The Los Angeles 100% Renewable Energy Study

Bulk Power System Modeling:
Key Considerations, Working Assumptions, and Ongoing Exploration

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Advisory Group Meeting

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Los Angeles Department of Water & Power

NREL Transforming ENERGY

Session Goals

1. Review the formulation of a 100% clean or renewable energy standard
2. Review key bulk-system modeling assumptions
3. Understanding outputs from capacity expansion and production cost models
4. Bulk power system pathways to 100%—what have we been learning?

Defining a Clean Energy Standard: Clean Generation

$$Clean\ Gen = Load$$

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- *Clean Generation* includes generation for all qualifying clean technologies (what qualifies as clean depends on scenario)

Defining a Clean Energy Standard: Load

$$Clean\ Gen = End\ Use\ Consumption + System\ Losses$$

- *Clean Generation* includes generation for all qualifying clean technologies
- *End Use Consumption* is the energy consumed at the point of end use: plug loads
- *System Losses* are the losses associated with transmission and distribution

Defining a Clean Energy Standard: Time

$$Clean\ Gen_t = End\ Use\ Consumption_t + System\ Losses_t$$

- Over what time period is this evaluated?

Defining a Clean Energy Standard: RECs

$$Clean\ Gen_t + RECs_t = End\ Use\ Consumption_t + System\ Losses_t$$

- Whether renewable energy certificates (***RECs***) are allowed to contribute toward compliance and restrictions on the types and quantities of RECs allowed depends on the scenario

Interpretation for Current Results Shown

- Load must be met with clean energy at all times unless RECs are allowed
- Exported clean energy does not count towards compliance; cannot offset natural gas generation with surplus renewable generation unless RECs are allowed

Key Assumptions for Bulk System Modeling and Analysis

Two of eight scenarios allow the use of RECs for a portion of compliance

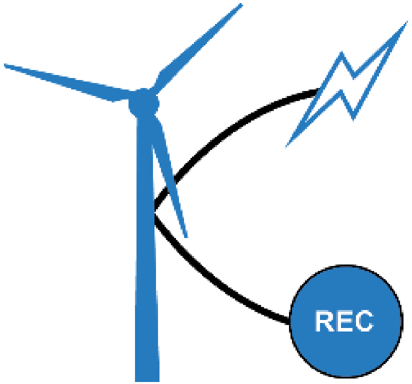
		LA100 Scenarios							
		SB100	LA-Leads	Transmission Renaissance	High Distributed Energy Future	Emissions Free	High Load Stress	Load Modern-ization	Western Initiatives
	2030 RE Target	60%	100% Net Renewable Energy						
	Compliance Year for 100%	2045	2035/2040	2045	2045	2045	2045	2045	2045
Technologies Eligible in the Compliance Year	Biomass	Y	Y	Y	Y	No	Y	Y	Y
	Biogas	Y	Y	Y	Y	No	Y	Y	Y
	Electricity to Fuel (e.g. H2)	Y	Y	Y	Y	Y	Y	Y	Y
	Fuel Cells	Y	Y	Y	Y	Y	Y	Y	Y
	Hydro - Existing	Y	Y	Y	Y	Y	Y	Y	Y
	Hydro - New	N	N	N	N	N	N	N	N
	Hydro - Upgrades	Y	Y	Y	Y	Y	Y	Y	Y
	Natural Gas	Yes	N	N	N	N	Yes	N	N
	Nuclear - Existing	Y	Y	No	No	Y	Y	No	No
	Nuclear - New	N	N	N	N	N	N	N	N
	Wind, Solar, Geo	Y	Y	Y	Y	Y	Y	Y	Y
	Storage	Y	Y	Y	Y	Y	Y	Y	Y
Repowering OTC	Haynes, Scattergood, Harbor	N	N	N	N	N	N	N	N
DG	Distributed Adoption	Reference	High	Low	High	Balanced	Balanced	Balanced	Balanced
RECS	Financial Mechanisms (RECS/Allowances)	Yes	N	N	N	N	Yes	N	N
Load	Energy Efficiency	Reference	High	Moderate	High	Moderate	Reference	High	Moderate
	Demand Response	Reference	High	Moderate	High	Moderate	Reference	High	Moderate
	Electrification	Reference	High	Moderate	High	Moderate	High	High	Moderate
Transmission	New or Upgraded Transmission Allowed?	Matches 2017 SLTRP	Only Along Existing or Planned Corridors	New Corridors Allowed	No New Transmission	Only Along Existing or Planned Corridors	Only Along Existing or Planned Corridors	Only Along Existing or Planned Corridors	Only Along Existing or Planned Corridors
WECC	WECC VRE Penetration	Reference	Reference	Reference	Reference	Reference	Reference	Reference	High

Defining RECs

A renewable energy certificate (REC) is a market-based instrument that represents the property rights to the environmental, social, and other non-power attributes of renewable electricity generation. **RECs are issued when one megawatt-hour (MWh) of electricity is generated and delivered to the electricity grid from a renewable energy resource.**

Use of RECs in Making RE Claims

- Every MWh of RE output generates two valuable assets:



Electricity
RE output may be used to reduce the customer's grid demand, sold into wholesale markets, or sold directly to a supplier via bilateral contract

RECs
RECs are used by customers to make RE use claims or sold into REC markets

- RECs are uniquely numbered and tracked;
- For compliance purposes (e.g., with a renewable portfolio standard), RECs are "retired" by obligated entities
- REC tracking and certification systems prevent double-counting

Modeling Assumptions: RECs

The LA100 study assumes that the CA SB 350 RPS REC usage restrictions apply in all scenarios that allow partial compliance with RECs

