Modeling of Long Duration Storage for Decarbonization of California Energy System

EPC-19-060 - UC Merced

CPR #1 March 25, 2021

UNIVERSITY OF CALIFORNIA
MERCED

Agenda

1. Introductions (5 min)
    a. Presenters and Attendees
    b. Team Members and Project Partners
2. Project Overview & Status (30 min)
    a. Project Timeline and Goals
    b. Results from the Introductory Public Workshop and Baseline Development (Task 2)
3. Project Approach (25 min)
    a. Approach to Storage and Energy Technology Summaries
    b. Plans for the Scenario Selection Public Workshop
    c. Challenges and Opportunities
4. Questions (30+ min)
5. CPR Determination April 8, 2021

UNIVERSITY OF CALIFORNIA MERCED

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

Students will be introduced as their work is introduced later…

Technical Advisory Committee members

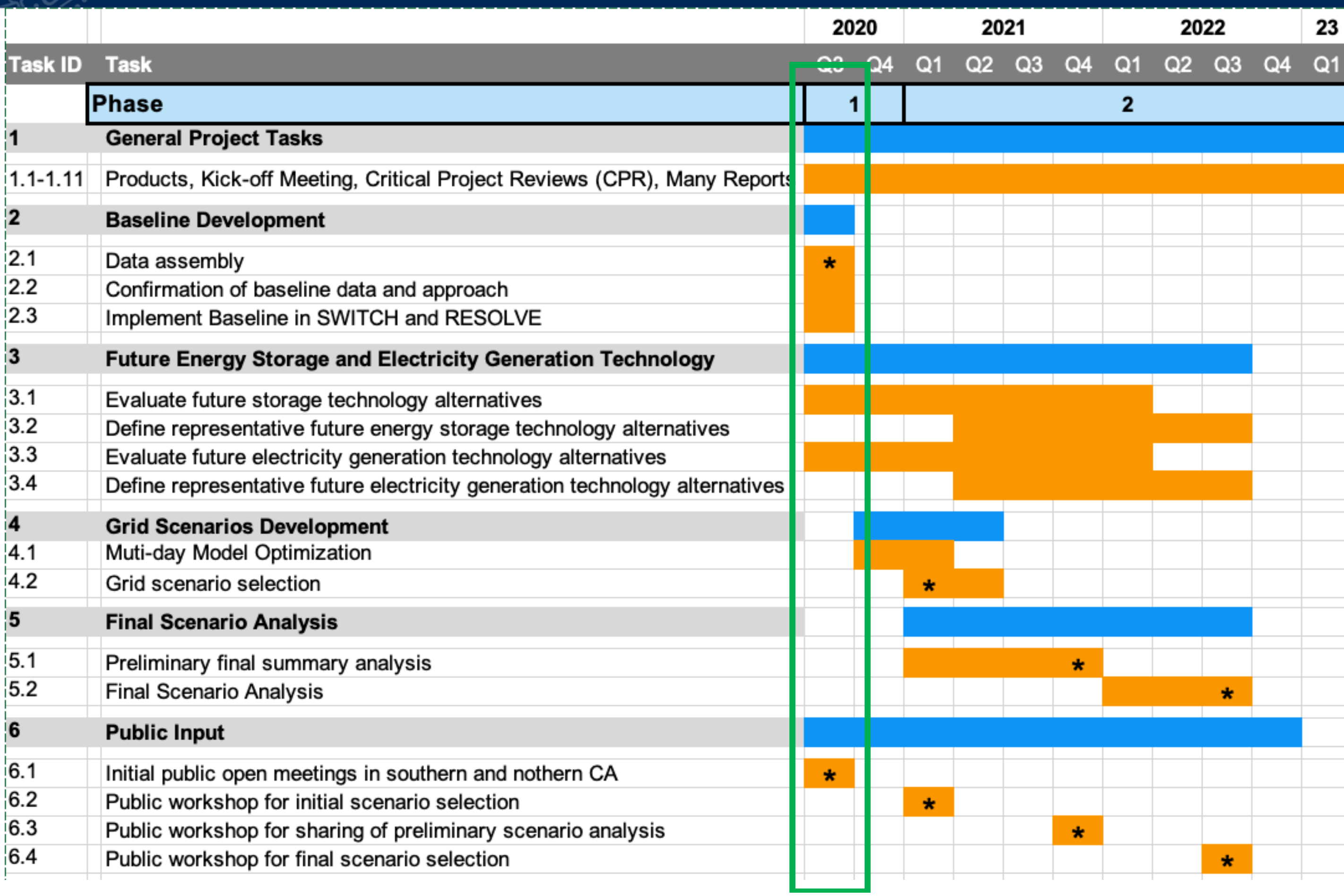
- Erin Childs (CESA) – CESA is doing similar modeling for California
- Paul Denholm (NREL) – NREL has been studying storage
- Jennifer Dowdell (TURN) – TURN studies equitable policies
- Shucheng Liu (CAISO) – CAISO representative
- Keith Parks (Xcel Energy) – Utility representative (Xcel is leader)
- Julia Prochnik (LDES Association of California) – Storage industry
- Ron Sinton (Sinton Instruments) – Has been participating in CO
- Priya Sreedharan (GridLab) – GridLab is studying transition
- David Williams – Brings business perspective

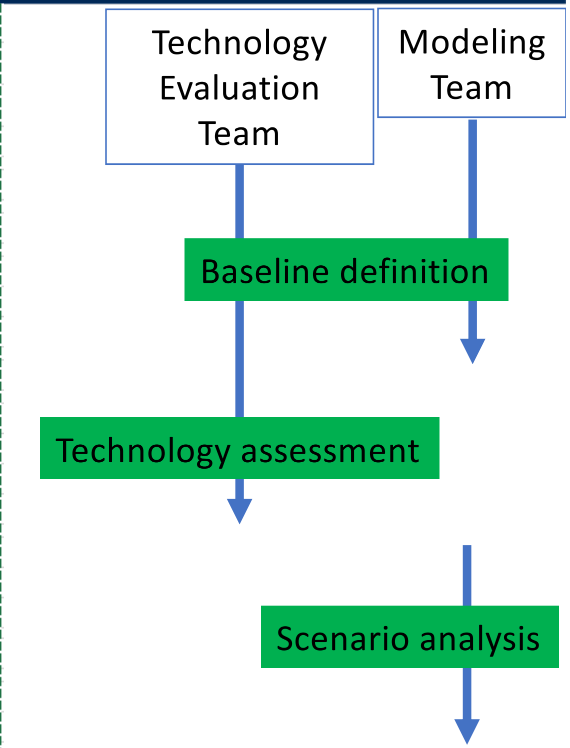
Storage specialists we have engaged with so far

- Antora Energy
- Cat Creek
- EDF
- Energy Vault
- ETES
- GE Renewables
- H2B2
- Harvard University
- Heliogen
- Highview Power
- Hydrostor
- NREL
- Quidnet
- Renewell Energy
- Solar Turbines
- Zinc8 Energy Solutions

