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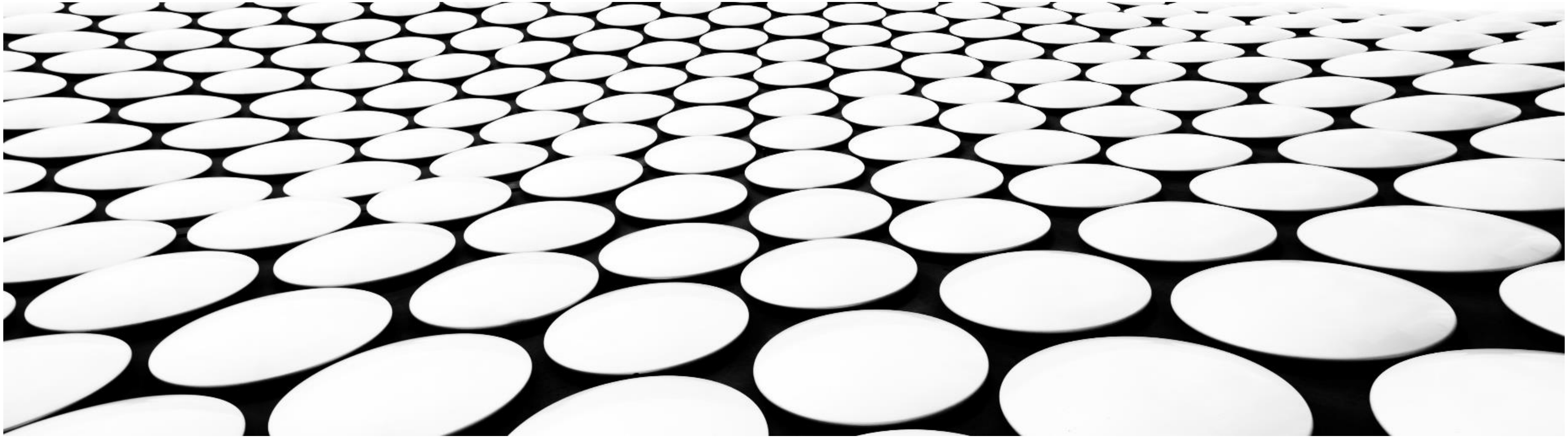

CHBC WEBINAR: LONG-DURATION ENERGY STORAGE: KEY TO ACHIEVING SB 100

OCTOBER 20, 2020

WEBINAR SPEAKERS

Diane Moss
Deputy Director
California Hydrogen Business Council

Dr. Nathan Lewis
Professor of Chemistry
California Institute of Technology

Jacqueline Dowling
Chemistry PhD Candidate
California Institute of Technology

Katherine Rinaldi
Graduate Research Assistant
California Institute of Technology

Dr. Josh Eichman
Senior Research Engineer
National Renewable Energy Laboratory

Dr. Jeff Reed
Chief Scientist
Advanced Power & Energy Program at UC Irvine

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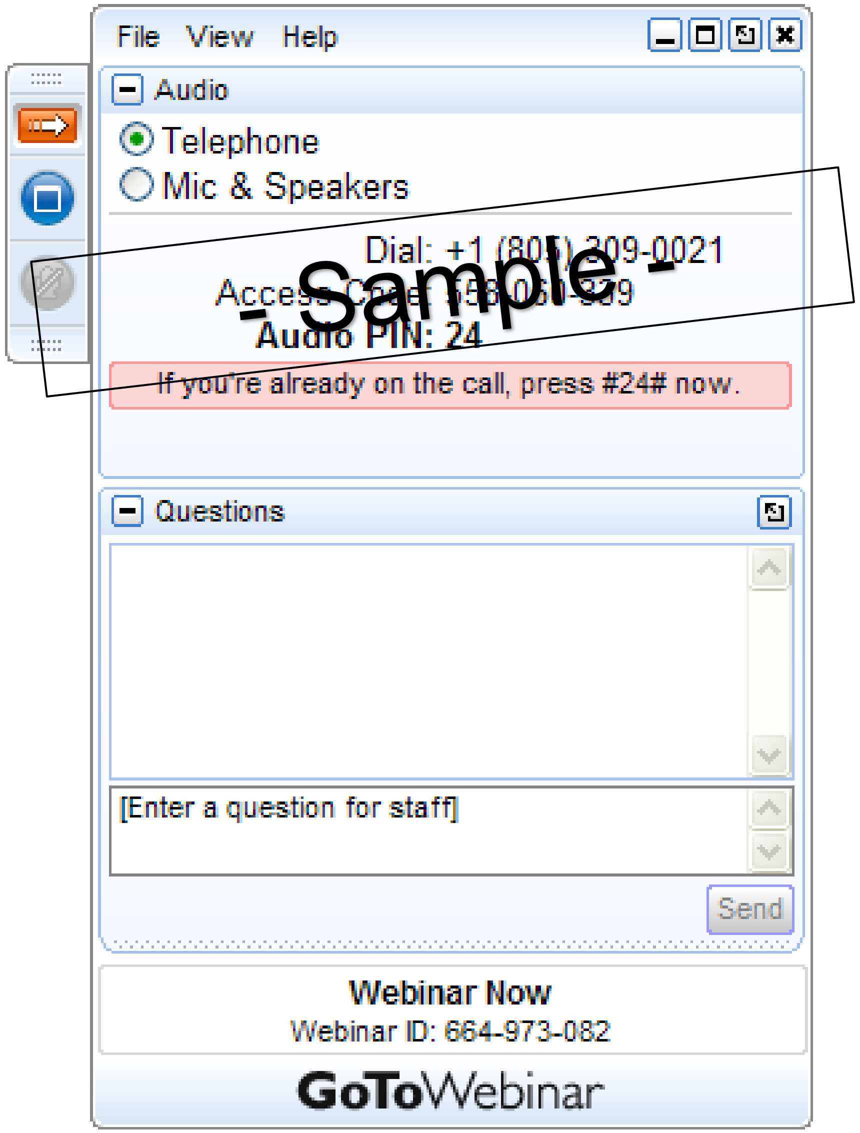

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ENERGY STORAGE AND RENEWABLE HYDROGEN

CALIFORNIA HYDROGEN BUSINESS COUNCIL

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  - CHBC is committed to advancing the commercialization of hydrogen in the energy and transportation sectors to achieve California's climate, air quality, and decarbonization goals.
- **Our Mission:**
  - Provide clear value to our members and serve as an indispensable and leading voice in promoting the use of hydrogen in the utility and transportation sectors in California and beyond.
- **Our Principals:**
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- **Our Objectives:**
  - Enhance market commercialization through effective advocacy and education of policymakers and policy influencers
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  - Accelerate market growth via networking opportunities and information exchange for the industry and its customers

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- Track record of success
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TOGETHER WE CAN INFLUENCE PUBLIC POLICY AND GROW YOUR BOTTOM LINE

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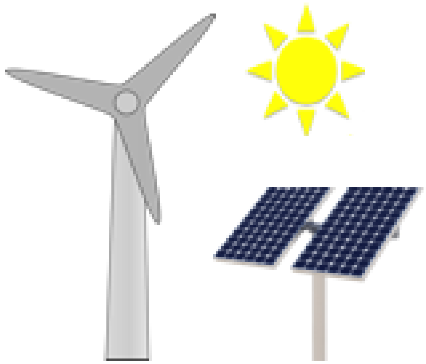
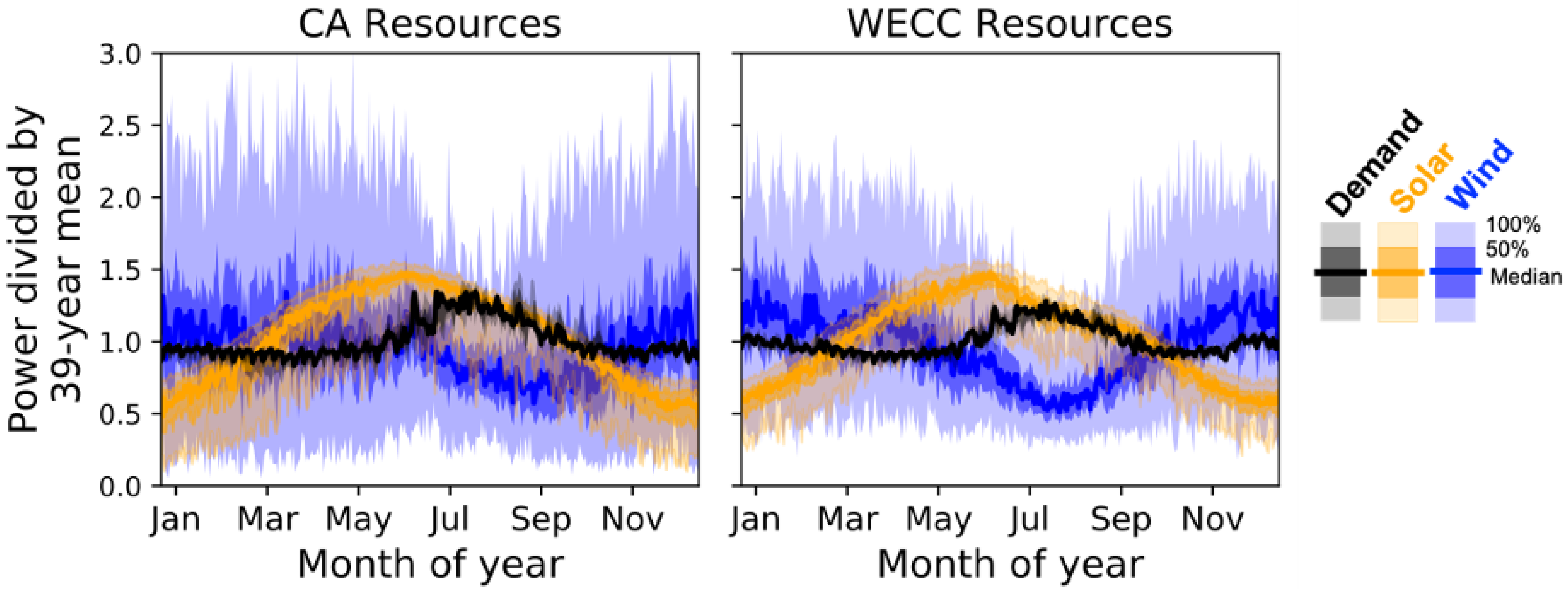
Evaluating a 100% reliable, 100% renewable electricity system for California



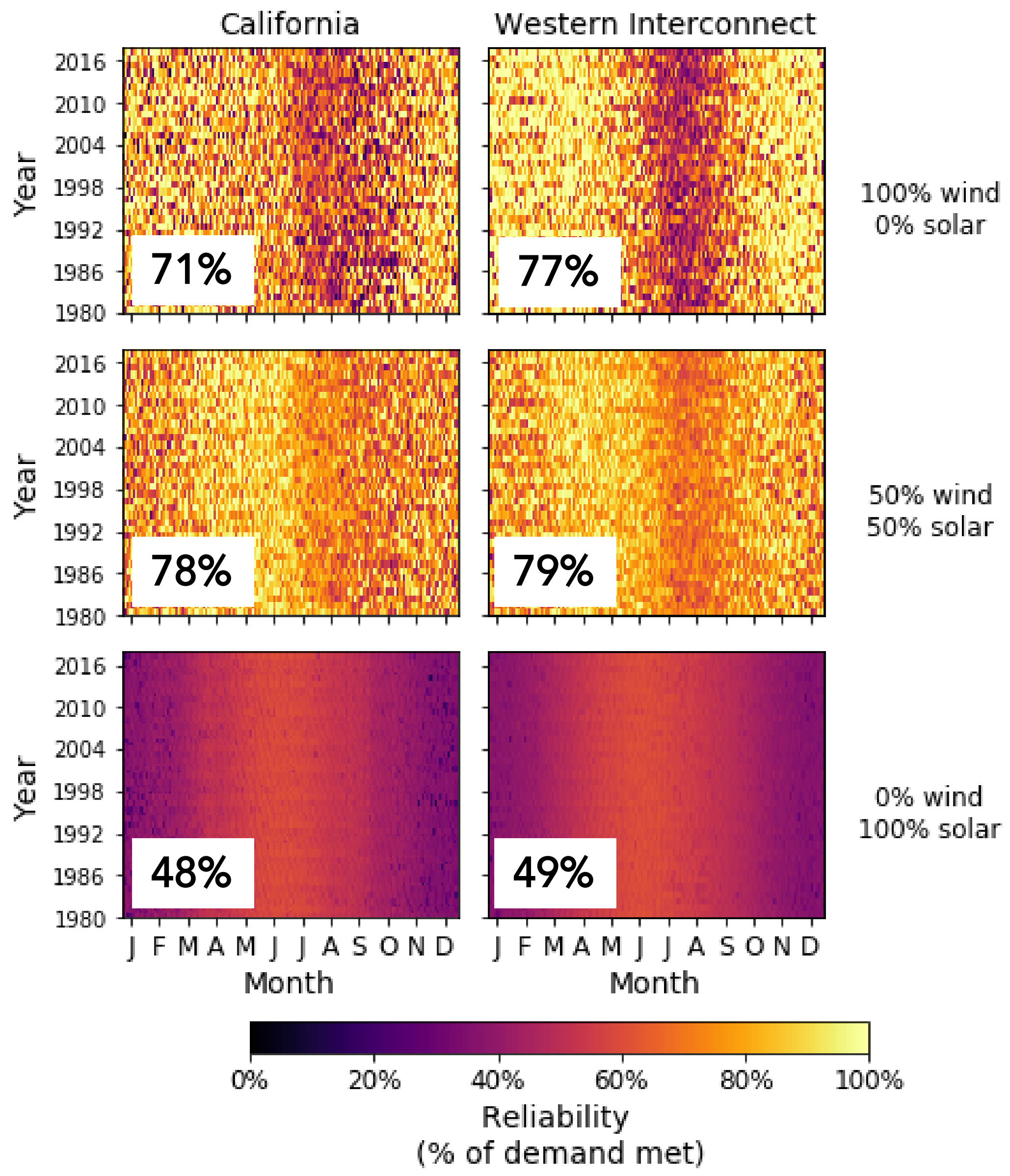
Nathan Lewis
Kat Rinaldi
Jackie Dowling
Ken Caldeira

