3[RD] ANNUAL ENERGY STORAGE GRAND CHALLENGE SUMMIT

Modeling Energy Storage's Role in the Power System of the Future

ENERGY STORAGE GRAND CHALLENGE
U.S. DEPARTMENT OF ENERGY

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NREL Storage Futures Study Highlights and Initial StorageShot Grid Analysis

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

Storage Futures Study Reports

1. The Four Phases of Storage Deployment
2. Energy Storage Technology Modeling Input Data Report
3. Economic Potential of Diurnal Storage in the U.S. Power Sector
4. Distributed Storage Customer Adoption Scenarios
5. The Challenges of Defining Long-Duration Energy Storage
6. Grid Operational Implications of Widespread Storage Deployment
7. Key Learnings for the Coming Decades

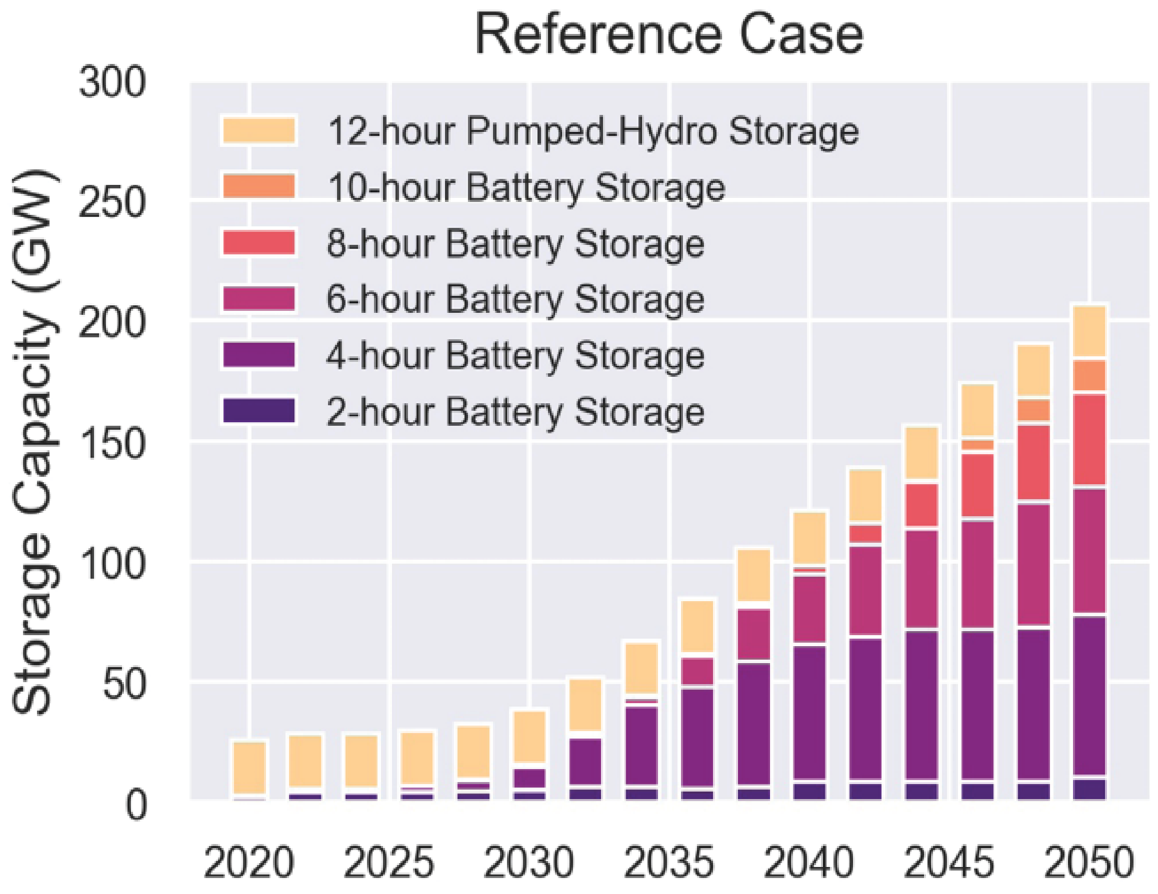
The Four Phases of Storage Deployment

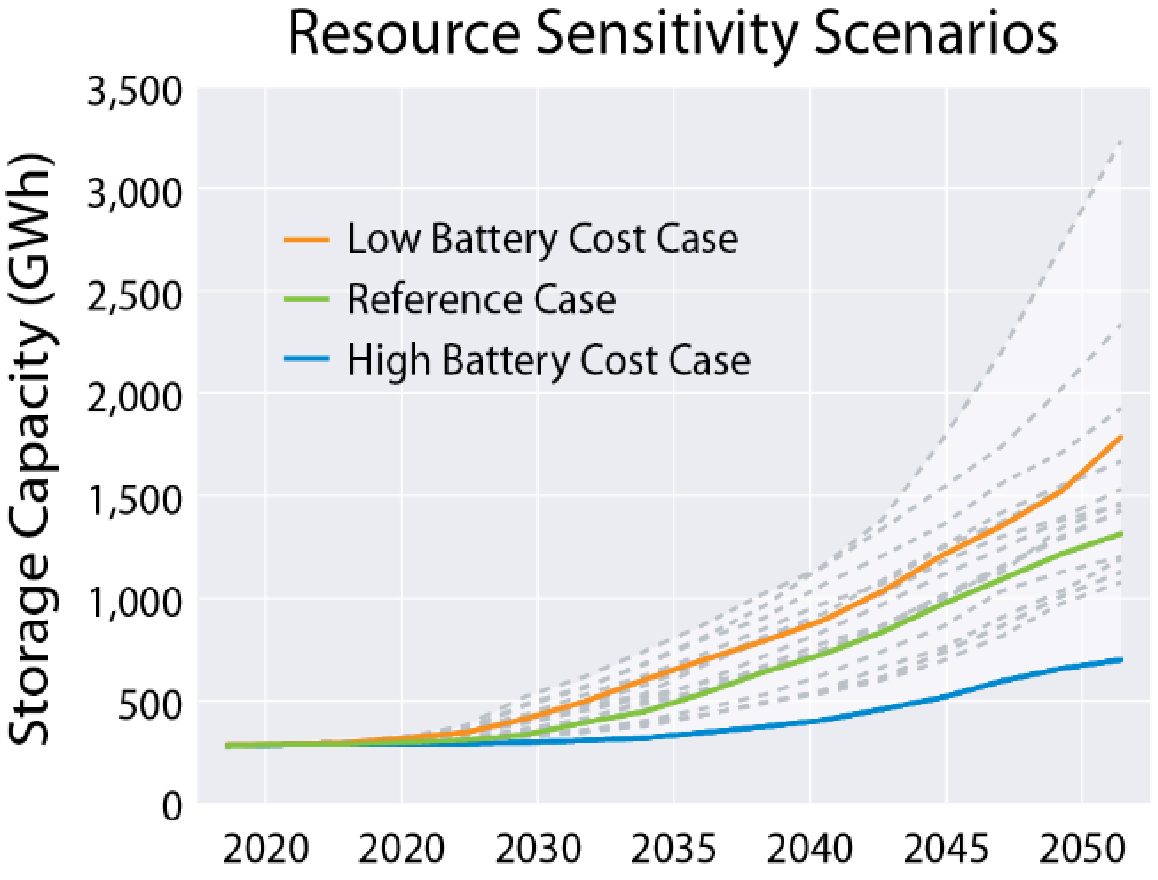
Phase	Primary Service	National Potential in Each Phase	Duration	Response Speed
Deployment prior to 2010	Peaking capacity, energy time shifting and operating reserves	23 GW of pumped hydro storage	Mostly 8–12 hr	Varies
1	Operating reserves	Relatively small <30 GW	<1 hr	Milliseconds to seconds
2	Peaking capacity	Moderate: 30–100+ GW, strongly linked to PV deployment	2–6 hr	Minutes
3	Diurnal capacity and energy time shifting	Large: >100+ GW. Depends on both on Phase 2 and deployment of variable generation resources	4–12 hr	Minutes
4	Multiday to seasonal capacity and energy time shifting	Variable: Zero to more than 250 GW	Days to months	Minutes

While the Phases are roughly sequential there is considerable overlap and uncertainty.

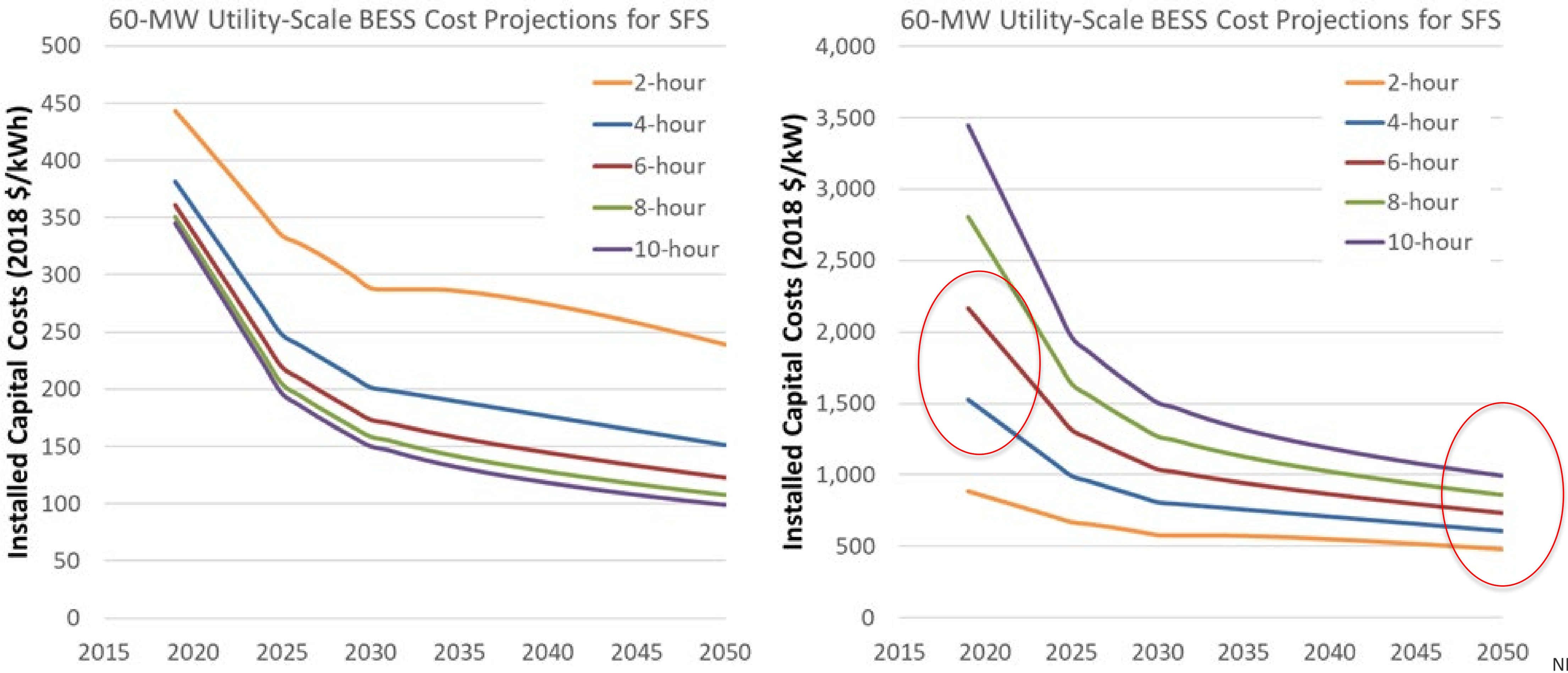
Key Learning 1: Storage is poised for rapid growth.