UNIVERSITY OF CALIFORNIA MERCED

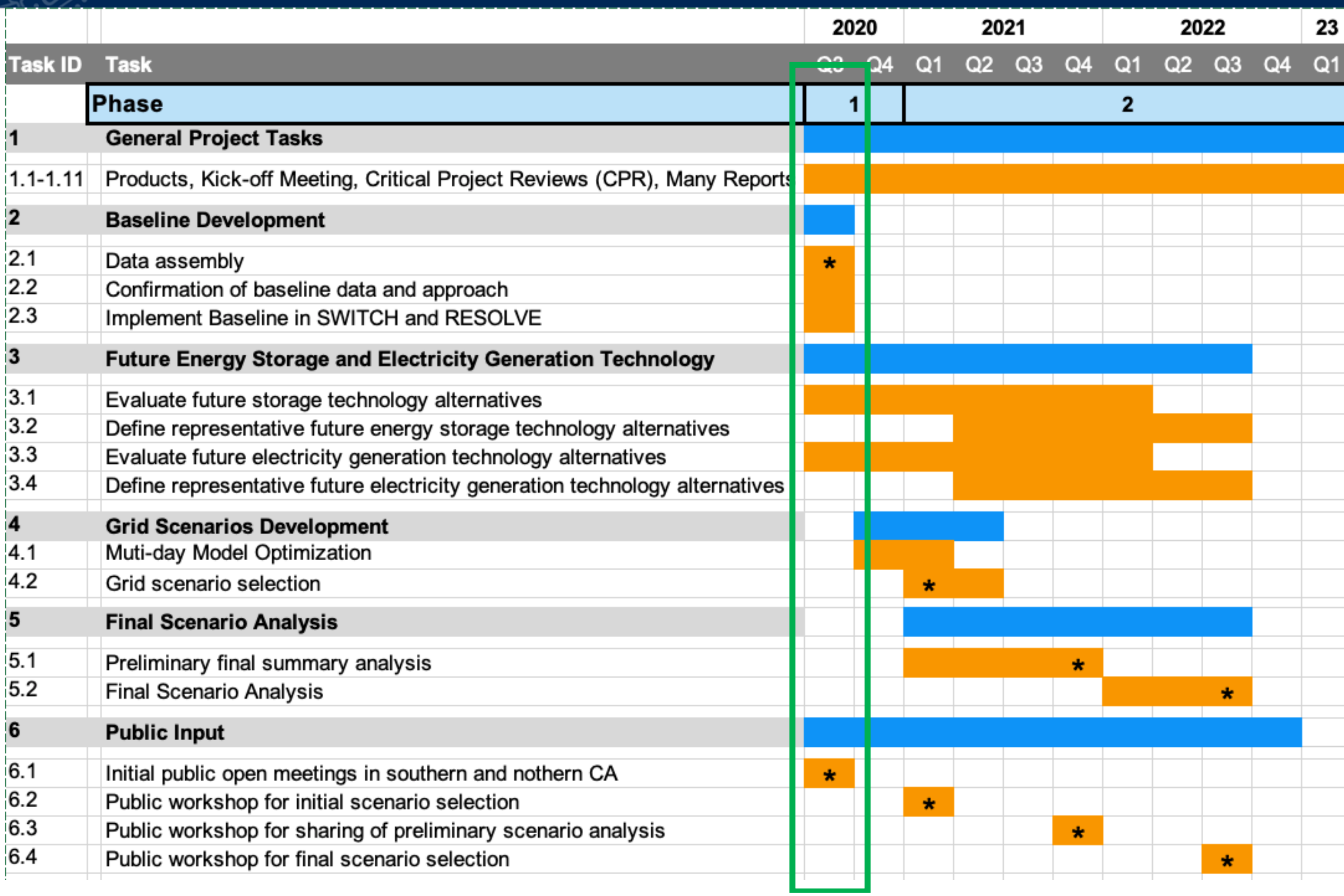
PROJECT SCHEDULE





UNIVERSITY OF CALIFORNIA
MERCED

PROJECT SCHEDULE



Completed work to be presented today:

Status on future work (2nd part of talk)

Task 2:
Baseline Development
Deliverables submitted

Task 3:
Technology Evaluation
Project initiation

Task 4:
Scenario Development
Initial results

Task 6:
Public workshop

UNIVERSITY OF CALIFORNIA MERCED

PROJECT OBJECTIVES

- **Study Value of Long-Duration Storage**
  - What role(s) will long-duration storage play? (e.g. nighttime vs cloudy days vs seasonal)
  - What cost target must a technology reach to be helpful?

- **Technical questions**
  - Is there an entry market?
  - What will a technology be competing against?
  - What will enable a technology to compete successfully?
    - Cost, efficiency, etc.

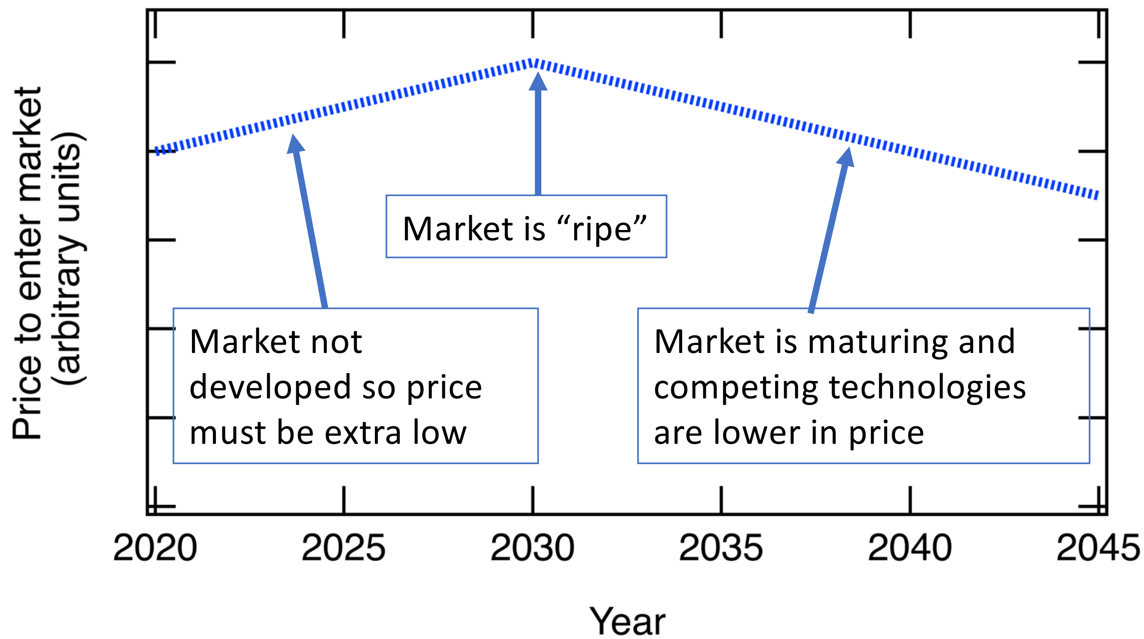
UNIVERSITY OF CALIFORNIA MERCED

Project goal – Entry market definition

Here is an example of the sort of outcome that will be useful

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

UNIVERSITY OF CALIFORNIA MERCED

Task 6: Results from Public Workshop

- Public workshop was held November 17, 2020
- Opportunities/Challenges:
  - During the workshop, the primary questions were around “What do we mean by ‘Long-duration storage’”?
  - The workshop motivated productive conversations
- Follow up:
  - Have written a draft “Talking about Long-duration Storage” (next slides)
  - *Issues in Science and Technology* is interested in publishing a non-technical version in April – revision in progress
  - May publish technical parts in second publication
  - Conversation has been valuable

UNIVERSITY OF CALIFORNIA MERCED

"Talking about Long-duration Storage"
From a modeling perspective – time element

- Modeling approach depends on application

- One-day models
  - Short-duration storage to meet peak demand
  - Diurnal storage (through the night)

- Multi-day models
  - Cross-day storage (get through a storm)

