Long Duration Energy Storage Workshop

December 3, 2020

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OVERVIEW

- Introduction to core team (Four universities)
- Motivation: Accelerate transition by using positive feedback
- Goals of the project:
  - Understanding long-duration storage to meet California targets
- Technologies to study
- Practical challenges
  - Computational & Complexity
- Next steps
  - Develop baseline & scenarios to study
- Outcomes
  - Cost targets and other metrics
- Q&A

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Introduction to team

University of California Merced
Sarah Kurtz

University of California Berkeley
Dan Kammen
Sergio Castellanos

University of California San Diego
Patricia Hidalgo-Gonzalez

University of North Carolina Chapel Hill
Noah Kittner

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Introduction to core team

- Dan Kammen has trained many students & post docs:
  - Noah Kittner – University of North Carolina: *Technology Evaluation*
  - Patricia Hidalgo-Gonzalez – UC San Diego: *SWITCH modeling*
  - Sergio Castellanos – University of Texas Austin: *Equity & Energy Analysis*
- Previously used SWITCH to help California set targets:
  - Establishing CA's AB 2514 storage mandate
  - Examining and proposing aggressive solar and EV targets
  - Integrating building and transportation plans
  - International Partnerships via role as former Science Envoy, US Department of State
- Provides CEC access to extensive UC computational resources

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Introduction to core team

- Sarah Kurtz
  - More than 30 years at the National Renewable Energy Laboratory (NREL) with focus on solar energy
- Transitioned to UC Merced in 2017 with goal of supporting California’s world-leading clean-energy efforts
- Focus on modeling with RESOLVE, technology evaluation, and coordination of project

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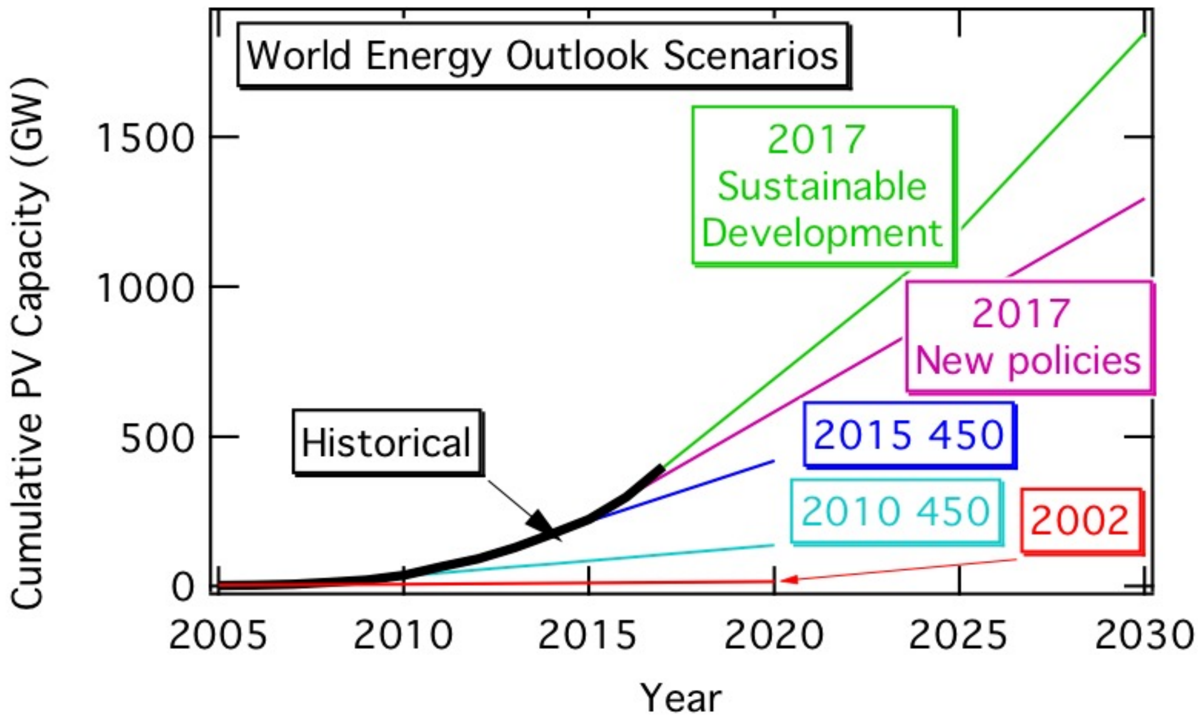
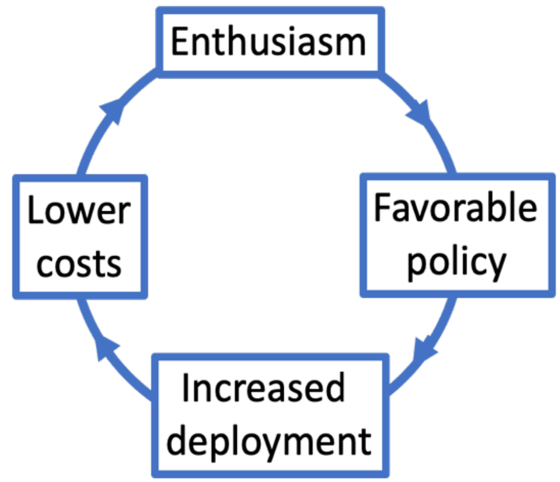
Growth of Solar is a Model for Success



PV grew much faster than was predicted



Positive feedback accelerated growth of solar

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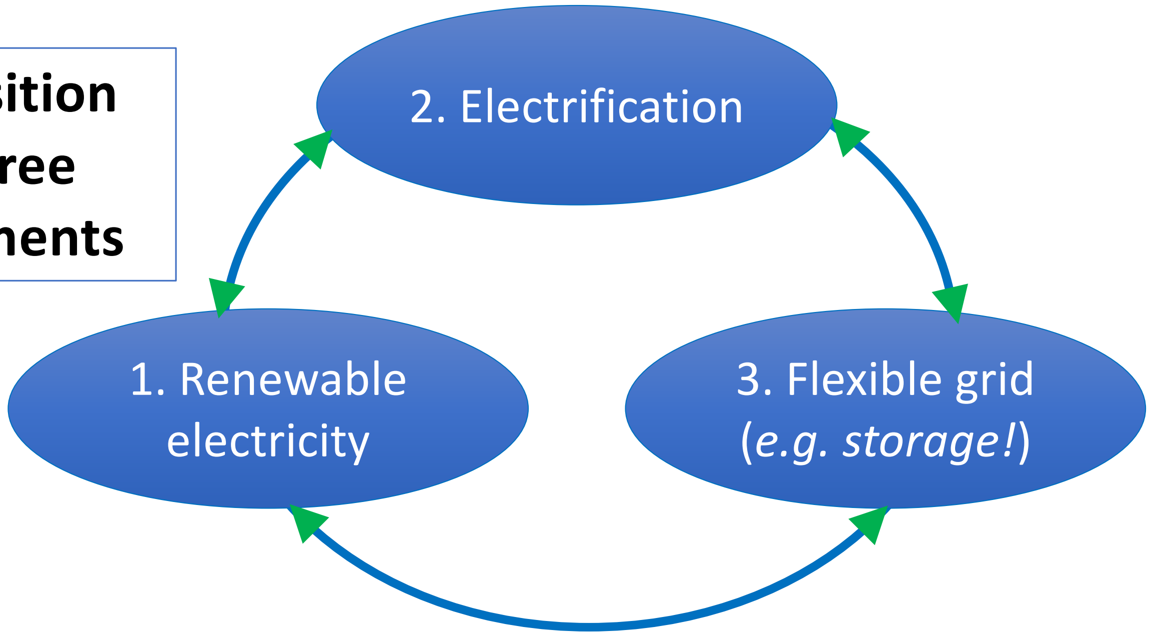
Can storage duplicate Solar's success?

The energy transition needs these three *coordinated* elements



Each green arrow represents an opportunity for positive feedback
Coordinating these 3 development efforts will accelerate change!
Our project will look for opportunities for positive feedback

