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Filer:	Jeffrey Sunquist
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CEC EPC-19-056
Assessing the Value of Long Duration Energy Storage

Final Public Workshop

May 9, 2023

Form energy

CER Center for Energy Research

Energy+Environmental Economics

Roderick Go, Associate Director, E3
Rachel Wilson, Manager, Form Energy
Kailash Raman, Senior Analyst, Form Energy
Dr. Ryan Hanna, Research Scientist, UCSD

Agenda

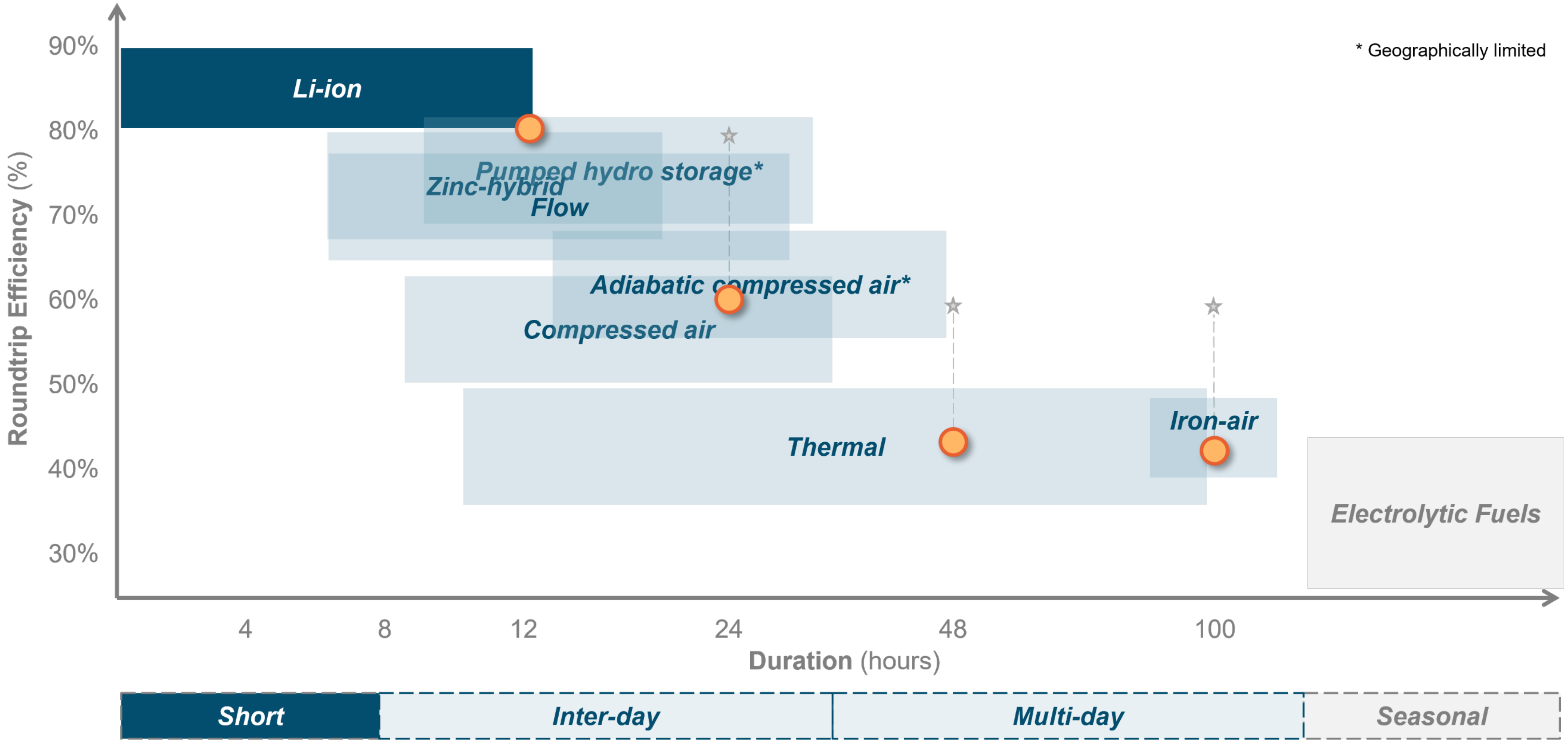
Time	Section
10:00 – 10:20	Project Overview & Key Takeaways
10:20 – 10:50	CAISO System Modeling
10:50 – 11:10	LA Basin Local Capacity Case Study
11:10 – 11:40	UCSD Microgrid Case Study
11:40 - 12:00	Discussion

Why LDES?

- **Historically, fuel storage (e.g., natural gas) has been a cost-effective way of storing energy to maintain system reliability across a range of system conditions**
  - Studies have demonstrated that we could cost-effectively achieve 80%+ decarbonization with existing technologies
  - However, as California moves toward a more decarbonized grid, there is a need to find new technologies to facilitate energy storage to enable cost-effective & reliable decarbonization

- **Recent industry trends:**
  - Recent California LSE procurements have signed contracts for 8-hour Li-ion and some emerging LDES demonstrations
  - Outside of California, utilities have announced LDES plans (e.g., Xcel Energy, Georgia Power, etc.)
  - Other states (New York, Massachusetts) have opened proceedings to study the value of LDES
  - DOE ”Liftoff” report concluded that 225-460 GW of LDES could be deployed US-wide to achieve a net-zero economy by 2060

LDES Archetypes Studied

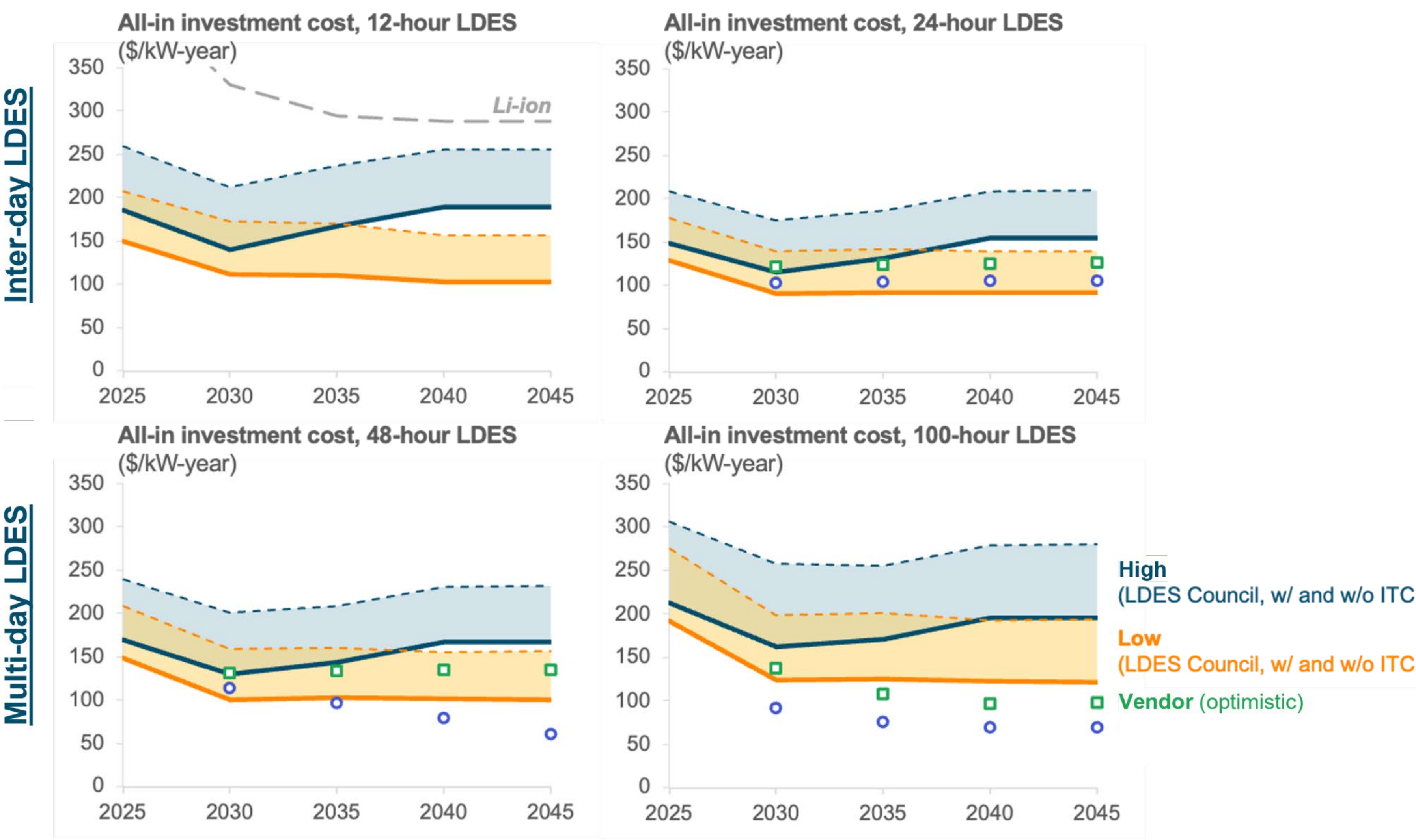


★ Higher RTE sensitivities were tested. Not shown today

LDES Cost Projections

- **Team leveraged survey data from LDES Council**
  - For inter-day storage techs, median energy storage cost* projected to be **$54-67/kWh**
  - For multi-day storage techs, median energy storage cost* projected to be **$8-10/kWh**

- **Team used standard financing assumptions to convert overnight into $/kW-year at archetypal durations shown to right**



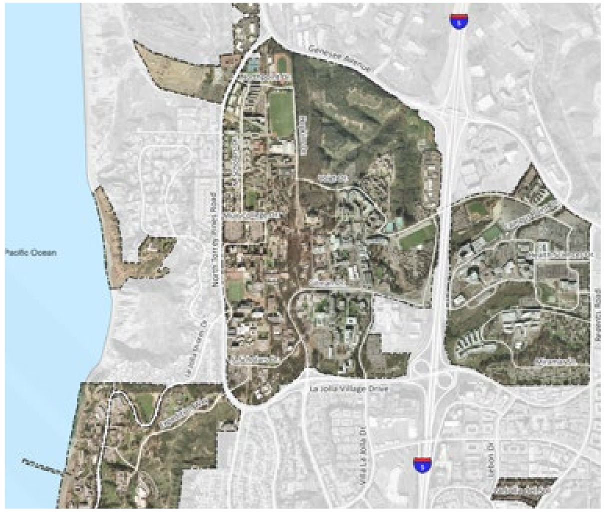
* *Energy storage cost component only, not including power and balance-of-system costs*

Meeting SB 100 & electric sector decarbonization goals

CAISO System

Local capacity and criteria air pollutant reduction benefits

LA Basin Local Capacity



LDES microgrids for institutional settings

UCSD Microgrid

Key Analytical Questions

CAISO System

1. What is the role for LDES under different scenarios of grid decarbonization in California?
2. What is the bulk system value of LDES technologies on the California grid?
3. What cost targets could LDES need to achieve for large-scale deployment?
4. Do different modeling choices result in LDES technologies being selected?

LA Basin Local Capacity

5. Can LDES be used to support local capacity needs, which have not been incorporated into previous CPUC IRP studies?
6. What are the potential criteria pollutant impacts benefits of LDES?

UCSD Microgrid

7. Does LDES help to enable zero-carbon microgrids? When used in microgrids, what roles does LDES play?
8. How do building characteristics and net-zero microgrid policies that prohibit CO_2 and criteria pollutant emissions from microgrids affect the role for LDES?

Key Takeaways

CAISO System

1. Limited role for emerging tech under SB 100 at system level
2. Significant role for LDES under deeper decarbonization scenarios
3. LDES operates throughout the year, providing intra-day through seasonal energy arbitrage
4. LDES can serve much the same role as gas, enabling additional in-state gas retirement
5. LDES supports operations during energy-constrained conditions
6. LDES significantly reduces renewable curtailment in highly renewable grids
7. LDES makes portfolios more robust to inter-annual renewable variability

LA Basin Local Capacity

8. LDES can be operated to meet CAISO local capacity requirements
9. LDES can displace in-basin fossil gas generation and capacity, reducing local air pollution in disadvantaged communities

UCSD Microgrid

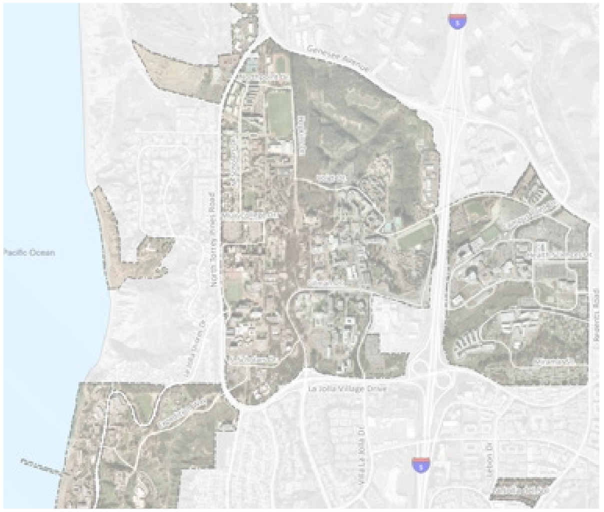
10. LDES can support high-reliability microgrid configurations
11. LDES has operational value through peak demand shaving
12. In most cases, LDES is not economic, due to cheap natural gas; the UCSD campus microgrid is already highly optimized, limiting the value of LDES
13. Falling DER costs help LDES but don't eclipse the case for gas
14. Policies that restrict emissions have a big effect, increasing costs of using gas generation and improving the *relative* economics of LDES

Meeting SB 100 & electric sector decarbonization goals

CAISO System

Local capacity and criteria air pollutant reduction benefits

LA Basin Local Capacity



LDES microgrids for institutional settings

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Modeling Framework & Scenarios Studied

- **Team used Resolve, Recap, and Formware models to study CAISO portfolio value**
- **Using Resolve, we developed 2030-2045 LDES cost targets**
  - Cost targets represent **bulk system value** of LDES additions (which displace other CAISO resources, such as gas, Li-ion)
- **Using Formware, we studied additional least-cost portfolios in 2045 under wider range of weather years & grid stress events**

	SB 100 Policy	0 MMT Policy
Base Policy	SB 100 31 MMT by 2030 12 MMT by 2045 Existing gas & unspecified imports allowed	SB 100 **24 MMT** by 2030 **0 MMT** by 2045 No in-state gas or unspecified imports in 2045
AB 525 Require 20 GW of offshore wind (OSW) by 2045.	✓	
High electrification & load flexibility Enable load flexibility as a candidate resources	✓	
Gas retirement Retire existing CA gas generation fleet in 2045	✓	✓
Emerging clean firm generation alternatives Enable adv. geothermal, CCS, and adv. nuclear as candidate resource options		✓

