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CEC EPC-19-056
Assessing the Value of Long Duration Energy Storage

Public Workshop 3. Preliminary Analysis Results

March 29, 2022

Form energy

CER Center for Energy Research

Energy+Environmental Economics

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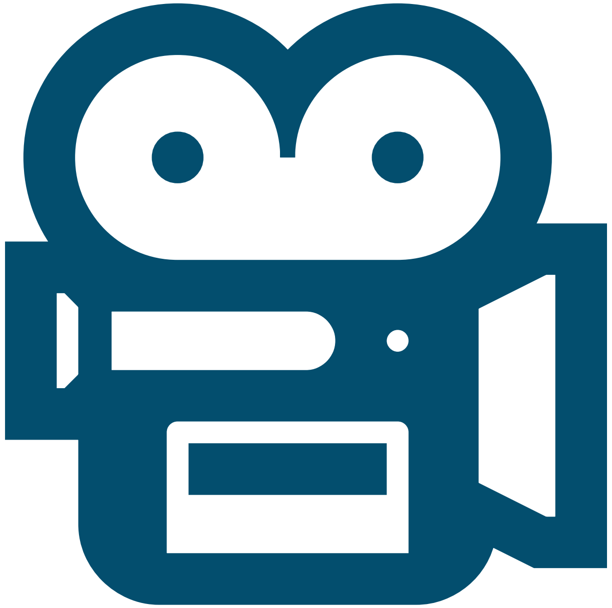
Recording Reminder



Throughout our discussion, we encourage you to use the Q&A or chat box; otherwise, you can use the "Raise Hand" feature , and we will call on you at designated times

Agenda

time	Topic
10:00 – 10:15	**Review project scope & purpose of preliminary analyses**
10:15 – 10:40	**Preliminary bulk system analysis results** • Identification of scenario for final bulk system analysis
10:40 – 11:00	**Lessons learned from preliminary bulk system analysis to inform New Modeling Toolkit functionality** • Initial demonstration of New Modeling Toolkit functionality
11:00 – 11:30	**Preliminary UCSD microgrid study**
11:30 – 12:00	**Discussion with stakeholders**

Project Overview

Energy+Environmental Economics

Jessie Knapstein, Sr. Managing Consultant, E3

What is long duration energy storage (LDES)?

+ **LDES is an umbrella term used to address a wide range of technologies**
  - Common industry shorthand for LDES is any storage with 6+ (NYSERDA) or 8+ (CEC, DOE) hours
  - ARPA-E DAYS program sets a goal for storage technologies with 10-100 hours of duration and levelized cost of storage (LCOS) less than 5¢//kWh
+ **Recent industry trends:**
  - Emerging LDES tech startups continue to attract investment to get to market
  - Emerging pipeline for LDES projects (e.g., CPUC MTR decision, Georgia Power, Portland General)
    - To-date, California LSEs have been procuring **8-hour li-ion** to meet CPUC MTR decision

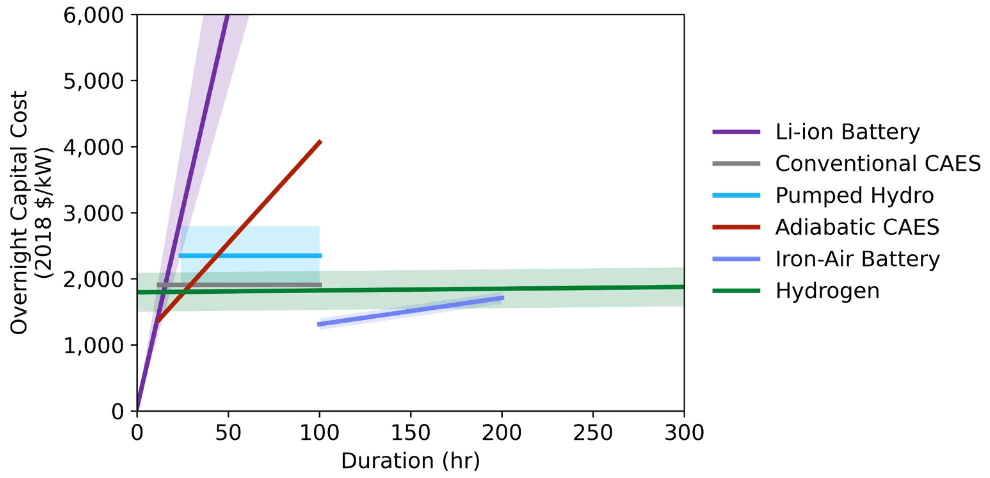
	Technology	TRL	Typical Duration	Geographic Constraints
Commercially available	Li-ion	9	Hours	No
	Vanadium Flow	8	Hours	No
	CAES	8	Hours - Days	Yes
	Pumped Hydro	11	Hours - Days	Yes
Emerging LDES	Hydrogen Storage	9-10	Weeks - Months	Yes*
	Synthetic Methane	6-7	Weeks - Months	Yes*
	Adiabatic CAES	7	Days	Yes
	Thermal Storage	5-9	Days	No
	Iron-Air Battery	5-6	Days - Weeks	No
	Zinc Hybrid	5	Hours	No
	Redox Flow	7	Hours	No
	Flywheel	7	Minutes - Hours	No

* Geographic constraints for underground storage sites

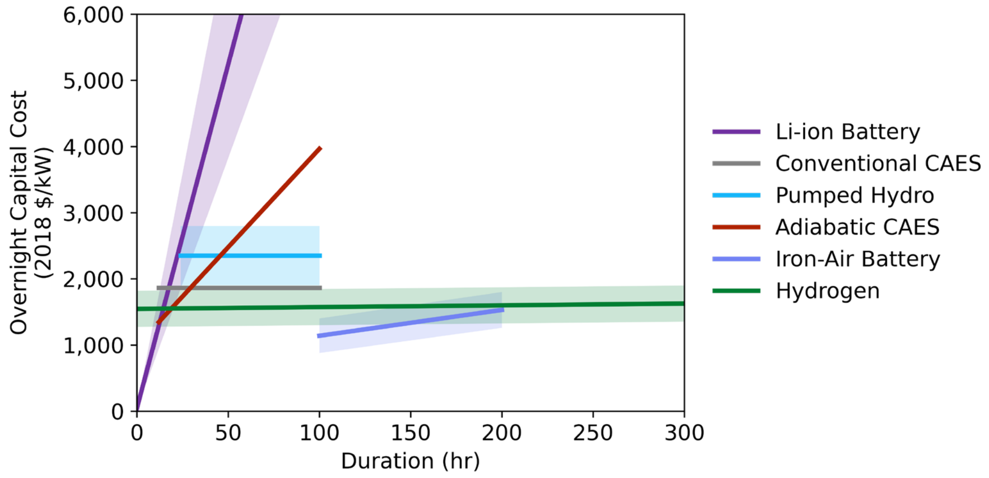
Preliminary LDES Cost Projections

- **Based on initial literature review, project team has developed cost projections for use in modeling**
  - Limited public data available on cost projection uncertainties for emerging technologies (dependent on learning curves, etc.)
- **Cost projection comparison shows that the answer to, "What's the differences between 2x short duration (Li-ion) storage vs. LDES?" comes down to cost & performance**

2035 Cost Projections



2045 Cost Projections



Project Objectives & Arc

1 Use existing tools to analyze long-duration storage for preliminary analysis

Define scenarios & sensitivities

Identify future scenarios under which to study value of long-duration storage for California

Analyze value of LDES in existing models

- Use RESOLVE & Formware to study the value of storage resources in California's statewide resource portfolio. Highlight limitations of existing planning models to indicate where additional study is needed in final analysis
- Develop a microgrid model to understand value of various storage technologies in a customer microgrid setting

2 Develop datasets & improved planning models to study wide range of storage technologies

Develop draft technology review

- Conduct initial review of storage & emerging technologies to use for preliminary analysis of LDES

Develop new modeling toolkit

- Improve RESOLVE representation of chronological storage dispatch to enable arbitrage across days
- Add ability for RESOLVE to model & optimally size cross-sectoral energy storage (e.g., power-gas-power)
- Develop methodology to correlate weather- and climate-driven impacts on loads, wind & solar

3 Conduct final analysis

Update modeling datasets

- Develop larger dataset of load, wind, solar & hydro data to study multi-day and seasonal energy needs
- Finalize updated storage & emerging technology modeling assumptions

Complete final analysis

- Deliver public New Modeling Toolkit
- Develop optimized portfolios to meet California's future energy needs that consider a broad range of options for long-duration storage
- Leverage Formware model for additional analysis

Preliminary Analysis Progress

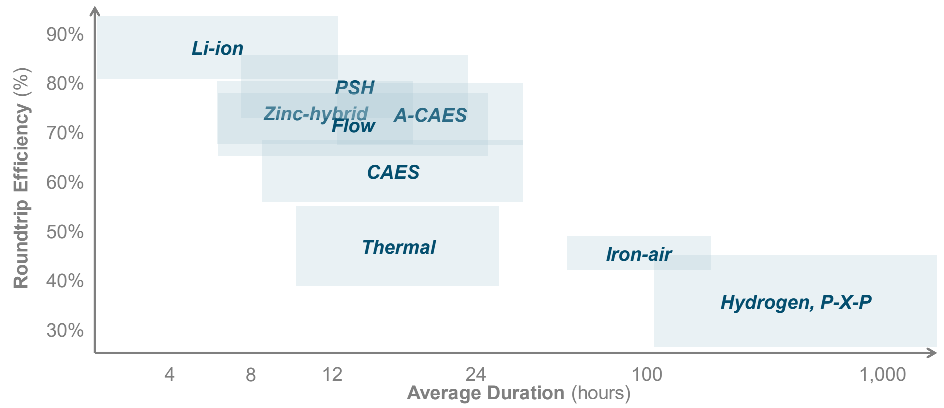
	Preliminary Goal	Goal Status	Areas for Further Research Identified
Bulk System	Build on the 2021 SB100 Joint Agency Report, which provided an initial assessment of the resources needed to achieve 100 percent clean energy and their associated costs	✓ Modeled IRP and SB100 and beyond SB100	Assess impacts of LDES on unspecified imports
	Begin to frame the role of LDES in California's power system, with emphasis on 3 policy futures	✓ Modeled IRP/SB100, SB100+ 2035, SB100+ 2045, & No Combustion	Explore the LDES impacts on GHG constraints
	Highlight the impact of time-aggregation modeling techniques by benchmarking against a model that optimizes over all 8,760 hours in a year	✓ Benchmarked RESOLVE and Formware	Incorporate longer load & generation profiles to study "renewable drought" events
	Develop ELCC assumptions to account for LDES contribution to system resource adequacy	✓ Develop initial (rough)	Focus final analysis on system reliability & refining ELCCs for LDES technologies, particularly capturing "renewable drought" events & interactive effects with other storage resources
	Identify the breakeven cost, or value, of LDES within California's resource portfolio	✓ Conducted in-out sensitivities of various LDES technology characterizations	Incorporate cost trajectory uncertainties into modeling and do further analysis to understand ELCCs of LDES technologies
Microgrid	Develop the model and run the baseline reference microgrid	✓ Model developed and reference cases run for UCSD	Identify the role for LDES in enabling zero-carbon microgrids and explore different market strategies and sensitivities

Differentiating within the long-duration storage technology range

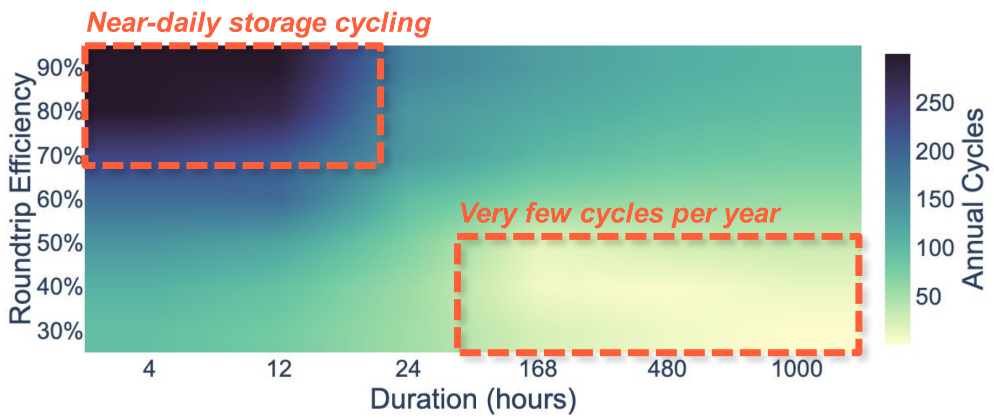
+ **We have a good understanding of the economics of diurnal storage cycling**
  - 8- to 12-hour storage does not operate significantly differently from 4-hour li-ion and are well-captured in today's models

+ **Significantly different cycling behavior for multi-day and seasonal storage suggests need for more data & updated tools to study technologies these effectively**
  - Hypothesis: Very-long duration, low RTE storage may be best suited for operations as "energy reserves" over very long timescales not well-modeled by today's planning tools

LDES Operational Problem Space



Illustrative Storage Cycling Behavior (from Workshop #2)



Thinking about storage cycling behavior, types of storage & storage value propositions

Operating reserves

Energy market participation, RPS & GHG policy compliance

Resource adequacy & reliability: Meeting energy needs (serving load) across range of system conditions

