The Economic Future of Grid-based Electricity Storage

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Credit: Shutterstock

Based on the *MIT Future of Storage* study, forthcoming 2022

Many of the results discussed here come from Chapter 6 of the *MIT Future of Storage* study, forthcoming 2022

Chapter 6: Properties of Deeply Decarbonized Electric Power Systems with Storage

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https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4037751

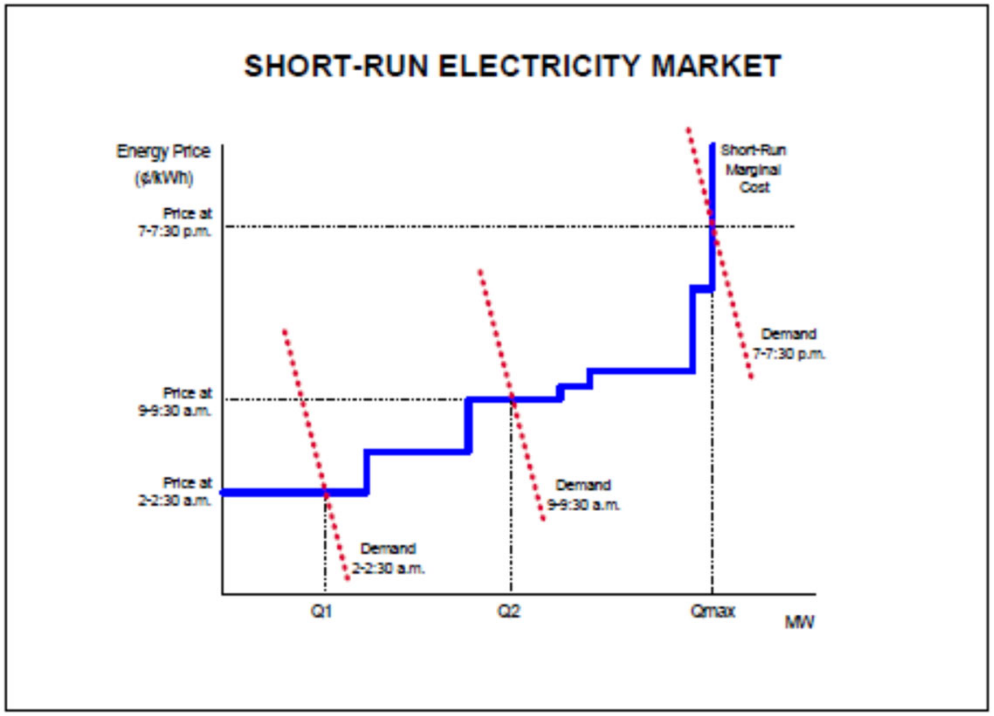
Electricity Sector is the Foundation for Decarbonizing the Economy

- "Net Zero" economy by 2050?
- Decarbonize the electricity sector ("net zero" electricity by 2050?)
- Use "clean" electricity to increase electrification of transportation, buildings, industry
- "Zero" carbon generating technologies
  - Hydro : Constrained by environmental and public acceptance considerations
  - Nuclear: Expansion constrained by high costs of construction and public acceptance barriers. Existing fleet is 20% of electricity generation in the U.S. but merchant plants are under financial pressure and only 2 new units are under construction in the U.S.
  - Wind: Dramatic cost reductions anticipated to continue
  - Solar PV: Dramatic cost reductions anticipated to continue
- Longer term possibilities
  - Gas + Carbon Capture and Storage
  - Small modular nuclear
  - "Green" Hydrogen
  - Allam-Fetvedt Cycle
  - Fusion
- The focus of electricity sector decarbonization by 2050 in the US and EU has been on dramatically expanding wind and solar
  - Wind and solar are intermittent generators (VRE) driven by weather conditions
  - Energy storage is critical for balancing the system and maintaining network reliability with deep penetration of wind and solar
  - Wholesale market price distributions change with deep penetration of wind and solar
    - Many more very low price and many more very high price hours creating arbitrage more economic opportunities for storage

Services Potentially Provided by Grid-based Storage

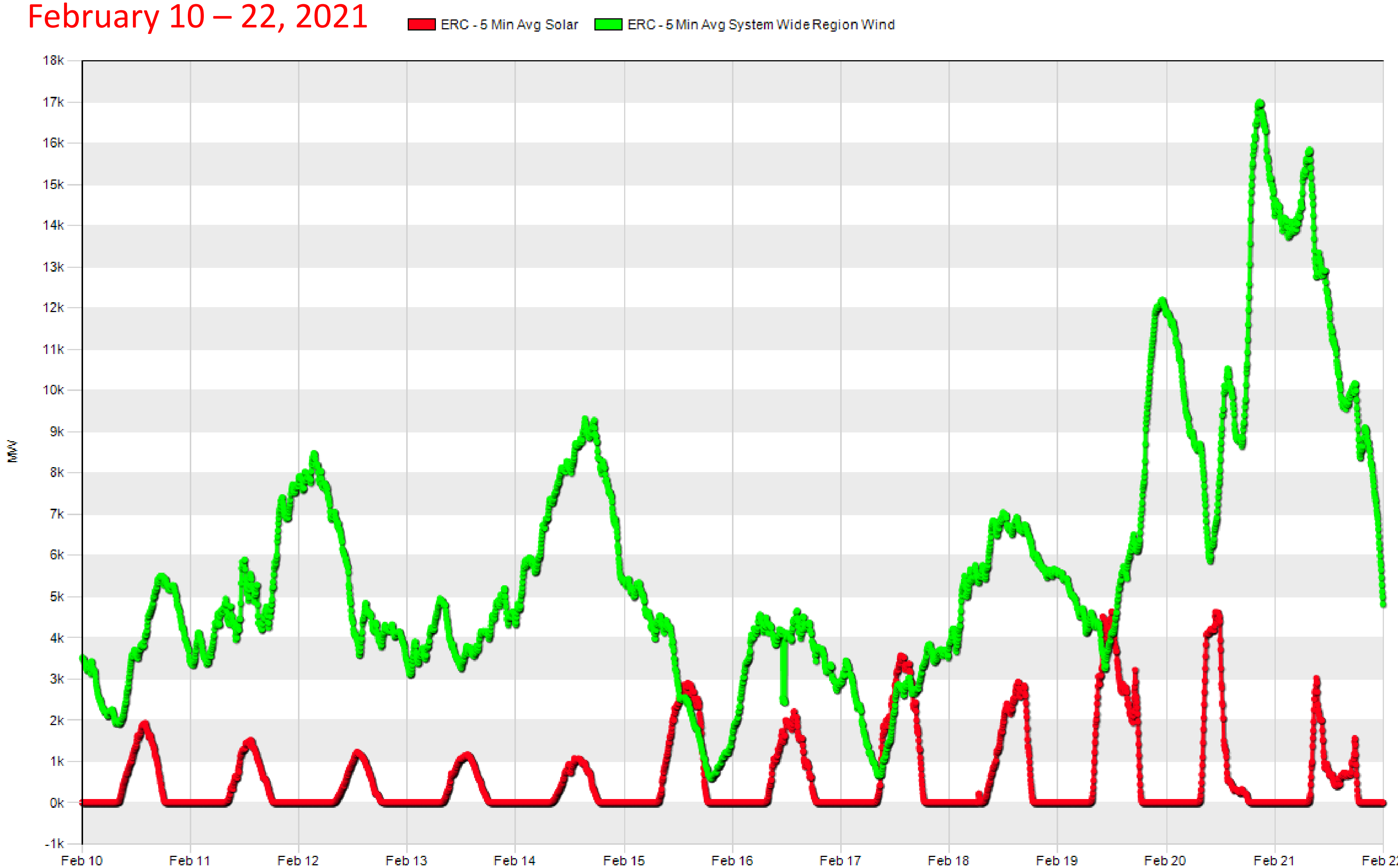
- Balancing Swings in Solar and Wind Generation
  - Shifting generation from one period to another via energy arbitrage: buy low (charge), store, and sell high (discharge)
  - Duration of balancing requirements is important
- Ancillary services
  - Frequency regulation
  - Operating reserves
- Network transmission congestion management
  - Substitute for transmission investment in certain circumstances
  - Both sides of a constraint
- In short, grid-based storage is a substitute for dispatchable generation <u>and</u> VRE generation <u>and</u> transmission investement in systems with deep penetration of wind and solar
  - All involve "moving" energy from one period to another via energy arbitrage (buy low, store, sell high)

