U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Key Takeaways from EERE's Clean Energy Scenario Modeling

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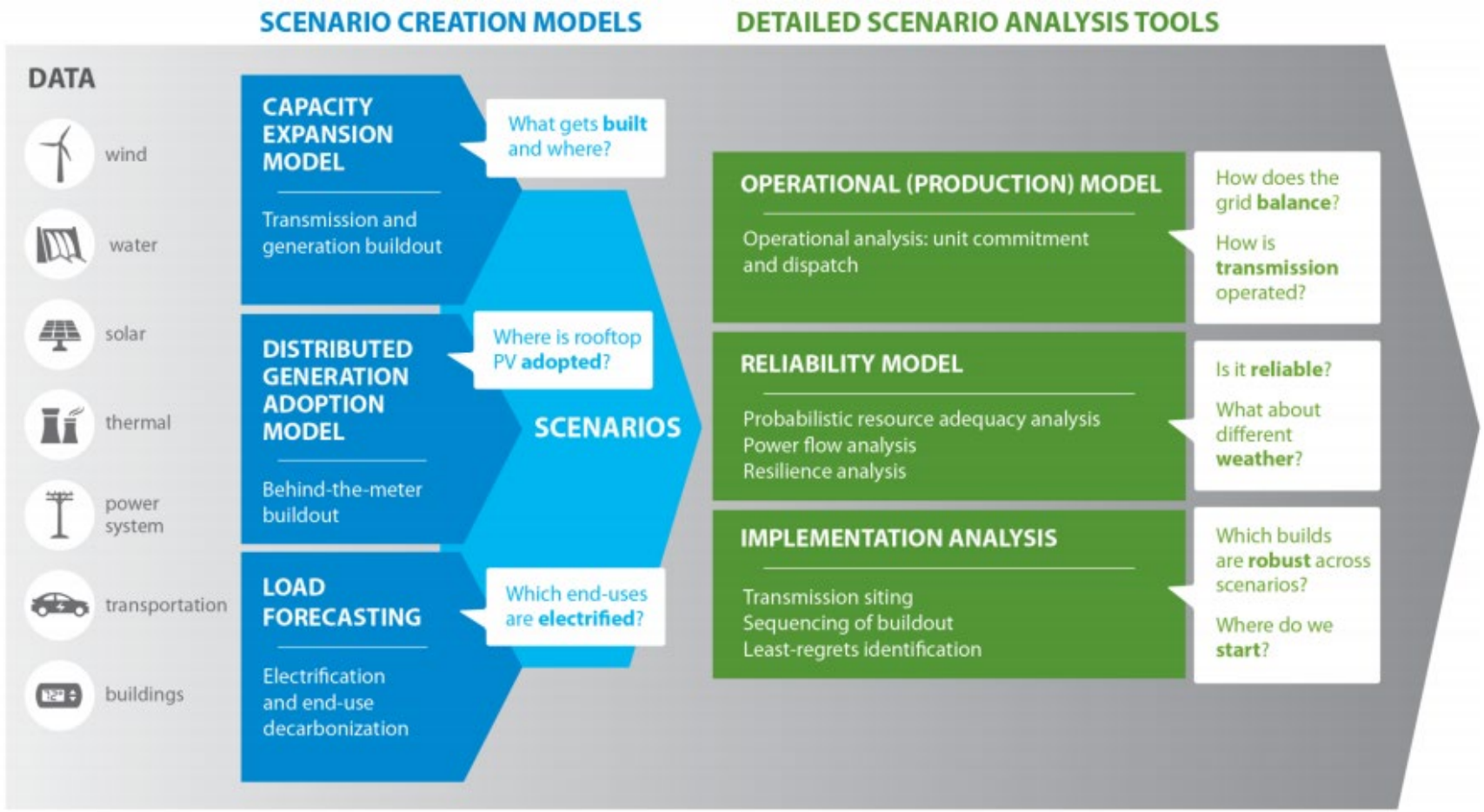
DOE Uses Scenario Analysis to Investigate Power Sector Evolution

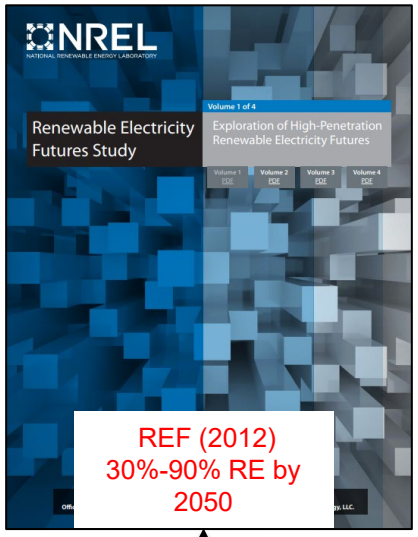
- DOE and the national laboratories develop future energy system scenarios to assess their make-up, cost, operability, and sustainability relative to potential counterfactuals



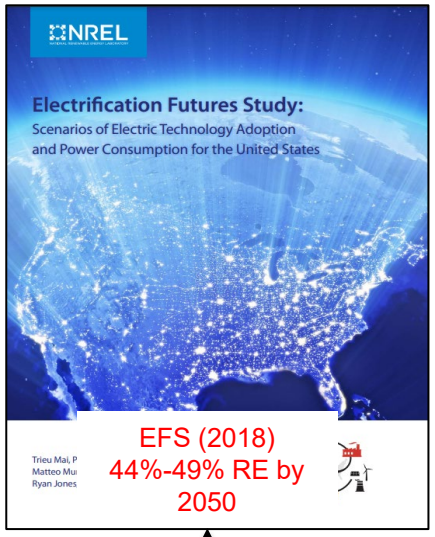
Specific topics of interest:

- Long-term pathways to a modern U.S. or North American power system
- Operational feasibility of very high-penetration scenarios
- Value of enabling technologies: flexible hydro, thermal generation, demand response, storage, and transmission
- Infrastructure requirements
- Weather variability and uncertainty
- Impact of existing or potential future policies

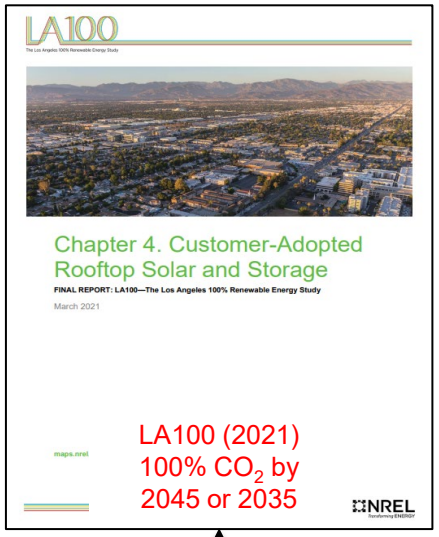
Growing Body of Work Assesses Increasingly Higher Levels of Decarbonization