Comparing Variability



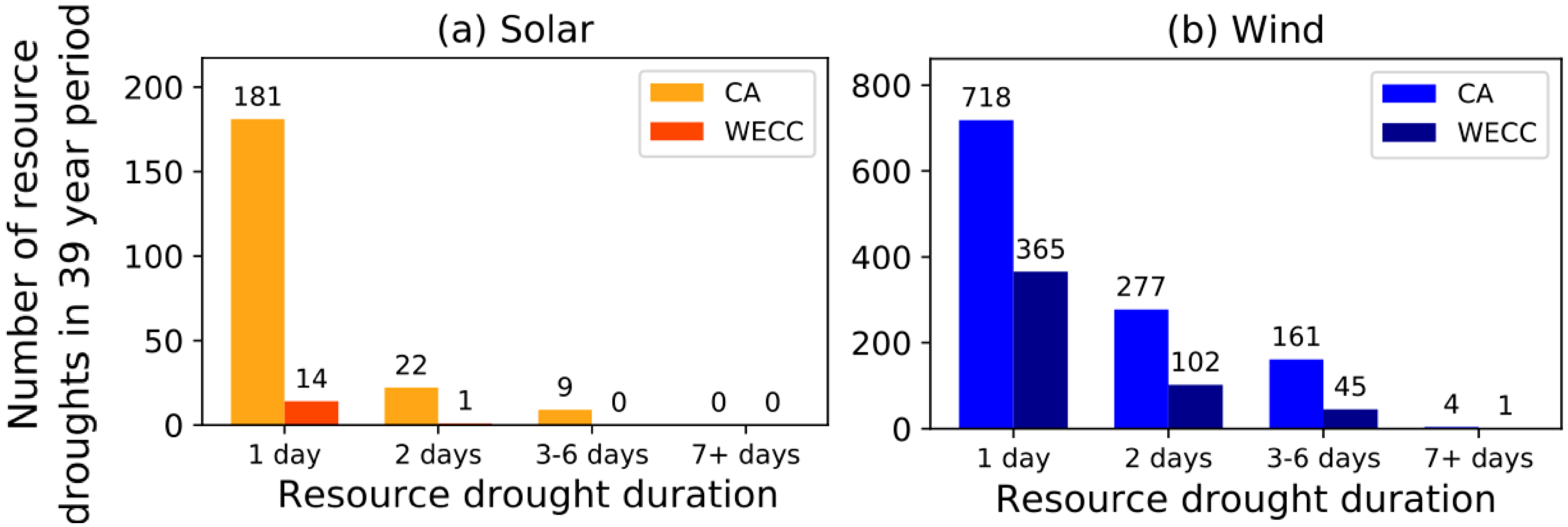
Tightened geographical constraints lead to more variability of renewable resource supply

Reliability



Overall, WECC has greater reliability, when wind and solar capacity are built to meet average demand without any storage, especially in more wind heavy mixes.

Wind and solar droughts

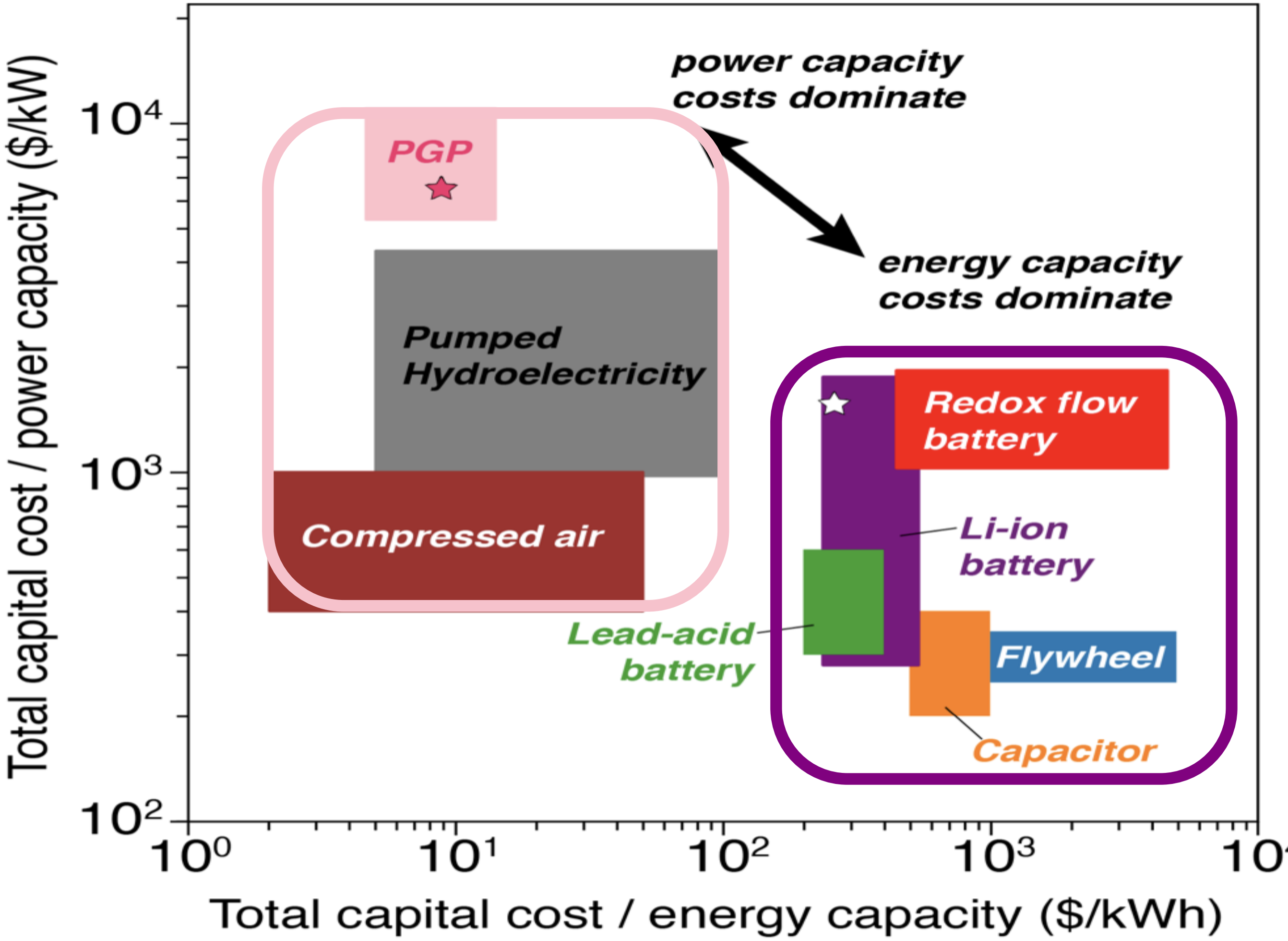


For both the wind and solar resources, *fewer resource droughts occur when aggregating resources over WECC compared to California*

Tightened geographical constraints lead to increased frequency of resource droughts

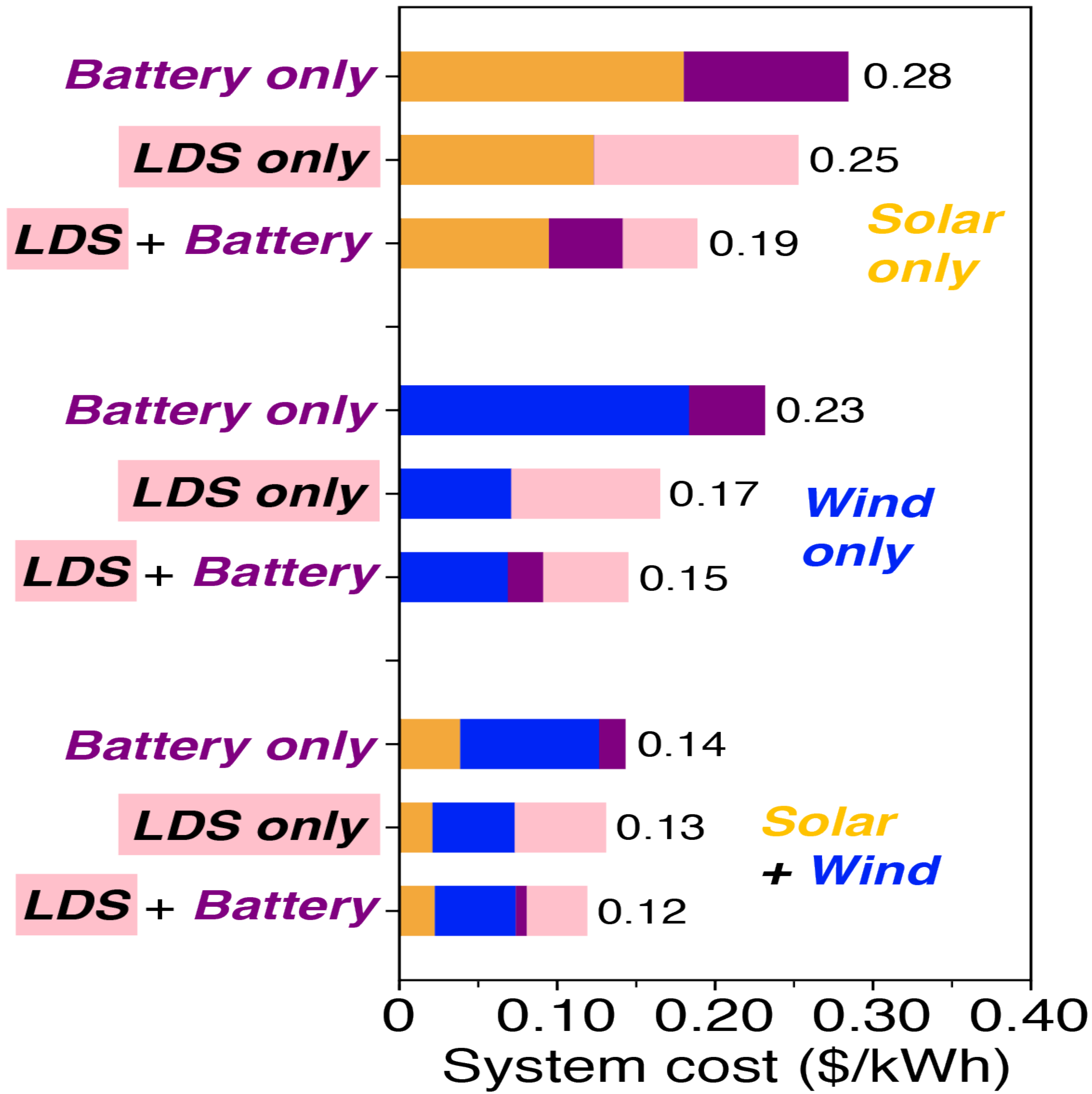
Power-to-Gas-to-Power (PGP) is a long-duration storage technology

Long-duration storage options



Short-duration storage options

Long-duration storage technologies (10 hours or greater) have very different cost structures compared with Li-ion battery storage.