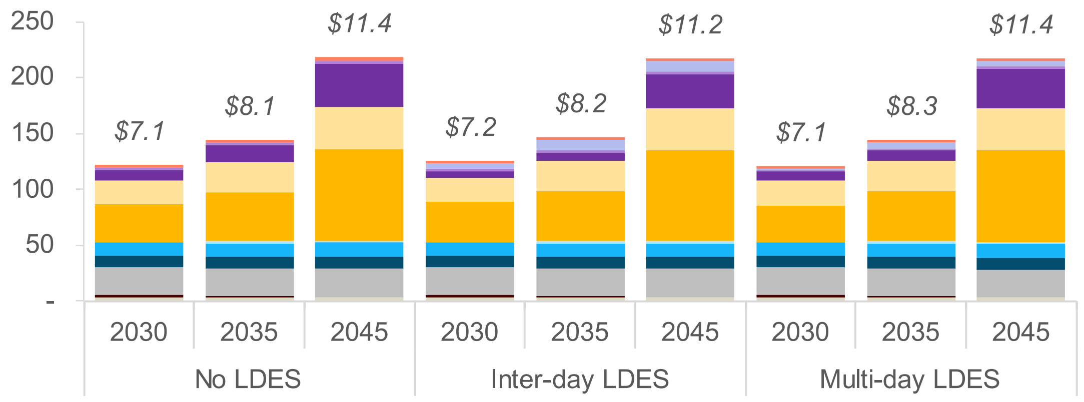
1. Under SB 100, California could see 5 GW LDES market by 2045

+ **Limited value differentiation between inter-day and multi-day LDES under SB 100**
  - Inter-day LDES archetypes tend to be slightly more cost-effective due to higher energy arbitrage value
  - Higher reliability contribution of multi-day LDES not as valuable if in-state gas capacity is retained

+ **Sensitivities:**
  - **AB 525:** Inter-day LDES value suppressed due to significant offshore wind deployment
  - ***Flexible loads*** *(not shown)****:*** *Flexible residential & commercial loads have no significant impact on LDES due to limited flexibility, up to 6 hours*

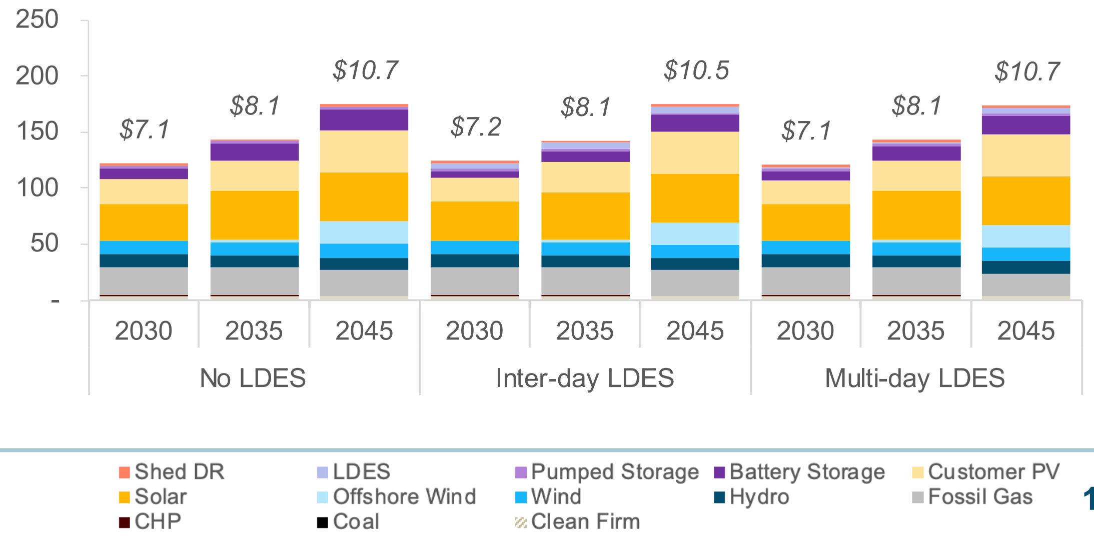
SB 100 Policy

Portfolio Capacity (GW) & Optimized Costs ($ billion/year)



SB 100, AB 525 Sensitivity

Portfolio Capacity (GW) & Optimized Costs ($ billion/year)



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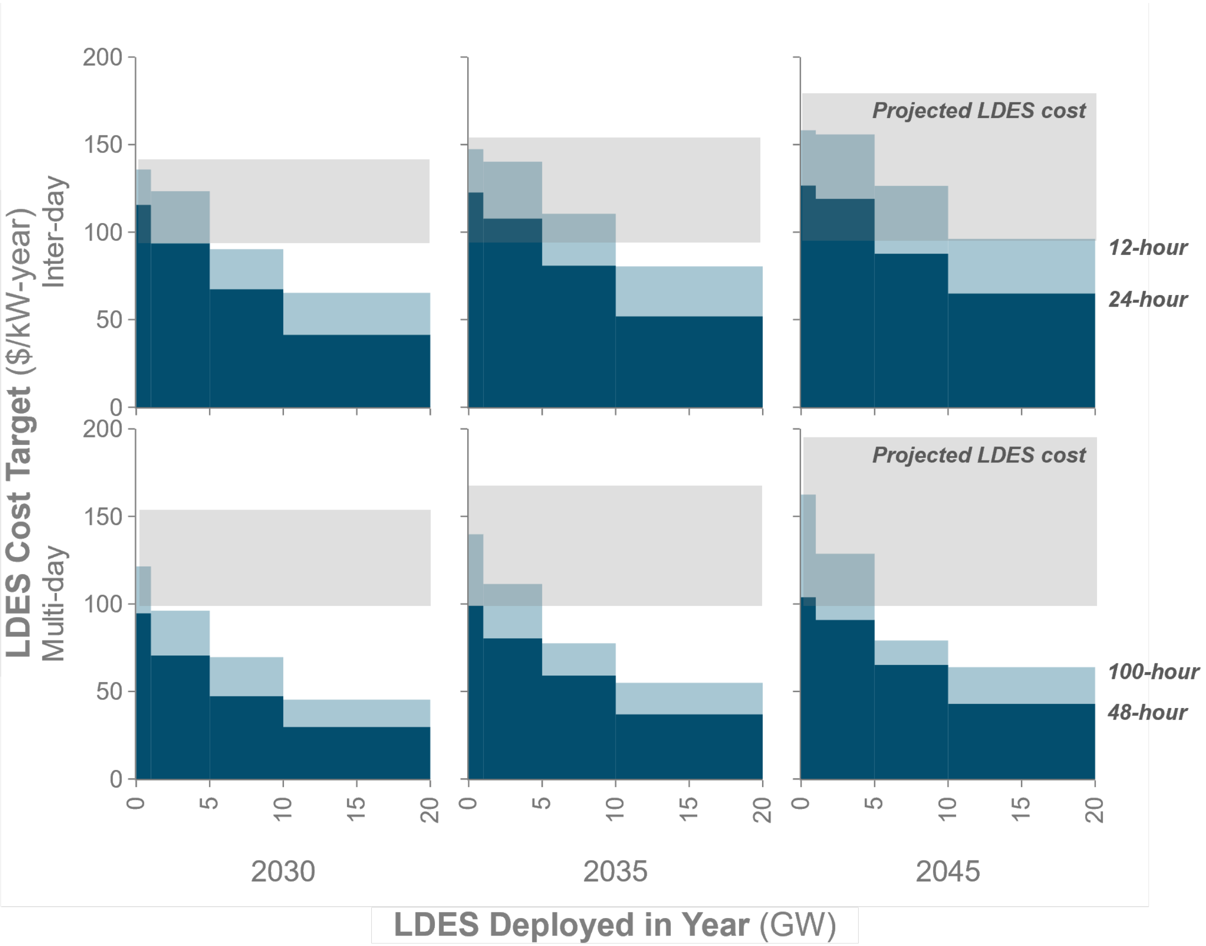
1. Under SB 100, California could see 5 GW LDES market by 2045

- **Inter-day LDES needs to target costs of $120-150/kW-year by 2045 to achieve 5 GW deployment**
- **Multi-day LDES needs to target costs of $90-125/kW-year by 2045 to achieve 5 GW deployment**
- **Greater LDES adoption could require cost reductions**
  - Further cost reductions of 23-37% by 2045 needed to double LDES market size (to 10 GW)

LDES Cost Targets under SB 100 Policy



2. Larger role for LDES & emerging tech to achieve a 0 MMT grid

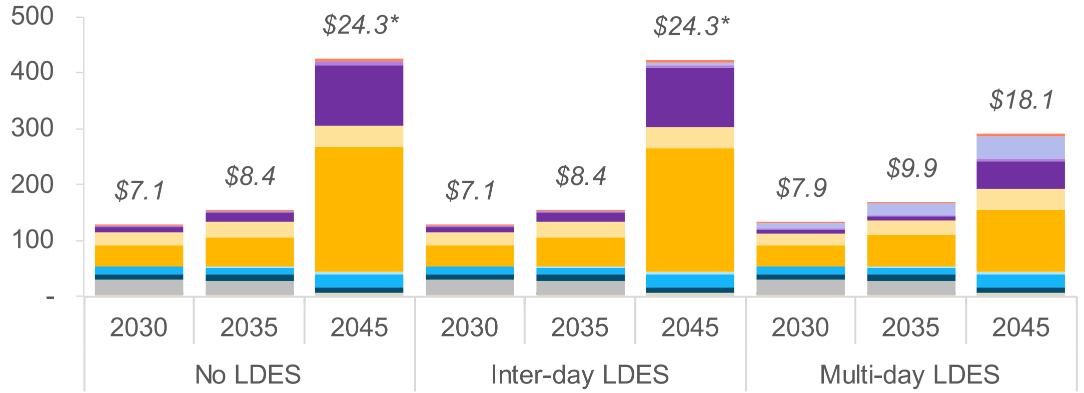
+ **Achieving 0 MMT without emerging technologies is extremely expensive & would require solar PV land-use**
  - Existing in-state gas must be replaced with clean resources while maintaining reliability

+ **Nearly 40 GW of multi-day LDES could be deployed to make 0 MMT more achievable**
  - Reduces the need for solar + storage investment by over **150 GW**

+ **Sensitivities:**
  - **CCS & advanced nuclear:** Role for LDES is smaller but still significant if CCS & advanced nuclear can achieve substantial cost declines

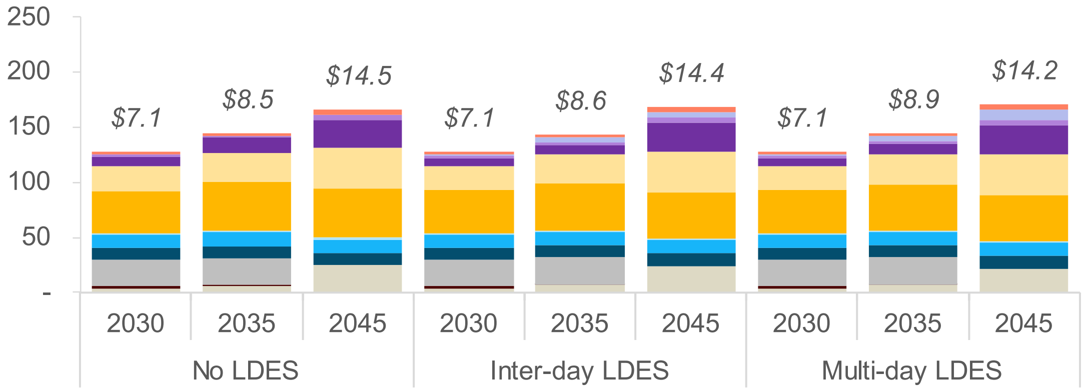
0 MMT Policy

Portfolio Capacity (GW) & Optimized Costs ($ billion/year)



0 MMT Policy, CCS & Advanced Nuclear Sensitivity**

Portfolio Capacity (GW) & Optimized Costs ($ billion/year)



* Optimized costs don't include transmission upgrade costs

** CCS & advanced nuclear cost projections are highly uncertain, E3 only modeled a low-cost sensitivity

Shed DR, LDES, Pumped Storage, Battery Storage, Customer PV, Solar, Offshore Wind, Wind, Hydro, Fossil Gas, CHP, Coal, Clean Firm

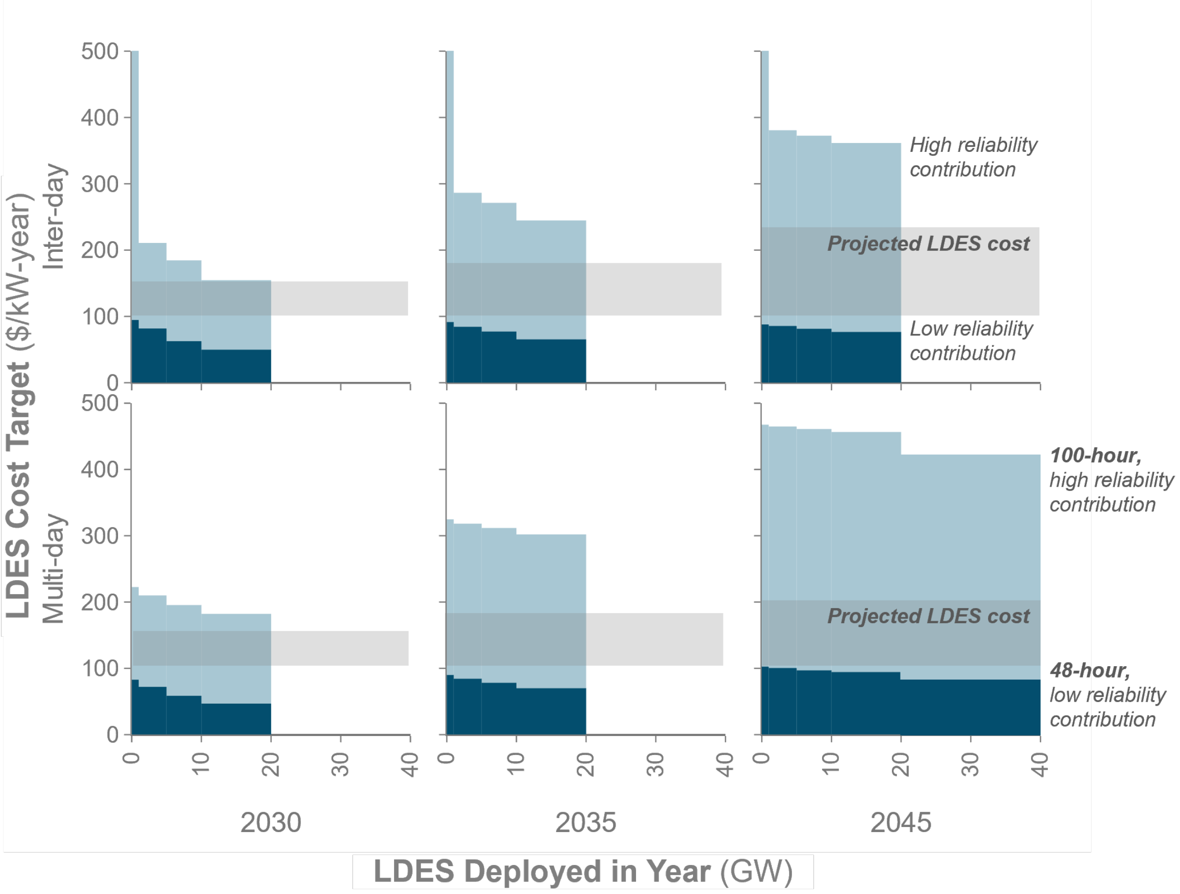
2. Larger role for LDES & emerging tech to achieve a 0 MMT grid