- Scenarios built 600 to 3000+ GWh in 2050, or 5X today's capacity
- Driven by storage costs, natural gas prices, renewable energy cost





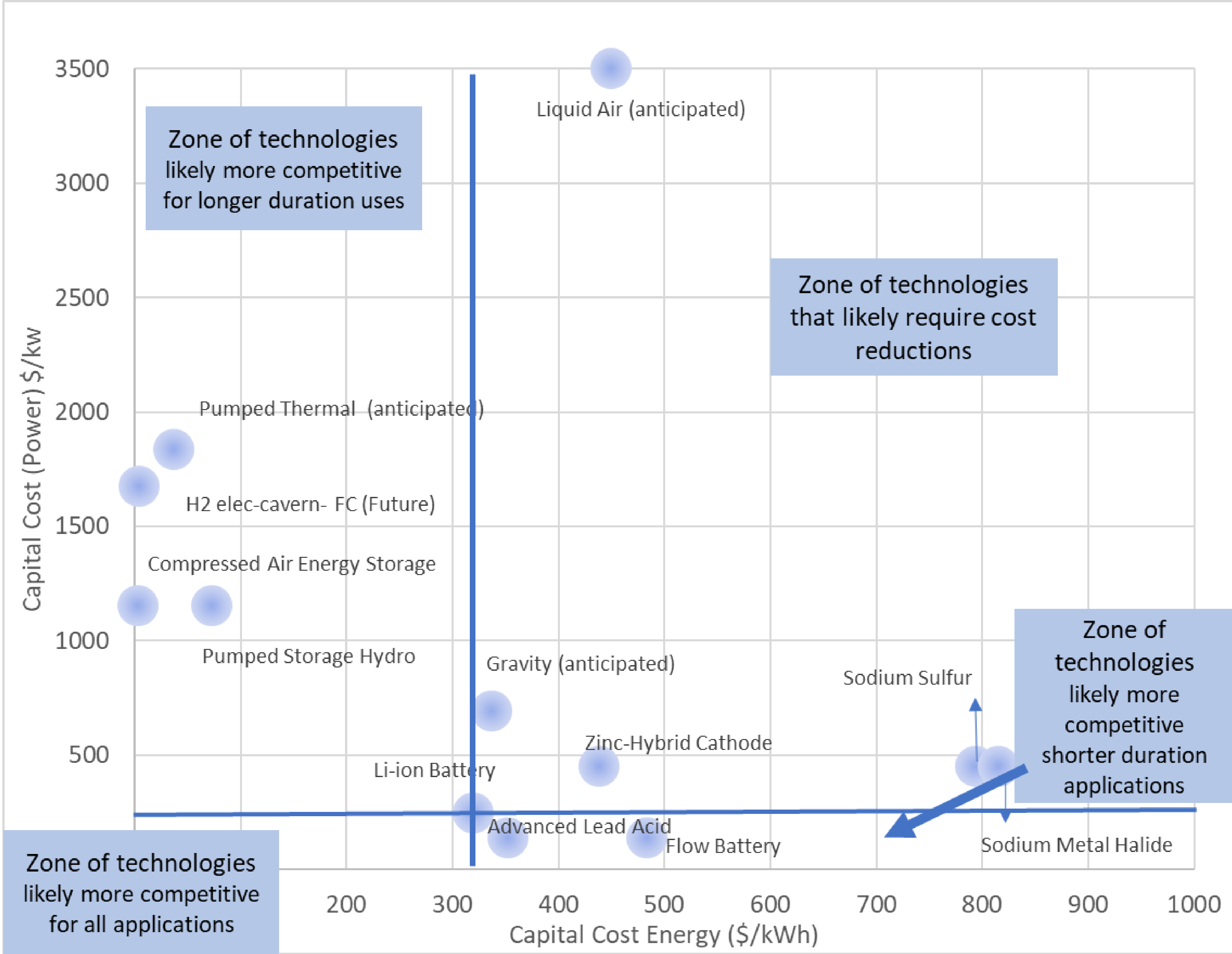
Key Learning 2: Recent storage cost declines are projected to continue, with lithium-ion batteries continuing to lead the market share for some time.



Capital cost for energy ($/kWh)

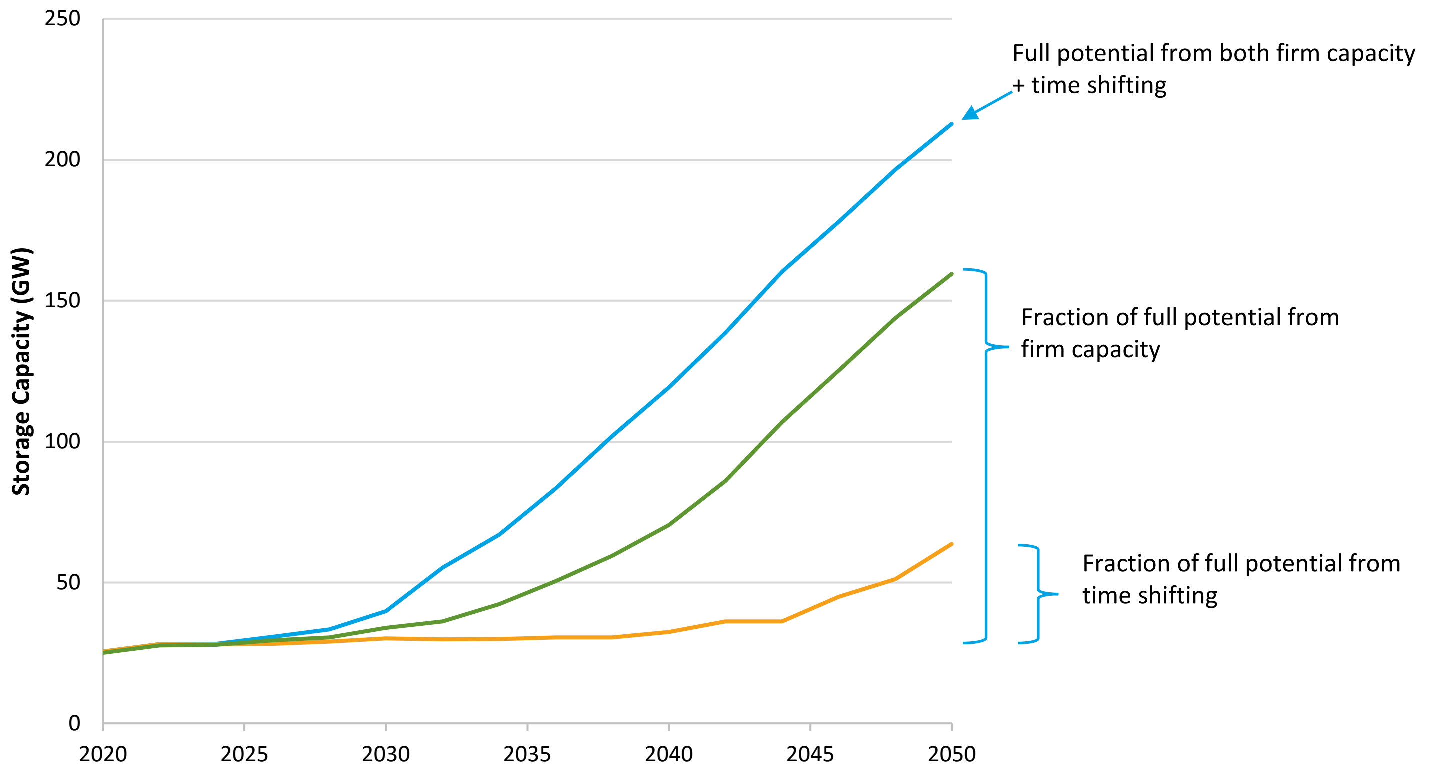
versus

Capital cost for capacity ($/kW)

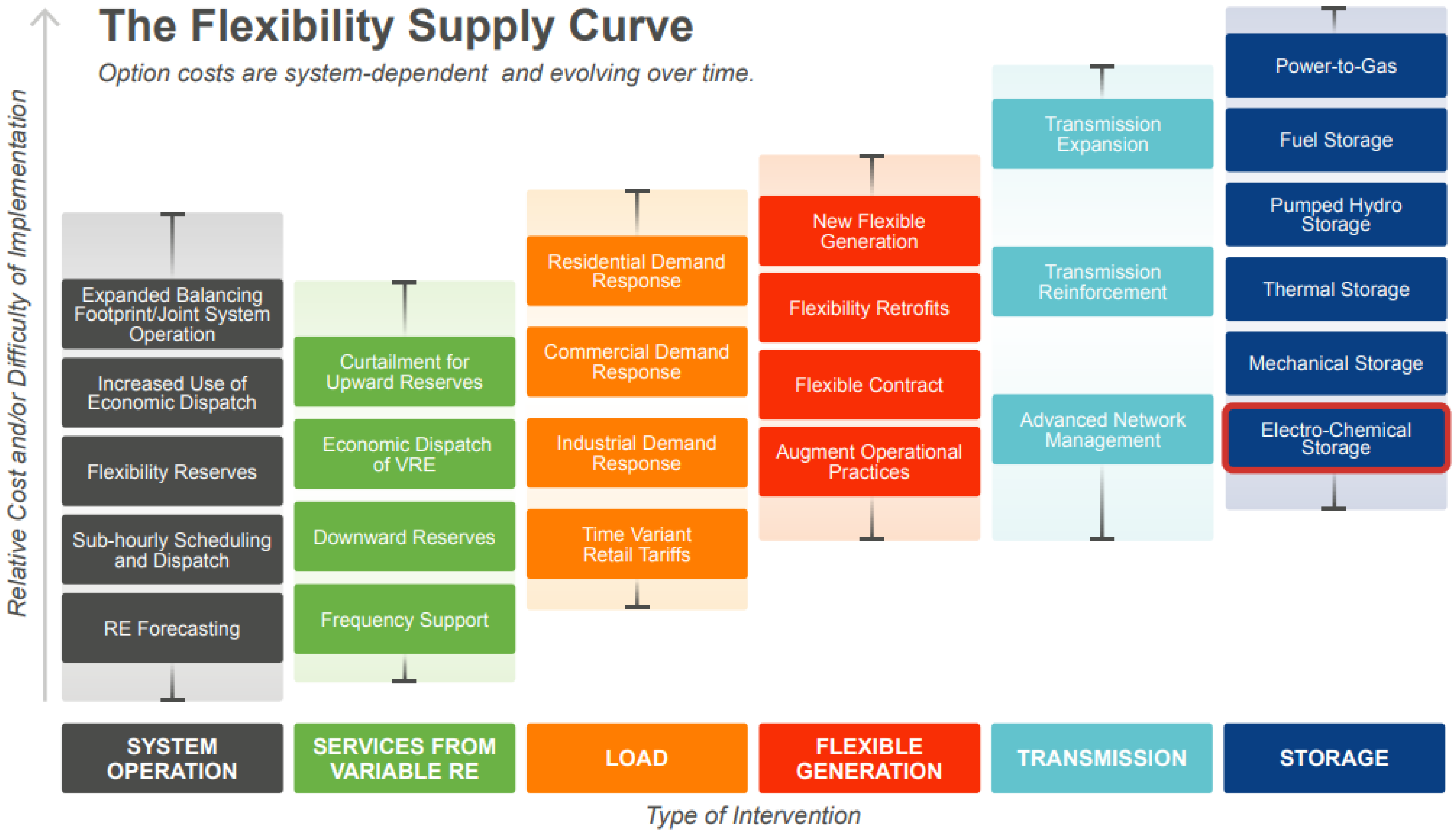


Key Learning #3: The ability of storage to provide firm capacity is a primary driver for cost-effective deployment

