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Demand Response Solutions and Perspectives on Energy Systems Integration

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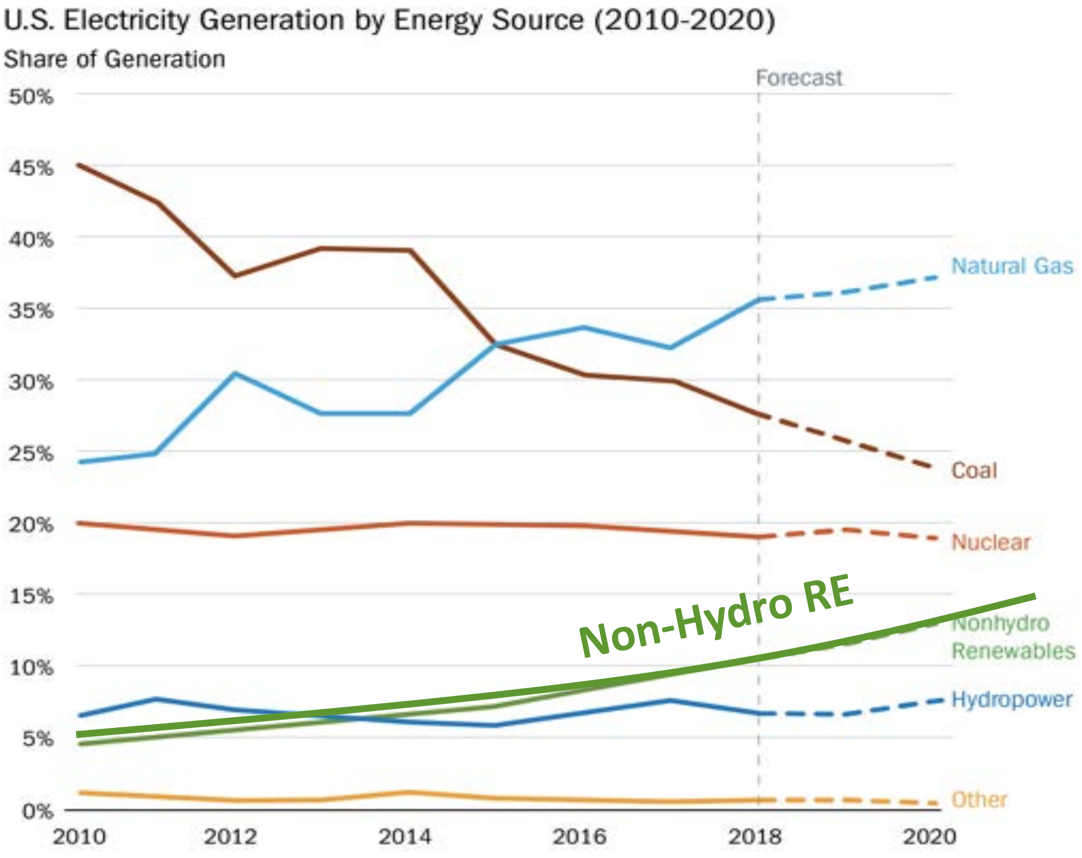
NREL - Driving innovation in Energy Systems Integration

The US Energy Supply is Shifting

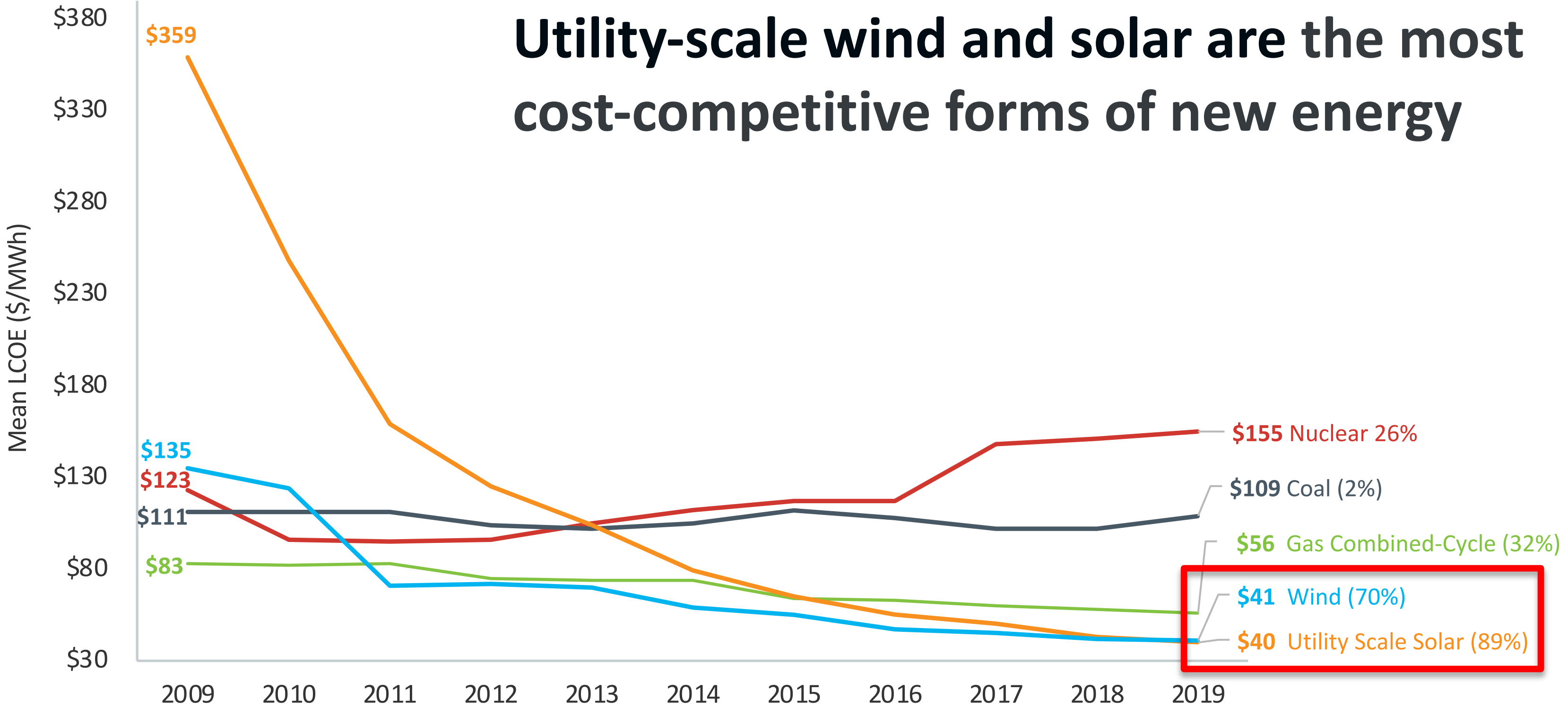


Source: United States Energy Information Agency, *Today in Energy*, 18 January 2019

