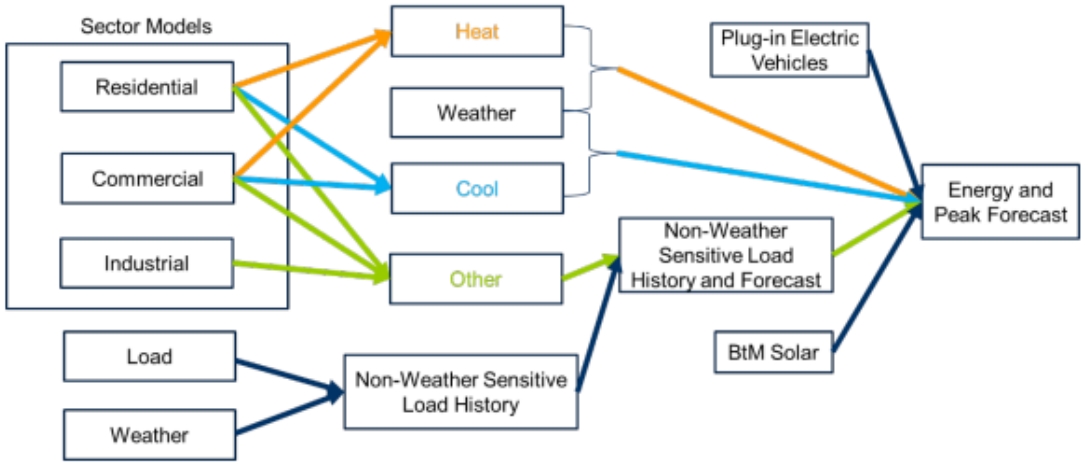
State of the Industry

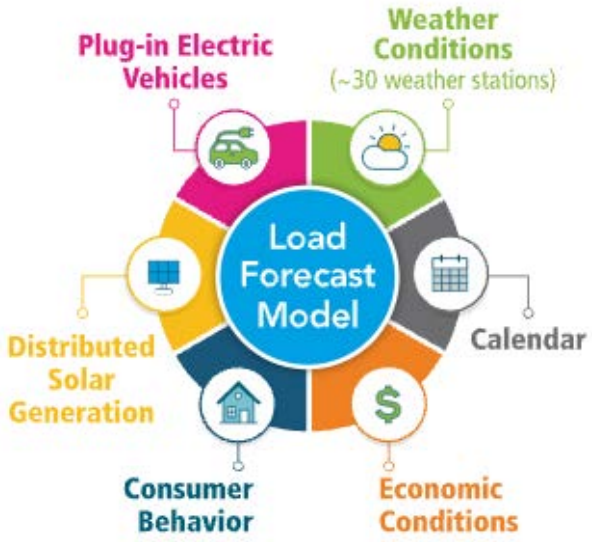
PJM Example

- PJM annually reports:
  - Seasonal peak demand, annual energy consumption
  - 15-year horizon
  - System and zonal resolution

- Includes bottom-up forecasts for key technologies
  - Distributed solar
  - Load management (DR)
  - EVs

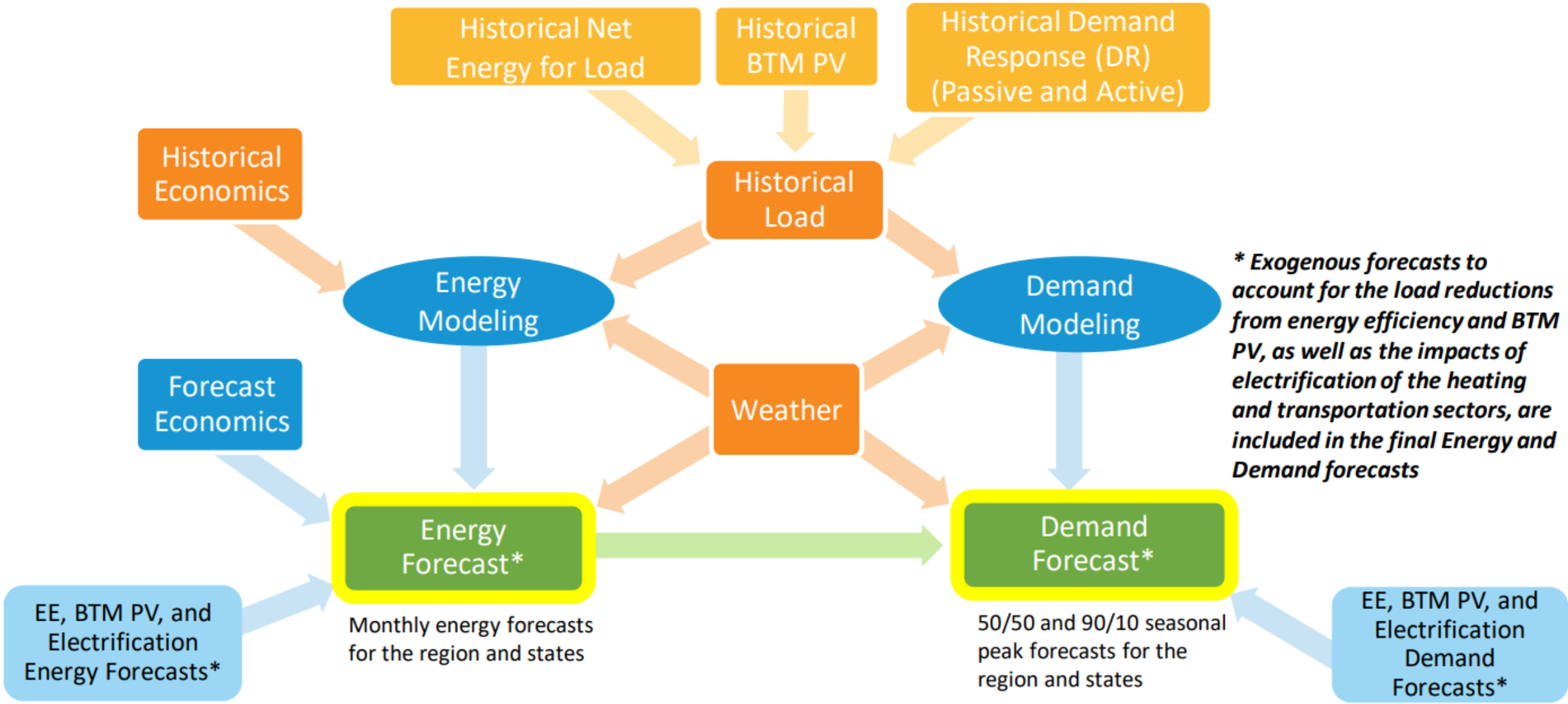
PJM Forecast Methodology





- PJM. "Load Forecasting – Predicting Electricity Demand Supports Grid Reliability & Efficiency." URL: https://learn.pjm.com/three-priorities/planning-for-the-future/load-forecasting.aspx
- PJM. "2024 Load Forecast Supplement." URL: https://www.pjm.com/-/media/DotCom/library/reports-notices/load-forecast/2024-load-report.ashx