- Full-year models
  - Seasonal storage

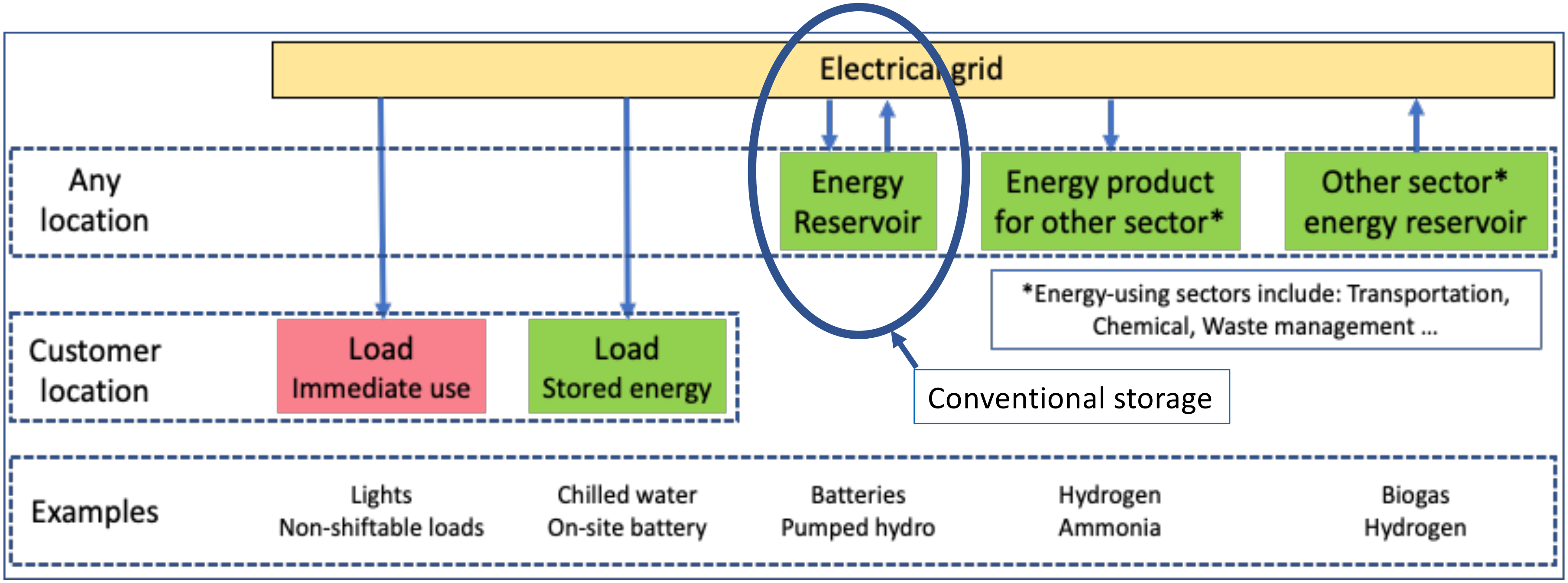
Some technologies may address multiple applications

To understand big picture, must model all applications simultaneously!

UNIVERSITY OF CALIFORNIA MERCED

"Talking about Long-duration Storage"
From a modeling perspective – energy flow

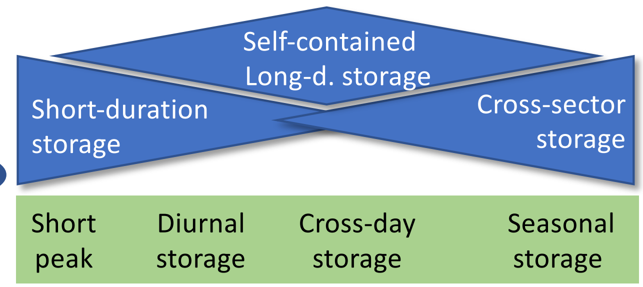
Modeling energy flows - need to consider all types



“Talking about Long-duration Storage”
Include all types in modeling

Table 1. Proposed taxonomy for differentiating storage opportunities

Figure 1 label	Load – stored energy	Energy reservoir	Energy product for other sector	Other-sector energy reservoir
Modeled electricity flow	Grid ↓ Storage	Grid ↓↑ Storage	Grid ↓ Storage	Grid ↑ Storage
Proposed taxonomy	**Customer-sited storage**	**Self-contained storage**	**Cross-sector storage**	
Examples modeled and included in taxonomy	Hot and chilled water Customer-sited batteries Thermal mass of building Water pumping	Batteries Gravity storage Hydrogen stored on-site for electricity generation	Hydrogen for transportation, etc. Power-to-X	Hydrogen brought from underground storage Ammonia or other fuel made from electricity
Examples included in electrical modeling, but not called “storage”	Energy efficiency Demand management not involving energy storage		Thermal energy used for industrial process	Biogas Natural gas plant with carbon sequestration



UNIVERSITY OF CALIFORNIA MERCED

The picture can't be displayed.

“Talking about Long-duration Storage” Include all types in modeling

Table 1. Proposed taxonomy for differentiating storage opportunities

Figure 1 label	Load – stored energy	Energy reservoir	Energy product for other sector	Other-sector energy reservoir
Modeled electricity flow	Grid ↓ Storage	Grid ↓↑ Storage	Grid ↓ Storage	Grid ↑ Storage
Proposed taxonomy	**Customer-sited storage**	**Self-contained storage**	**Cross-sector storage**	
Examples modeled and included in taxonomy	Hot and chilled water Customer-sited batteries Thermal mass of building Water pumping	Batteries Gravity storage Hydrogen stored on-site for electricity generation	Hydrogen for transportation, etc. Power-to-X	Hydrogen brought from underground storage Ammonia or other fuel made from electricity
Examples included in electrical modeling, but not called “storage”	Energy efficiency Demand management not involving energy storage		Thermal energy used for industrial process	Biogas Natural gas plant with carbon sequestration

For our purposes: it’s more important to agree on what must be modeled, not what is called “storage”
However, if CEC creates a solicitation to fund “long-duration storage”, the companies will want a broad definition

UNIVERSITY OF CALIFORNIA MERCED

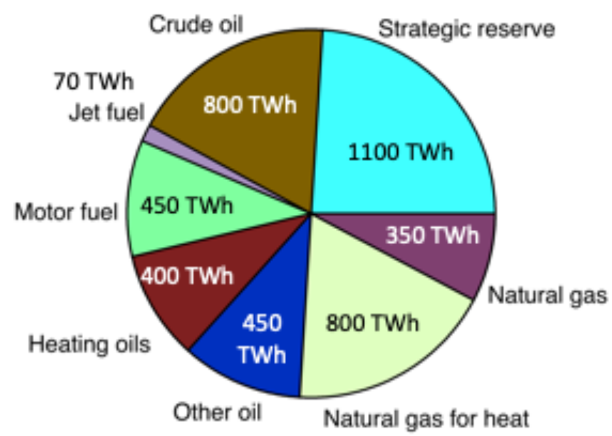
"Talking about Long-duration Storage"
Why think broadly?

The picture can't be displayed.

Current energy storage for all sectors is huge

Will tomorrow's energy system need more or less energy storage?

Current energy storage in USA



Natural gas may be stored for:

- Power generation
- Heating
- Chemicals

"cross-sector" storage: reduces costs for all sectors

Conclude:

- *When studying long-duration storage, need to also consider options for large-scale (cross-sector) storage*
- *How will self-contained storage projects compete with these?*
- ***Including cross-sector storage will stimulate innovation***

UNIVERSITY OF CALIFORNIA MERCED

The picture can't be displayed.

"Talking about Long-duration Storage"
Status

- Writing version for non-technical audience for April in *Issues in Science and Technology*
- Will look for periodical that is appropriate for more technical version
- Will include slides in next Public Workshop

UNIVERSITY OF CALIFORNIA
MERCED

Task 2: Baseline definition – status

The picture can't be displayed.

Task 2 Deliverables completed

- Baseline Description (Feb. 4 – draft; 25 – final)
- Modeling Approach Description (Feb. 4 – draft; 25 – final)
- Summary of Baseline Model Results (March 23)

All have been completed on time using 2018 version of RESOLVE

E3 is updating RESOLVE to include cross-day capability needed for long-duration storage and other changes. *The above will be reimplemented in the new version of RESOLVE after we have it from E3*.