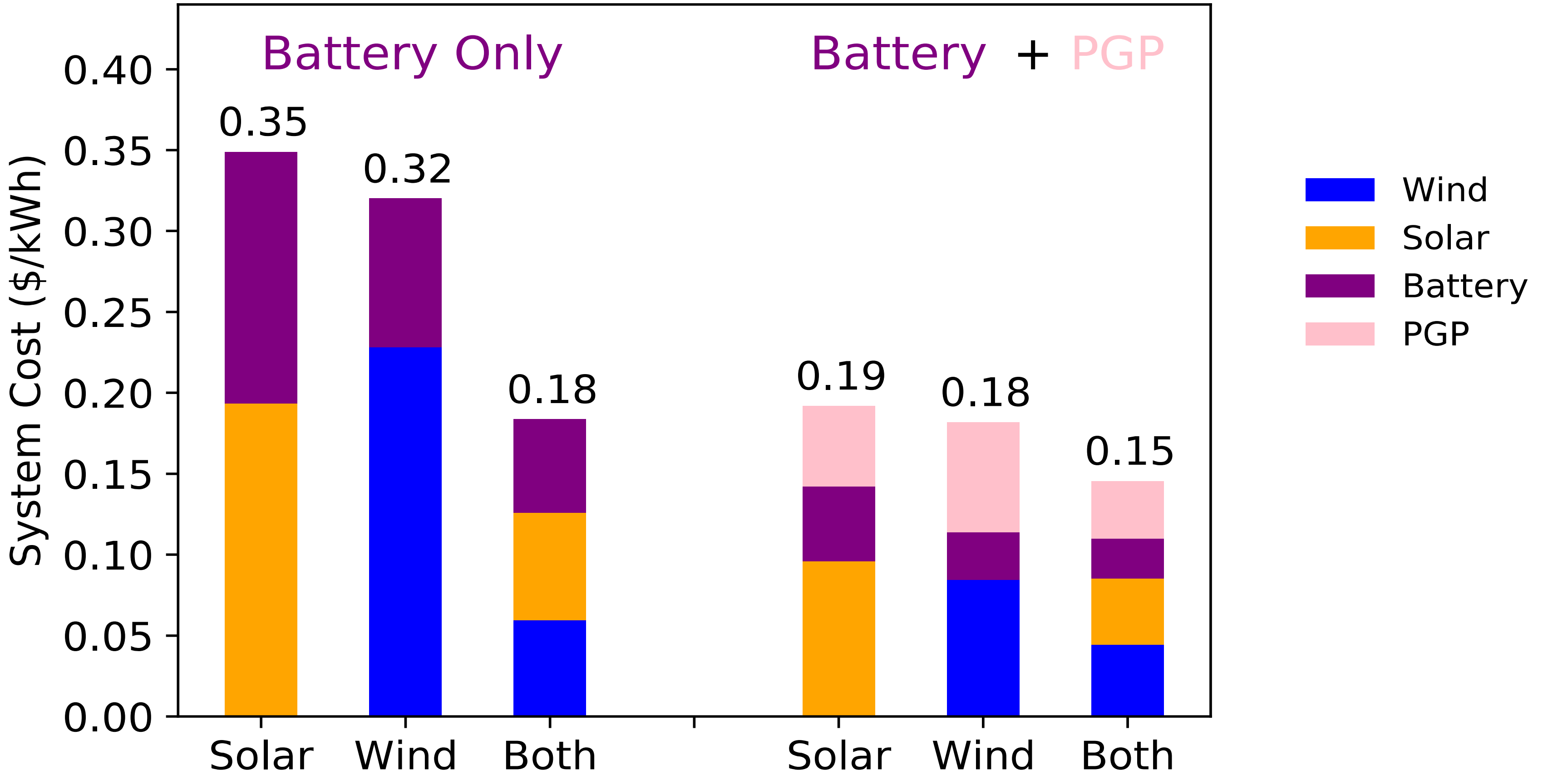
Long-duration storage:

- *can reduce costs of wind-solar-battery systems at current technology costs*

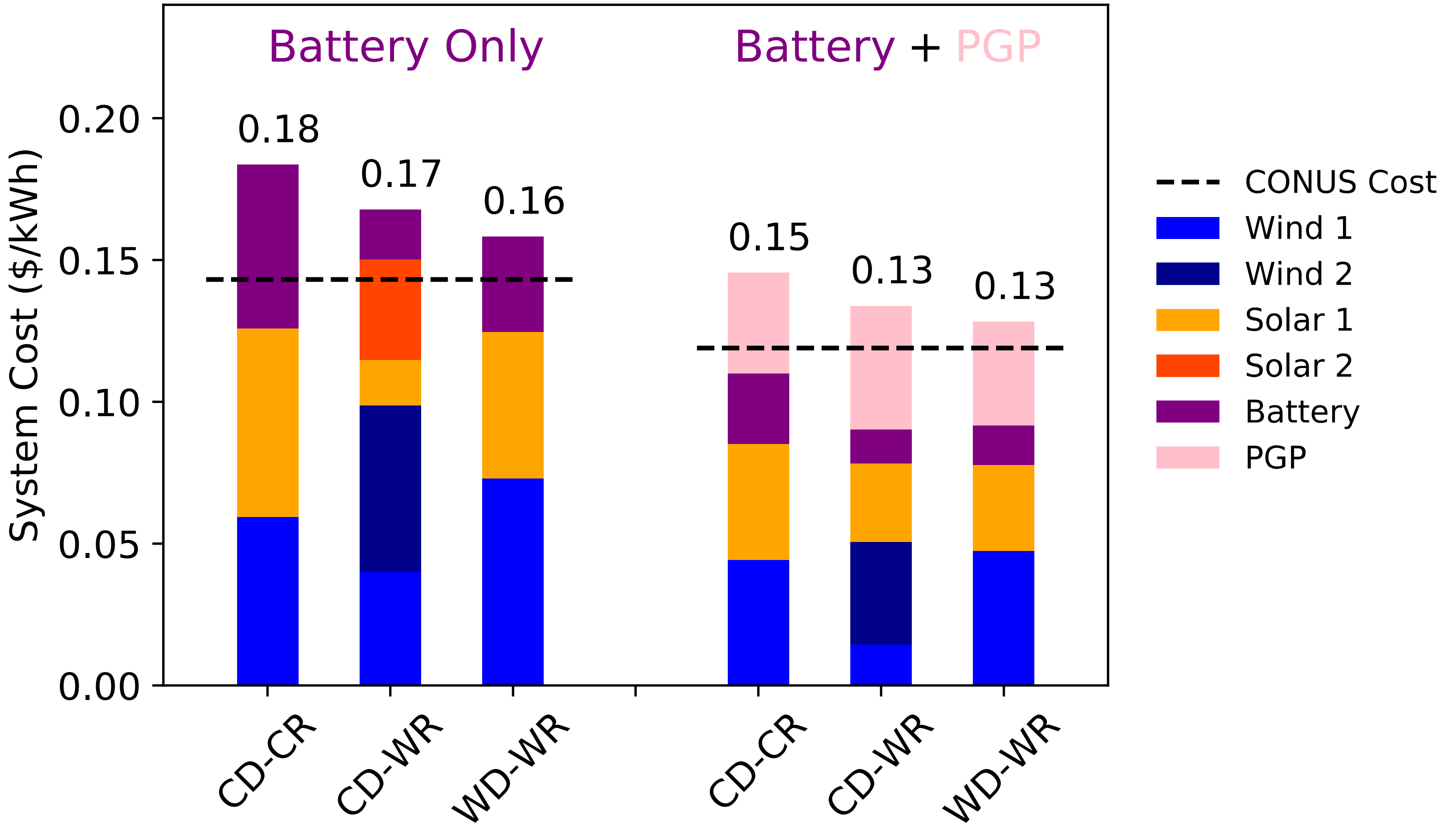
Addition of LDS reduces costs in all cases considered.

Long-duration storage:

- ***can reduce costs of wind-solar-battery systems in CA at current technology costs***



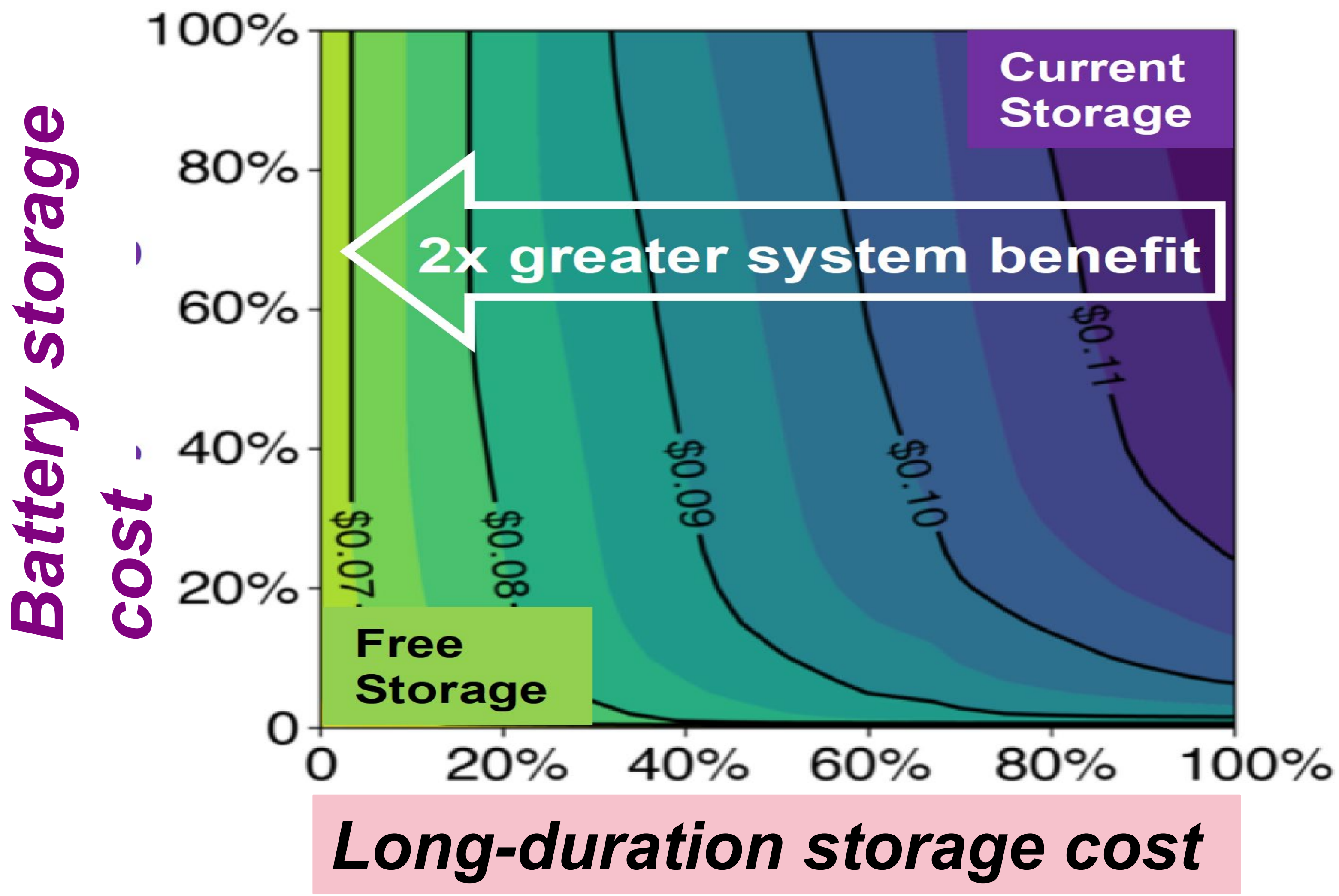
Overall Modeling Results



Reliable systems are always most expensive when you treat CA as an island

Addition of PGP lowers costs and CA buys fewer resources from other the rest of WECC

Reliable systems are always least expensive when you treat WECC as an island



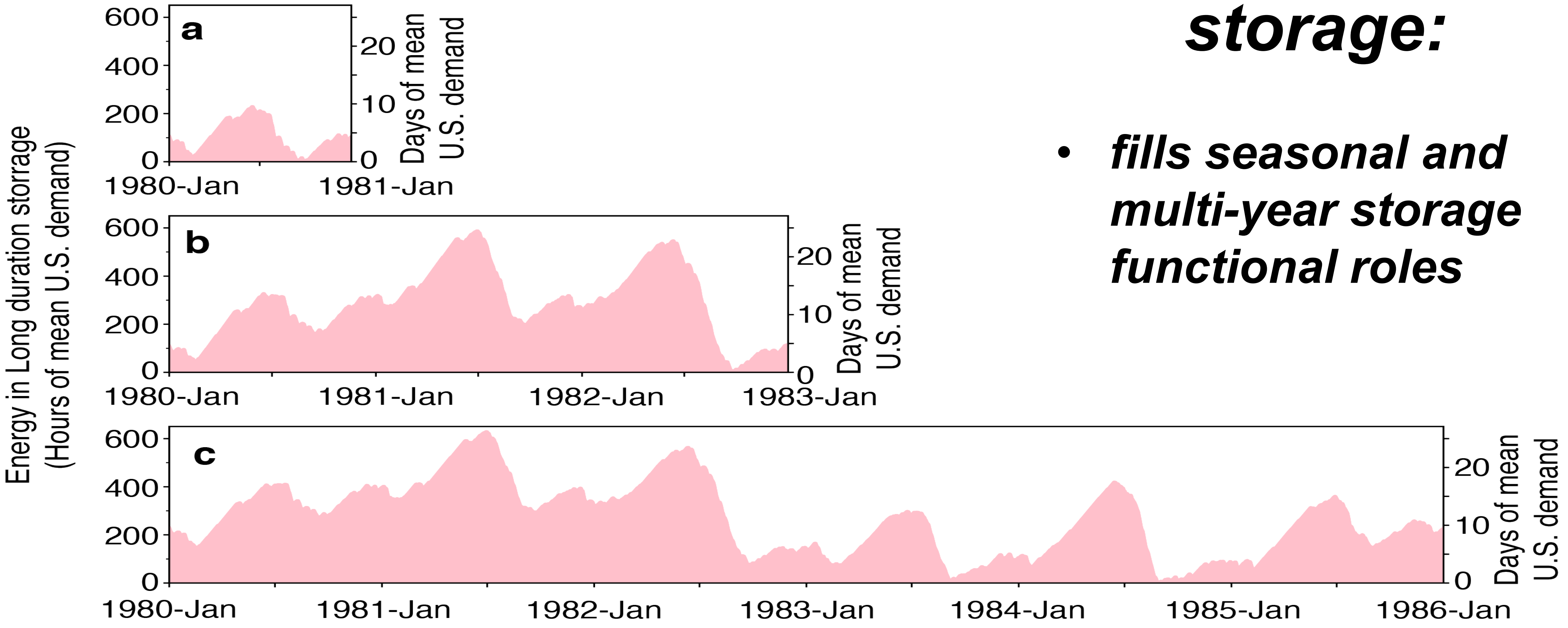
Long-duration storage:

could further reduce system costs with future cost improvements

A 10% reduction in LDS costs would reduce system costs 2x more than a 10% reduction in battery costs.