+ **Cost targets are much higher in 0 MMT due to need for in-state clean firm resources, with greater uncertainty on portfolio reliability interactions**

+ **Inter-day LDES targeting below $380/kW-year could see 5 GW of deployment by 2045**
  - Further cost reductions of 5% could increase deployment to 20 GW

+ **Multi-day LDES targeting below $450/kW-year could see 5 GW of deployment by 2045**
  - Further cost reductions of 2% could increase deployment to 20 GW
  - 100-hour LDES archetype provides significant reliability value and is cost-effective through 40 GW of deployment

LDES Cost Targets under 0 MMT Policy

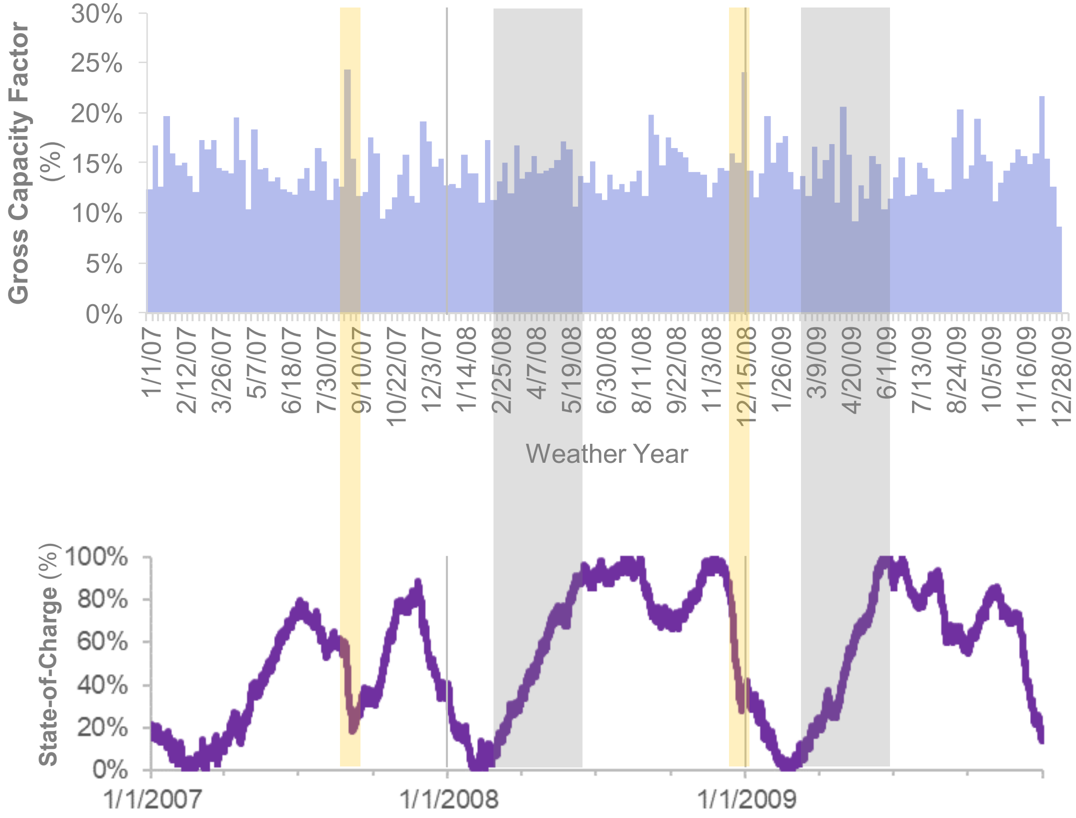


3. LDES operates throughout the year

+ **Both inter-day & multi-day LDES operate throughout the year**
  - On "typical" weeks, LDES cycles largely diurnally
  - Ahead of energy-constrained conditions (e.g., summer, winter), LDES ***charges over longer periods*** with excess renewables
  - During energy-constrained conditions, LDES ***discharges across multiple days***

+ **In the 0 MMT policy scenario, LDES operates at 8-24% discharge capacity factor (equivalent to 7 – 21 cycles per year)**

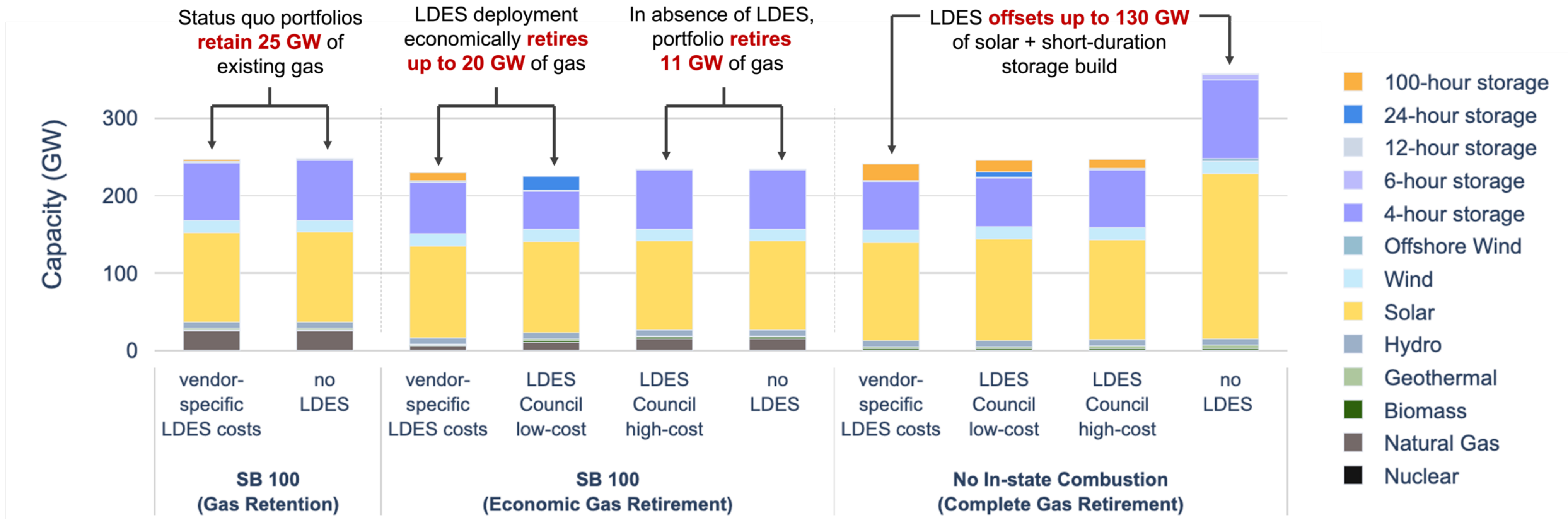
Example Multi-day LDES Operations
(0 MMT Policy, 2045, 40 GW)



4. LDES can enable cost effective in-state gas retirement

+ LDES can support retirement of existing CAISO gas generation capacity

- Least-cost portfolios optimized to meet CAISO demand in all 8760 hours across 8 weather years (using weather-correlated load and renewable data)
- Modeled scenarios include retention, economic retirement, and complete retirement of existing in-state gas generation capacity

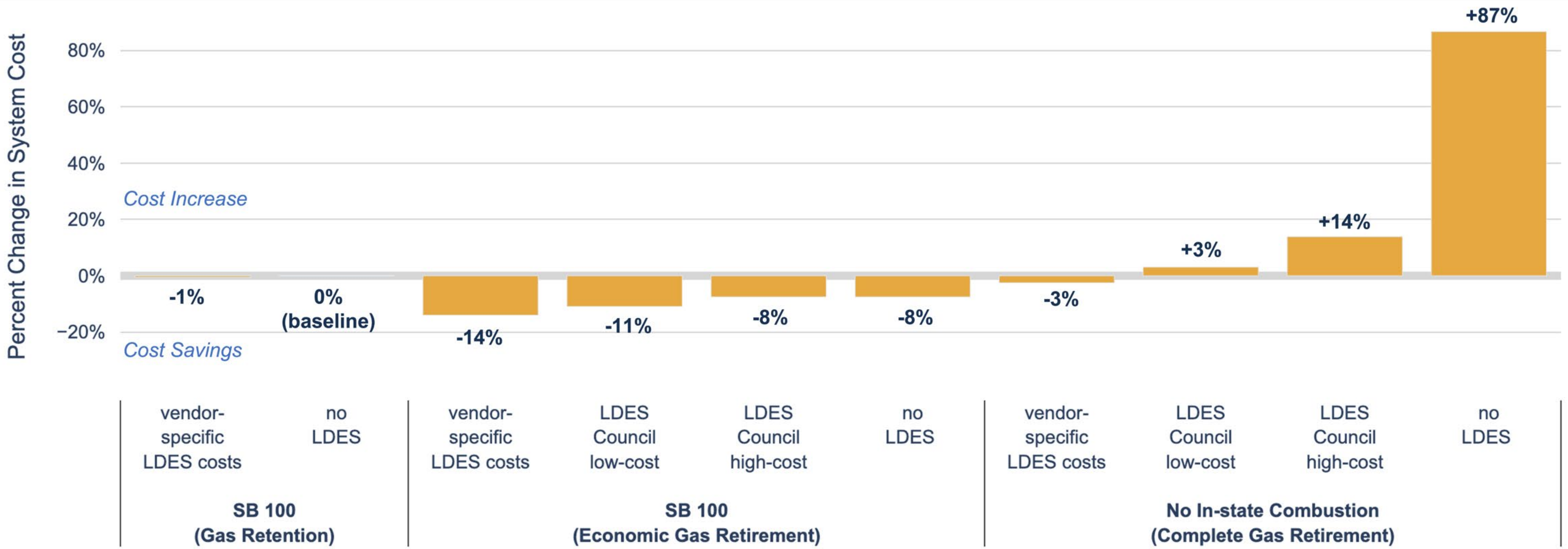


LDES (GW)	2	0	11	18	0	0	21	22	13	0
Natural Gas (GW)	25	25	5	10	14	14	0	0	0	0
Solar + Short-duration Storage (GW)	190	193	185	167	190	190	190	194	203	322

4. LDES can enable cost effective in-state gas retirement

+ **LDES portfolios that retire gas capacity can potentially achieve cost savings relative to portfolios that retain all existing gas capacity**
  - Gas retirement with LDES avoids operational costs required to keep gas generation online
  - In the complete gas retirement scenario, portfolio costs increase significantly without LDES due to overbuild of solar and short-duration storage

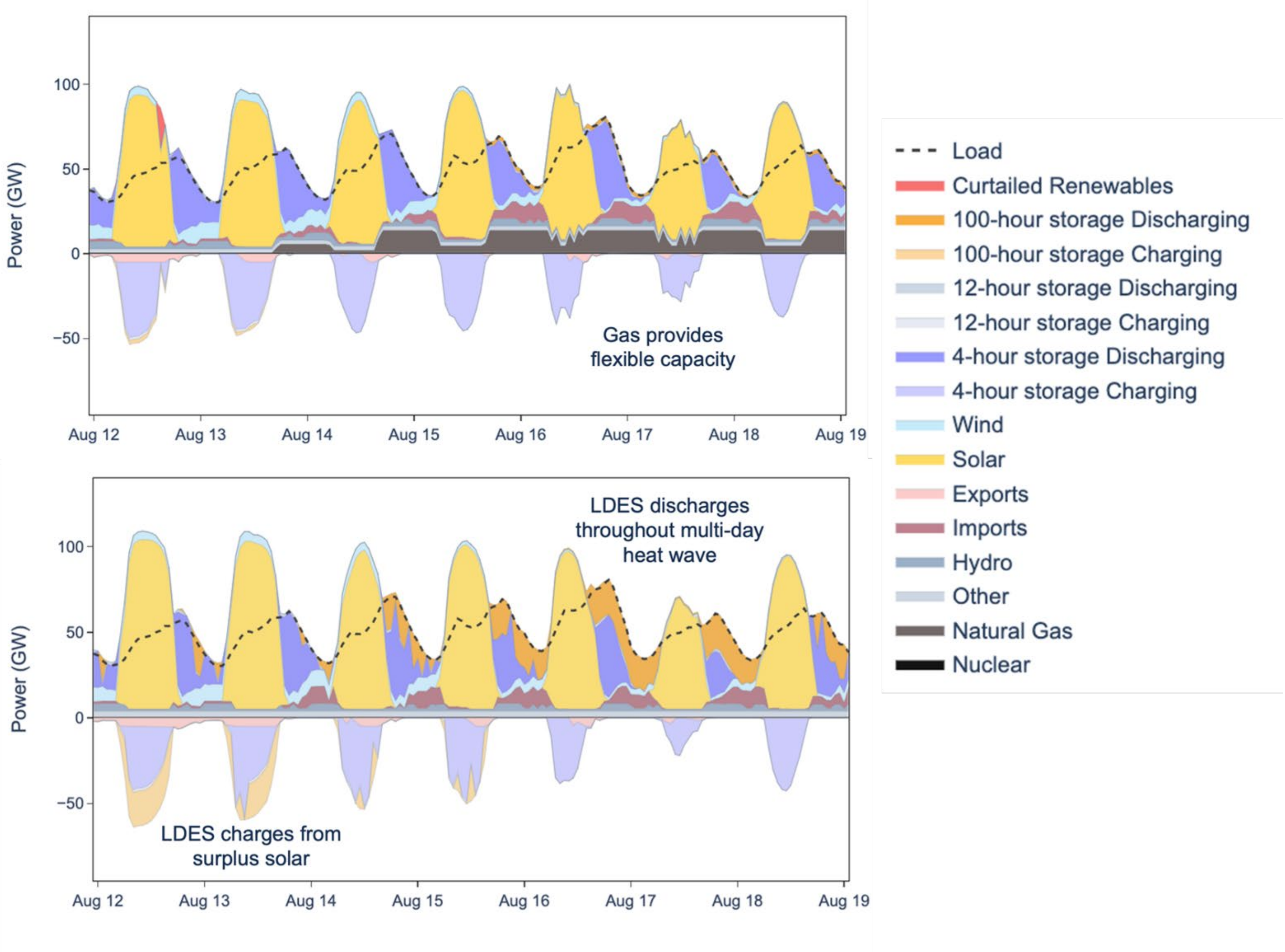
Percent change in system cost relative to status quo portfolio (SB 100, no LDES, no gas retirement)