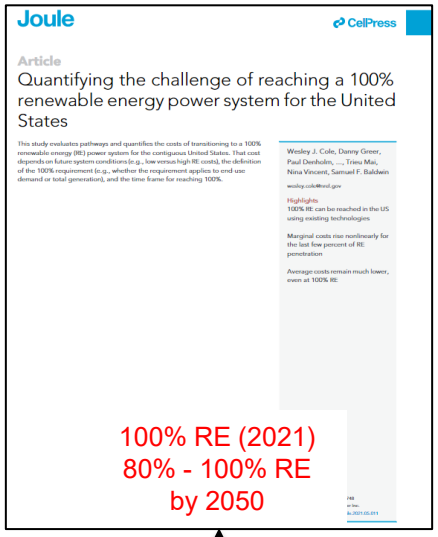
REF (2012)
30%-90% RE by 2050



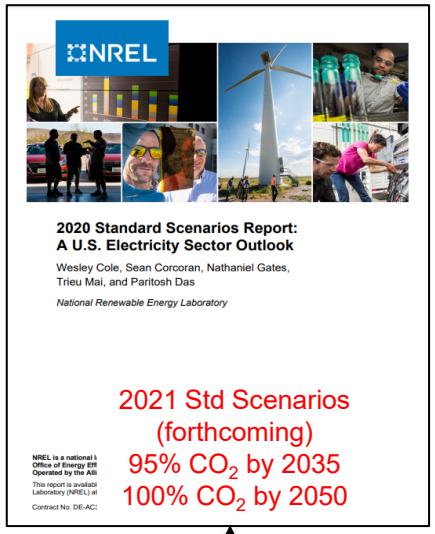
EFS (2018)
44%-49% RE by 2050



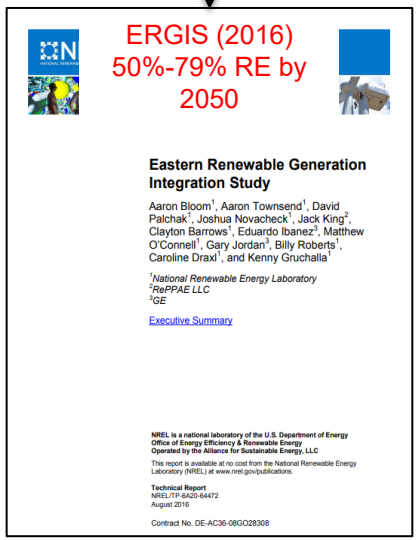
LA100 (2021)
100% CO_2 by 2045 or 2035



100% RE (2021)
80% - 100% RE by 2050

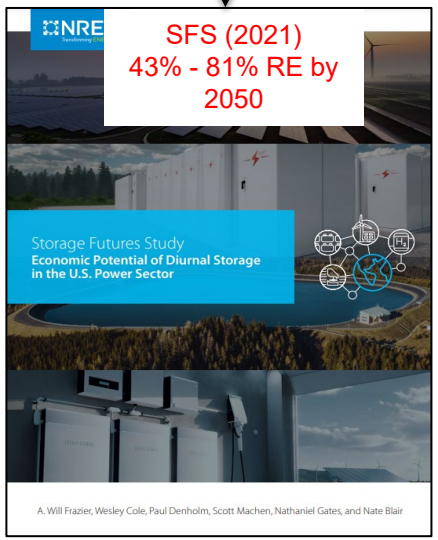


2021 Std Scenarios (forthcoming)
95% CO_2 by 2035
100% CO_2 by 2050

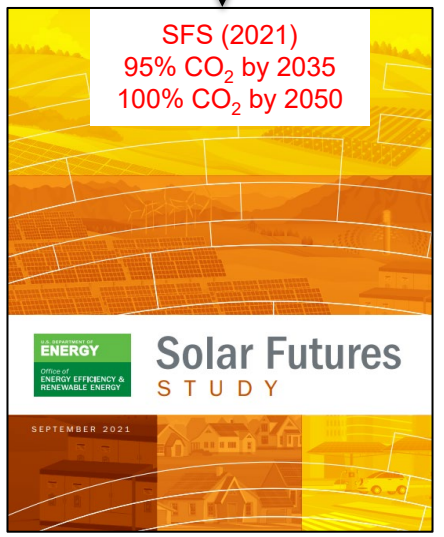


ERGIS (2016)
50%-79% RE by 2050

NARIS (2021)
50%-79% RE by 2050



SFS (2021)
43% - 81% RE by 2050



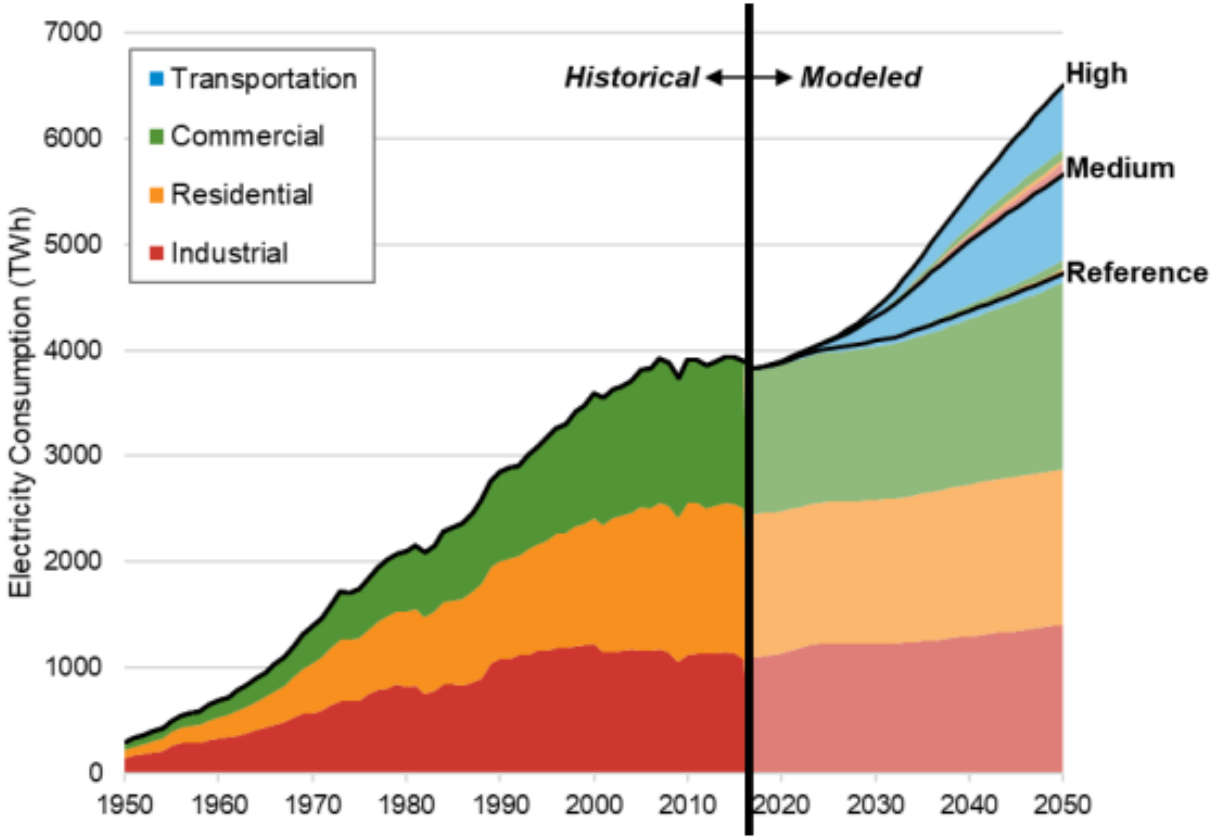
SFS (2021)
95% CO_2 by 2035
100% CO_2 by 2050

100% by 2035 (forthcoming)
100% Power Sector CO_2 by 2035
Economy Net-Zero by 2050

Pathways to 100% Decarbonization Power Sector by 2035

Draft

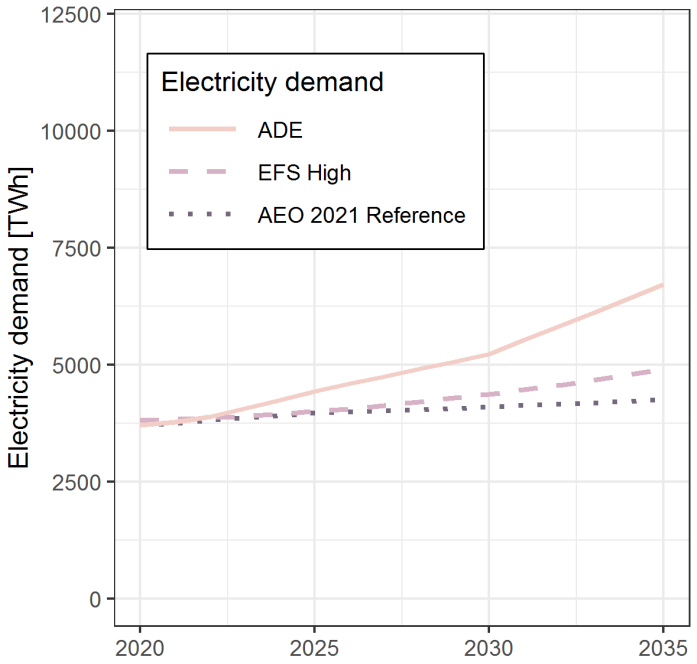
Electrification May Dramatically Increase Electricity Demand