Traditional Economic Dispatch Curve (SRMC or Competitive Auction-based)



Courtesy of Prof. William Hogan

ERCOT Wind and Solar Generation
February 10 – 22, 2021



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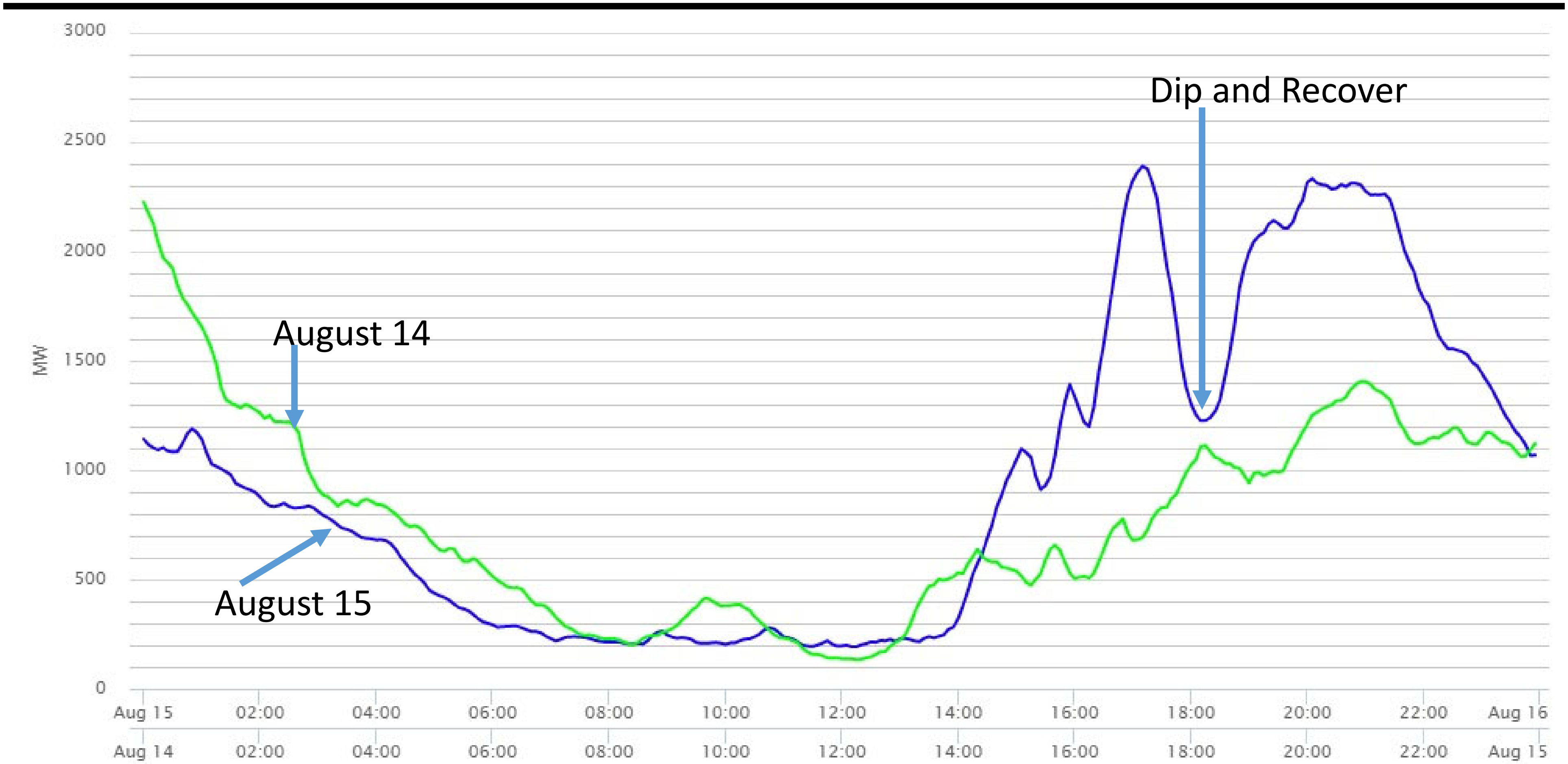
CAISO WIND GENERATION ON AUGUST 14 and 15, 2020



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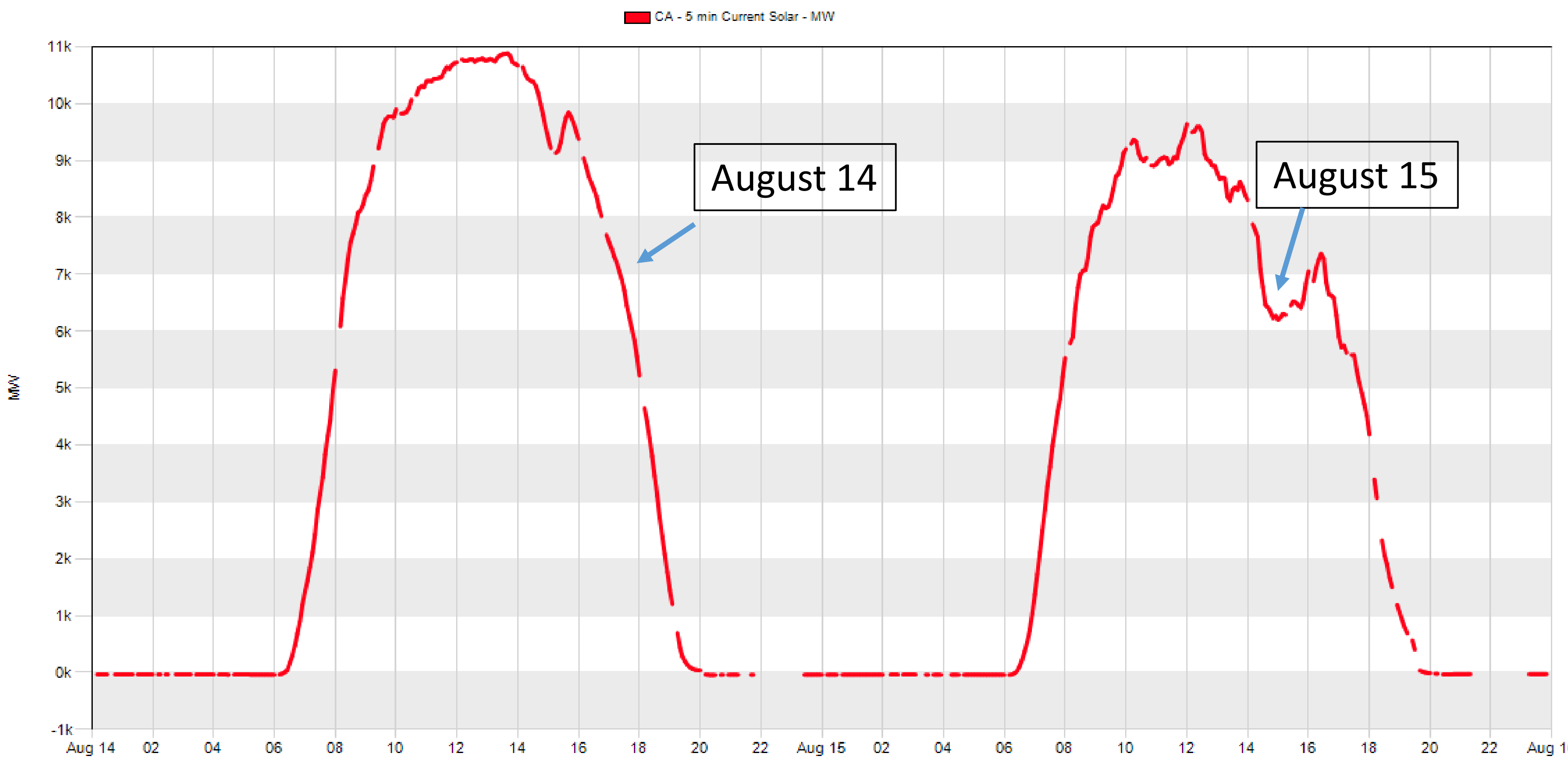
CAISO Solar Generation on August 14 and August 15, 2020