4. LDES can enable cost effective in-state gas retirement

- **LDES maintains reliability during extreme weather conditions in absence of in-state gas generation**
  - Optimal least-cost portfolios with and without in-state gas generation were dispatched under 2020 heat wave conditions
  - Simulation illustrates that LDES can hold a high state of charge prior to a grid stress event, and discharge continuously over a multi-day period to maintain reliability
  - Similar behavior observed during renewable lull periods
- **LDES provides flexible capacity, like existing thermal resources, during extreme grid stress events**

Dispatch of 2045 portfolios with gas (top) and without gas (bottom) during 2020 CAISO heat wave conditions

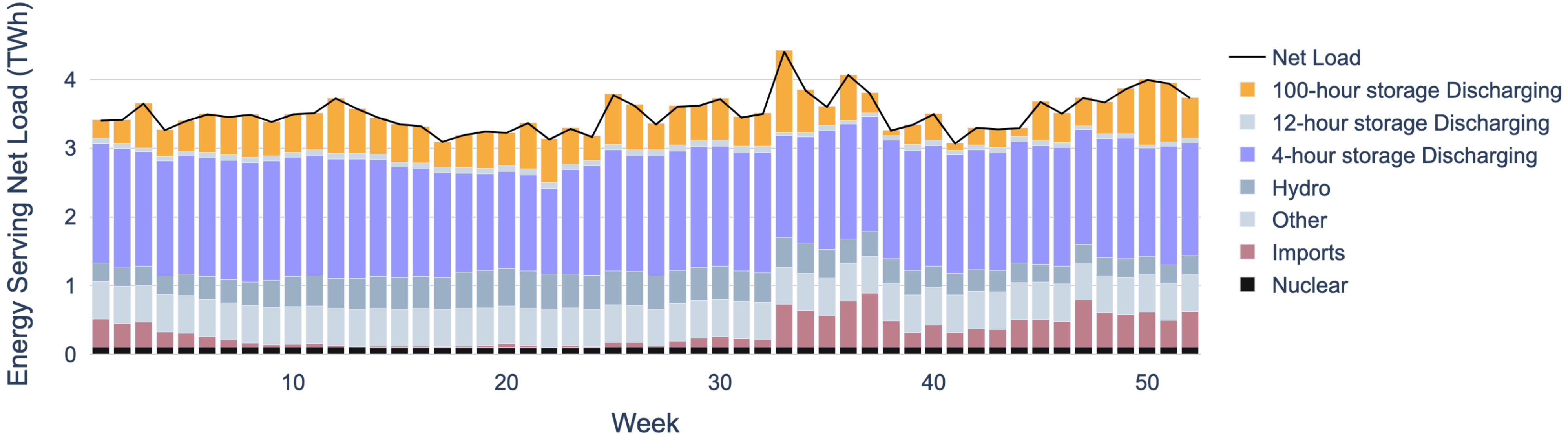


5. LDES can support system operations during grid stress

+ LDES maintains year-round reliability in the absence of in-state gas generation

- Periods of grid stress can occur year-round when renewable generation is insufficient to meet demand
  - In a no-combustion case, net load (demand that is unmet by solar and wind) is served by storage, hydro, imports, and other resources
- 62 GW of 4-hour storage serve 47% of annual net load, primarily through diurnal energy shifting of solar
- 21 GW of LDES serve 15% of annual net load, delivering energy to balance load during multi-day shortfalls in renewable generation

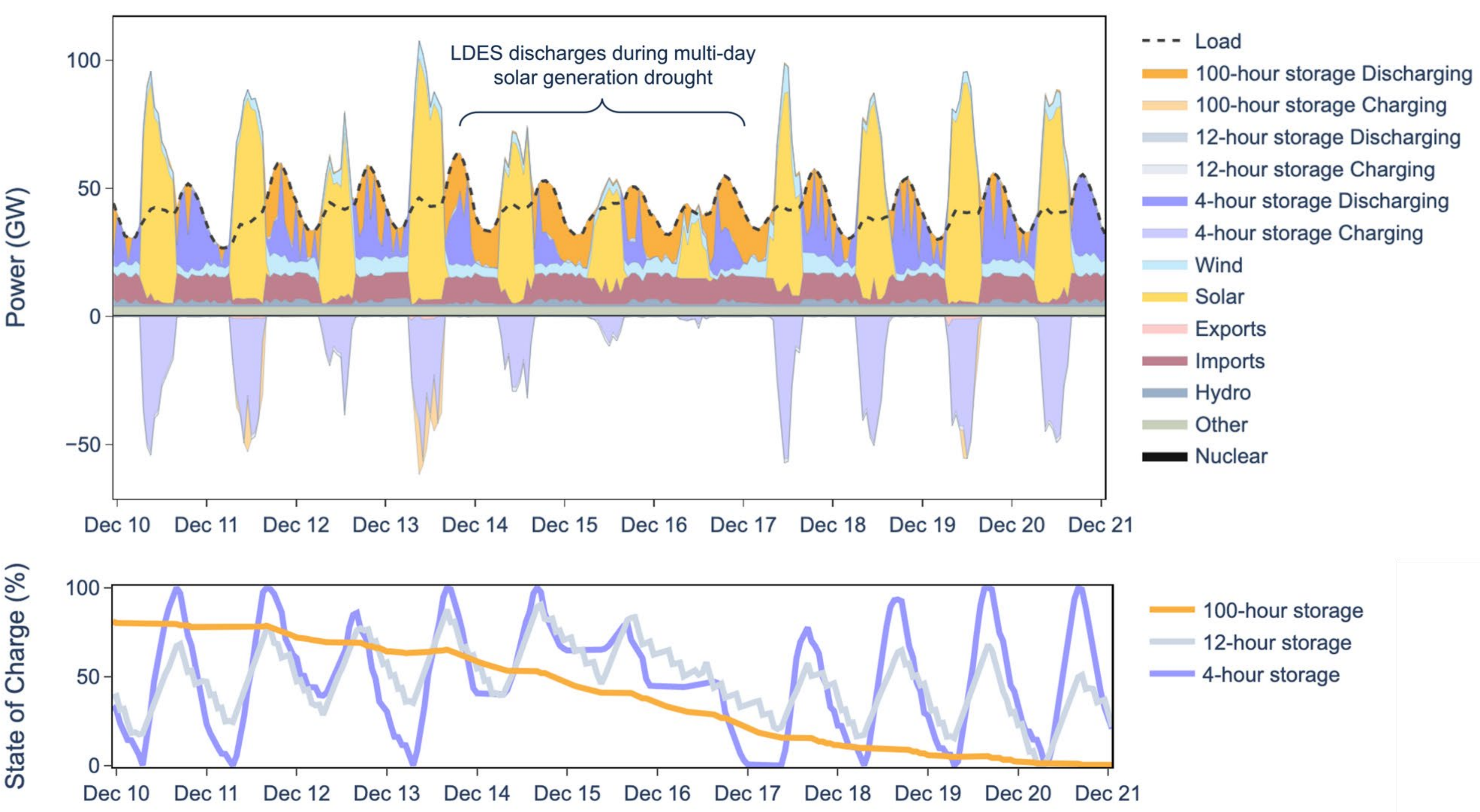
Weekly energy dispatched to serve net load,
***No in-state combustion* scenario**



5. LDES can support system operations during grid stress

- **LDES holds stored energy prior to solar lull event (~80% state of charge)**
  - Stored energy provides a hedge against imperfect foresight risk
- **Continuous discharge of energy from LDES maintains reliability throughout late afternoon and nighttime hours**
- **LDES does not recharge during solar-limited week, saving energy for 4-hour storage to recharge and provide peaking capacity**

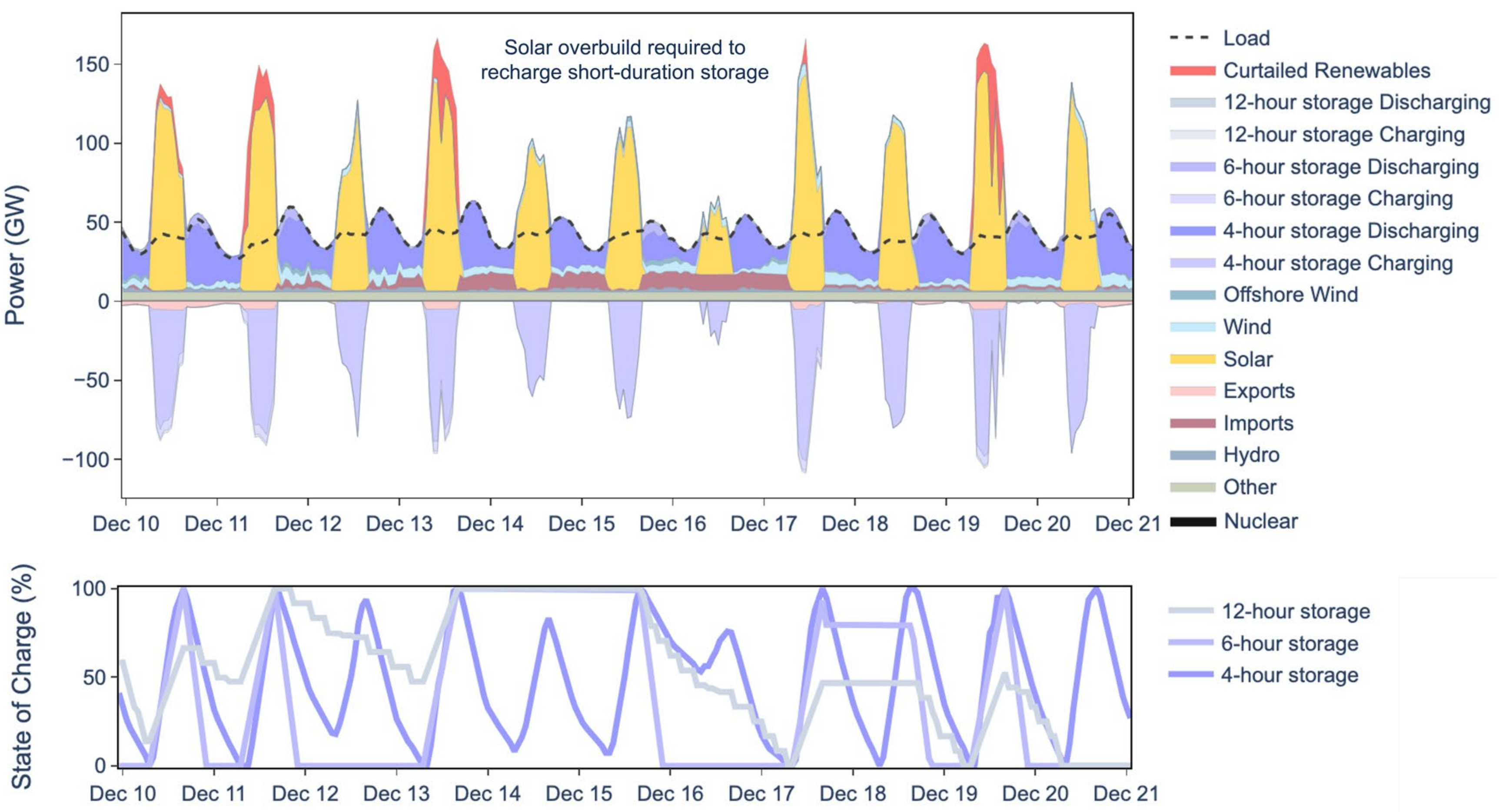
Winter Renewable Lull, *No in-state combustion* scenario with LDES



5. LDES can support system operations during grid stress

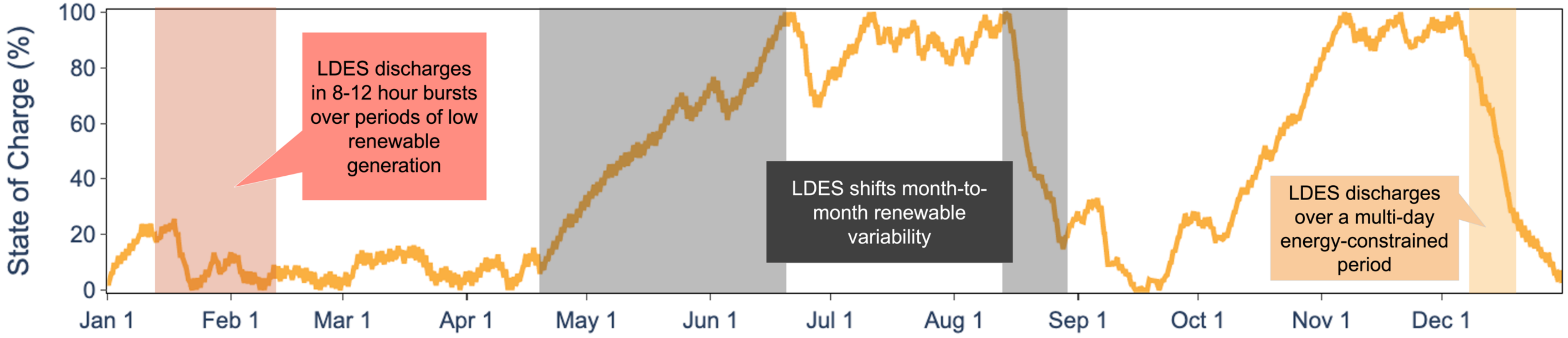
Winter Renewable Lull, *No in-state combustion* scenario without LDES

- **In absence of LDES, the no in-state combustion portfolio includes additional 90 GW of solar overbuild to meet demand during energy-constrained periods such as lulls**
- **At end of each day, 4-hour and 6-hour storage is completely depleted**
  - Without LDES or gas capacity, system has less backup energy that can be delivered during an unforeseen grid stress event



5. LDES can support system operations during grid stress

Annual state of charge profile for 100-hour storage,
***No in-state combustion* scenario**



Intra-Day

Seasonal Up
(net charge with excess renewables)