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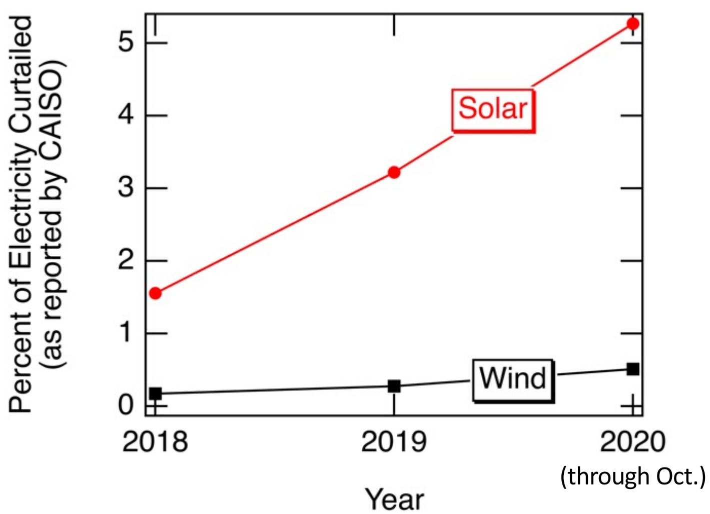
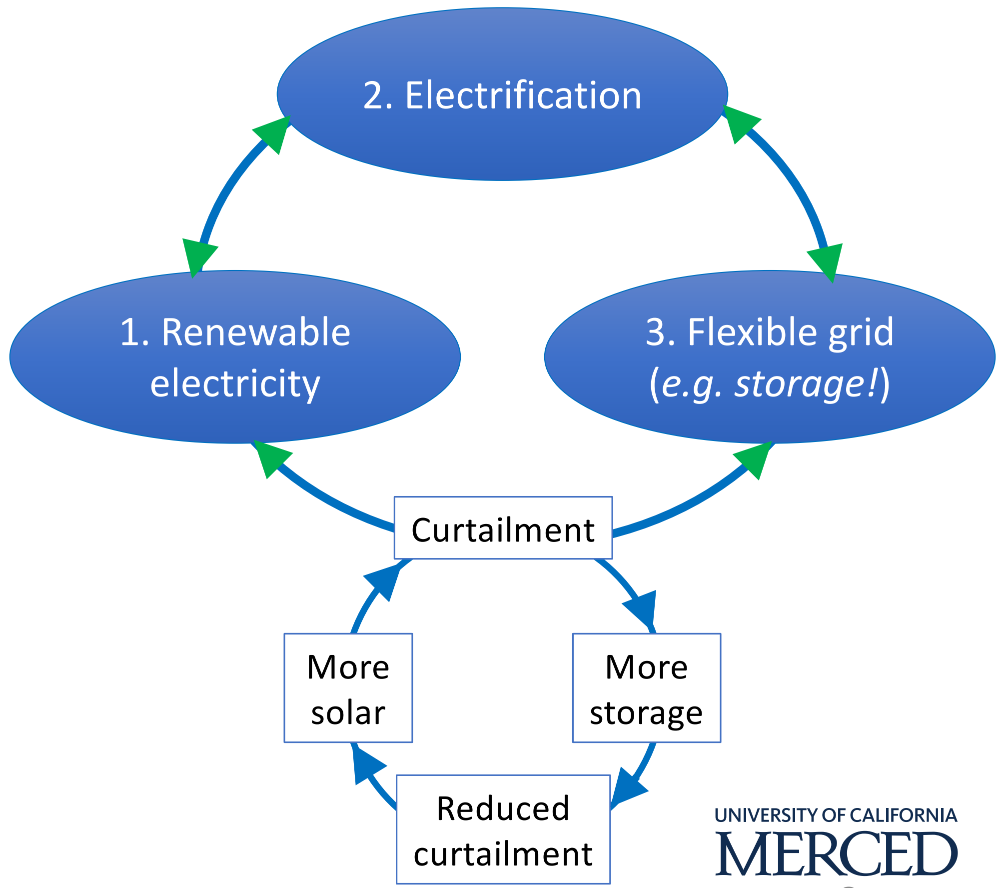
Example of opportunity for coordination

The energy transition needs these three *coordinated* elements





End goal: Achieve SB100 goals gracefully

CBS NEWS NEWS 2020 ELECTIONS SHOWS LIVE

California to go 100 percent carbon-neutral

BY IRINA IVANOVA
SEPTEMBER 10, 2018 / 3:45 PM / MONEYWATCH

FOX BUSINESS Personal Finance Economy Markets Lifestyle Real Estate Tech TV Podcasts More

WEATHER · Published August 19

California power troubles, rolling blackout threat draw ire over renewable energy transition

California Gov. Gavin Newsom has said that 'capacity for storage' needs improvements

gtm: A Wood Mackenzie Business

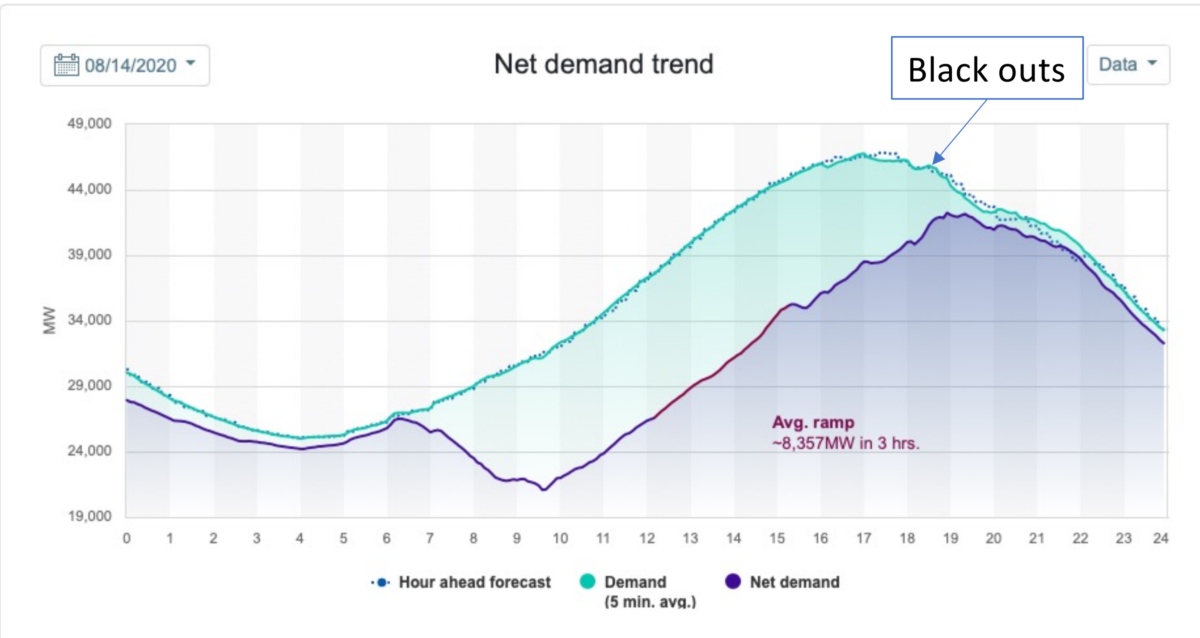
California's Shift From Natural Gas to Solar Is Playing a Role in Rolling Blackouts

California's grid operator warns that the state has become overly reliant on power imports: "The rest of the West is hot too."

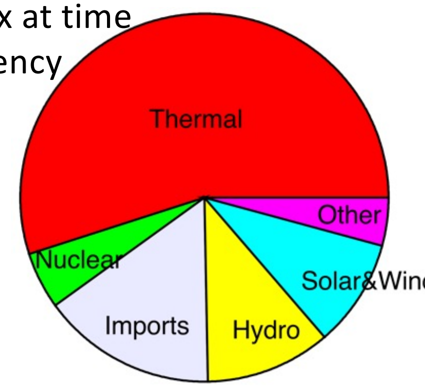
by Jeff St. John
August 17, 2020

State leaders would like to meet targets without blackouts
How do we meet resource adequacy with storage?

Envision Aug. 14th with no fossil fuels
Resource adequacy for delivering *Power*



Power mix at time of emergency



In 2020 – meet resource adequacy by adding thermal plants

In zero-carbon world, we have no thermal (without sequestration), nuclear or imports.

Then, how will we meet > 50 GW resource adequacy when the sun sets and the wind dies?

In zero-emissions world, California needs > 40 GW of storage, demand management, etc.

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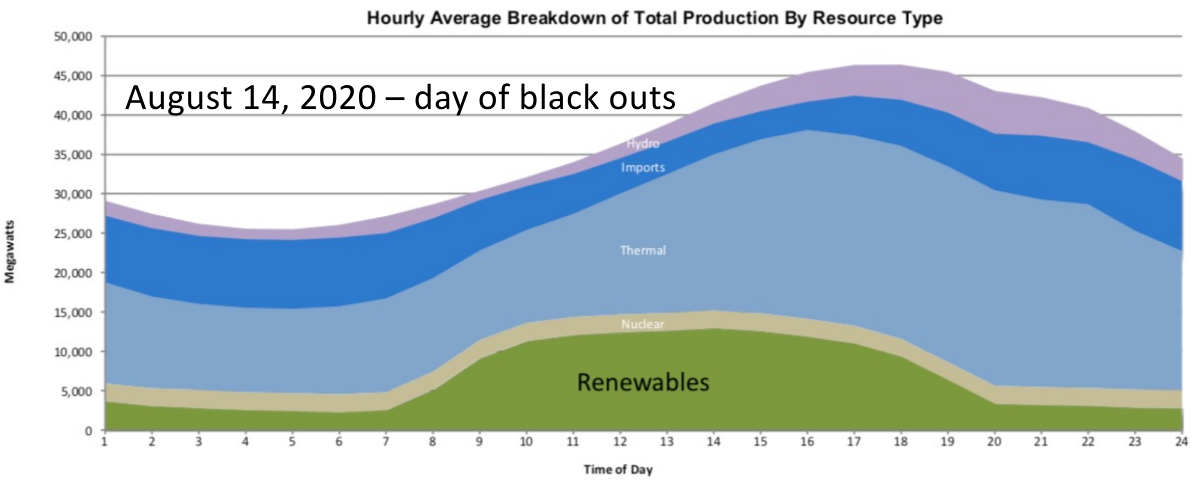
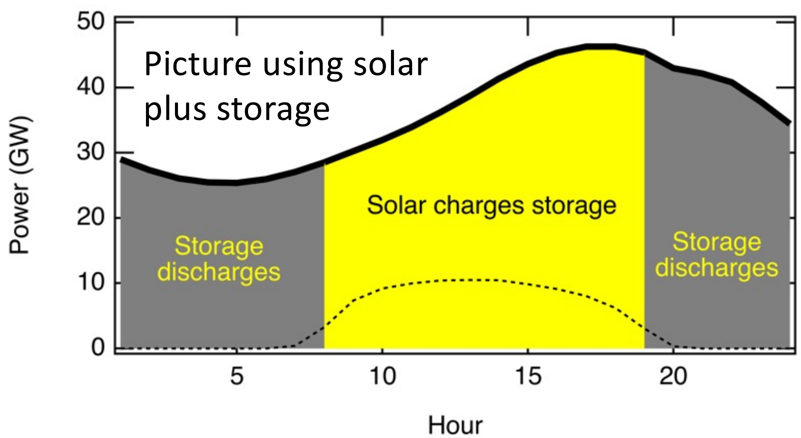
Envision Aug. 14th with no fossil fuels
Resource adequacy for delivering *Energy*





What would Aug. 14th look like in a solar plus storage system?

Need 10 hours of 40 GW of storage (total of 400 GWh)

Then, what about winter?