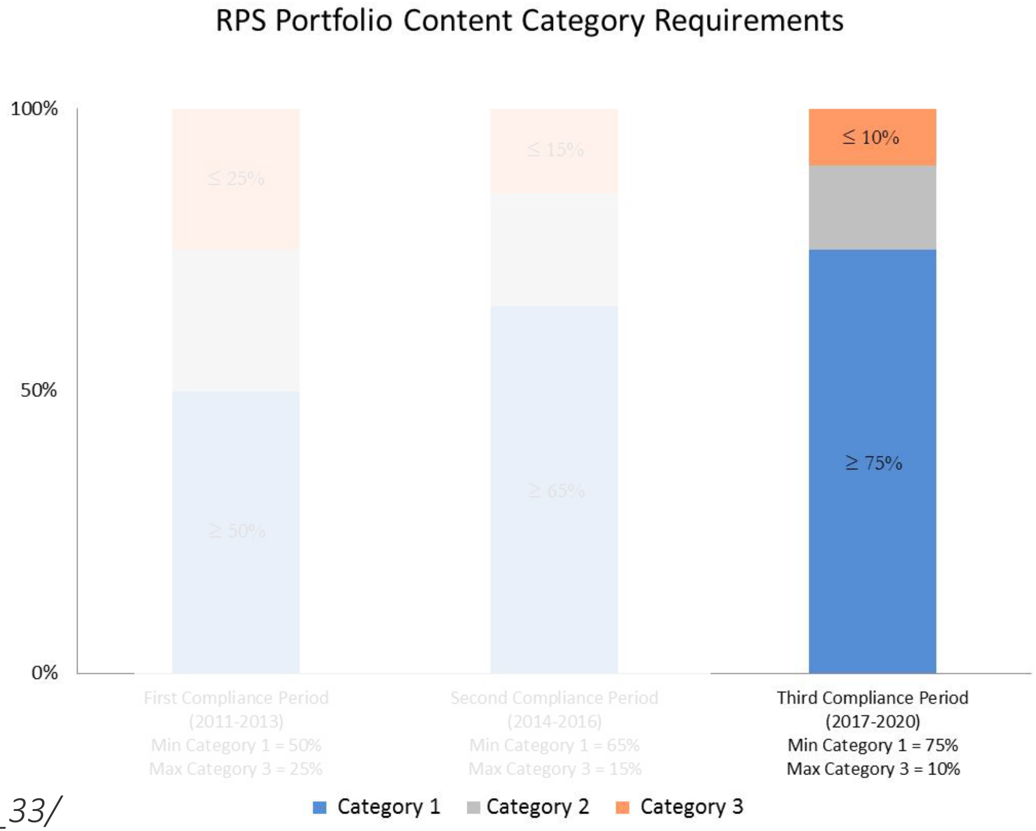


Figure from the California PUC: https://www.cpuc.ca.gov/RPS_Procurement_Rules_33/

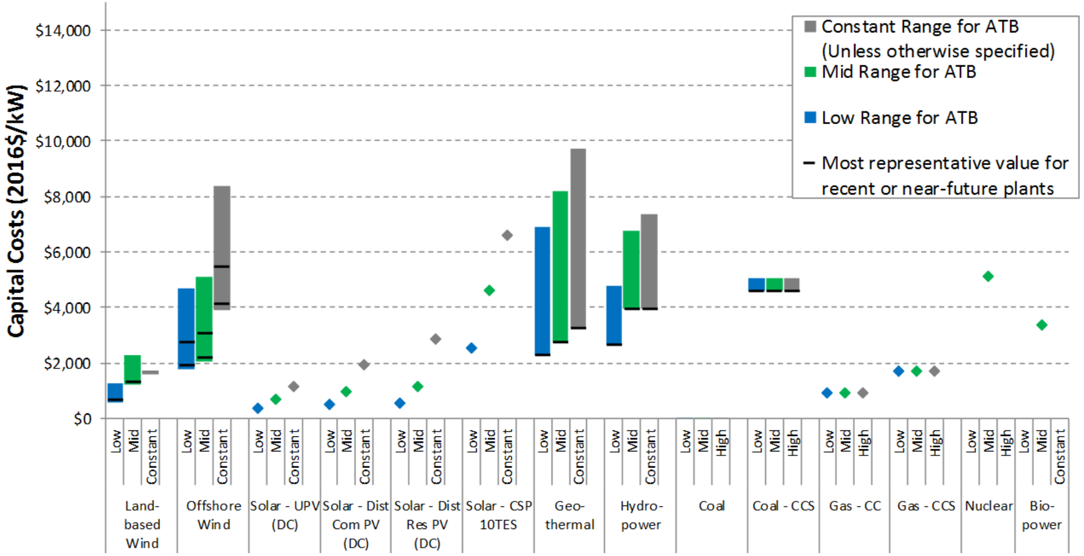
Modeling Assumptions:
Coordination with Other Entities

- **Planning/investment (RPM)**: LADWP system designed for *self-sufficiency*: all electricity services (energy, capacity, planning reserves, and operating reserves) must be met with LADWP owned or contracted assets
- **Dispatch/operations (PLEXOS)**: examine both dispatch based solely on LADWP-owned or -contracted assets, **and** *fully coordinated* dispatch

Assumptions: Technology Costs and Performance

NREL's Annual Technology Baseline (ATB)

- The ATB provides a consistent set of cost and performance projections for renewable and conventional generation and storage technologies from present day to 2050
- Costs covered: capital (including financing costs), fixed and variable (non-fuel) O&M