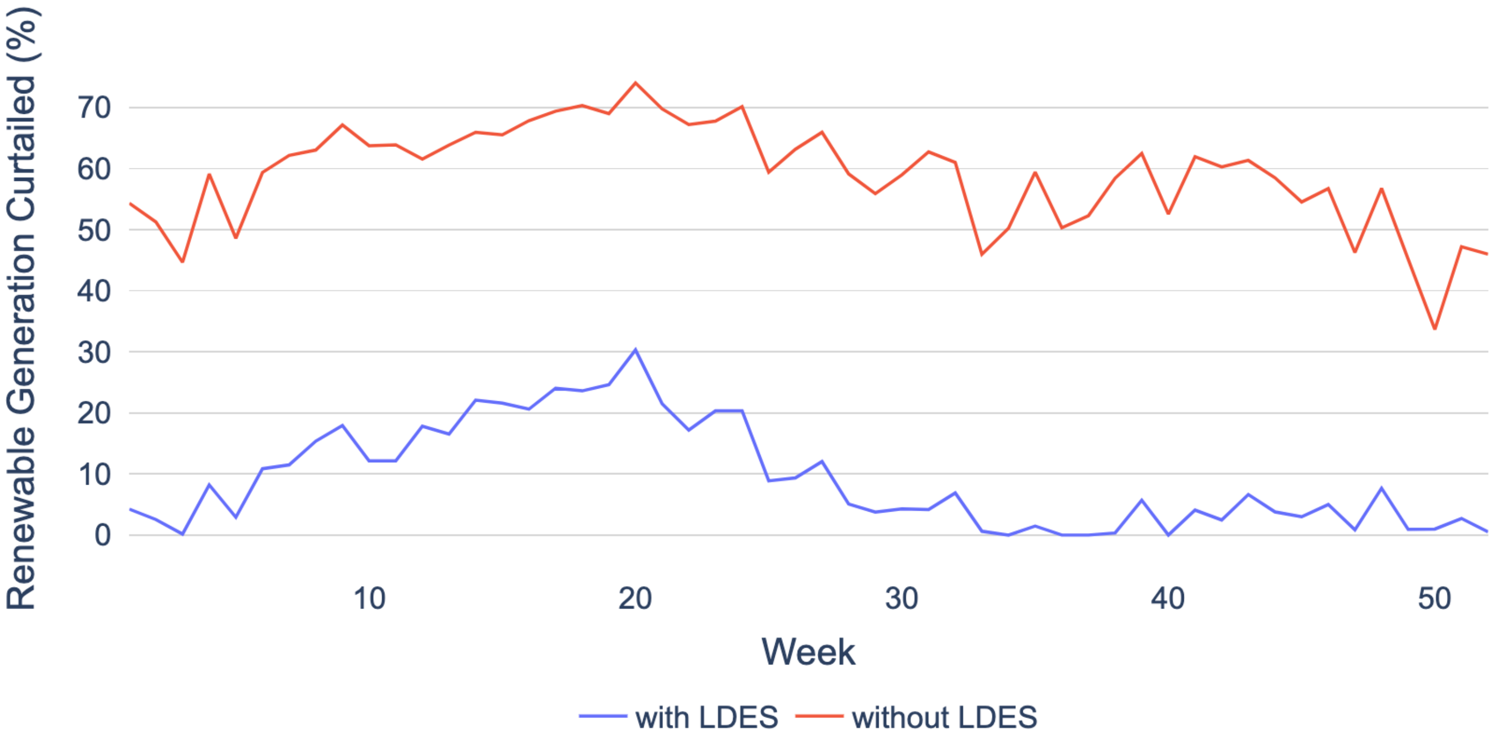
Seasonal Down
(net discharge during peak load season)

Multi-Day

6. LDES reduces renewable curtailment

+ **In portfolios which retire in-state combustion resources, LDES reduces total annual curtailed energy by 94%**
+ **Reduction of curtailment in LDES portfolios is driven by reduced renewable build and greater energy capacity**
  - LDES reduces solar overbuild by 90 GW in no-combustion portfolios, resulting in less overgeneration
  - LDES can charge continuously over consecutive days to fully absorb surplus generation during high renewable weeks

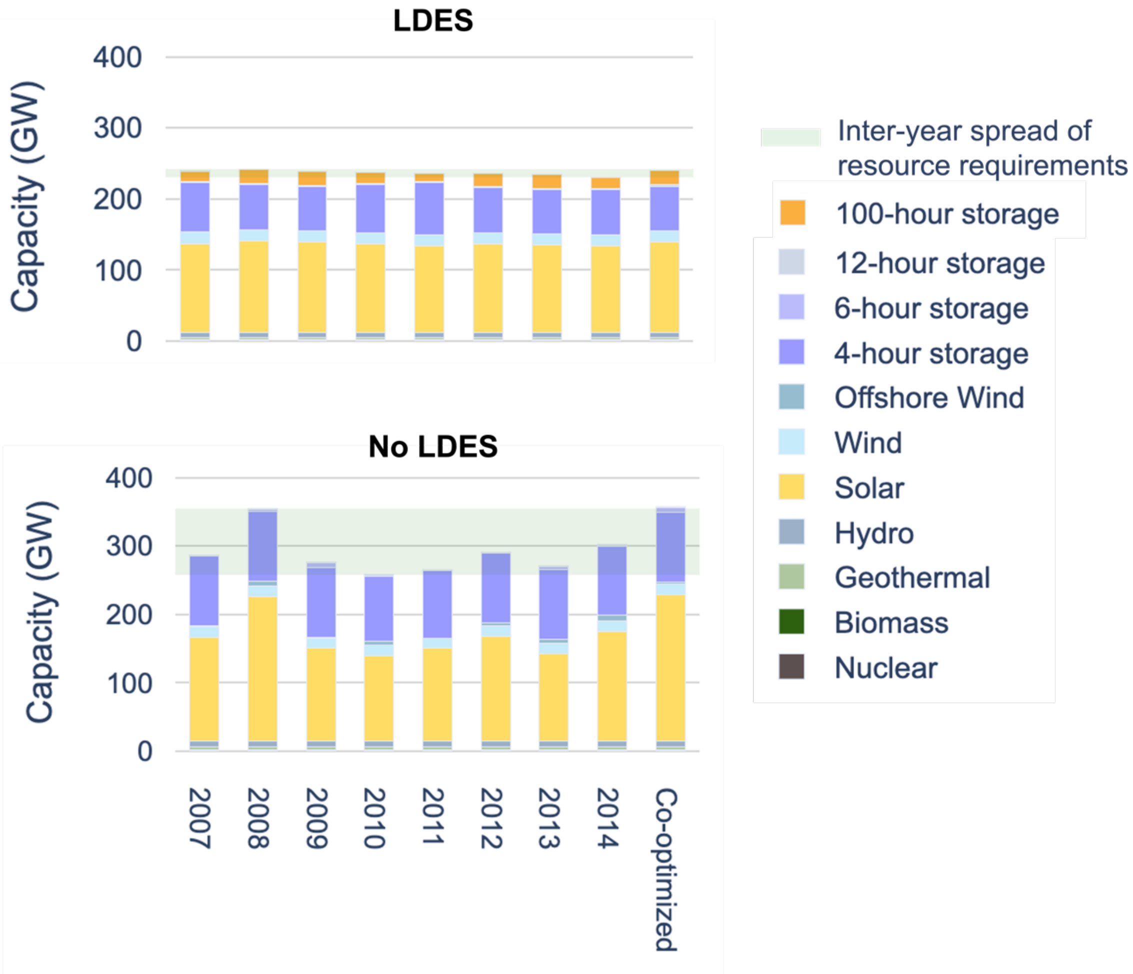
Renewable curtailment by week, *No in-state combustion* scenario



7. LDES makes portfolios more robust to weather uncertainty

+ **LDES maintains system reliability and reduces resource overbuild in the face of inter-year weather variability**
  - Least-cost portfolio optimization was performed on eight individual weather years, and co-optimized across all eight years
  - LDES deployment improves reliability in the face of varying weather patterns, allowing resource requirements to remain nearly constant across many weather years
  - Co-optimized portfolio with LDES avoids more than 100 GW of resources (29% of installed capacity) relative to portfolio without LDES
+ **In the absence of LDES, resource portfolios are highly sensitive to weather-driven variation in load and renewables**

Least-cost 2045 portfolios across weather years, *No in-state combustion* scenario



Key Takeaways

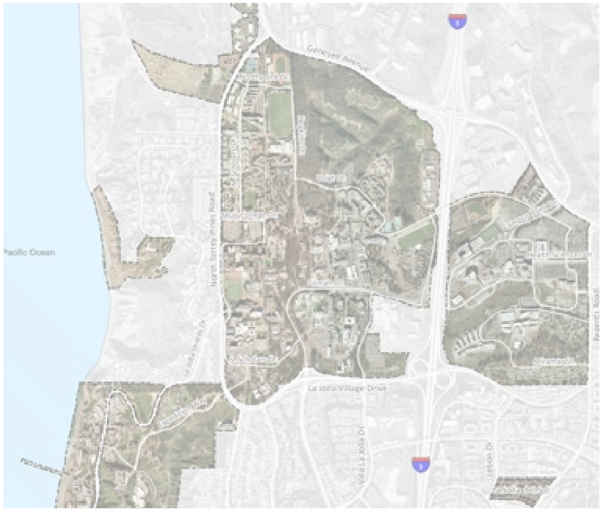
- **The type of LDES deployed depends largely on which technologies achieve commercialization & projected cost declines**
  - Without considering locational value, this study shows varying bulk system need for emerging techs like LDES under SB 100 (0 GW under high costs, 18 GW under low costs)
  - LDES could make gas retirement economic and reliable under SB 100 policy
  - LDES could make more aggressive policy scenarios (e.g., 0 MMT, in-state gas retirement) significantly more cost-effective
  - Additionally, this study estimates cost targets for inter-day & multi-day LDES that would achieve greater deployment levels
- **LDES supports reliable operations across a variety of system conditions, including adverse weather and other energy-constrained periods, enabling more cost-effective retirement of in-state gas capacity**
- **LDES makes the system more robust to a variety of weather conditions, including inter-annual renewable variability**

Meeting SB 100 & electric sector decarbonization goals

CAISO System

Local capacity and criteria air pollutant reduction benefits

LA Basin Local Capacity



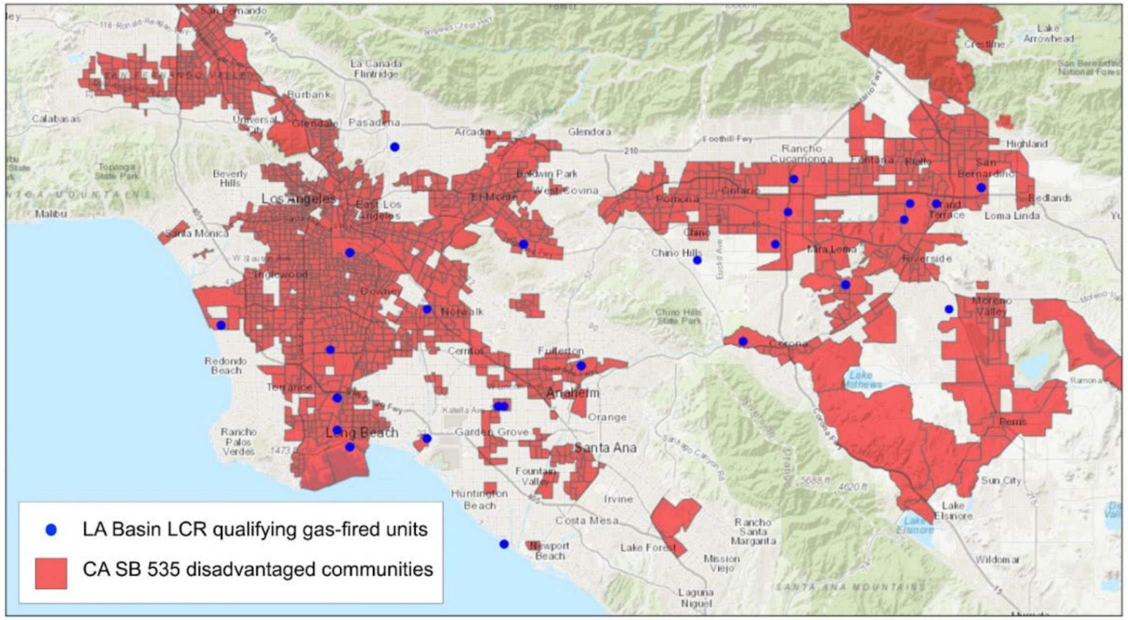
LDES microgrids for institutional settings

UCSD Microgrid

Modeling Framework & Scenarios Studied

+ **Evaluated the role of LDES in meeting 2030 local reliability needs within the LA Basin**
  - Modeled transmission-constrained operations within LA Basin across 8760 hours, while enforcing local capacity requirement
  - Data inputs and assumptions consistent with the 2027 CAISO LCR Technical Study
+ **Modeled retirement of gas plants in disadvantaged communities**
  - LA Basin LCR area contains 6.4 GW of local gas capacity, of which 3.4 GW are sited in disadvantaged communities (DAC)
  - Determined least-cost mix of storage resources required to maintain local reliability in absence of DAC gas units

Siting of gas-fired generators in LA Basin LCR area, overlaid with SB 535-defined Disadvantaged Communities



8. LDES can help meet CAISO local capacity requirements

+ LDES maintains reliability in LA Basin in absence of DAC gas

- Without retirement of DAC gas, LA Basin's planned resources are sufficient to meet LCR
- When DAC gas units are retired, least-cost portfolio optimization builds 2,000 MW of LDES and 1,340 MW of 4-hour storage
- LDES and 4-hour storage deliver energy to LA Basin that otherwise would have been generated by DAC gas units