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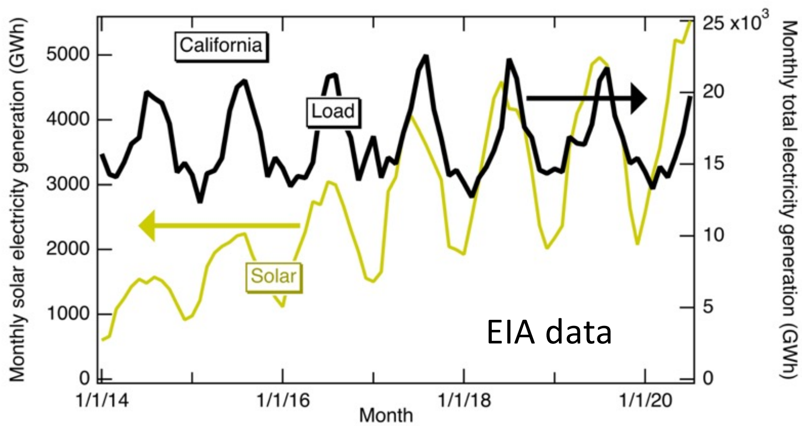
What about winter? – Seasonal storage?

- To provide adequate power in the winter, what are our options?:
  - Solar – need to build about twice as much as need in the spring-summer
  - Wind – wind balances solar in many locations (see next slide)
  - Hydro – hydropower currently provides 7% (dry year) to 20% (wet year)
  - Geothermal – currently provides 6% (can it increase?)
  - Nuclear – Diablo Canyon scheduled to shut down in 2025
  - Bio – currently provides 6% (can it increase?)
- Need Solar & wind: 80%?
- What can wind provide?



Load in winter may increase (heat pumps)

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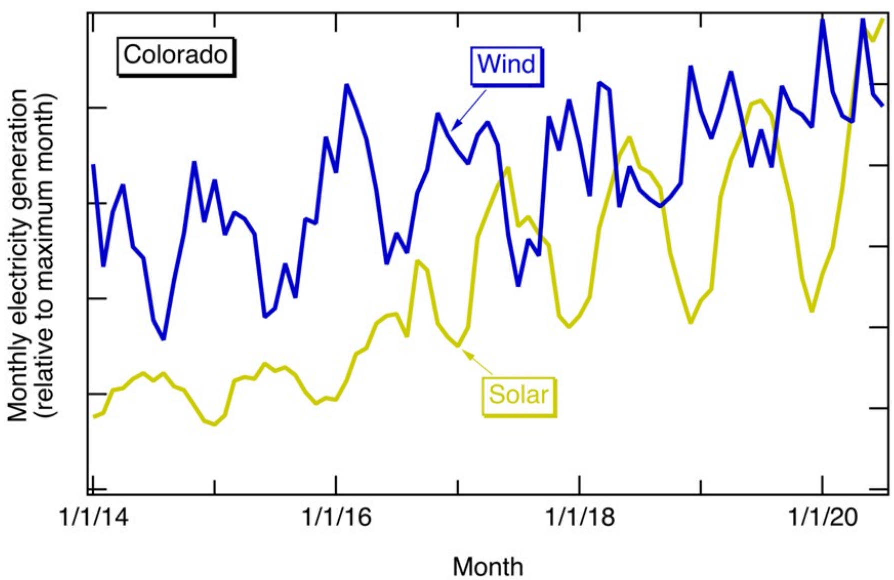
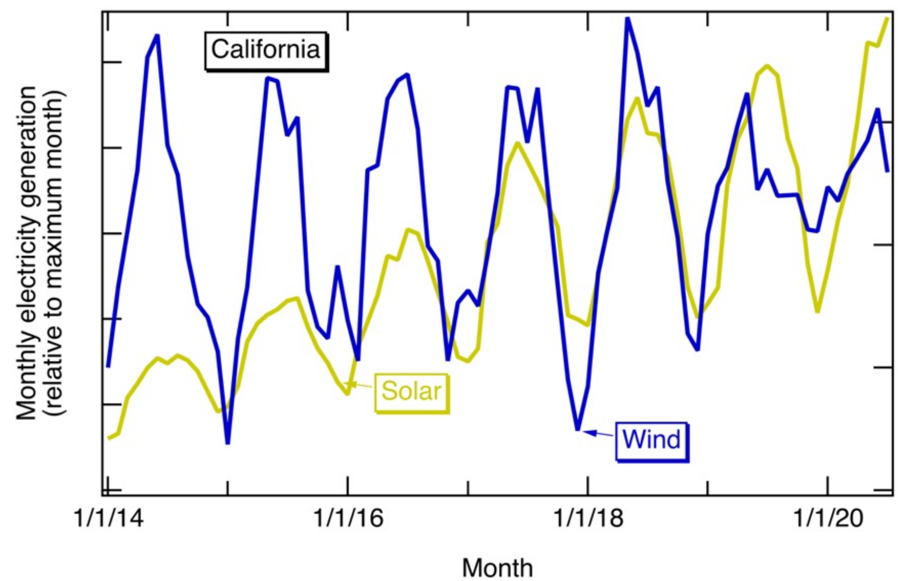
What role might wind play in the winter?

Colorado wind ALWAYS blows during the winter!



In California, the winter wind isn't reliable!



Land-based wind helps California when the sun sets, but not much during the winter!

Offshore or imported wind might help…

Data source: EIA

In California, how will we address seasonal variation?

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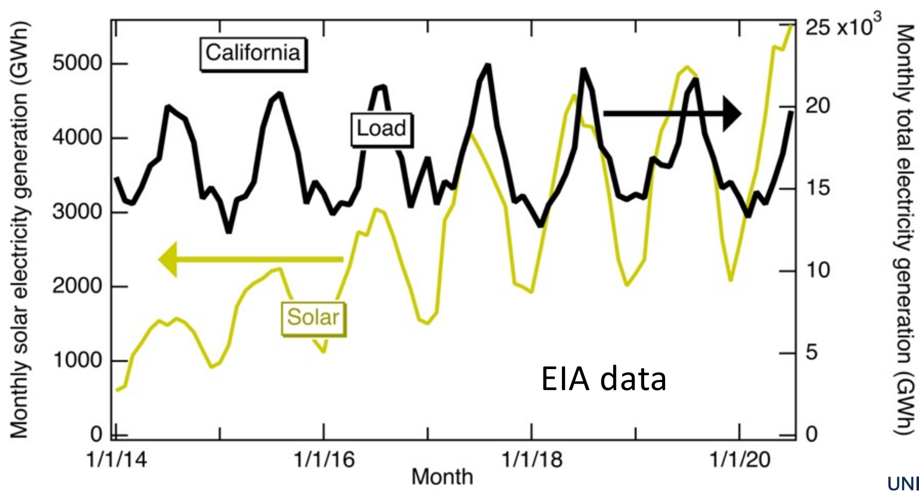
Options for seasonal balance

- Overbuild solar
  - Find a use for the surplus electricity in spring/summer (maybe hydrogen for?!)
  - Curtail the extra electricity
- Build optimal solar and identify functional seasonal storage
  - Pumped hydro?
  - Offshore or imported wind
  - Gas plus sequestration?
  - Other options…

Seasonal storage will be more useful to California than to some locations and will affect need for 10-100 hour storage



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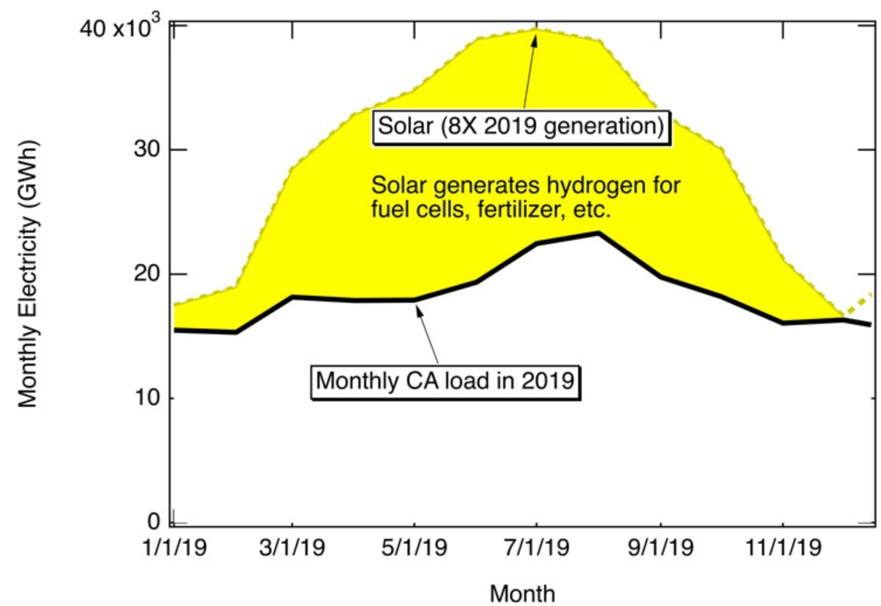
Bird's eye view of storage in zero-carbon CA

- ~40 GW of storage to meet peak demand
- ~10 hours to get through the night
- ~150 hours seasonal storage if overbuild solar by factor of 2
- ~500 hours seasonal storage if build solar to meet annual load

Note: 40 GW X 150 h = 6 TWh,
Hoover Dam generates 4 TWh/y

- *Overbuilding solar will trade off with seasonal solutions*
- *Understanding seasonal solutions will be critical*



PROJECT OBJECTIVES

- **Study Value of Long-Duration Storage**
  - What role(s) will long-duration storage play?
  - What cost target must a storage technology reach to be competitive?