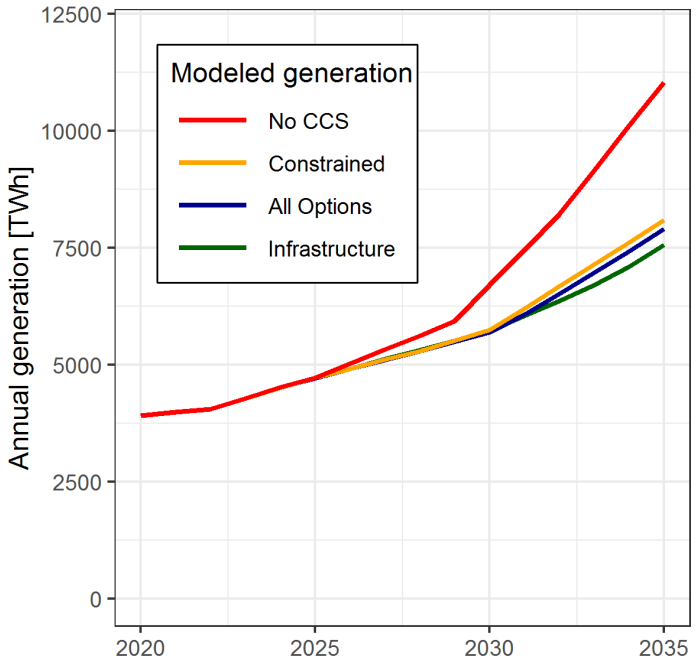


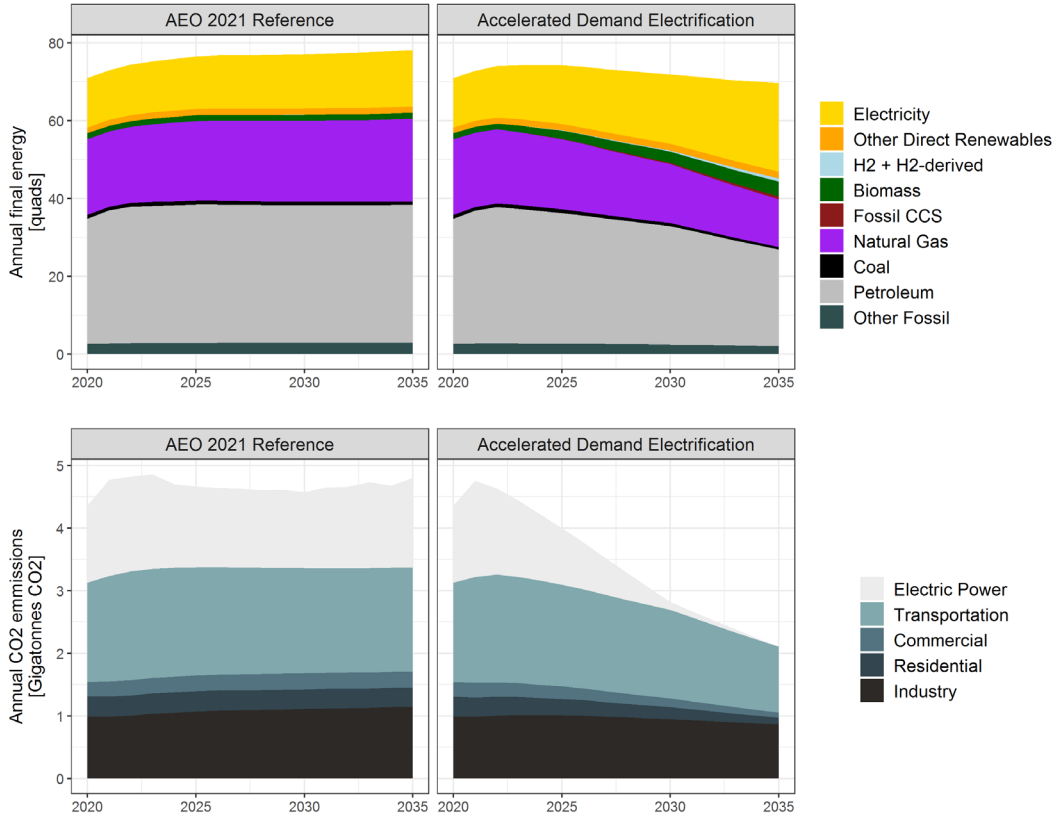
- Continued acceleration of electric vehicle adoption in the transportation sector could dramatically increase total electricity demand.
- While energy consumption in buildings is already highly electrified, adoption of increasingly competitive commercial and residential high-efficiency electric heat pumps could significantly alter the shape and timing of peak electricity demand.
- While it's challenging to electrify industrial processes with existing technologies, there are broad range of low-temperature applications that electro-technologies could fill.

Source: NREL Electrification Futures Study (2018)

Getting on a path to economy-wide decarbonization by 2050 will significantly increase electricity demand by 2035





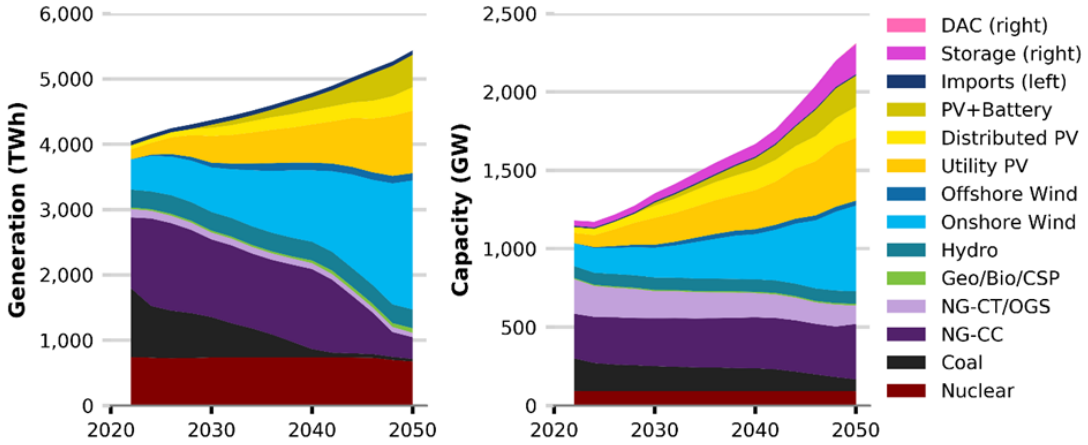


- Demand consistent with economy-wide net-zero is significantly larger than electrification alone and is partially driven by power demands for other sectors, e.g., clean fuel production.

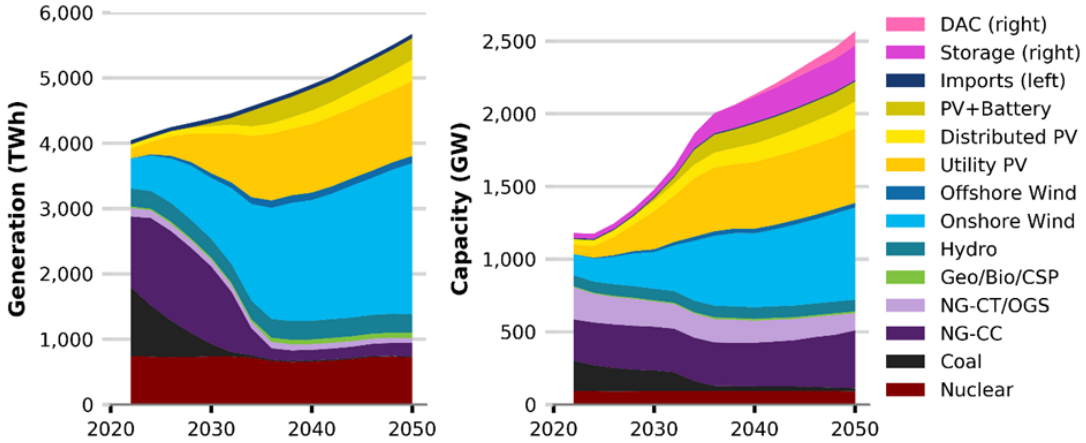
Source: NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