Renewable Energy

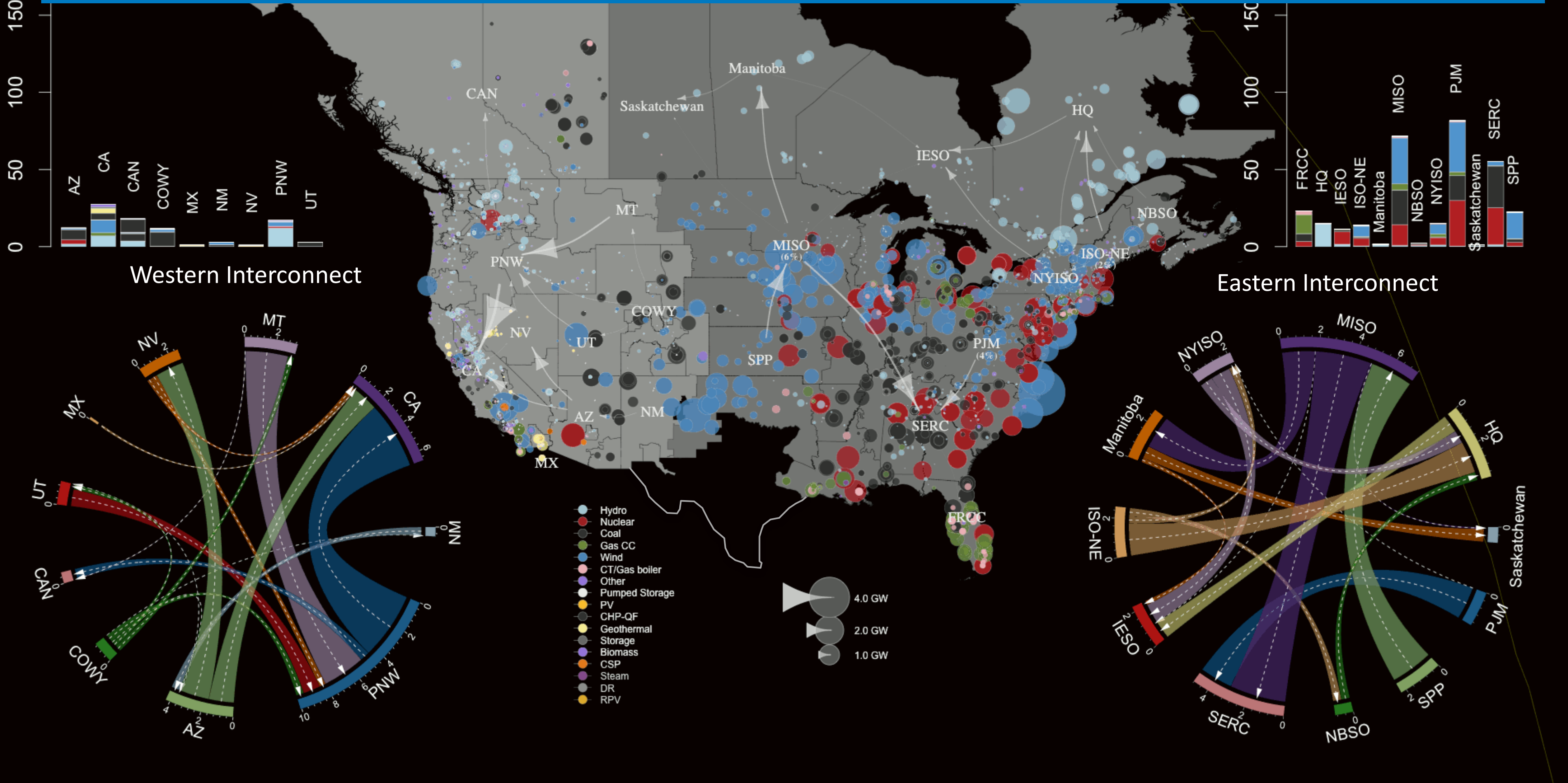
- Renewables accounted for 20% of the electricity generation in 2019 in the U.S.
- Wind and solar deployments are significantly growing in the U.S.
- Currently 12 U.S. States have goals of 100% clean energy – more are considering these levels
- Other areas of the world (e.g. Denmark, Ireland, South Australia) significantly exceed these levels

Cost of Renewables is Falling

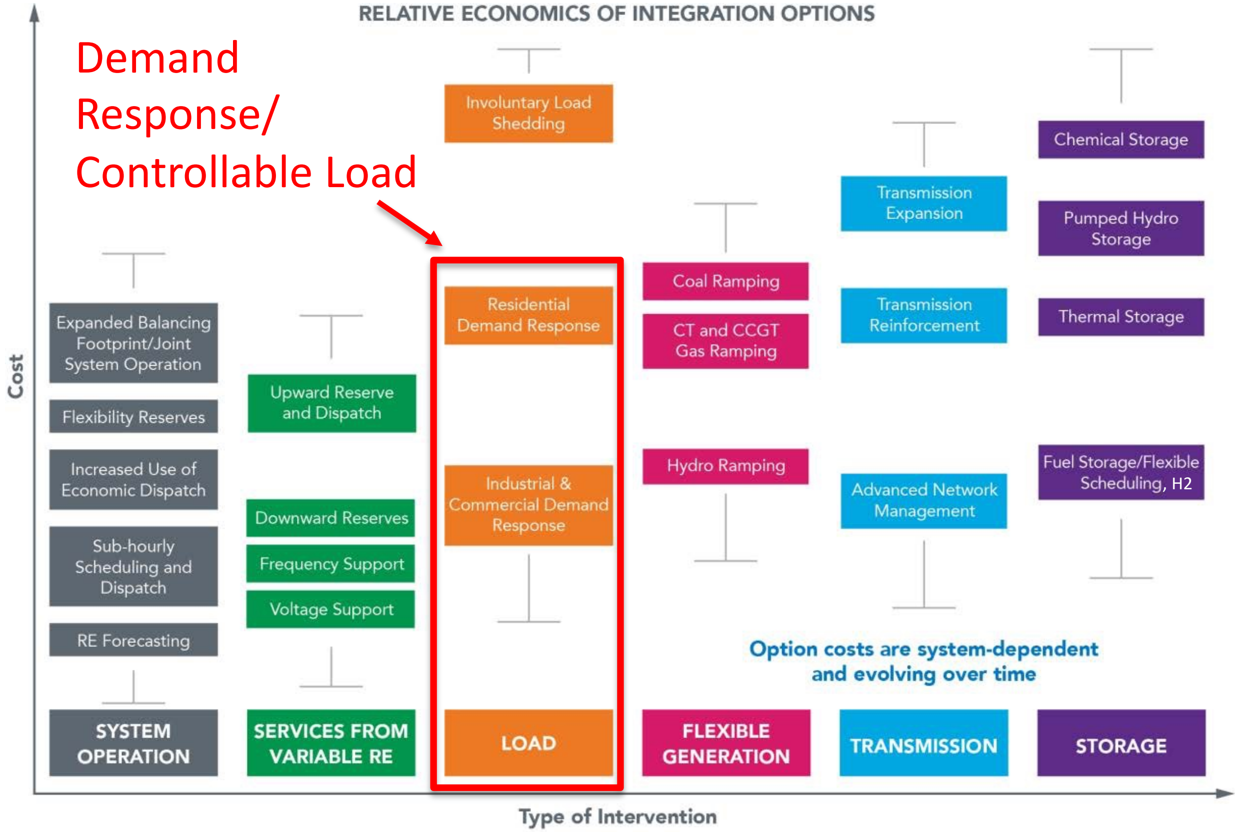


Source: *Lazard's 2019 Levelized Cost of Energy Analysis*

Need to balance generation and load at every time period



Options for Dealing with Variability and Uncertainty
-Creating System Flexibility



Solutions:

- Utilize geographic diversity.
- Utilize flexible conventional generation.
- Increase sharing among balancing authority areas.
- Expand the transmission system.
- Curtail excess VRE production.
- Coordinate flexible loads (active demand response).
- Enhance VRE and load forecasting.
- Add electrical storage.
- Interact with other energy carriers.

Source: *Impact of Flexibility Options on Grid Economic Carrying Capacity of Solar and Wind: Three Case Studies*
P. Denholm, J. Novacheck, J. Jorgenson, and M. O'Connell, National Renewable Energy Laboratory, NREL/TP-6A20-66854, December 2016, https://www.nrel.gov/docs/fy17osti/66854.pdf

Electrification of the Economy

NREL’s Electrification Futures Study

https://www.nrel.gov/analysis/electrification-futures.html

- Decreasing electricity costs from PV and wind represent a real paradigm shift in the competitiveness of different power generation options. They are now the lowest cost of forms of new electricity.
- Building loads, transportation, and industry can migrate to electrification for economic and environmental reasons. Electric energy needs will double to handle this transition.
- As variable renewable penetrations grow, energy system flexibility becomes more important at higher VRE levels.

Jadun, Paige, Colin McMillan, Daniel Steinberg, Matteo Muratori, Laura Vimmerstedt, and Trieu Mai. 2017. *Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70485. https://www.nrel.gov/docs/fy18osti/70485.pdf

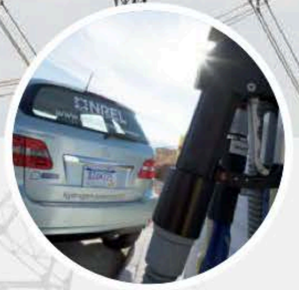
Answering crucial questions about:

Technologies

What electric technologies are available now, and how might they **advance**?

Consumption

How might electrification impact electricity **demand** and **use patterns**?



System Change

How would the electricity system need to **transform** to meet changes in demand?