Intra-day | **Daily** | **Multi-day** | **Seasonal** | **Inter-annual**

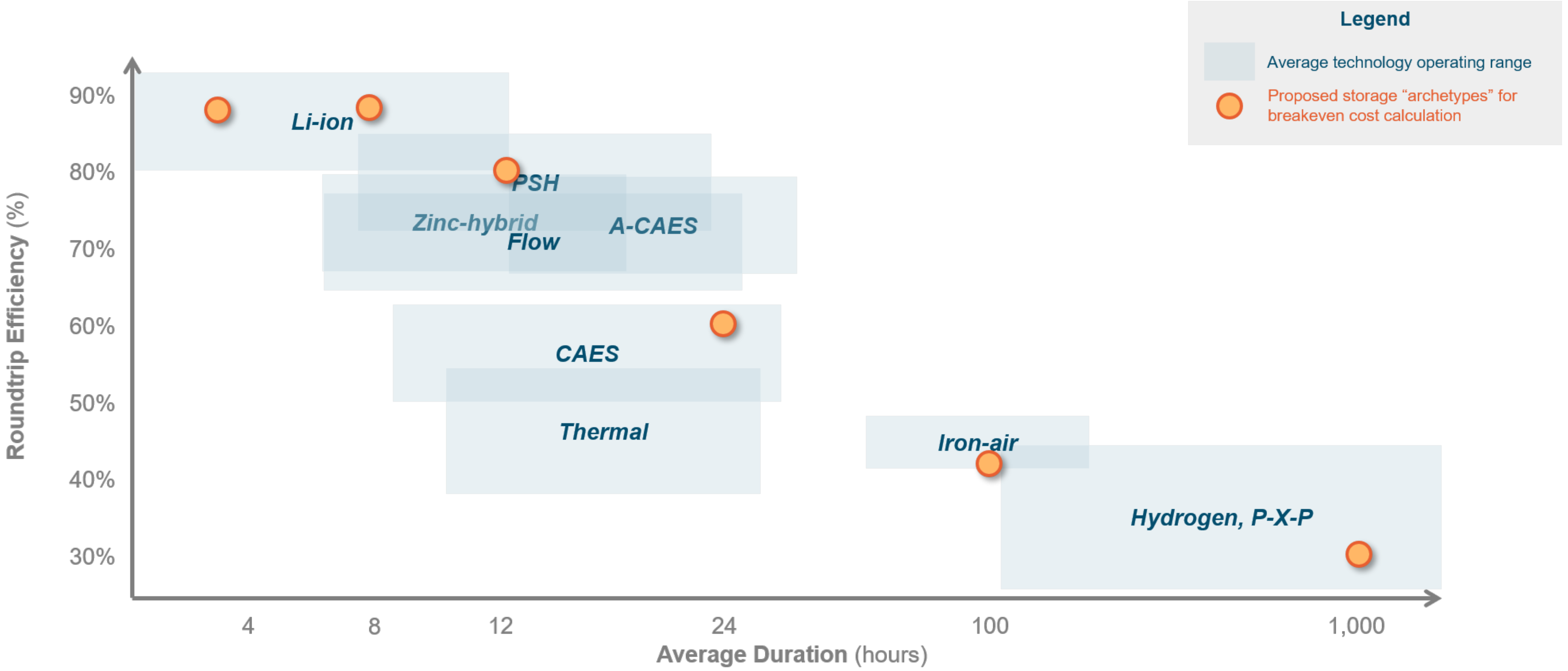
Existing models like RESOLVE capture most of these operations

Preliminary analysis: Expand modeling to 8760-hour granularity

Final analysis: Study reliability & storage dispatch over more weather years

Framing the LDES problem:

What storage characteristics are most valued in the future California grid, and are there commercially-viable or emerging storage technologies that can provide those characteristics?



Preliminary Bulk System Portfolio Analysis

Energy+Environmental Economics

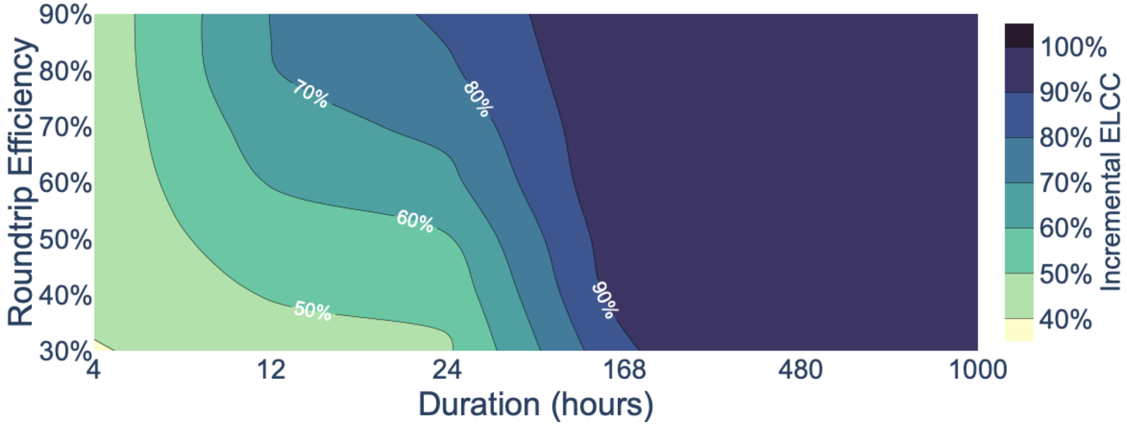
Rachel Orsini, Senior Analyst, Form Energy

Key Inputs & Drivers of Resource Selection

+ **Resource selection in capacity expansion models is driven by:**
  - Candidate resource costs
  - Effective Load Carrying Capacity (ELCC), which capture declining ability to meet system reliability needs
  - Stringency of policy targets

+ **Initial, but uncertain, LDES ELCC and cost projections were developed and used for the preliminary analysis**
  - Given sensitivity to these inputs, further analysis is warranted

2045 ELCC* (5 GW incremental)



Assumed Overnight Capital Costs (2018 $/kW)

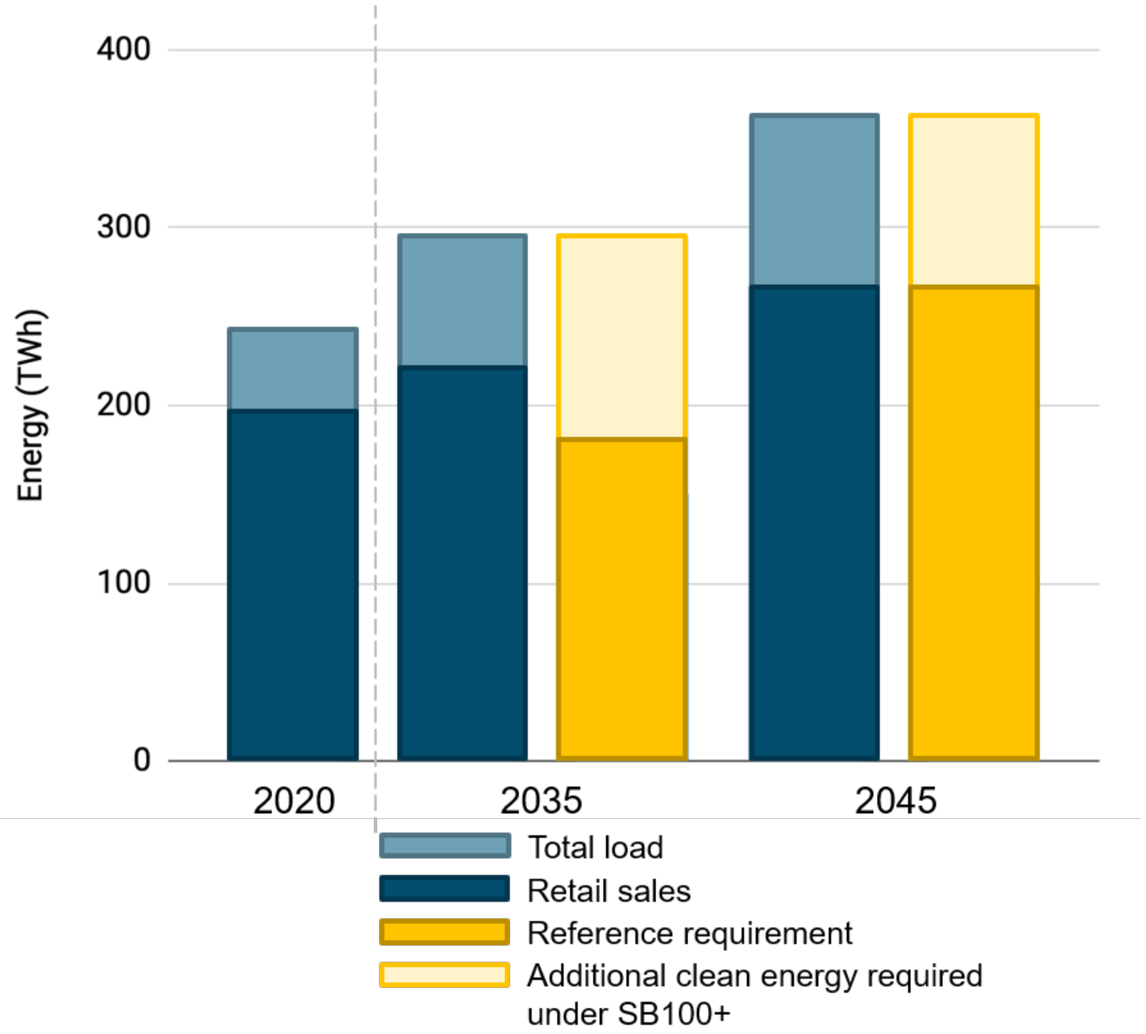
	12-hour	24-hour	100-hour	1000-hour
2035	$2,352	$1,746	$1,313	$2,064
2045	$2,352	$1,703	$1,139	$1,814

Note: Overnight costs are adjusted to align modeled technology lifetimes with capacity expansion modeled time horizon.

Core Scenario Definitions

- **Two core scenarios for 2045:**
  - **Reference (CPUC IRP RSP 46MMT)**
    100% of retail sales served by clean resources
  - **SB100+**
    100% of retail sales, state, and T&D losses covered by clean resources, all CAISO gas retired
- **In addition to 2045 scenarios, we studied:**
  - Accelerated SB100+ by 2035
  - No Combustion sensitivities
- **Preliminary bulk system analysis was conducted using "snapshot" years**

Policy Requirement by Modeled Year



Core Scenario Assumptions

+ **Candidate resource options are aligned with IRP RSP assumptions and include additional 12-, 24-, 100-, and 1000-hour LDES “archetypes”**
+ **For SB100+ scenarios, additional constraints are applied to resource portfolio to force retirement of existing gas generation in California**
  - Gas plants can be retrofitted for combustion of zero-carbon fuels (H_2)
  - For No Combustion sensitivity, emitting resources are further restricted, retiring biomass capacity as well

	2035		2045		
	Reference (IRP RSP 46 MMT)	**SB100+**	**Reference** (IRP RSP 46 MMT)	**SB100+**	**Reference, No Combustion Sensitivity**
RPS Targets	~81% of retail sales from SB100-eligible generation	100% of load from RPS-eligible generation excluding unspecified imports	100% of retail sales from SB100-eligible generation	100% of load from RPS-eligible generation excluding unspecified imports	100% of retail sales from RPS-eligible generation
Forced Retirements	n/a	All gas retired	n/a	All gas retired	All gas and biomass retired

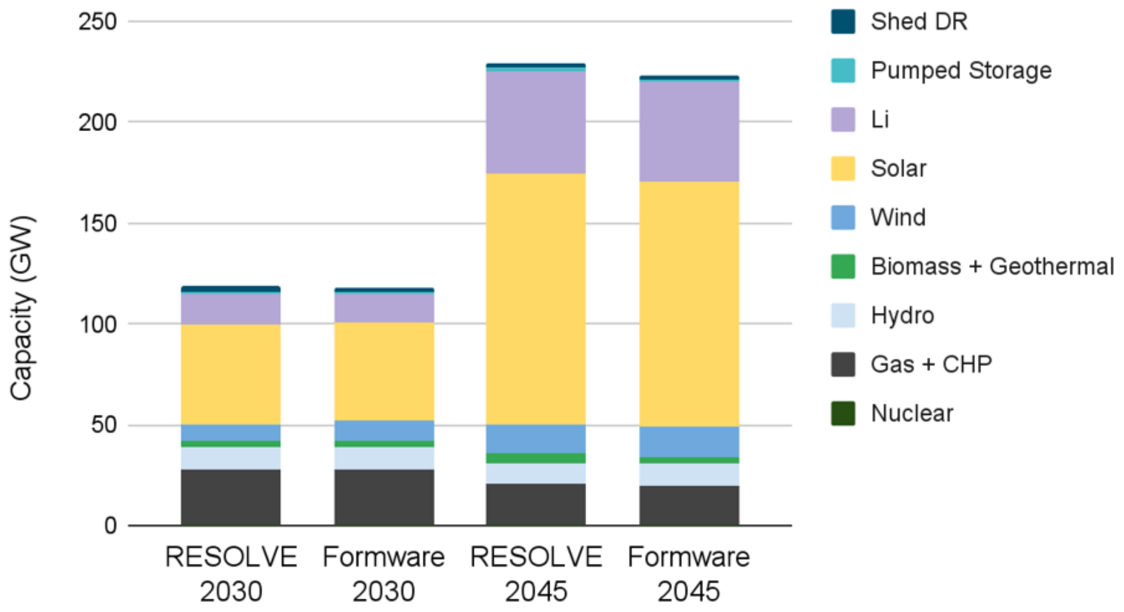
Benchmarking Exercise: Formware and CPUC IRP Reference System Plan

- Prior to scenario analysis, project team benchmarked Formware model to CPUC IRP Reference System Plan (RSP) (2021 46MMT)

- Formware and CPUC IRP Reference System Plan matched well on selected resource capacity and energy generation, with small differences that resulted from differences in modeling methodologies

- LDES scenarios adopted baseline inputs in-line with the CPUC IRP RSP, but incorporated additional input assumptions for the LDES analysis