Long-duration storage:

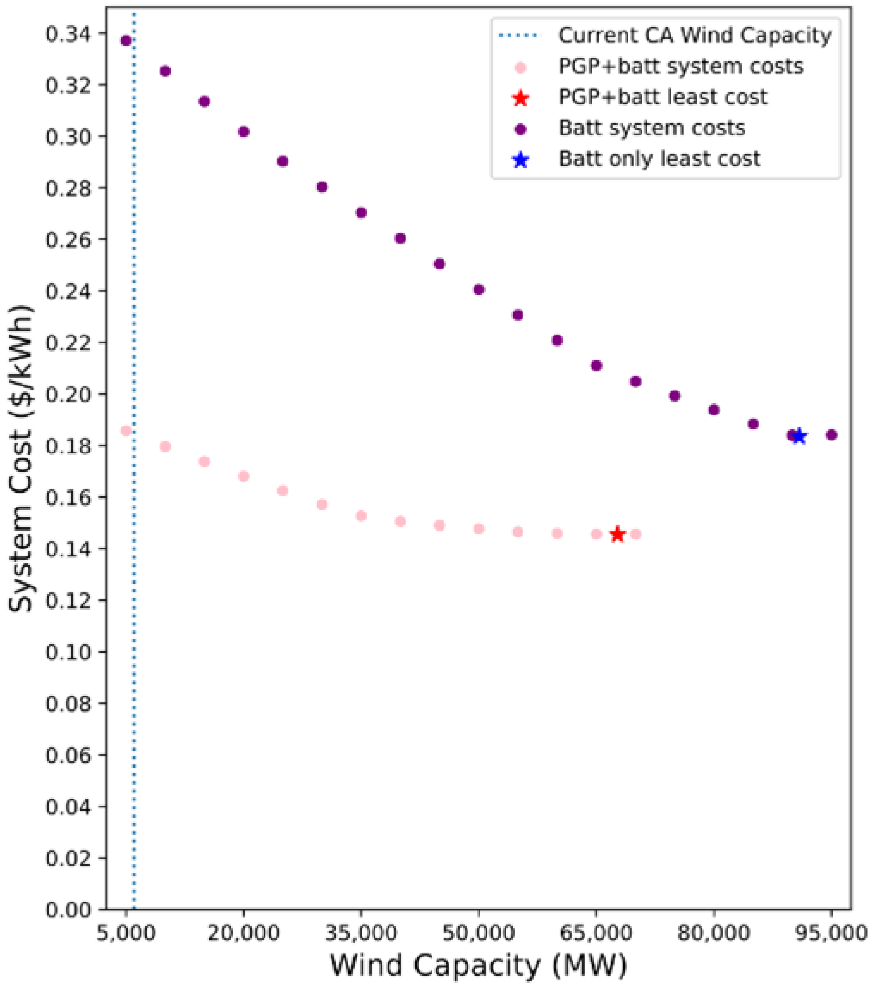
- ***fills seasonal and multi-year storage functional roles***



Long-term modeling captures the role and value of long-duration storage.

Dependence on long-duration storage increases with optimizations over more years.

California fixed wind capacities



Restricting installed wind capacity increases system costs for systems with and without PGP

For lower installed wind capacities, the difference systems without PGP are nearly 2x more expensive than those with PGP

Land use restrictions will make it difficult to increase wind capacity to the levels observe in our least cost system without any restrictions on wind

At lower installed wind capacities, PGP becomes more valuable in lowering system costs

Conclusions

- Increasing geographical constraints increases variability of wind and solar, frequency and duration of resource droughts, and reduces reliability of wind/solar based electricity systems

- For 100% renewable, 100% reliable wind/solar generation systems, system costs are highest when CA is treated as an island both with and without long-term storage

- For these regions, seasonal-scale storage can reduce costs even at current costs and minimizes cost difference between CA as and island and WECC as an island scenarios

In order for CA to comply, it should incorporate in a larger grid and/or invest in long-duration storage

Resources and Acknowledgments

Fellowships from SoCalGas, Resnick Institute, Carnegie Institution for Science

http://new-energy-options.org

NEW ENERGY OPTIONS

RESEARCH BRIEF

JULY 2020

KEY POINTS FOR DECISION-MAKING

To make 100% renewable reliable electricity more affordable, include currently available long-duration storage technology. Long-duration storage would reduce costs of reliable solar and/or wind systems with or without battery storage.

Long-duration storage plays unique roles, such as seasonal and multi-year storage, that increase the affordability of electricity from variable renewable energy. Long-duration storage meets demand during summertime lulls in wind power, and fills in for interannual variations in wind and solar power. Reliable systems that plan for more years increasingly depend on long-duration storage.

Variable renewable electricity costs are more sensitive to reductions in long-duration storage costs than they are to reductions in battery costs. Technology innovations and future cost improvements in long-duration storage could further reduce the cost of renewable, reliable electricity.

Reduce the cost of reliable renewable electricity with long-duration energy storage

Several U.S. states mandate zero-carbon electricity systems based primarily on renewable technologies such as wind and solar power. Reliable and affordable electricity systems based on these variable resources may depend on the ability to store large quantities of low-cost energy over long timescales. Multi-decadal datasets reveal the role and value of long-duration (10 hours or greater) energy storage, and inform policy and technology investment decisions.

The inclusion of long-duration storage lowers costs of renewable electricity systems over a range of modeled technologies. These system benefits remain robust across multiple decades of historical wind and solar weather data, for different electricity systems (solar only, wind only, wind and solar), with and without battery storage, in the U.S. and three

NEW ENERGY OPTIONS

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NEXT UP

Dr. Josh Eichman
Senior Research Engineer
National Renewable
Energy Laboratory

NREL
Transforming ENERGY

The value proposition for long duration and seasonal energy storage

Josh Eichman, Omar Guerra, Jiazi Zhang

CHBC Webinar – Long-Duration Energy Storage: Key to Achieving SB 100

October 20, 2020

Background

Why long duration or seasonal energy storage?

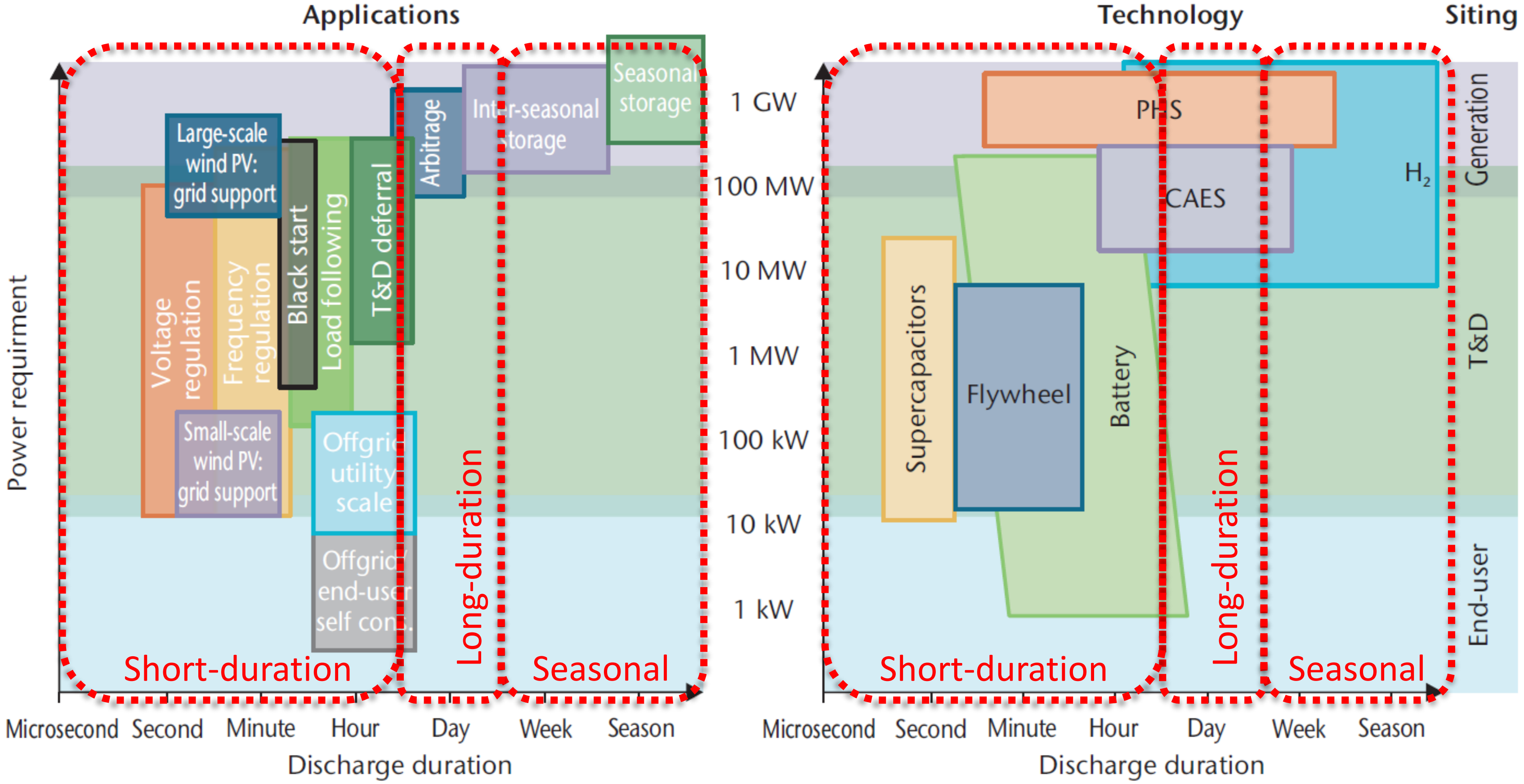
- Mismatch in renewable production (daily and seasonal)
- Resiliency during multi-day extreme events

Storage can be generally separated into three categories.

1. Short-duration (<10 hours at rated discharge power)
2. Long-duration (10-100 hours at rated discharge power)
3. Seasonal (>100 hours at rated discharge power)

Electricity storage applications and technologies

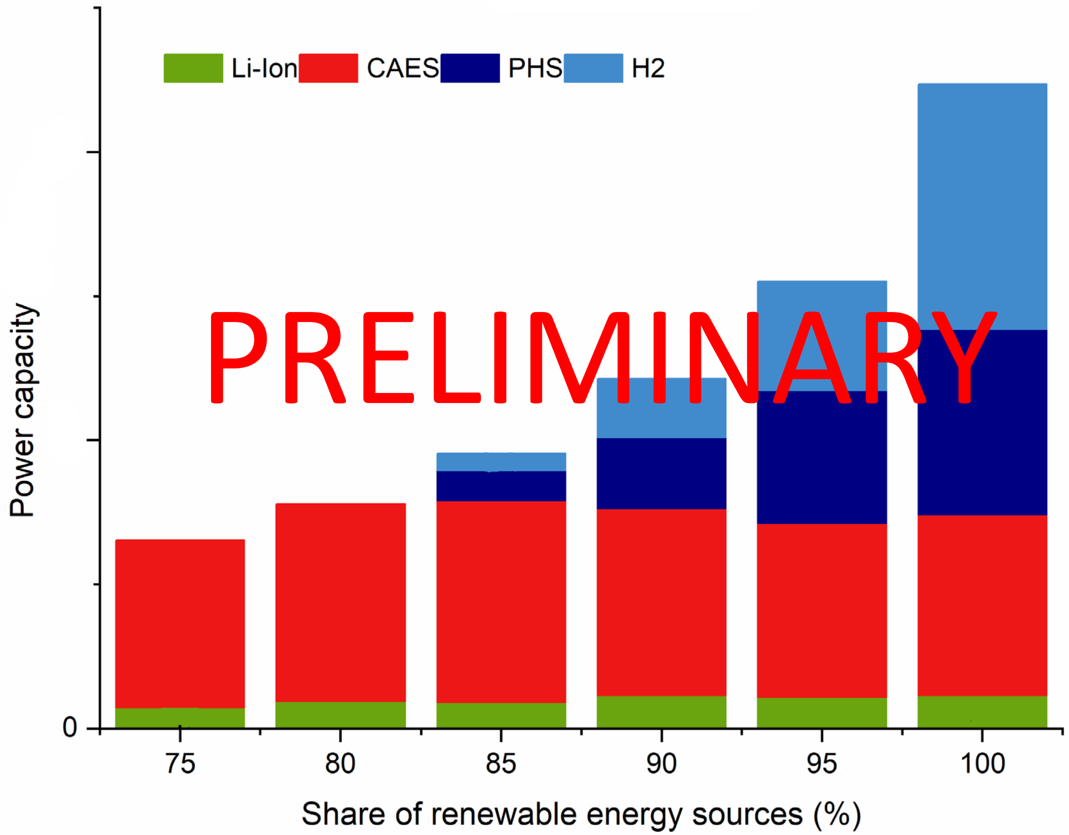
(IEA, 2014 "Technology Roadmap: Hydrogen and Fuel Cells")