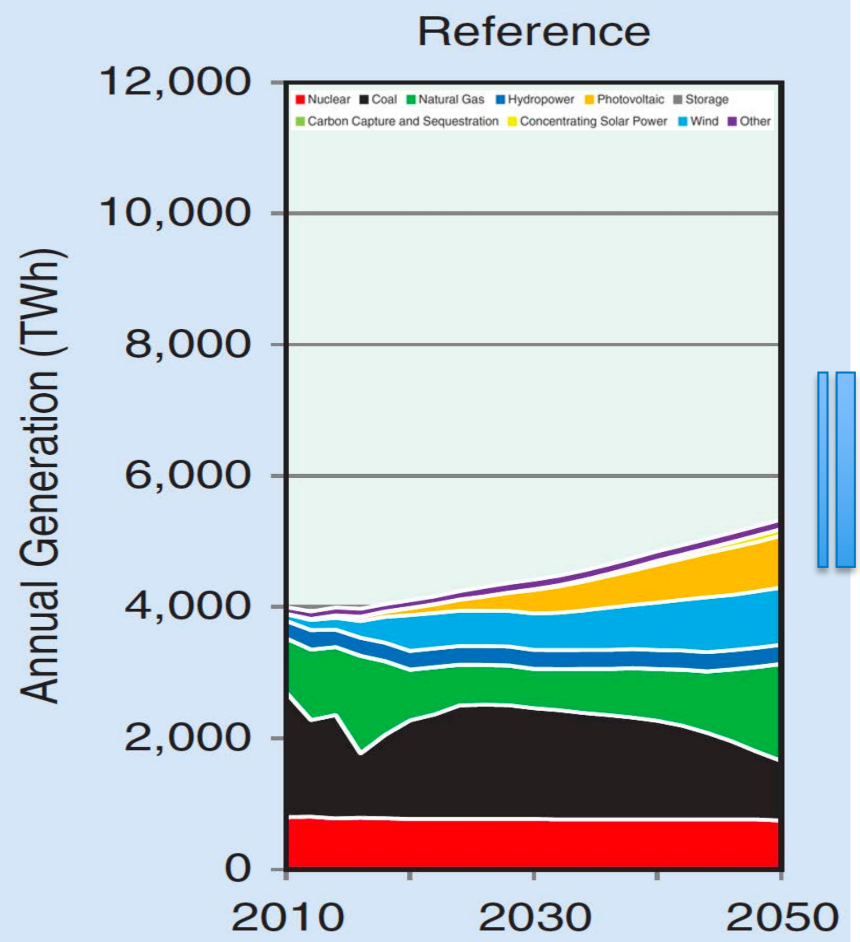
Flexibility

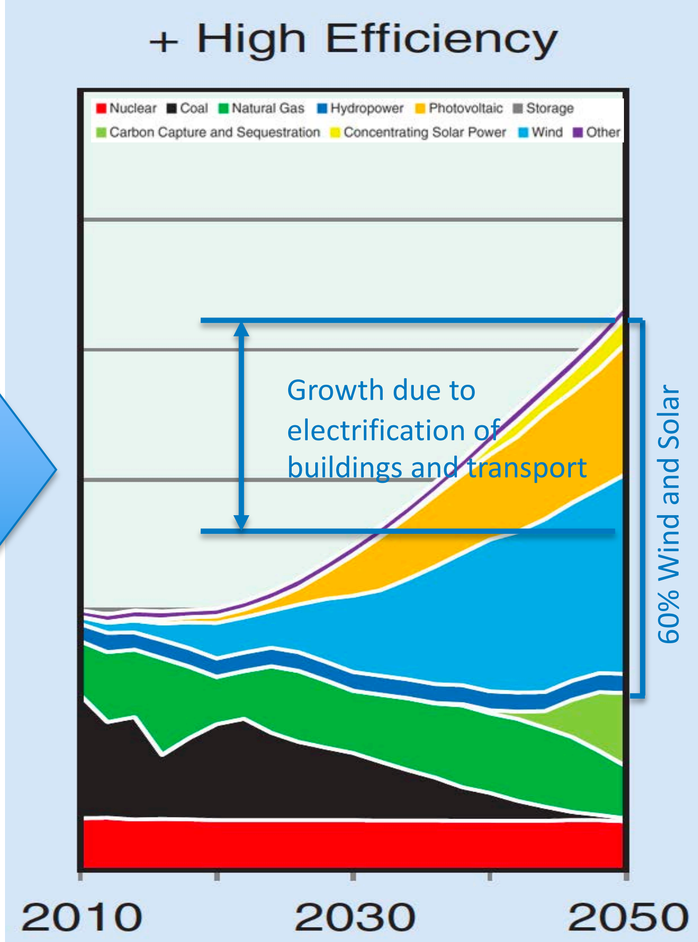
What role might **demand-side flexibility** play to support reliable operations?

Impacts

What are the potential **costs, benefits, and impacts** of widespread electrification?

Enabling an affordable, reliable, secure, flexible, and sustainable energy system of the future





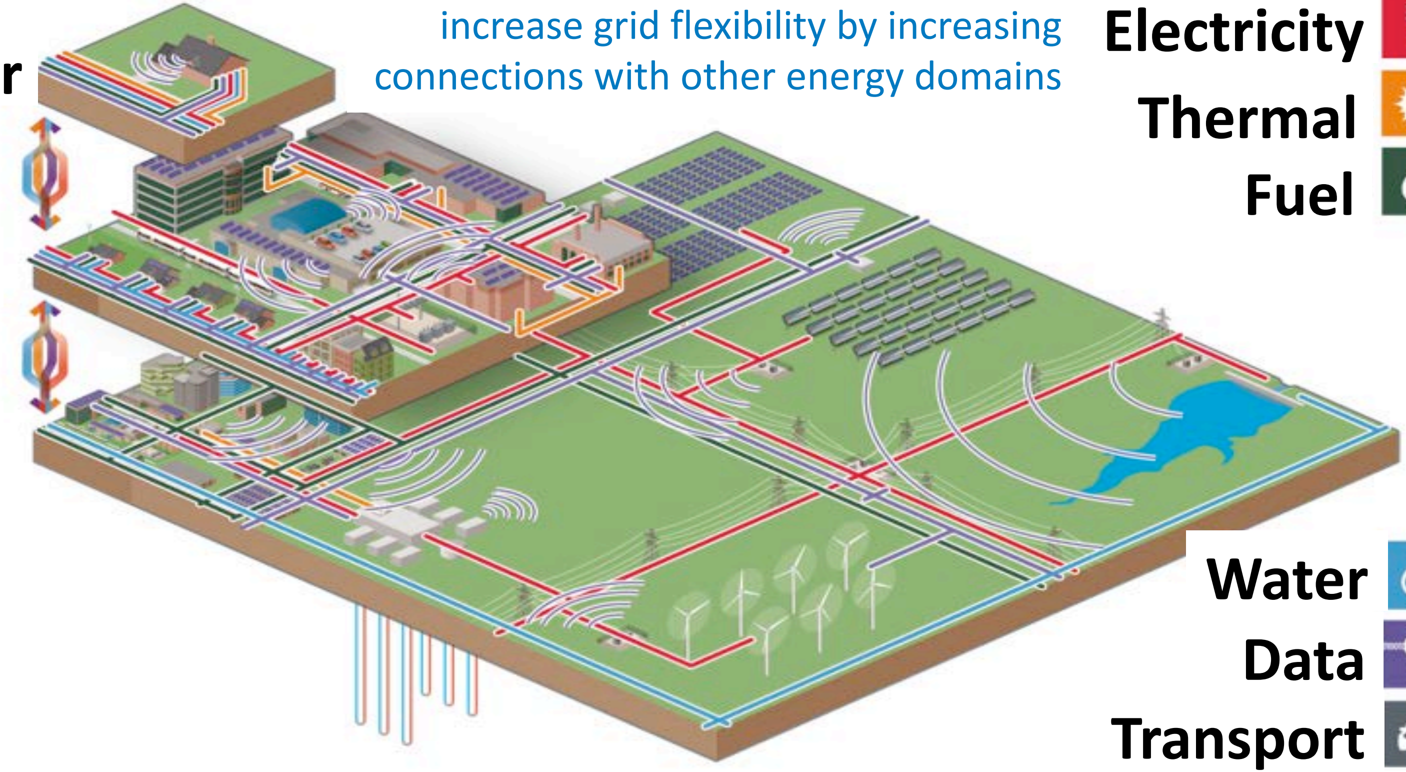
Energy Systems Integration is Key to Addressing Grid Flexibility

Energy System Integration (ESI) can increase grid flexibility by increasing connections with other energy domains