ISO-NE Example

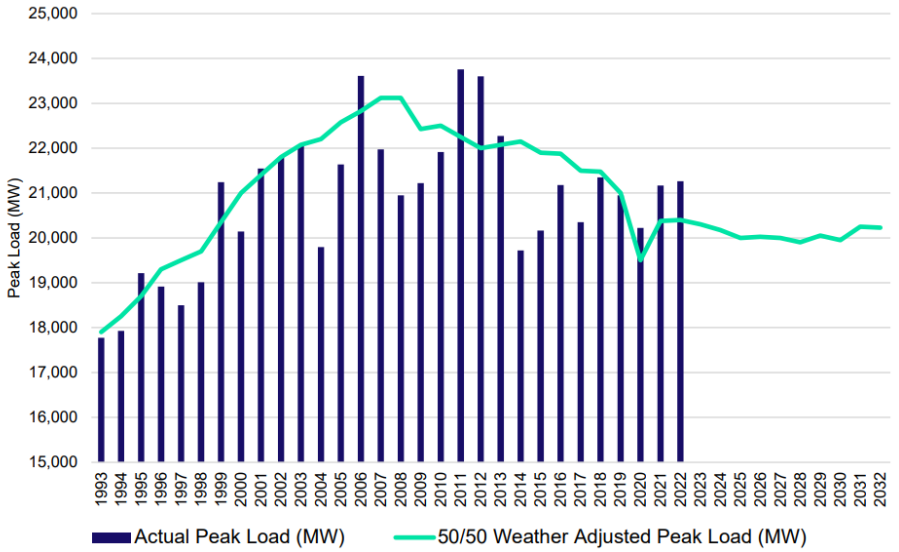


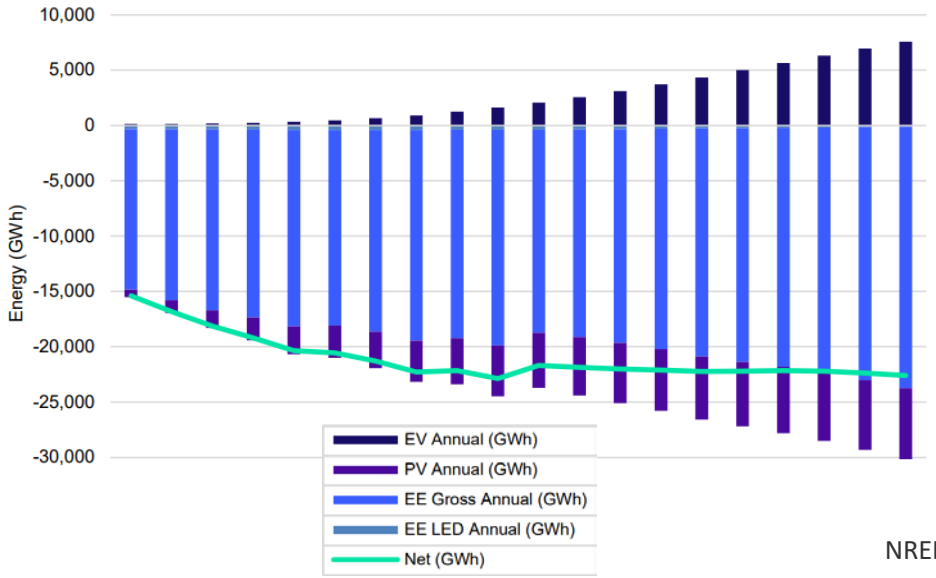
BTM: Behind-the-Meter

John Black, ISO New England, Introduction to Long-term Load Forecasting, Presented at the Energy Systems Integration Group (ESIG) 2023, URL: https://www.esig.energy/download/opening-introduction-to-load-forecasting-jon-black/?wpdmdl=10289&refresh=6490810b8c12f1687191819

ComEd Integrated Grid Plan

- System-wide, weather-adjusted annual peak demand
- Annual energy consumption by sector (next slide)
- Technology-specific impacts from:
  - EV load growth
  - Distributed PV
  - Energy efficiency



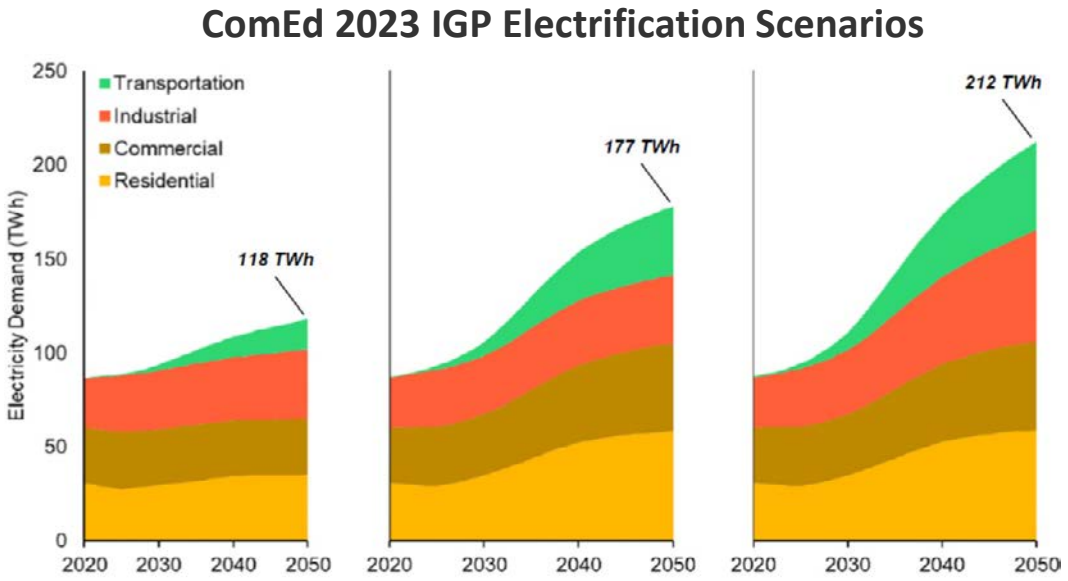


ComEd Multi-Year Integrated Grid Plan. 2023. ComEd. URL: https://icc.illinois.gov/downloads/public/edocket/578620.PDF

Scenario-Based Planning

- Common method for utility planning
  - Quantifies uncertainty in loads
  - Easier than probabilistic methods
  - Required in eight states

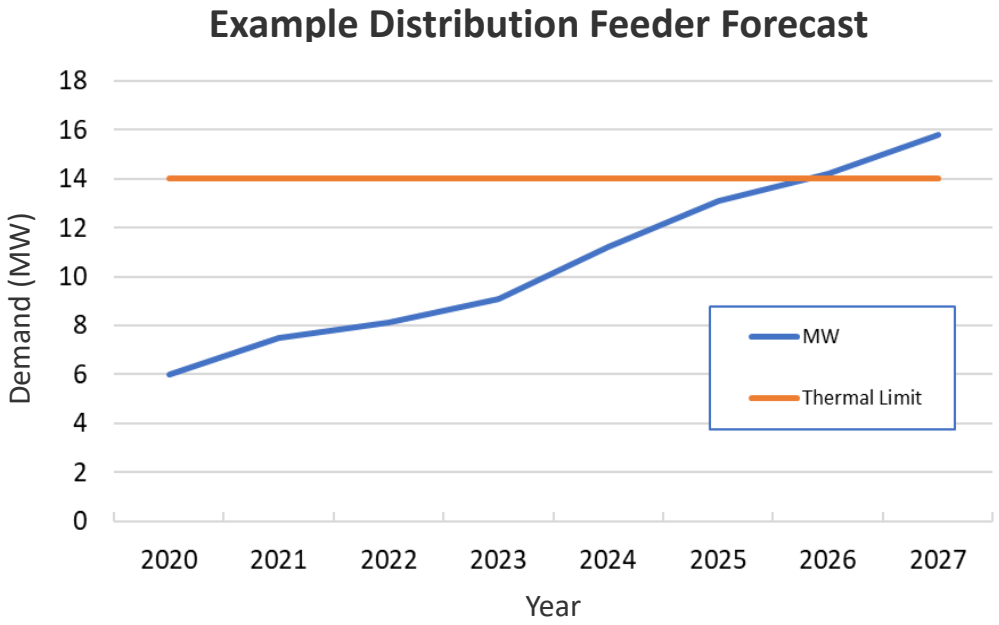
- Scenario examples:
  - Base case
  - High/low economic growth
  - Technology-based (e.g., high distributed energy resource (DER) growth)
  - Policy-based scenarios



ComEd. 2023. *ComEd Multi-Year Integrated Grid Plan.* URL: https://icc.illinois.gov/downloads/public/edocket/578620.PDF

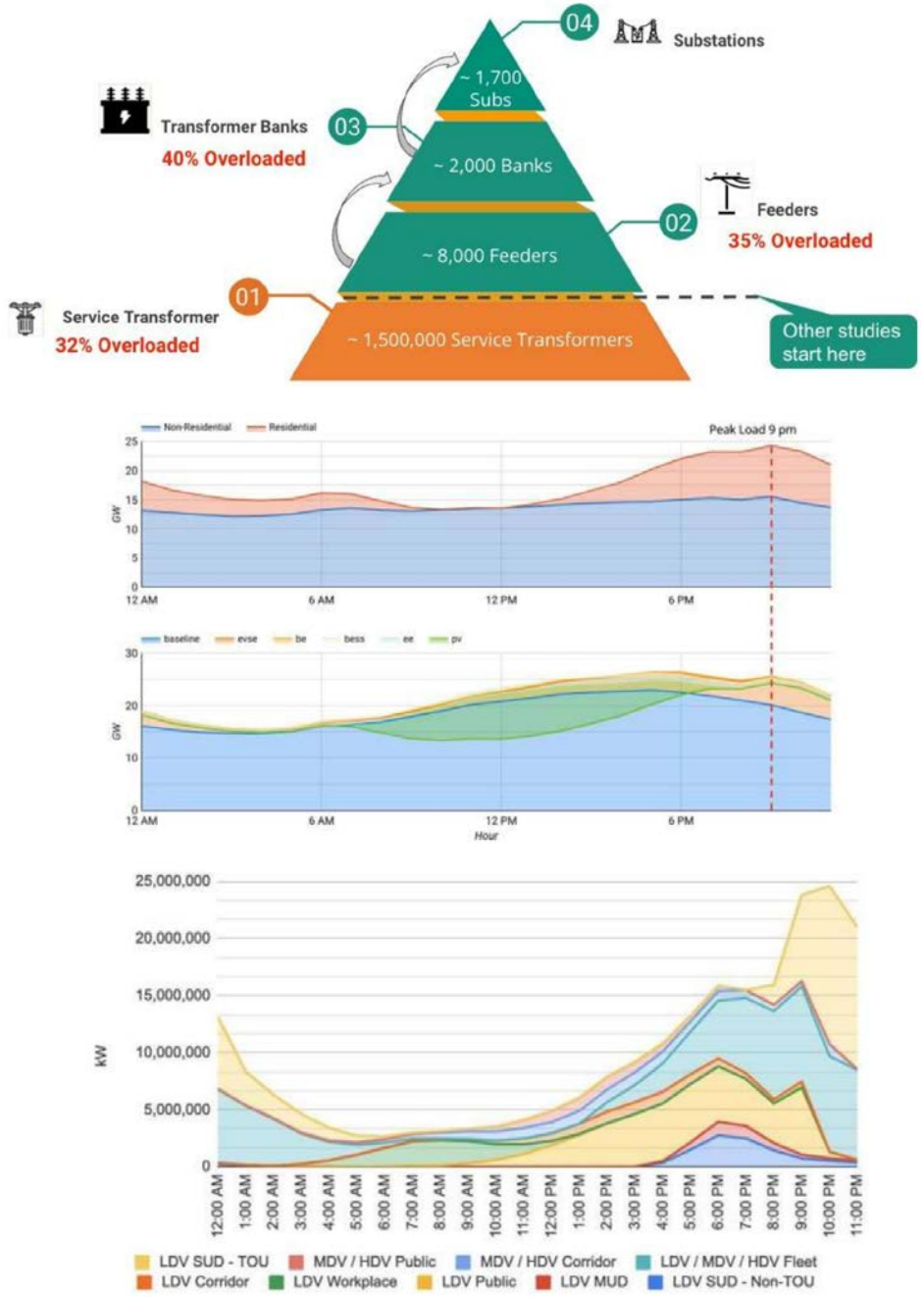
Distribution Load Forecasting

- Focused on asset upgrades
  - Peak demand used to project thermal limit violations
  - Feeder or substation assets
  - Shorter horizons
- Often only top-down methods
  - Load growth projections based on Supervisory Control and Data Acquisition data
  - Rarely proactive about new technology growth