Benchmarking System Capacity



Executive Summary

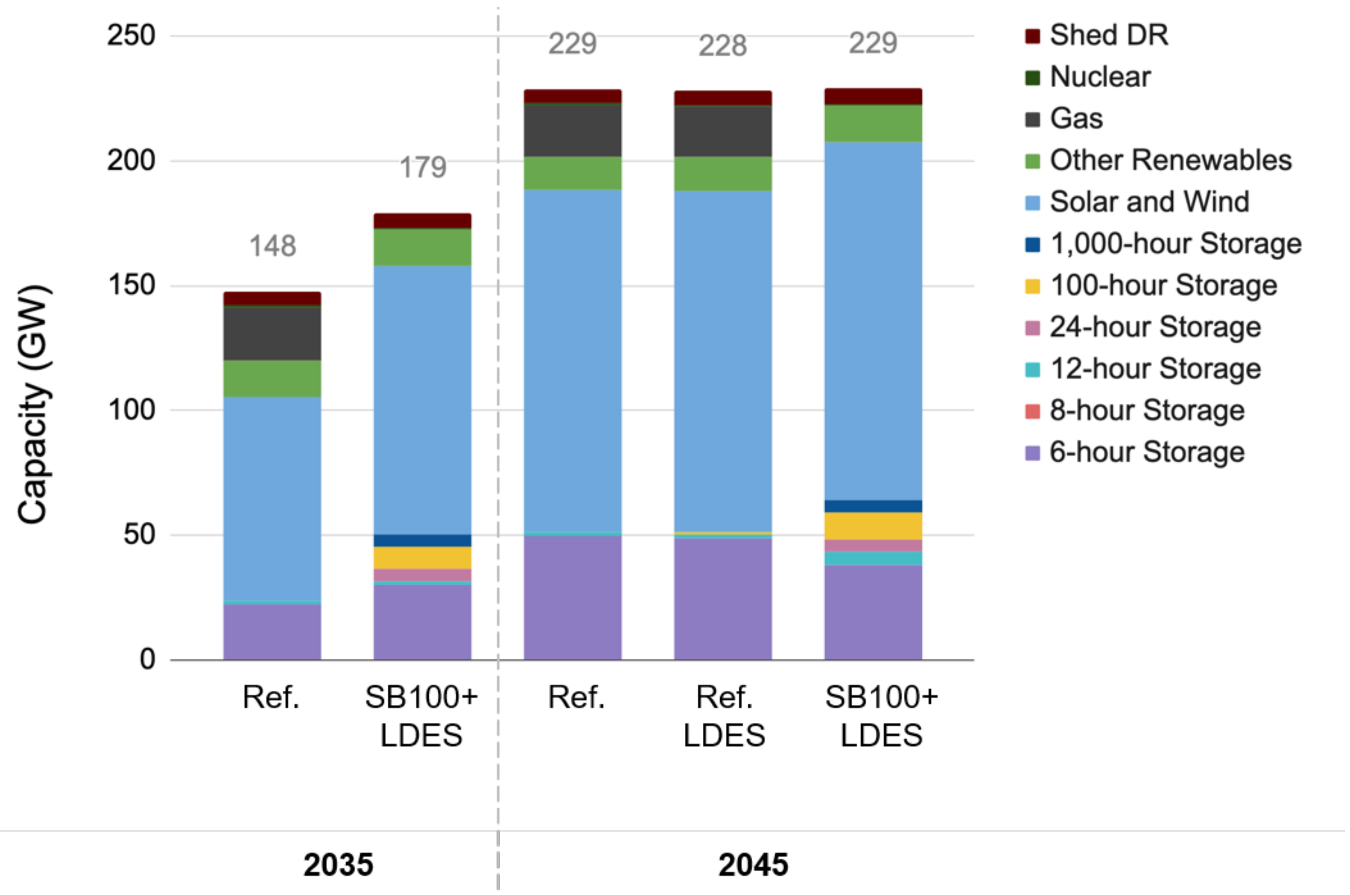
Least-Cost Portfolio Resource Build

+ **In Reference scenarios, LDES only selected in 2045 and not in 2035**
    - 46 MMT IRP RSP assumptions are not stringent enough to drive significant LDES build

+ **In SB100+ scenarios, significant amounts of LDES selected in both 2035 and 2045**

+ **Selection of LDES driven by:**
    - Meeting Resource Adequacy (RA) planning constraint (in particular, replacing retired gas capacity)
    - More stringent clean generation target (Reference vs. SB100+ policy on slide 16)

Total Resource Portfolio by Scenario & Model Year

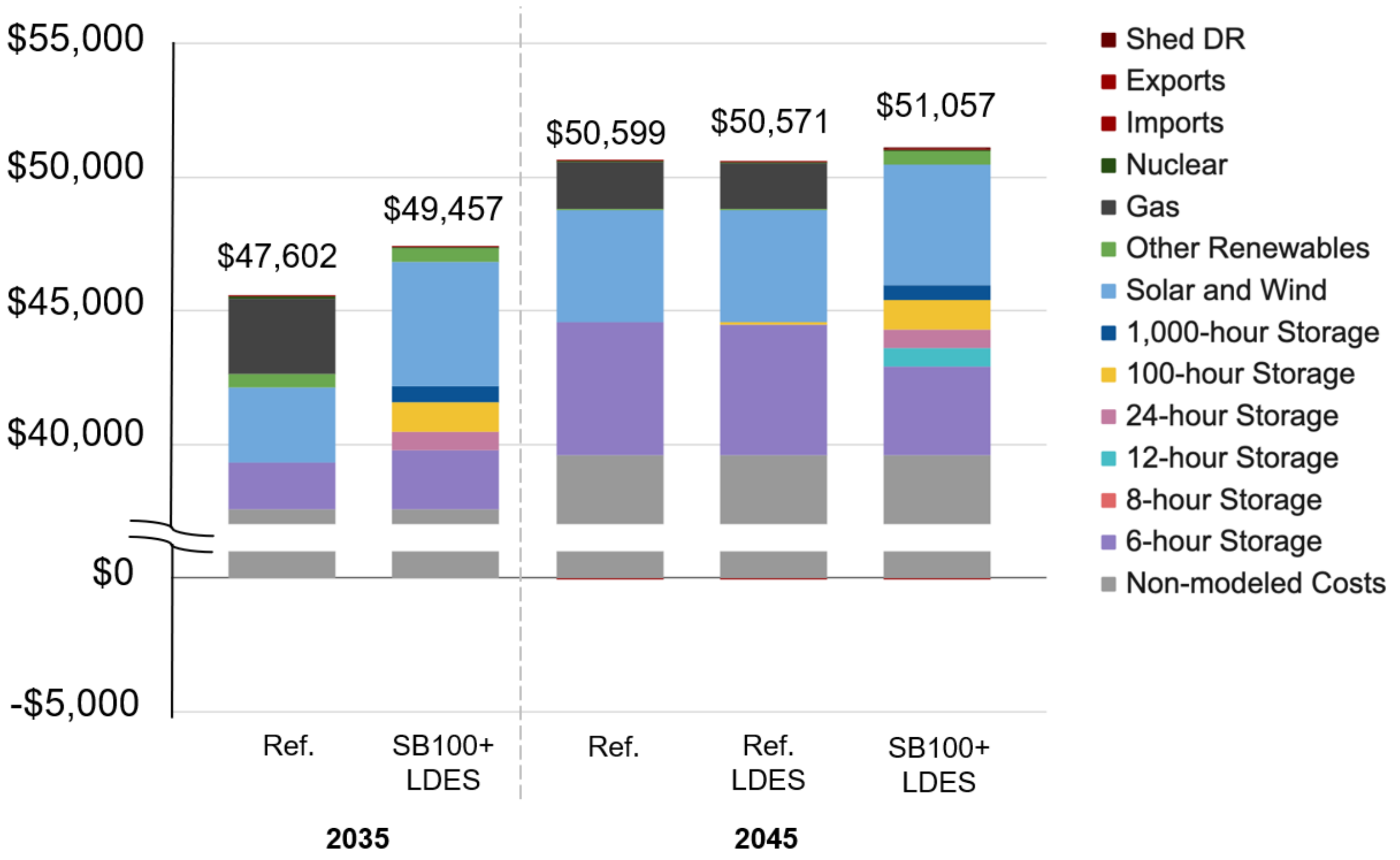


Executive Summary

Least-Cost Portfolio Total Cost

- In Reference scenarios, availability of LDES options has no or relatively small cost savings
- In more stringent SB100+ scenarios, model selected LDES options to meet policy for small incremental cost relative to Reference scenarios
- In final analysis, we will further study sensitivity of portfolio selections to a range of input assumptions

Annual CAISO Resource Cost by Scenario*



LDES options allow more stringent policy target to be met for similar system cost

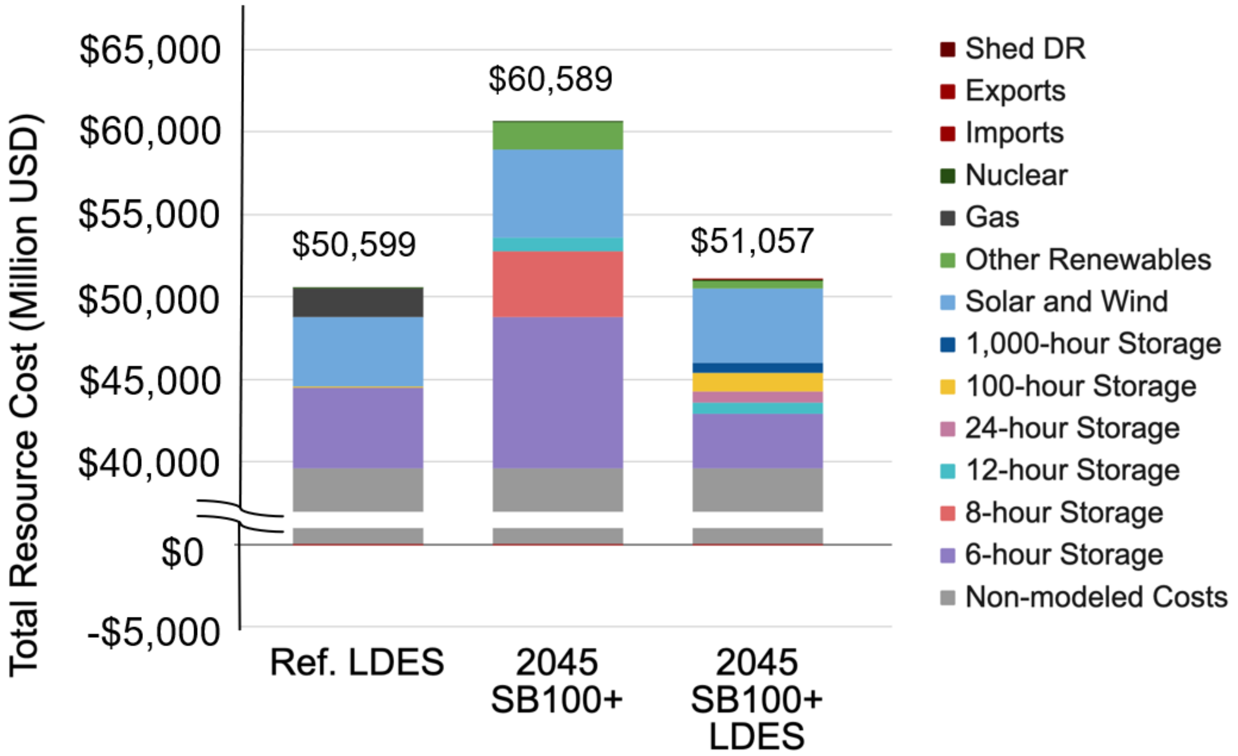
+ Without LDES options, achieving SB100+ scenario in 2045 is expensive (comparing Reference to SB100+)

- Meeting more stringent SB100+ policy requires significantly more resource build without LDES

+ Availability of LDES options allows SB100+ policy to be met at cost parity to Reference policy scenario

- SB100+ LDES portfolio selects a range of LDES technologies

Total Portfolio Costs in 2045

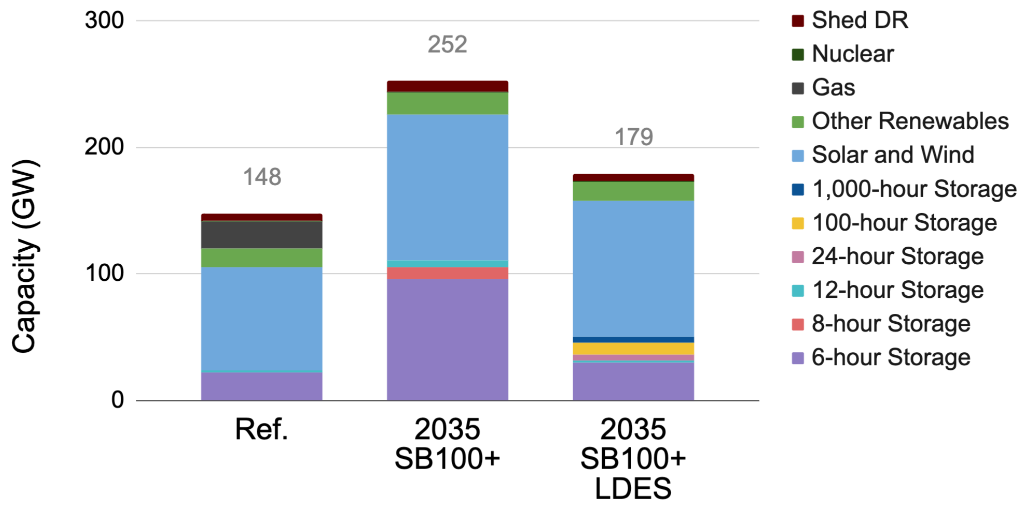


LDES options reduce total GW deployment to achieve more stringent SB100+ policy scenario

+ **Addition of LDES options enables 1/3 reduction in total capacity**

+ **SB100+ policies require similar amount of annual solar deployment—regardless of LDES availability—to provide required eligible clean generation MWhs**

Total 2035 Resource Portfolio by Scenario



Annual Resource Build to Achieve 2035 Portfolio

Scenario	Solar (GW/year)	Storage (GW/year)
Reference	2.1	1.6
SB100+	4.6	8.2
SB100+ LDES	4.1	3.6

Longer duration storage is valuable to system

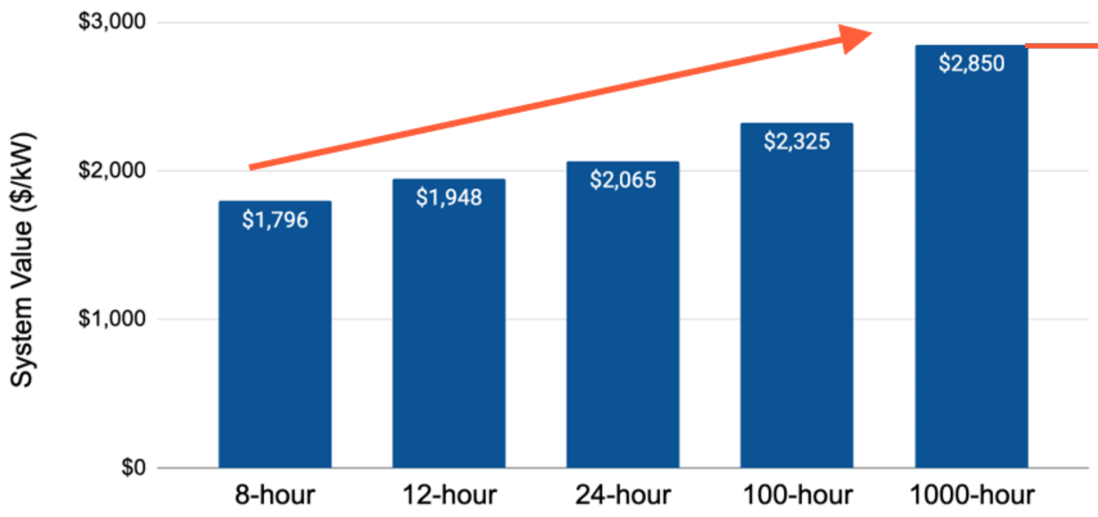
+ Longer duration storage is consistently more valuable to California system

- To test this, we forced in 1 GW of storage of increasing durations while holding roundtrip efficiency constant