Customer

City

Region



Electricity

Thermal

Fuel

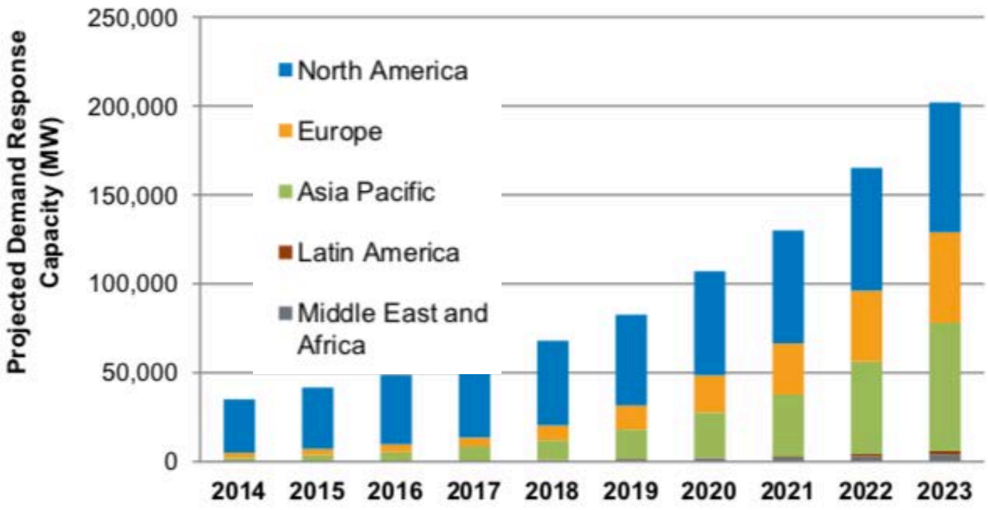
Water

Data

Transport


Importance of Demand Response

Understanding Demand Response



Feldman, Brett, and Bob Lockhart. 2014. "Demand Response: Commercial & Industrial DR, Residential DR, and DR Management Systems: Global Market Analysis and Forecasts." Navigant Research.

Residential

Commercial

Industrial

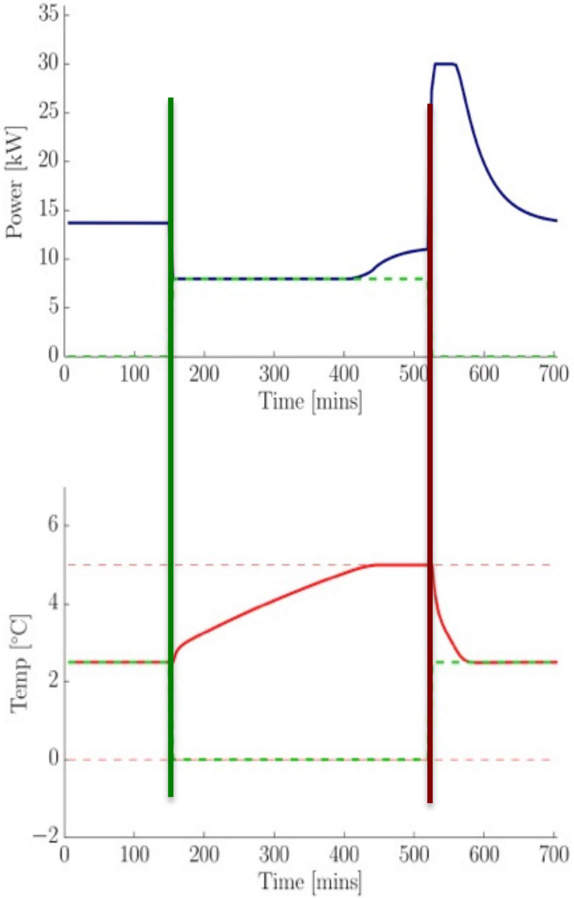
Transportation

NREL and DTU Examined how to model DR

- Focused on Supermarket Refrigerators
- Characterizing Demand Response through the Saturation Curve
- Developed and Understanding of Resource Efficiency
- Seasonality in the Demand Response Resource

Source: *On the Inclusion of Energy Shifting Demand Response in Production cost Models: Methodology and a Case Study*, N. O' Connell, E. Hale, I. Doebber, and J. Jorgenson, NREL/TP-6A20-64465, July 2015 http://www.nrel.gov/docs/fy15osti/64465.pdf

NREL and DTU Examined how to model DR

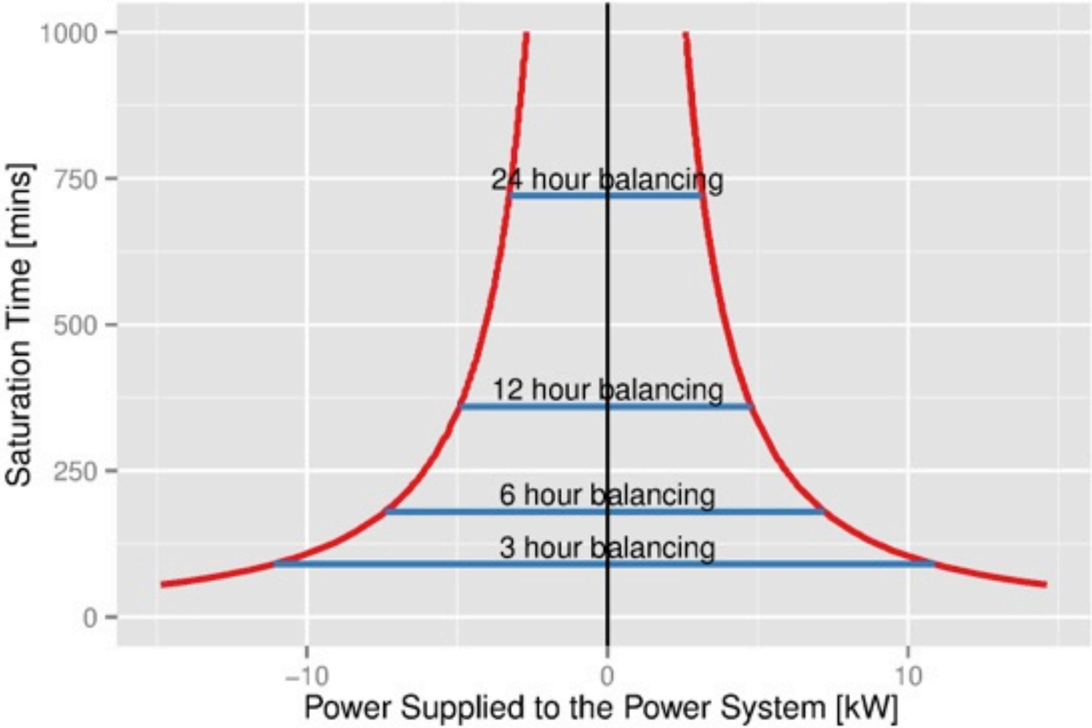


- Top figure shows that the power consumption is steady until it is reduced from 14kW to 8kW.
- The reduction of 6kW can be maintained until the temperature in the refrigeration system reaches its upper bound (as seen in Bottom Figure).
- Once the upper temperature limit is reached the prescribed reduction can no longer be maintained, at this point it is said that the response has saturated.
- When the power reference is no longer active, the system will recover the energy lost during the response event by increasing consumption to the maximum allowable level.