California Electrification Impacts Study

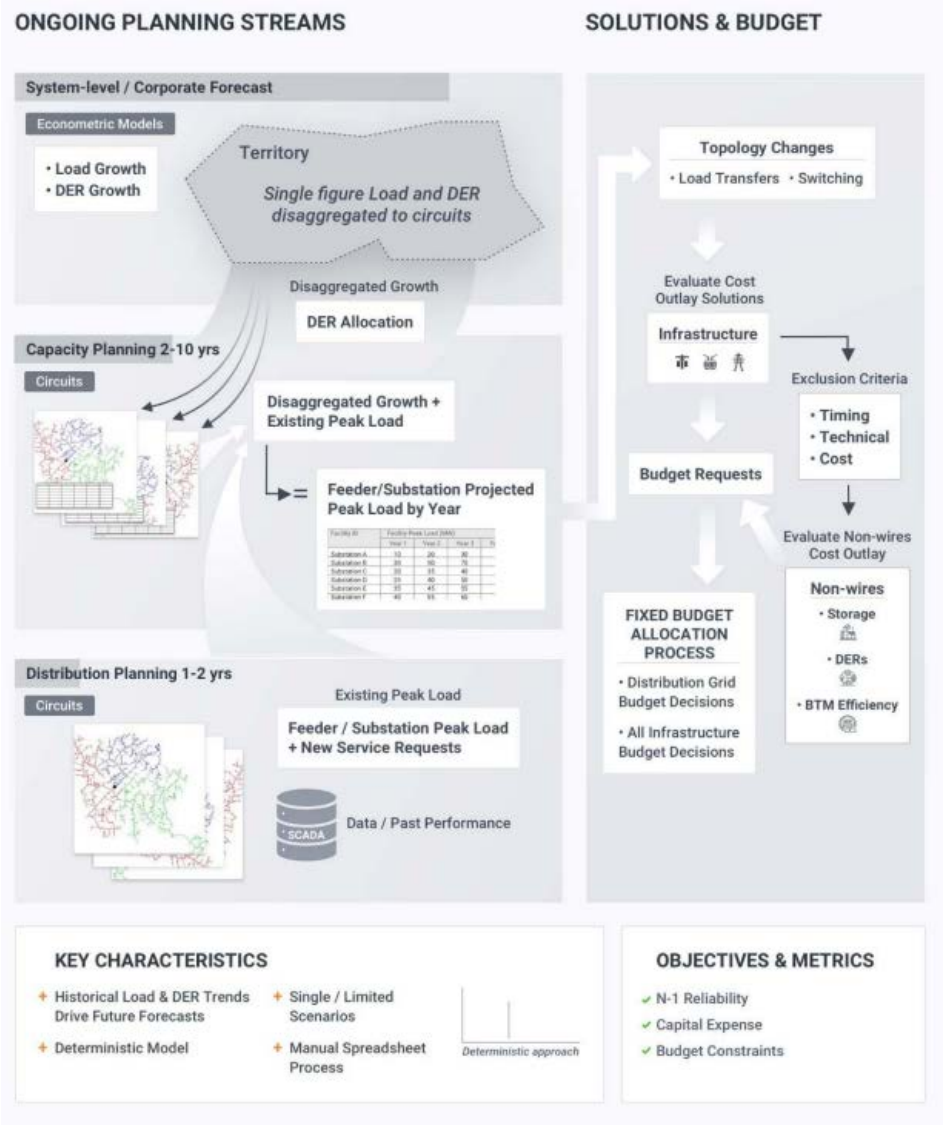
- Customer-level resolution
  - AMI data
  - Service transformer mapping
  - Load and DER modifiers
- Bottom-up modeling
  - PV and batteries
  - Efficiency
  - Building electrification
  - EVs (many sub-sectors)
- Five scenarios based on electrification and rates



California Public Utilities Commission. 2023. *Electrification Impacts Study Part 1.* URL: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M508/K423/508423247.PDF

Distribution vs. Bulk Planning

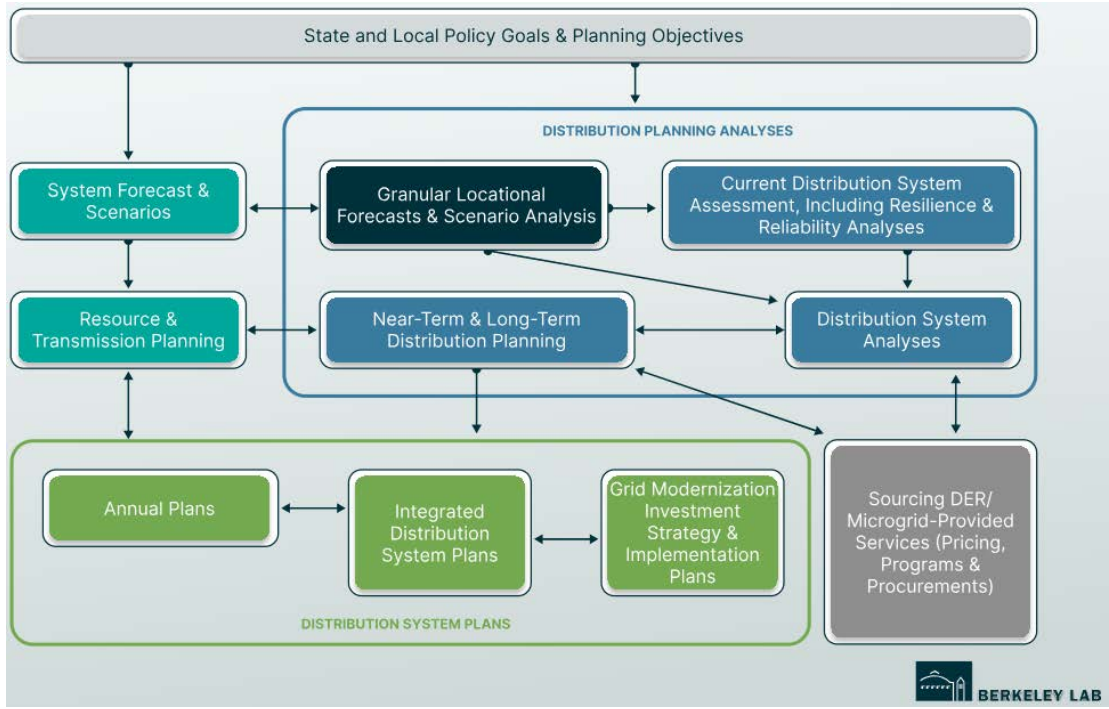
- Bulk system:
  - Five- to 20-year horizon
  - Lower spatial resolution
  - Considers technology impacts
- Distribution:
  - three–five-year horizon
  - Higher spatial resolution
  - Rarely considers technology impacts



J. Keen, Jeremy, Julieta Giraldez, Elizabeth Cook, Andy Eiden, Scott Placide, Alan Hirayama, Brian Monson, David Mino, and Fathalla Eldali. 2022. "Distribution Capacity Expansion Planning: Current Practice, Opportunities, and Decision Support." National Renewable Energy Laboratory. URL: https://www.nrel.gov/docs/fy23osti/83892.pdf.