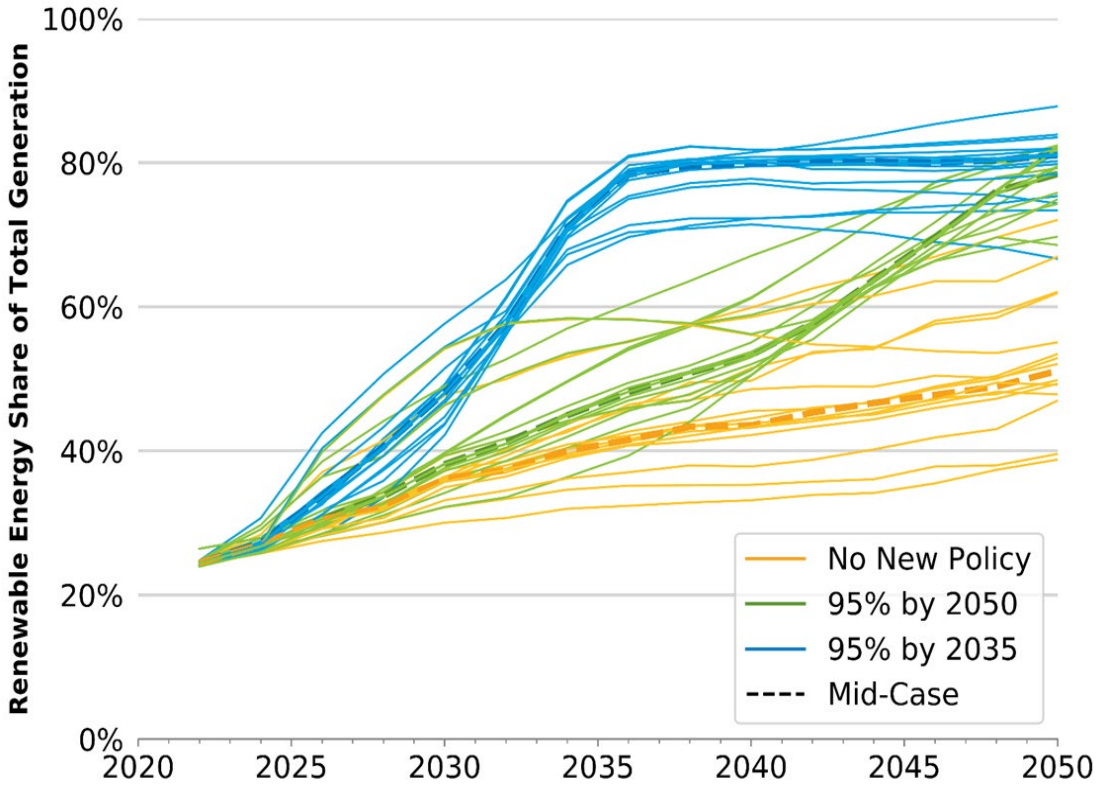
Clean Energy Technologies Need to be Deployed at an Unprecedented Rate

95% Power Sector CO_2 Reductions by 2050



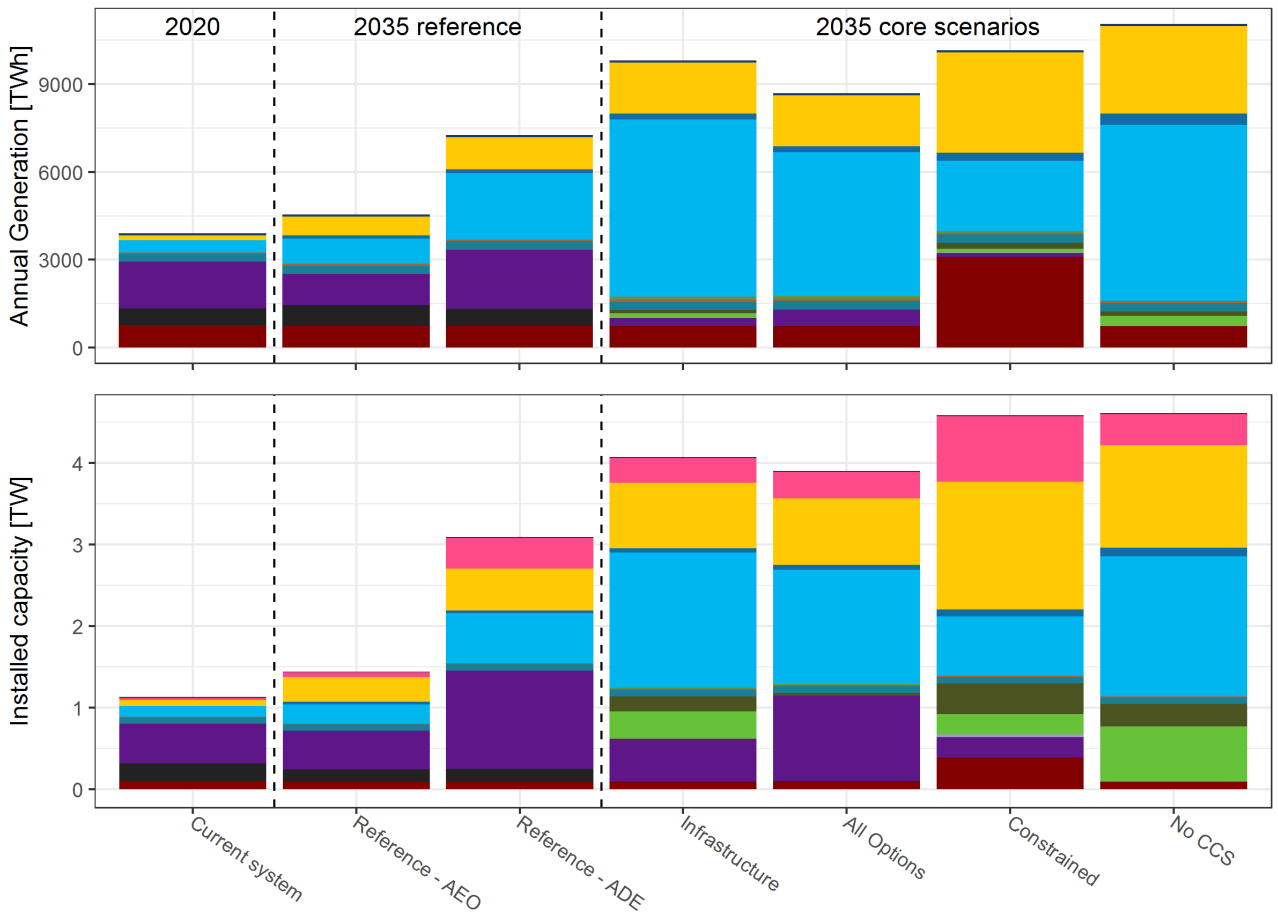
95% Power Sector CO_2 Reductions by 2035, 100% by 2050

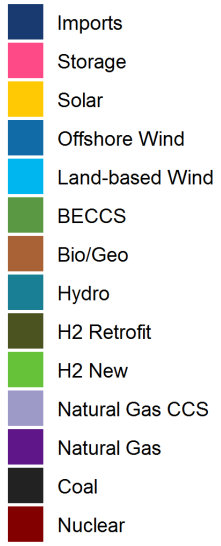




Source: NREL 2020 Standard Scenarios (Forthcoming)

Meeting Net-Zero Demand Increases the Magnitude and the Speed of Required Buildout