Saturation curve of DR

- Saturation Curve - The relationship between a power adjustment in a flexible load and the duration for which the adjustment can be maintained

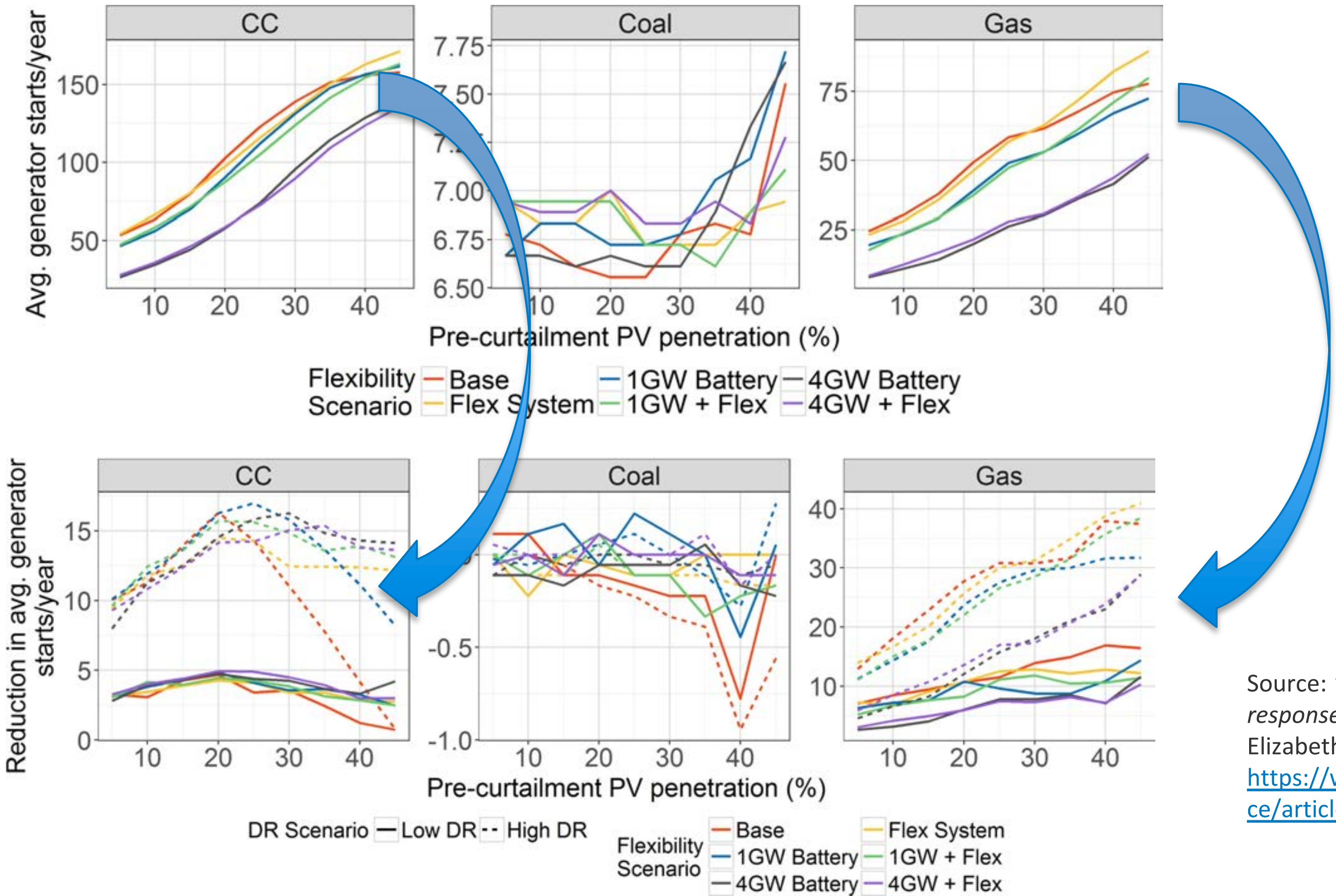
- It is not suitable for direct inclusion in a power system model or market clearing algorithm because it is non-linear



Tapping into Demand Response (DR)

No DR

With DR

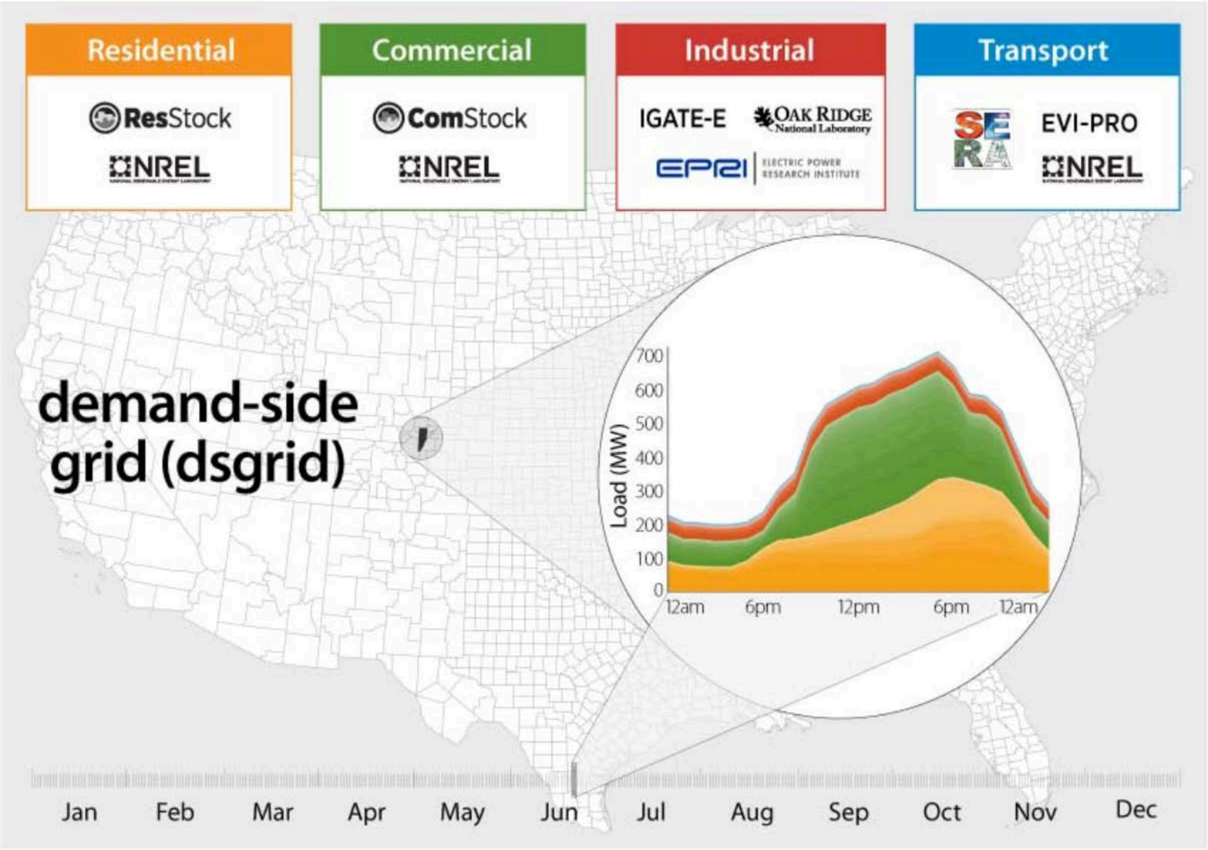


Reduced number of Combined Cycle and Gas Turbine Starts due to using demand response

Source: *"The value of demand response in Florida"*, Brady Stoll, Elizabeth Buechler, and Elaine Hale, https://www.sciencedirect.com/science/article/pii/S1040619017302609

NREL's dsgrid: Demand-Side Grid Model

https://www.nrel.gov/analysis/dsgrid.html



NREL's demand-side grid (dsgrid) model harnesses decades of sector-specific energy modeling expertise to understand current and future U.S. electricity load for power systems analyses.

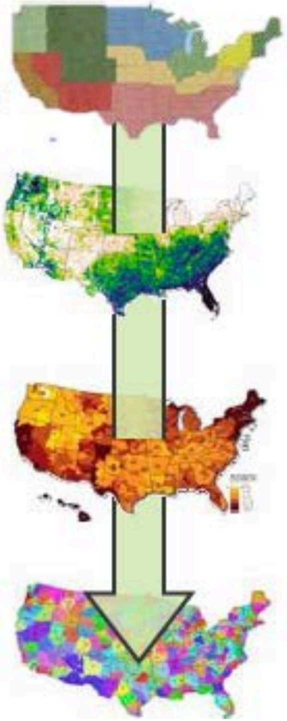
The primary purpose of dsgrid is to create comprehensive electricity load data sets at high temporal, geographic, sectoral, and end-use resolution.

These data sets enable detailed analyses of current patterns and future projections of end-use loads.

Data required for full-resolution U.S. Model

Housing stock characteristics database + Physics-based computer modeling + High-performance computing

Building Characteristics	EIA	**Res. Energy Consumption Survey (RECS)**
	NAHB	**Homebuilder Surveys**
	IECC	**Historical Energy Codes**
Census Data	Census	**American Community Survey (ACS)**
Costs	EIA	**Electricity and fuel costs**
	NREL	**OpenEI.org Utility Rate Database**
	NREL/Navigant	**Measure Cost Database**
Climate Locations	NREL	**TMY3 weather data**



Examining how DR can help a large city

LA100

The Los Angeles 100% Renewable Energy Study

https://www.nrel.gov/analysis/los-angeles-100-percent-renewable-study.html

LA100 Methodology for understanding Demand Response

The Los Angeles 100% Renewable Energy Study

Input models

What is electricity demand and customer-driven supply?