UNIVERSITY OF CALIFORNIA MERCED

Criteria used to define new baseline for RESOLVE

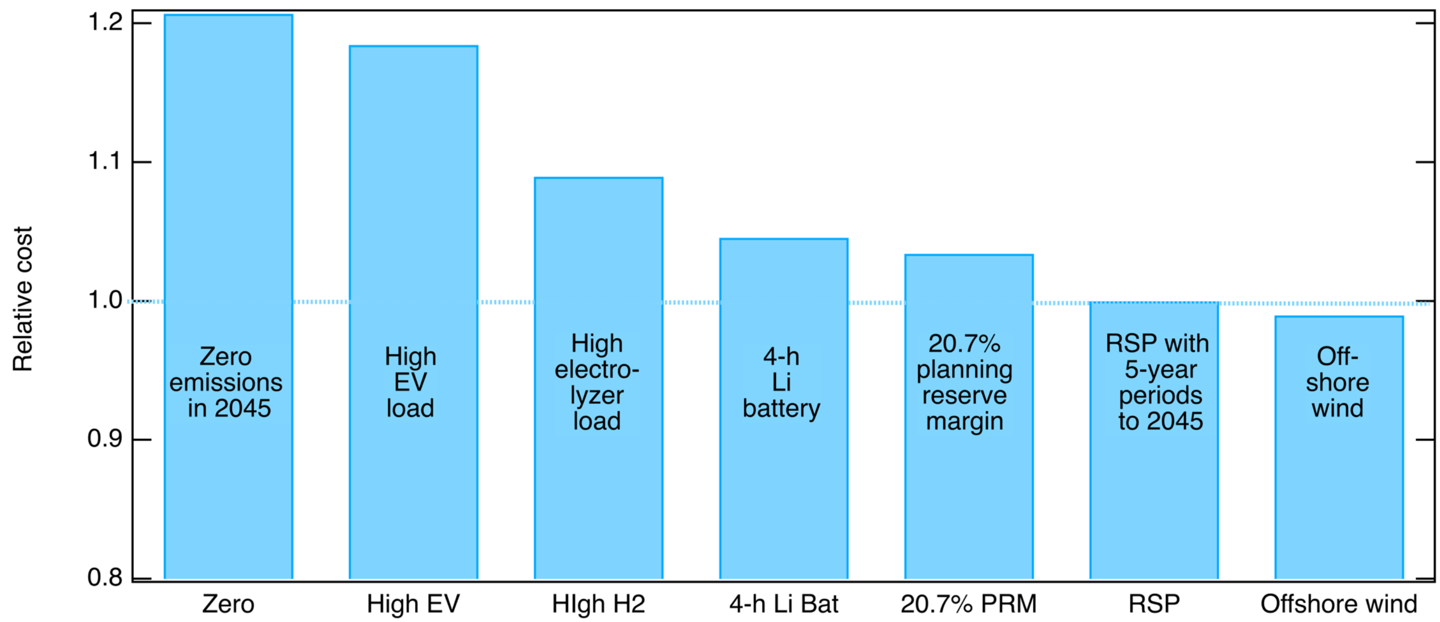
Start from 2018 RSP – will update this when E3 releases new version

Things that have changed:

- Governor's goal for electric vehicle sales (increase EV charging load)
- Increased investment in hydrogen (increase electrolyzer load)
- Advancement of off-shore wind (add off-shore wind options)
- Li batteries built as 4-hour resource (redefine Li_battery)
- Proposed increase of planning reserve margin from 15% to 20.7%
- Increased enthusiasm to reach zero emissions (zero in 2045)

UNIVERSITY OF CALIFORNIA
MERCED

Implications of changes to baseline
Sensitivity to each change individually



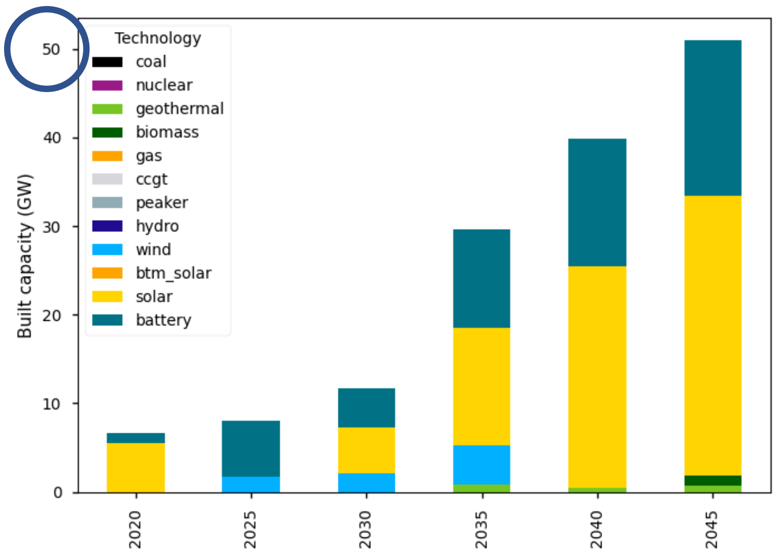
These results raise questions – addressed in the following slides

UNIVERSITY OF CALIFORNIA
MERCED

Implications of changes to baseline – zero GHG in 2045 New builds each year

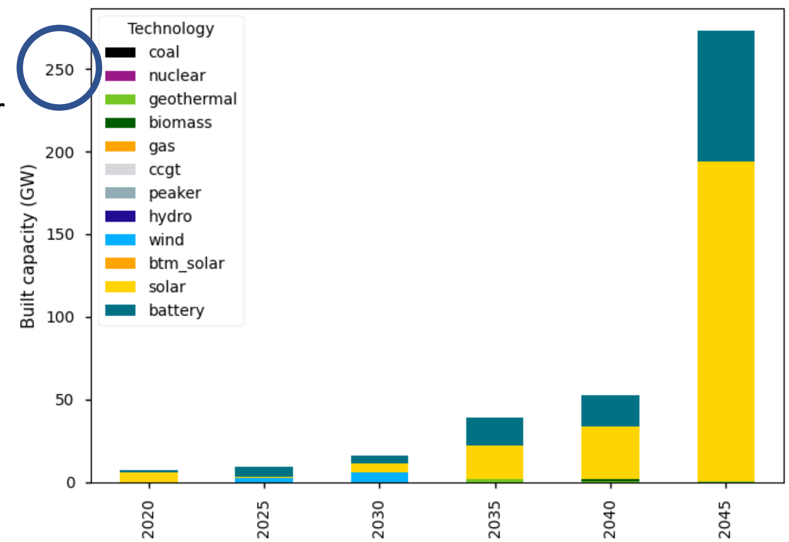
California data – no imports in 2045

5-year RSP (2018 version)



5-year RSP with zero-emissions target in 2045

Scale is 5 X bigger



Builds 200 GW solar in 2045! Could change for multiple reasons…

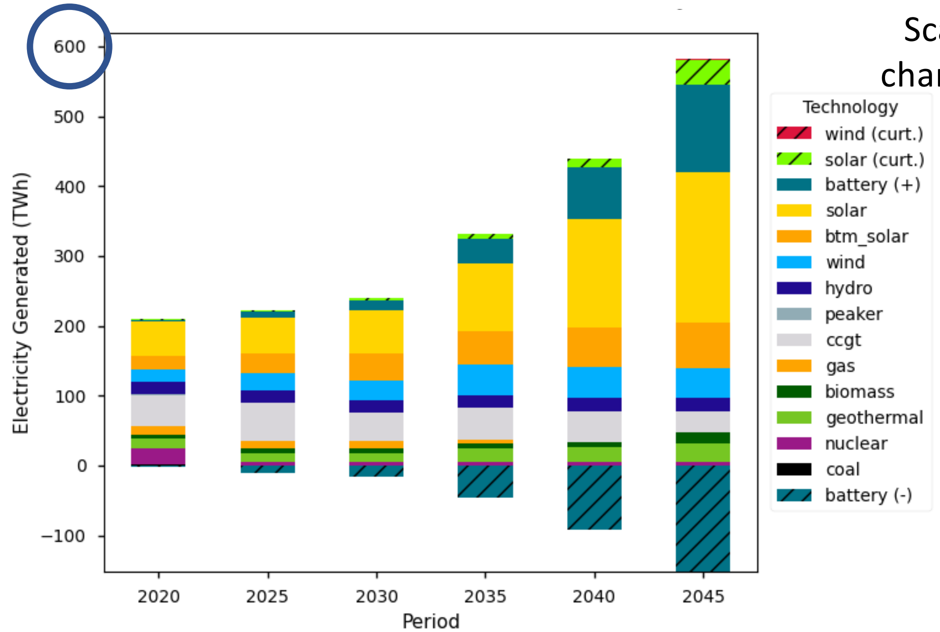
However, recall that RESOLVE uses 37 independent days: There is no opportunity for cross-day storage.