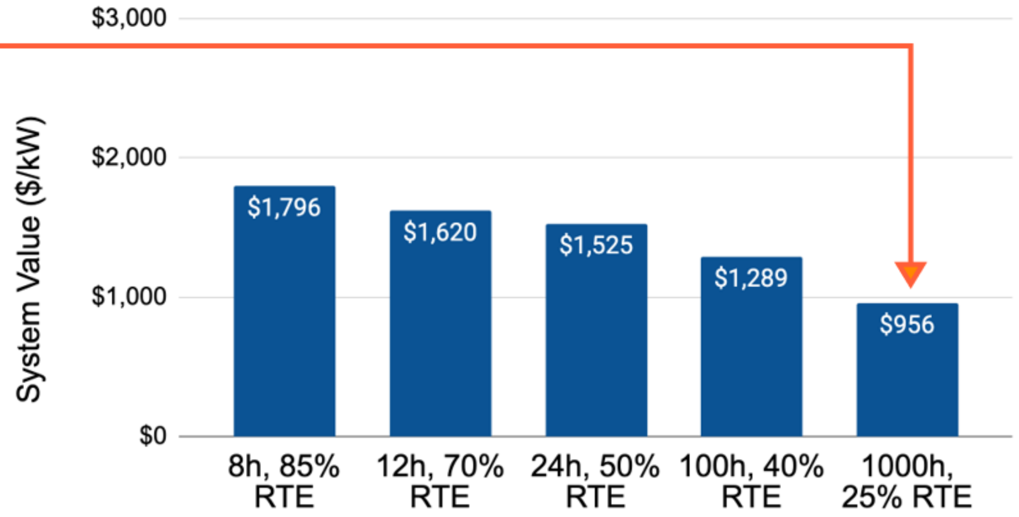
+ However, roundtrip efficiency losses significantly reduce value of storage to system

- Lower RTE technologies must be cheaper to be cost-competitive in California's future resource portfolio

Effect of Duration (Constant 85% RTE) on Breakeven Cost
(1 GW forced-in, Reference scenario, 2045)



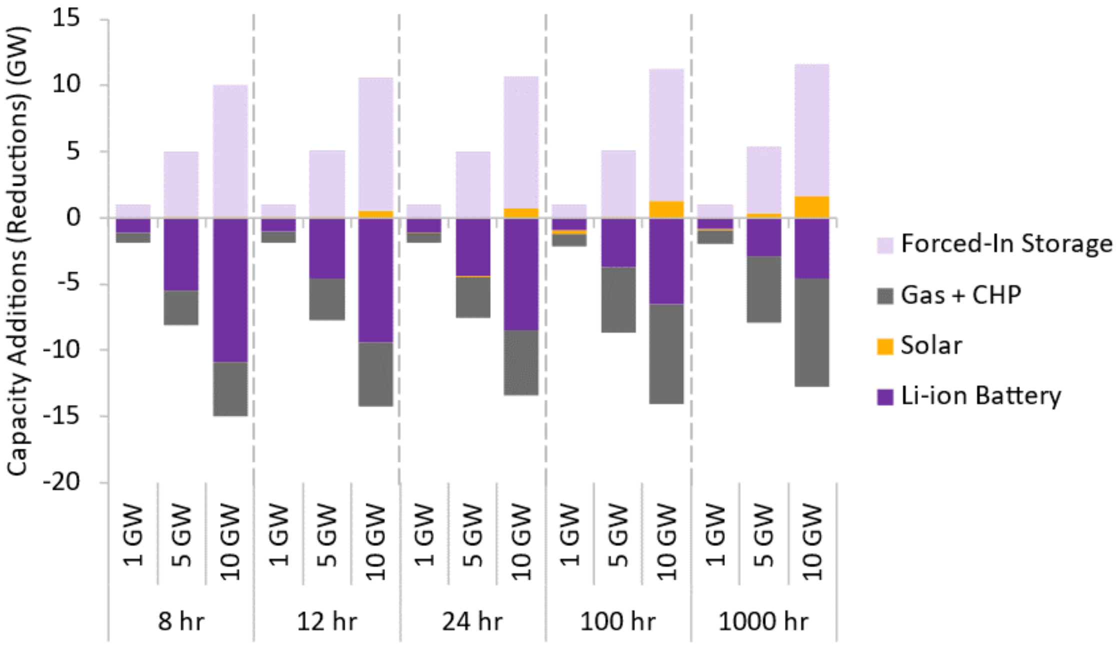
Effect of Lower RTE on Breakeven Cost
(1 GW forced-in, Reference scenario, 2045)

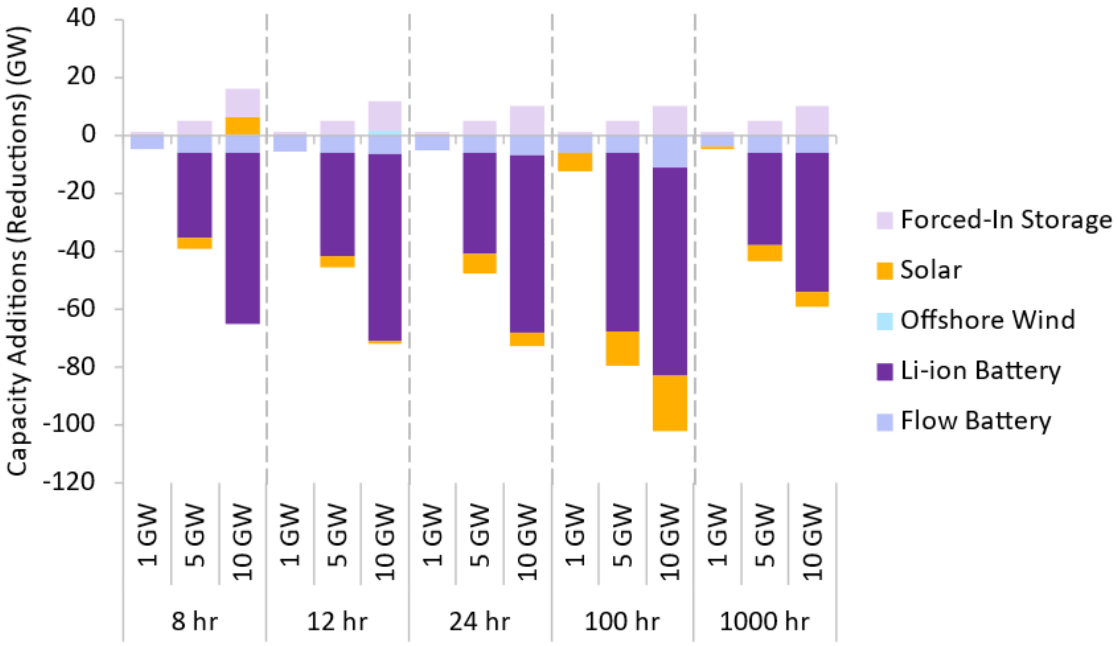


What resources do LDES options compete with in California's resource portfolio?

+ **In Reference scenario: LDES competes with li-ion and firm capacity**
  - LDES is <u>complementary</u> to solar build (i.e., allows system to build more solar) due to multi-day shifting

+ **In SB100+ scenario: LDES competes with other storage resources (first lower efficiency flow batteries, then higher efficiency li-ion)**
  - LDES <u>reduces</u> need for solar build to meet policy & reliability constraints



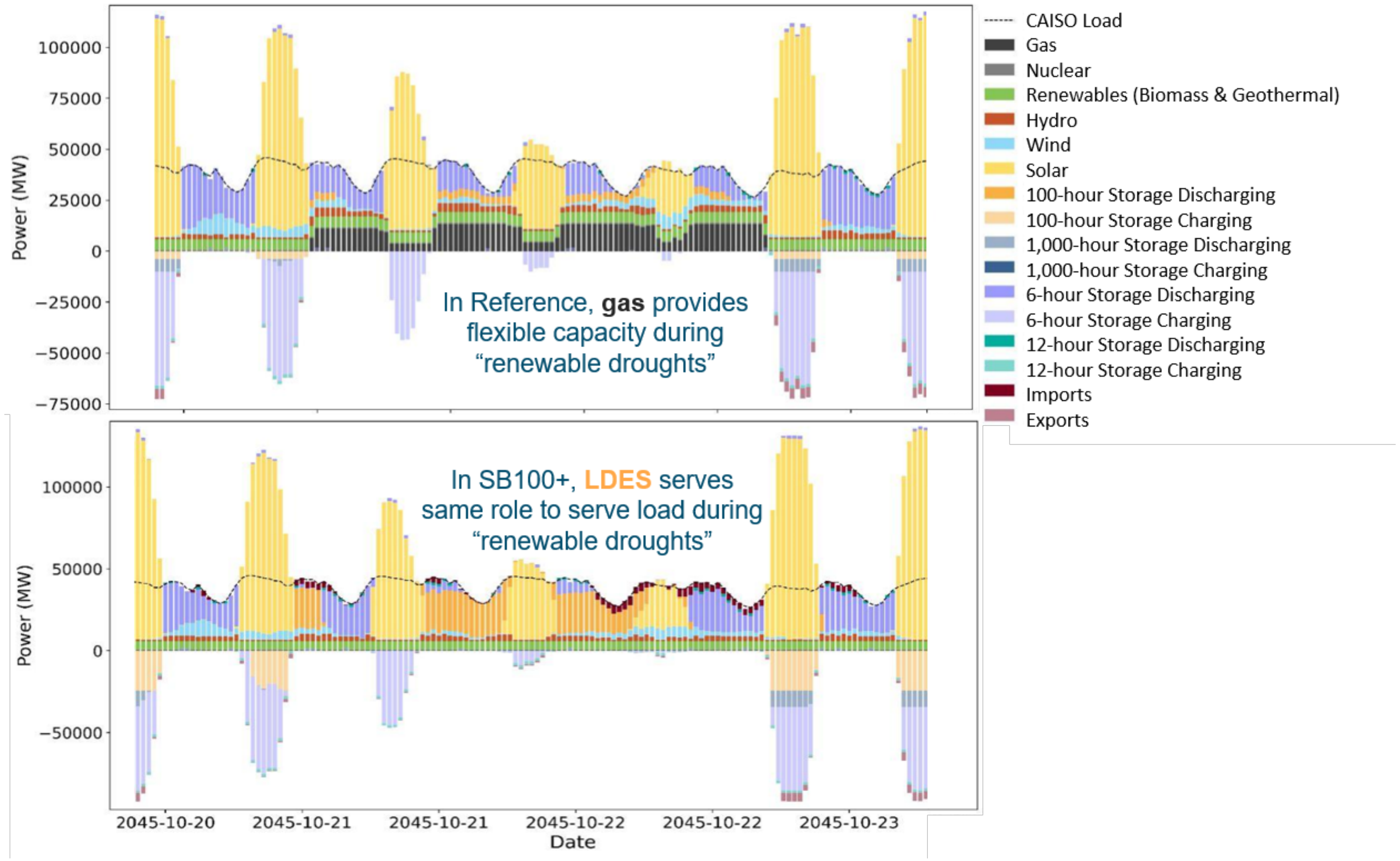


LDES Can Enable System Reliability Through "Renewable Droughts"

+ **LDES of sufficient duration can allow system to ride through "renewable droughts" and preserve system reliability**

+ **Better data & further study of "renewable drought" events needed to understand system operations during these kinds of reliability events**
    - Better data can ensure ELCCs appropriately reflect resource availability during these events

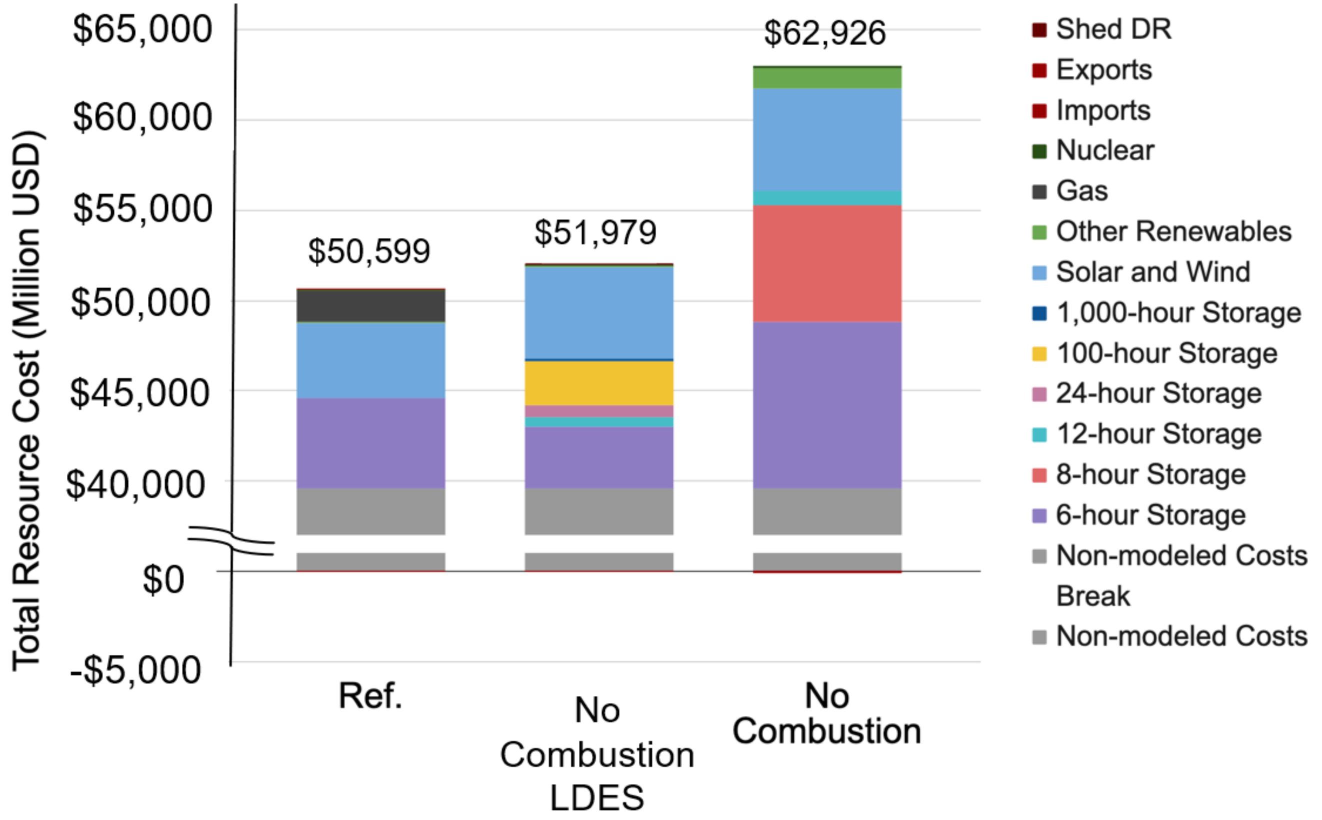
Illustrative "Renewable Drought" Events
(with and without gas capacity and LDES)