- Electricity demand
- Demand response
- Renewable resource analysis
- Customer-driven solar

Main scenario models

What does LADWP build?

- Generation
- Transmission
- Distribution upgrades

Output and validation models

How do we know it's right?

- Load balancing
- Resource adequacy
- Power flow and stability analysis
- Integrated distribution and transmission analysis

Impact models

What are the impacts?

- Economic and workforce analysis
- Environmental analysis

Types of Demand Response Programs

Interruptible Load

- Commercial, Institutional & Industrial (CII, modeled on current program)

Energy-shifting

- Scheduled electric vehicle charging
- Scheduled water system operations

- Residential
  - cooling
  - hot water
  - heating
  - refrigeration
  - schedulable appliances
  - pool pumps
- Commercial
  - cooling
  - heating
  - hot water
  - refrigeration

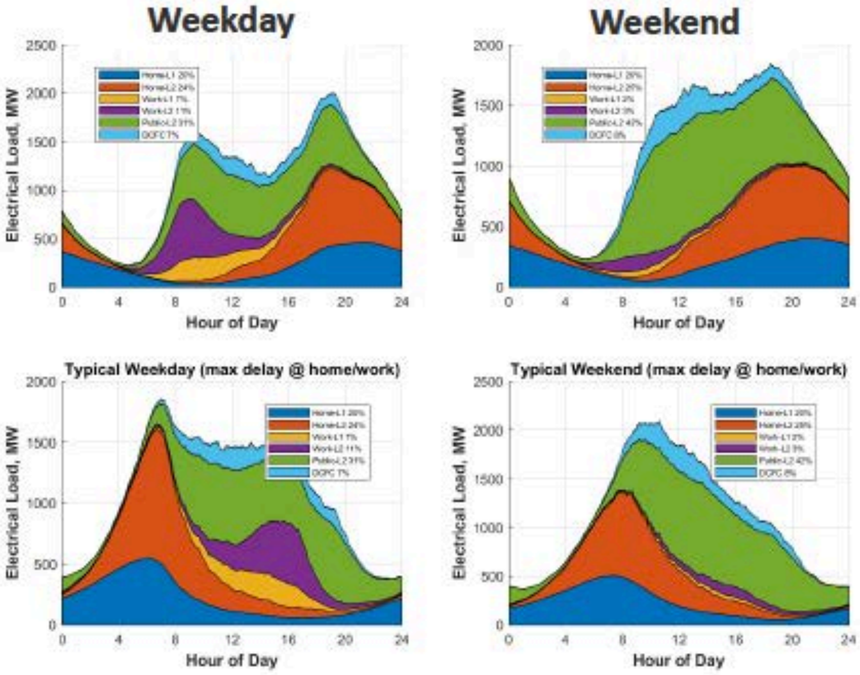
Demand Response Assumptions

- **Interruptible load** – Load shed up to 4 h/day, 48 h/year (e.g., 4 hour load shed on top-12 peak days)
- **Water system scheduling** – Half of water system load shiftable up to 12 hours in High Projection, 2035 and later only
- **Residential and commercial end-use shifting** – Participating fraction of end-use can be shifted, subject to
  - Shifting windows
  - Times of day by which all service in the previous period must be delivered

Demand Response Assumptions

- **Electric vehicle schedulable load** – Dynamic model of shiftability is assembled from min-delay and max-delay profiles