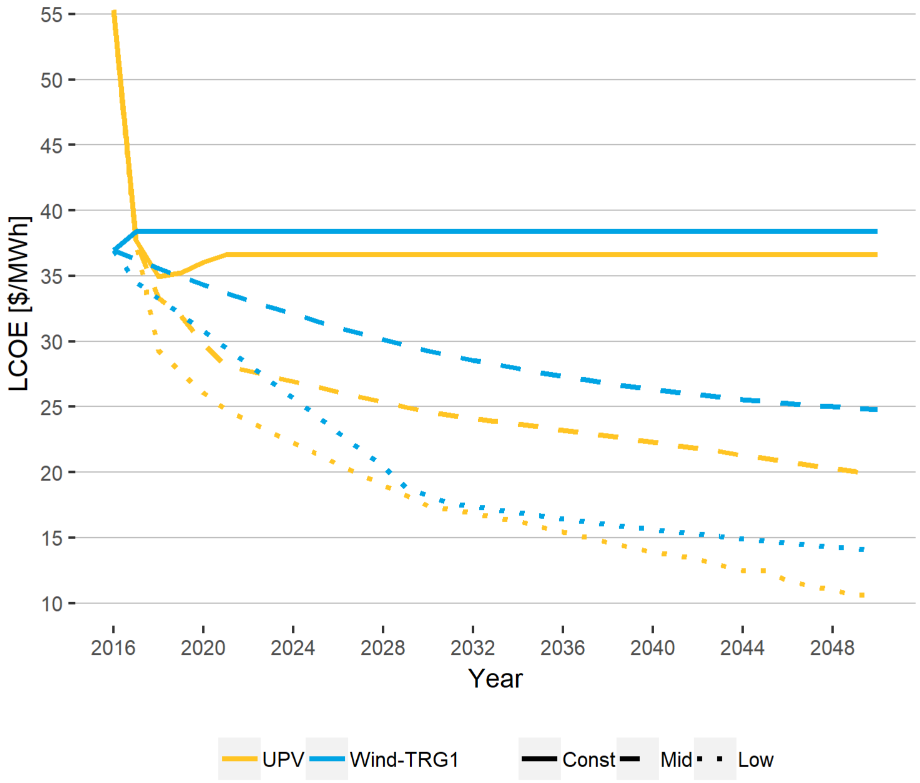


2018 ATB CAPEX range by technology for 2050

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

Assumptions: Technology Costs and Performance

- **Constant:** Current technology costs held constant; represents limited/no technology improvement; No additional R&D
- **Mid:** Improvements characterized as "likely" or "not surprising;" continued public and private R&D; continued deployment and market growth
- **Low:** Improvements at the "limit of surprise"; not an absolute low bound; increased public and private R&D, breakthroughs; accelerated market growth



Assumptions: Technology Prices
Sources of Base Year (2016)

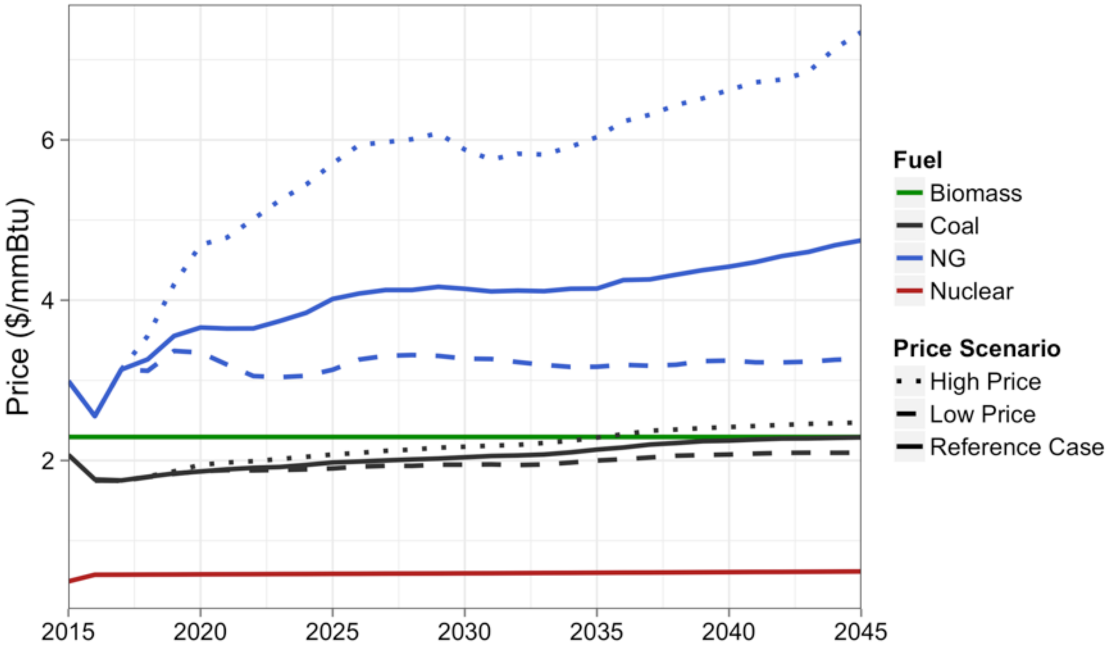
Technology	Methods	Main Sources
Wind - Land-based - Offshore	Use of market data Bottom-up modeling	2016 Wind Technologies Market Report (LBNL 2017) 2016 Cost of Wind Energy Review (NREL 2017) Assessment of Economic Potential of Offshore Wind in the United States (NREL 2017)
Solar Photovoltaics (PV) - Utility - Commercial and industrial - Residential	Market data Bottom-up model	Utility-Scale Solar 2016 (LBNL 2017) Tracking the Sun 10 (LBNL 2017) U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017 (NREL 2017)
CSP	Market data Unpublished data Bottom-up model	Utility-Scale Solar 2016 (LBNL) On the Path to SunShot (DOE/NREL 2016) Survey of in-development projects (DOE unpublished)
Hydropower - New stream-reach - Non-powered Dams	Market data Bottom-up model	Hydropower Baseline Cost Modeling (ORNL 2015)
Geothermal - Binary and flash - EGS	Bottom-up model	Geothermal Energy Technology Evaluation Model (DOE 2016)
Fossil, Nuclear, and CCS	Engineering estimates	AEO2018 assumptions (EIA 2018)

Assumptions: Technology Prices
Sources of Projections

Technology	Methods	Main Sources
Wind - Land-based - Offshore	Expert elicitation Bottom-up model Expert assessment	Expert elicitation survey on future wind energy costs (LBNL 2016) SMART Wind (NREL 2017)
Solar PV - Utility - Commercial and industrial - Residential	Literature survey Bottom-up model	Internal analysis (Feldman/NREL 2018) On the Path to SunShot (DOE/NREL 2016)
CSP	Market data Unpublished data Bottom-up model	Internal analysis (Kurup/NREL 2018) On the Path to SunShot (DOE/NREL 2016)
Hydropower - New stream - Non-powered Dams	Expert assessment Learning	Hydropower Vision (DOE 2016) NEMS (EIA 2017)
Geothermal - Binary and flash - EGS	Bottom-up model	Same as ATB 2017. Will be updated after Geothermal Vision Study is published.
Fossil, Nuclear, and CCS	Learning	AEO2018 outputs (EIA 2018)