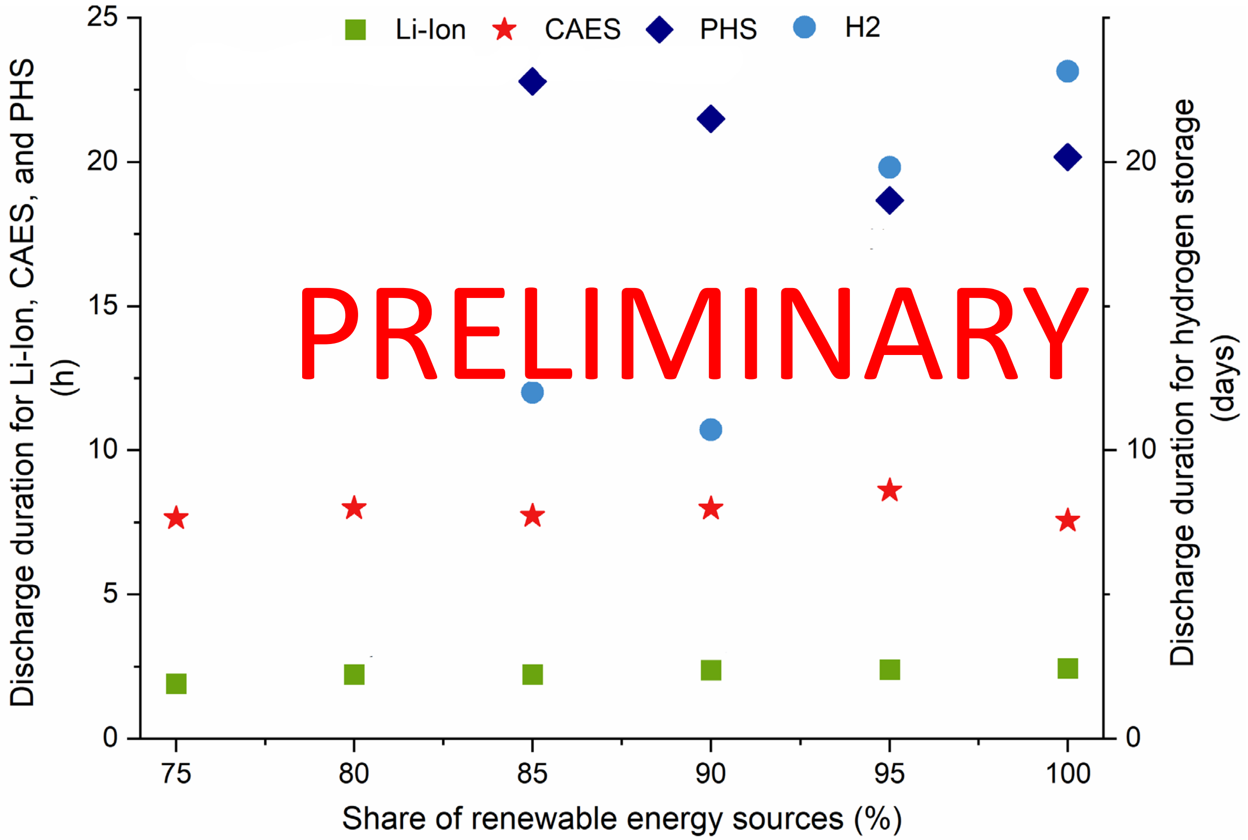


Note: CAES = compressed air energy storage; PHS = pumped hydro energy storage.

The role of long duration and seasonal storage in future power systems

- A cost optimized storage portfolio will include a variety of technologies, each providing unique value to support grid operations.





Preliminary modeling of storage portfolios finds that long duration and seasonal storage play a key role in achieving the lowest cost high renewable power system

System Benefits

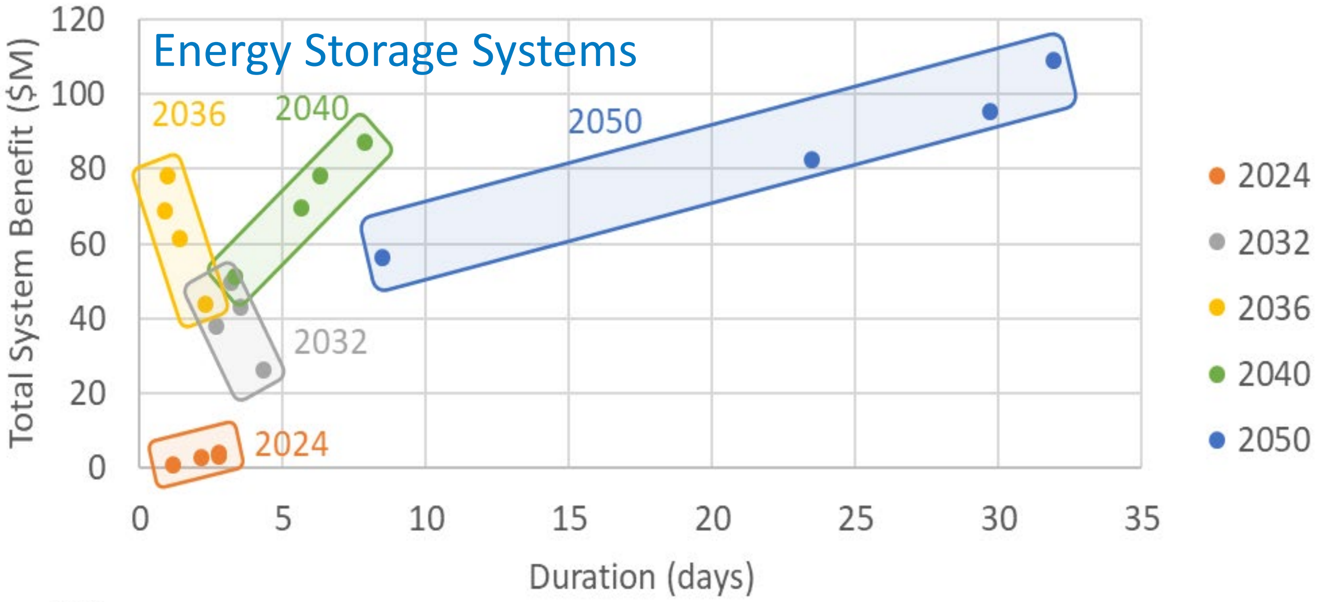
Benefits include:

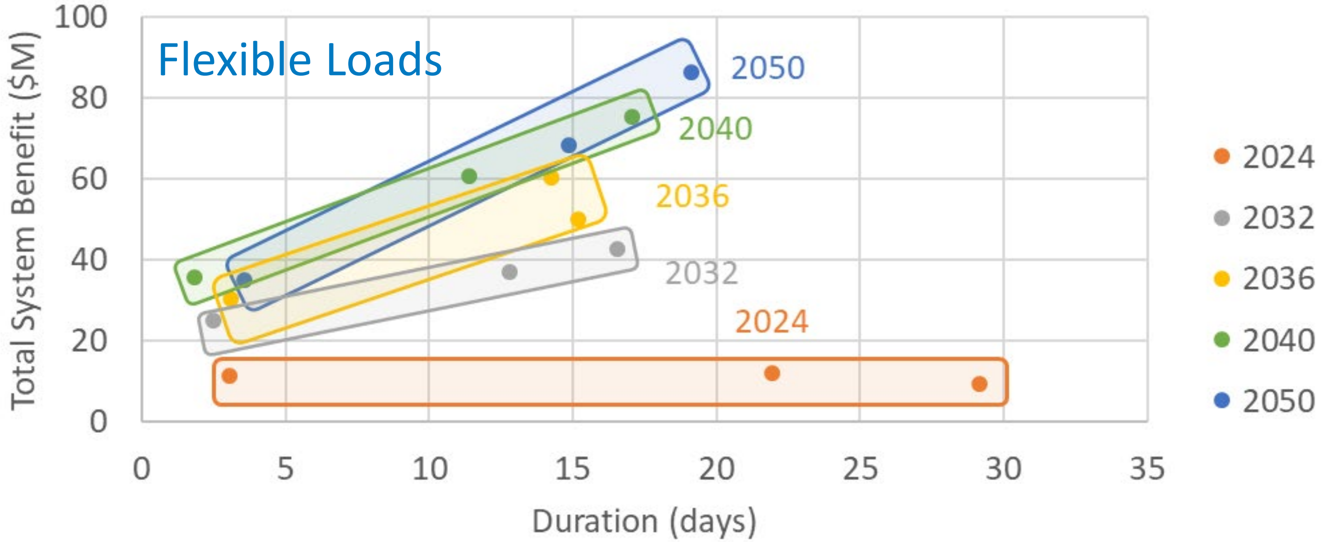
- Energy arbitrage
- Ancillary service provision
- Improve efficiency and reduce starts for fueled generators
- Capacity for resource adequacy
- Congestion management
- Transmission and distribution deferral
- Resiliency support

Source:
Zhang, J.; Guerra, O.; Eichman, J.; Pellow, M. (in review) Benefit Analysis of Long-Duration Energy Storage in Power Systems with High Renewable Energy Shares

- Long duration and seasonal energy storage, and highly flexible loads reduce operating costs (see figures to the right).
- This study considered, in detail, the first four items above.

Source:
Valuation of Hydrogen Technology on the Electric Grid Using Production Cost Modeling: Final Report. EPRI, Palo Alto, CA: (Forthcoming). 3002016621.

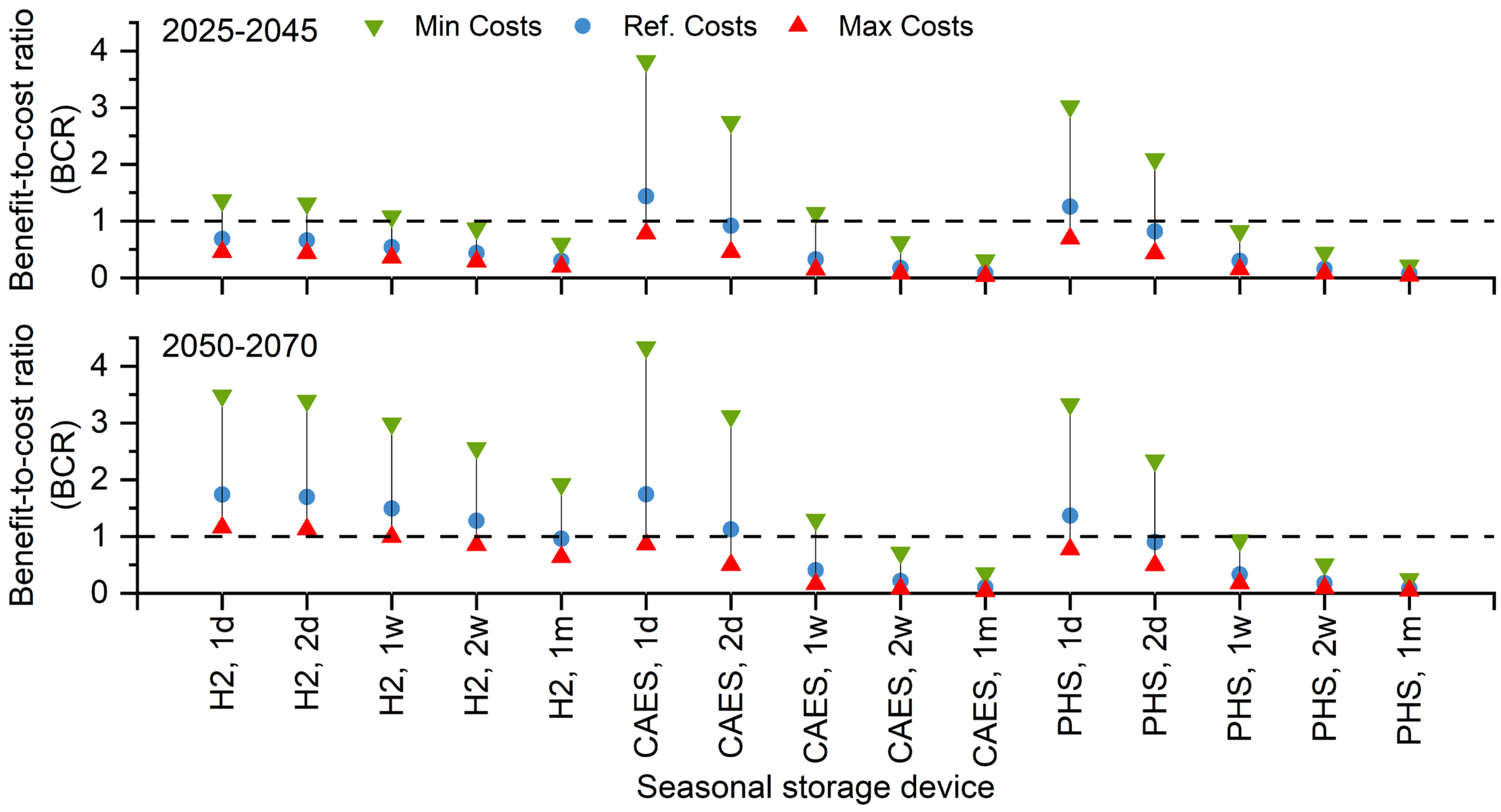




Considers the benefit (not including capital cost) of a 2GW storage system added to the Western Interconnect with up to 85% renewable shares in 2050 (includes large hydro). Same color points represents different round-trip efficiency values for top figure and different capacity factors for bottom figure

Determining Cost-effectiveness

- A recent publication explored cost competitiveness (benefits versus costs) of seasonal storage in 2025-2045 and 2050-2070 timeframes
- Despite the benefit of longer durations, the added storge capacity cost often means shorter durations are more cost effective.



Considers a 2GW storage system added to the Western Interconnect.

Source: Guerra, O.; Zhang, J.; Eichman, J.; Denholm, P.; Kurtz, J.; Hodge, B. The Value of Seasonal Energy Storage Technologies for The Integration of Wind and Solar Power. Energy Environ. Sci. 2020, 13, 1909–1922. https://doi.org/10.1039/D0EE00771D

Looking forward

- Grid planning and operations need to include consideration for long duration and seasonal storage as well as highly flexible loads (e.g., hydrogen power-to-gas)
- Need to consider the entire range of benefits that long duration storage, seasonal storage, and flexible loads can provide.
- Market design that appropriately compensates longer duration storage systems for the value they provide (an important step to encourage deployment).