Question: will overbuild be decreased when cross-day storage is included?

UNIVERSITY OF CALIFORNIA MERCED

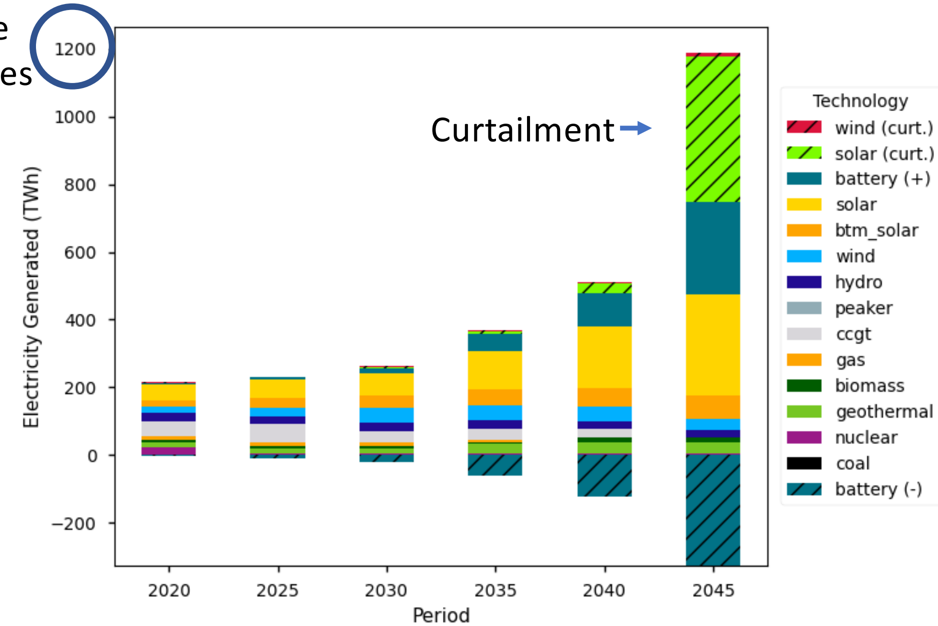
Implications of changes to baseline – zero in 2045

5-year RSP (2018 version)



Scale changes

5-year RSP with zero-emissions target in 2045

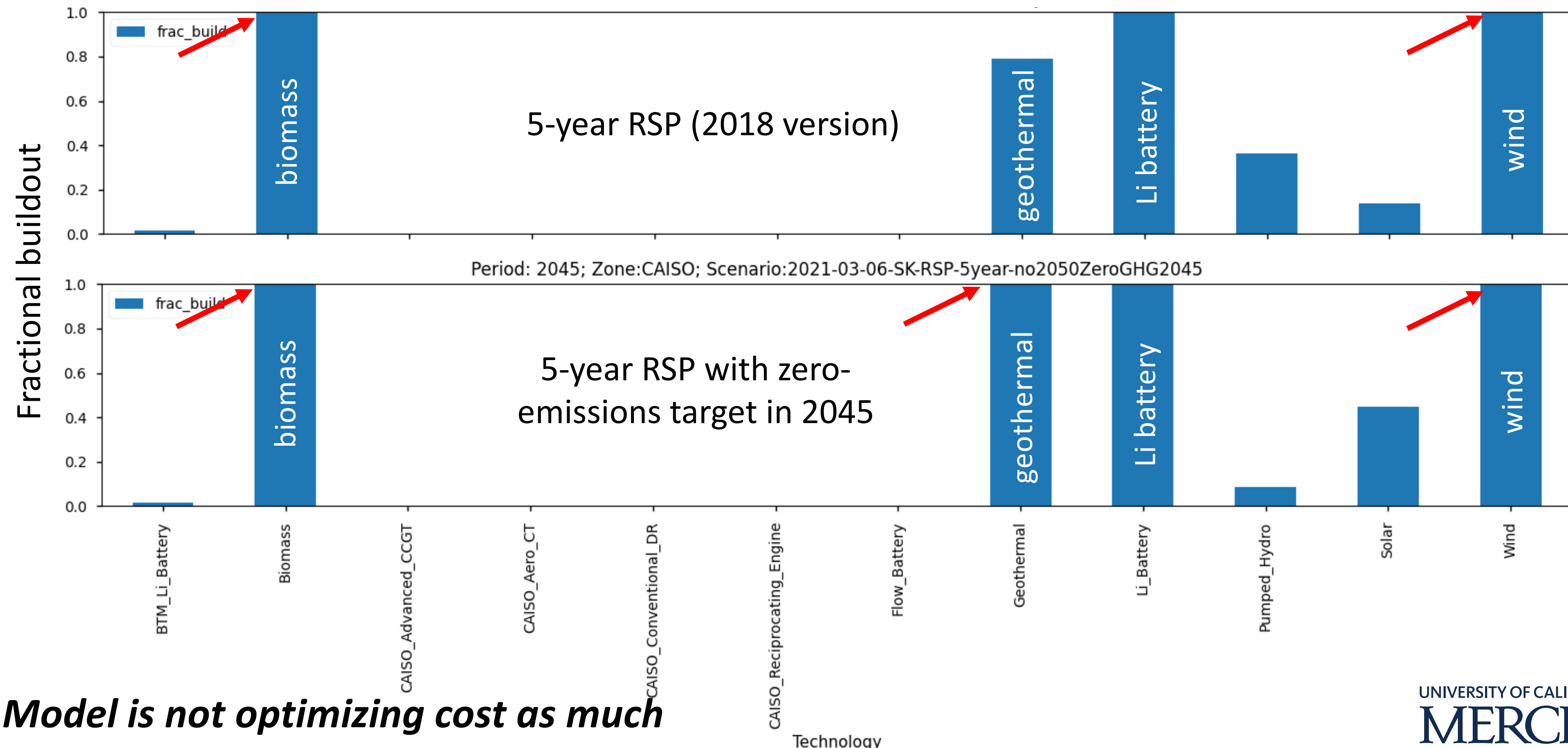


Thermal generation is replaced by more solar and more storage
Use of storage doubles and curtailment approaches total load!
Next slides show more details…