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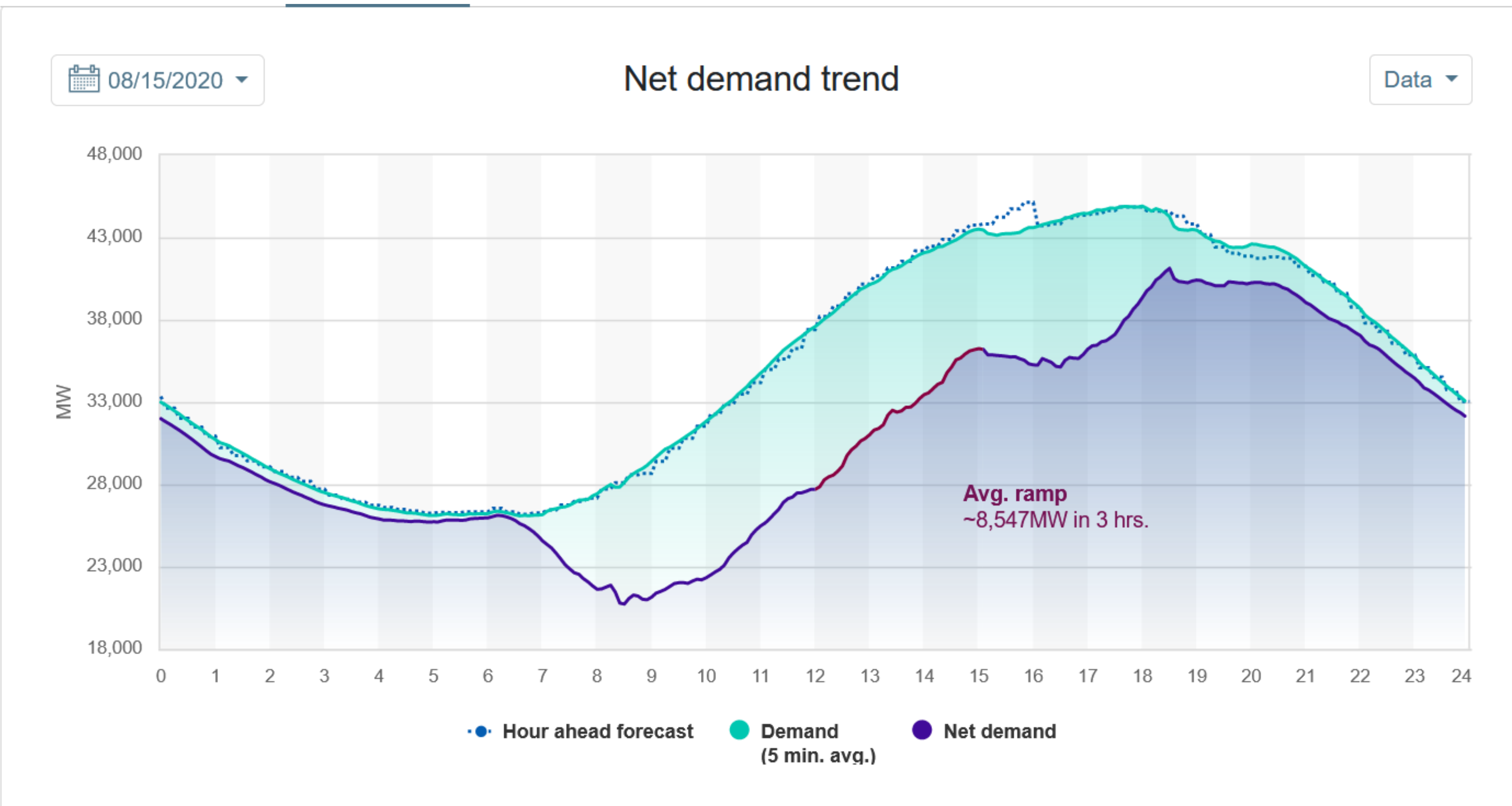
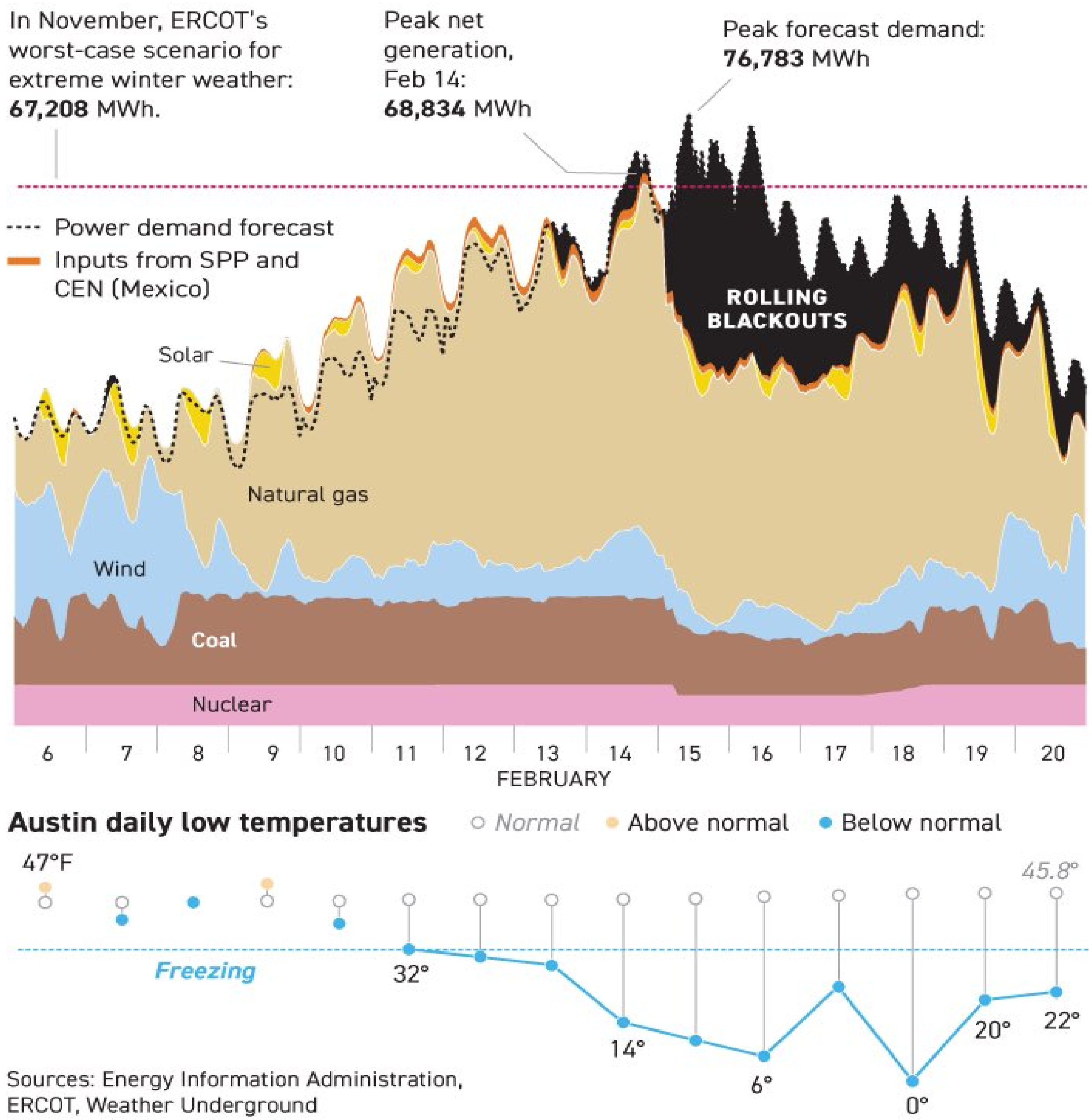
CAISO Demand and Net Demand August 15, 2020