Load Forecasting Tools

- Many tools used to create bulk and distribution load forecasts
  - LoadSEER
  - Kevala
  - Itron Metrix
  - SAS Energy Forecasting
  - Eviews
  - Clean Power Research PowerClerk Analytics
  - AdopDER
- Developed in-house or with load forecasting vendors or consultants



"Integrated Distribution System Planning." Lawrence Berkley National Laboratory. 2024. URL: https://emp.lbl.gov/projects/integrated-distribution-system-planning

Challenges and Interests

Data Sources

- Workshop and survey on Integrated Distribution System Planning
  - Workshop in June 2024, hosted by Association of Edison Illuminating Companies (AEIC) and Georgia Power
  - Survey developed by NREL
  - 20 utilities attended
  - Significant focus on load forecasting

- Other research and industry reports

Utility Interest by Technology

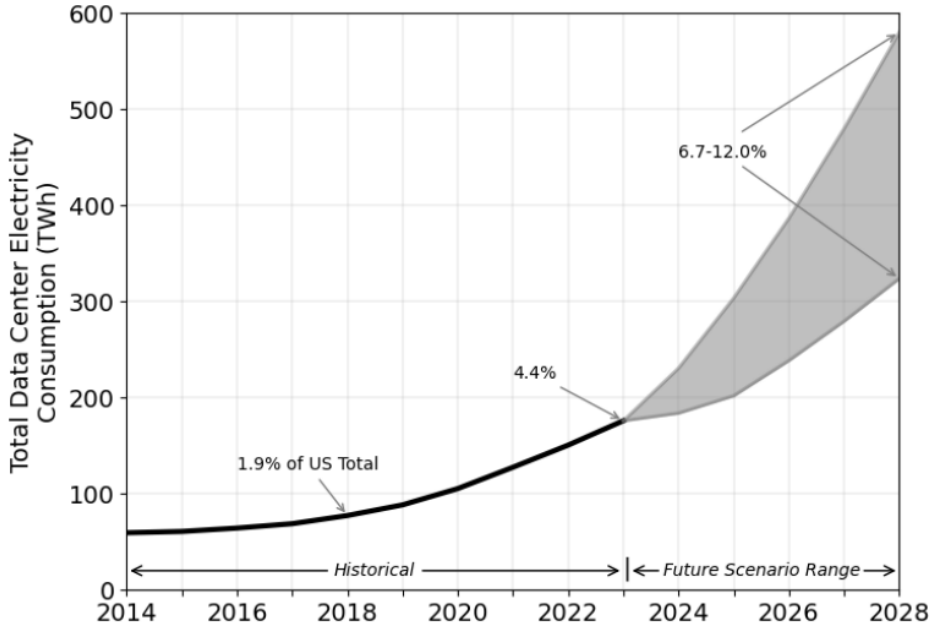
Average Utility Response by Readiness Level (%)

Technology to include in distribution load forecast:	*Run*				*Jog*				*Walk*			
	Importance	Timeline	Fluency	Easiness	Importance	Timeline	Fluency	Easiness	Importance	Timeline	Fluency	Easiness
Industrial load growth (e.g., data centers, grow houses)	93	86	71	67	100	75	63	63	50	0	25	0
PV adoption	93	100	93	75	75	75	13	38	100	0	25	0
Residential electric vehicle adoption	93	100	79	75	75	75	38	38	100	0	25	0
Non-residential electric vehicle adoption	86	93	71	50	75	63	38	38	100	0	25	0
Energy efficiency	93	93	79	67	88	75	25	33	100	0	25	0
Residential electrification (e.g., heat pumps, water heaters)	79	93	86	75	75	63	25	38	50	0	25	0
Industrial electrification	93	86	64	58	100	63	38	50	100	0	25	0
Price-based demand response (e.g., time-of-use rates)	93	93	57	67	63	75	25	25	0	0	25	0
Residential battery adoption	79	71	57	50	50	50	0	25	100	0	25	0
Demand response	93	86	50	67	50	38	0	25	0	0	25	0

[1]NREL Integrated Distribution System Planning Survey – From Workshop hosted by Associated Edison Illuminated Companies (AEIC) and Georgia Power, June 2024.

Data Centers

- High uncertainty in data center loads
  - 13–27% annual growth rate
  - 74–132 GW in United States by 2028
- Other unknowns:
  - Location and size of new loads
  - Interconnection speed
  - Flexibility/price responsiveness



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Utility Interest in Enhancements

[1]

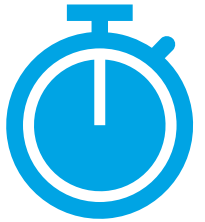
Distribution load forecast enhancements:	*Run*				*Jog*				*Walk*			
	Importance	Timeline	Fluency	Easiness	Importance	Timeline	Fluency	Easiness	Importance	Timeline	Fluency	Easiness
Higher temporal resolution (e.g., time-series)	93	100	86	67	88	63	25	38	100	0	25	0
Higher geographic resolution	86	93	64	75	100	75	50	38	50	0	25	0
Probabilistic forecasting	100	93	57	67	75	38	25	25	0	0	25	0
Scenario-based forecasts	93	93	86	58	75	50	17	63	0	0	25	0
Longer horizon forecasts (10–30 years)	86	79	64	33	38	25	25	13	0	0	25	0
"Backcasting" to improve future forecasts	57	71	64	50	50	38	0	25	0	0	25	0

Distribution load forecast coordination:	*Run*				*Jog*				*Walk*			
	Importance	Timeline	Fluency	Easiness	Importance	Timeline	Fluency	Easiness	Importance	Timeline	Fluency	Easiness
Coordination with transmission planning	93	100	93	83	88	88	75	88	100	0	25	0
Coordination with distribution operations	86	86	79	67	75	75	25	75	100	0	25	0
Coordination with regulatory proceedings	86	79	43	58	63	38	50	38	50	0	25	0
Incorporating policy changes	79	86	64	50	75	50	25	50	0	0	25	0

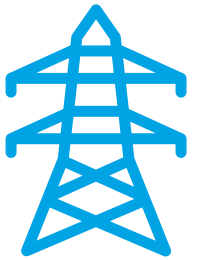
[1]NREL Integrated Distribution System Planning Survey – From Workshop hosted by Associated Edison Illuminated Companies (AEIC) and Georgia Power, June 2024

Key Topic – Granularity

- Need for higher temporal resolution
  - Consider winter/dual peak impacts
  - Consider minimum net load days
  - High interest in time-series forecasts
  - Interest in longer forecast horizons to align with IRP



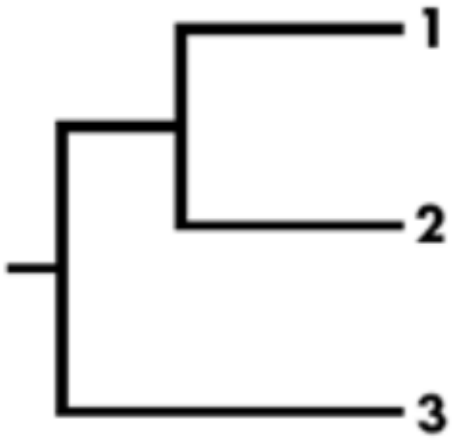
- Need for higher spatial resolution
  - Interest in feeder-level forecasting
  - Consider load diversity
  - Limited “peanut butter spread” data



Key Topic – Uncertainty

- Concerns about increasing uncertainty, for example:
  - Load growth
  - Technology adoption rate
  - Load profile changes
  - Spatial diversity of growth
  - Climate impacts
  - Behavioral changes

- Methods for managing uncertainty:
  - Scenario planning
  - Weighted scenarios
  - Probabilistic forecasting



Key Topic – Data

- Data needed for higher resolution forecasts
  - AMI data
  - Distribution network and connectivity models

- Data needed for higher accuracy forecasts
  - Customer metadata
  - Customer-level adoption data (or sub-metering)
  - Climate models
  - “High quality” distribution data

Load Forecasts Are Changing

Bulk System Forecasts

- Load growth
- Efficiency
- Demand response

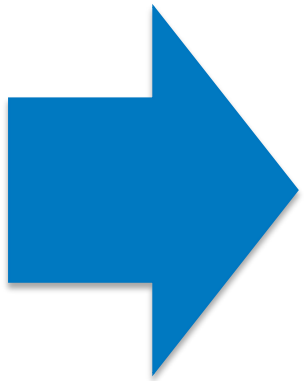
- Five–20-year horizon
- Peak demand + annual energy

+

Distribution Forecasts

- Load growth
- Efficiency

- Three- to five-year horizon
- Peak demand only



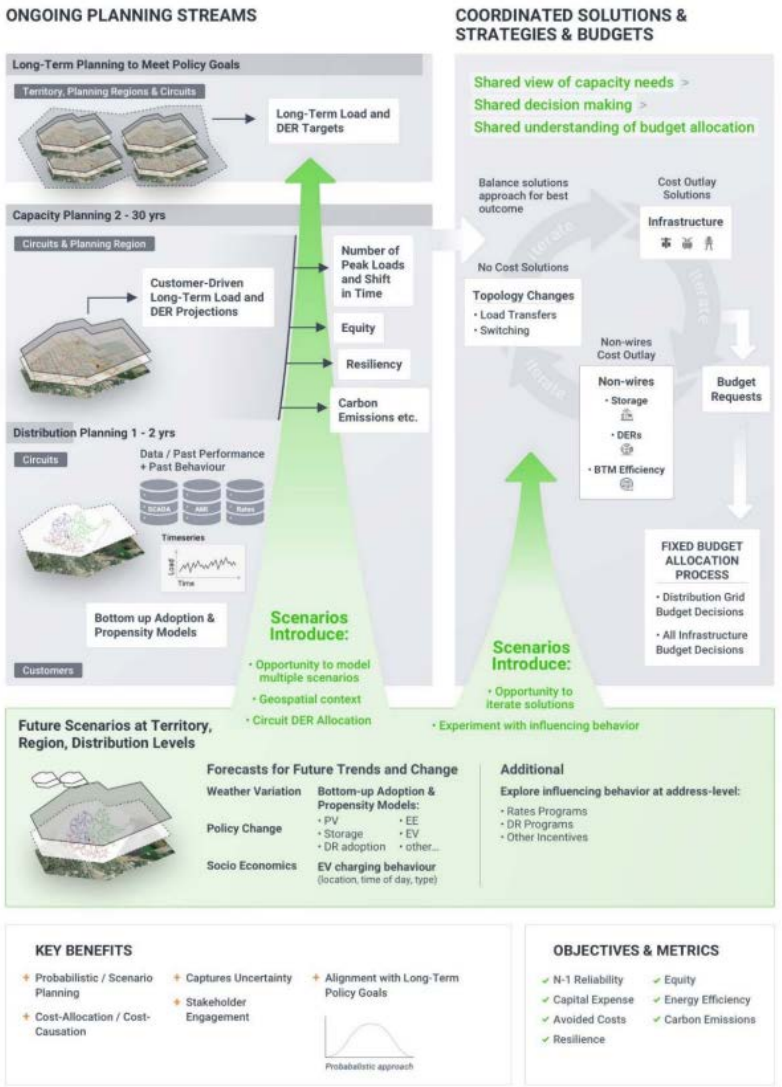
Integrated Forecasts

- Load growth
- Efficiency
- Electrification
- Demand flexibility (coordinated and behavioral)
- DER adoption
- Weather event impacts