UNIVERSITY OF CALIFORNIA
MERCED

UNIVERSITY OF CALIFORNIA
MERCED

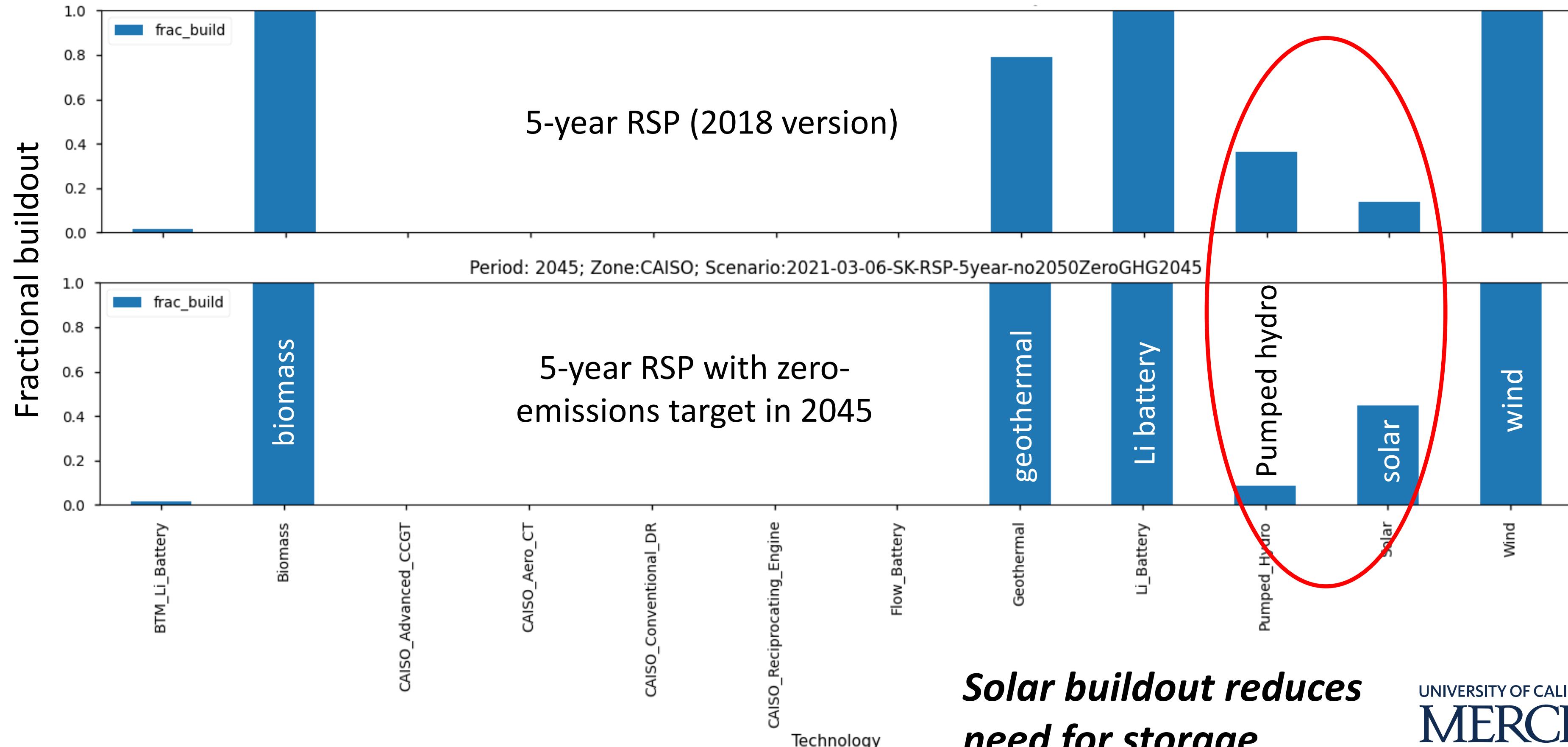
Implications of changes to baseline – zero in 2045
Buildout relative to allowed buildout



Model is not optimizing cost as much as building to imposed limits

UNIVERSITY OF CALIFORNIA MERCED

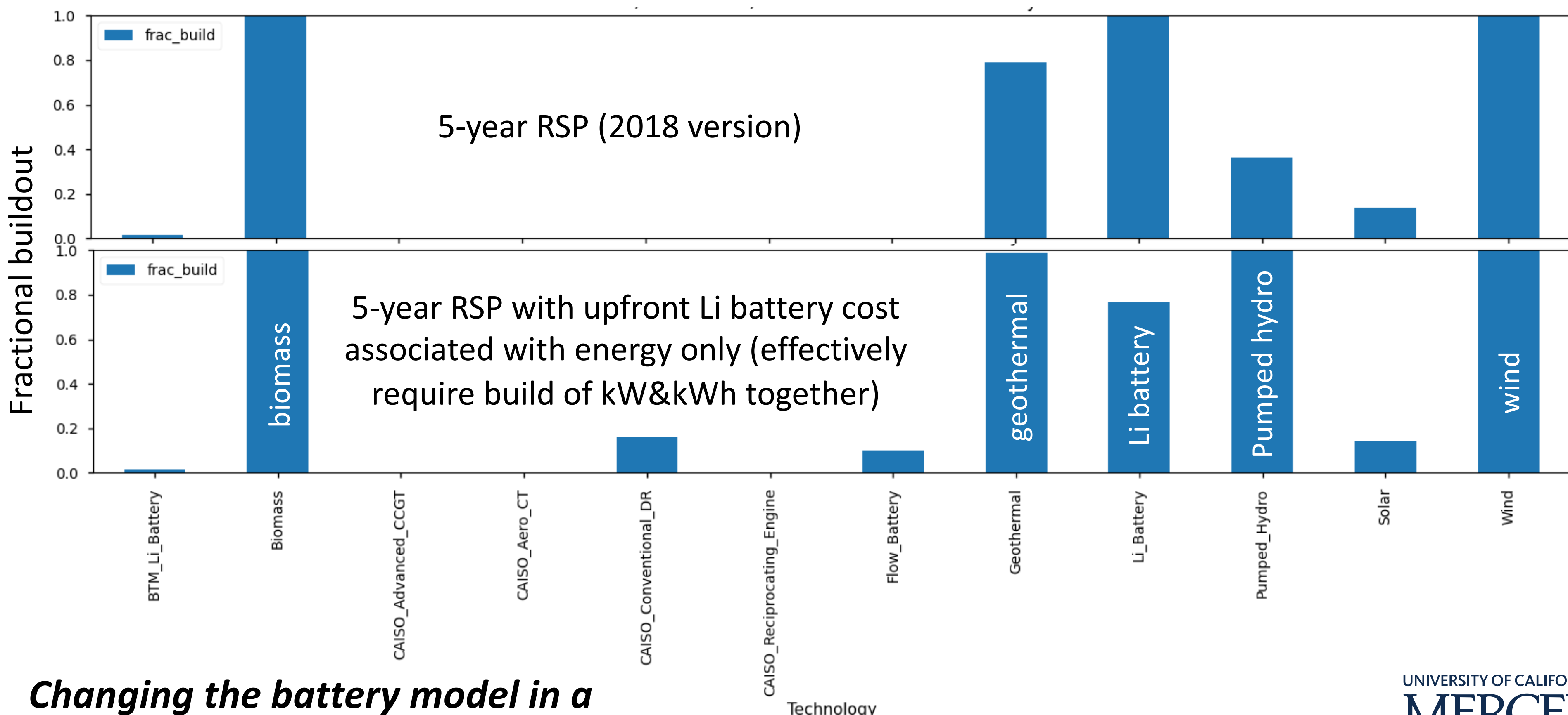
Implications of changes to baseline – zero in 2045
Buildout relative to allowed buildout



Solar buildout reduces need for storage

UNIVERSITY OF CALIFORNIA MERCED

Implications of changes to baseline – revised Li battery model

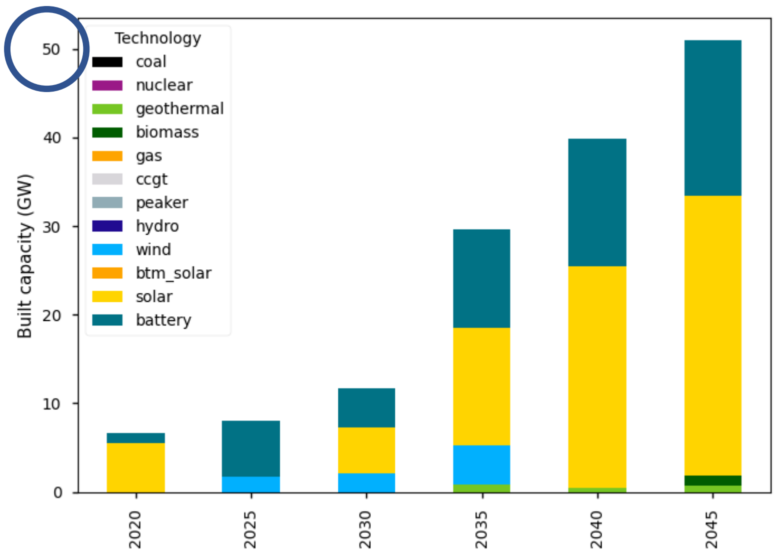


Changing the battery model in a subtle way can make a BIG difference!