+ LDES satisfies LCR requirements at cost parity to the status quo

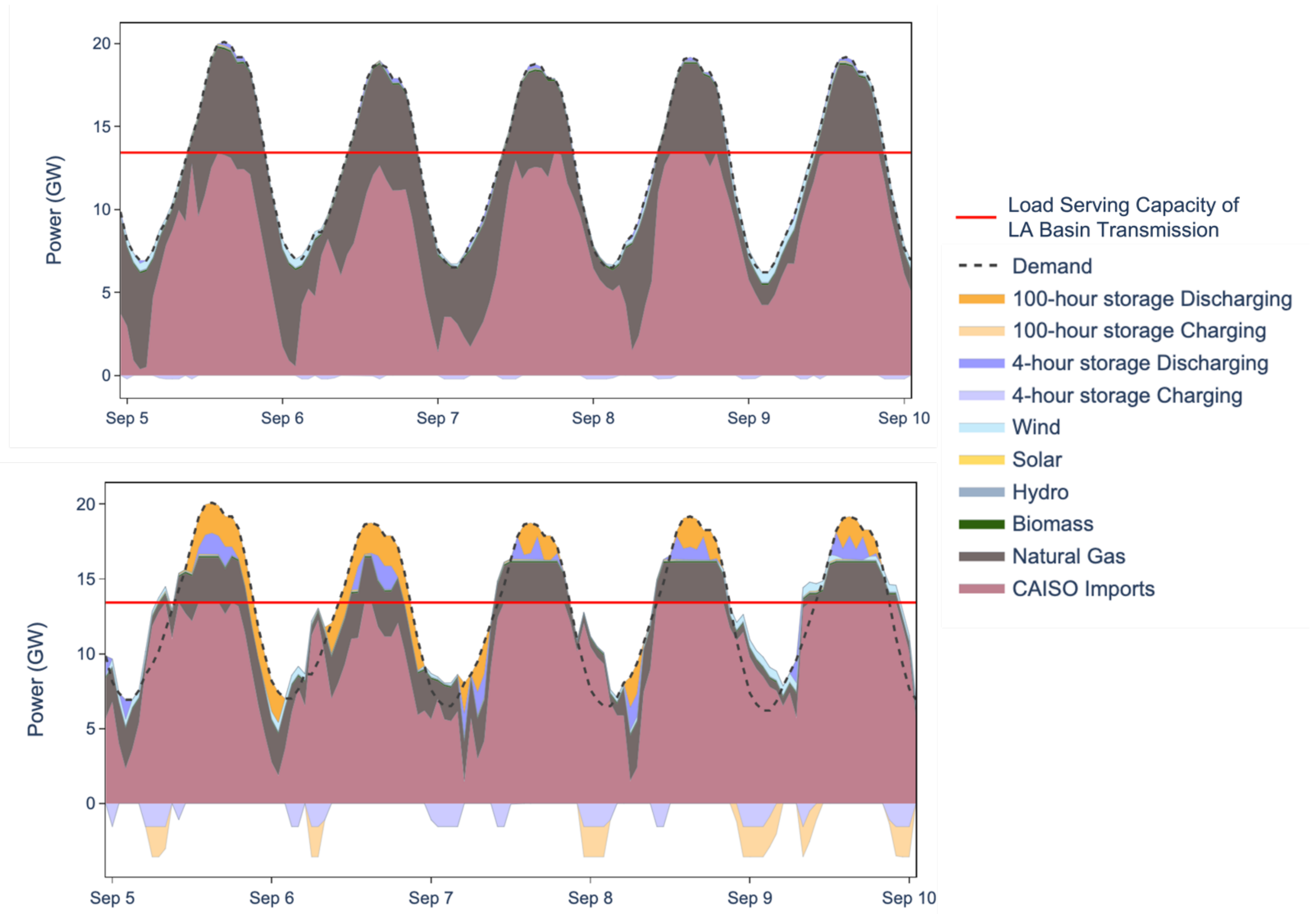
- Replacement of DAC gas-fired units with LDES and lithium-ion technologies results in annual system cost savings of 3% relative to retaining existing gas

LA Basin 2030 local reliability portfolio dispatch, with and without retirement of gas capacity in DAC areas

8. LDES can help meet CAISO local capacity requirements

+ **LDES provides flexible capacity to LA Basin during transmission-constrained periods**
  - Local flexible capacity maintains reliability when LA Basin load exceeds load serving capacity of transmission connections to the CAISO bulk system
  - LDES continuously discharges stored energy reserves for 7-14 hours on peak demand days, while short-duration storage delivers peaking capacity for 4-6 hours

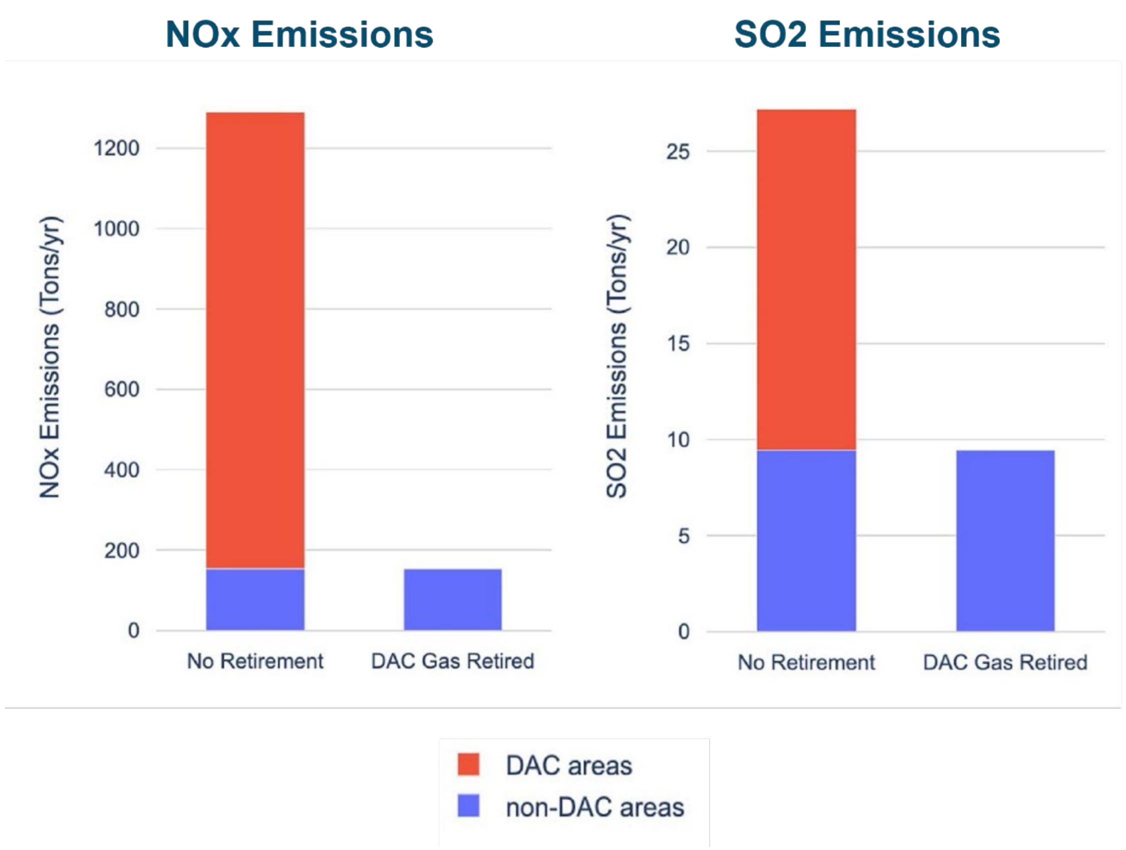
LA Basin 2030 resource dispatch during peak demand week, with DAC gas (top) and without DAC gas (bottom)



9. LDES can reduce local air pollution

+ **Criteria pollutant emissions from LA Basin's gas generation occur disproportionately in disadvantaged communities**
  - These pollutants are linked to chronic respiratory illness in local communities
  - Emissions estimates based on simulated dispatch and historical plant-level emissions data from EPA
+ **Replacement of DAC gas with LDES and short-duration storage reduces pollution burden in the LA Basin**
  - LA Basin's power sector NOx emissions reduced by 88% and sulfur dioxide emissions reduced by 65%

Local air pollution reductions



Key Takeaways

+ **Bulk system analysis does not include transmission constraints; inclusion of those constraints demonstrates that there are pockets within CAISO in which LDES has increased value**
+ **LDES and short-duration storage can economically support the retirement of DAC gas units, while meeting local reliability requirements**
    - Portfolios which replace DAC gas with storage resources can potentially achieve cost parity with existing portfolios which retain gas
    - Storage deployment can eliminate criteria pollutant emissions from the power sector in disadvantaged communities
+ **Future studies should further investigate the reliability implications of LDES deployment and gas retirement within LCR areas**

Meeting SB 100 & electric sector decarbonization goals

CAISO System

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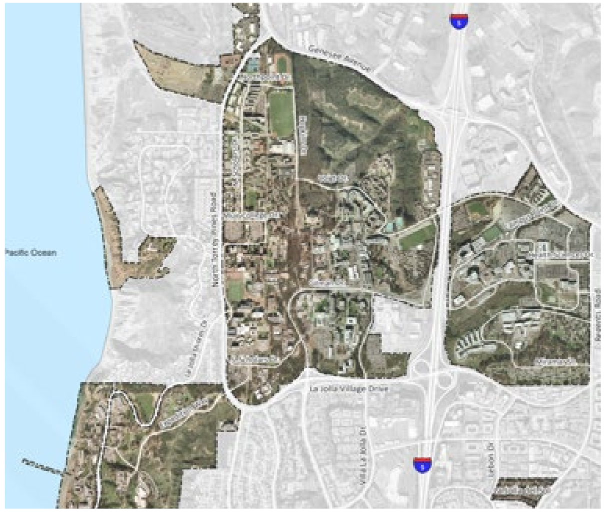
LA Basin Local Capacity



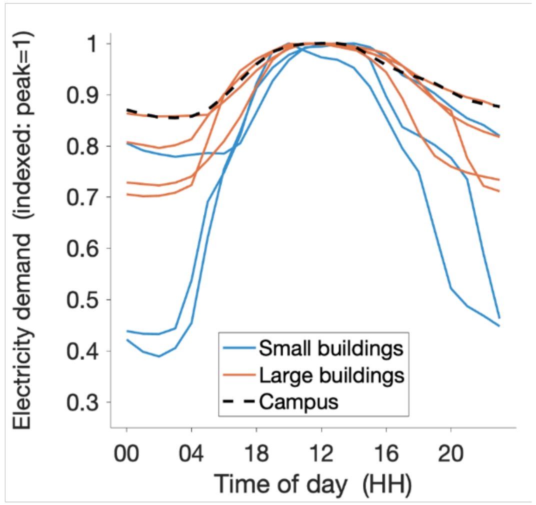
LDES microgrids for institutional settings

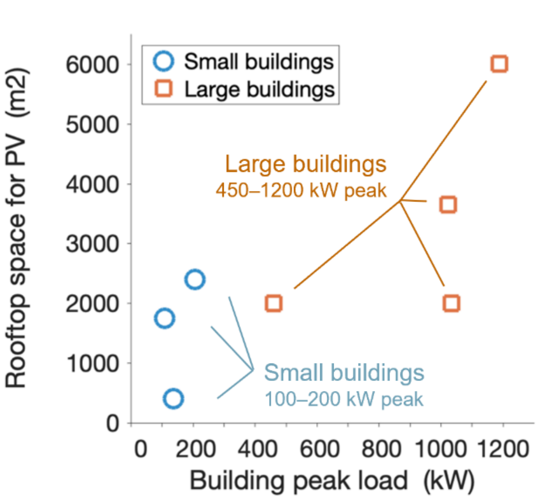
UCSD Microgrid

Scenarios Analyzed

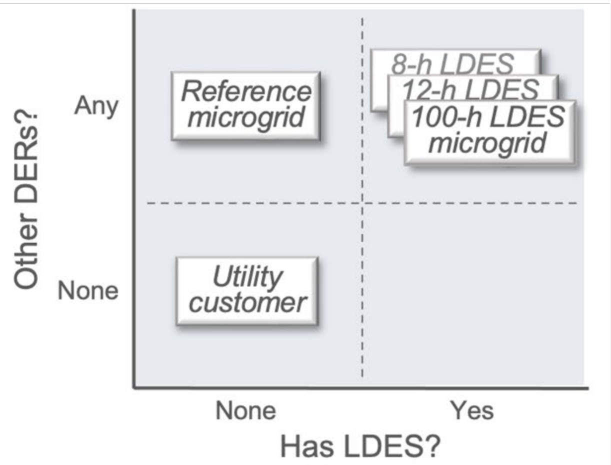
+ **We design a case study to analyze variation in**
  1. Building type
  2. DER portfolios (with and without LDES)
  3. DER and energy costs that change over time
  4. Microgrid emissions policy
+ **All of these affect the environment for LDES**
+ **8 buildings x 5 DER portfolios x 3 build years x 3 policies = 360 total scenarios**

1 **8 Buildings**—3 small, 4 large, and the campus.





2 **5 DER Portfolios**—utility customer, reference (non-LDES) microgrid, 3 LDES microgrids

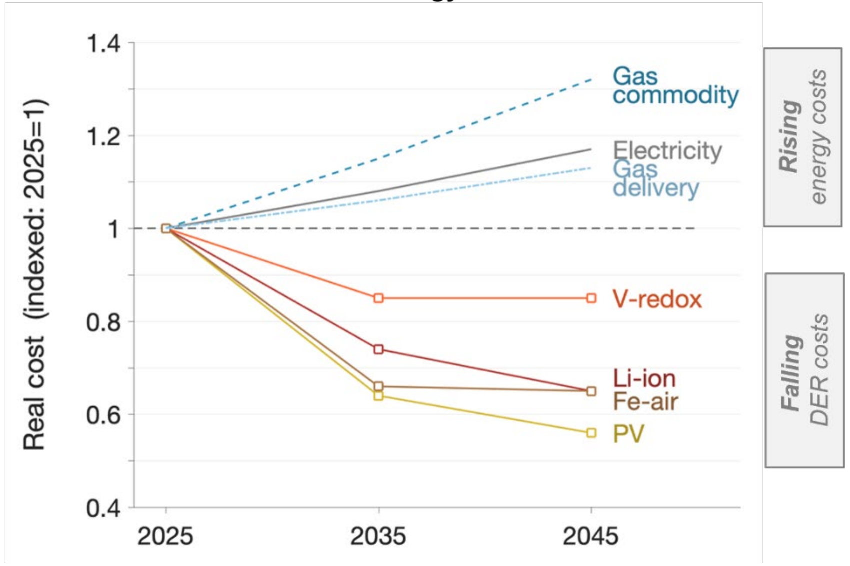


UCSD Microgrid Case Study

Scenarios Analyzed

+ **We design a case study to analyze variation in**
  1. Building type
  2. DER portfolios (with and without LDES)
  3. DER and energy costs that change over time
  4. Microgrid emissions policy
+ **All of these affect the environment for LDES**
+ **8 buildings x 5 DER portfolios x 3 build years x 3 policies = 360 total scenarios**