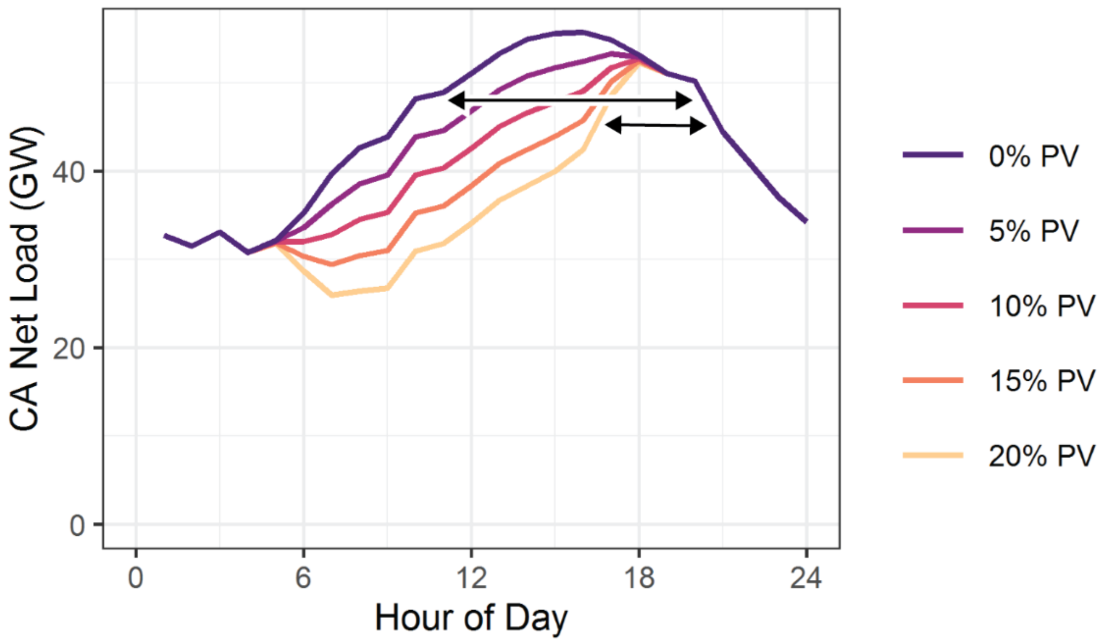
Storage achieves 75% of its full potential when it can provide firm capacity



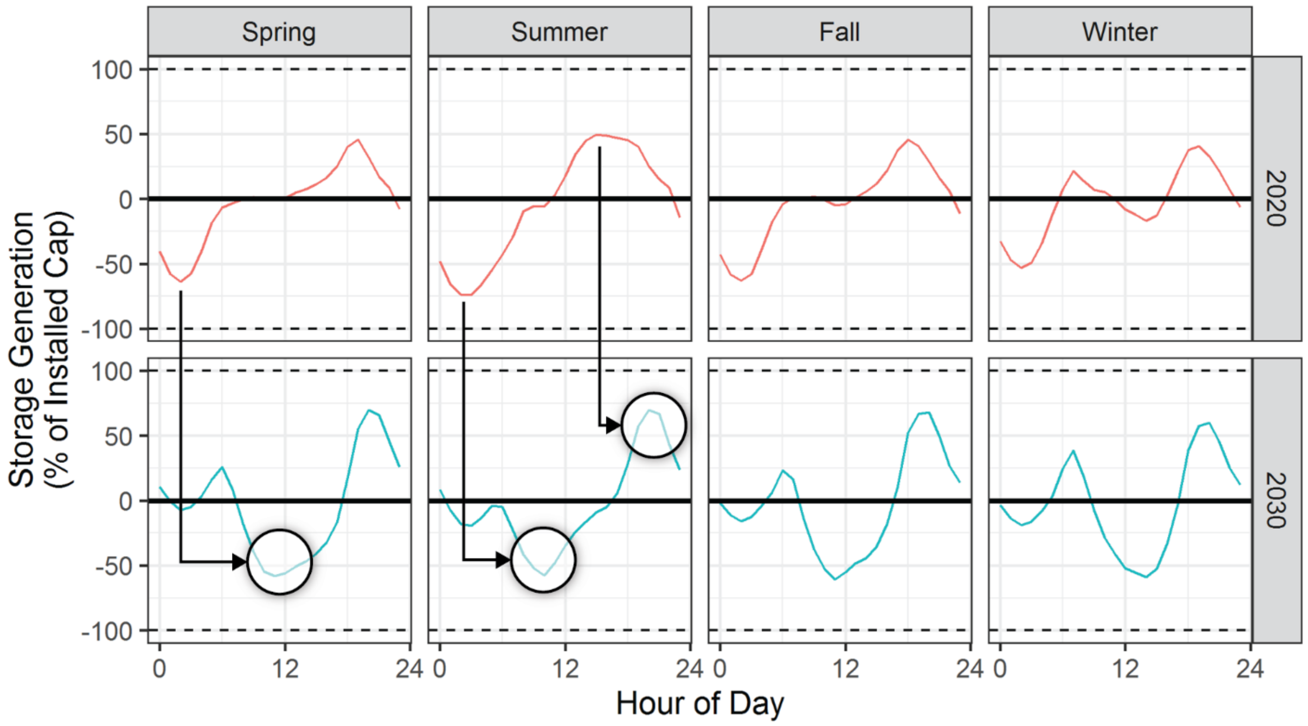
Key Learning 4: Storage is not the only flexibility option, but its declining costs have changed when it is deployed vs. other options.



Key Learning 5:
Storage and PV complement each other.

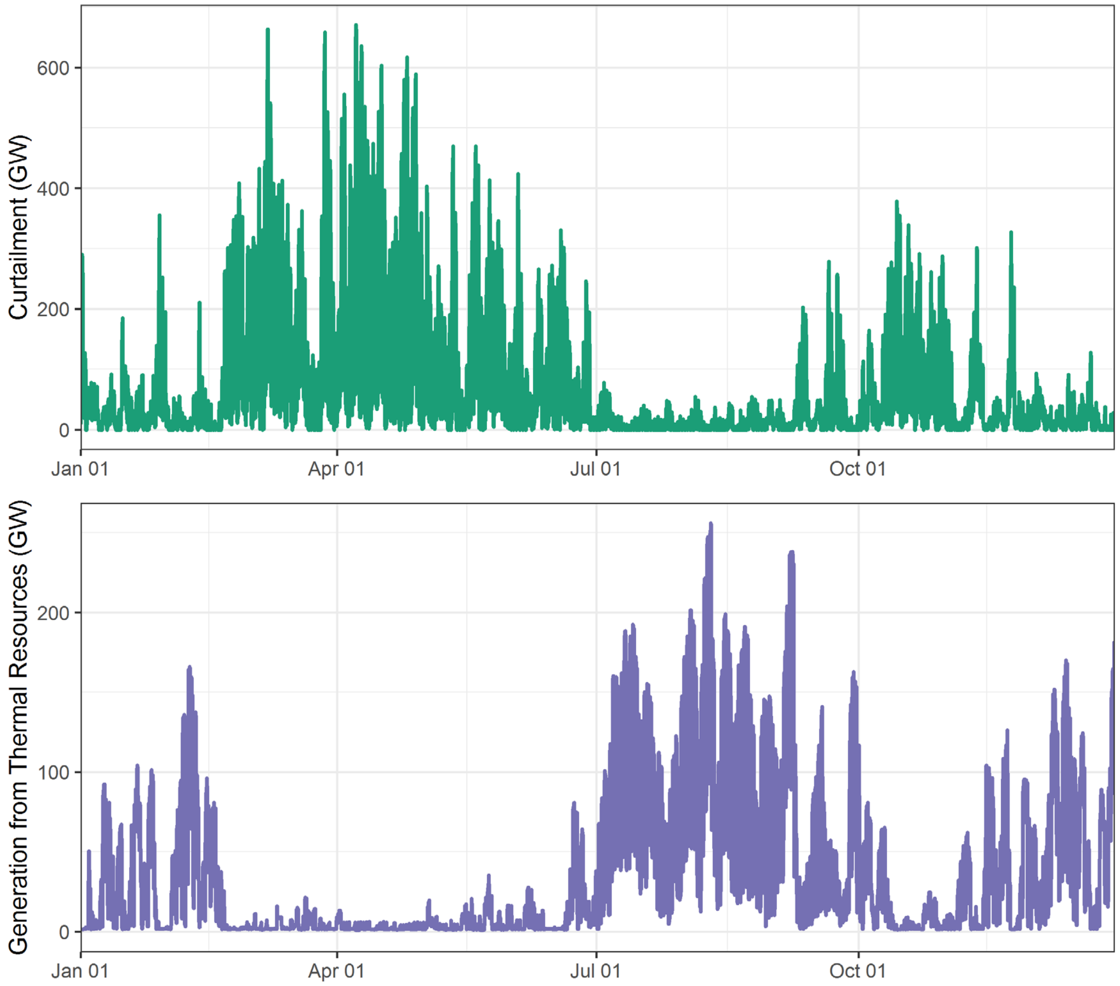


Increased PV deployment reduces duration required for energy storage to provide firm capacity.



More PV on the system in 2030 (vs. 2020) moves charging from nighttime to daytime and shortens the peaks

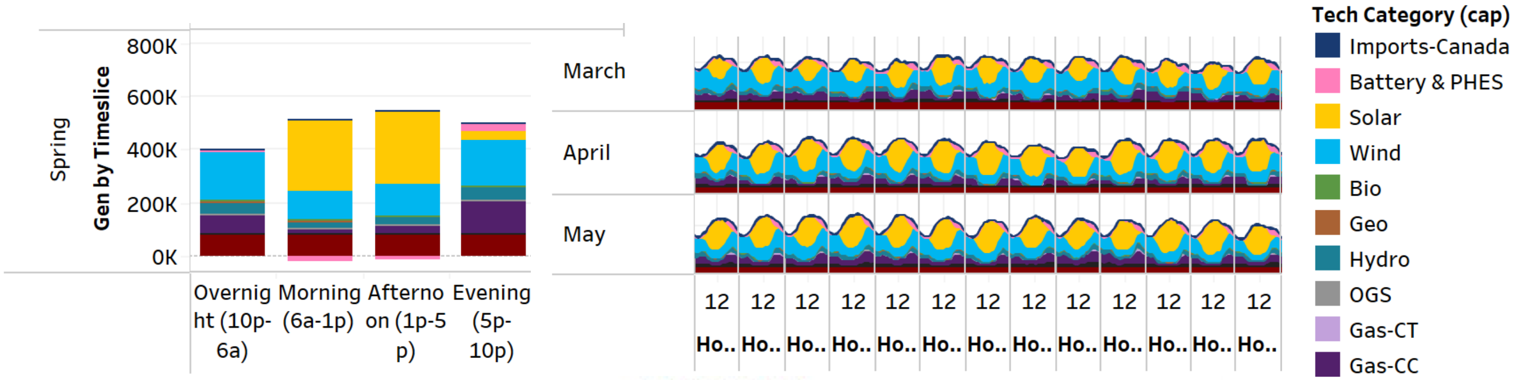
Key Learning #8: Seasonal storage technologies become especially important for 100% clean energy systems