UNIVERSITY OF CALIFORNIA MERCED

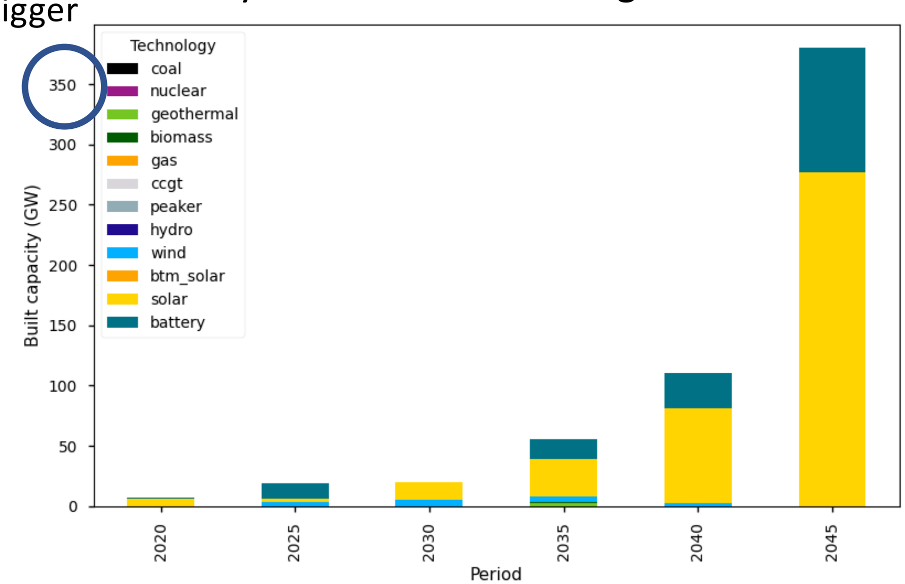
Implications of changes to baseline – all changes

5-year RSP (2018 version)



Scale is 7 X bigger

5-year RSP with all changes



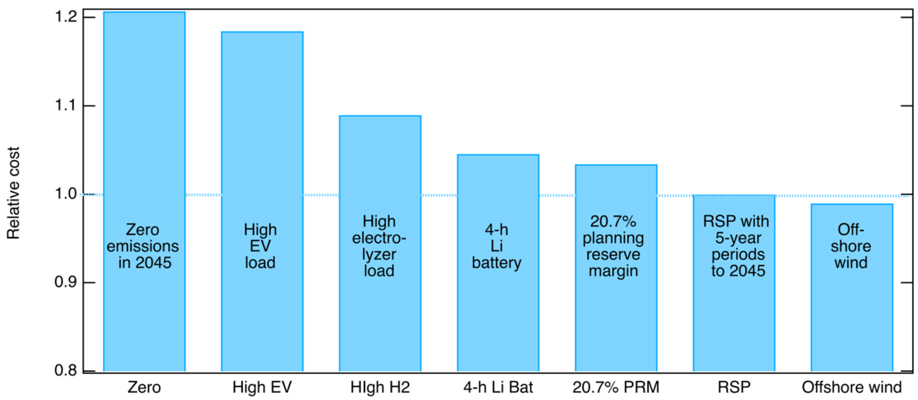
Builds 300 GW solar in 2045!

However, recall that RESOLVE uses 37 independent days: There is no opportunity for cross-day storage.

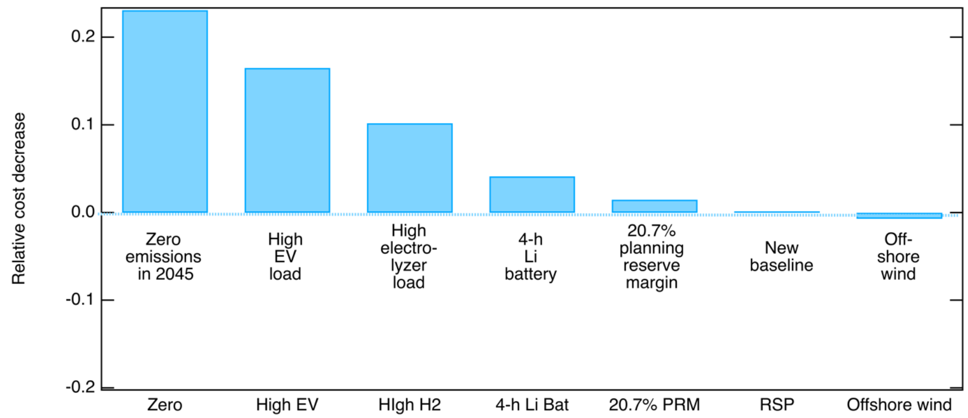
Question: will overbuild be decreased when cross-day storage is included?

UNIVERSITY OF CALIFORNIA MERCED

Implications of changes to baseline
Sensitivity to each change individually



Start with RSP and add individual changes



Start with proposed baseline and remove individual changes

Take away messages:

- Need cross-day storage model to reach zero emissions gracefully: Reevaluate with revised RESOLVE
- Results from RESOLVE are limited by allowed new builds: Compare with inputs used in SWITCH
- Storage will depend a LOT on the overbuild of other generation: Can study energy balance in simple model
- Details of storage selected depends on the details of how the storage is modeled: Will be special focus

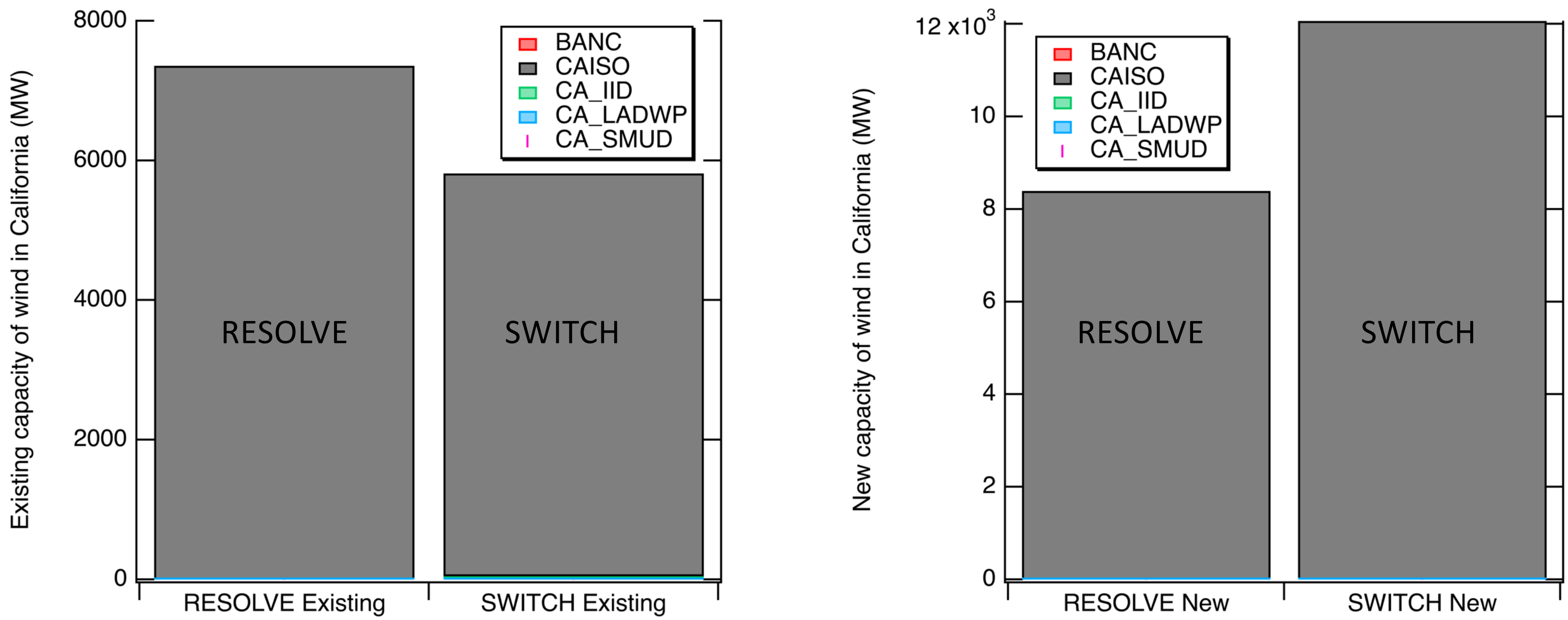
Details in Modeling results deliverable

UNIVERSITY OF CALIFORNIA MERCED

Question – how reasonable are the build out limits?