"No Combustion" sensitivity shows similar resource selection trends to SB100+ but addresses additional EJ concerns

+ **In the "No Combustion" sensitivity, we further restrict all fuel-burning resource options (gas, biomass, hydrogen) in portfolio**
  - Simulates a policy that prioritizes local air quality impacts
+ **Similar to SB100+ scenarios, LDES options allow model to meet "No Combustion" requirement with:**
  - Similar total portfolio cost relative to Reference scenario
  - Significant reduction in resource procurement relative to "No Combustion" without LDES options

2045 Resource Cost by Sensitivity



Preliminary Takeaways & Next Steps

Key Takeaways

- Long-duration storage provides value in achieving increasingly stringent or accelerating policy targets
  - Going beyond SB100 goals is achievable at near cost parity with the Reference Scenario when LDES is included in the portfolio
  - LDES reduces the total amount of resources needed to meet goals and alleviates build rate needs
- In more stringent scenarios, LDES technologies are valued as a firm capacity resource replacement for existing gas generation
  - Preliminary findings show increasing value for increasing storage durations

Next Steps

- Complete final analysis with New Modeling Toolkit and Formware
- Simulate system operations over wider range of weather years (pending ongoing data development)
  - Additional study needed to understand the operational value of LDES for "renewable droughts", particularly compared to other resource portfolio options
- Use RECAP loss-of-load probability model to study:
  - Reliability of optimized portfolios presented today
  - Refine ELCCs used for storage technologies, particularly in zero-carbon portfolios with limited firm capacity
- Compare value of LDES in CAISO system to other emerging zero-carbon technologies
  - Refine geographic constraint assumptions for emerging storage technologies

Initial New Modeling Toolkit Model Runs

Energy+Environmental Economics

Roderick Go, Technical Manager, E3

Purpose of New Modeling Toolkit Development

+ Goals:

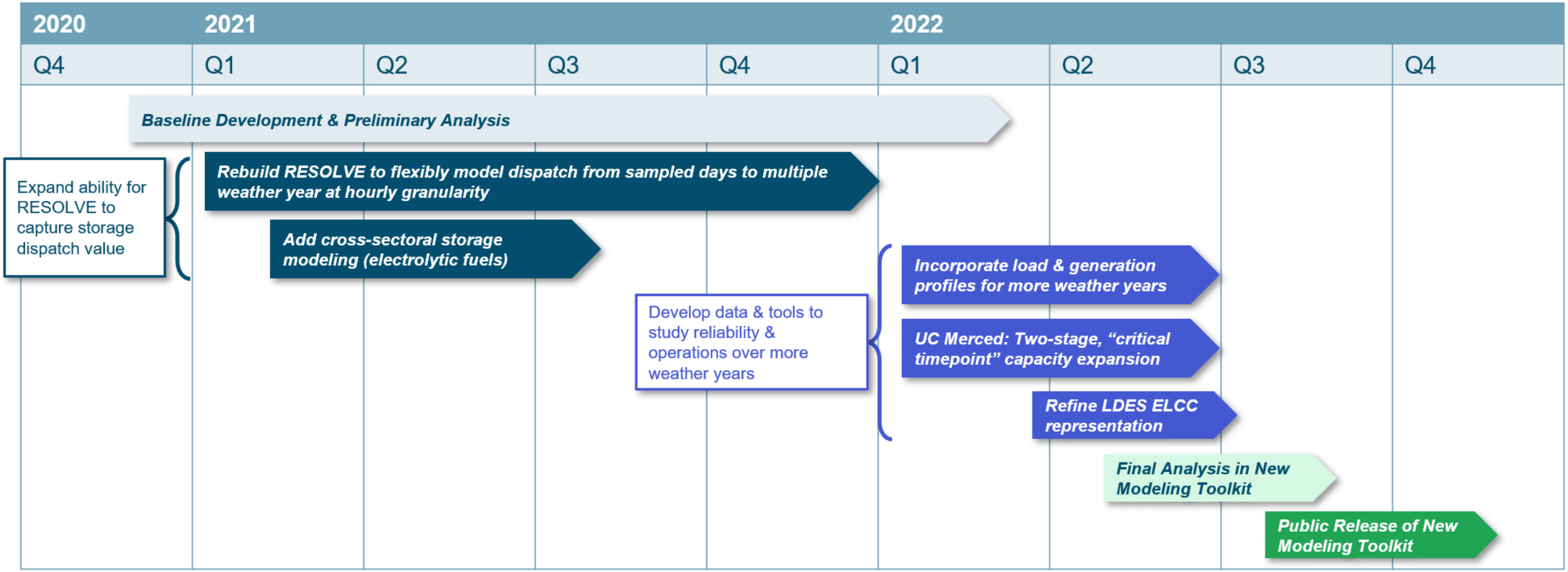
- Develop an updated modeling toolkit that addresses shortcomings of existing capacity expansion modeling, investigating & implementing new time domain reduction techniques to better capture the value of LDES
- Develop an updated dataset of hourly load & renewable profiles, capturing a wider range of weather years to study the value of LDES
- Update from CPUC IRP 2019 Reference System Plan assumptions used in preliminary analysis to latest 2021 Preferred System Plan assumptions to stay aligned with latest California policy analysis

+ Model functionality findings from preliminary analysis

- Chronological dispatch of storage is important to capture LDES value
- 8760-hour dispatch is computationally expensive; for the purposes of preliminary analysis, we focused on "snapshot years" to keep model runtimes reasonable
  - In contrast, the CPUC IRP Preferred System Plan cases typically included 11 modeled years to capture 2022-2045 portfolio build dynamics
- Since RA contribution is a major driver of LDES value in CA portfolio, priority is to refine ELCC values & representation of LDES ELCCs in new modeling toolkit

Status of New Modeling Toolkit Development

- Updated modeling tools (i.e., RESOLVE) enable more detailed study of (a) storage dispatch and (b) reliability impacts of future California resource portfolios in our final analysis phase



How do we reduce the temporal dimension in our models while preserving necessary detail?

What do we do about timeseries sampling for economically-driven long duration energy storage operations (i.e., multi-day and seasonal cycling)?

Introducing some ***new vocabulary***

For discussion purposes, let's operate on units of hours and days (i.e., not multi-day dispatch).

We can segment our full year into 365 ***chronological periods*** (days)

Using statistical timeseries clustering techniques, we can get:

1. A set of ***representative periods*** (like 37 representative days in CPUC IRP RESOLVE)
2. A ***map*** of which chronological periods are represented by which representative periods

If we selected 3 representative periods (1, 5, 363), we can map all 365 days to one of the 3 days:

How does this solve our seasonal storage question?

If we were to model chronological dispatch without sampling, we need **8760 dispatch variables**:

Representative periods capture ***intra-period*** (i.e., hourly) load, wind, solar. For our three representative days, we only need **72 (3 x 24) dispatch variables** to cover all 365 days:

To capture day-to-day shifting, we introduce **365 dispatch variables** that represent the ***inter-period*** energy excess/deficit that we want to shift chronologically in the year. The "full" dispatch for the year is reconstructed as the **sum of the intra- and inter-period** dispatch

365 + 72 dispatch variables is a significant reduction from 8760!

This formulation is supported in the literature

Proof-of-Concept Reduced LDES Dispatch

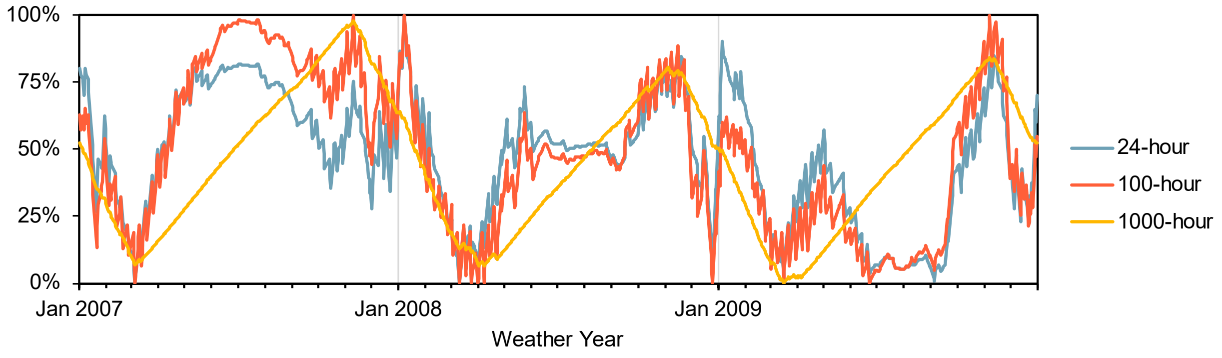
Reference (SB100) Scenario

- **Project team has set up New Modeling Toolkit in preparation for final analysis phase**
  - Model is updated to include 2021 CPUC IRP Preferred System Plan data
- **Initial testing of reduced form dispatch demonstrates good fidelity of seasonal arbitrage patterns**
  - Formulation also has benefit of modeling multiple weather years of system dispatch
  - Additional work will test new functionality (e.g., electrolytic fuels) and continue benchmarking to preliminary modeling
  - Updated formulation yields >3x speed-up in model runtime compared to equivalent 8760-hour cases

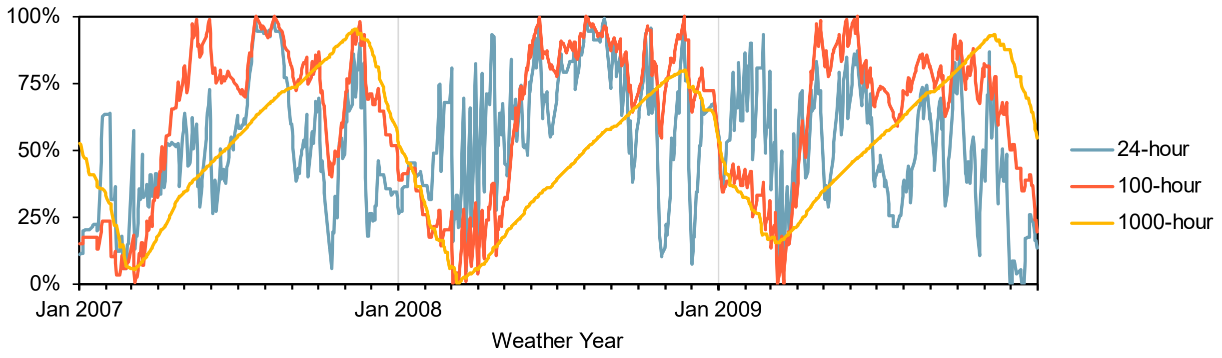
Annual Storage Cycles

	12 Rep. Periods	36 Rep. Periods	8760-hour
Li-ion	327	346	365
24-hour	59	58	74
100-hour	11	10	12.5
1000-hour	<1	<1	<1

New Modeling Toolkit (12 representative periods): LDES State of Charge
(% of Storage Capacity)

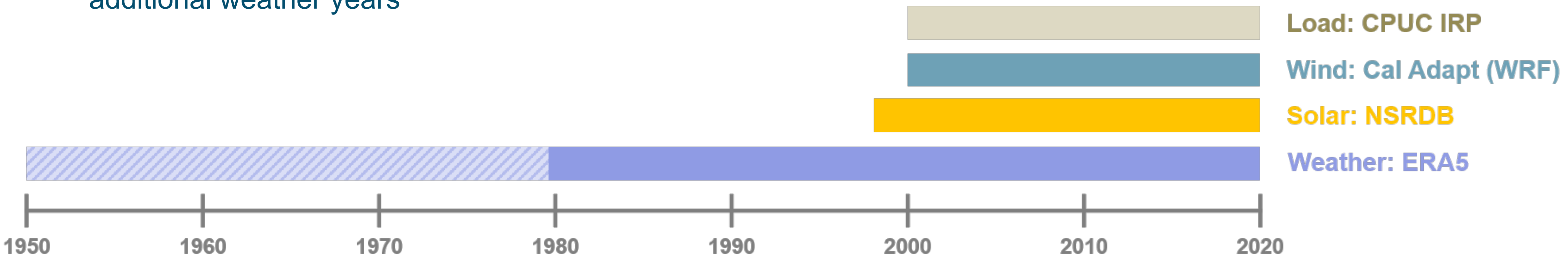


New Modeling Toolkit (36 representative periods): LDES State of Charge
(% of Storage Capacity)



Data Sources for Extended Load & Renewable Profiles

- **The project team is working with relevant CEC and CPUC teams to develop updated load & renewable profiles to study of the CAISO system over more weather years (~2000-2020)**
  - Project team is also evaluating value of correlating load & renewables with longer weather datasets (ERA5) to study additional weather years



- **Additional data will allow us to study:**
  - **Energy vs. capacity value:**
    In principle, ELCCs should reflect a resource's availability to serve load to maintain reliability over many weather years. How do we understand ELCC vs. economic dispatch value over many weather years?
  - **Storage dispatch over many weather years:**
    Dowling, et al study over many weather years (using MERRA-2 data). Can we better understand the impact of perfect foresight assumptions in our models on LDES value over many weather years?