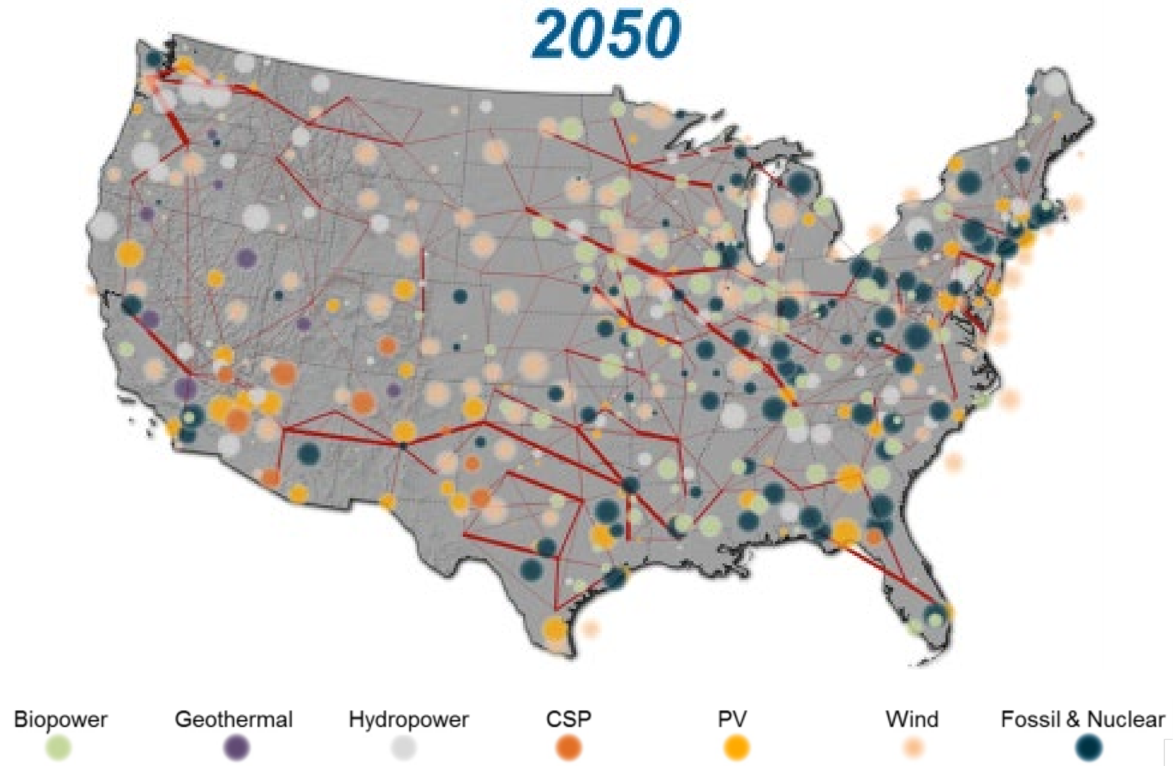


- 100% decarbonization scenarios
- 94% of national demand is met by VRE plus hydropower and geothermal
- 6% of demand is met by renewably-fueled thermal resources such as combustion turbines burning hydrogen and biofuels.
- Thermal resources used during low wind and lower solar periods.

Storage Shot Goals are Implemented in the Regional Energy Deployment System (ReEDS)

- Minimizes total investment and operating costs of the U.S. electric sector to 2050 or beyond
- 134 balancing regions and 356 renewable resource regions
- 17 time slices for investment-operation co-optimization and 8760-hour dispatch module characterizes variable renewables and storage
- Full suite of generation, storage and transmission technologies with multiple subcategories and vintages
- Includes existing policies, resource constraints, capacity requirements, and planned capacity changes





Learn more about the Storage Futures Study

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Modeling the Long Duration Storage Shot

Alexander Laska
Deputy Director, Climate and Energy Program
July 26, 2023

THIRD WAY

Methodology

(and some important caveats)

- Modeled a baseline “no innovation” scenario, individual Earthshots, and a Combined Earthshot scenario
- Earthshot scenarios assume current policy, plus innovation needed to achieve the Shot
- Used Regional Investment and Operations Model to determine least-cost investments
- Model projects *economic* deployment enabled by innovation
- We do not keep renewables in-sector; other sectors can compete for overgeneration

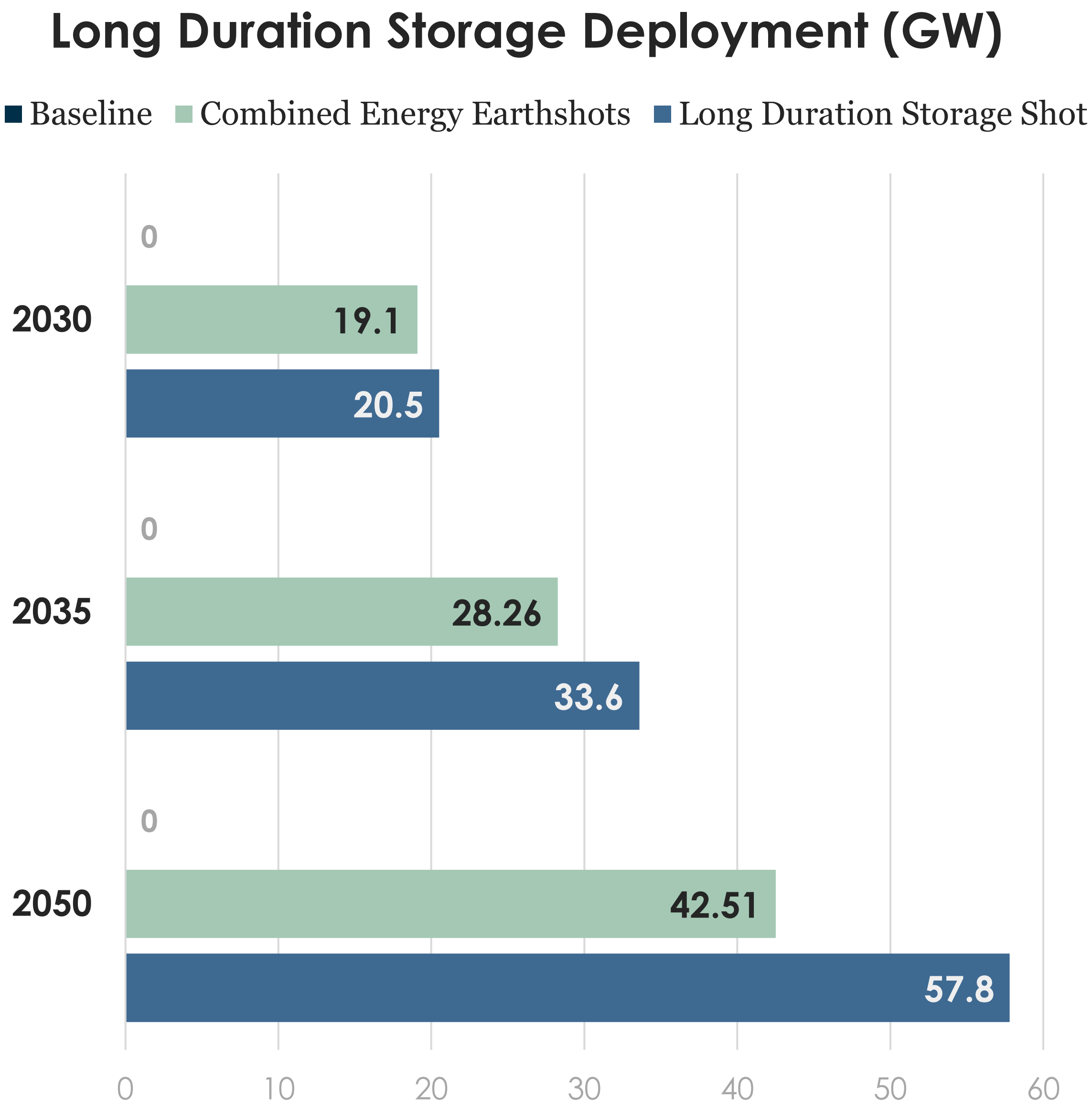
Long Duration Storage Shot

- **Goal**: reduce storage costs by 90% (from a 2020 li-ion baseline) in systems that deliver 10+ hours of duration by 2030
- **Implementation**: model a generic long duration storage (LDS) technology with a total installed cost in 2030 that is 90% less than today
  - Include 10-hour minimum duration

Category	Unit	Today	2030: Energy Earthshot
Duration	hours	10	10
Total installed cost	**$/kWh**	**440**	**44**
	% Δ from today	**--**	**-90%**

Achieving the Shot is Critical to Deploying LDS

There's no economic deployment of LDS if costs don't come down—and that requires innovation.



Emissions and Cost Impacts of the LDS Shot

- LDS deployment avoids battery storage and gas resources and slightly more renewables are deployed
- Emission and cost benefits are muted since the resources that are avoided run infrequently (e.g., gas-fired combustion turbines)

Summary of Cumulative Impacts, 2021-2050	
Impact	Value
Emission Savings (Mt CO_2)	50
Cost Savings ($billion)	4

LDS is not one of the heavy-hitters in emission or cost reduction—but it's key to enabling a net-zero economy.

Impacts are net of the Baseline scenario

Energy Earthshots	Cumulative Emission Savings 2021-2050 (Mt CO2)	Cumulative Cost Savings 2021-2050 ($B)
Hydrogen Shot	663	502
Carbon Negative Shot	995	49
Industrial Heat Shot	2,369	n/a*
Long Duration Storage Shot	50	4
Enhanced Geothermal Shot	524	46
Floating Offshore Wind Shot	150	94
Combined	3,943	853

*Costs not reported since technologies are assumed to be economic.


DECARB AMERICA RESEARCH INITIATIVE
Building A Clean Energy Economy
THIRD WAY
Bipartisan Policy Center
CLEAN AIR TASK FORCE

In a high renewables scenario, energy storage grows with solar.