- Three- to 20-year horizon
- Hourly resolution
- Customer resolution (for affordability and resilience impacts)

Future Integrated Forecasting

- Combine distribution and bulk planning processes
- Single set of scenarios
- Bottom-up methods for many technologies
- Higher resolution forecasts



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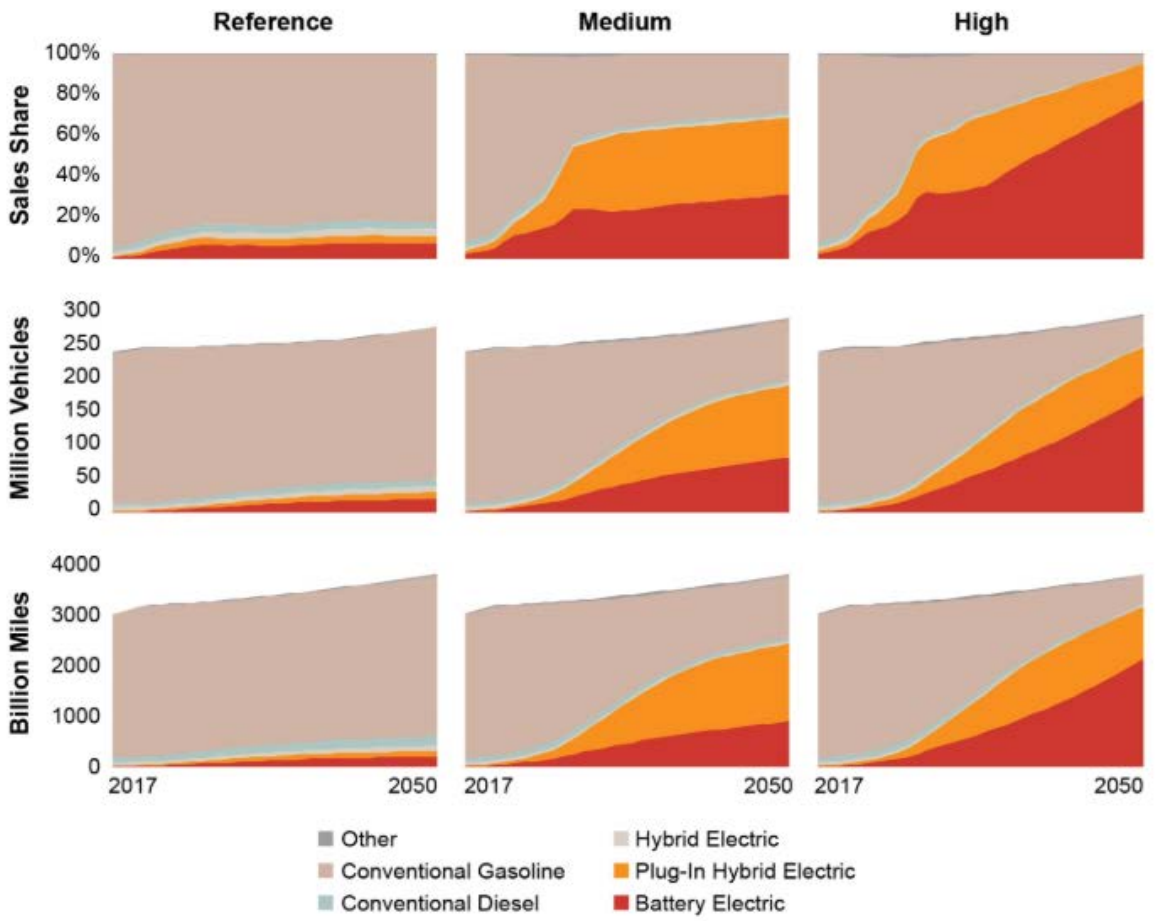
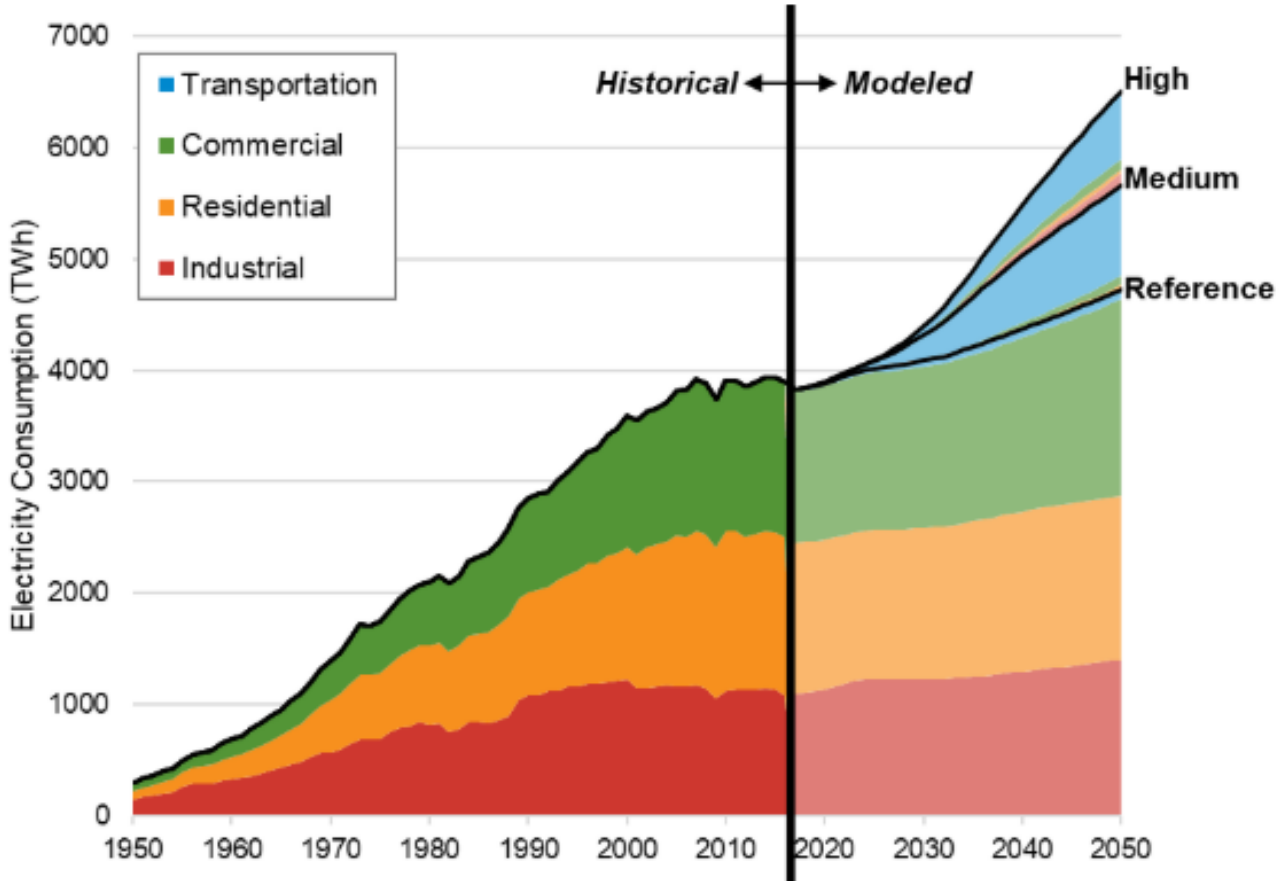
NREL Capabilities