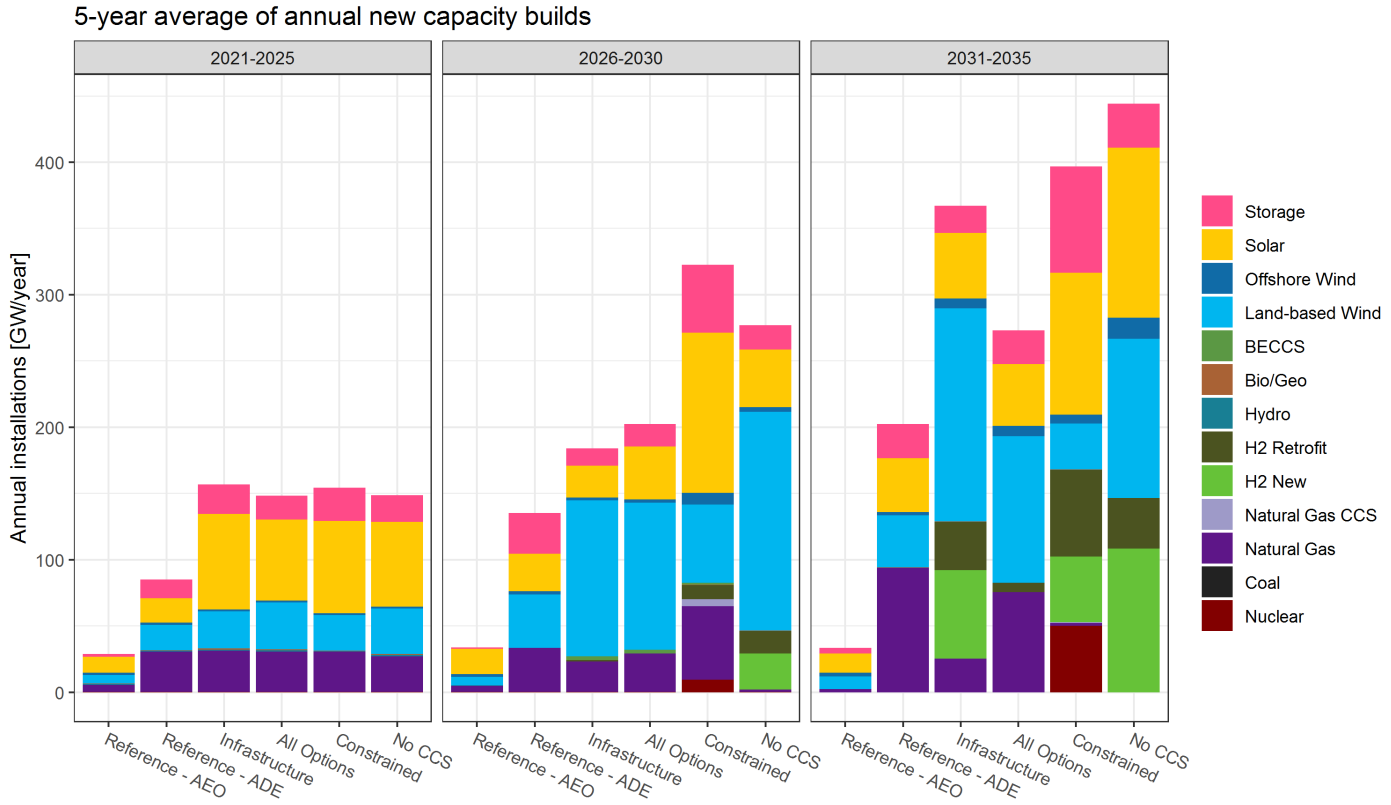


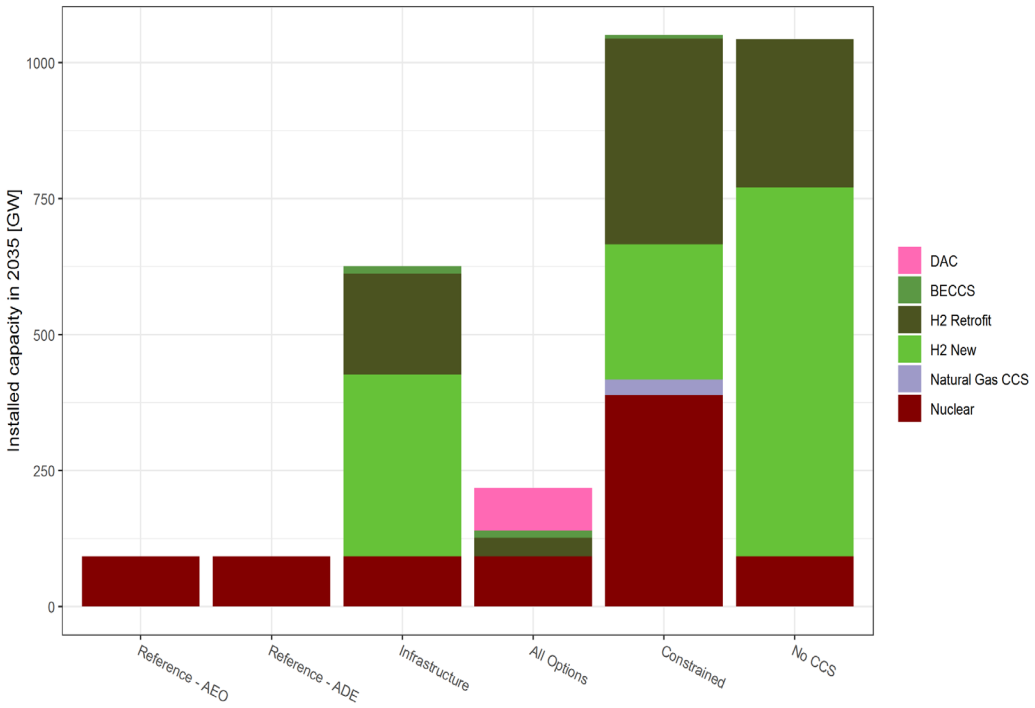


- Over 2 TW of combined wind and PV by 2035 in many scenarios
- Renewable technologies are providing the majority of energy
- Combination of other resources providing capacity

Source: NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

Meeting Net-Zero Demand Increases the Magnitude and the Speed of Required Buildout

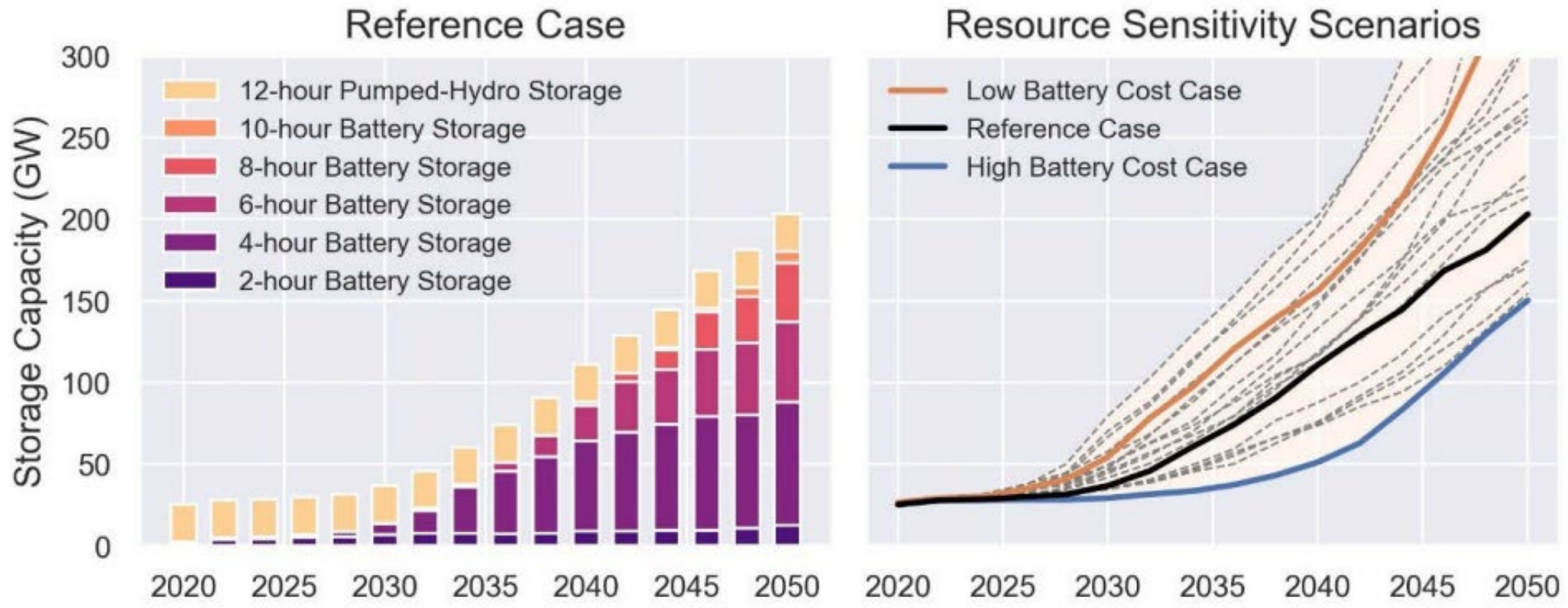




- In all scenarios, capacity deployment levels exceed historic deployment records, e.g., in 2020, China installed 48 GW wind and 52 GW PV.
- To achieve the 100% power sector cap, negative emission technologies (BECCS and DAC are required)

Source: NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

Energy Storage Enables the Reliable Operation of a Clean Electricity Grid



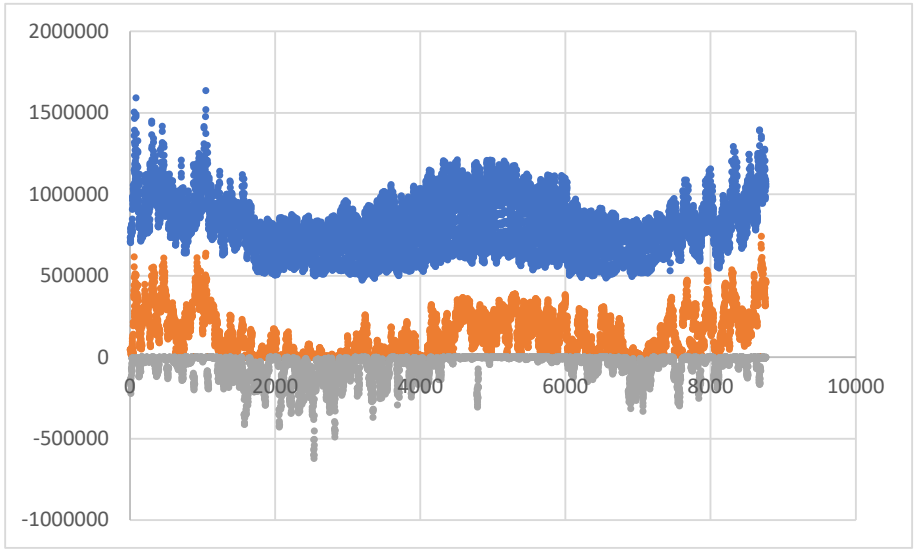
Energy storage can solve two main challenges:

- Diurnal Imbalances – can be overcome with 2- to 12-hour storage technologies
- Seasonal Imbalances – requires new longer duration storage or fuel-based solutions

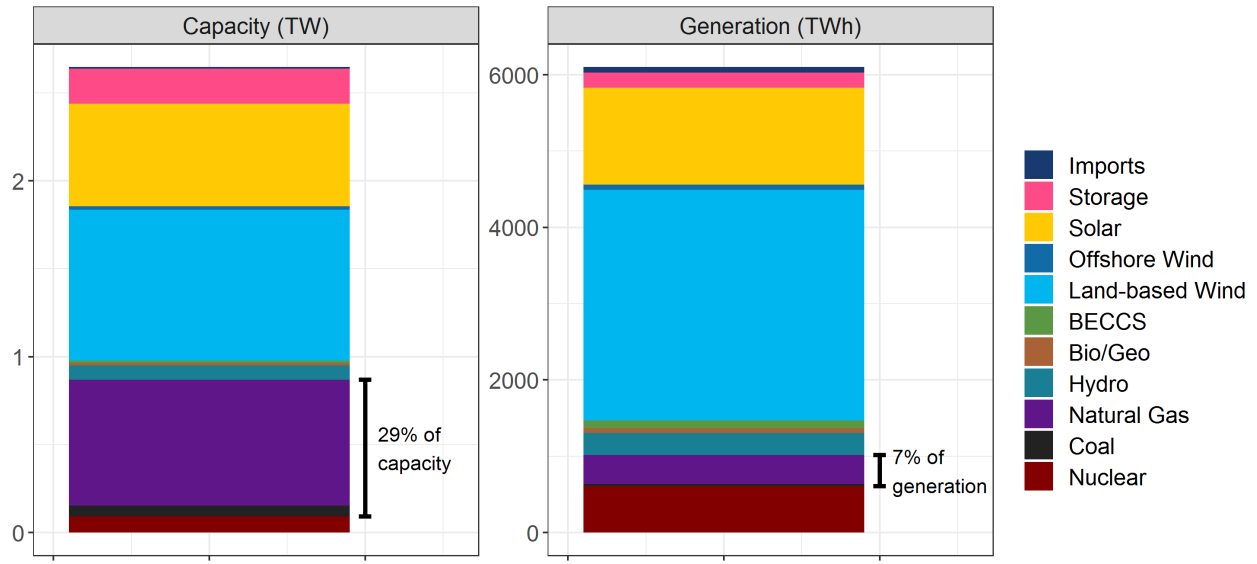
Source: NREL Economic Potential of Diurnal Storage in the U.S. Power System (2021)

Moving to 100% Introduces Seasonal Imbalances & Firm Capacity Challenges

Seasonal Mismatch Challenge



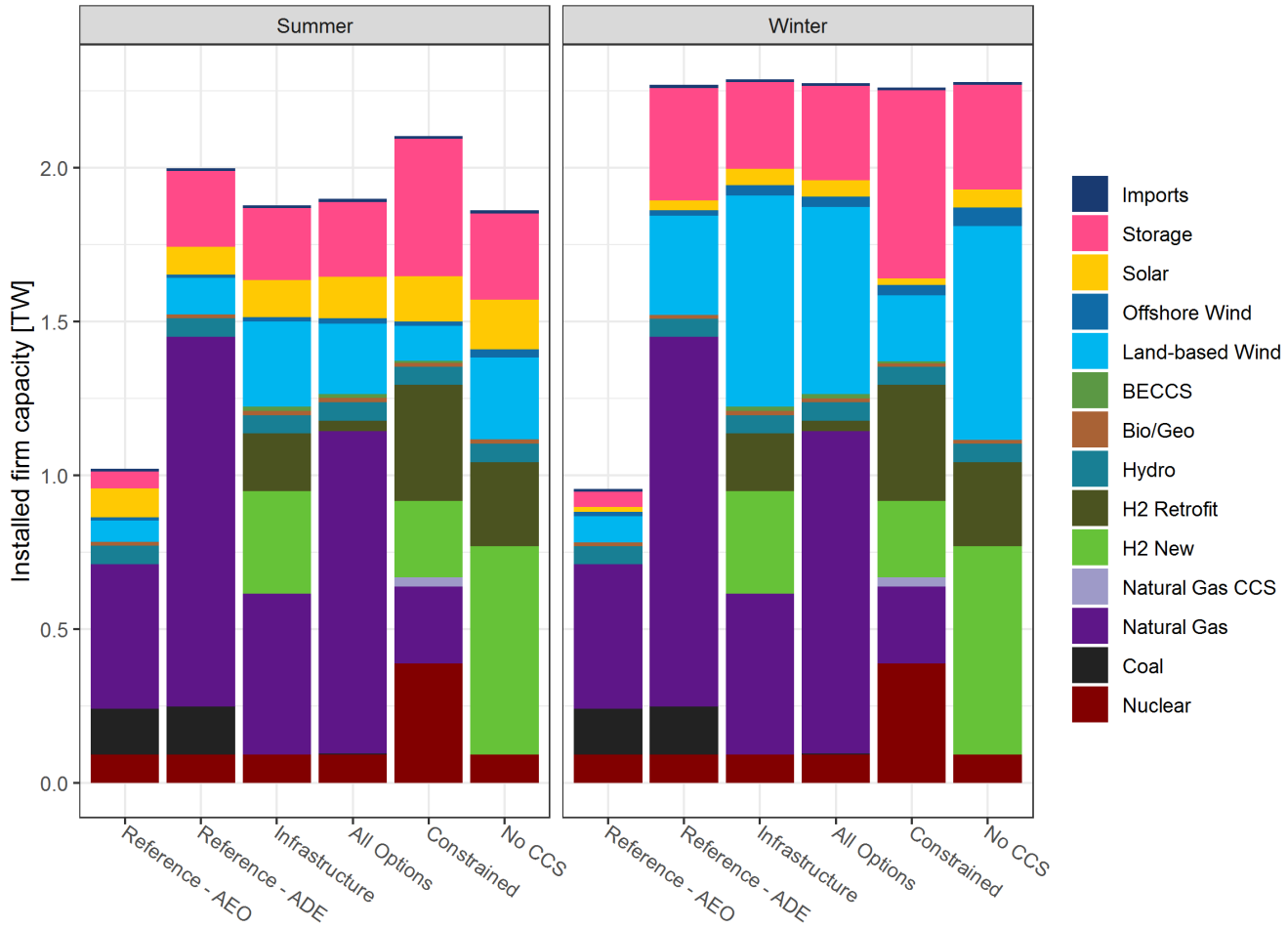
2030, All Options pathway



- Need to build a lot of new capacity operating at very low-capacity factor just to meet the last 10%
- VRE is often cheaper than fossil, but firm RE is not, especially compared to the variable costs of depreciated assets
- Modeled options: RE (Bio, CSP, Geo, Hydro), H2-CT, BECCS, DAC, Fossil-CCS, Nuclear