3 **Future variation in DER and energy costs.**



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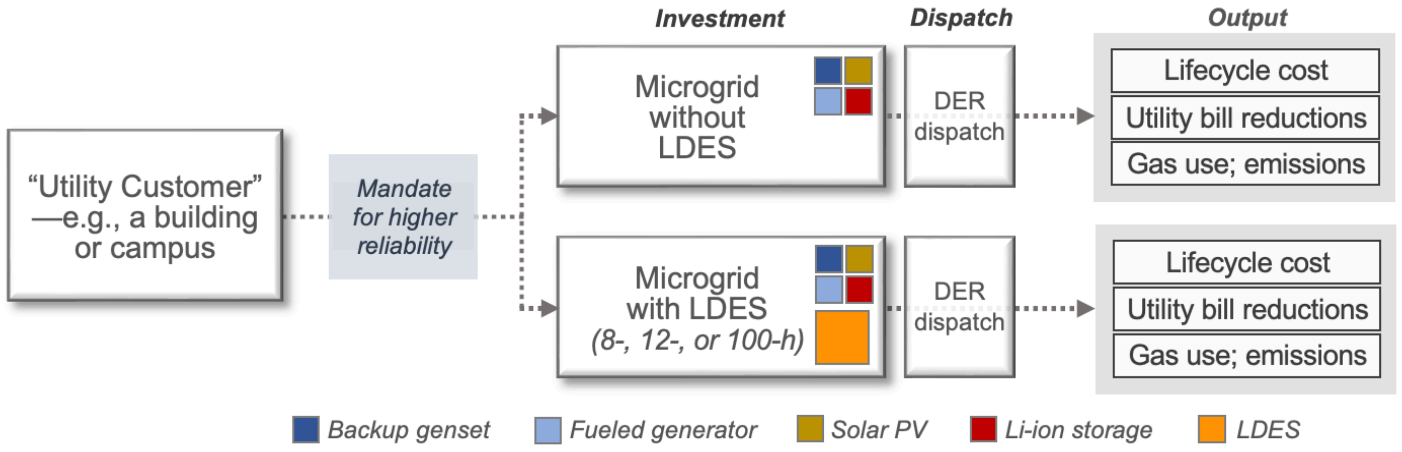
Policy Scenario	Restrictions on Emissions from Onsite Generation	Description	Practical Effect on Designing Microgrids
Reference *(Ref)*	None	Policy today for small decentralized generation sources	–
Zero-Carbon *(Zc)*	No CO_2 emissions	Aligned with California's goal of 100% clean electricity	Requires substitution of fossil gas ($5.50/MMBtu) for zero-carbon RNG ($17–25/MMBtu) options *(3–4.5x increase in fuel price)*
Zero-Carbon + zero-pollution *(Zc+Zp)*	No CO_2 emissions, no criteria air pollutants	Aligned with 100% clean electricity and environmental justice goals	Requires further substitution of combustion generators (e.g., gas turbines) for non-combustion alternatives (e.g., fuel cells) *(2–2.6x increase in fueled generator capex)*

Modeling Framework

- All microgrids deliver a minimum level of reliability (by requirement), powering a building's critical load during grid outages for ≥48 consecutive hours
- During "blue sky" days, microgrids operate to reduce customer energy bills (e.g., through demand charge clipping and time-of-use energy arbitrage)
- CO_2 emissions are a byproduct of cost-minimizing investment and dispatch decisions

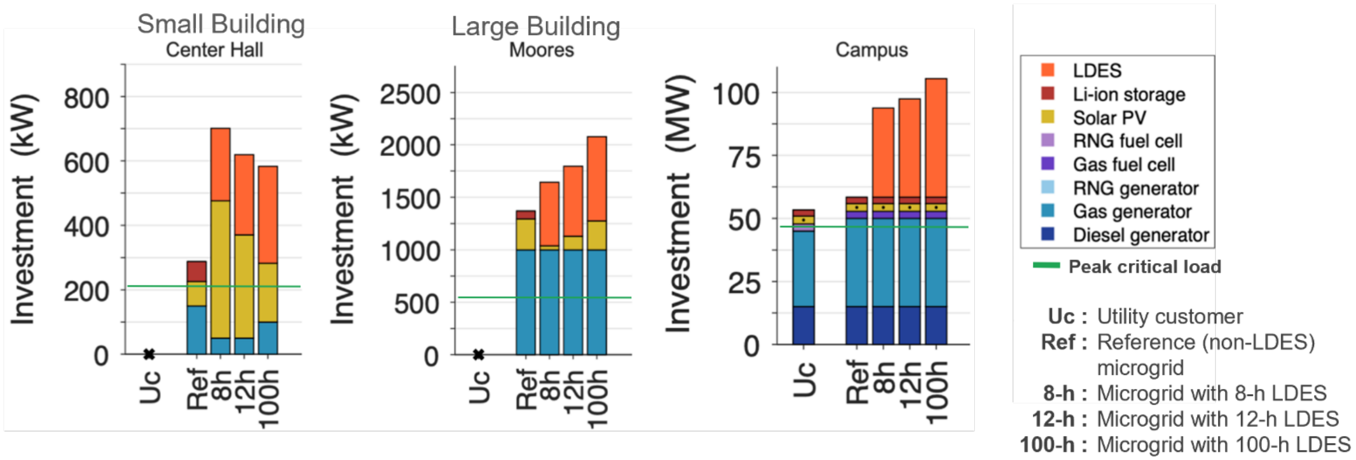


For LDES, the key question is then: What does LDES do—to a microgrid's economics, DER portfolio, use of fossil fuels, and CO_2 emissions—when added to the microgrid?

UCSD Microgrid Case Study

10. LDES can support high-reliability microgrid configurations

DER Portfolios for the 4 microgrid configurations—Reference (no LDES) and 3 LDES microgrids with *8-h*, *12-h*, & *100-h* LDES.



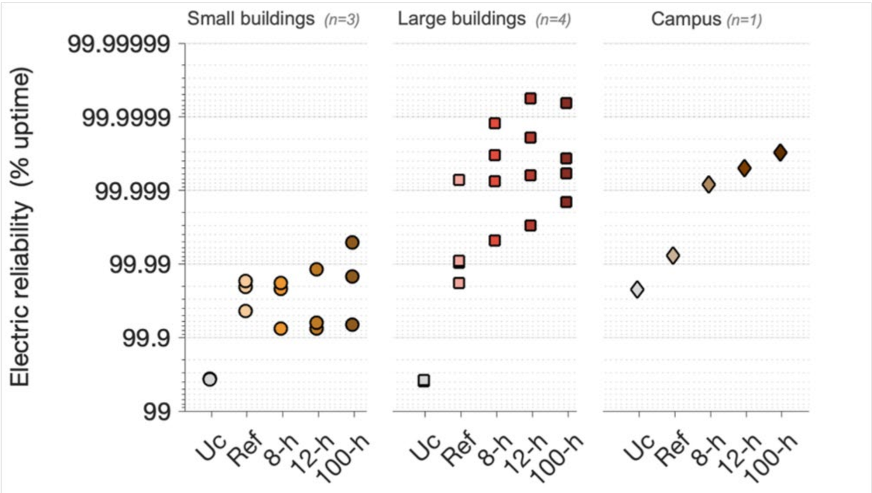
+ Reliability during "gray-sky" days

- When added to microgrids, LDES typically combines with many other DERs—fueled generators, solar PV, Li-ion storage—to meet the 48-h reliability requirement

+ Overall electric reliability

- Service uptimes across microgrids are 99.9% to 99.9999%
- Utility service has 99.6% uptime

Electric service reliability. By building type and microgrid type.



11. LDES has operational ("blue-sky") value—through peak shaving and energy load-shifting

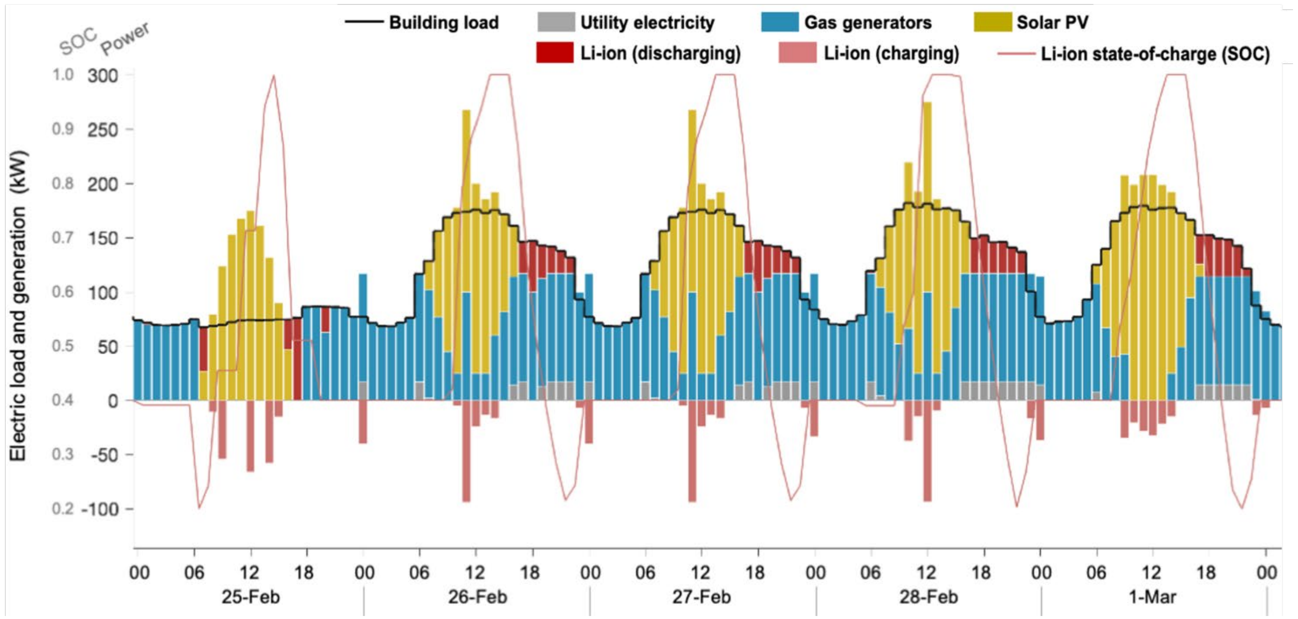
+ During "blue-sky" days when the grid is up, LDES peak-shaves and load-shifts to reduce utility bills

- Peak shaving: 35–85% of residual peak load for small buildings and 1–25% for large buildings; (residual: after considering power output from other DERs)
- Cycles: 2–105 cycles/yr for small buildings; 1–150 cycles/yr for large buildings
- LDES's share of electricity supply: 8–15% for small buildings; 1–4% for large buildings

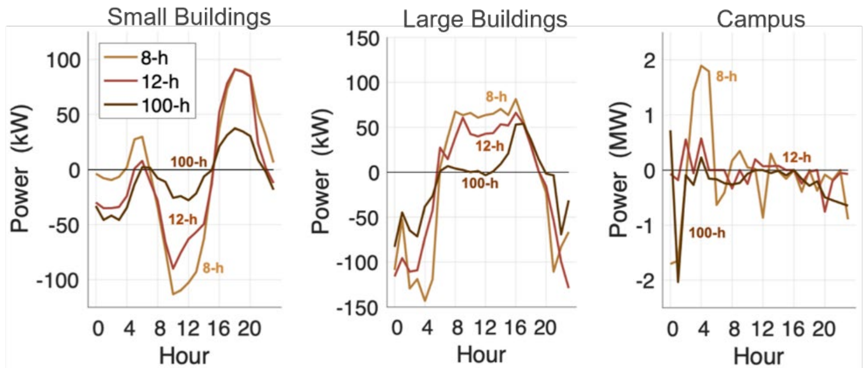
+ Operational role depends on type of LDES

- Higher-RTE LDES (8-h) is cycled more
- Lower-RTE LDES (100-h) is cycled less

Dispatch over several days. Center Hall (a small building), 8-h LDES microgrid.

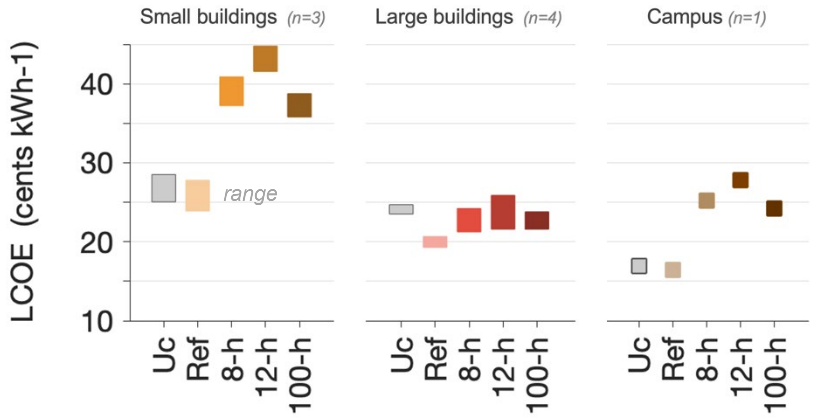


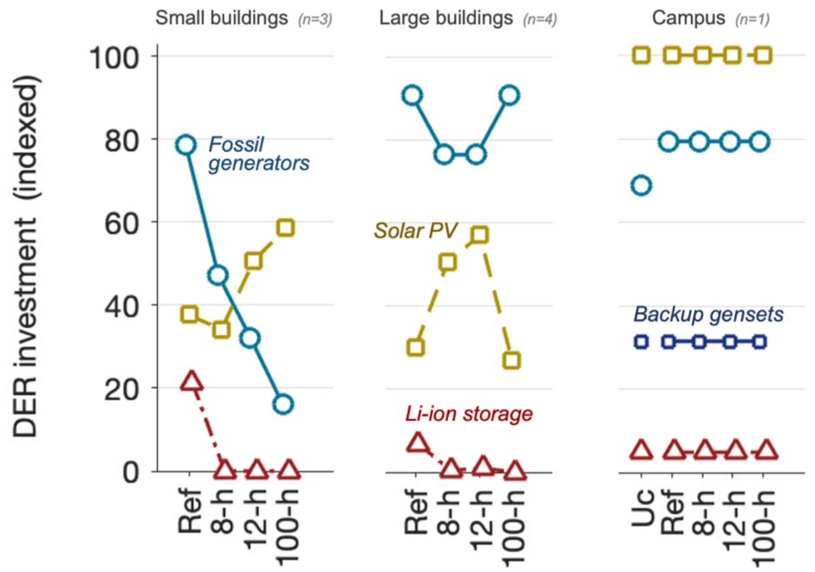
Daily dispatch, averaged over all days. By LDES type.