- Technology adoption modeling
- Energy modeling

Electrification Futures Study





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Technology Adoption Tools

Building Technologies

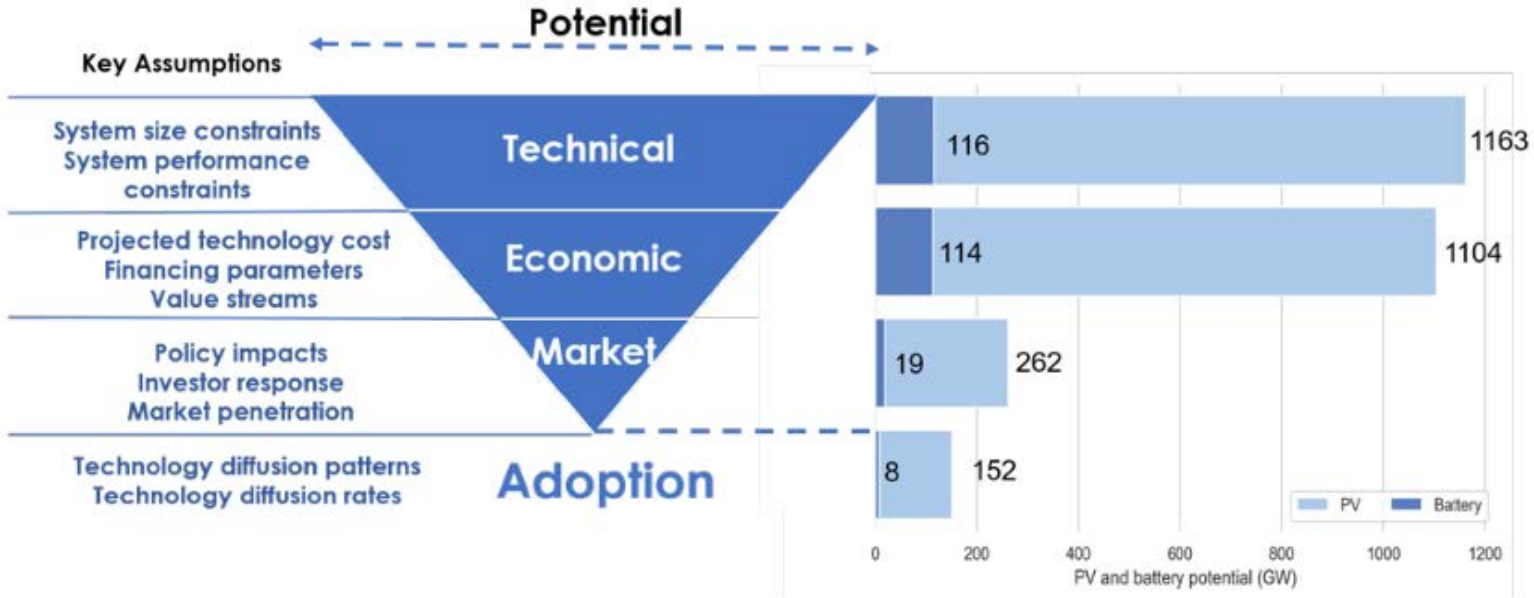
scout

Transportation Technologies

TEMPO

Distributed Generation and Storage

dGen



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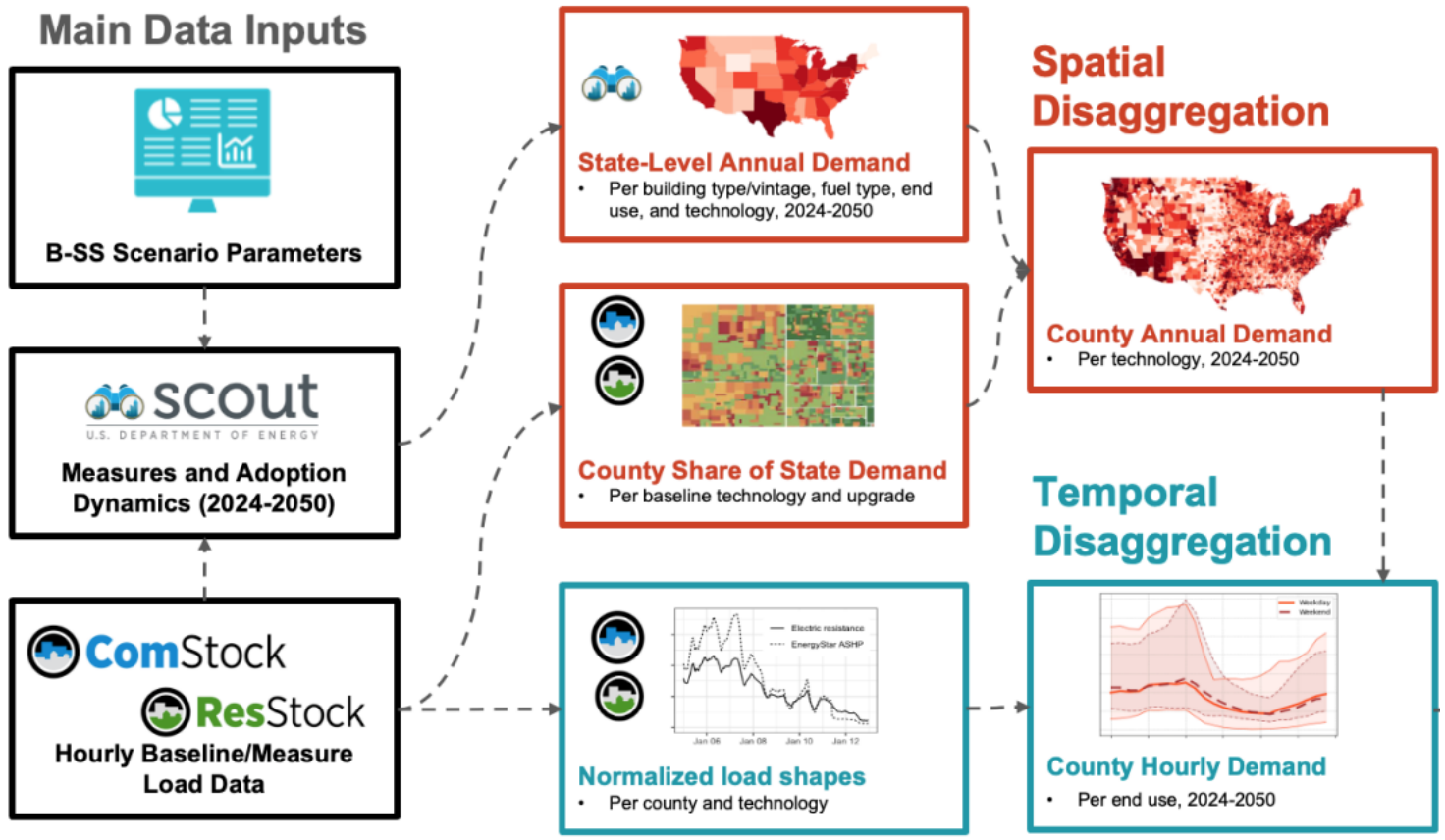
- National Renewable Energy Laboratory. TEMPO: Transportation Energy & Mobility Pathway Options Model. URL: https://www.nrel.gov/transportation/tempo-model.html
- National Renewable Energy Laboratory. Distributed Generation Market Demand Model (dGen). URL: https://www.nrel.gov/analysis/dgen/.
- National Renewable Energy Laboratory. 2021. Storage Futures Study - Distributed Solar and Storage Outlook: Methodologies, and Scenarios. URL: https://www.nrel.gov/docs/fy21osti/79790.pdf

Building Energy Modeling

- Integrated framework for granular building load forecasting
- Includes:
  - Economic and policy scenarios
  - County-level and hourly resolution
  - Forecasts to 2050
- Data viewer coming soon!



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Transportation Energy Modeling

Inputs → *Feedback*

Vehicle and Fuel Assumptions

TEMPO

Mobility Demand; Vehicle Sales; Stock; Energy Needs

Charging Infrastructure

EVI-Pro

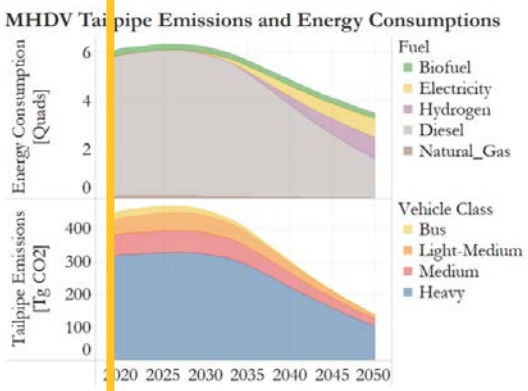
Charging Infrastructure; Spatiotemporal Load Profiles

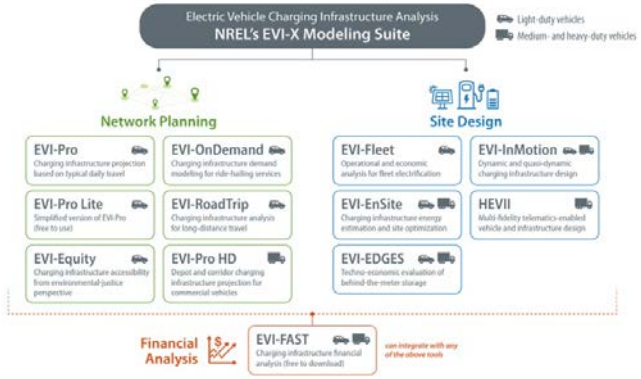
Grid Hosting Capacity

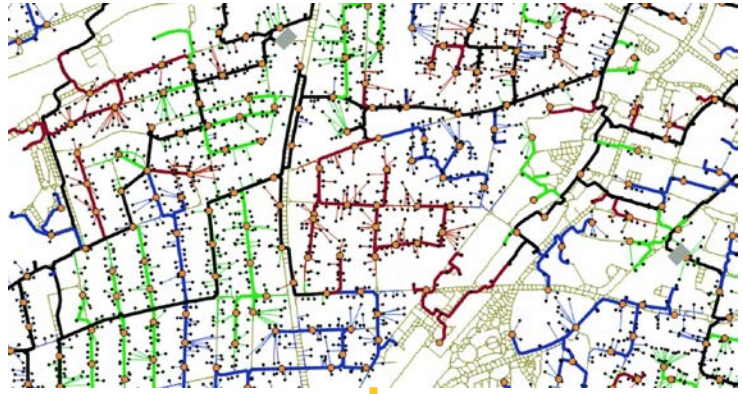
NREL Grid Modeling Tools

dsgrid
ReEDS
PLEXOS
Sienna
RPM
Smart-DS

and more…







Electricity Costs, Greenhouse Gas Emissions, Generation/Distribution Capacity Expansion