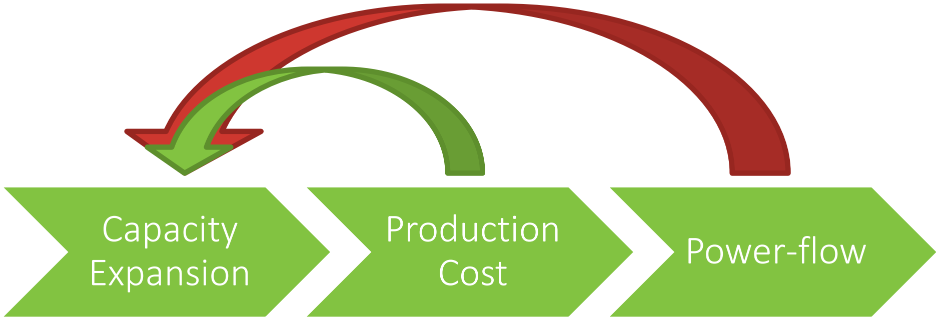
Assumptions: Fuel Prices

- **Current and near-term** (through 2020) fuel prices are based on LADWP’s existing contracts with fuel providers
- **Future** fuel prices (2020–2045) are based on projections used within LADWP’s SLTRP analyses, and standard projections for power sector delivered fuel prices from the U.S. Energy Information Administration’s Annual Energy Outlook (AEO2018)



What kind of plots are we going to see?

General Approach: Estimate, Then Refine

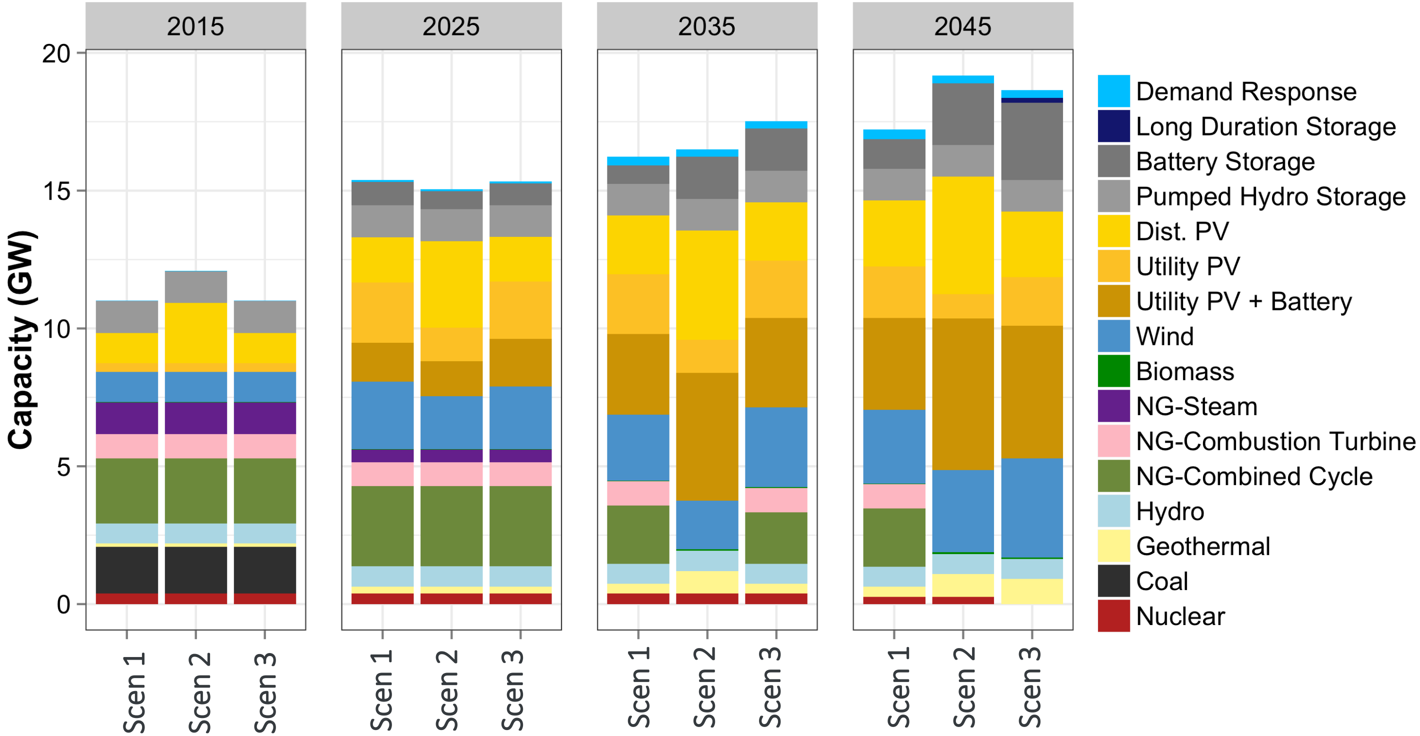


Estimate investment & reduced-form operational costs

Calculate detailed operational costs; identify additional investments needed to address congestion