Preliminary Microgrid Study

CER
Center for Energy Research

Energy+Environmental Economics

Dr. Ryan Hanna, Research Scientist, UCSD

Research Question & Aims

Research Questions

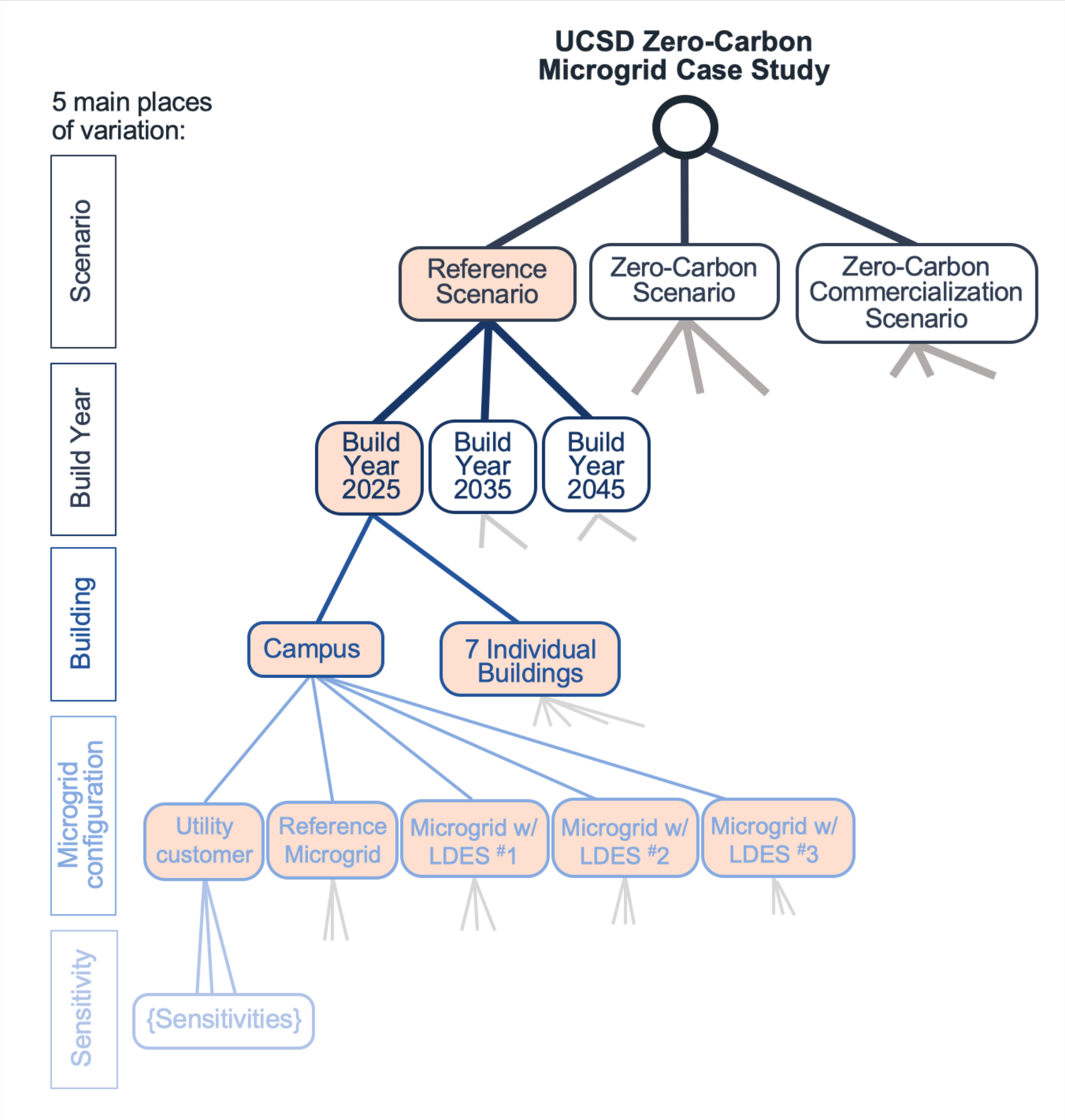
- **Broadly: what is the role for LDES in enabling zero-carbon microgrids?**
- **For Preliminary Analysis, goals were to develop the model and model the reference microgrid case**

Approach

- **Case study using UC San Diego campus**
- **Model least-cost DER portfolios that include various LDES technology options**
- **Within these microgrid portfolios, identify the role(s) for LDES**
  - Technological: how does it affect other *DER choices*?
  - Economic: does it help to lower system *lifecycle cost*?
  - Does it lead to electric *reliability* improvements?
- **Explore alternative scenarios in which the role for LDES may substantially change/grow**
  - New blue-sky revenue streams (i.e., market access) made available to a microgrid
  - Policy requirements for low- or zero-carbon in microgrids

UCSD Microgrid Case Study

+ **Scenarios frame key policy decisions**
  - CO_2 constraints; revenue streams
+ **UCSD campus and individual campus buildings**
  - Hourly building load & critical load; vary in size, rooftop space, existing DERs
+ **Build years**
  - 2025, 2035, 2045
+ **Microgrid configurations vary in use of LDES**
  - 8-h, 12-h, and 100-h LDES systems
+ **Sensitivities capture exogenous variables**
  - Frequency of PSPS; cost of LDES; demand for reliability

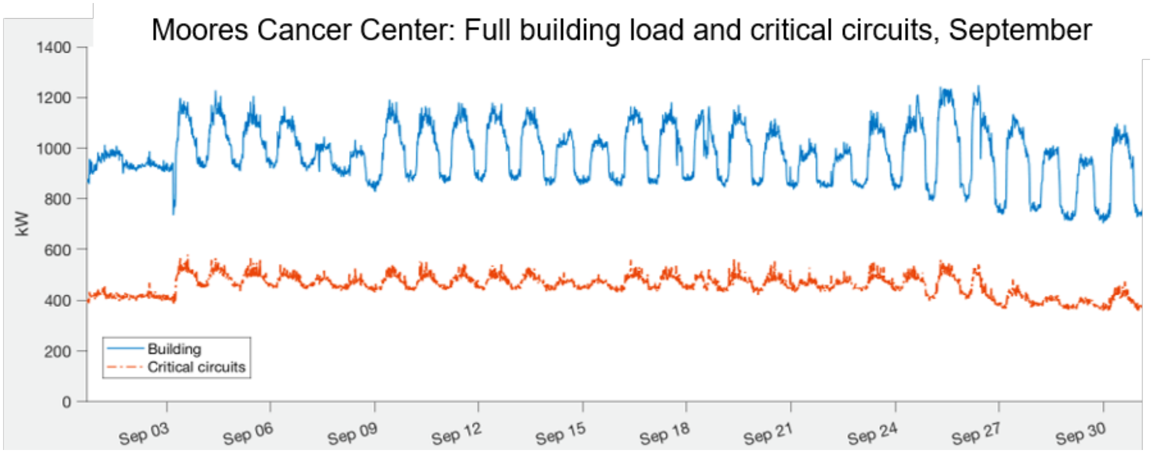


UCSD Microgrid Case Study, cont'd

- **Scenarios frame key policy decisions**
  - CO_2 constraints; revenue streams
- **UCSD campus and individual campus buildings**
  - Hourly building load & critical load; vary in size, rooftop space, existing DERs
- **Build years**
  - 2025, 2035, 2045
- **Microgrid configurations vary in use of LDES**
  - 8-h, 12-h, and 100-h LDES systems
- **Sensitivities capture exogenous variables**
  - Frequency of PSPS; cost of LDES; demand for reliability

Building	Annual Load (GWh)	Peak Load (kW)	Average Daily Load Factor [a] (–)	Has Critical Circuits?	Average Critical Load (% of full building load)
Campus	297	47,600	0.94	No	–
Individual Buildings					
Moores Cancer Center	8.3	1,200	0.87	Yes	47%
Biomedical Research II	7.5	1,030	0.92	Yes	39%
Pharmacological Sciences	6.7	1,040	0.88	Yes	32%
Cellular & Molecular Medicine W	3.5	460	0.94	Yes	10%
Center Hall	1.0	210	0.79	No	–
Robinson Hall	0.8	140	0.90	No	–
Pepper Canyon	0.5	110	0.78	No	–

[a] The load factor is the ratio of average load to peak load and is calculated for each of 365 days in the year, and the average is presented here.



For details on the UCSD campus microgrid, see:
Silwal et al. 2021, *J. Renewable and Sustainable Energy*

UCSD Microgrid Case Study, cont'd

- **Scenarios frame key policy decisions**
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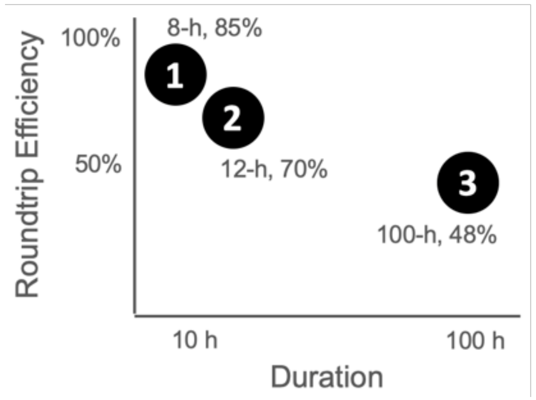
Name	Baseline DER Investment [a]	Incremental Forced DER Investment
Utility customer	None	None
Microgrid reference case	Any DER	None
Microgrid, with LDES #1	Any DER except LDES	LDES: 8 h, 85% RTE
Microgrid, with LDES #2	Any DER except LDES	LDES: 12 h, 70% RTE
Microgrid, with LDES #3	Any DER except LDES	LDES: 100 h, 48% RTE

[a] DERs available for investment include backup diesel gensets, gas-fired gensets, gas-fired fuel cells, solar PV, Li-ion energy storage, and long-duration storage. In future scenarios with limits on CO_2 emissions, we have the option to include decarbonized gaseous fuels

Key features of the 3 LDES types



Modeling DER Deployment in Microgrids

UCSD Microgrid Model

+ **Two main functions:**
  1. Determines least-cost DER investment & operation: capacity expansion & economic dispatch model for DERs in a microgrid
  2. Evaluates reliability: 8760-h sequential Monte Carlo simulation to simulate power outages, calculate electric reliability

For details on the model, see:
Hanna et al. 2019, *J. Renewable and Sustainable Energy*
Hanna et al. 2018, *PMAPS*

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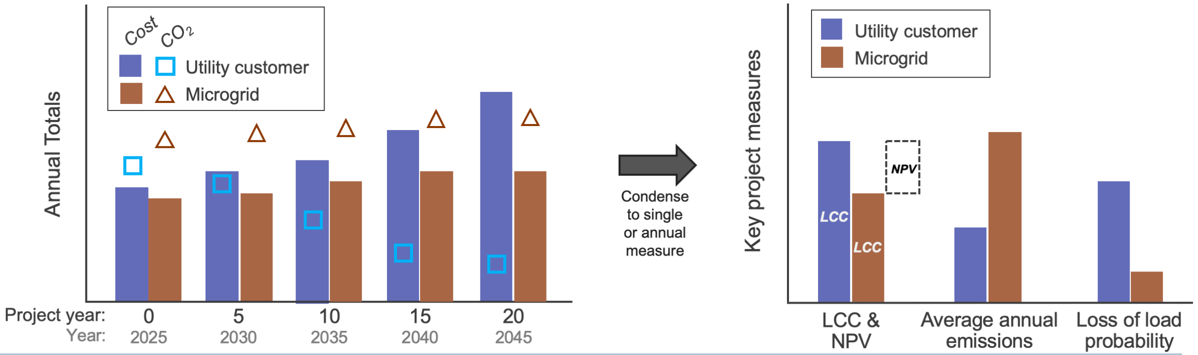
$$\begin{aligned} \text{minimize} \quad & C_{\text{total}}(\boldsymbol{x}, \boldsymbol{y}) := C_{\text{investment}}(\boldsymbol{x}) + C_{\text{operation}}(\boldsymbol{x}, \boldsymbol{y}) - R(\boldsymbol{y}) \\ \text{subject to} \quad & \text{physical constraints} \\ & \text{DER, resource, and fuel availability constraints} \\ & \text{reliability and resilience constraints} \\ & \text{financial constraints} \\ & \text{emissions constraints} \\ & \text{policy constraints} \end{aligned}$$

where $\boldsymbol{x}$ is the set of DER capacities; $\boldsymbol{y}$ are operational set points for DERs and energy purchases; and $R(\boldsymbol{y})$ are revenues.

The total lifecycle cost C_{total} is the present value of all costs that accrue over the project lifetime T:

$$C_{\text{total}}(\boldsymbol{x}, \boldsymbol{y}) := \sum_{t=0}^{T} \frac{C_{\phi}(\boldsymbol{x}, \boldsymbol{y}, t)}{(1+r)^t}$$



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Stochastically simulates grid downtimes for momentary, sustained, and PSPS outages…

…which are known from likelihood and duration probability distribution functions.

Measures the microgrid's ability to withstand this variety of grid outages.

Calculates reliability indices:

- number of interruptions per year
- hours of interruption per year
- unserved energy

For details on the model, see:
Hanna et al. 2019, *J. Renewable and Sustainable Energy*
Hanna et al. 2018, *PMAPS*

Modeling DER Deployment in Microgrids

UCSD Microgrid Model

+ **Two main functions:**
    1. Determines least-cost DER investment & operation: capacity expansion & economic dispatch model for DERs in a microgrid
    2. Evaluates reliability: 8760-h sequential Monte Carlo simulation to simulate power outages, calculate electric reliability
+ **Core outputs:**
    - DER investment & operation
    - Utility electricity & gas purchases
    - Total system cost, system reliability, CO_2 emissions
    - Shifts in cost ($) and reliability (unserved load; kWh) → "effective" or "implied" VOLL ($/kWh)

For details on the model, see:
Hanna et al. 2019, *J. Renewable and Sustainable Energy*
Hanna et al. 2018, *PMAPS*

Modeling Reliability, PSPS, & Other Outages

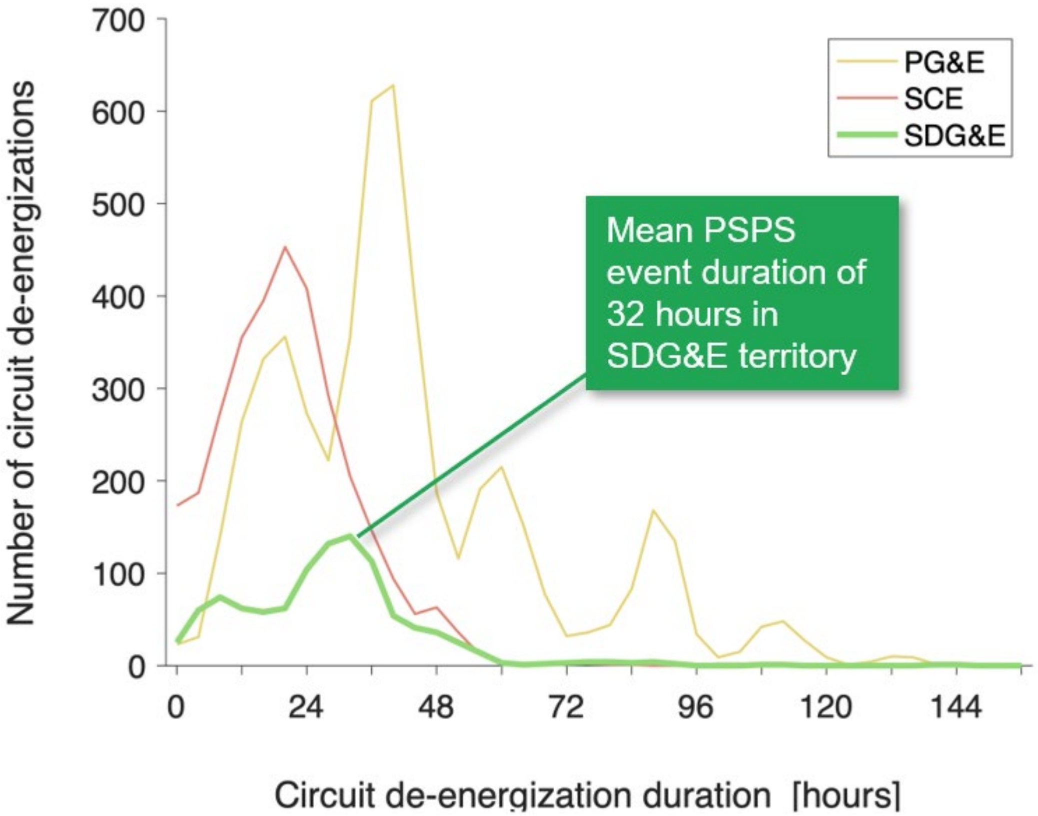
Reliability

- **Modeled as a** minimum *islanding requirement***—a duration for which the microgrid, when islanded, must be capable of carrying critical loads**
- *VOLL* **is not input directly to the model; rather, it is back-calculated based on shifts in energy cost and electric reliability from investing in the microgrid**