- National Renewable Energy Laboratory. TEMPO: Transportation Energy & Mobility Pathway Options Model. https://www.nrel.gov/transportation/tempo-model
- National Renewable Energy Laboratory. EVI-X Modeling Suite of Electric Vehicle Charging Infrastructure Analysis Tools. https://www.nrel.gov/transportation/evi-x

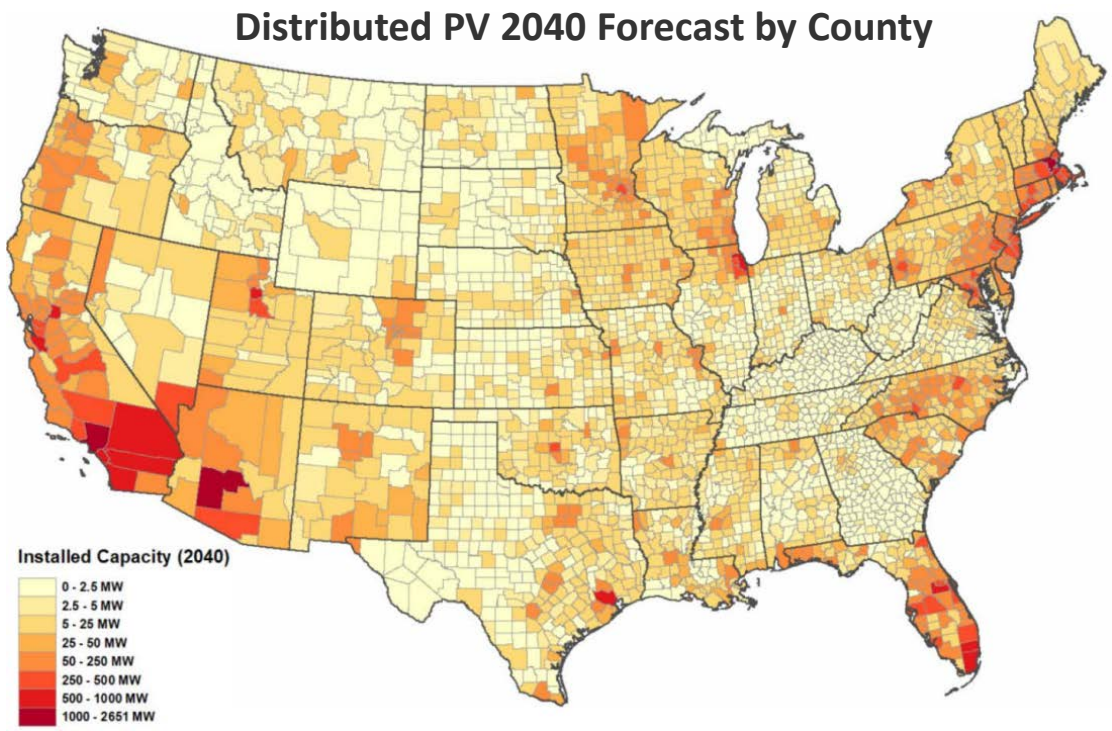
Distributed Energy Resources

- Forecasts DER adoption through 2050
  - By county and by customer sector
  - Incorporates technical potential
  - Accounts for technology economics and customer behavior

- Many distributed technologies:
  - Solar PV
  - Battery storage
  - Wind
  - Geothermal

dGen

2021 R&D 100 WINNER



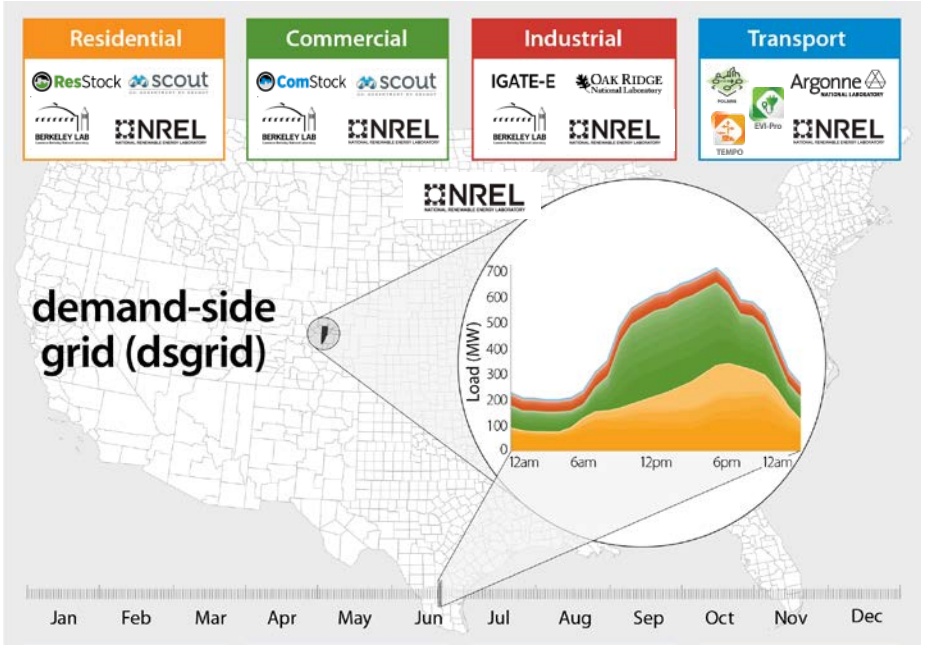
- National Renewable Energy Laboratory. Distributed Generation Market Demand Model (dGen). https://www.nrel.gov/analysis/dgen
- T National Renewable Energy Laboratory. 2021. The North American Renewable Integration Study: A U.S. Perspective. URL: https://www.nrel.gov/docs/fy21osti/79224.pdf

Data Integration and Synthesis

- End-use datasets often differ in:
  - Time resolution and horizons
  - Geographic resolution or boundaries
  - Sectors or end-use
  - Scenario parameters

- Framework to combine data from many sources
  - Aligns data for project-based scenarios
  - Enables faster modeling and analysis
  - Designed for grid planning studies

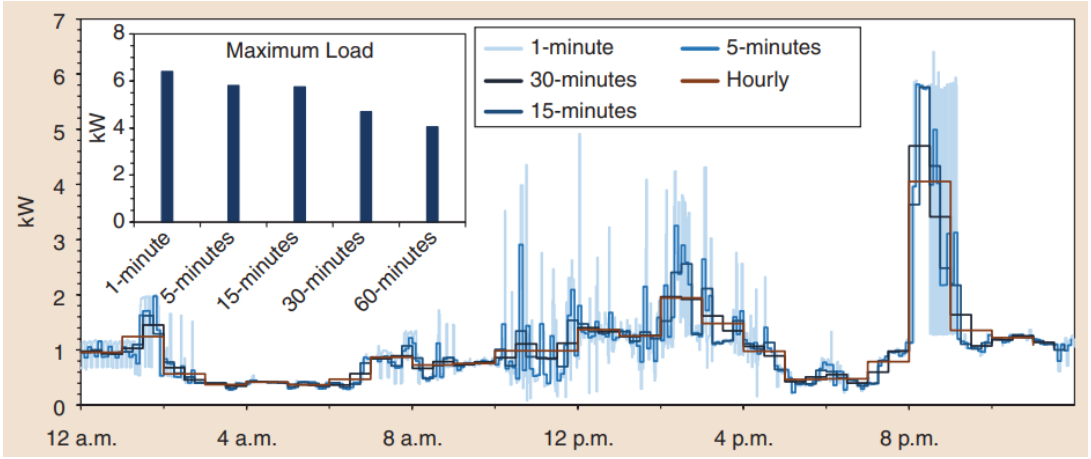
dsgrid



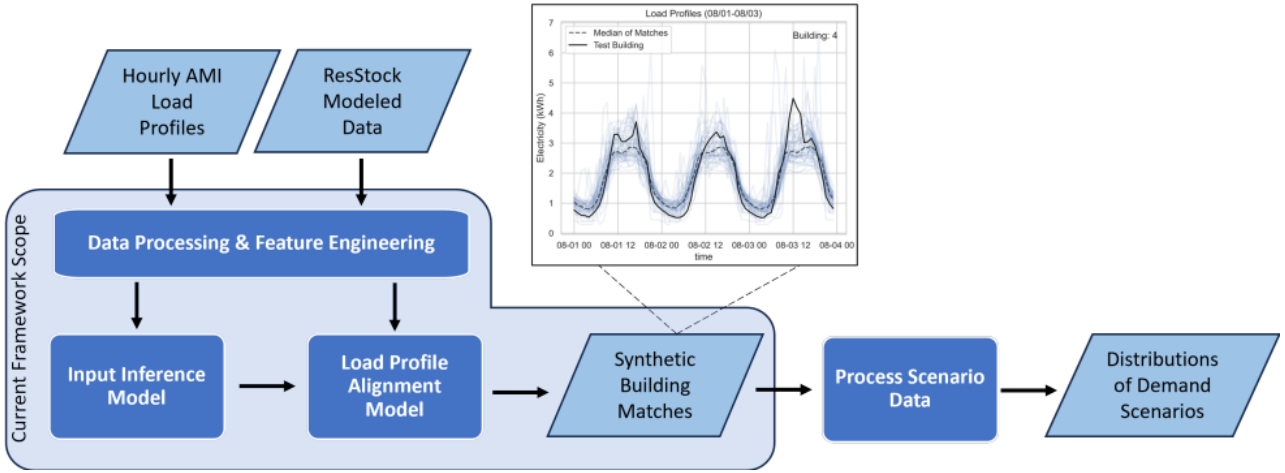
National Renewable Energy Laboratory. *dsgrid: Demand-Side Grid Toolkit. URL:* https://www.nrel.gov/analysis/dsgrid.html