Source: NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

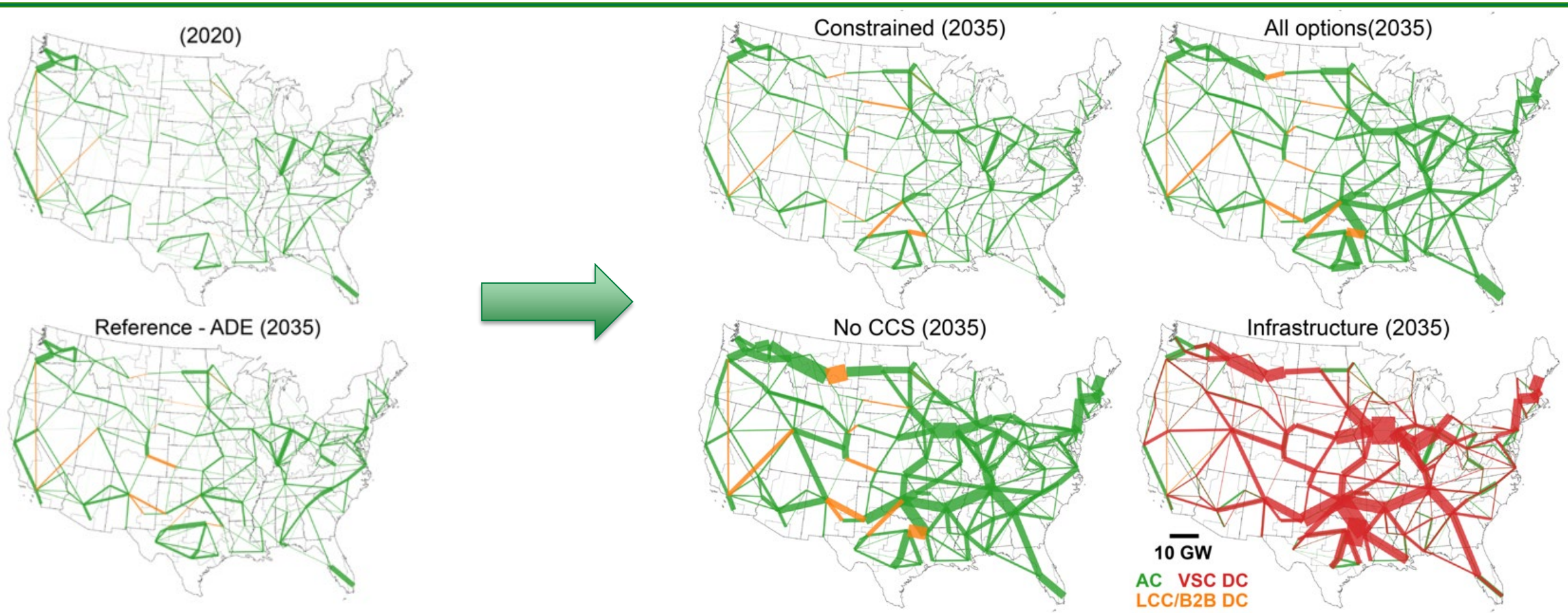
Moving to 100% Introduces Seasonal Imbalances & Firm Capacity Challenges



- We shift to winter peaking overall, makes it even more difficult for PV+diurnal storage to provide firm capacity
- Seasonal mismatches are typically multi-day events, so storage with 12 or even 24 hours of duration are typically insufficient

Source: NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

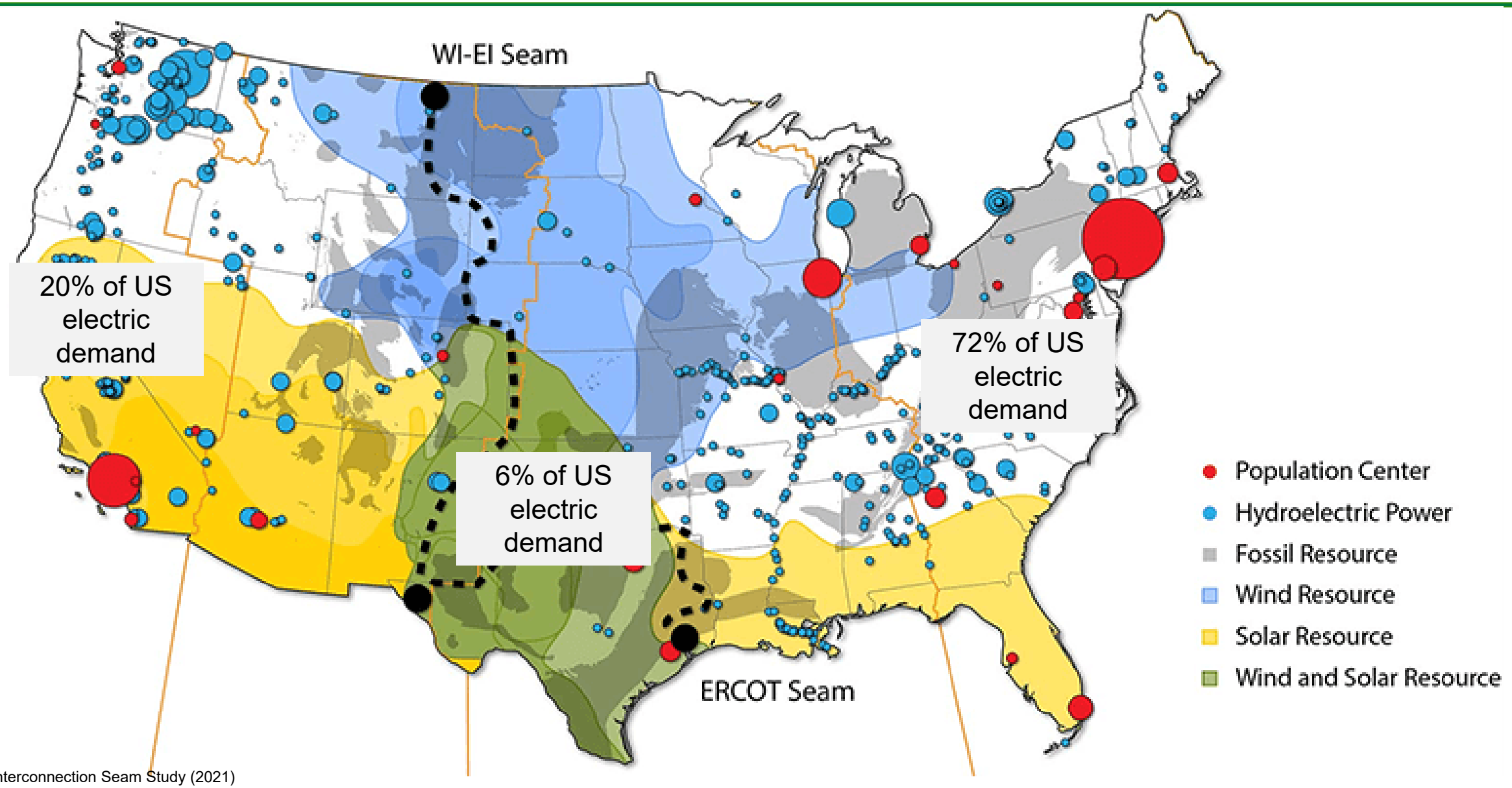
Transmission Expansion Increases RE Deployment and Efficient Grid Operation



- Transmission allows access to higher quality resources, and can provide a greater amount of spatial diversity, which reduces variability of both supply and demand across various timescales.
- Regional and international cooperation can provide significant net system benefits. The NARIS Study found transmission plays an important role in minimizing costs, inter-regional Tx was estimated to provide roughly $180 billion in net-benefits through 2050.

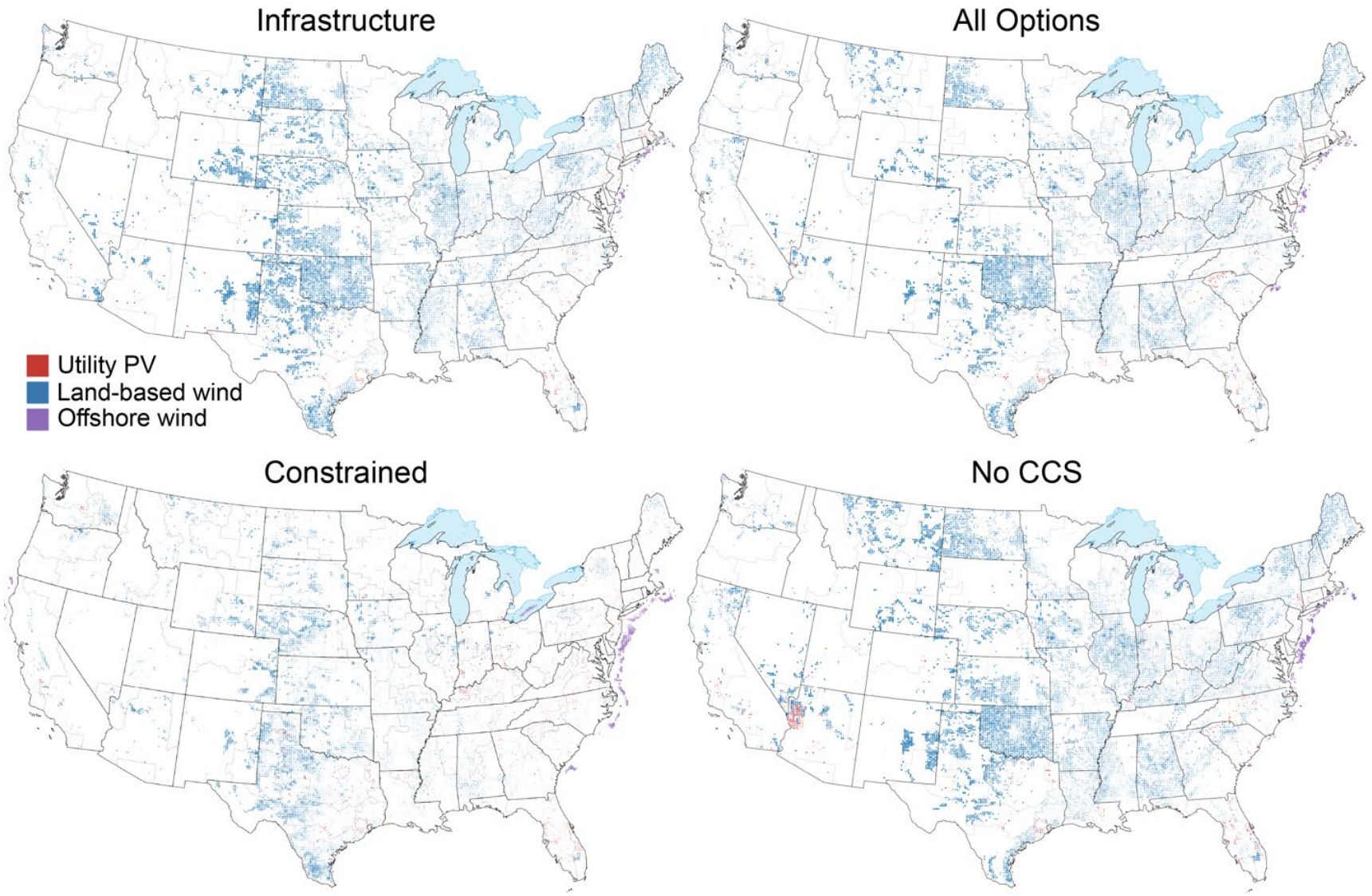
Source: NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