PSPS and other outages

- **PSPS data are reported to the CPUC – cpuc.ca.gov/psps/**
- **Momentary and sustained outages are reported to the EIA – eia.gov/electricity/data/eia861/**

PSPS Event Length by Utility Service Territory



Preliminary Microgrid Study

Results for the Reference Case

Center for Energy Research

Energy+Environmental Economics

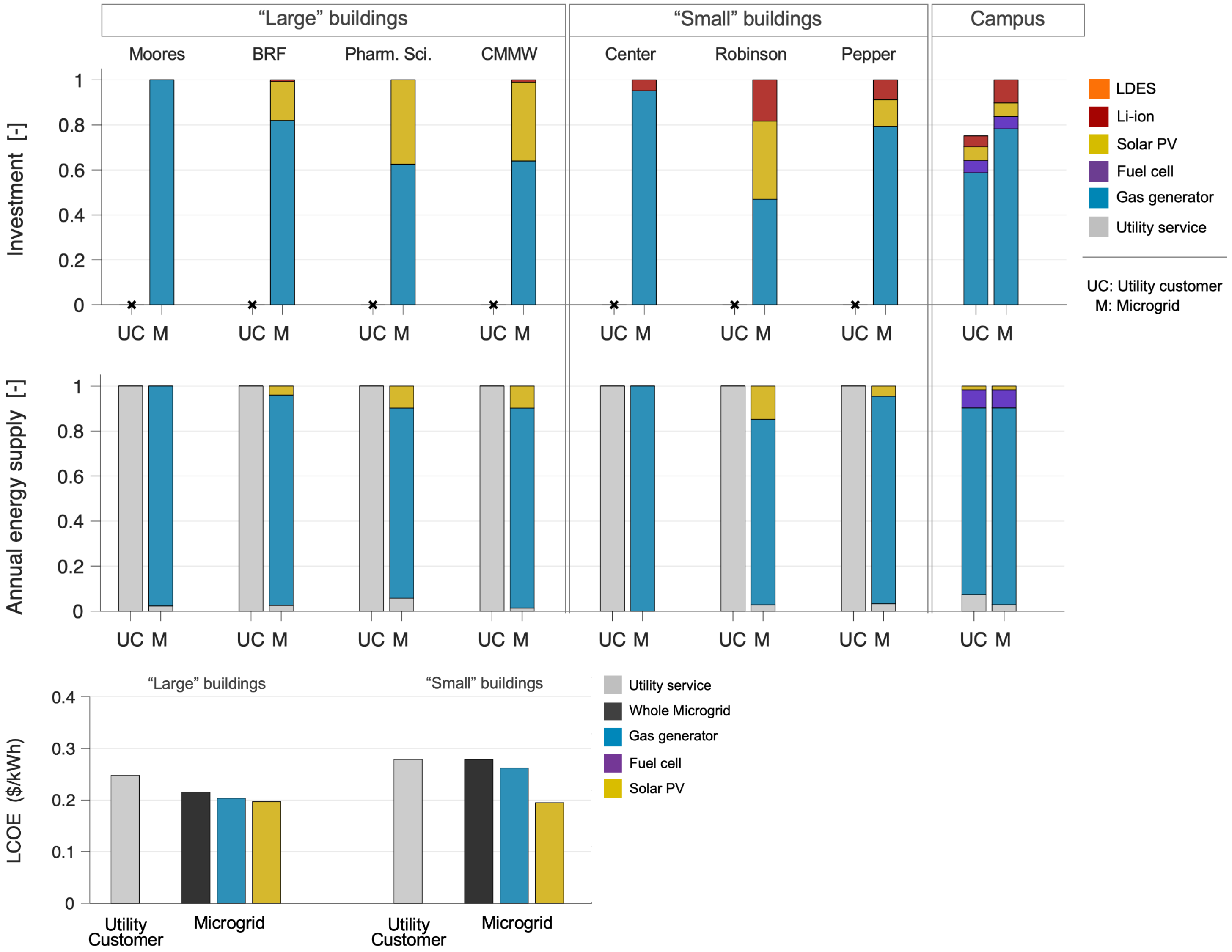
Executive Summary: Reference Case

+ **LDES is not selected as part of the optimal DER portfolio**
  - Optimal mix includes gas gensets, PV, and Li-ion
+ **When added to the portfolio, LDES...**
  - does not reduce lifecycle cost (LCC)
  - reduces reliance on gas, increases use of solar PV, and hence leads to lower emissions—but effects are small
  - often increases reliability

Scenario	Building Type	LDES Type (duration, RTE)	Lowers LCC?	Lowers CO_2 Emissions?	Increases Reliability?
Policy today: no CO_2 constraints	Campus *(very large; all load is critical)*	8 h, 85%	X	✓	X
		12 h, 70%	X	✓	X
		100 h, 48%	X	✓	✓
	Large building *(partial critical load)*	8 h, 85%	X	✓	✓
		12 h, 70%	X	✓	✓
		100 h, 48%	X	✓	✓
	Small building *(all load is critical)*	8 h, 85%	X	●	●
		12 h, 70%	X	●	●
		100 h, 48%	X	●	✓

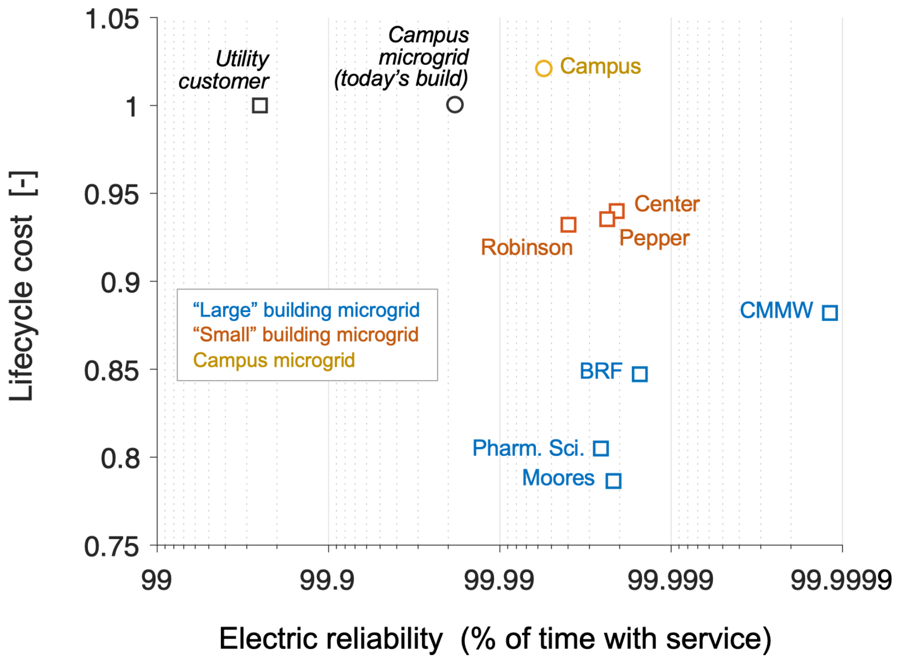
Least-cost DER Selection & Energy Supply

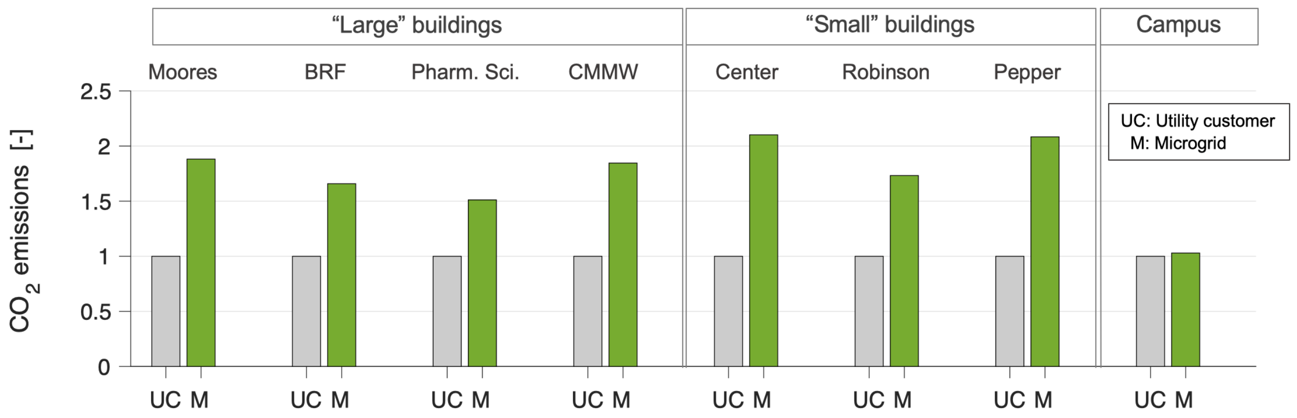
- **Model selects chiefly gas generation**
  - Some solar PV, little Li storage complement gas
  - Campus is space-constrained—cannot add more rooftop PV
- **Model does not select LDES**
- **With relatively cheap gas and high electric rates, the microgrid…**
  1. reduces utility bills during blue-sky days
  2. meets minimum islanding requirements because it protects against long-duration outages



Lifecycle Cost & Reliability; CO_2 Emissions

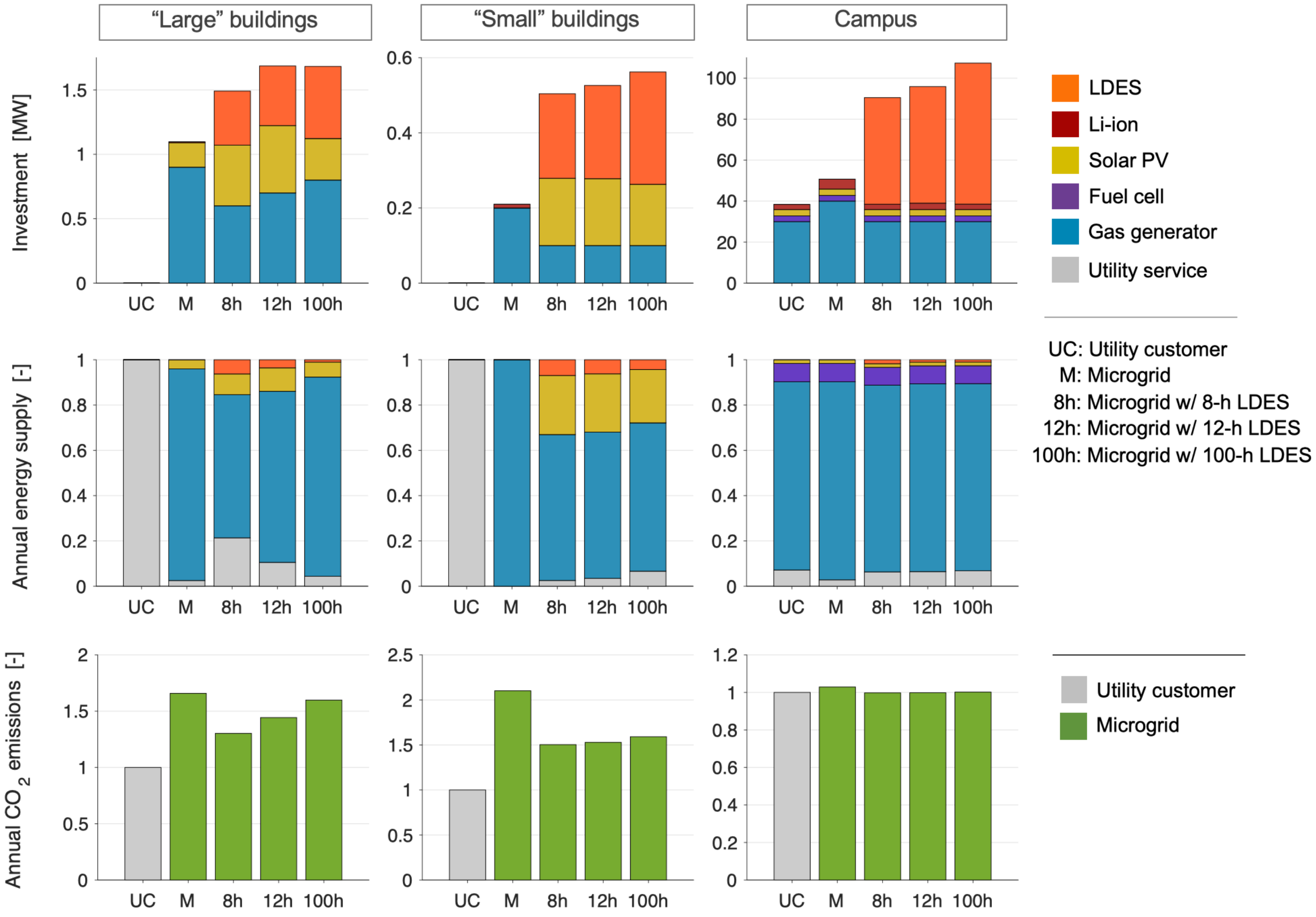
- **For every building, the shift to microgrids increases electric reliability while reducing lifecycle cost**
  - “Blue sky”–”black sky” synergy: energy cost savings while the grid is up; reliability benefits if it fails
  - ~99% or greater reduction in expected outage downtime
- **Shifts to gas increase CO_2 emissions—which are made worse as the bulk grid decarbonizes over the 25-y microgrid lifetime**
  - 50–100% increase in lifecycle CO_2 emissions





Forcing Investment in LDES

+ **LDES is added to the microgrid*; model re-selects DERs around it**
  - 8 h, 85% RTE
  - 12 h, 70% RTE
  - 100 h, 48% RTE
+ **Adding LDES leads to:**
  - A shift away from gas, albeit small
  - Increased investment in solar PV
  - Lower CO_2 emissions, albeit marginally
+ **However, increasing storage duration actually leads to a reversion to gas—longer duration LDES has lower RTE and so is used less**