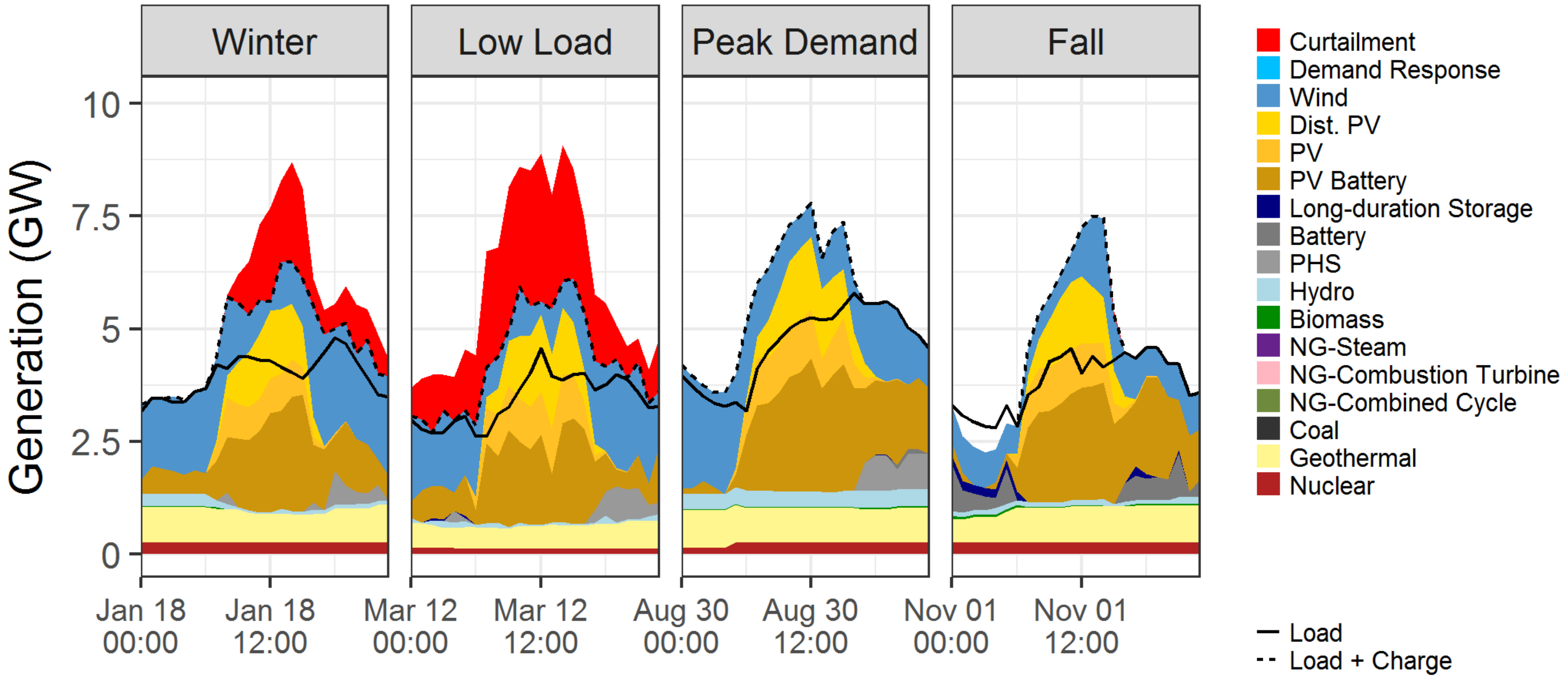
Identify any other necessary infrastructure to mitigate power-flow issues

Capacity Expansion/Evolution



Example figure for demonstration purposes only

Dispatch (Hourly Generation)



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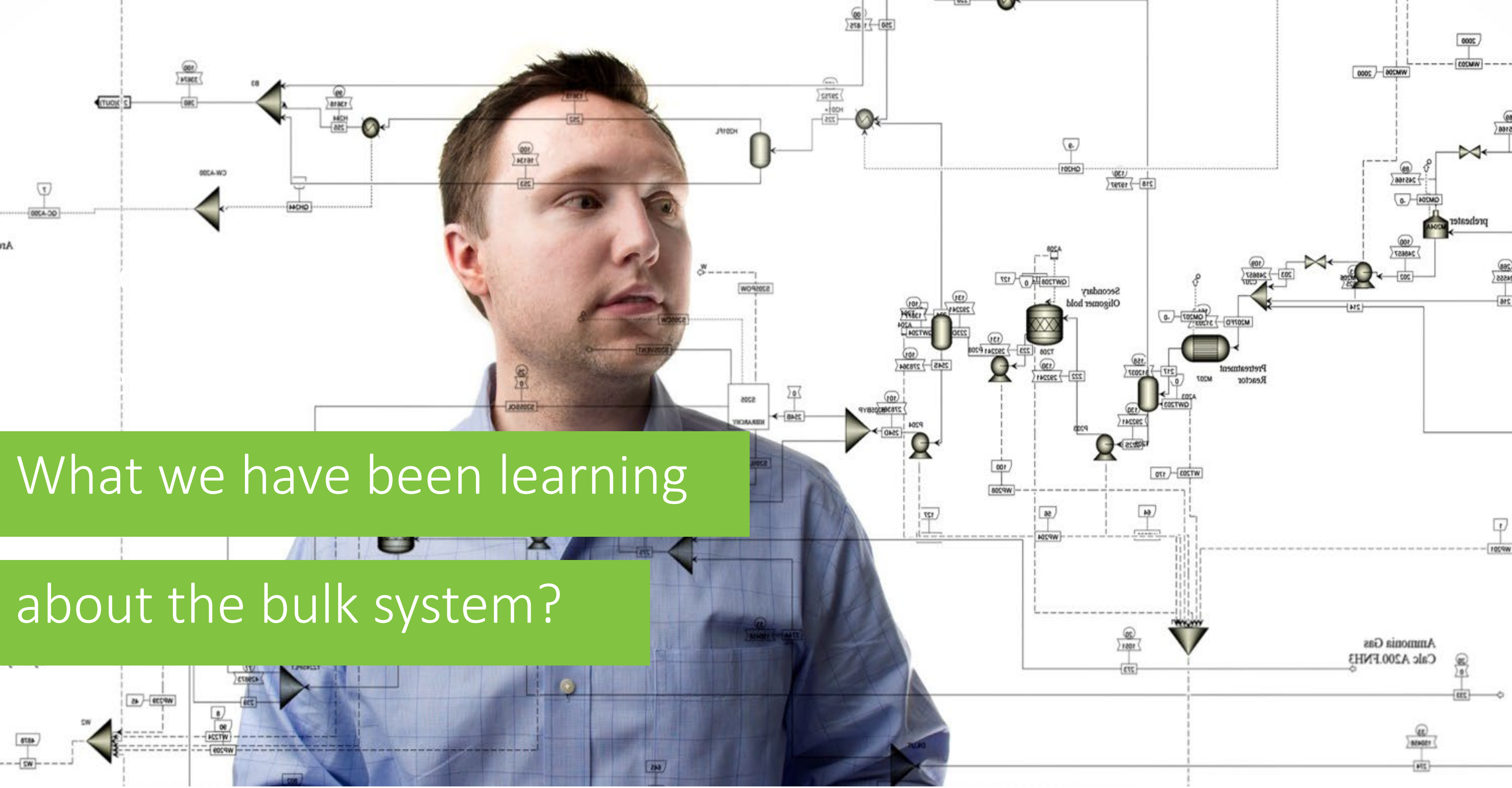
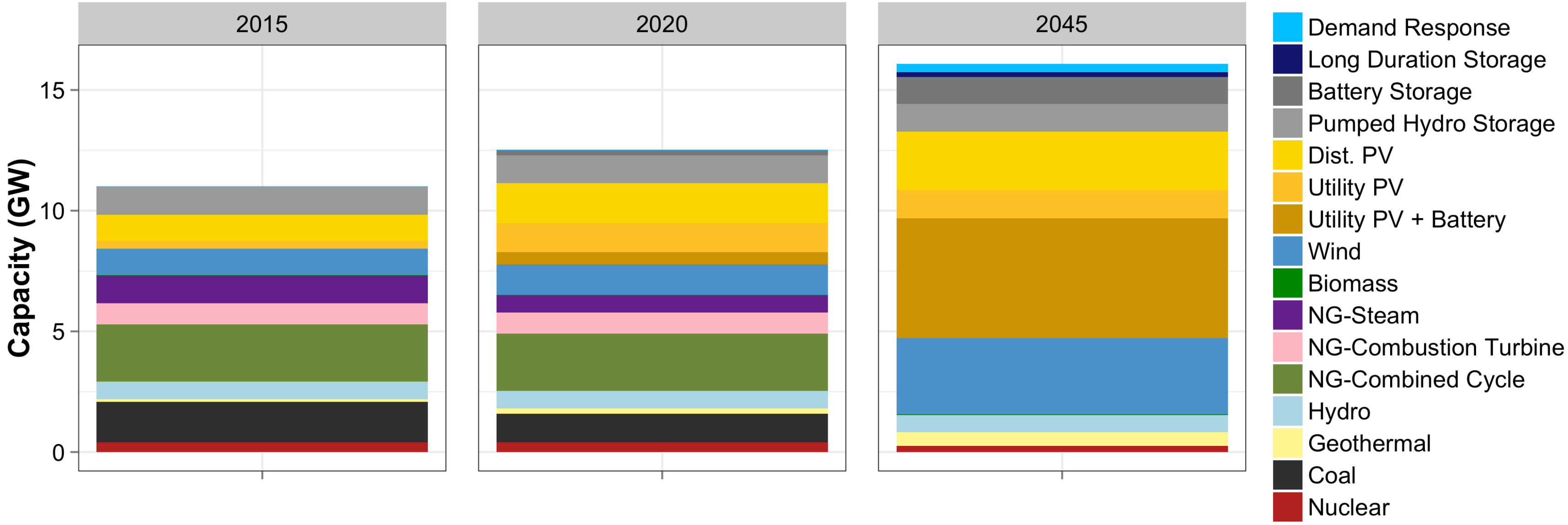