A cold knockout to the Electric Reliability Council of Texas

NET GENERATION AND FORECAST DEMAND, IN MEGAWATT-HOURS



Sources: Energy Information Administration, ERCOT, Weather Underground

Table ES1. Incremental ELCCs by MTR Tranche

	Tranche 1 2,000 MW 2023 In effect	Tranche 2 6,000 MW 2024 In effect	Tranche 3 1,500 MW 2025 Indicative**	Tranche 4 2,000 MW 2026 Indicative**
4-Hour Battery	96.3%	90.7%	74.2%	69.0%
6-Hour Battery*	98.0%	93.4%	79.6%	75.1%
8-Hour Battery*	98.2%	94.3%	82.2%	78.2%
8-Hour Pumped Storage Hydro	N/A	N/A	N/A	76.8%
12-Hour Pumped Storage Hydro	N/A	N/A	N/A	80.8%
Solar - Utility Scale and BTM PV	7.8%	6.6%	6.7%	5.7%
Wind CA	13.9%	16.5%	22.6%	21.6%
Wind WY	N/A	N/A	N/A	33.9%
Wind NM	N/A	N/A	N/A	36.1%
Wind Offshore	N/A	N/A	N/A	36.4%

* *The 6 and 8 hour battery rows were each simulated with one tranche of 6 or 8 hour. The underlying tranches are assumed to be comprised of only 4-hour batteries. For example, tranche 3 for the 6 hour battery row is comprised of 8 GW of incremental effective capacity from 4-hour batteries with an additional 1.5 GW of 6-hour battery capacity.*

** *For information only. The values for these compliance dates are required by OP 15 to be finalized and published by no later than December 31, 2022.*

Source: Astrapé Consulting 2021

Many Types of Storage Technologies Being Studied

- Electrochemical (e.g. Li-ion, Redux Flow, Metal Air)
- Mechanical (e.g.Pumped Stored Hydro, Compressed Air)
- Thermal (e.g. use materials to store heat and then convert to steam and electricity)
- Chemical (e.g. clean Hydrogen)
- A variety of cost attributes, conversion efficiencies, and practical experience

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Storage Technologies

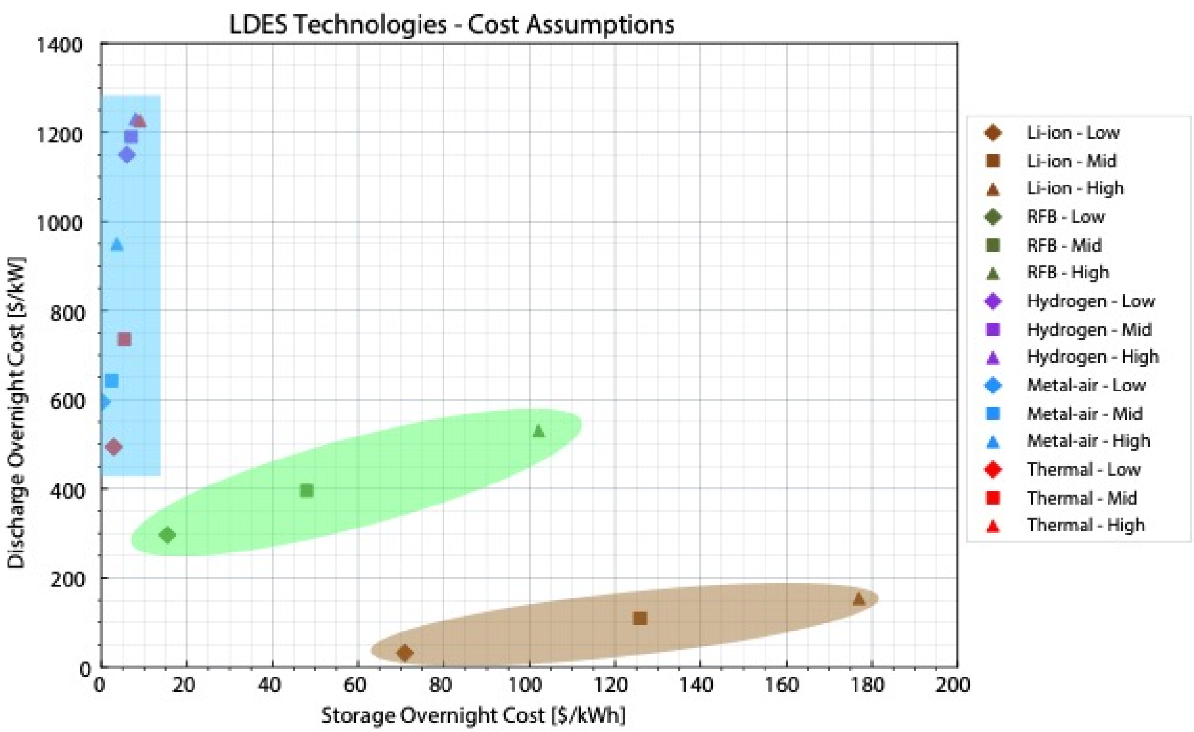

Figure 6.7: Classes of energy storage technologies, grouped by discharge power and storage overnight capital costs. *We define the classes as: (1) technologies with the lowest power cost, relatively high energy capacity cost, high RTE; (2) technologies with mid-range power and energy capacity costs and RTE; and (3) technologies with high power costs, low energy capacity costs, and low RTE. Other salient design attributes can be seen in Table 6.3. Pumped hydro storage is modeled with a fixed duration of 12 hours for this study; since we do not have a breakdown of pumped hydro costs we do not include this storage option on the chart.*