Siting, Especially for Transmission Becomes Important Since Load Centers and Low-Cost Renewable Resources are Often Not Co-Located



Source: NREL Interconnection Seam Study (2021)

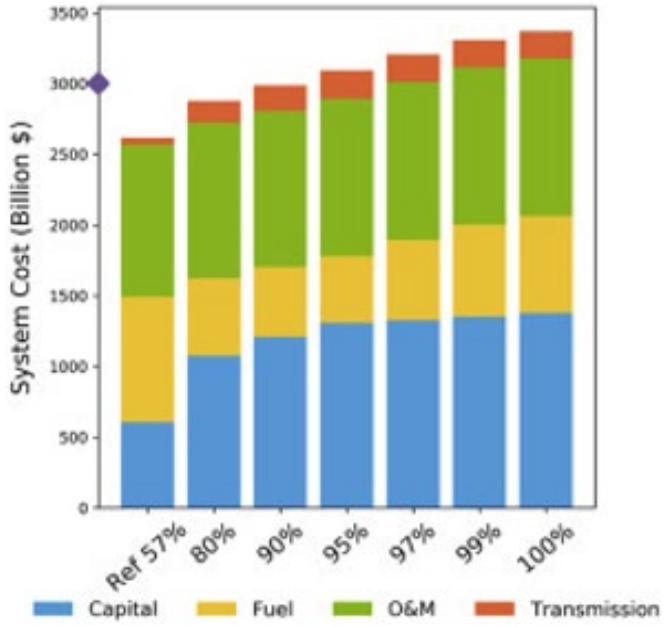
Siting Will be Critical for Minimizing Cost & Ensuring Public Acceptance

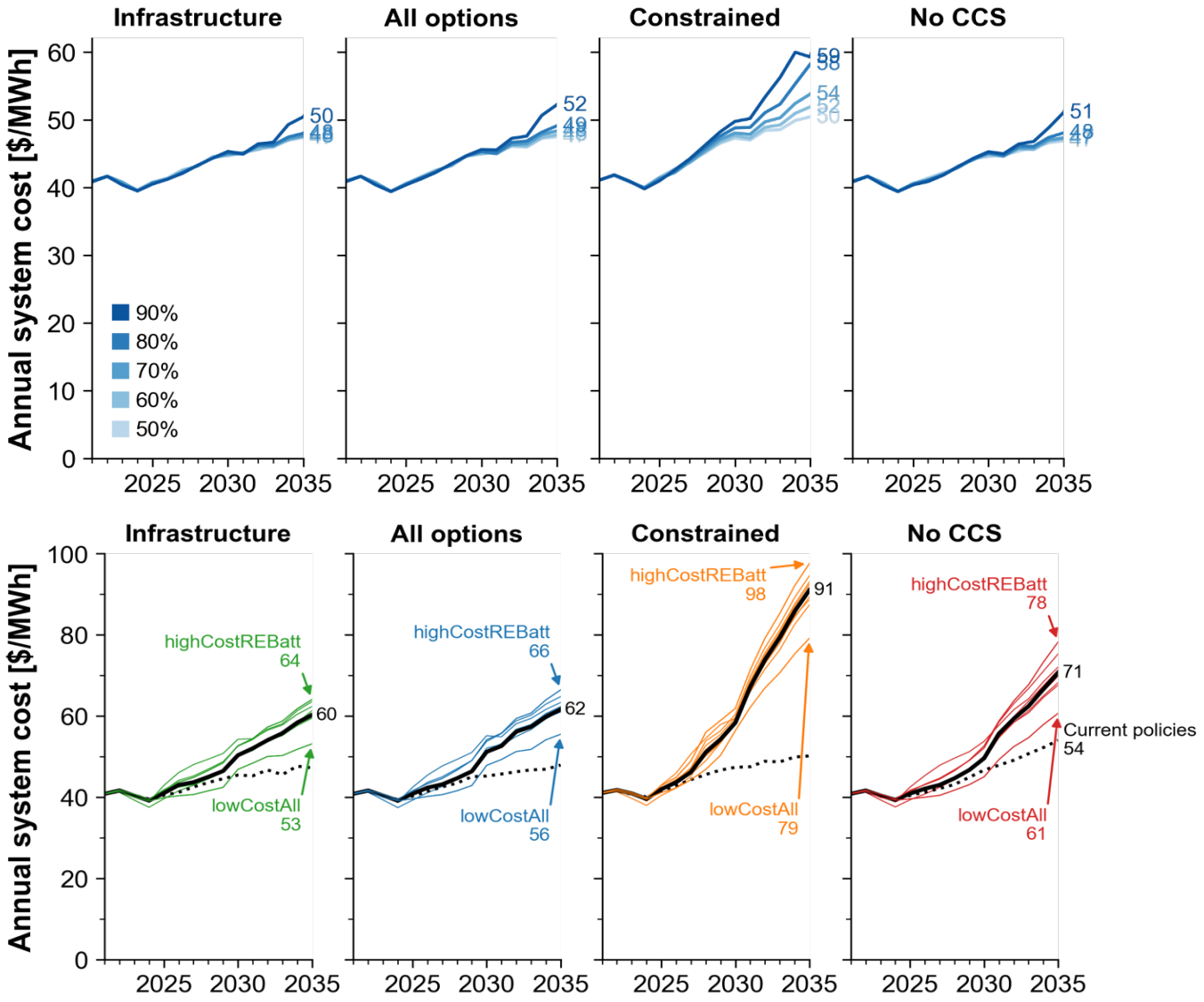


- Buildout represented in 11.5 km X 11.5 km square. (Includes indirect land-use)
- A large portion of the eligbible supply curve (already includes exclusions) is mostly used up

Source: NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

Very high levels of clean energy can be achieved at relatively low cost





Source: NREL Quantifying the challenge of reaching a 100% renewable energy power system for the United States (2021) & NREL Pathways to 100% Decarbonization Power Sector by 2035 (forthcoming)

Key Takeaways across all of DOE's Scenario Analyses

1. Electrification and the power required to decarbonize other sectors will significantly increase load growth
2. An unprecedented build-out (magnitude and speed) is required to meet this elevated demand
3. Wind and solar are expected to be the least cost resources.
4. Energy storage will be critical for diurnal balancing
5. There are a variety of technologies that could be used to overcome seasonal imbalances and firm capacity challenges, however their future cost and performance are uncertain
6. Expanded transmission is essential for accessing RE resources and minimizing system cost
7. Overcoming siting challenges will be crucial to minimize system costs and ensure public acceptance
8. Very high levels of clean energy can be achieved at relatively low costs
9. While more work is needed to quantify the full range of benefits, the likely benefits from CO_2 reductions exceed the costs in most cases

Questions?