What we have been learning about the bulk system?

Getting to 100% Means Leveraging a Diverse Set of Power System Technology Options

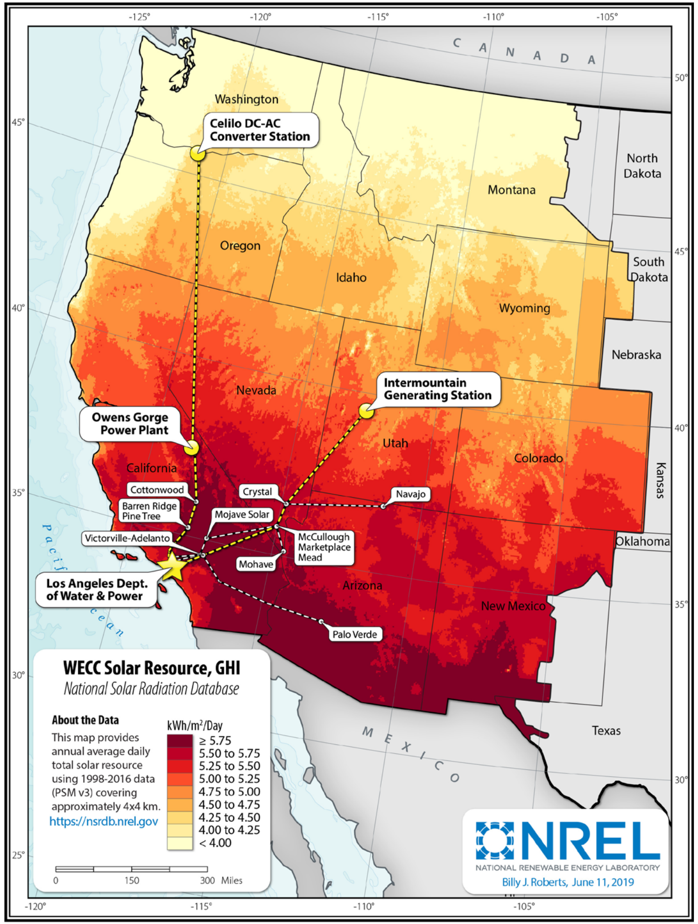
- New wind and solar **capacity** is crucial
- **Storage** is needed to manage diurnal and, in cases without the option to leverage of thermal generation, seasonal variability
- Eligibility of **RECs** allows usage of non-eligible generation during hours of stress
- With high penetrations of variable resources comes increased economic **curtailment**