Thank you

www.nrel.gov

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NATIONAL RENEWABLE ENERGY LABORATORY

NEXT UP

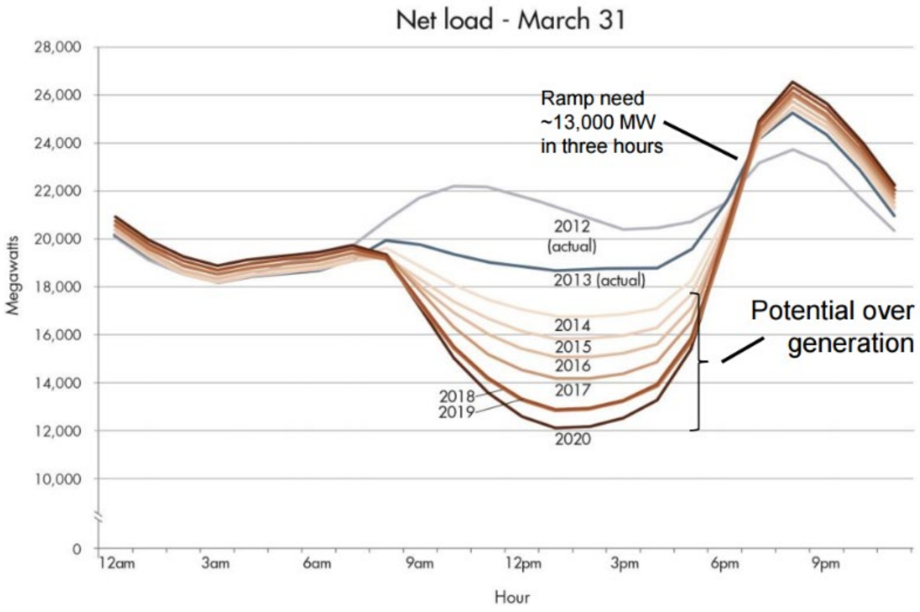
Dr. Jeff Reed
Chief Scientist
Advanced Power & Energy Program at UC Irvine

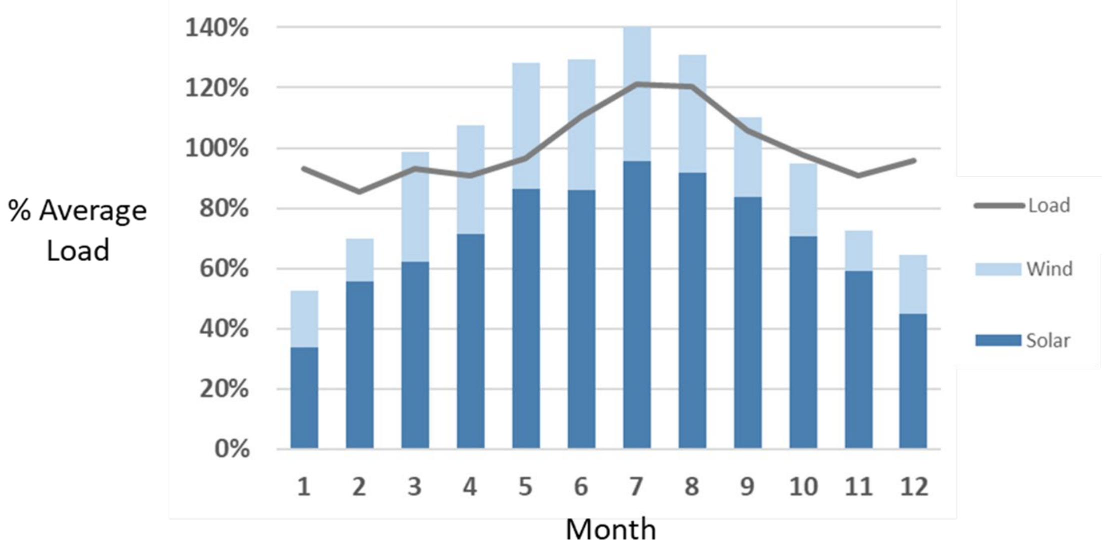
Assessment of Renewable Gas (RH2 and RNG) for Renewables Firming

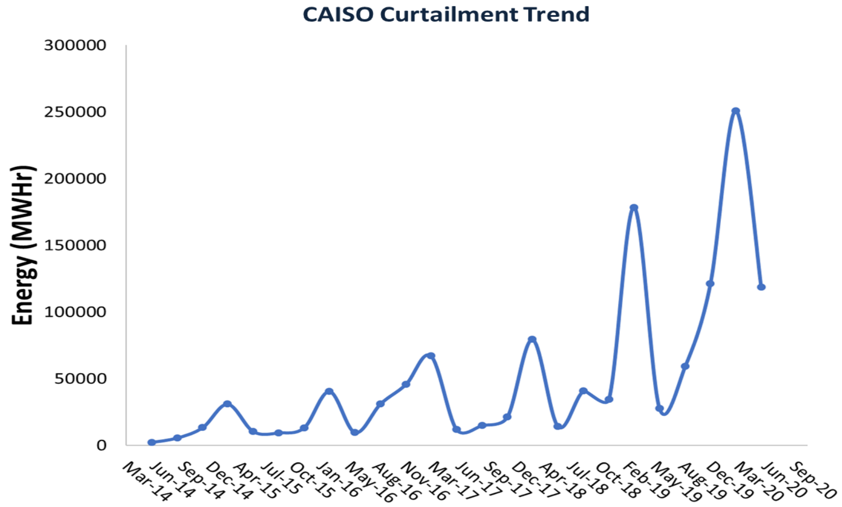
ADVANCED POWER & ENERGY PROGRAM
UNIVERSITY of CALIFORNIA · IRVINE

October 20, 2020

Growing Need for Storage at All Timescales





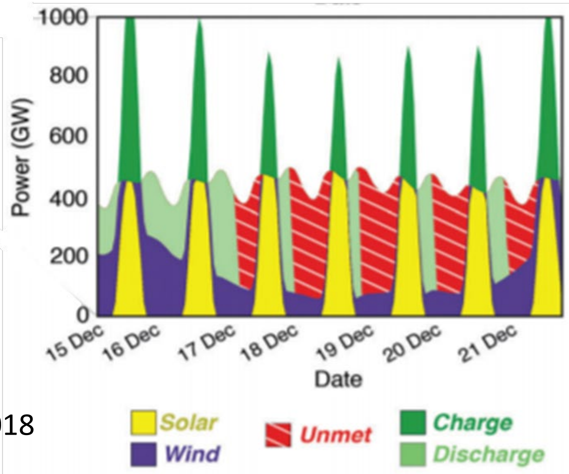


Supply System:

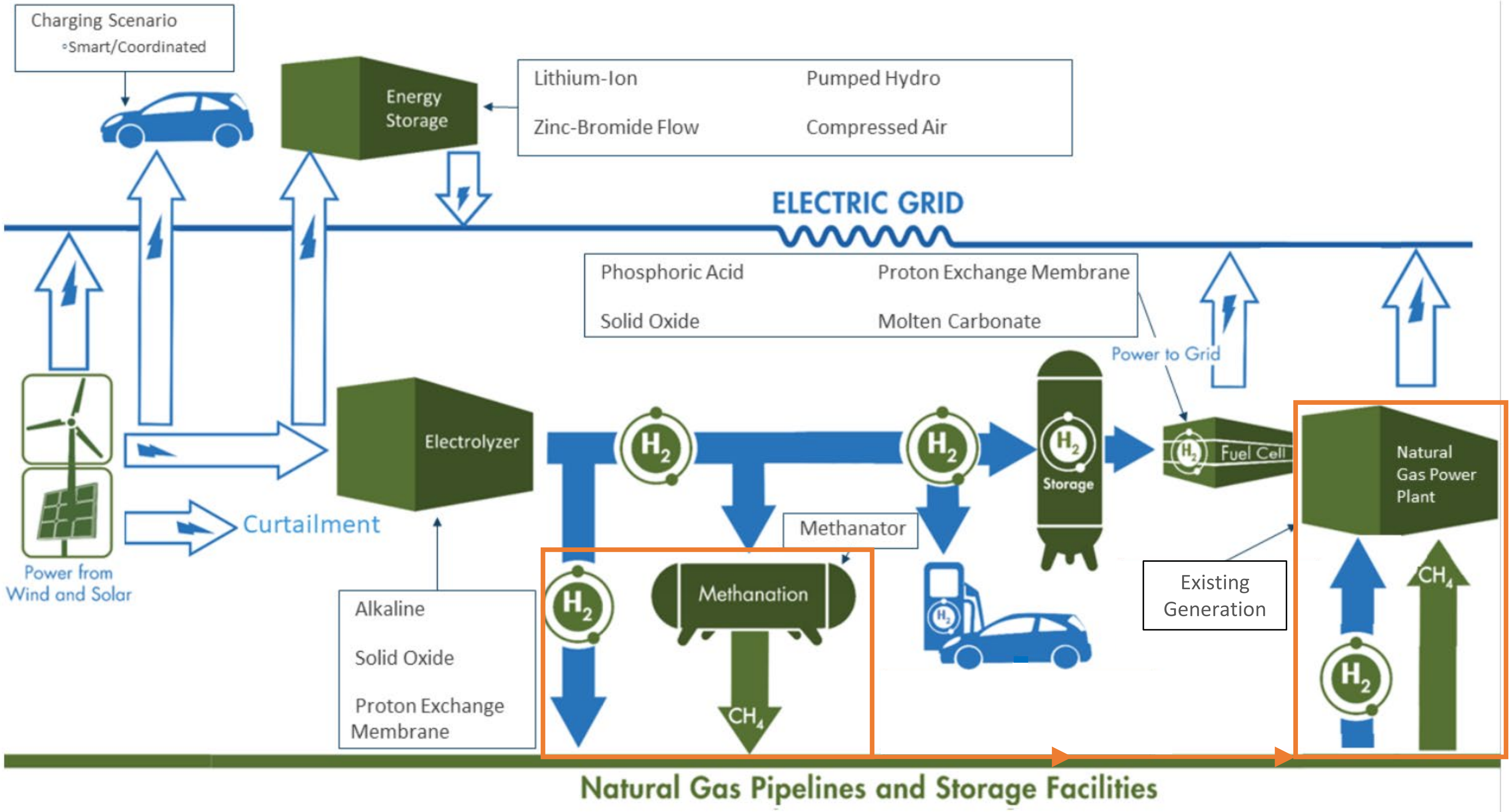
- 75% Solar 25% Wind
- 1.5 x generation
- 12 Hours Storage

Reliability 98.7% -- nearly 5 days per year of unserved load

Source: Shaner et al. 2018



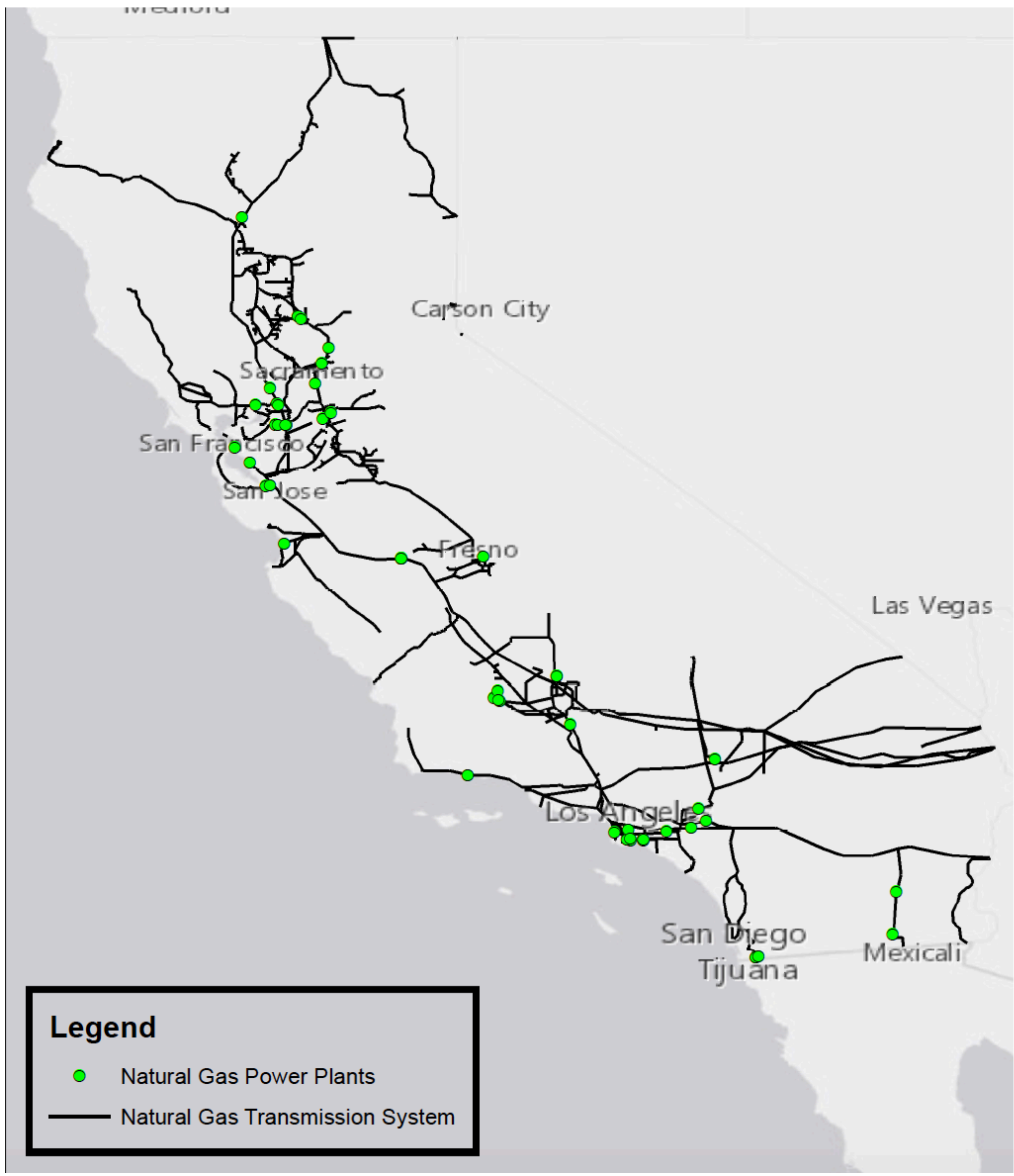
The Use Case Considered – Electrolytic Fuel to Existing Generation



What's in a Name?