2050 Decarbonization Base Case
Li-ion

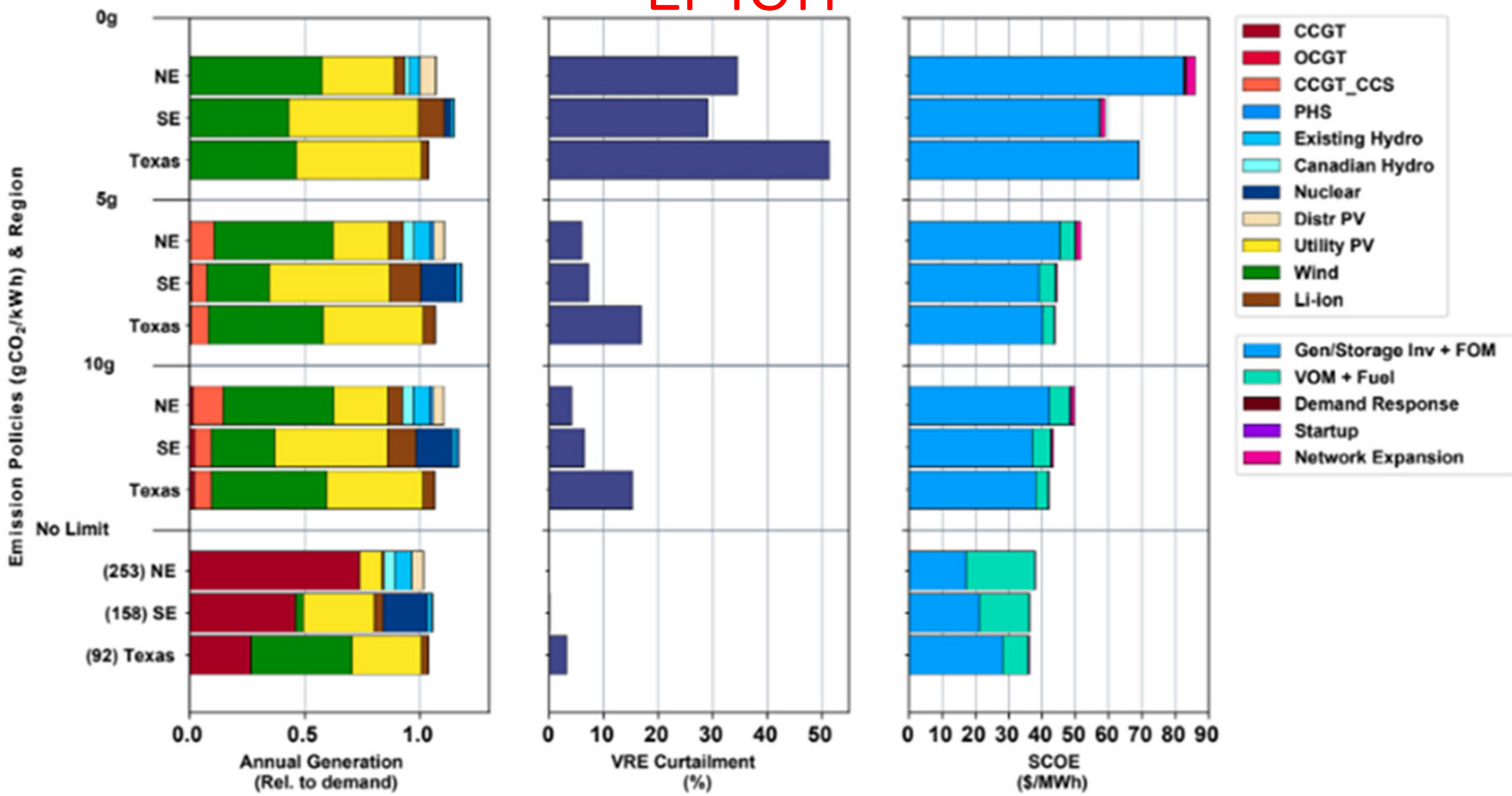

Figure 6.4: Annual generation, VRE curtailment, and system average cost of electricity (SCOE) in the Northeast (NE), Southeast (SE), and Texas (TX) under tightening CO_2 emissions constraints. *SCOE includes total annualized investment, fixed O&M, and operational costs of generation, storage, and transmission, as well as any non-served energy penalty. Emissions intensity under the No Limit policy case is noted in parentheses in the bottom panel. For the Northeast region, "Wind" represents the sum of onshore and offshore wind generation.*

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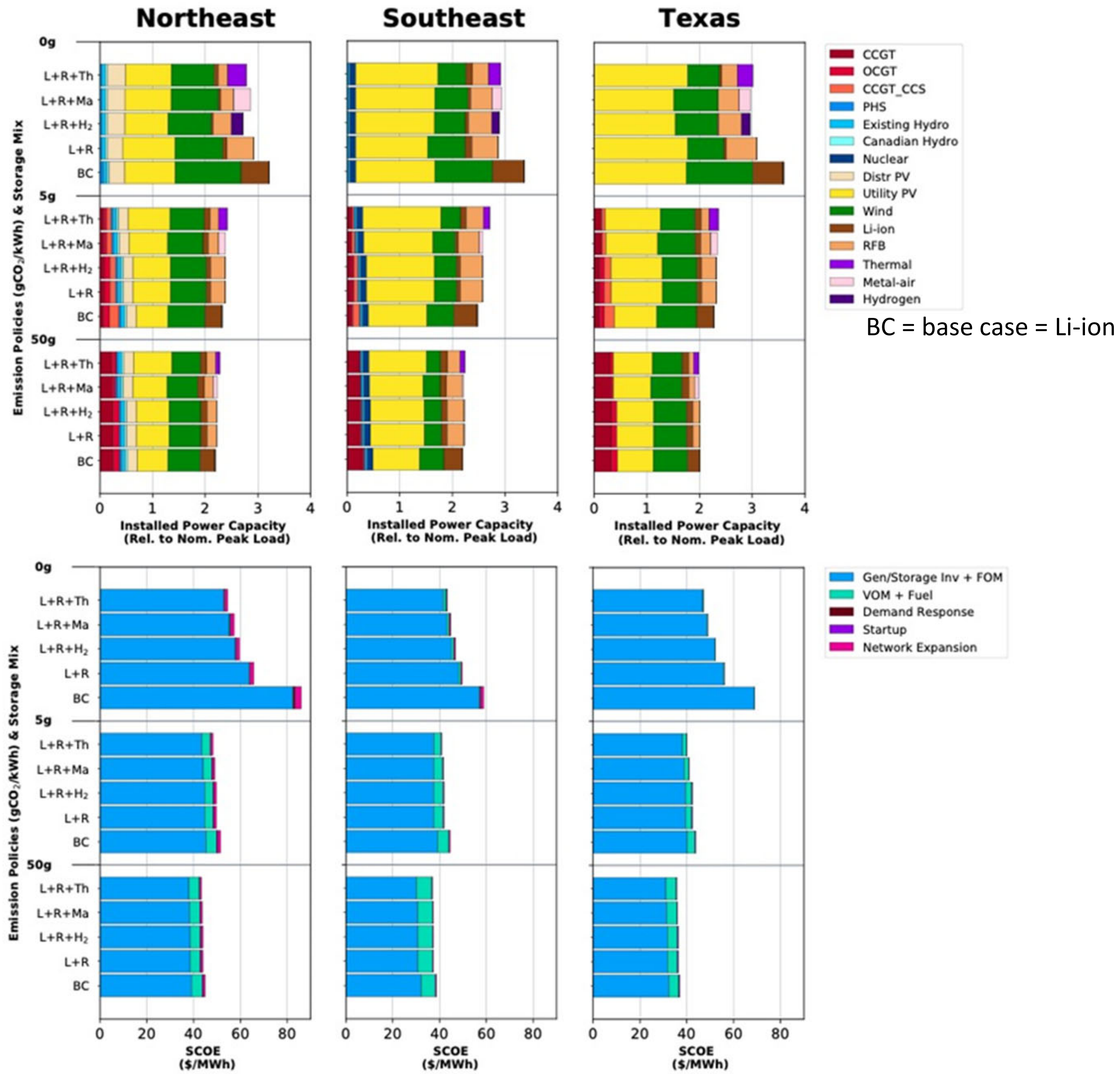