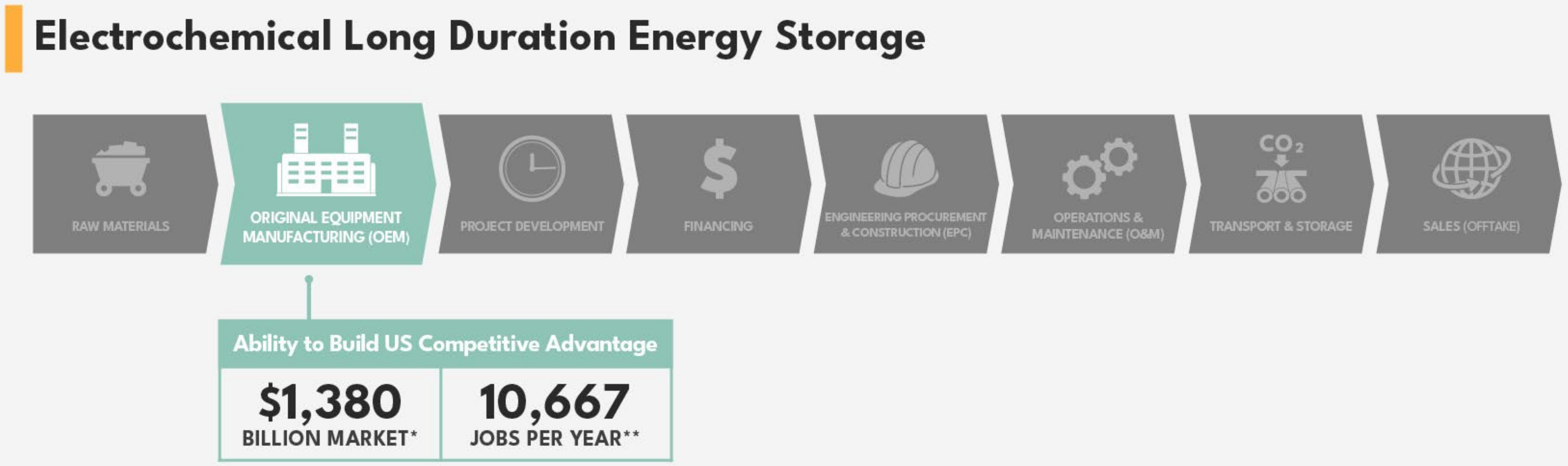
Source: Decarb America

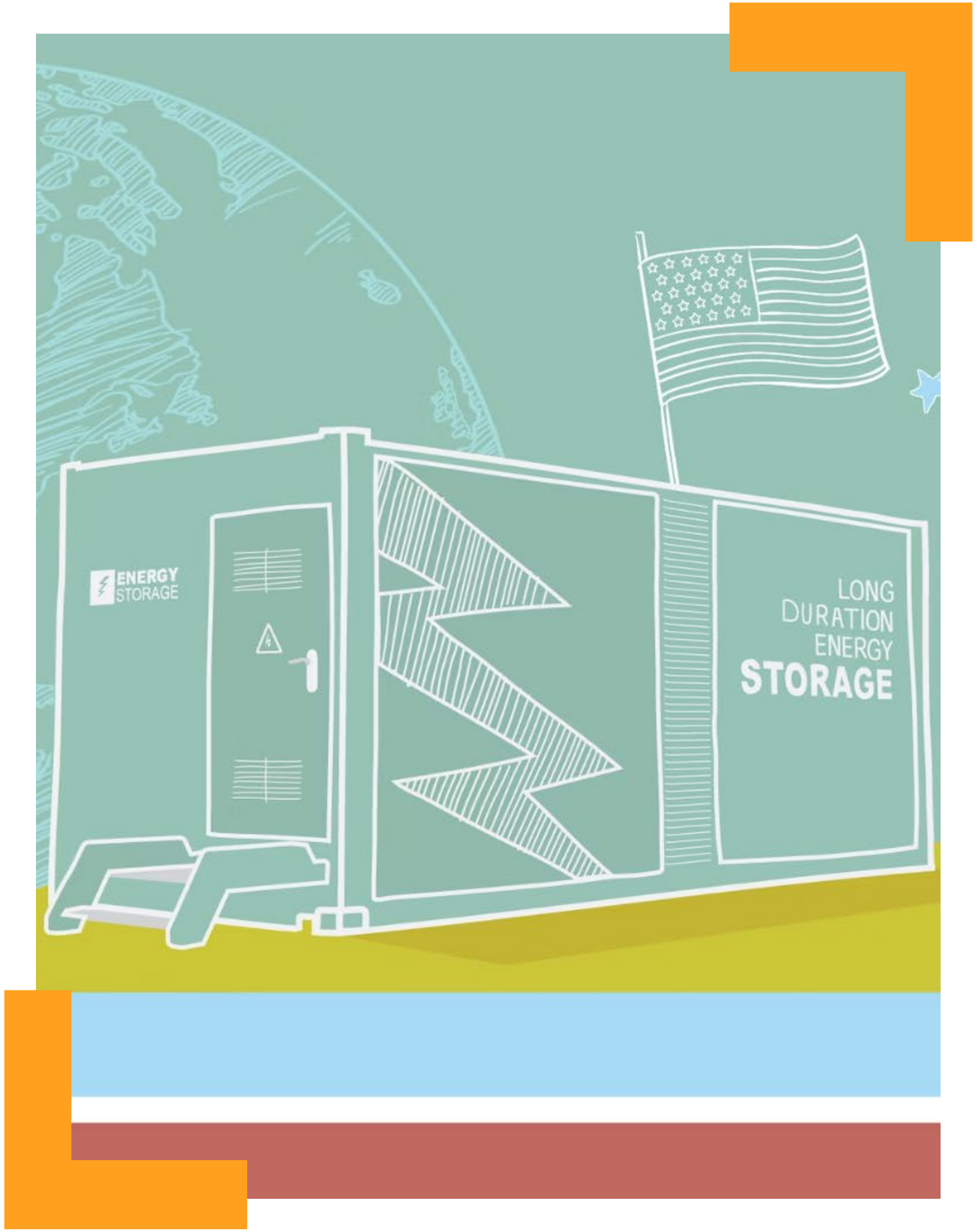

WHEN AMERICA LEADS

OEM is a key opportunity for the US to build a durable competitive advantage

US companies have built an early lead in electrochemical LDS—but we lag East Asia in research and IP.

Our long-term advantage depends on reducing manufacturing costs so we can efficiently build battery modules at scale.



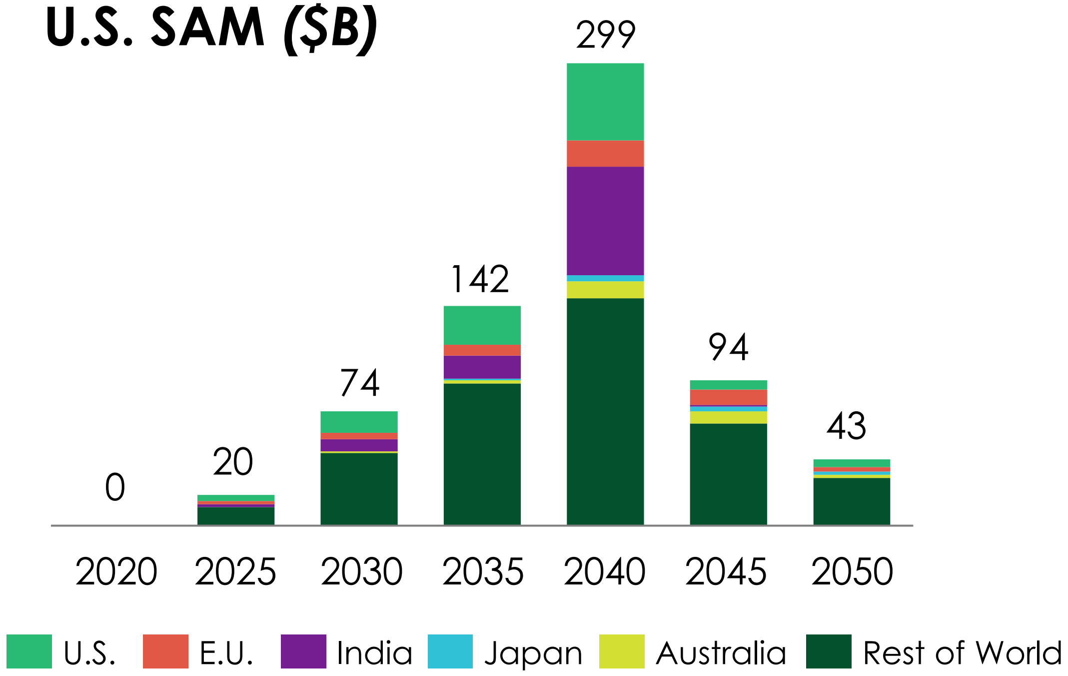


LDS OEM Market Spikes in a Net Zero Emissions Scenario

Cumulative U.S. Serviceable Addressable Market:
(2020 – 2050)

$3.5T

U.S. SAM (*$B*)



THANK YOU

Modeling Long-Duration Energy Storage in Resource Planning Studies

Rachel Wilson

Energy Storage Grand Challenge Summit

July 26, 2023

Form energy

Energy Storage
For A Better World

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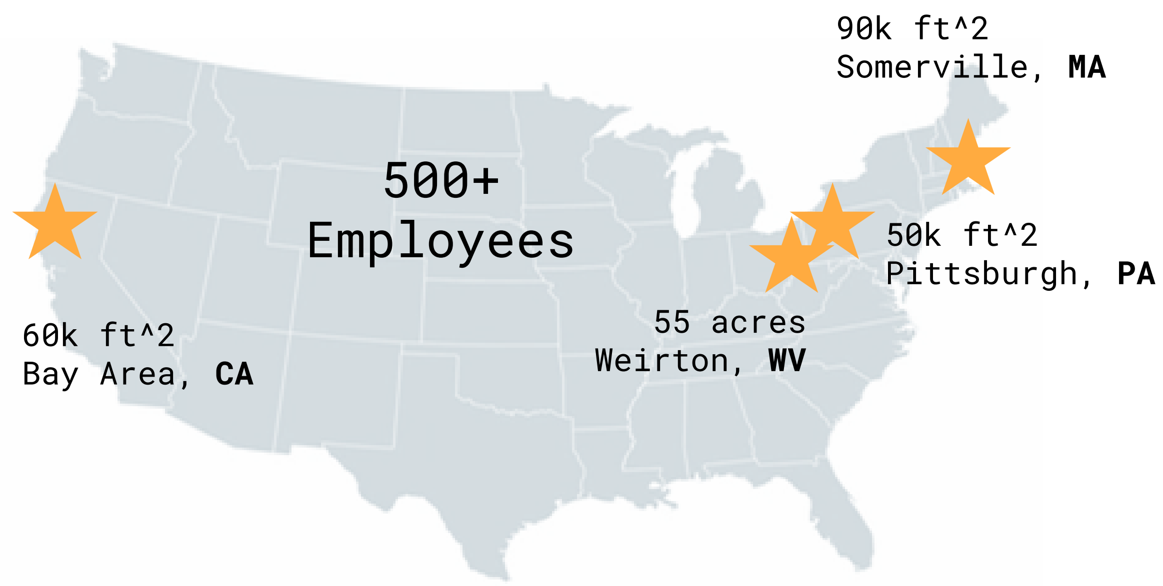
Form Energy: Meeting the challenge of multi-day storage with a team that will deliver



LED BY ENERGY STORAGE VETERANS

Decades of cumulative experience in energy storage

- 100's of MW of storage deployed

OUR INVESTORS: LONG-TERM AND IMPACT-FOCUSED

$820M+ in venture capital from top investors including: Breakthrough Energy Ventures (BEV), TPG's Climate Rise Fund, Coatue Management, GIP, NGP Energy Technology Partners III, ArcelorMittal, Temasek, Energy Impact Partners, Prelude Ventures, MIT's The Engine, Capricorn Investment Group, Eni Next, Macquarie Capital, Canada Pension Plan Investment Board, and other long-term, impact oriented investors

Capturing the value of long-duration (LDES) and multi-day energy storage (MDS) technologies in electric grid planning

Recommended input assumptions and modeling methodologies

- **Model energy storage**
  - *Include both established and emerging energy storage technologies in simulation modeling*
- **Use the right modeling tools and input assumptions**
  - *Capacity optimization modeling should use a chronology that includes all 8,760 hours of the year, rather than a "typical day" or "typical week" methodology*
  - *Weather-correlated load profiles and renewable generation profiles should be used as input assumptions to capacity optimization models*
- **Analyze the right scenarios**
  - *Model resource needs over multiple weather years to capture periods of real grid stress, such as multi-day lulls in renewable energy generation, extreme heat and cold, or periods of high commodity prices*
  - *Model deep decarbonization scenarios, with and without thermal units, to better understand the impacts of policy and/or technology pathways*

Model energy storage:

New York LDES/MDS analysis

Prior NY studies identified a multi-GW need for dispatchable, emission-free resources (DEFRs)

But none included emerging long-duration storage technologies as candidate resources

NYISO Grid Evolution Study

"**We modeled RNG as a proxy for potential future zero emission technology** to illustrate the potential role of these technologies."

"RNG cost assumptions (were) drawn from multiple sources, but given the uncertainty in technology costs, we recommend **further scenario analysis** to develop more robust understanding of the role **of long duration storage**."

– Brattle Group, 2020

Climate Action Council Scoping Plan (Appendix G)

"The '**zero-carbon firm resource'…is modeled as a hydrogen fuel cell**."