- Hydrogen Energy Storage
- Power-to-Gas
- Power-to-Gas-to-Power
- Electricity in / Electricity Out
- Grid Storage Resource
- Renewables Integration
- Renewables Firming Resource
- Long-Duration Storage (High Energy Storage Capacity)
- Long-Stand-by Storage (Store and Wait for Long Periods)
- Reliability and Resilience Resource

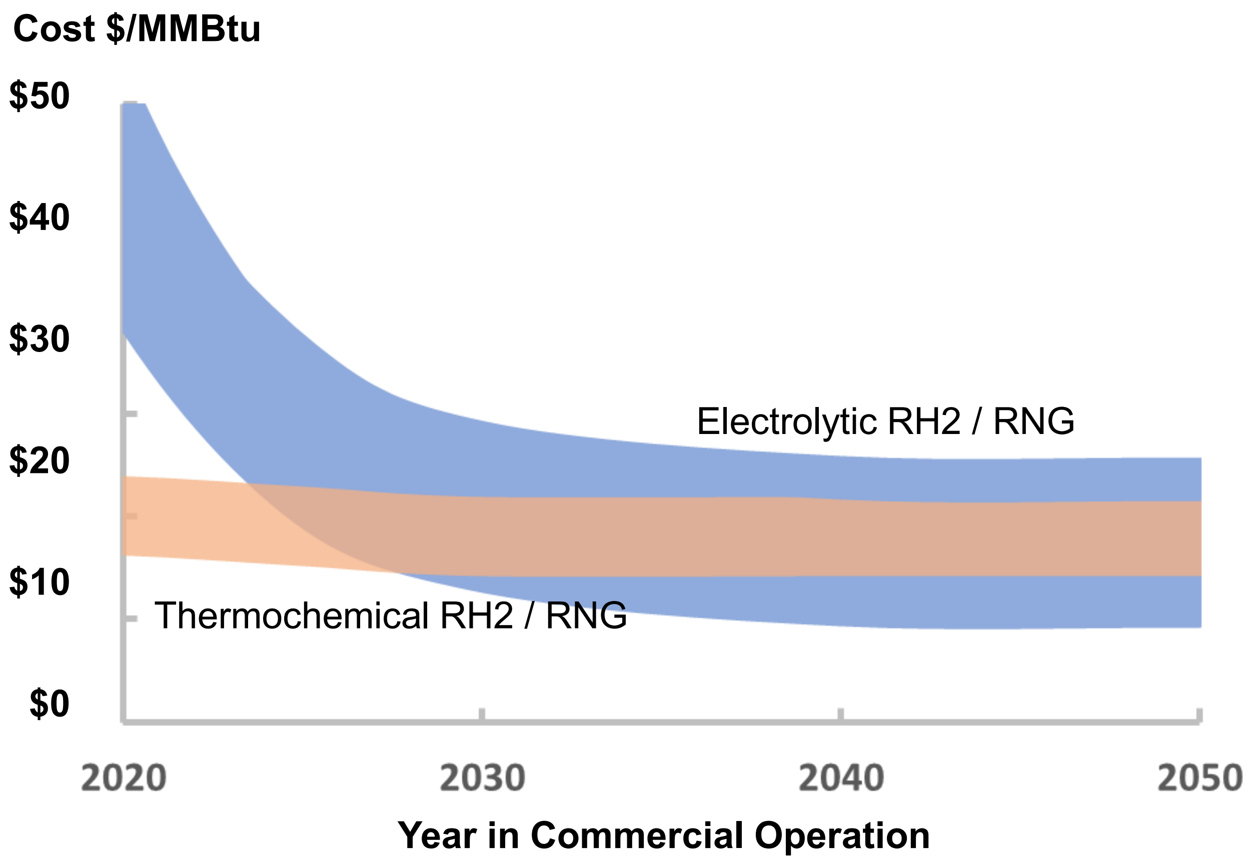
The Gas Grid is the Dominant Resource for Renewable Integration Today



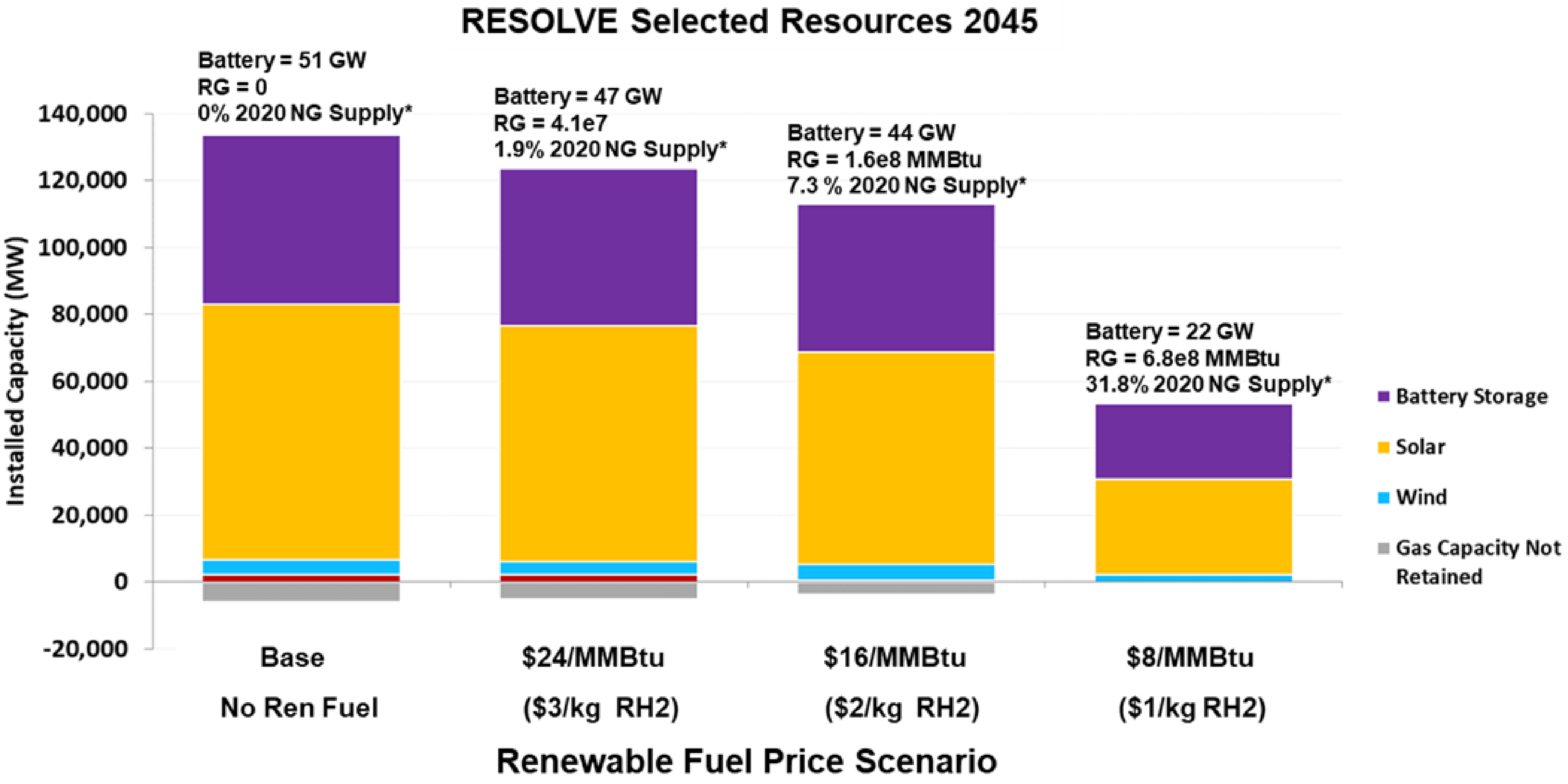
How Important a Role Could RH2 / RNG Injected on the Gas Grid Play?

- The renewable gas (biomethane) feature in the CPUC resource planning model **RESOLVE** was used to investigate the question
- **Renewable Gas price was varied** across cases to determine if and how much RG would be selected in the optimization
  - **Selection of renewable gas** in the optimization **begins at around $24/MMBtu** (equivalent to $3/kg for RH2)
  - Making low-cost hydrogen available for use in thermal resources **reduces the need for battery storage** and reduces the amount of thermal capacity that is retired
  - **Curtailment is also reduced** substantially
- Analysis notes
  - **Renewables for electrolytic hydrogen production are external to the model** – costs for electrolyzers and renewable electricity supply for fuel production are included in the cost of fuel
  - All renewable gas **scenarios use the 30 MMT base scenario variables** other than those related to renewable fuel availability and cost
  - **No costs for modifications to the gas system or gas power plants are included** – the ability to blend hydrogen (as opposed to RNG) is will be limited without infrastructure and generator modifications