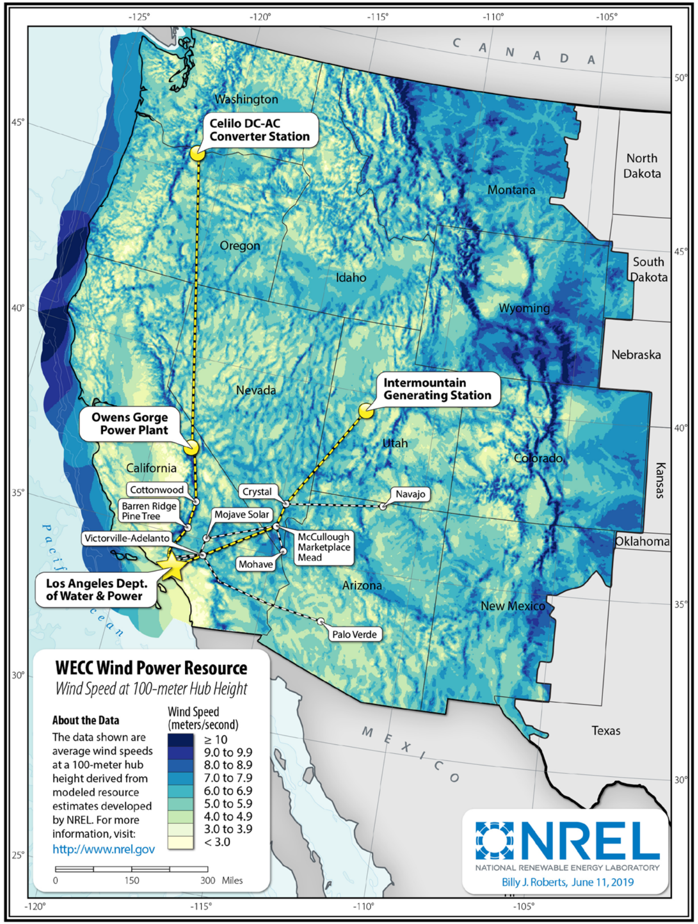
New Renewable Capacity Is Required



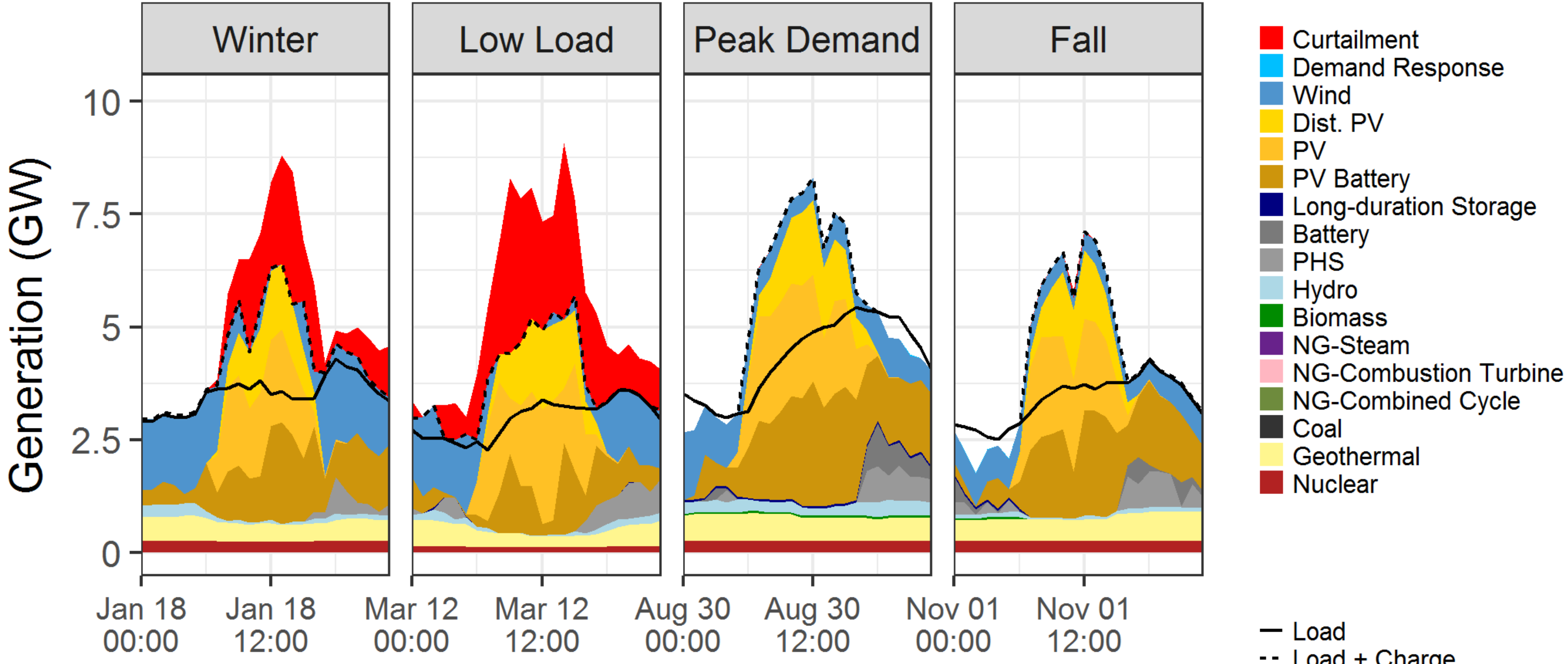
Preliminary Insights—for Discussion Purposes Only