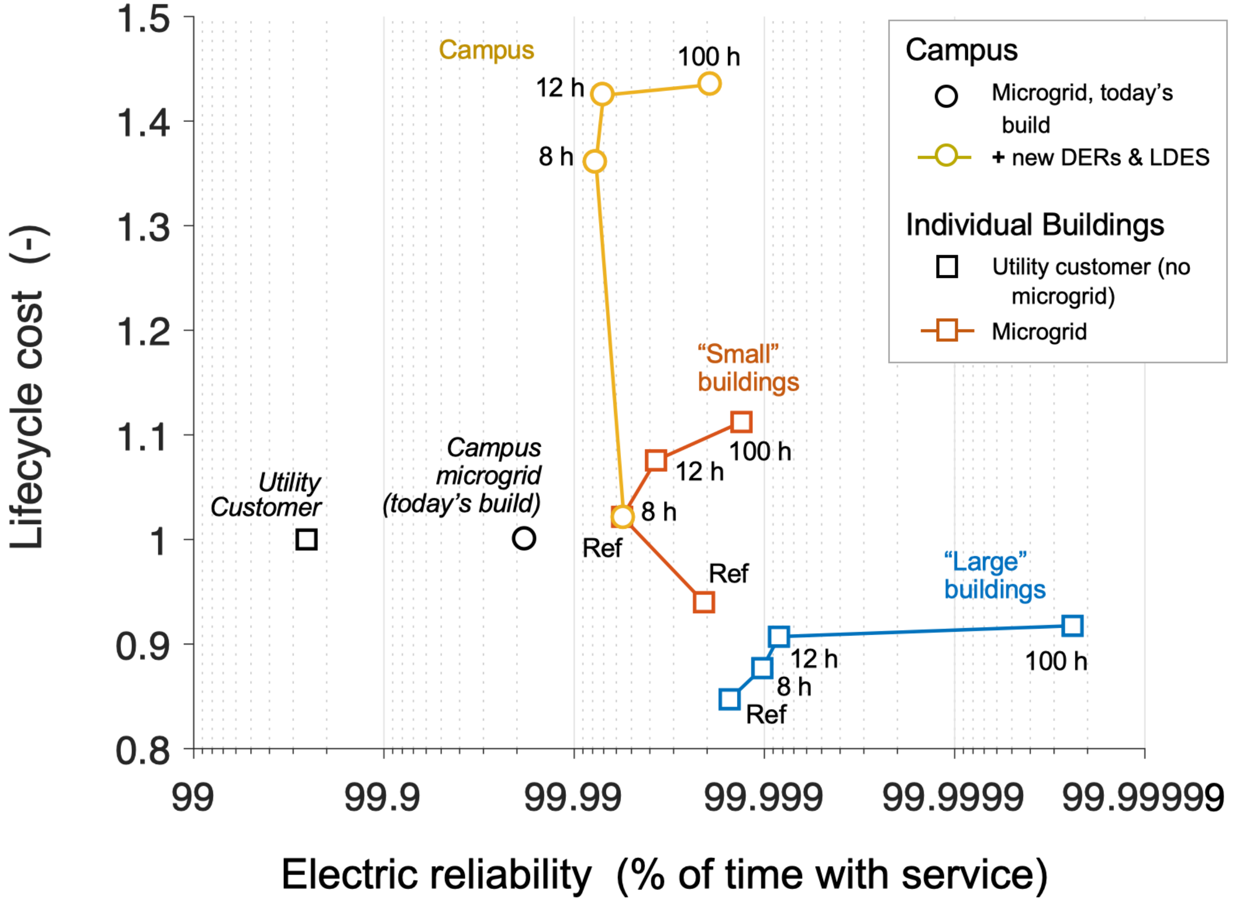
* Sized to meet critical load

Forcing Investment in LDES, cont.

- **Adding LDES leads to:**
  - Higher reliability (generally but not always) and higher lifecycle cost

- **The Reference microgrids already increase reliability significantly—mitigating ~99% of downtime**
  - There is therefore only a small margin for improvement when adding LDES

- **LDES looks most economic with large buildings that have partial critical load—due to smaller LDES sizing and cost**

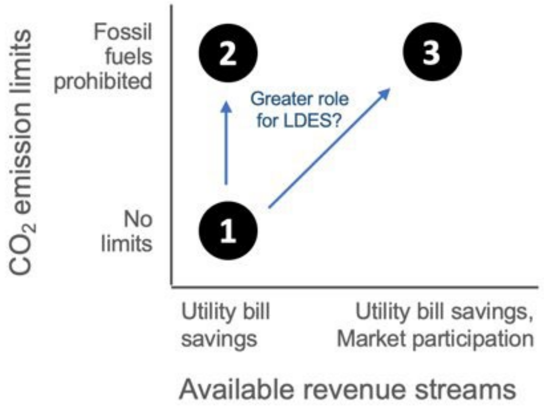


Key Trends & Next Steps

Preliminary Trends

- Under conditions today*, gas gensets are the basis for cost-effective, reliable microgrids
  - Tradeoff is increased CO2 emissions—suggesting a role for policy interventions to make low-carbon alternatives economically attractive
- There is no clear **techno-economic role** for LDES—because gas is economic
  - LDES, even when zero cost, is cycled minimally and has only small effect on other DER choices
- However, it's clear that LDES can play a **reliability role**
  - With limits on CO2, LDES could be an important complement alongside PV and Li storage.
- There's also potential for LDES to support grid reliability through exports

Next Steps



- (2) Explore how carbon constraints impact the role for LDES
  - **Question: Through which policies should we explore possible shifts away from fossil gas use?**
- (3) Explore how microgrid market participation impacts the business case of microgrids and role for LDES and how

* Relatively cheap gas and high electricity rates; no constraints on CO_2

Where We Are Heading Next

Scenario or Sensitivity	Scenario Configuration	Expected Impact on Deployment of LDES
"Reference" Scenario	Today's policy environment	—
Sensitivities		
Higher demand for reliability	–	▼: Longer islanding requirements met with fossil gas generation
More frequent PSPS	–	▼: Fossil gas microgrids appear even more reliable & cost-effective
More severe PSPS events	–	▼: Fossil gas microgrids appear even more reliable & cost-effective
"Zero-carbon" Scenario	Fossil gas limits + decarbonized gaseous fuels	▲: High cost of decarbonized fuels tilts investment toward PV+Li-ion with a reliability role for long-duration storage
	CO_2 taxes	▲: Higher cost of gas generation tilts investment toward PV+Li-ion with a reliability role for long-duration storage
"Zero-carbon commercialization" Scenario	Includes additional revenue streams (e.g., ancillary services)	▲▼: Encourages greater uptake of Li-ion storage, which can efficiently cycle to meet AS dispatch curves; lesser change in LDES investment relative to Reference

General Discussion

Energy+Environmental Economics

Key Trends & Unknowns

Next Steps

- **Bulk System Study**:
  - Transition to New Modeling Toolkit for final analysis phase, modelling all years at hourly granularity
  - Produce simulations over wider range of weather years, incorporating impacts from climate change into renewable generation profiles and loads
  - Use RECAP loss-of-load probability model to study:
    - Asset reliability of optimized portfolios
    - Refine ELCCs used for storage technologies, particularly in zero-carbon portfolios
  - Compare value of LDES in CAISO system to other emerging zero-carbon technologies
- **Microgrid Study**:
  - Develop scenarios to test the value of LDES in carbon constrained microgrids
  - Develop scenarios which allows excess generation to be sold into the wholesale market

Stakeholder Questions

- **Do stakeholders have any feedback on the scenario & additional analysis that the project team is proposing to study for the final analysis phase?**
- **Are there other way to present or visualize the results to clarify the value proposition of LDES?**
- **Bulk System Study**:
  - Are there other key features, scenarios, or conditions beyond what has been identified that should be considered?
- **Microgrid Study**:
  - Are there any sizeable value propositions not being captured by the scenarios? Are there other distribution reliability solutions we should be comparing to?
  - Through what policy means should we explore possible shifts away from fossil gas use for microgrids?

Appendix

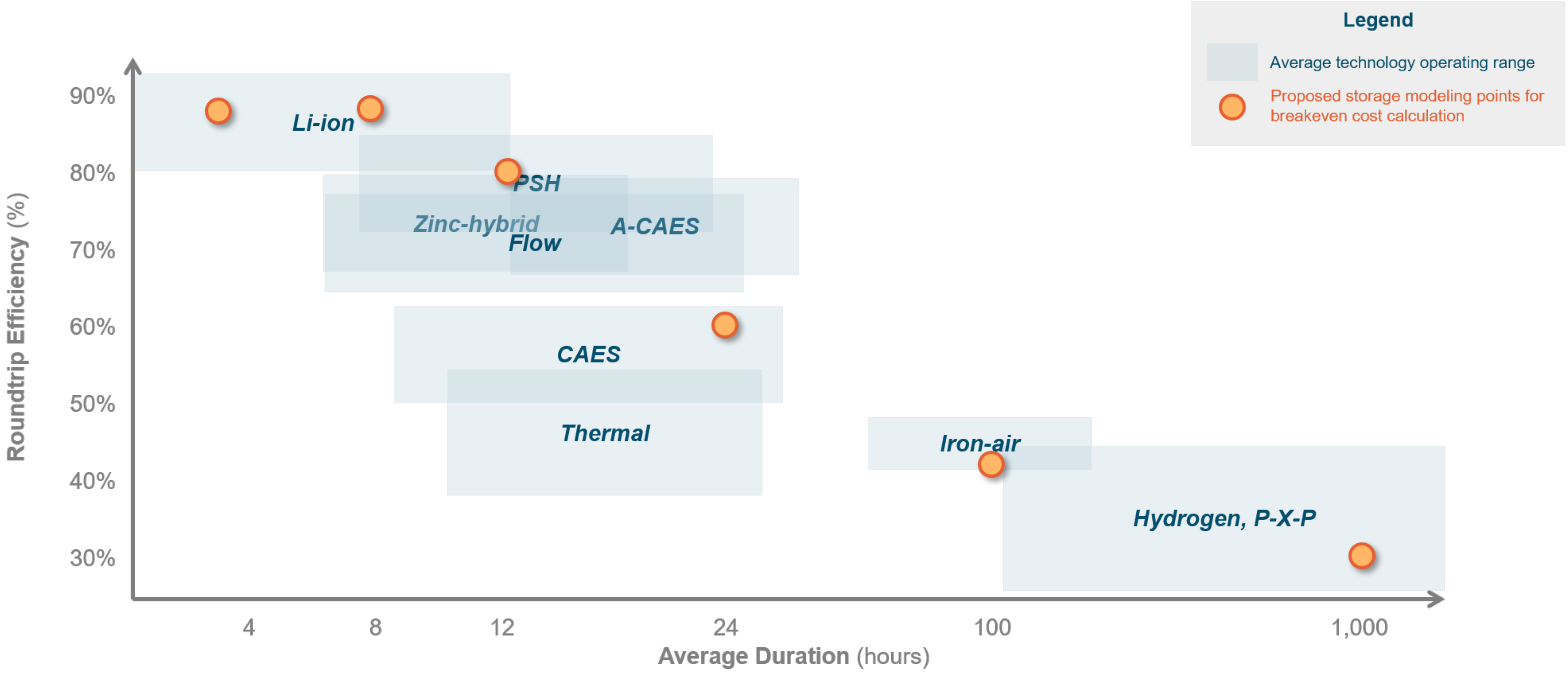
Review of Reference System Plan Assumptions

+ **Technologies (new build) allowed: thermal (gas CC, CT, reciprocal engine), renewables (onshore wind, solar, geothermal, biomass), storage (Li-ion battery, flow battery, pumped hydro), shed DR**
  - Note: RESOLVE benchmarking case is based on the Transmission Planning Process (TPP) 46 MMT scenario published in December 2020, which does not allow offshore wind
+ **Policy: SB100**
+ **Electric Sector GHG target: 46 MMT statewide by 2030**
+ **PRM assumptions**
  - **1-in-2 peak:** 2030: 55.8 GW; 2045: 60.4 GW
  - **15% planning reserve margin** on top of 1-in-2 peak
+ **Formware benchmarking focus on 2030 & 2045**
  - Our work on preliminary analysis started before 2021 IRP PSP was released, so note that we are referencing the older RSP. Final analysis will have us realigning with latest applicable datasets

Storage ELCC Assumptions

Storage Duration (hr)	Roundtrip Efficiency (%)	Tranche	2035 Marginal ELCC (%)	2045 Marginal ELCC (%)
4-6	85%	0-6 GW	75%	75%
4-6	85%	6-15 GW	50%	50%
4-6	85%	15-21 GW	25%	25%
4-6	85%	21+GW	6%	6%
8	70%	0-1 GW	72%	72%
8	70%	1-5 GW	53%	53%
8	70%	5-10 GW	35%	35%
8	70%	10+GW	15%	15%
12	81%	1-4 GW	75%	75%
12	81%	4+ GW	40%	40%
24	60%	0-1 GW	90%	80%
24	60%	1-5 GW	75%	60%
24	60%	5-10+GW	50%	40%
100	42%	0-5 GW	100%	100%
100	42%	5-10+GW	75%	50%
1,000	25%	0-5 GW	100%	100%
1,000	25%	5-10+GW	80%	60%

Reducing the problem space for preliminary analysis



Previous Grant Materials

- 1st Public Workshop (December 3, 2020)
  Project Introduction & Goals
- 2nd Public Workshop (June 30, 2021)
  Preliminary Data Development & Scenario Selection

UCSD Microgrid Case Study, cont'd

- **Scenarios frame key policy decisions**
- **UCSD campus and individual campus buildings**
  - Hourly building load & critical load; available rooftop space
  - Existing DERs
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- **Microgrid configurations vary in use of LDES**
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- **Sensitivities capture exogenous variables**
  - Frequency of PSPS (public safety power shutoffs)
  - Cost of LDES
  - Demand for reliability

Scenario	CO_2 Constraints	Available Revenue Streams	Comments
1. Reference	None	Utility bill savings	Reflects conditions today
2. Zero-carbon	Limits on direct CO_2 emissions	Utility bill savings	Reflects a move to limit carbon emissions
3. Zero-carbon commercialization	Limits on direct CO_2 emissions	Utility bill savings, market participation (energy, AS)	Reflects a move to limit carbon emissions and parallel efforts to open new markets for DERs and microgrids

Reference Scenario modeling includes:

- No incentives
- Historical PSPS rates
- Existing DER build on campus

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2025, 2035, and 2045.

Capture multiple shifts in exogenous model parameters:

- DER costs
- Utility electricity and gas rates
- Grid marginal emission factors

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Other potential drivers for LDES in microgrids

- Economic (LDES cost)
- Reliability
  - PSPS rates and severity
  - Demand for reliability: operable hours in islanded mode