***Figure 6.9: Impacts of adding RFB+ LDES on installed power capacity and SCOE, across a range of CO_2 constraints for the Northeast, Southeast and Texas regions**. They are, in ascending order: (1) base case (i.e., Li-ion only, BC); (2) Li-ion + RFB (L+R); (3-5) Li-ion + RFB + incrementally adding an LDES option in the form of hydrogen (+H_2), metal-air batteries (+MA), or thermal storage (+Th)—all at mid-cost assumptions. As discussed previously, we evaluate the Class 3 LDES technologies one at a time, with the assumption that any or all these technologies could be commercially scalable by 2050. Mid-cost assumptions for each storage technology are defined in Table 6.3.*

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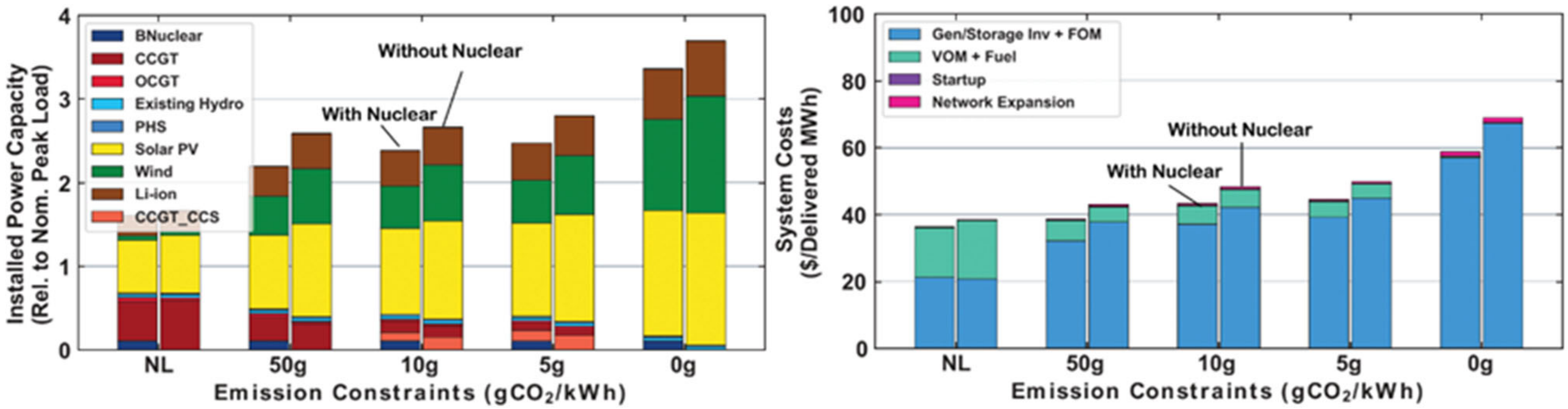

Figure 6.6: System impacts of nuclear availability in the Southeast*. The two scenarios compare optimal generation capacity deployed and SCOE under two assumptions: (1) existing nuclear plants remain part of the portfolio and can be dispatched to meet demand; and (2) all existing nuclear plants retire by 2050, and no new nuclear is added.*

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2050 Wholesale Market Price Distributions for Texas

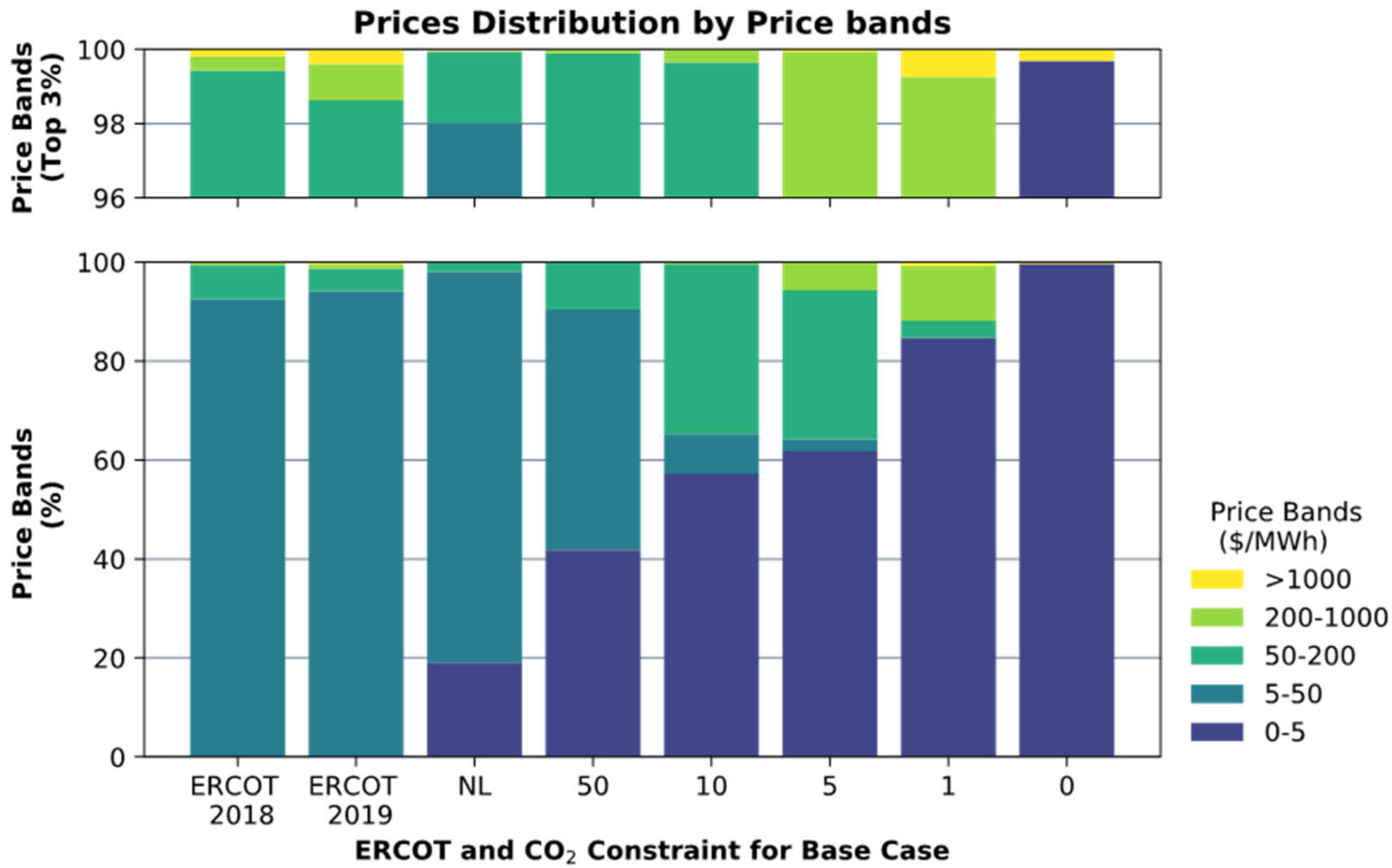

Figure 6.22: Marginal value of energy under base case assumptions (Li-ion battery storage only) for Texas. *The price bands are based on the known marginal cost of various generation technologies; we zoom in on the top 3% to show the price distributions at that extreme. Results for the Northeast and Southeast are presented in Appendix D. ERCOT historical prices are from ERCOT (2021).*

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Effects of Storage Technologies on Wholesale Price Distributions 2050