New Renewable Capacity Is Required



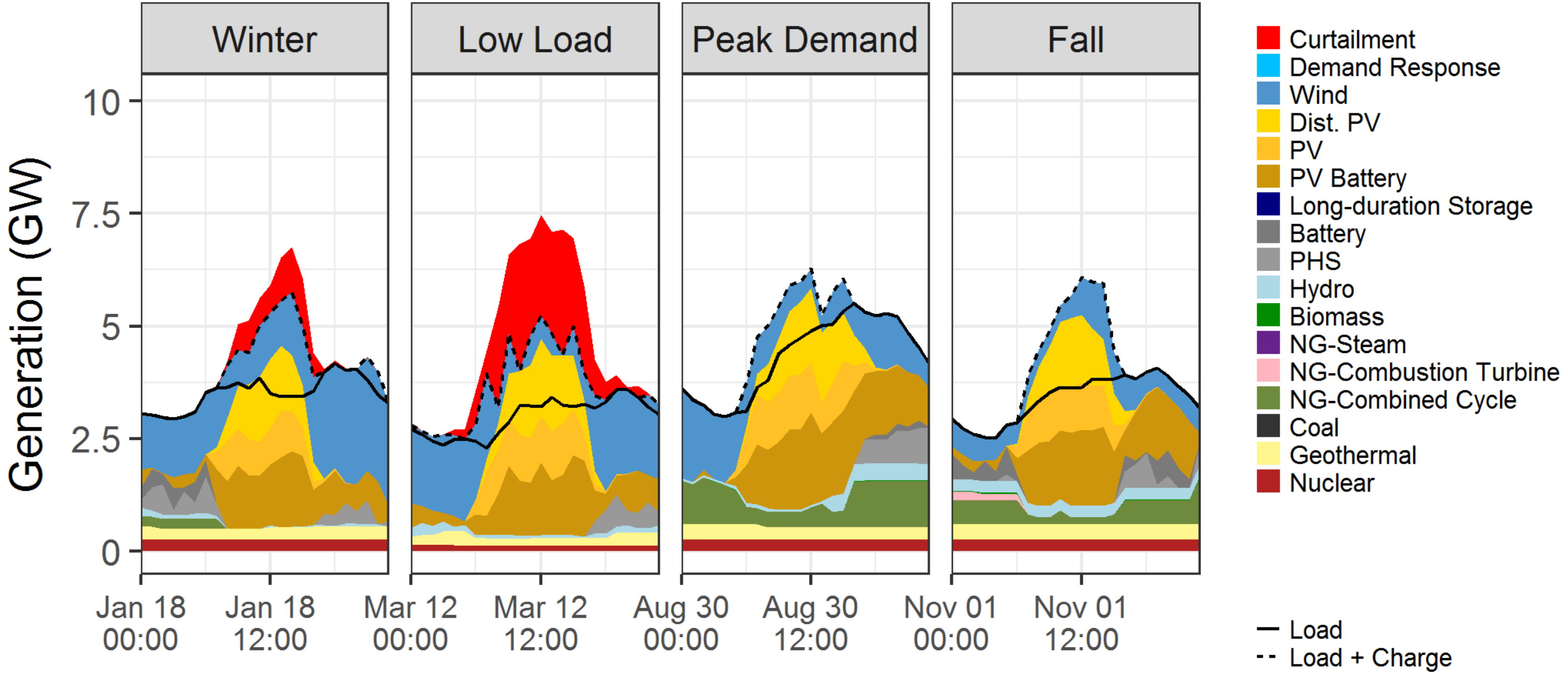


Storage Is Crucial to Manage Variability

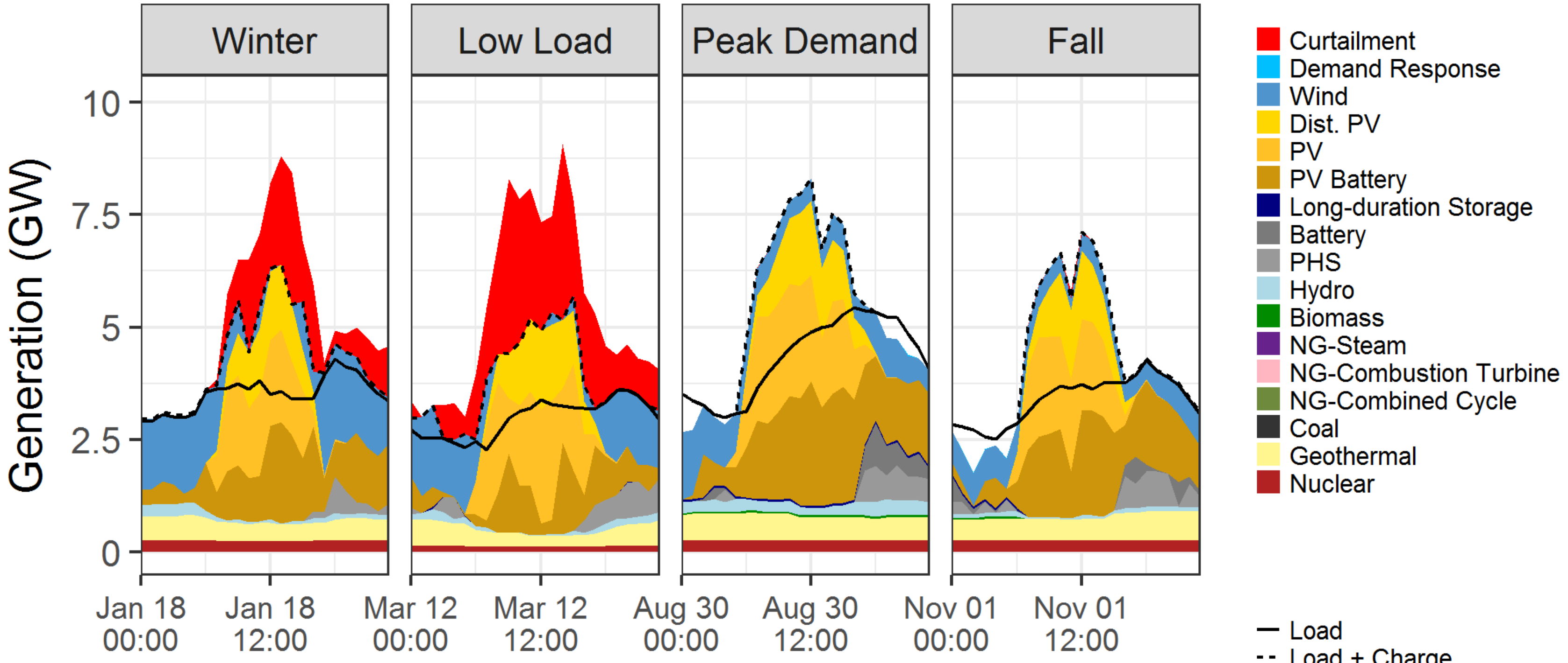


Preliminary Insights for Discussion Purposes Only—Do Not Cite or Distribute

RECs Allow Flexibility to Leverage Thermal Capacity in Times of System Stress



At 100% Renewable, Curtailment Is Also High



Thank you

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