"During a week with persistently low solar and wind generation, additional firm zero-carbon resources…are needed to avoid a significant shortfall…**Firm zero-carbon capacity needs could be met by a number of different technologies**...[which] are at varying levels of technology readiness, **though none have been deployed at commercial scale**."

–E3, 2021

NYISO 2021-2040 System & Resource Outlook

"**Long-duration, dispatchable, and emission-free resources will be necessary** to maintain reliability and meet the objectives of the CLCPA. Resources with **this combination of attributes are not commercially available at this time but their successful development will be critical** to future grid reliability."

– NYISO, 2022

Motivating question of Form Energy's study

What is the least-cost portfolio of long-duration and multi-day energy storage for meeting New York's clean energy goals and fulfilling its dispatchable emissions-free resource needs?

Distinguishing features of Form Energy's study

01 **Includes emerging technologies:** Includes diverse emerging long-duration and multi-day energy storage resources among the candidate resources in resource optimization, vs. studying only li-ion

02 **Optimizes with hourly resolution:** Conducts capacity expansion optimization over 8,760 hourly resolution to accurately model long-duration storage, vs. optimizing based on a few sample days*

03 **Parallels prior NY studies in all other regards**: Replicates assumptions and data sources used in NY's Climate Action Council Scoping Plan and the Storage Roadmap as much as possible

* Independent research has confirmed the importance of optimizing energy resources across an 8,760 hour chronology when modeling long-duration energy storage. Sanchez-Perez, et al, demonstrated that when the optimization horizon is increased from 1 week to 1 year, the optimal build of >12-hr storage increases by an order of magnitude. See Sanchez-Perez et al., 2022. Effect of modeled time horizon on quantifying the need for long duration storage. Applied Energy; 317, https://doi.org/10.1016/j.apenergy.2022.119022

Storage technologies modeled

Representative technologies to capture short, long and multi-day storage classes

Form Energy's Modeling Assumptions				In NYSERDA Storage Roadmap?
Reference Technology	**Duration (hrs)**	**Storage Category**	**Cost & Technology Specification Reference**	
Li-ion Battery	4	<12 hr storage	2022 NREL ATB moderate	Yes
Li-ion Battery	8	<12 hr storage	2022 NREL ATB moderate	Yes
Flow Battery	12	12-24 hr storage (LDES)	McKinsey 2022 LDES Benchmarking	No
A-CAES	24	12-24 hr storage (LDES)	Hydrostor publicly released data	No
Iron-air Battery	100	>24 hr storage (MDS)	Form Energy	No
H2 Electrolyzer + Turbine, aboveground storage	24-100	>24 hr storage (MDS)	2022 PNNL ESGC	No. Zero Carbon Firm Resource modeled a gas turbine
H2 Electrolyzer + Turbine, belowground storage	100-1000	>24 hr storage (MDS)	2022 PNNL ESGC	

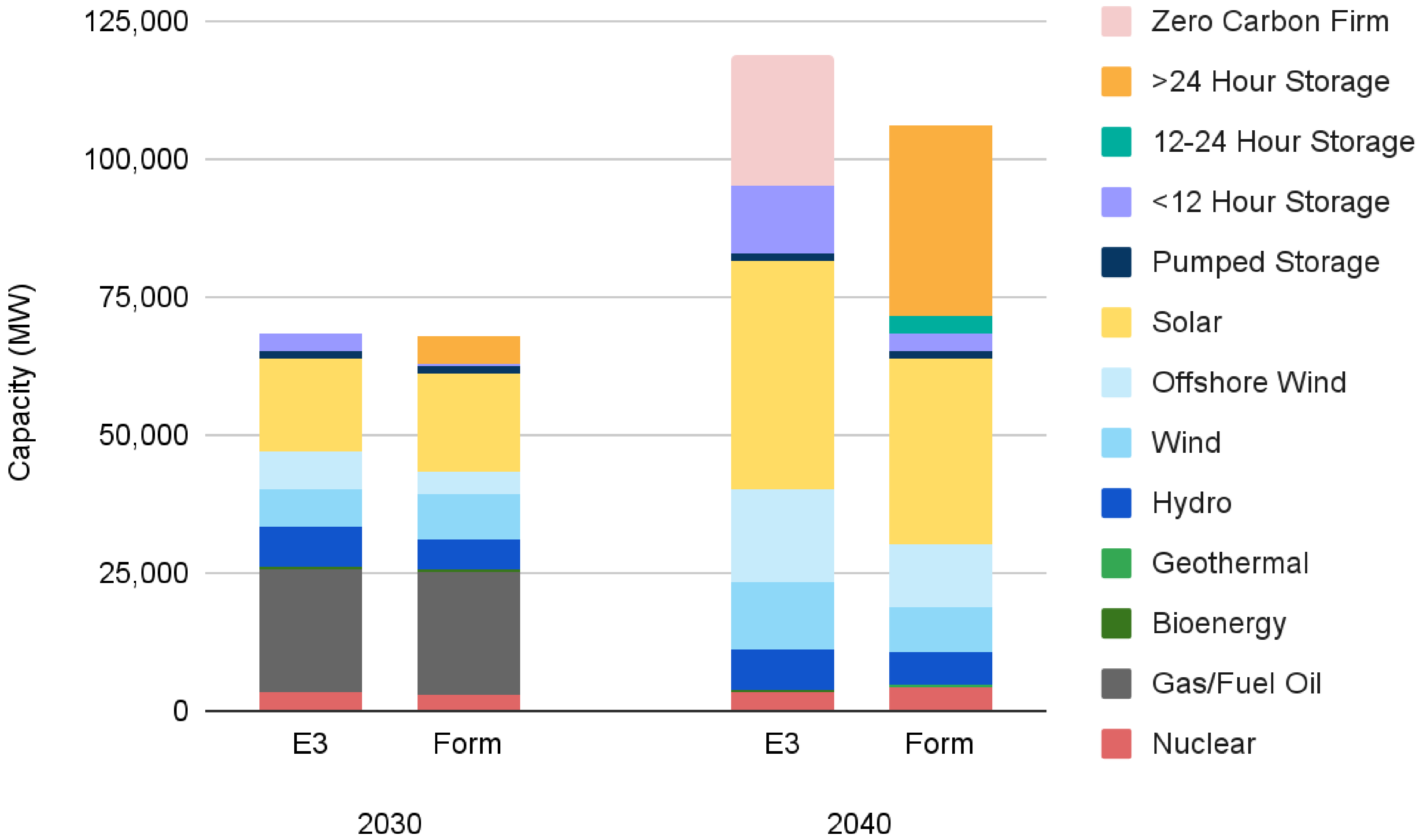
LDES = Long-duration energy storage (≥12-hr duration)

MDS = Multi-day energy storage (≥24-hr duration)

Resource availability and modeling methodologies affect optimized portfolio builds in New York

Form model selects 4.8 GW of MDS in 2030, which increases to 35 GW of MDS in 2040

- **E3**
  - *Includes only 4-hour and 8-hour lithium-ion batteries, at NY's 3,000 MW target in 2030*
  - *Resolve model used 37 representative days to conduct optimization*
- **Form Energy**
  - *Formware model selects a range of storage technologies*
  - *Optimizes over 8,760 consecutive hours in the year*

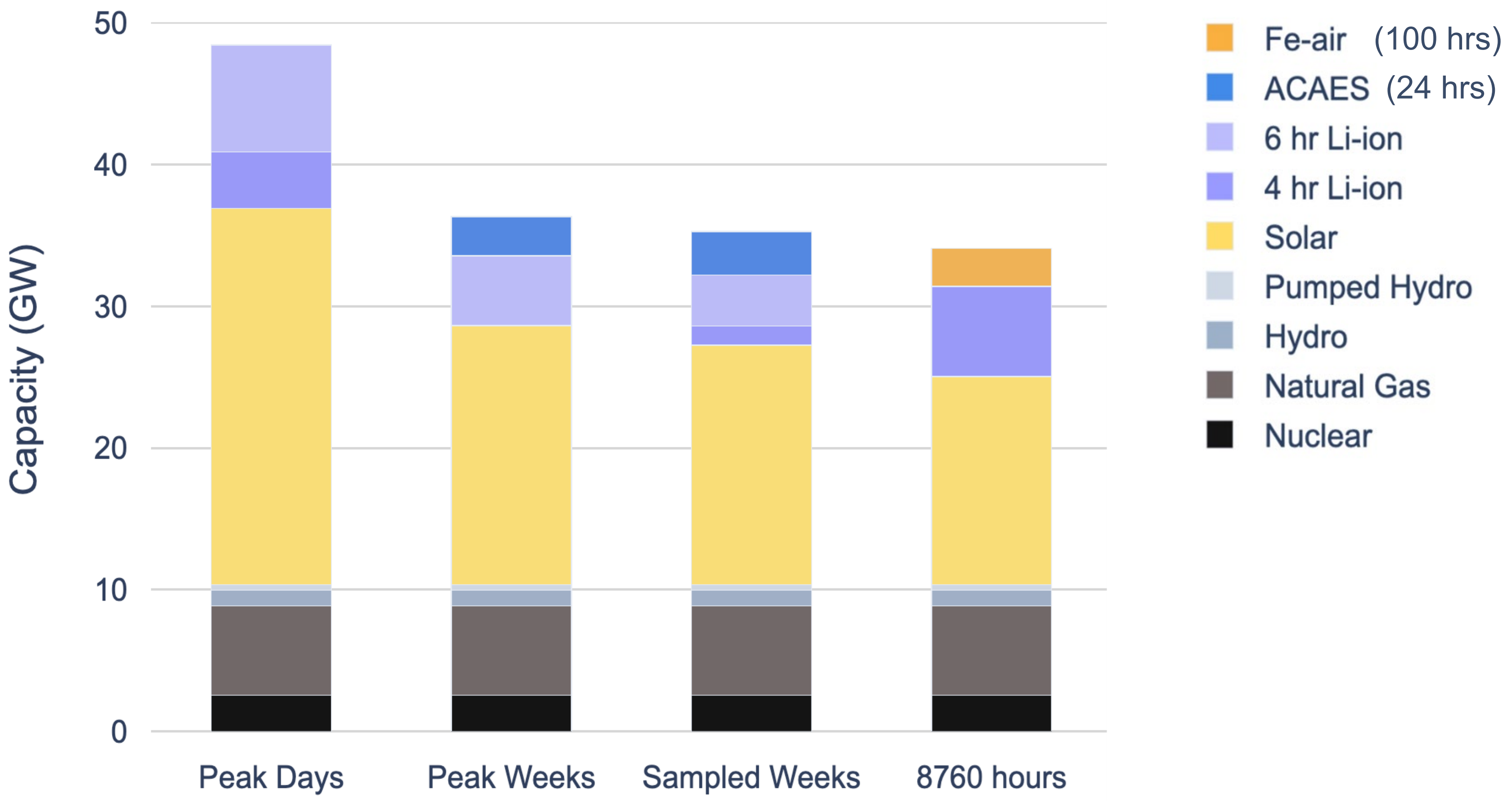


Use the right tools:

Georgia Power LDES analysis

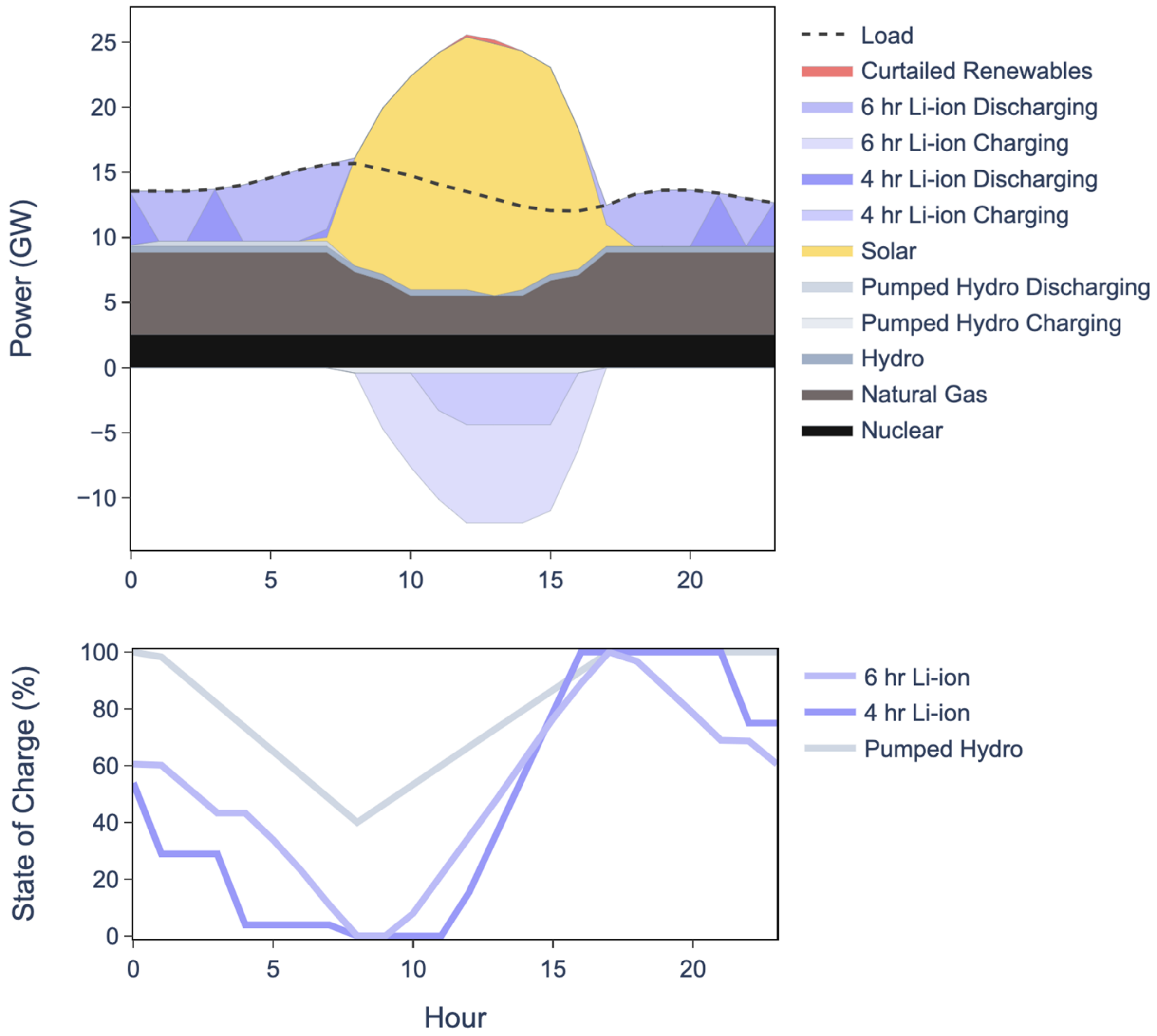
The least-cost 2035 Georgia Power resource portfolio varies based on modeled chronology

Tested chronologies include: peak days, peak weeks, sampled weeks, and 8760 hours



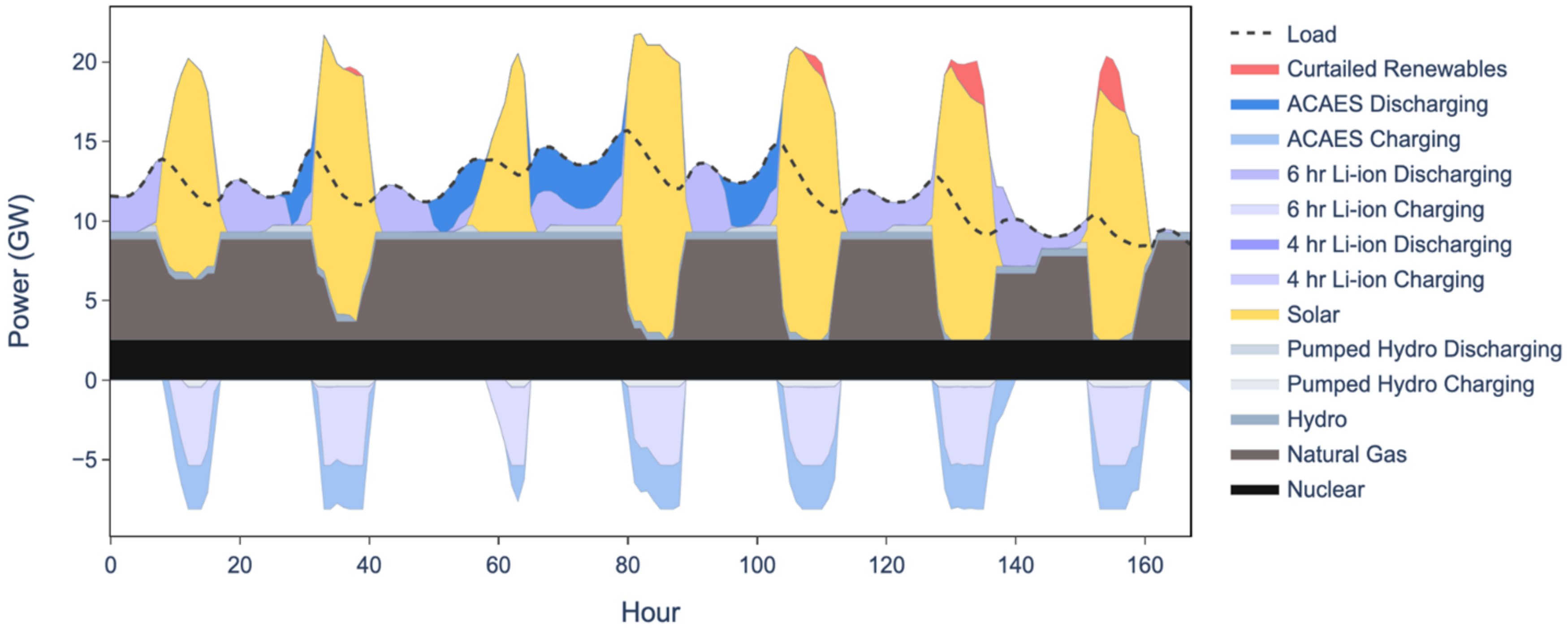
Note: Data for this analysis were taken from publicly available sources.

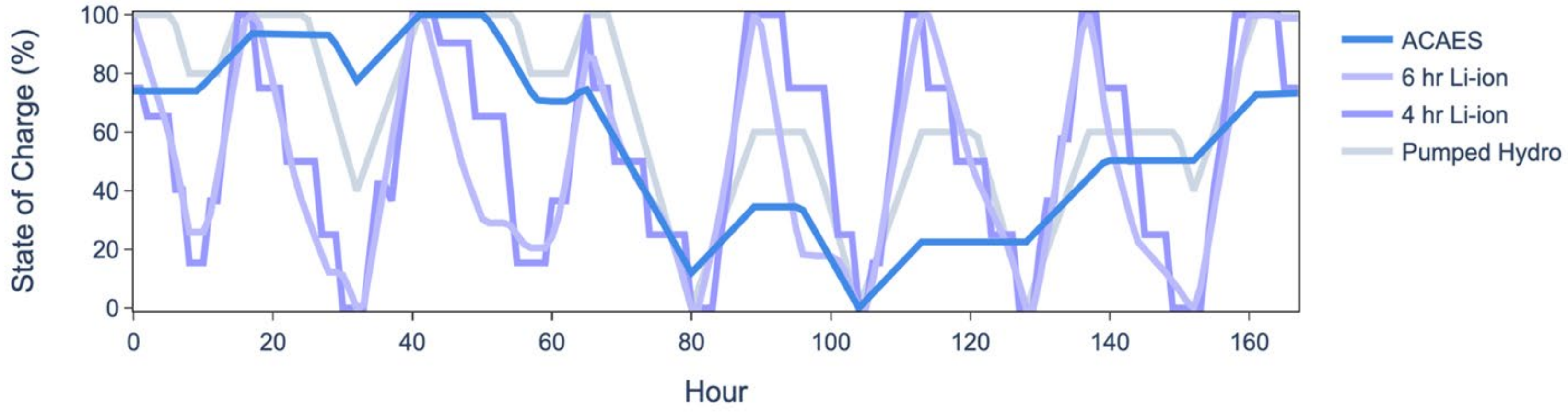
Analysis of the "peak day" optimization horizon



- **Assumptions**
  - *Storage can only arbitrage surplus energy from the 24-hr period modeled*
  - *The starting charge of storage equals the final charge each day*
  - *Storage can't begin a day fully charged*
- **Limitations of approach**
  - *Ignores the ability of multi-day storage to shift energy from previous days, weeks and months*
  - *Results in significant overbuilding of renewables (assumes storage needs to fully charge and discharge each day)*
  - *Results in significant undervaluation of multi-day storage*

Analysis of the "peak week" optimization horizon





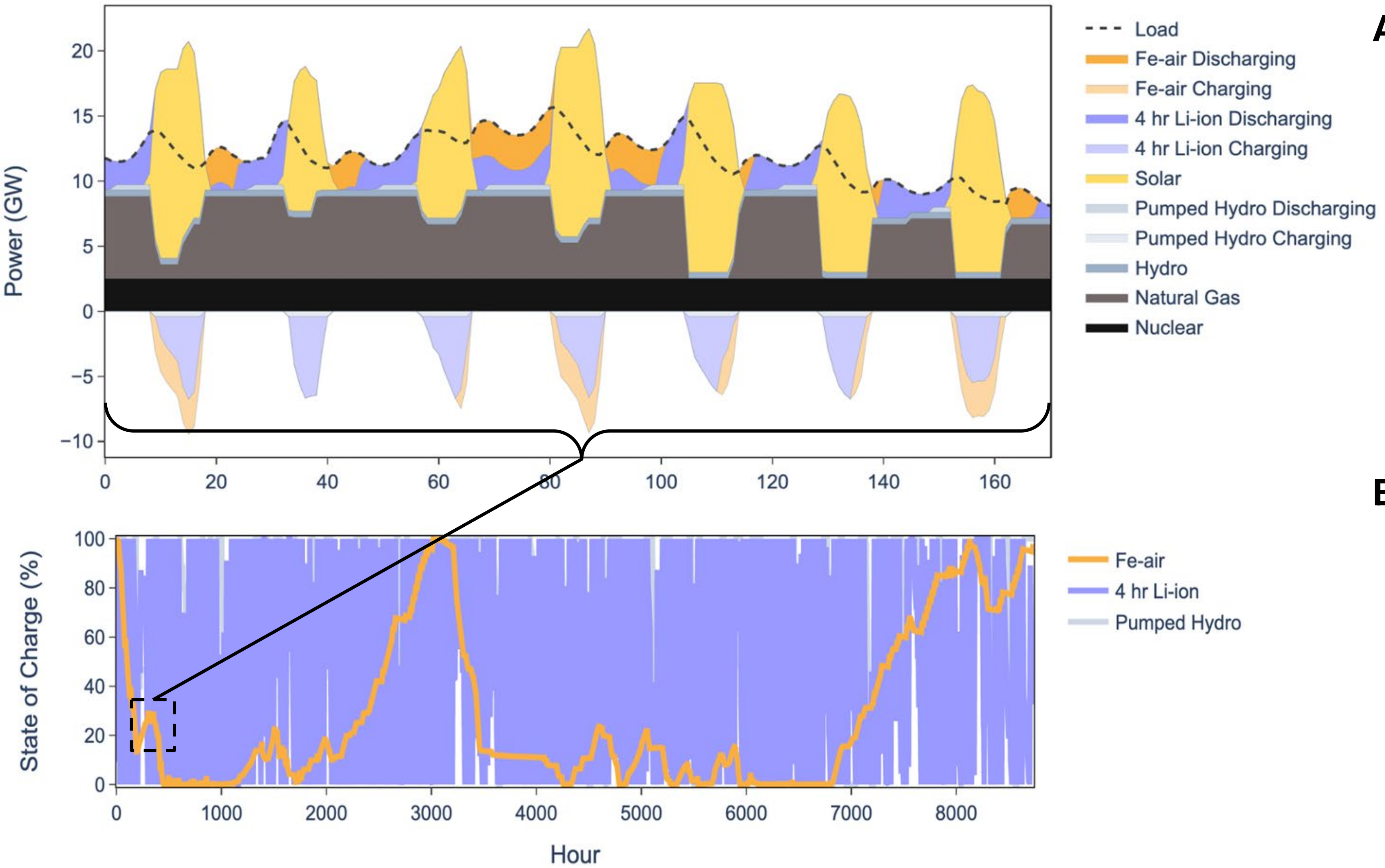
Assumptions

- *Annual resource needs are based on a single peak week*
- *Assumes storage cannot shift energy from one week to another*