- **Larger goal: Provide value to ratepayers**
  - Low electricity prices
  - Reliable electricity
  - Meet SB100 and other CA targets
  - Technical societal goals
    - Address climate change
    - Reduce air & water pollution
    - Adequate clean-water supplies
  - Broader societal goals
    - Stability of jobs
    - Social justice – move toward a more equitable world…

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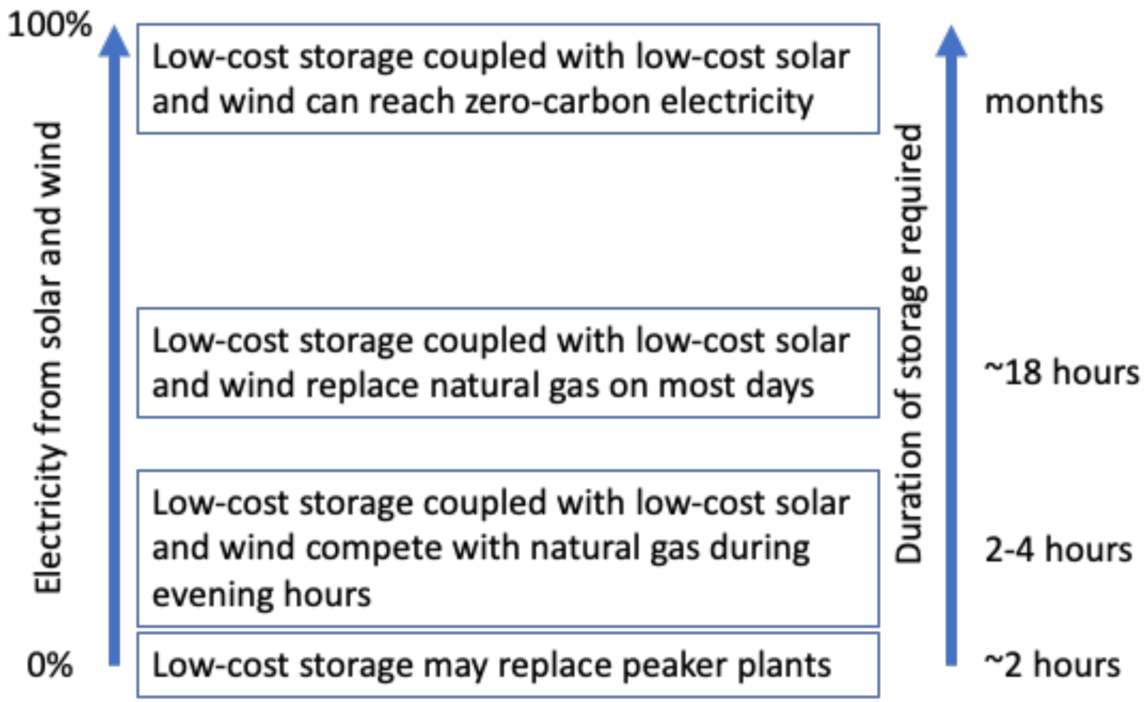
Scope: Include multiple roles for storage

- Ancillary services
- Arbitrage – same day (“baseload solar”)
- Arbitrage – cross day; several weeks
- Seasonal storage – cycle maybe once per year
- Resource adequacy – maybe never cycle
- Resilience (provide local power during outages)

- Reduced pollution
- Jobs
- Environmental issues (including water usage/effects)

Value of storage is a function of many things



Role of storage is function of amount of storage, solar, etc.

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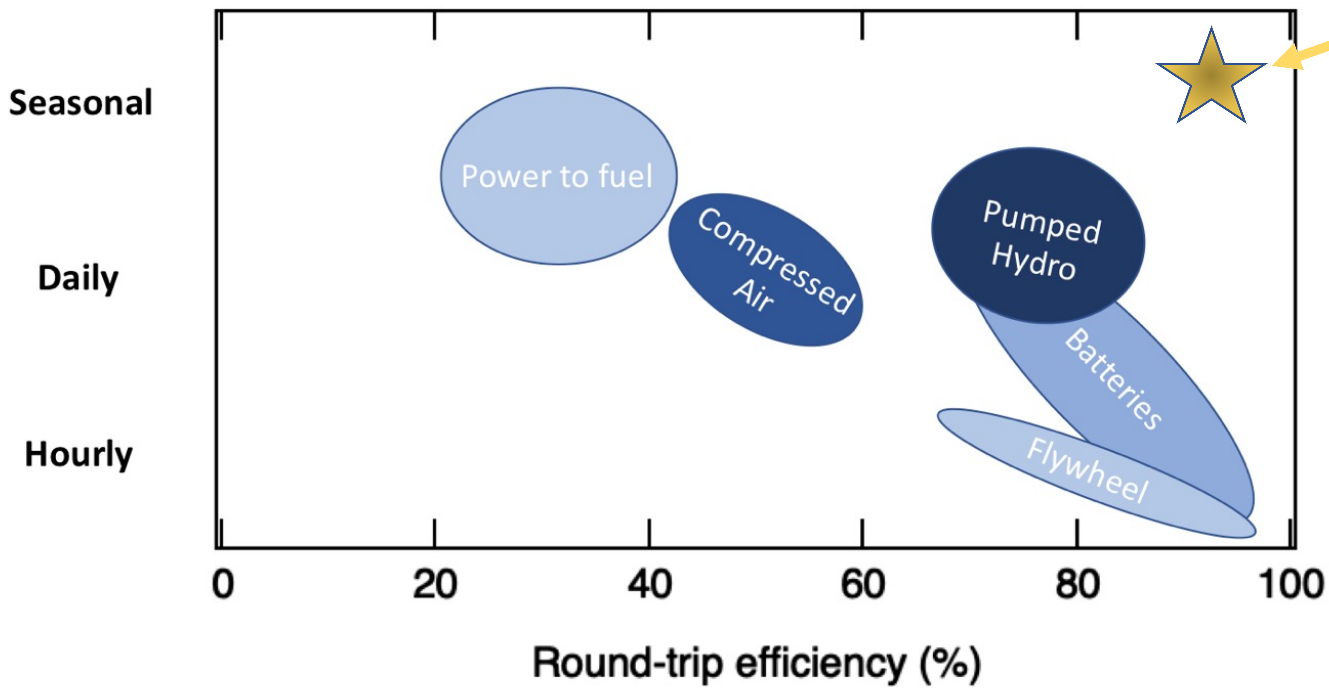
Pathway to end goal



Perfect solution would be:

- Low cost
- High efficiency
- Seasonal

As we move to longer duration will we need to sacrifice efficiency?

What is storage competing with?

Green Hydrogen

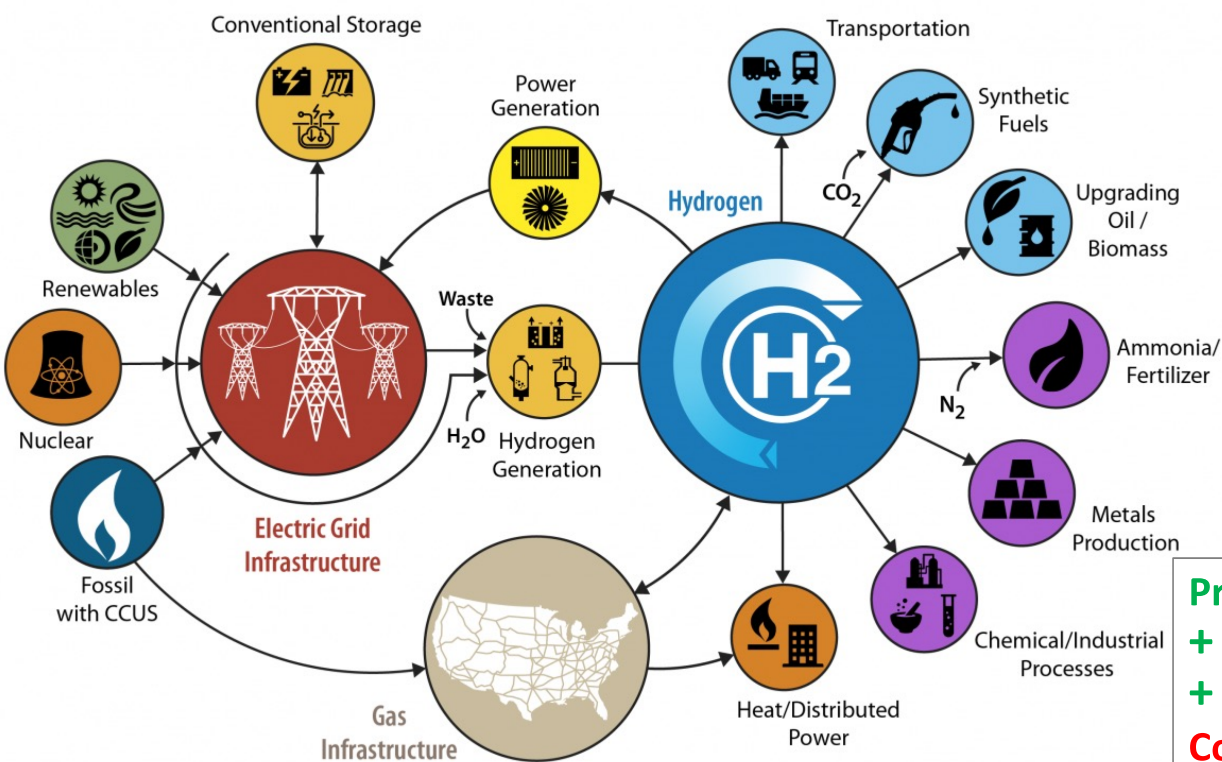
Long-duration Storage

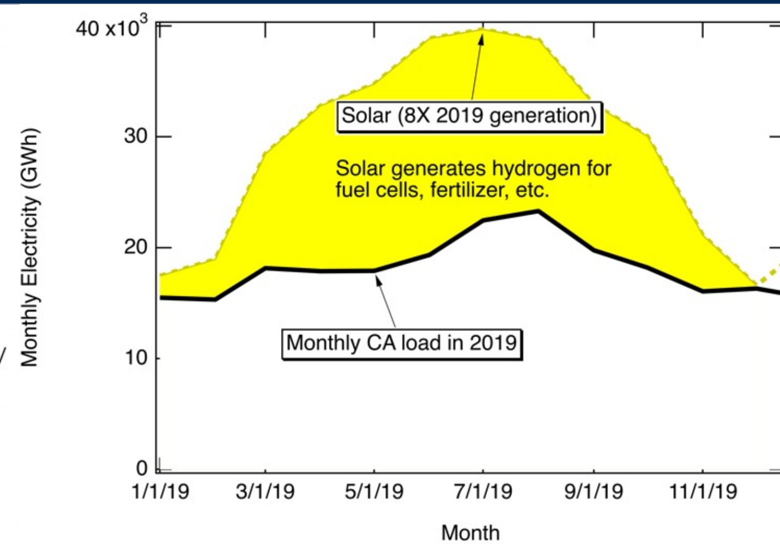
Carbon sequestration with gas

Overbuilt solar plus a range of solutions

Next slides summarize many storage technology options

Candidates for seasonal solution - hydrogen





Pros:

+ Hydrogen can be used for many things

+ As variable load, is a tool to balance the grid

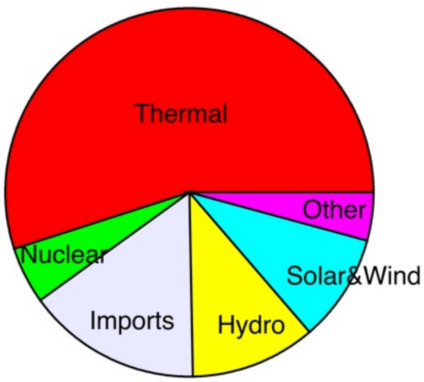
Cons:

- Needs lower cost

- Round-trip efficiency is somewhat low

Candidate for seasonal solution – gas + sequestration

Keep today's thermal plants



+ Carbon Sequestration = Addresses seasonal storage challenge

+ Leverages existing investment/technology
+ Seasonal capability is huge
- Does not eliminate pollution

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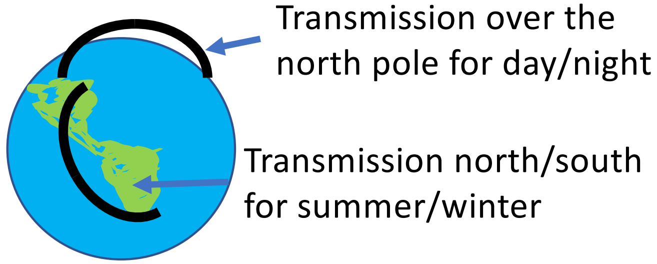
Candidate for "pseudo" storage – **transmission**

Regional grid provides more stable renewables

+ Many studies find: transmission is least-cost path to high penetration of renewables

- Politically challenging

Global transmission system could replace storage



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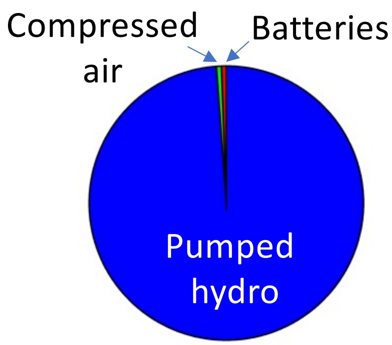
Candidates for storage – pumped hydro

Today's storage



Closed-loop pumped hydro storage avoids some environmental problems – can it be successful?

Fig. 2. Presenzano hydroelectric plant in Italy showing the reservoirs (upper right and lower left). This closed-loop pumped storage system has a head of 500 m, a power capacity of 1 GW, and storage of about 6 GWh (Google Earth image).

Image: BLAKERS et al.: PATHWAY TO 100% RENEWABLE ELECTRICITY

+ Best-established storage technology
+ New innovations provide opportunities
- Limited geographical opportunity
- Closed-loop cost not well established
- Sites are generally lacking transmission; expected to have high upfront costs

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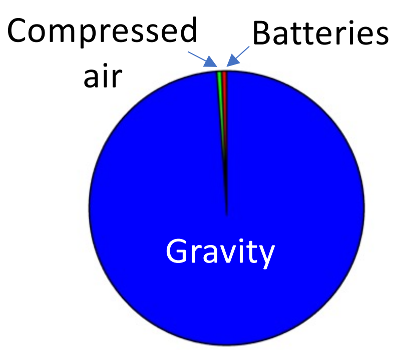
Candidates for cross-day storage – gravity

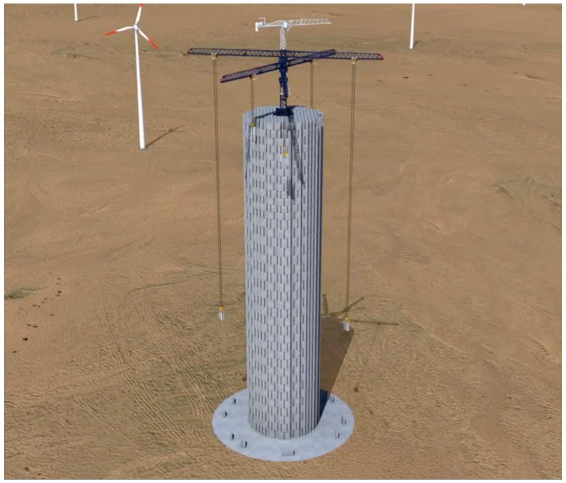
Today's storage



Other forms of gravity storage besides pumped hydro
i.e. rail, stacked weights

Electricity → Potential Energy → Electricity

+ Can be efficient with essentially no loss over months
+ Flexible geographically (relative to hydro)
- Cost not well established
- Large footprint

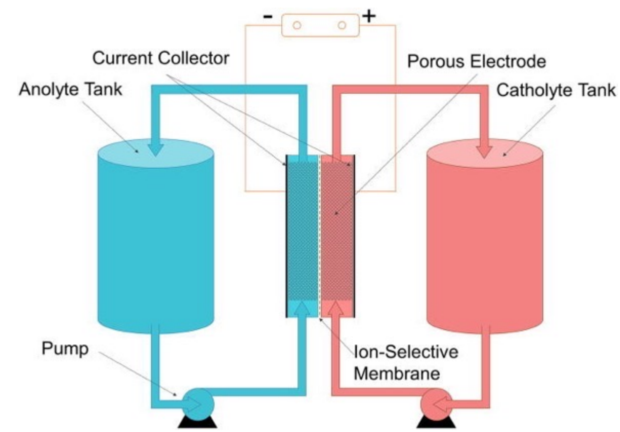


Energy Vault
- **Uses composite bricks**
- **High efficiency 80%-90%**
- **> $100 M in funding**
- **No energy loss with time**

Note: organizations described in blue form our technical advisory board

Candidates for long-duration storage – flow battery

- Flow batteries are being built using vanadium
- Aqueous-sulfur flow batteries have potential
- Other electrolytes are being developed



+ Can be scaled to large volumes at low cost

+ Flexible geographically (relative to hydro)

- Technology path not yet established

- Energy density is low (large footprint)

Harvard University
- **Organic electrolyte**
- **Demonstrating adequate stability**

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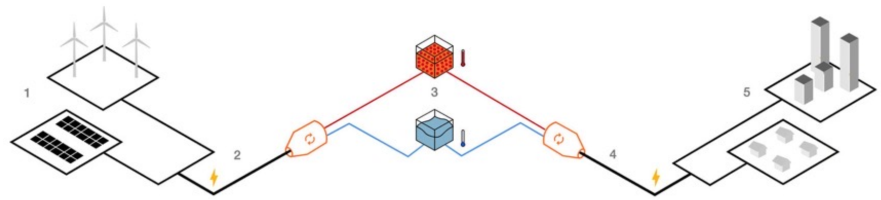
Candidates for cross-day storage – thermal

JOURNAL OF RENEWABLE AND SUSTAINABLE ENERGY **9**, 044103 (2017)

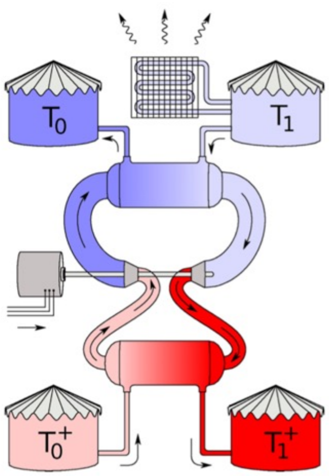
Pumped thermal grid storage with heat exchange

Robert B. Laughlin[a] (Nobel laureate)

Department of Physics, Stanford University, Stanford, California 94305, USA



Malta, Inc.
- **Incubated at Google X**
- **Funded by Breakthrough Energy**
- **Leverages existing technology**



Electricity → Thermal storage → Electricity

+ Potentially: safe, reliable, scalable, low cost

+ Could retrofit existing fossil plant

- Not yet demonstrated

- Not suitable for small scale

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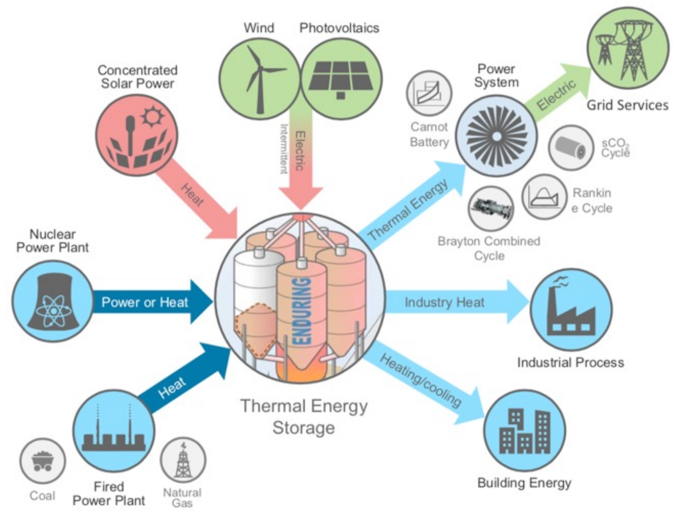
Candidates for cross-day storage – thermal

Electricity → Thermal storage → Electricity



+ Potentially: safe, reliable, scalable, low cost

+ Could retrofit existing fossil plant

- Not yet demonstrated at scale

- Must be implemented on large scale

NREL "ENDURING"
- **Solid particle high-T storage**
- **Working toward retrofit of existing power plants**