Data Processing Tools

- AMI Data Analytics
  - Data cleaning and processing
  - Data aggregation and analysis
  - Load disaggregation methods



- AMI Mapping Tool
  - Links AMI data to building models
  - Enables more accurate modeling of upgrades or new weather scenarios



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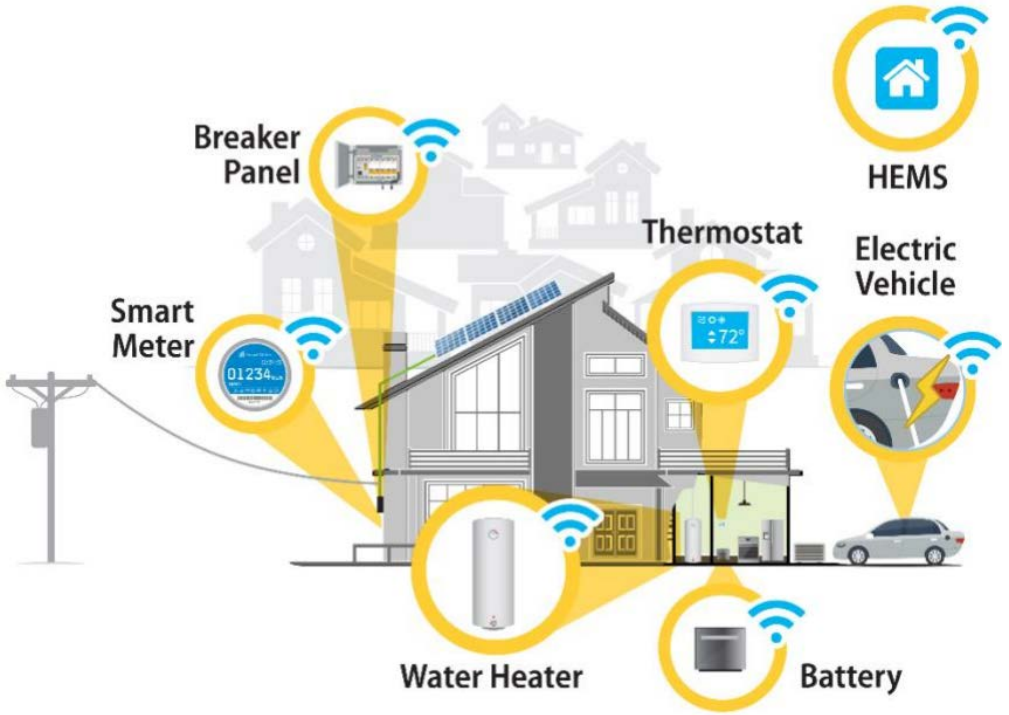
- Speake, Andrew, and Andrew Parker. 2024. "A Framework for Identifying Building Energy Models of Localized Utility Service Areas Using Smart Meter Data." NREL/TP-5500-90443. https://www.nrel.gov/docs/fy25osti/90443.pdf.

Demand Flexibility

- dsgrid-flex: Aggregate flexibility profiles for bulk system analysis
- Customer-level building modeling tools for demand flexibility
  - OCHRE: residential and EV
  - Alfalfa: commercial buildings



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- OCHRE: Object-Oriented Controllable High-Resolution Residential Energy Model. https://www.nrel.gov/grid/ochre
- Petersen, A, et al. BTO Peer Review: Alfalfa. 2024. https://www.nrel.gov/docs/fy25osti/91457.pdf

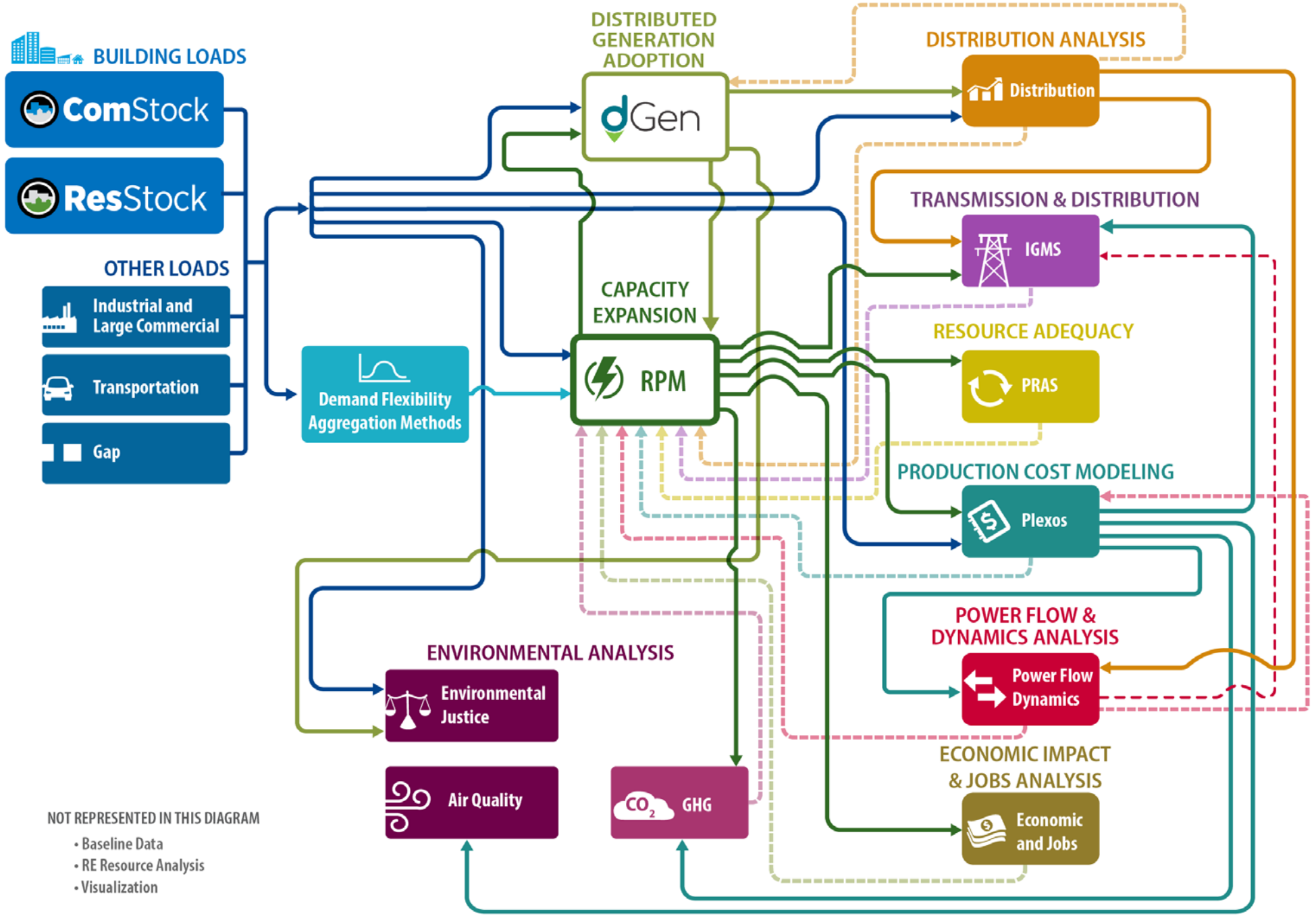
NREL Publicly Available Datasets

- **Buildings and Load Profiles**
  - ResStock – Residential building characteristics and load profiles
  - ComStock – Commercial building characteristics and load profiles
  - End-Use Load Profiles – Load profiles under different efficiency and electrification scenarios

- **Transportation Electrification Infrastructure and Charging Profiles**
  - 2030 National Charging Network Study and Datasets – EV adoption and EVSE port counts
  - EV Infrastructure Toolbox – EV charging requirements for states and metropolitan areas under different scenarios

- **Electric Futures Scenarios**
  - Electrification Futures Study – Electrification and generation scenarios
  - Standard Scenarios – Data viewer for U.S. grid planning scenarios

Load Forecasting Use Case



LA100: The Los Angeles 100% Renewable Energy Study. https://www.nrel.gov/analysis/los-angeles-100-percent-renewable-study

Q&A + Discussion

Thank You

www.nrel.gov

Contact: Michael.Blonsky@nrel.gov

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