12. In most cases, LDES is not economic; building type matters

- **LDES economics are limited by cheap gas, finite rooftop space**
- **Building type determines PV+storage potentials—hence, whether/how LDES interacts with gas generation**
  - Lack of load "peakiness" (large buildings in our analysis) tends to favor baseload gas generation
  - Peaky load aligned with peak solar output (small buildings in our analysis) is more auspicious for PV+storage
    - Hence, for small buildings, LDES added in increasing duration generally displaces more gas generation
- **Existing DER portfolios can affect LDES's role**
  - Extant microgrids are (typically) already optimized for high reliability and low energy costs (as with the UCSD campus microgrid)
    - In these cases, there is little room for LDES to generate additional cost reductions and reliability gains
- **Need wider analysis of the California building stock**

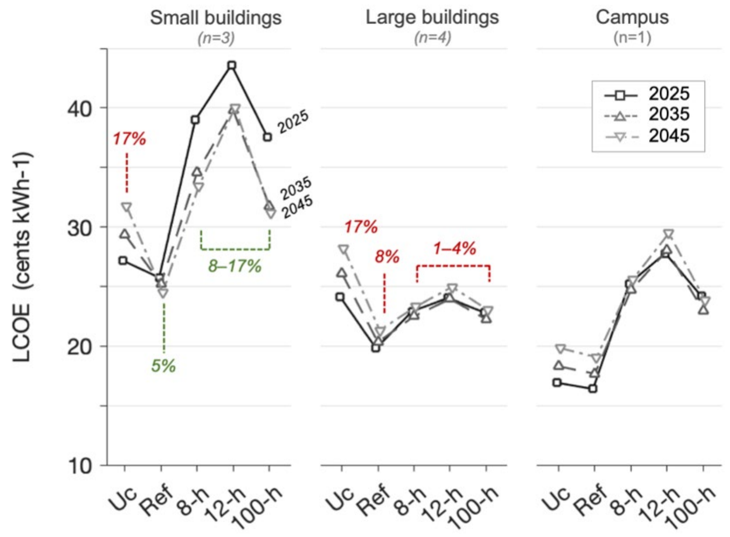


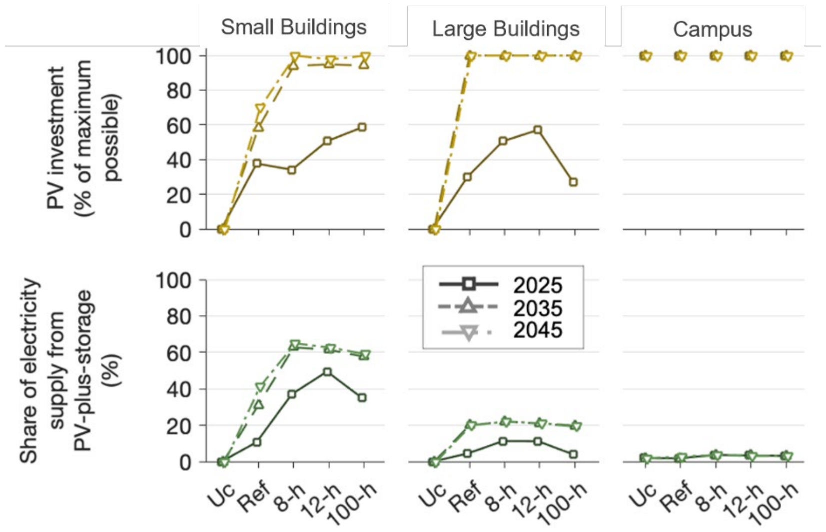


13. Over time, DER costs fall, utility costs rise, and the case for PV-plus-storage improves

- **Lifecycle LCOE depends on when the microgrid is constructed and begins operation**
- **Over time, LCOE...**
  - Increases for utility customers
  - Increases for gas-dominant microgrids
  - Decreases for PV-plus-storage–centric microgrids
- **However, even as PV-plus-storage costs fall, LDES is still not economic**
  - Rooftop space limits deployment potentials
  - The case for gas in microgrids remains strong

Technology and markets do not, of themselves, lead to zero-carbon outcomes for microgrids

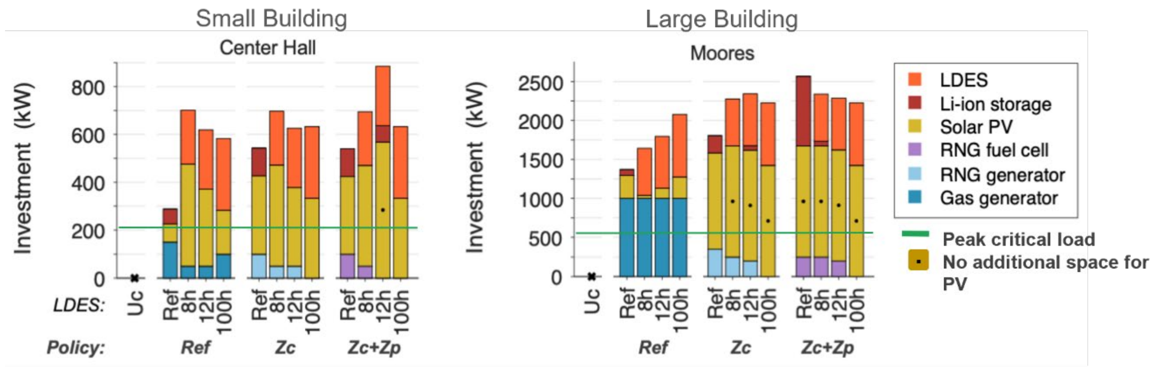


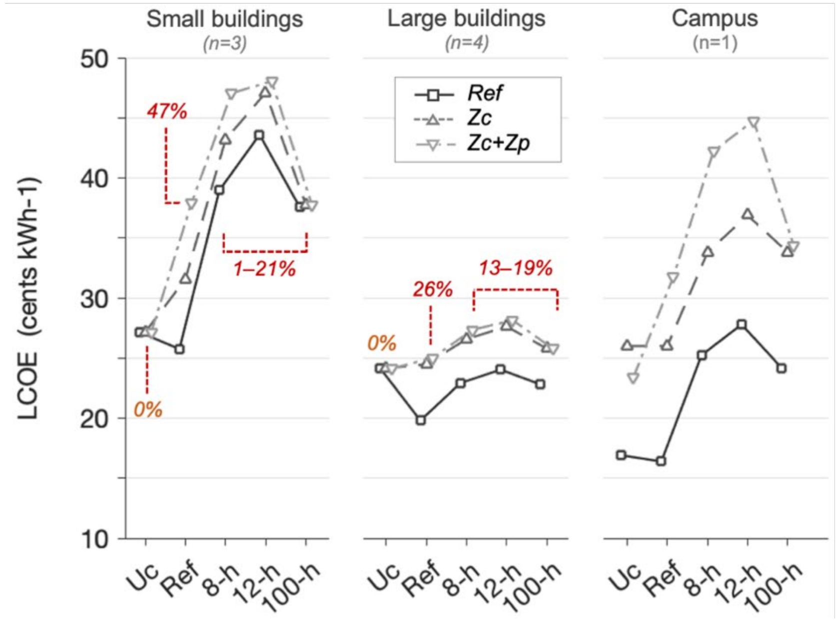


14. Policies that restrict emissions improve the *relative* economics of LDES microgrids—by driving up gas generation costs

- **Such emissions policies radically change the outlook for microgrid DER portfolios and economics**
  - With policy: less investment in gas capacity, more PV-plus-storage, more utility electricity imports, higher costs
- **Policies impose costs on all microgrids that use fossil gas**
- **Even with higher gas generation costs, LDES is generally still not economic**

Gaseous fuels have very high value for cost-effectively improving customer reliability.



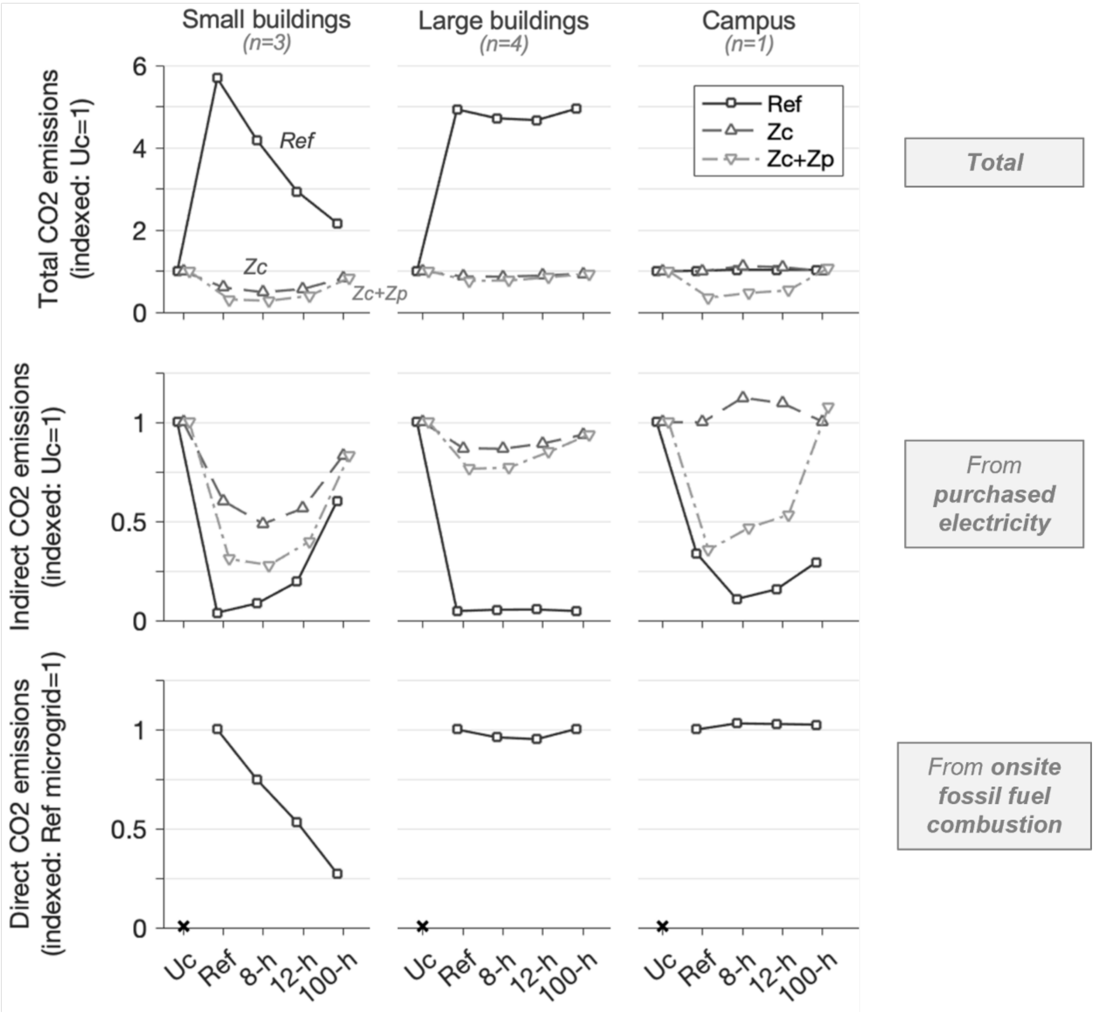


15. CO_2 emissions: Low-carbon microgrids still rely on grid electricity—and hence decarbonize only as quickly as the grid

- **In our analysis, microgrids don't operate to minimize emissions; rather, emissions are a byproduct of *cost-minimizing* operation**
- **Policy is the dominant driver of CO_2 emissions**
  - Under *Ref* policy, all microgrids increase system-wide emissions—due to substantial use of gas
  - Under *Zc* and *Zc+Zp* policy, all microgrid reduce emissions—by zero-carbon mandate
- **Within policy environments, LDES can be a driver of CO_2 emissions**
  - Particularly for small buildings in our analysis

In many cases, microgrids are zero-carbon by DER portfolio, but not by delivered energy

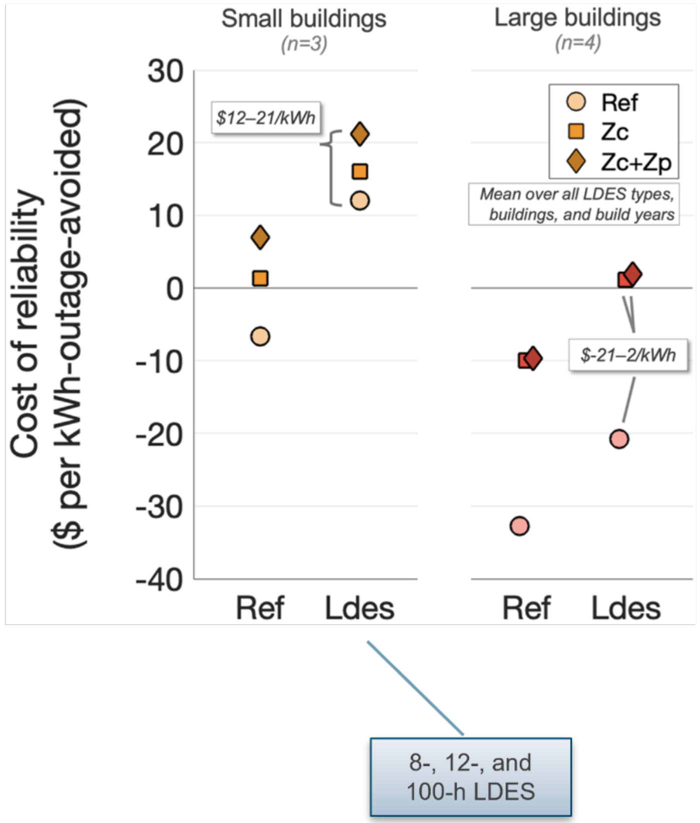
Total, indirect, and direct CO_2 emissions. For the utility customer and all microgrid configurations.



Key Takeaways

- **In most cases in our analysis, LDES is not economic**
- **LDES fairs *relatively* better in policy environments that price emissions; such policies raise costs on all microgrids**
- **Under such policies, gaseous fuels and fueled generators are still valuable for improving reliable (even as fuel prices reach $17–25/mmbtu)**
- **Although costly, microgrids improve customer reliability at relatively low *cost of reliability* (e.g., lower than many reported VOLLs)**
  - LDES microgrids deliver higher reliability at $-32–8/kWh
  - Non-LDES microgrids deliver reliability at $-20–22/kWh
- **Limitations of our analysis and need for additional investigation**
  - Additional revenue streams:
    - utility resilience payment: ↑ for longer duration
    - emergency load reduction program: ↑ for longer duration
    - ancillary services: ↑ for shorter duration

Cost paid for improved reliability. For non-LDES and LDES microgrids.



Areas for Future Research

Areas for Future Research

1. **Continued research to track progress of emerging technologies**
   - Seasonal storage & siting of hydrogen infrastructure (particularly with IRA tax credits)

2. **Resource adequacy & resilience will be a major component of long-term portfolio planning**
   - Better datasets to characterize loads & renewable generation for more weather years may reveal additional value for multi-day or seasonal LDES
   - Climate impacts will change the nature of resource availability & reliability events in the future
   - Continued innovations in modeling methods for resource adequacy under deep decarbonization are needed

3. **More information on locational value, local capacity needs & local air pollution may reveal additional use-cases for LDES**

4. **New revenue streams & tariff structures that might improve the economics (and realize the full value) of customer-sited LDES**

Knowledge Transfer

- **Updated Resolve model will be released on GitHub later in the spring**
- **Weather-correlated renewable and load data from Form Energy will be released on Zenodo**
- **Updated Resolve model is being used in multiple ongoing & upcoming California studies:**
  1. **CEC EPC-19-060**
     Modeling of LDES for Decarbonization of California Energy System
  2. **2023 CPUC IRP Preferred System Plan and 2024-25 Transmission Planning Process**
     - *Proposed scenarios will include emerging technologies (e.g., offshore wind, electrolytic fuels), long lead-time procurements, and updated electrification & load flexibility assumptions from LBNL Phase 4 DR study*
  3. **CEC EPC-21-041**
     Climate-Informed Load Forecasting & Electric Grid Modeling to Support a Climate Resilient Transition to Zero-Carbon
  4. **CEC GFO-22-304** (proposed award)
     Assessing the Role of Hydrogen in California's Decarbonizing Electric System

Discussion

Form energy

CER Center for Energy Research

Energy+Environmental Economics