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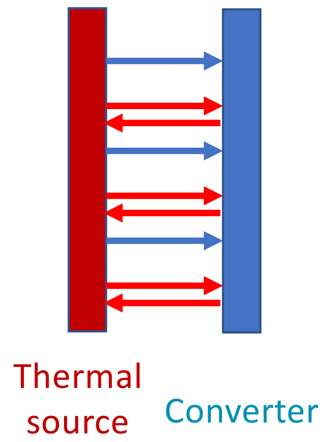
Candidates for cross-day storage – thermal

Thermophotovoltaic conversion

Electricity → Thermal storage → Electricity



Thermal source is hot and “glows”

Semiconductor converter reflects subbandgap light and converts absorbed light

+ **Potentially: safe, reliable, scalable, low cost**
+ **Could be implemented on small scale**
- **Under development (early stage)**

Antora Energy
- **Photovoltaic converter**
- **Working to optimize the converter**
- **Builds on decades of research**

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Candidates for cross-day storage – liquid air

Compressed air storage has been demonstrated at scale
If the air is cooled to a liquid, it takes less space and can be stored in tanks like those used for liquid nitrogen

Electricity → Liquid air → Electricity

+ Uses readily available equipment

+ Several demonstrations completed

+ Claimed to be low cost

- Not well established

Highview Power
- **CRYOBattery cheaper than lithium ion batteries for > 4 h**
- **10 MW to > 200 MW**
- **Moving from development into scale up**

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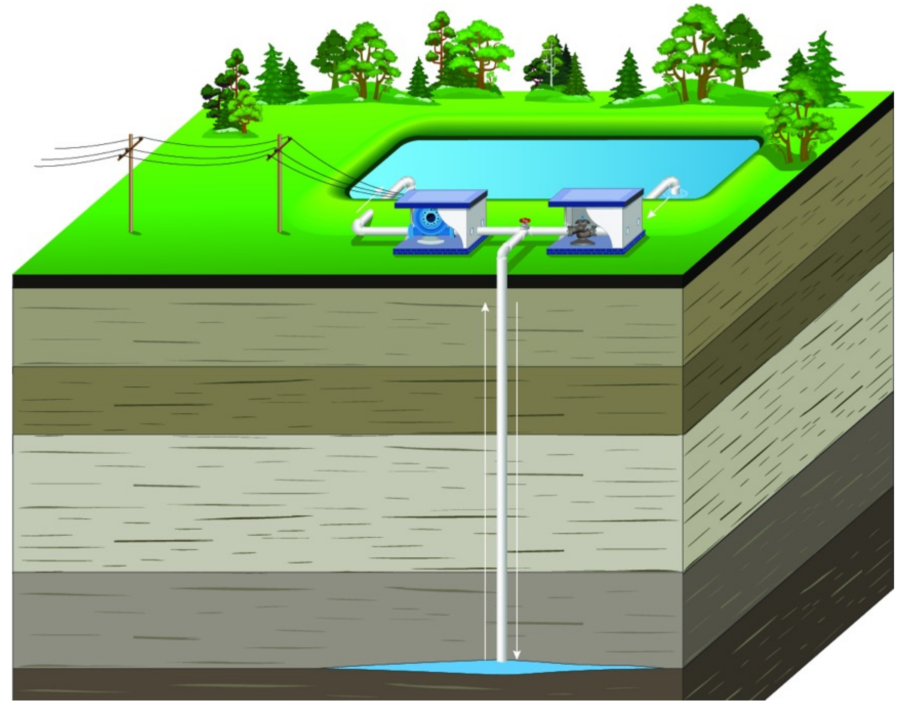
Candidates for cross-day storage – geomechanical

Water is pressurized and pumped into the rock deep in the earth
Then the pressure is released to turn a generator



Electricity → Compressed rock → Electricity

+ Can store a LOT of energy

+ Leverage idled drilling rigs and technology

- Not yet demonstrated

Quidnet Energy
- **Store energy by compressing the rock (injected water)**
- **Planning commercial demo**

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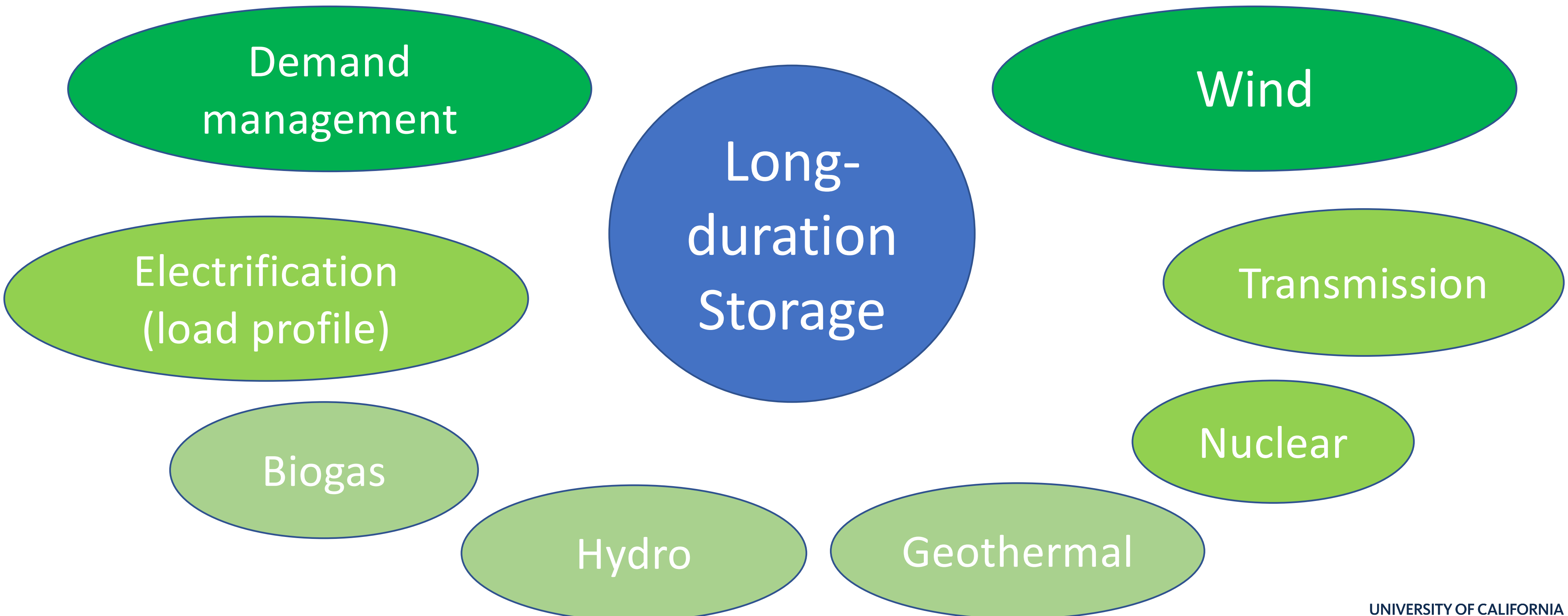
What affects the market size for storage?



All of these will affect the amount of storage that is needed

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Two Biggest Challenges

1. Computational

- Must include seasonal effects
- Modeling a full year is computationally demanding
- RESOLVE looks at one day at a time. Code needs to be updated to address long-duration storage.

2. Complexity

- Many inputs
- Many inputs are highly uncertain
- Many inputs have large effect on storage
- Many outputs – need to derive meaningful metrics

Note: plan to use RESOLVE and SWITCH

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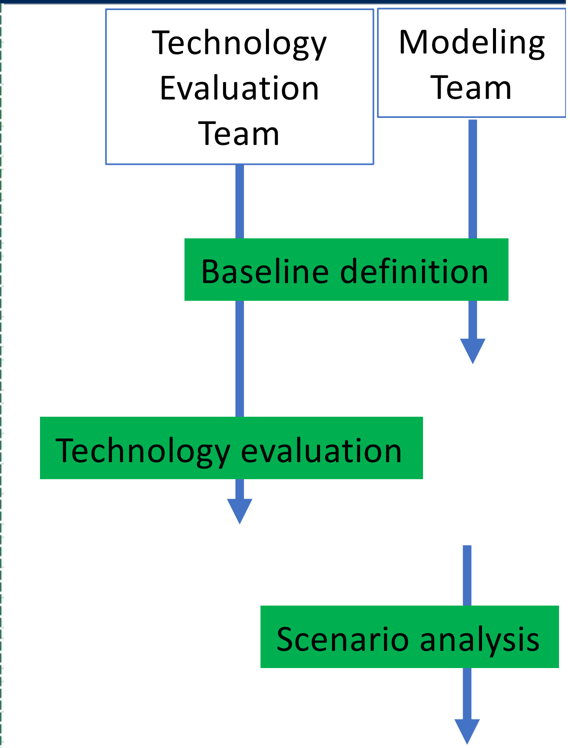
PROJECT SCHEDULE

Task ID	Task
	Phase (1, 2)
1	**General Project Tasks**
1.1-1.11	Products, Kick-off Meeting, Critical Project Reviews (CPR), Many Reports
2	**Baseline Development**
2.1	Data assembly
2.2	Confirmation of baseline data and approach
2.3	Implement Baseline in SWITCH and RESOLVE
3	**Future Energy Storage and Electricity Generation Technology**
3.1	Evaluate future storage technology alternatives
3.2	Define representative future energy storage technology alternatives
3.3	Evaluate future electricity generation technology alternatives
3.4	Define representative future electricity generation technology alternatives
4	**Grid Scenarios Development**
4.1	Muti-day Model Optimization
4.2	Grid scenario selection
5	**Final Scenario Analysis**
5.1	Preliminary final summary analysis
5.2	Final Scenario Analysis
6	**Public Input**
6.1	Initial public open meetings in southern and nothern CA
6.2	Public workshop for initial scenario selection
6.3	Public workshop for sharing of preliminary scenario analysis
6.4	Public workshop for final scenario selection



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Methodology: Coordinated, 2-prong approach