Min-delay (Baseline) profile



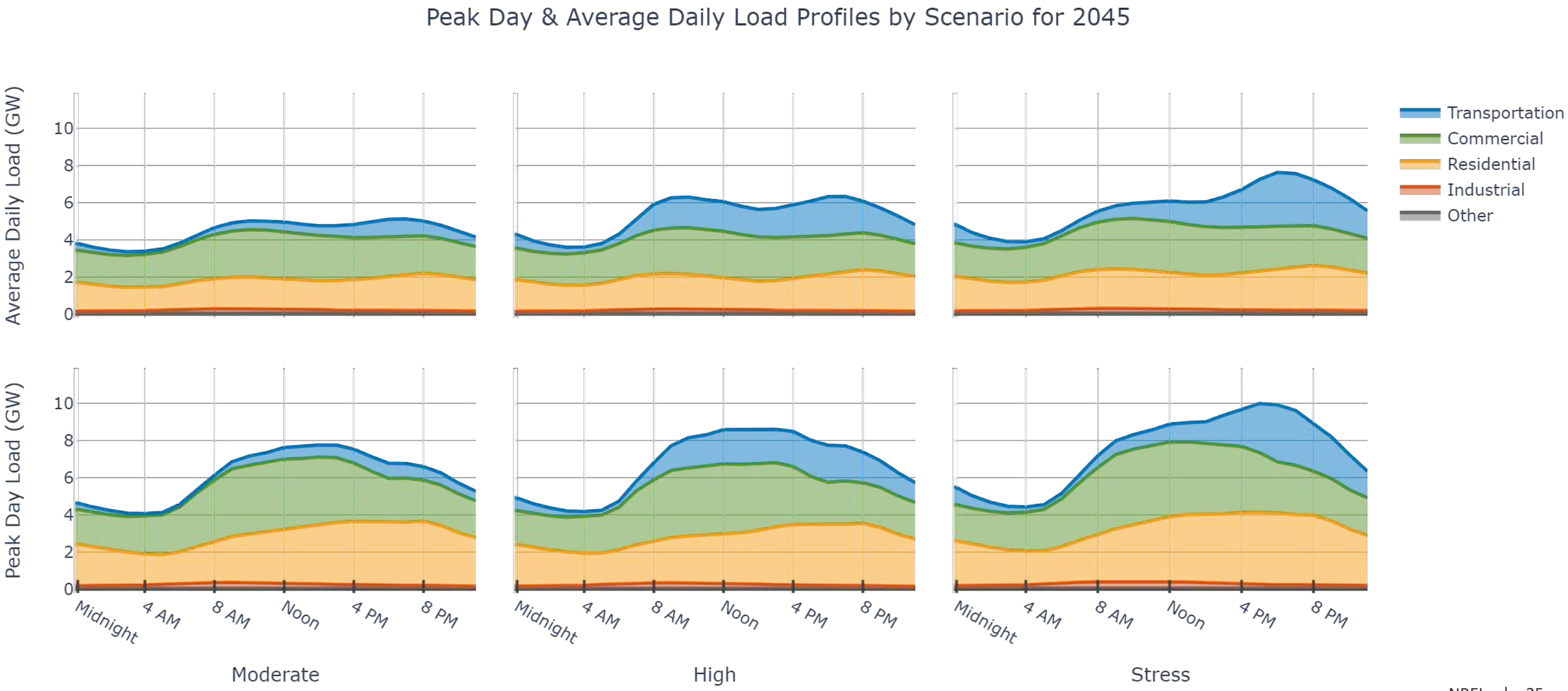
Max-delay profile

*Charging **proceeds as quickly as possible** as soon as you plug your car in.*

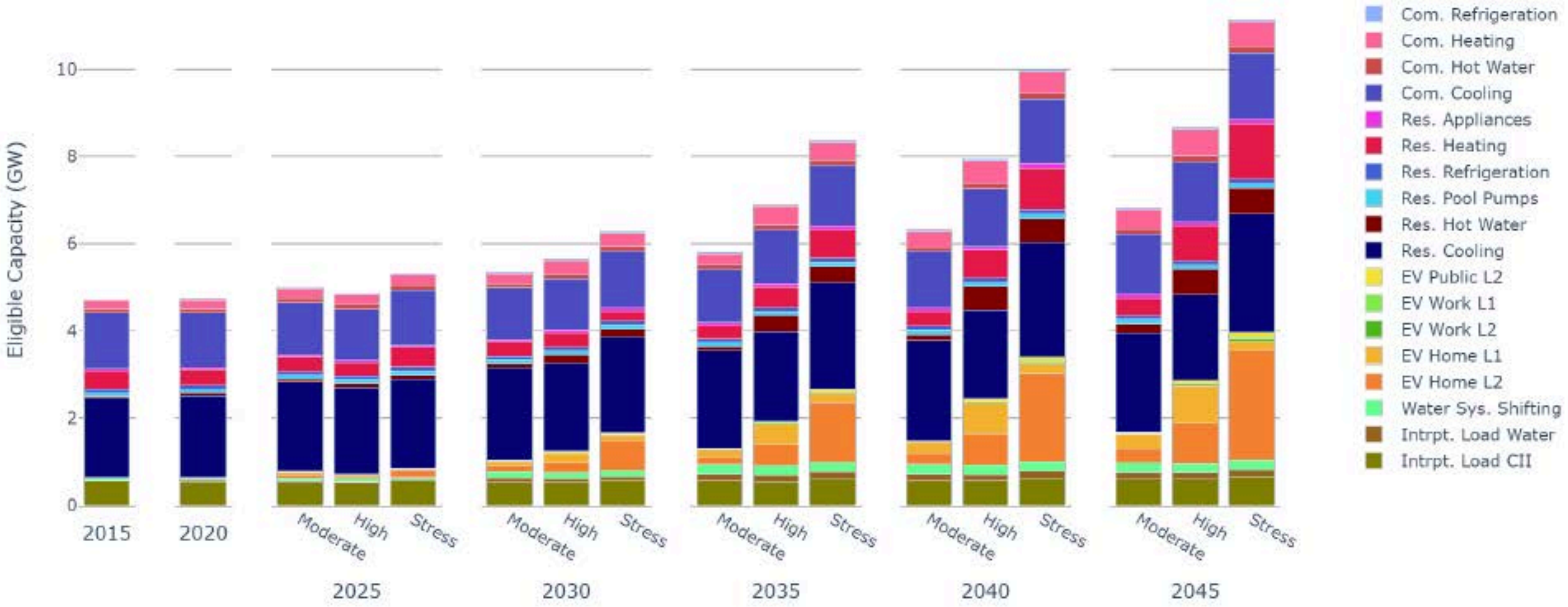
*Charging is **delayed as long as possible** while ensuring you have sufficient charge for your next trip.*

Only L1 and L2 charging is considered shiftable

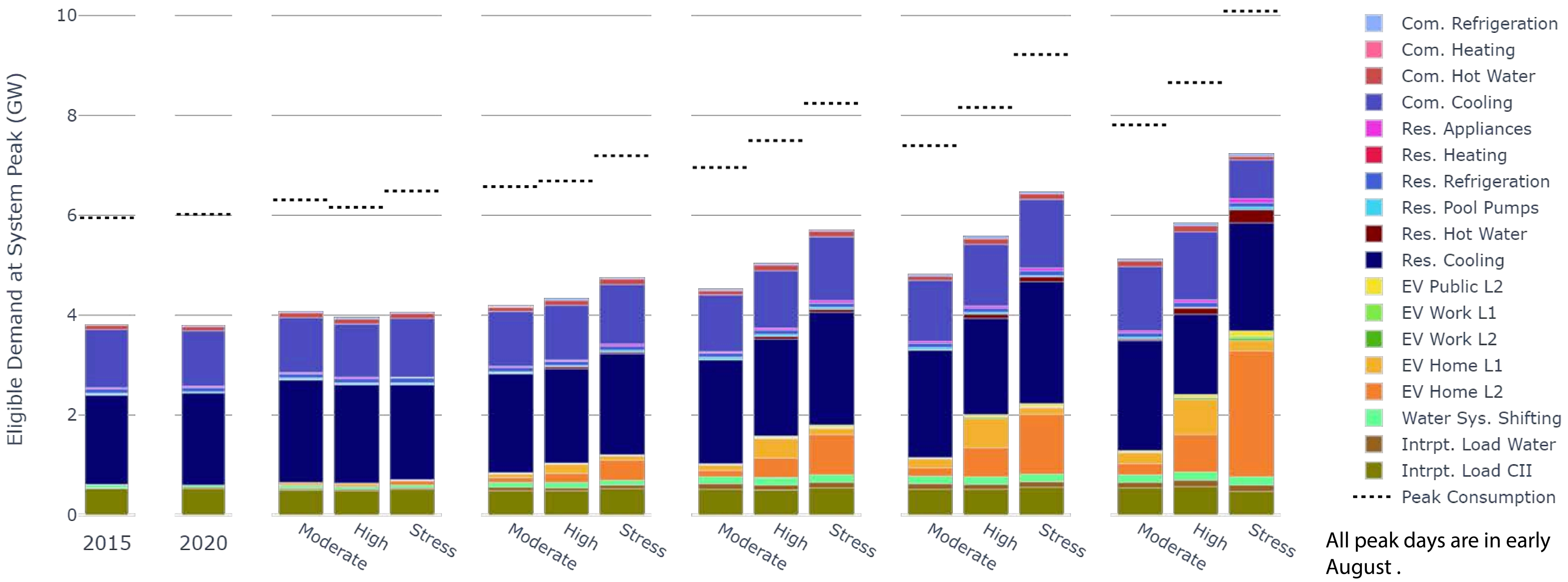
Peak Day and Average Daily Load Profiles for 2045



DR Eligibility – end-use peak demand, non-coincident with system



DR Eligibility – end-use demand at time of system peak



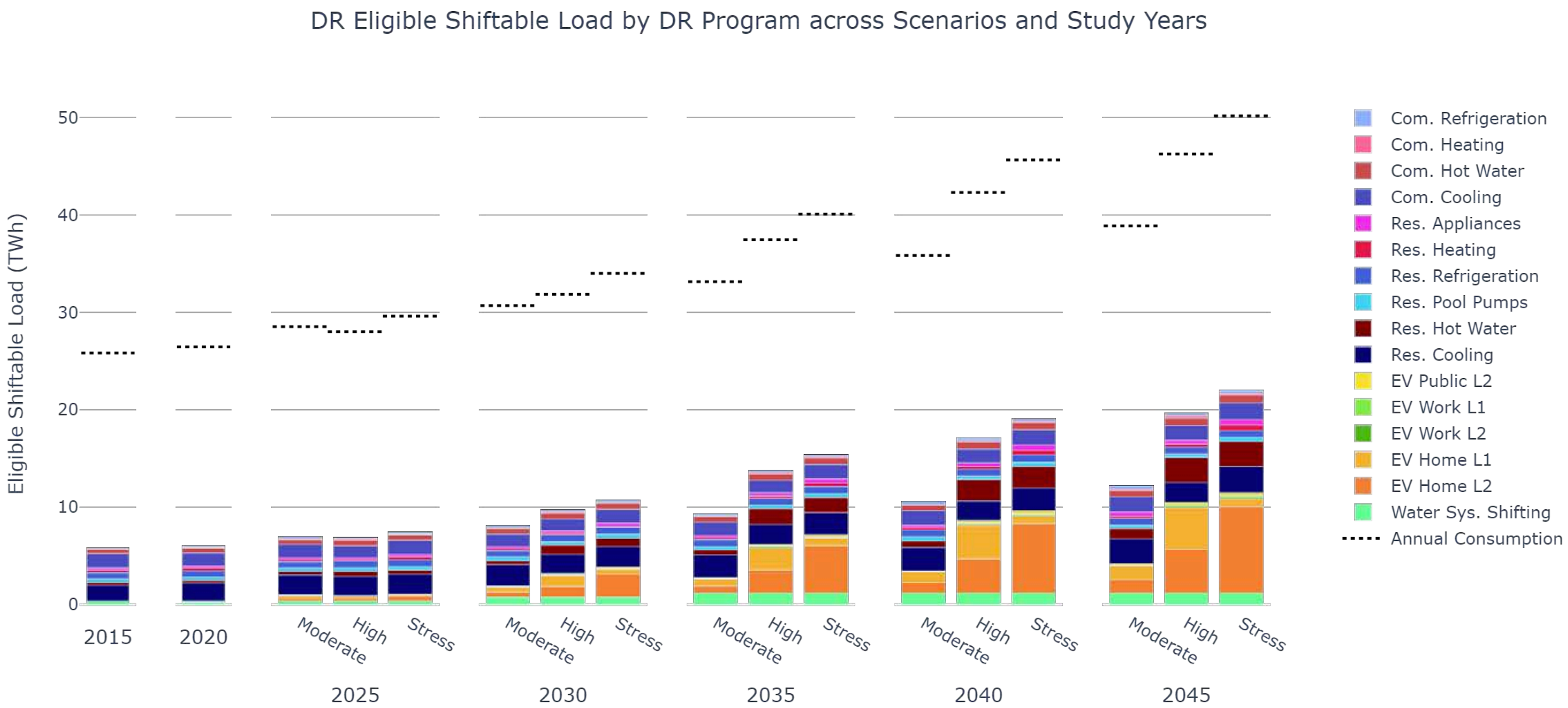
4pm 4pm 4pm (2030)

4pm 2pm 7pm (2045)

All peak days are in early August .