The Future Role Renewable Gas on the Grid Depends on Cost Evolution

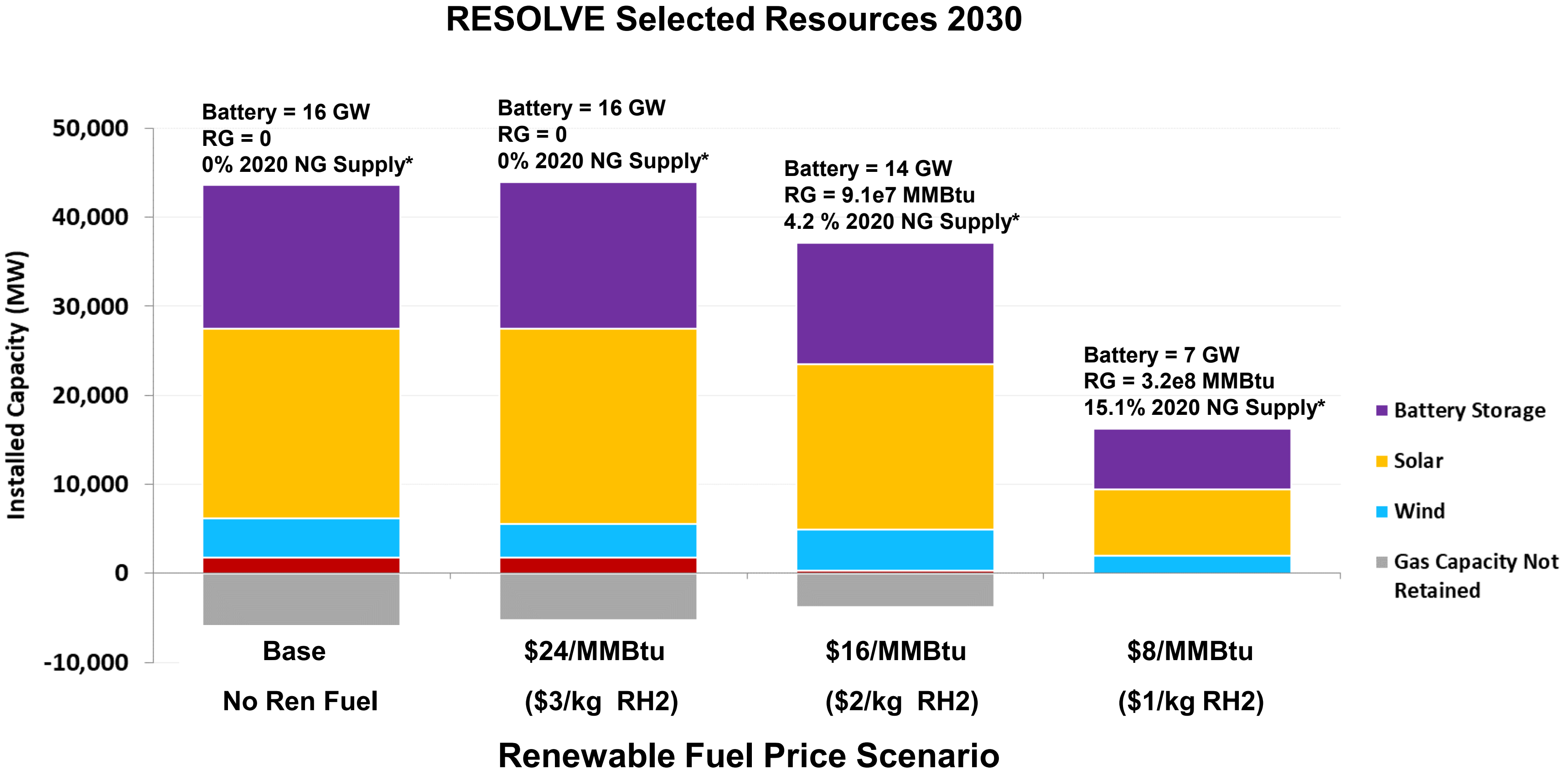


RG is Used in 2045 Optimization Beginning at ~$24/MMBtu



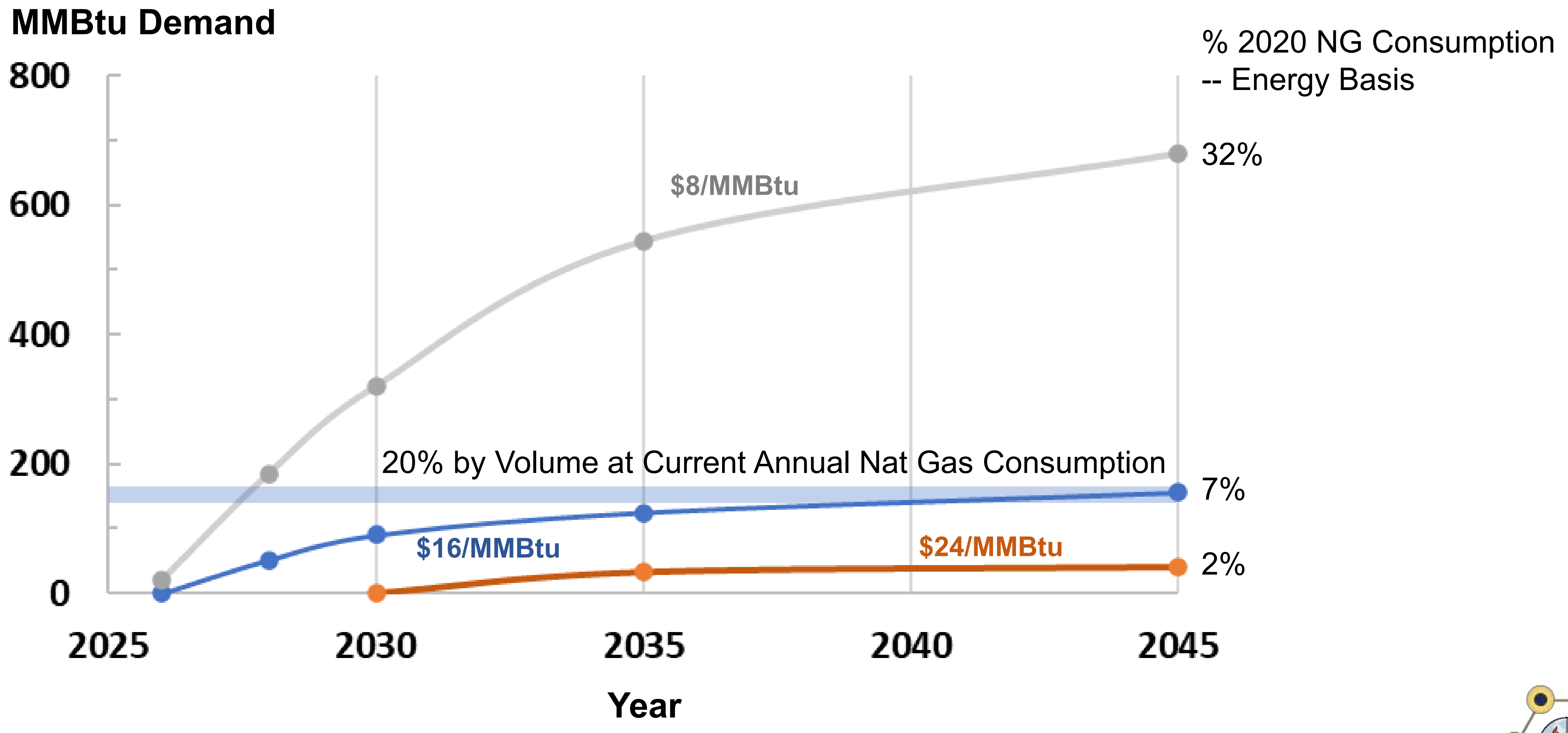
* Supply percent on an energy basis. ~3x for volume fraction.

Adoption threshold a bit lower in 2030 (no use at $24/MMBtu, some at $16/MMBtu)

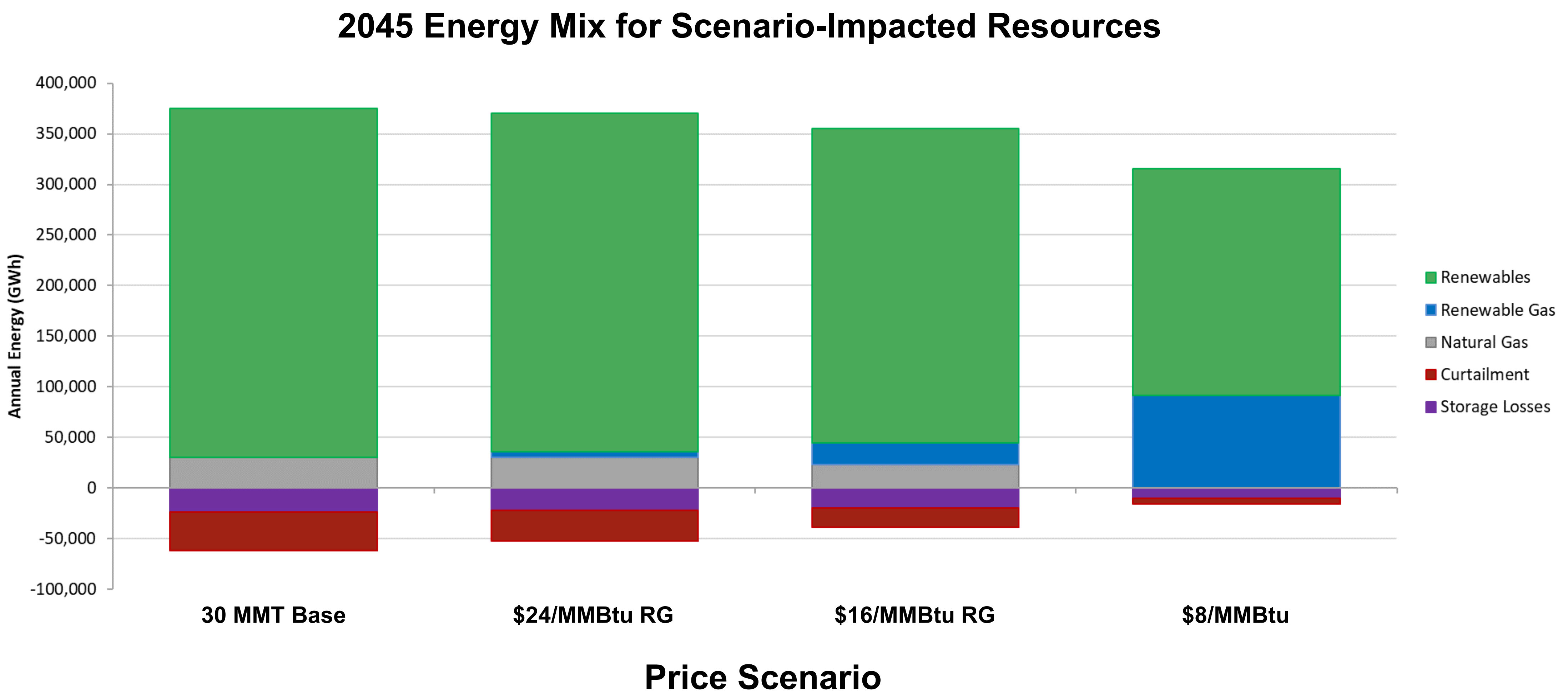


* Supply percent on an energy basis. ~3x for volume fraction.

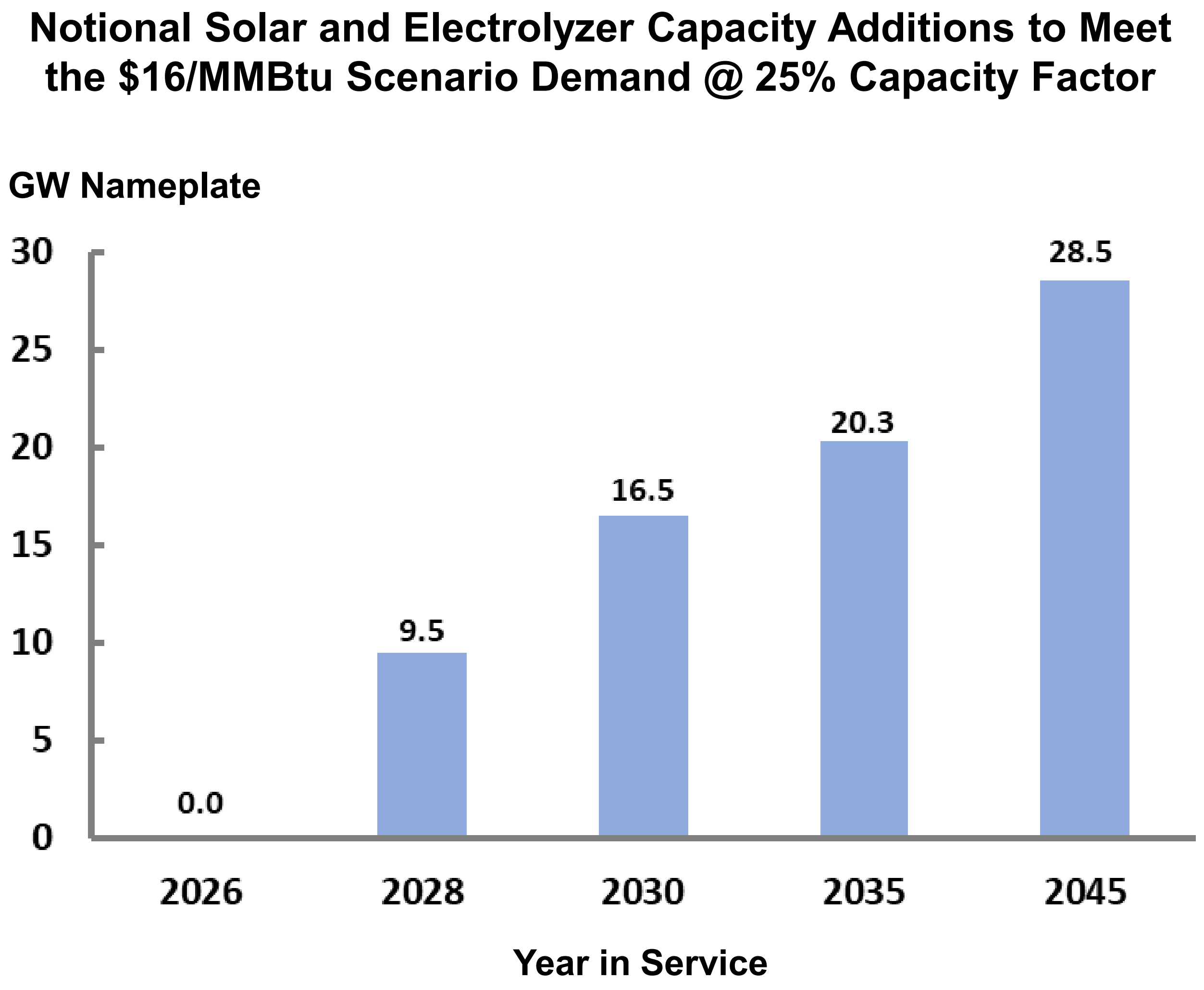
Demand for Renewable Fuel for Renewables Firming



Impact of RG on the 2045 Energy Mix (not All Resources Shown)



Order of Magnitude Resource Additions Exogenous to RESOLVE



Some Take-aways

- Renewable Gas should be included in California resource planning for the electric grid in a more comprehensive way
- Achieving the highest renewable gas use scenarios will require that:
  - Either most of the supply is synthetic renewable methane
  - Or gas system and generation resource modifications will be required to accommodate higher volumes of renewable hydrogen
- A key planning trade-off is the relative cost of decarbonized methane (RNG, NG with CCUS) and the cost of renewable hydrogen inclusive of infrastructure and generation resource additions and modifications – currently being analyzed

Q&A

- Submit your question in the Q&A Panel on your right.

Diane Moss
Deputy Director
California Hydrogen Business Council

Dr. Nathan Lewis
Professor of Chemistry
California Institute of Technology

Jacqueline Dowling
Chemistry PhD Candidate
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Katherine Rinaldi
Graduate Research Assistant
California Institute of Technology

Dr. Josh Eichman
Senior Research Engineer
National Renewable Energy Laboratory

Dr. Jeff Reed
Chief Scientist
Advanced Power & Energy Program at UC Irvine

UPCOMING CHBC AND PARTNER EVENTS

- **October 20-22**
  - Center for Hydrogen Safety, European Conference
  - https://www.aiche.org/chs/conferences/center-hydrogen-safety-europe-conference/2020
- **October 27**
  - ACORE State of the Industry Webinar: How Can Hydrogen Enable 100% Renewable Targets?
  - https://register.gotowebinar.com/register/7808985977661010444
- **November 10**
  - S&P Global Platts Hydrogen Markets Americas Virtual Conference
  - https://plattsinfo.spglobal.com/Hydrogen-Markets-Americas-Virtual-Conference-2020.html
- **December 8**
  - CHBC Annual Membership Meeting

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