Limitations of approach

- *Identifies some LDES but omits multi-day storage*
- *Results in uneconomic renewable energy overbuild (curtailment)*

Analysis of the 8760 optimization horizon



Assumptions

- *Optimizes resource needs over 8,760 hourly operations*
- *Optimization captures realistic reliability risks over all seasons*

Benefits of approach

- *Recognizes value of multi-day storage*
- *Less renewable energy is needed (less curtailment)*
- *More accurately captures storage operations*

Analyze the right scenarios:

California LDES analysis

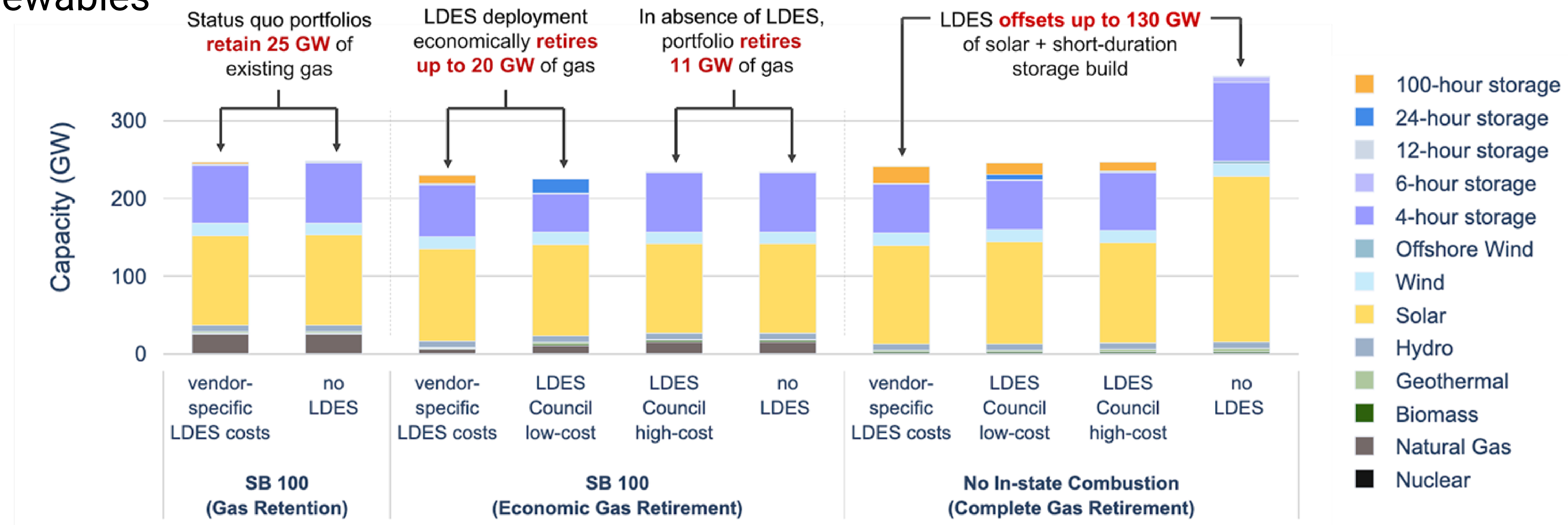
E3 and Form analyzed the role of LDES under different policy scenarios in California

Summary findings

- **The role of LDES varies significantly across policy scenarios**
  - *Up to 5 GW of LDES could be cost effective in 2045 under existing policy (SB 100 scenario), which allows 12 MMT of electric sector emissions and retains existing fossil resources*
  - *The volume of cost effective LDES increases to 37 GW in deeper decarbonization scenarios (No In-State Combustion scenario with zero emissions)*
- **LDES provides energy during grid stress events to maintain system reliability**
  - *LDES operates throughout the year and provides intra-day, multi-day, and seasonal energy balancing while reducing renewable energy curtailment*
- **LDES can enable reliable zero-carbon portfolios at cost parity or savings relative to existing state policy**
  - *LDES maintains reliable grid operations in simulations across 35 unique weather years*

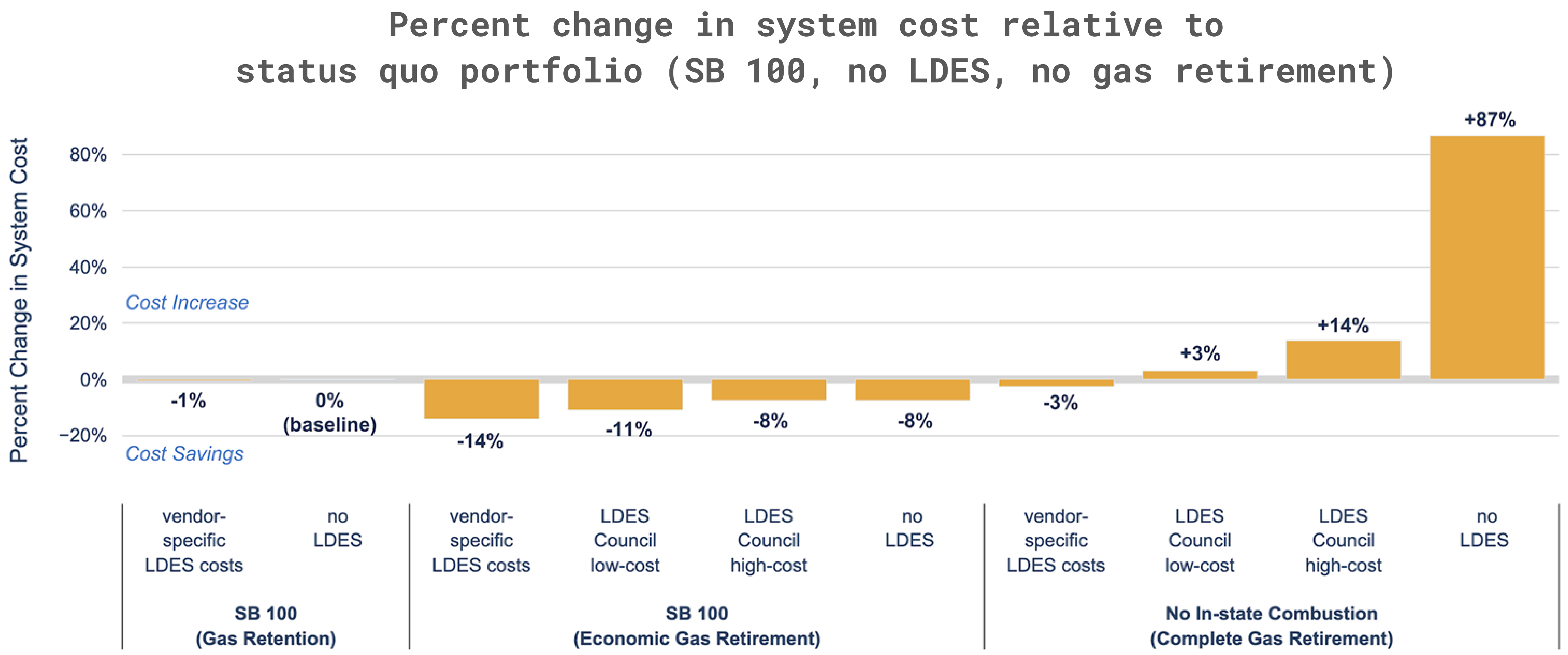
Needs for LDES vary significantly based on policy scenarios

LDES acts as a firm zero carbon resource that supports reliability & integrates renewables

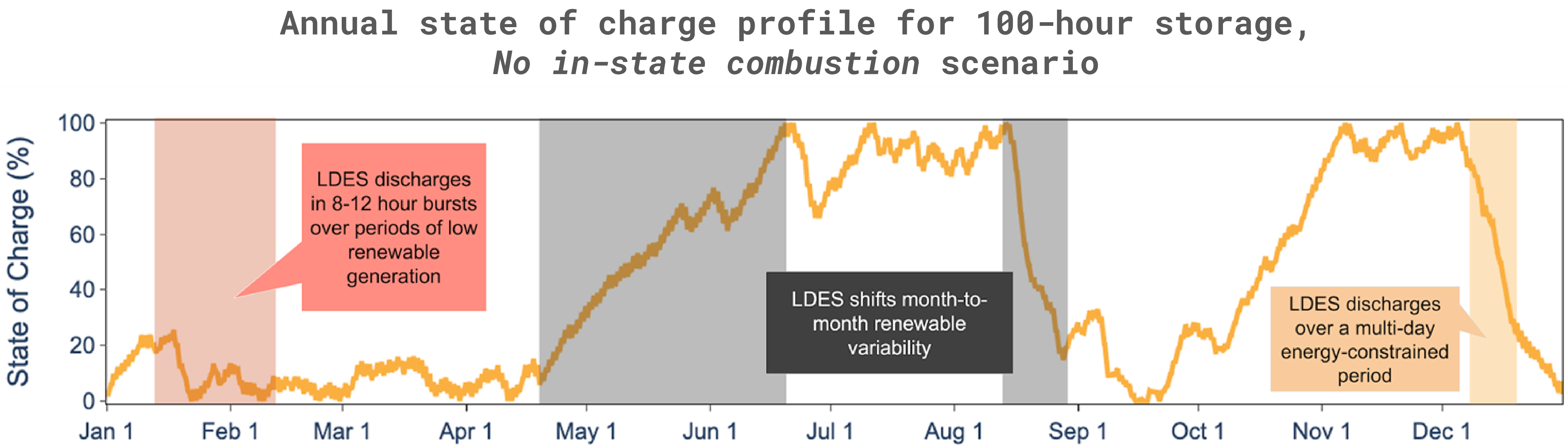


LDES (GW)	2	0	11	18	0	0	21	22	13	0
Natural Gas (GW)	25	25	5	10	14	14	0	0	0	0
Solar + Short-duration Storage (GW)	190	193	185	167	190	190	190	194	203	322

With LDES, true zero carbon portfolios (no combustion resources) can achieve cost savings relative to the status quo



LDES supports system operations during periods of grid stress



Intra-Day

Seasonal Up
(net charge with excess renewables)

Seasonal Down
(net discharge during peak load season)

Multi-Day

Form energy

Thank you!

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