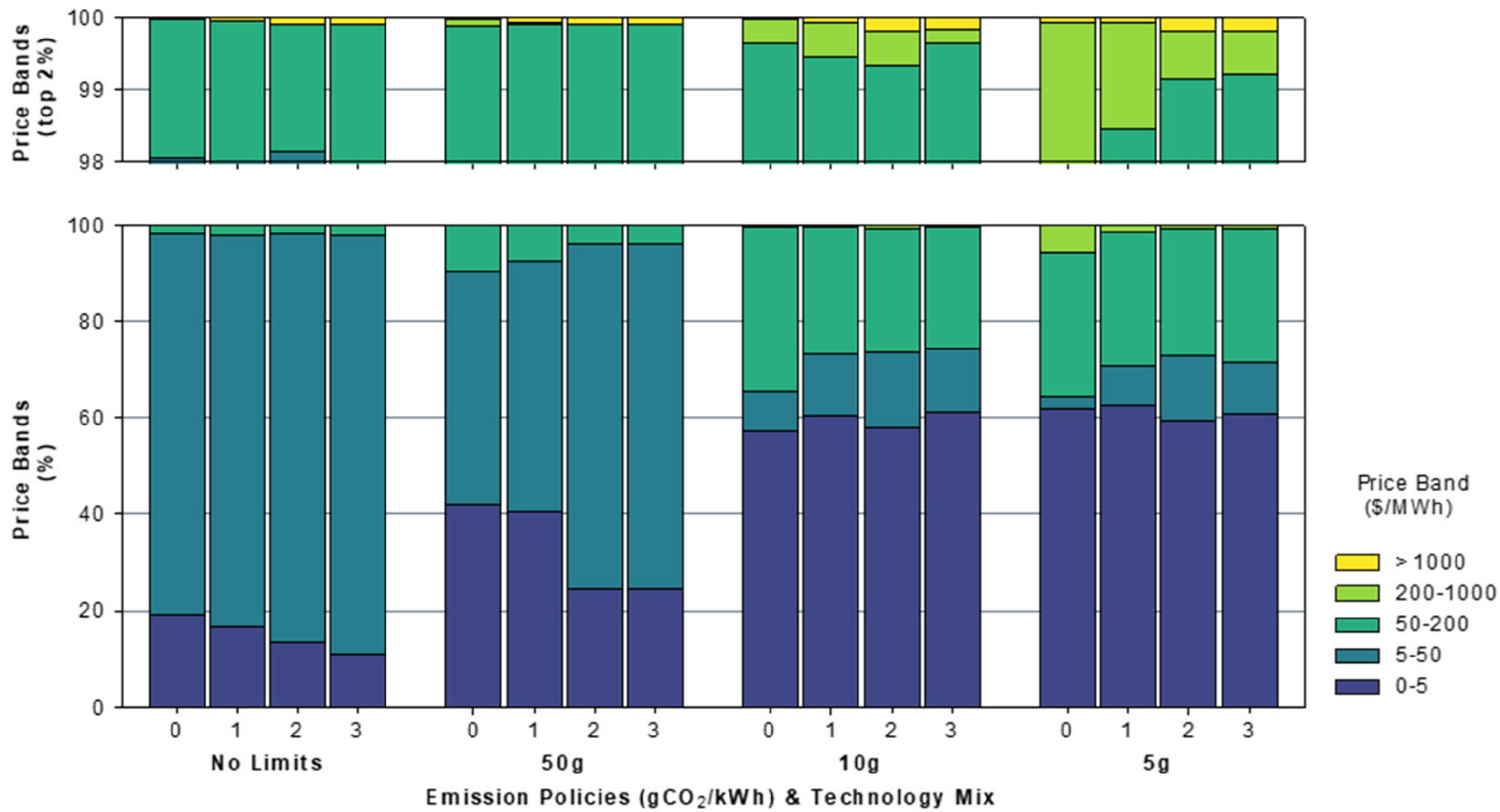

Figure 6.24: Marginal value of energy across different storage mixes for Texas. *Scenarios shown are, from left to right: (0) base case (i.e., Li-ion battery storage only), (1) Li-ion + RFB + H_2, (2) Li-ion + RFB + metal-air, and (3) Li-ion + RFB + thermal. The price bands reflect the costs of the marginal technology; we zoom in on the top 2% to show the price distributions at that extreme.*

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Price Bands and Revenues by Generating Technology

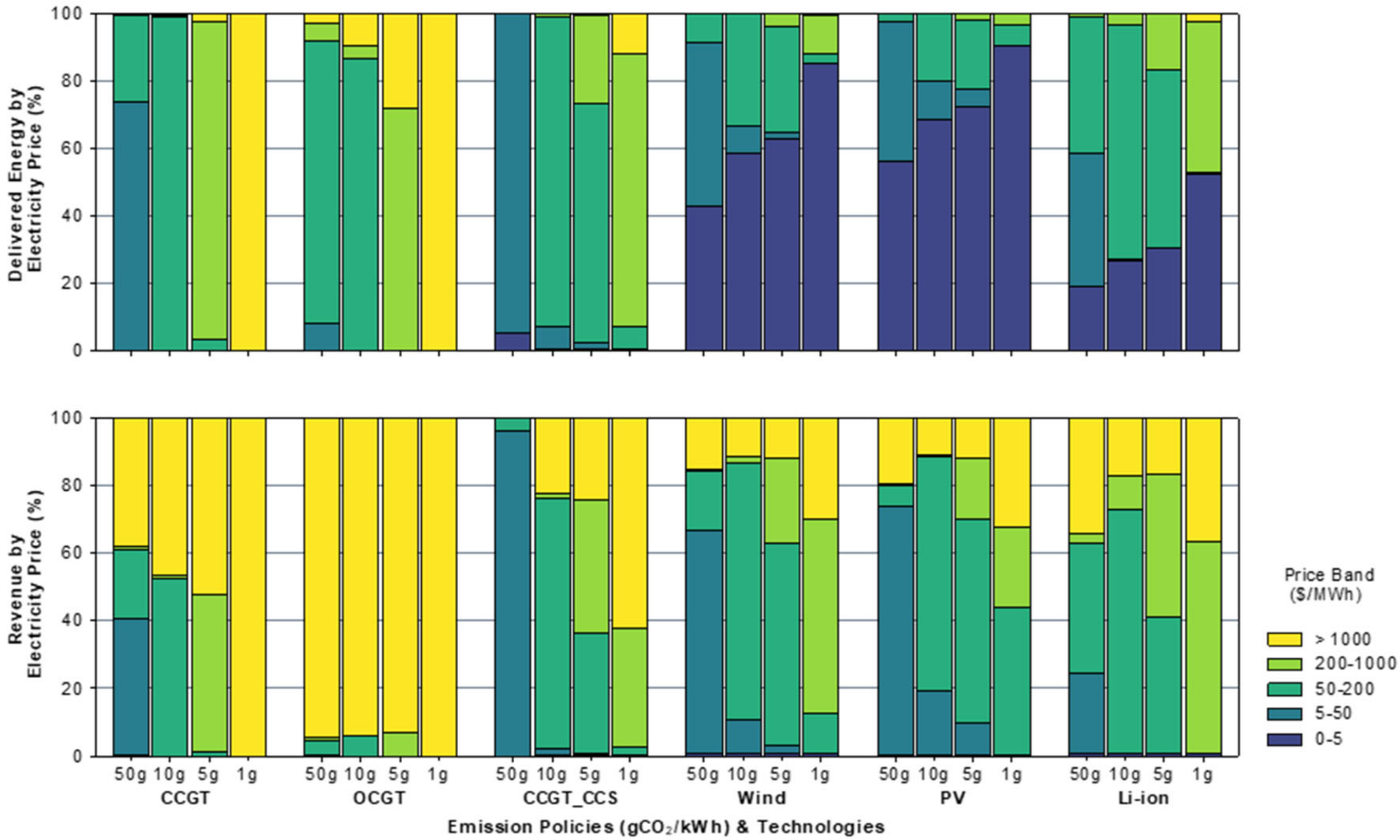


Figure 6.25: Technology operation by price band in Texas – base case. The upper panel shows the distribution of delivered energy by price band for different technologies and emission constraints. *The lower panel shows the revenue distribution by price band.*