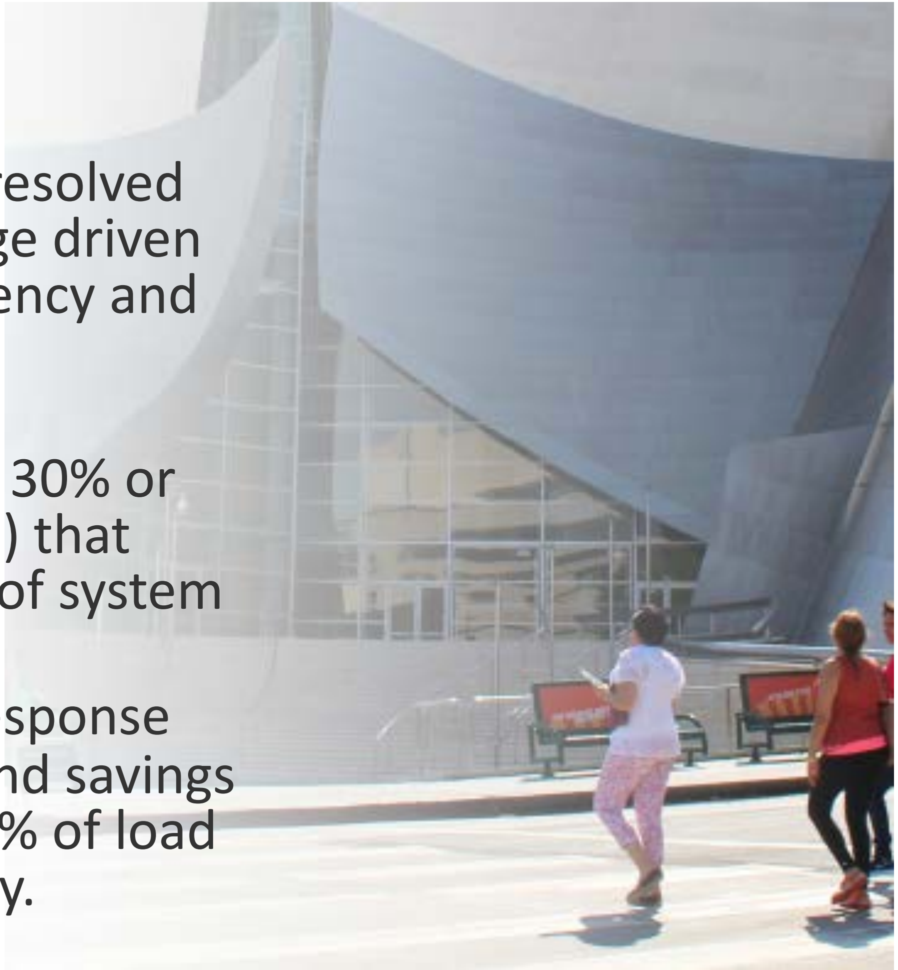
Peak times are shown in local time, PDT.

DR Eligibility – Shiftable end-use demand



LA100 Conclusions

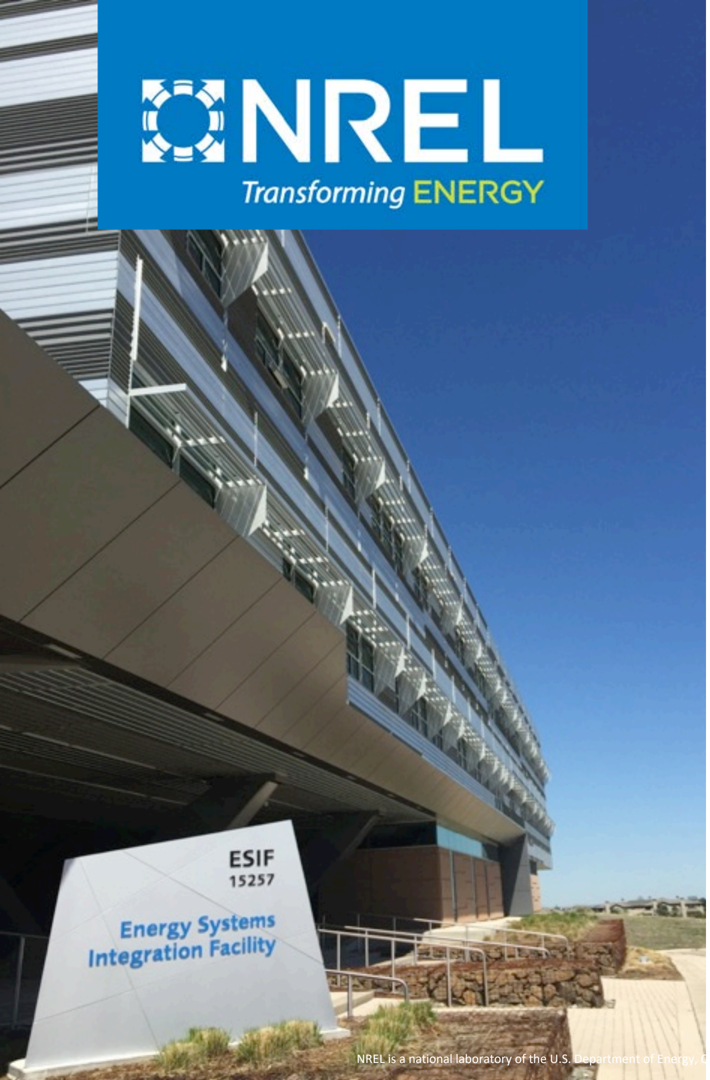
- LA100 load projections are highly resolved descriptions of demand-side change driven by economic growth, energy efficiency and electrification.
- All projections include significant transportation electrification (e.g., 30% or 80% of the light-duty fleet by 2045) that influences the amount and timing of system demand.
- High electrification and demand response could unlock over 10% peak demand savings and the potential to shift about 10% of load to better align with available supply.



Summary

- Future energy systems will need to pair variable generation with controllable loads
- Demand response will be important to economically reaching higher levels of clean energy
- Critical to be able to model DR deployments and controllability

https://www.nrel.gov/analysis/demand-response.html



Thank You!

For Further Reading

- "Achieving a 100% Renewable Grid – Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," B. Kroposki et al., IEEE Power & Energy Magazine, Nov/Dec 2017 http://ieeexplore.ieee.org/document/7866938/
- *"Addressing technical challenges in 100% variable inverter-based renewable energy power systems"*, B. Hodge et al., WIREs Energy and Environment, April 2020, https://onlinelibrary.wiley.com/doi/full/10.1002/wene.376
- "Energy Systems Integration: Defining and Describing the Value Proposition ", O'Malley, Kroposki, Hannegan, Madsen, Andersson, D'haeseleer, McGranaghan, Dent, Strbac, Baskaran, Rinker., NREL/TP-5D00-66616. June 2016
- *"Energy Systems Integration: An Evolving Energy Paradigm"*, M. Ruth and B. Kroposki, *The Electricity Journal*, 2014
- *On the Inclusion of Energy Shifting Demand Response in Production cost Models: Methodology and a Case Study*, N. O' Connell, E. Hale, I. Doebber, and J. Jorgenson, NREL/TP-6A20-64465, July 2015 http://www.nrel.gov/docs/fy15osti/64465.pdf
- *Jadun, Paige, Colin McMillan, Daniel Steinberg, Matteo Muratori, Laura Vimmerstedt, and Trieu Mai. 2017. Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70485. https://www.nrel.gov/docs/fy18osti/70485.pdf.*
- *Mai, Trieu, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson. 2018. Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71500. https://www.nrel.gov/docs/fy18osti/71500.pdf*
- *Hale, Elaine, Henry Horsey, Brandon Johnson, Matteo Muratori, Eric Wilson, et al. 2018. The Demand-side Grid (dsgrid) Model Documentation. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71492. https://www.nrel.gov/docs/fy18osti/71492.pdf*
- *LA100 – 100% Renewable Energy Study Advisory Group Meeting #11 – Virtual Meeting #1 Electricity Demand Projections and Demand Response, May 2020 https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-power/a-p-cleanenergyfuture*