Technology evaluation

Study storage and RE technologies

- Cost analysis (power & energy)
  - Learning curve analysis
- Other metrics:
  - Efficiency (round trip & loss rate)
  - Market entry strategy
  - Jobs creation
  - Response time
  - Footprint (energy density)
  - Permitting – environmental concerns
  - Geographical flexibility

Long-duration Storage

Modeling

RESOLVE & SWITCH

- Modifications of RESOLVE
  - Coordinate with E3 to update RESOLVE for long-duration storage
- Select scenarios and implement in RESOLVE and SWITCH
- Analyze results

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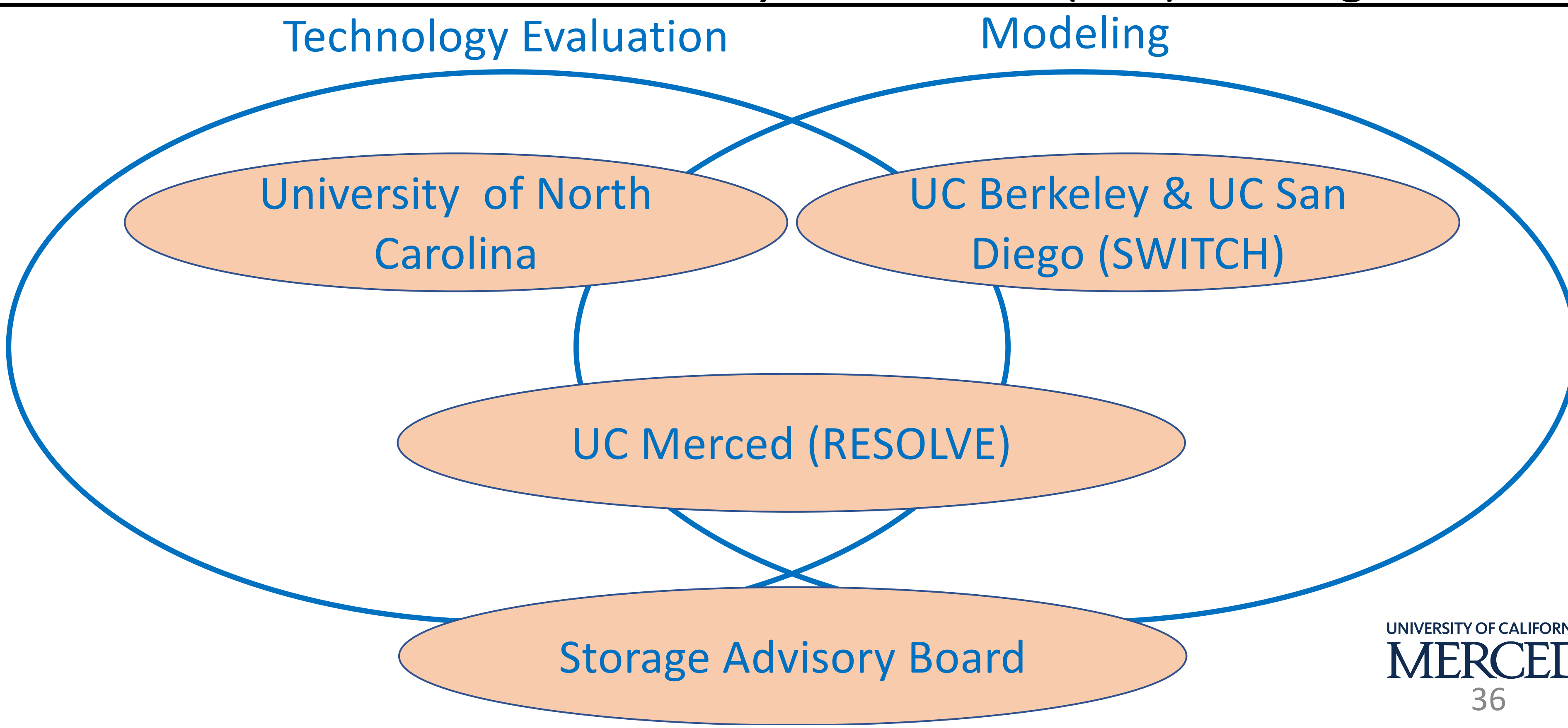
Project Team Organization

CEC and Technical Advisory Committee (TAC) Oversight



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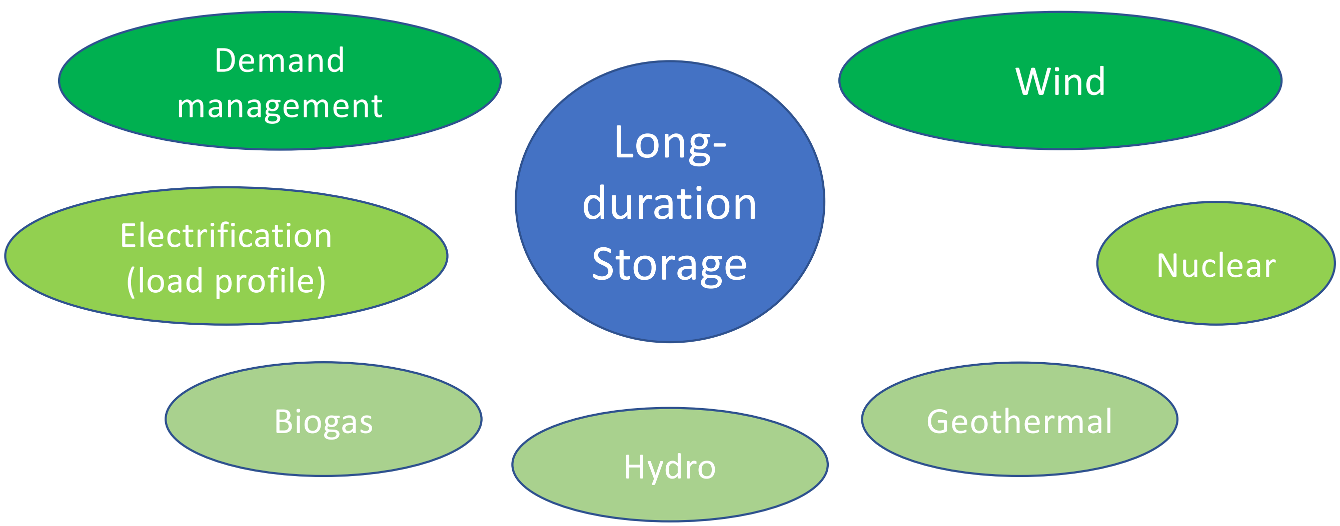
Strategies for Complexity Challenge

- Use Technology Evaluation to inform the Modeling
- Use inputs from Storage Advisory Board and others
- Compare outputs of RESOLVE, SWITCH, and other modeling
- Do thorough sensitivity analyses using knowledge of key factors



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FIRST STEP – BASELINE DESCRIPTION – COST, etc.

Baseline development is currently underway:

• RESOLVE Reference System Portfolio (RSP) and NREL Annual Technology Baseline (ATB) used as basis for inputs:

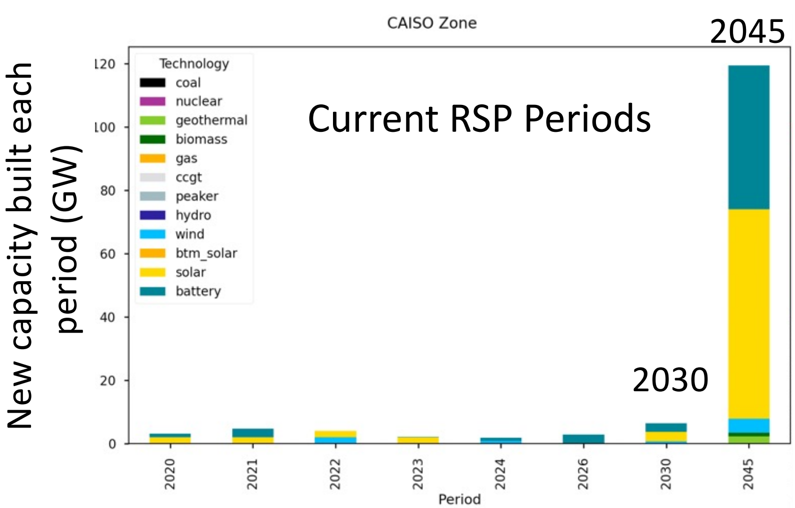
• Update **cost** and **build limits** numbers

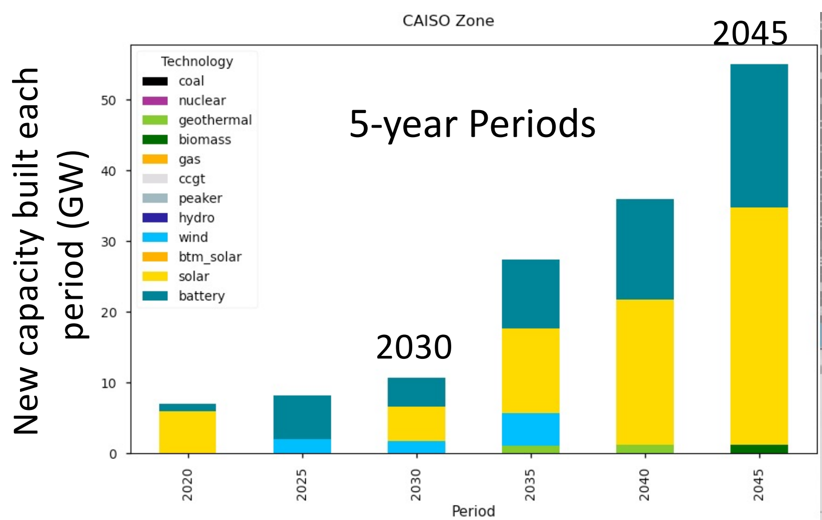
• Example: *Offshore wind has decreased in cost*. Others show small changes.