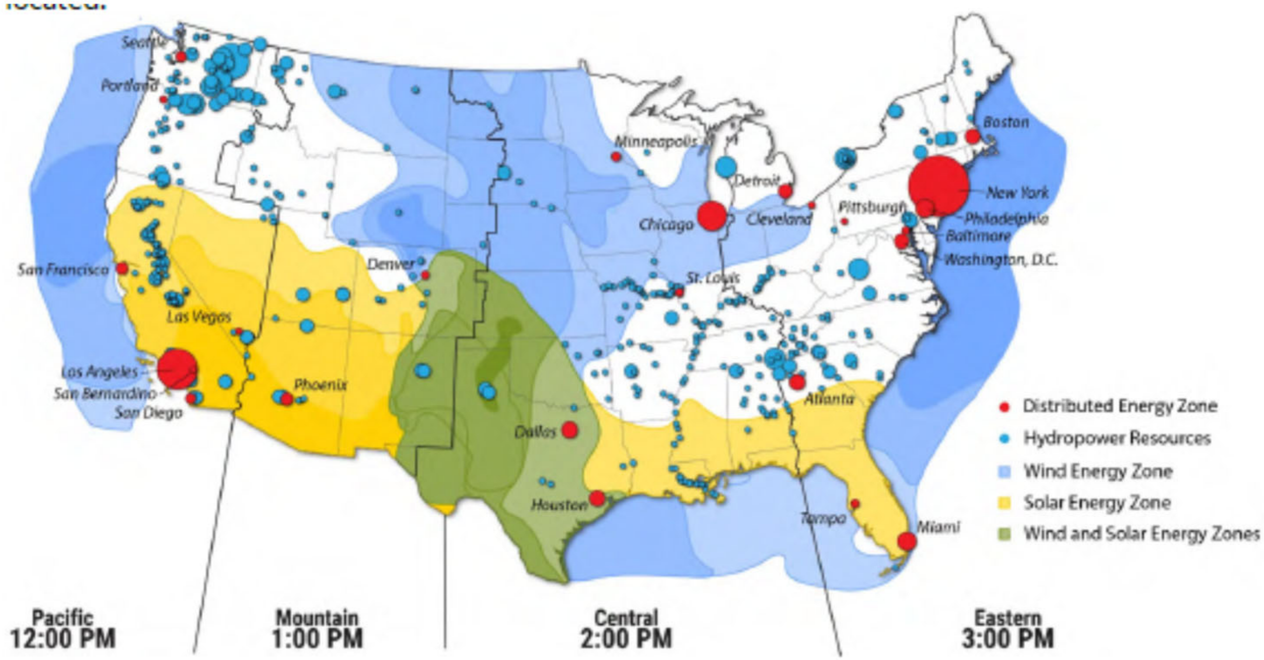
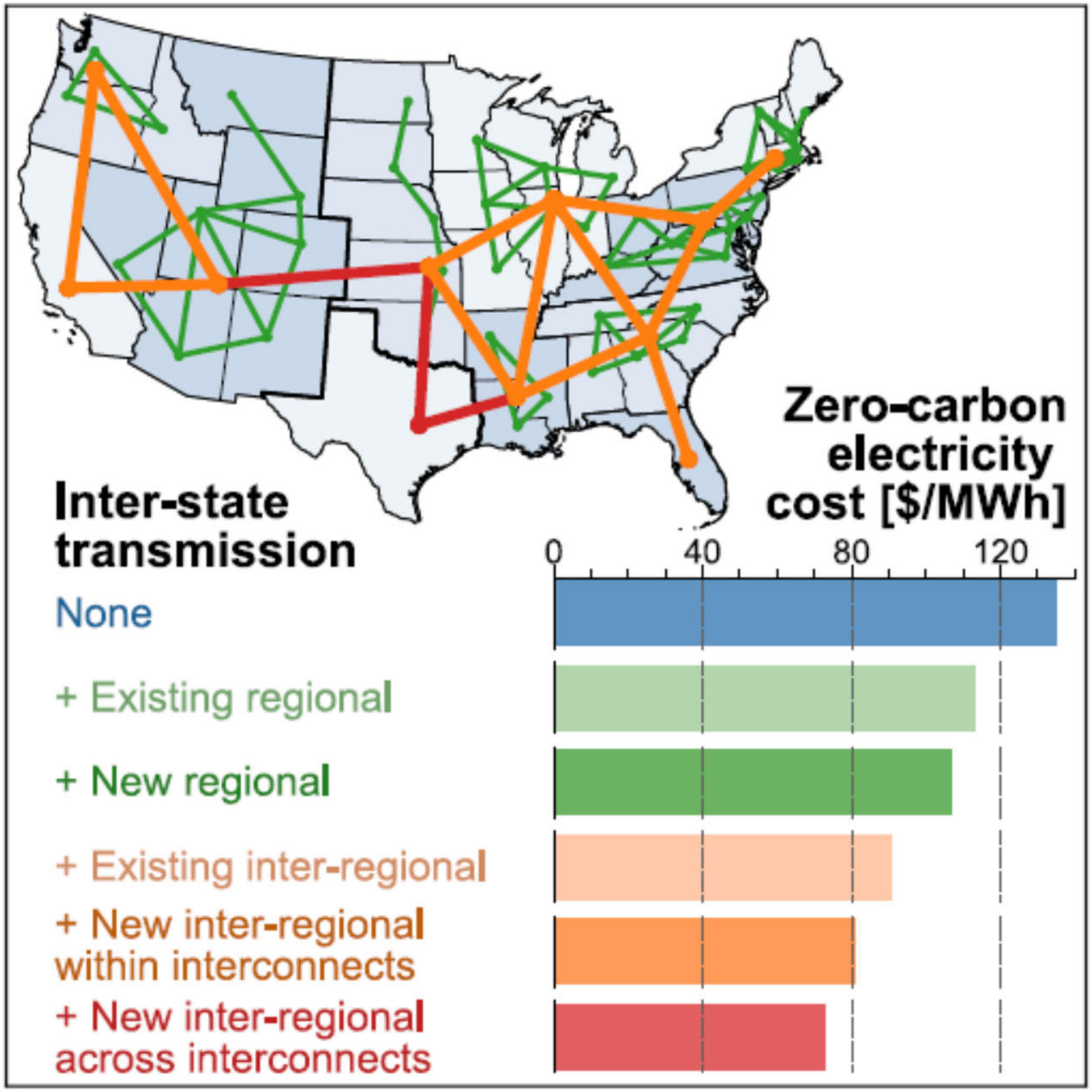


Figure 6. *Renewable energy zones that must be connected to efficiently transition to a clean energy economy.*

https://www.vibrantcleanenergy.com/wp-content/uploads/2020/11/ESIG_VCE_11112020.pdf



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HIGHLIGHTS

US electricity demand can be met with currently available zero-carbon technologies

Inter-regional coordination and transmission construction significantly reduce cost

Nuclear, if available, plays a smaller role than renewables at central cost projections

Nationally planned decarbonization is more efficient than state or regional approaches

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Agenda for Using Storage Efficiently and Developing New Long-duration Technologies

- Full participation in wholesale markets (or in VI utilities in resource planning and economic dispatch)
  - Energy and ancillary services markets
  - Capacity markets and resource adequacy evaluations
    - ELCC and related RA valuations
  - Resource adequacy to maintain reliability
  - FERC Order 841
- Better integration between wholesale markets and BTM storage and distribution-based storage
  - FERC Order 2222
- Lots of experience with pumped storage and Li-ion batteries
- Need more R&D and experience with technologies that may be more economical especial for longer durations or energy stored