BASELINE DESCRIPTION – PERIODS & TARGETS

Baseline development is currently underway:

- Select analysis **periods**: 2020, 2025, 2030, 2035, 2040, 2045





- GHG emissions **target** in 2045 = 0 (RSP targets 87% reduction)

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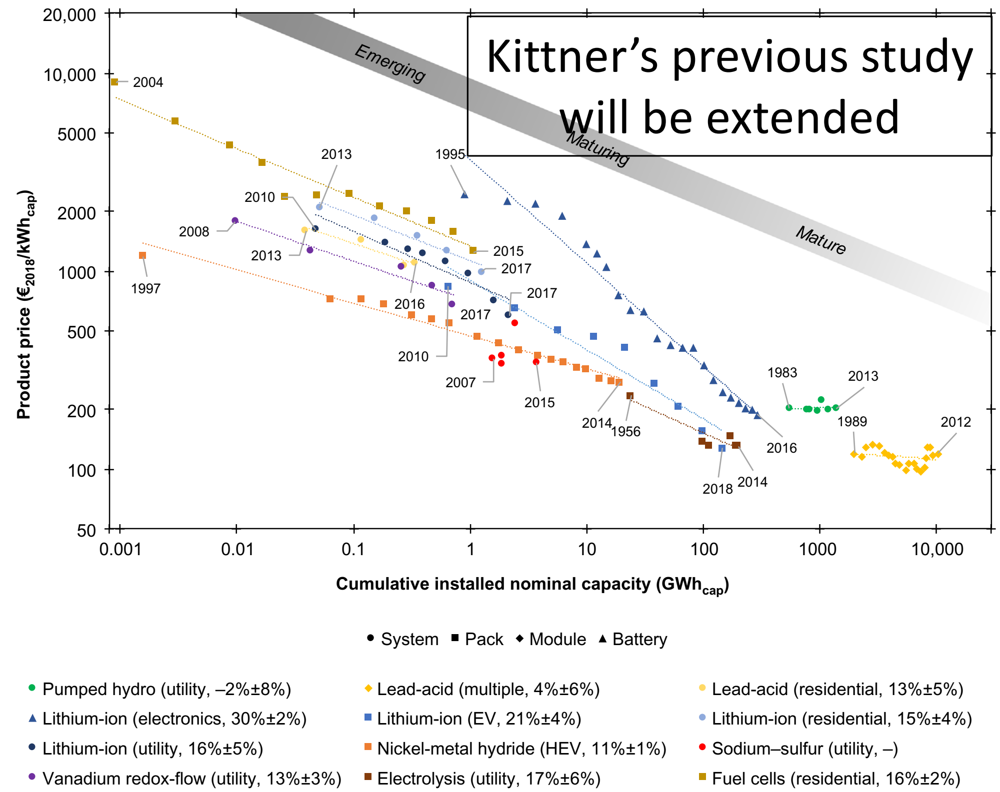
Technology Evaluation

Technology evaluation will include:

- Cost analysis (power & energy)
  - Learning curve analysis
- Other metrics:
  - Efficiency (round trip and loss rate)
  - Market entry strategy
  - Jobs creation
  - Response time
  - Footprint (energy density)
  - Permitting – environmental concerns
  - Geographical flexibility

Kittner's previous study will be extended



Scenario development

Second step of project is to identify scenario to study (choice is coordinated with E3)

Example candidates:

- Hydrogen scenarios (for transportation, fertilizer, chemicals…)
- EV charging strategies
- Electrification of buildings and other sectors
- Demand management
- Transmission deployment
- Local storage vs central storage
- Off-shore wind deployment
- Geothermal deployment
- Biofuel deployment
- Hydro variability with wet/dry; pumped hydro deployment
- Carbon sequestration

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Strategies for Computational Challenge

Current Reference System Portfolio for RESOLVE uses 37 days and 8 periods:

37 days X 24 h/day X 8 periods = 7104 timesteps

Can strong computational power extend this to 365 days to model a full year?

Example 2-step approach:

1. Optimize capacity expansion for:

- 365 days X ***2*** steps/day X 7 periods = 5110 timesteps

2. Optimize dispatch using identified capacity expansion for:

- 365 days X ***24*** h/day = 8760 timesteps
- repeat for multiple periods & weather sets, as needed

Vary numbers in bold to be most efficient

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Outcomes – Pathways to transition

Identify opportunities:

- What developments would lead to:
  - Lower cost transition
  - Faster transition
- Example: electrification of transportation coupled with day-time charging is an opportunity to quantify – what others can we find?

A smart transition will be a smooth transition

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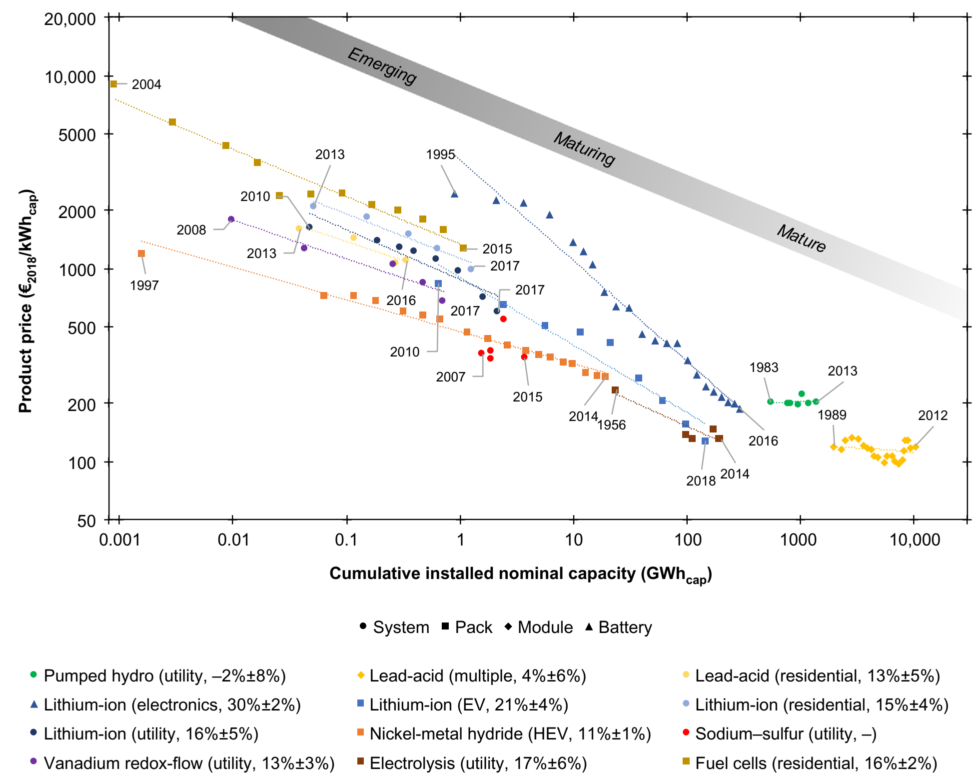
Outcomes – Assessment of technology options

Which storage technologies:

- Are best suited for each application?
- Have adequate readiness to help meet targets?
- Will benefit from investment to overcome their unique challenges?
- Will provide jobs and other benefits to California?



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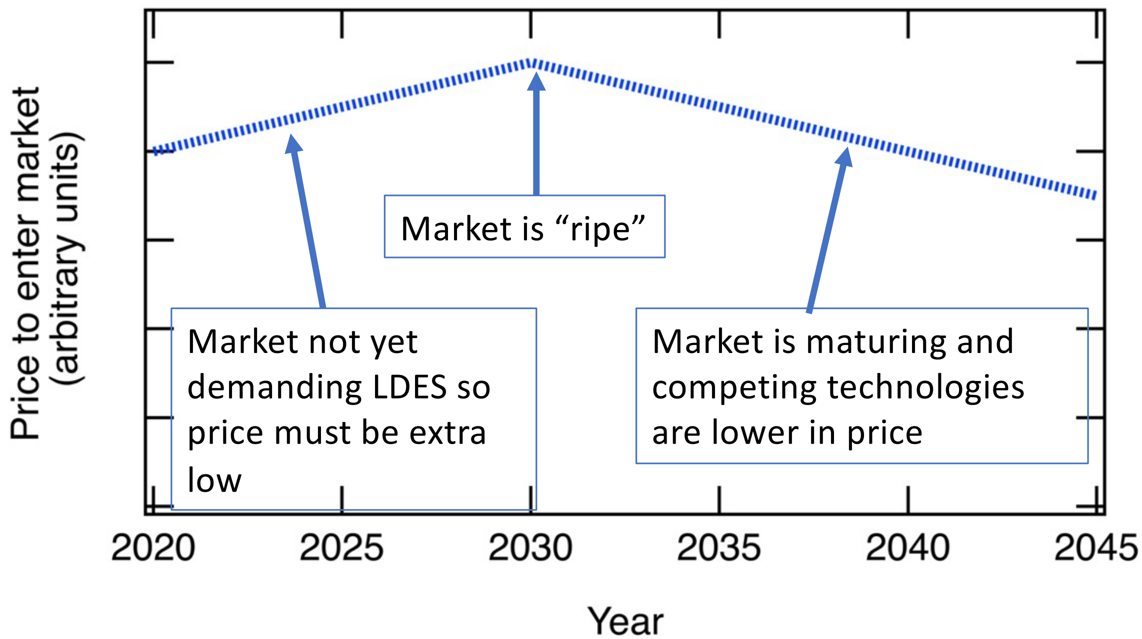
Outcomes – Entry market definition

Create price target graph for
- Each storage application
- Hours of duration
- Efficiency

Compare graph to expected price of each technology



This sort of analysis can help companies align their product design with market entry timing

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Conclusion

We are just getting started on our study of long-duration storage

We plan additional public workshops:

- Present proposed scenarios – summer or fall of 2021
- Present preliminary analysis – spring 2022
- Present final analysis – Fall of 2022

Public input desired at each step

How to be in touch with us: For public comment, submit to CEC website

Docket link is in the workshop announcement and in the introduction

Or send private email (see next page)

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We welcome collaboration:

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Thank you for your attention!