- In the next slide we compare the build out limits used in SWITCH and in RESOLVE
- For RESOLVE: compare five zones
- For SWITCH: compare locations listed by EIA within California

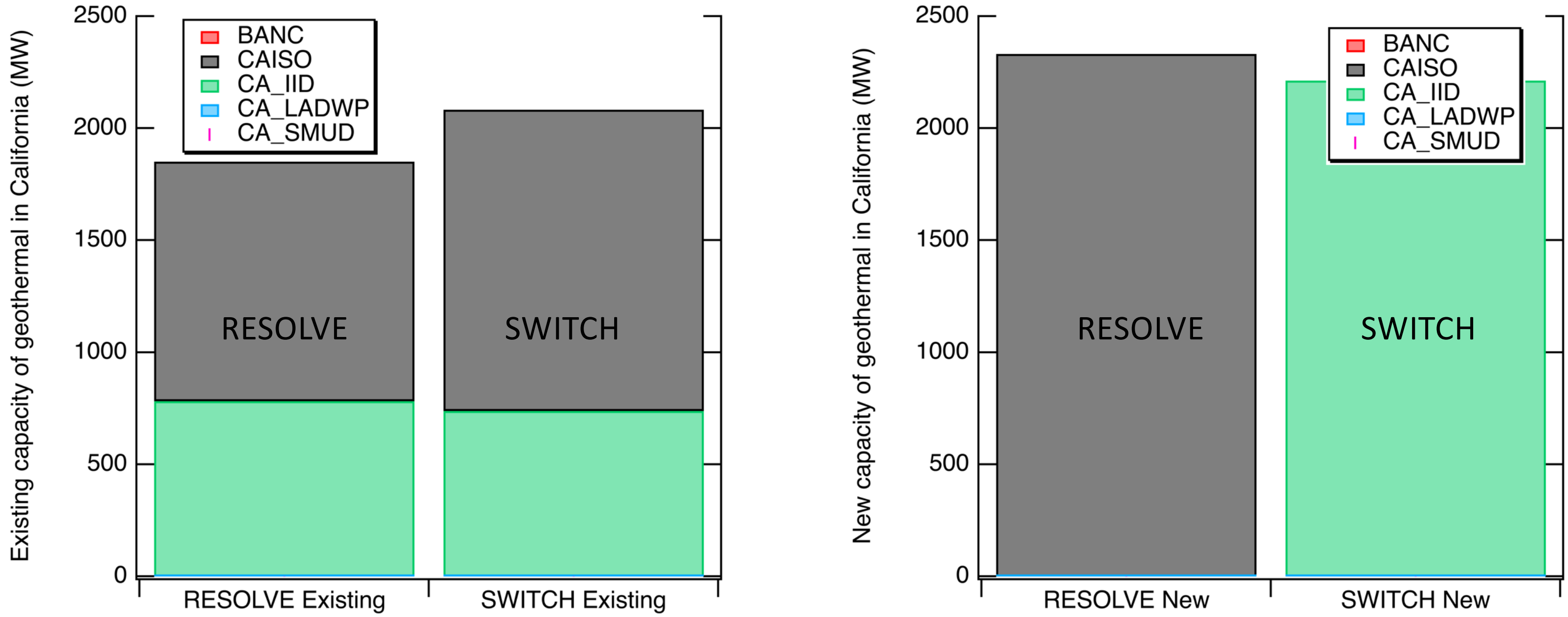
Wind capacity



SWITCH provides for relatively more growth of wind, but starts with less
Note: Wyoming wind is worth discussing in addition to offshore wind

UNIVERSITY OF CALIFORNIA MERCED

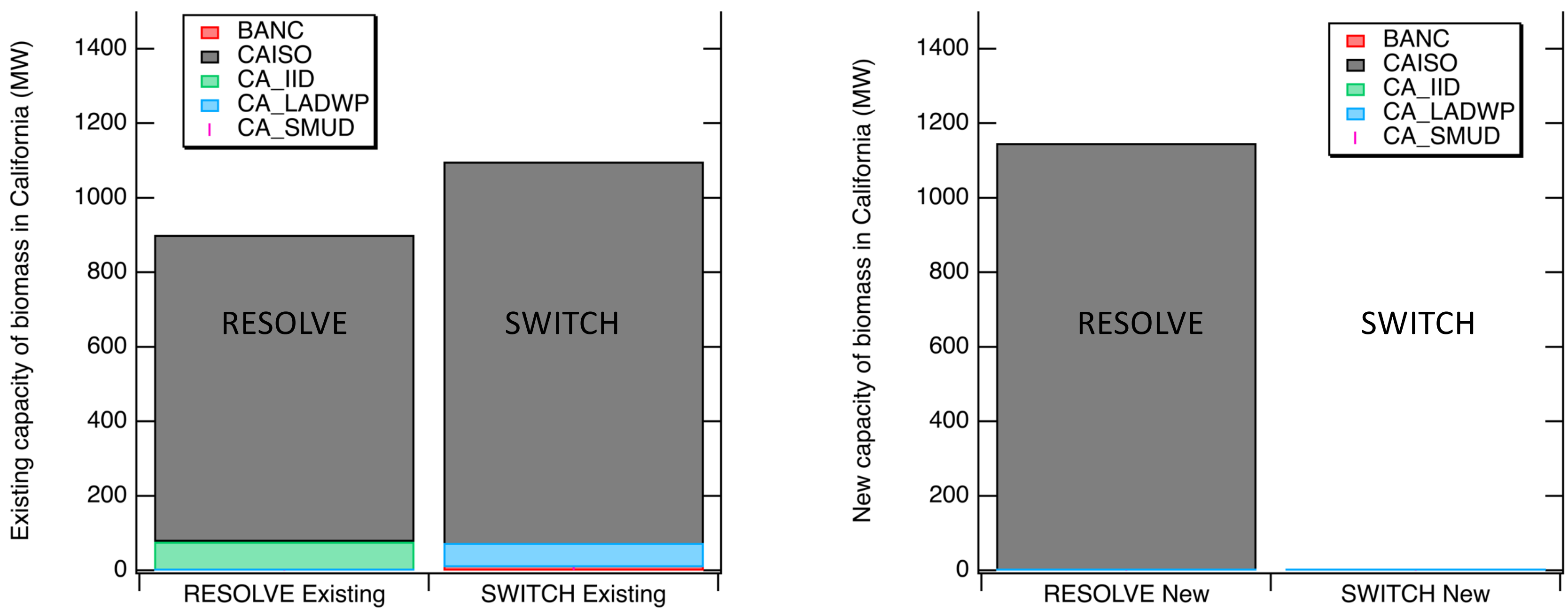
Geothermal capacity



RESOLVE and SWITCH have fairly similar assumptions for Geothermal (except for the location of the possible additions.)

UNIVERSITY OF CALIFORNIA MERCED

Biomass/gas capacity



SWITCH provides no new biomass/gas options

UNIVERSITY OF CALIFORNIA MERCED

Preparation of SWITCH Baseline

The work that has been completed to prepare SWITCH can be classified in two categories:

- Software development
- Baseline development

Preparation of SWITCH Baseline

Software development

- Updated to Python 3.7+ from Python 2.7
- Developed (still in progress) long-duration storage module: analytical formulation for required features (e.g. separate charging and discharging efficiencies) and efficient code implementation
- Started developing capability to use different time sampling strategies
- Implemented module to model California imports constraints from other states
- Implemented module to model assumptions on residential PV growth in California
- Implemented module to track and restrict air pollutants (optional)

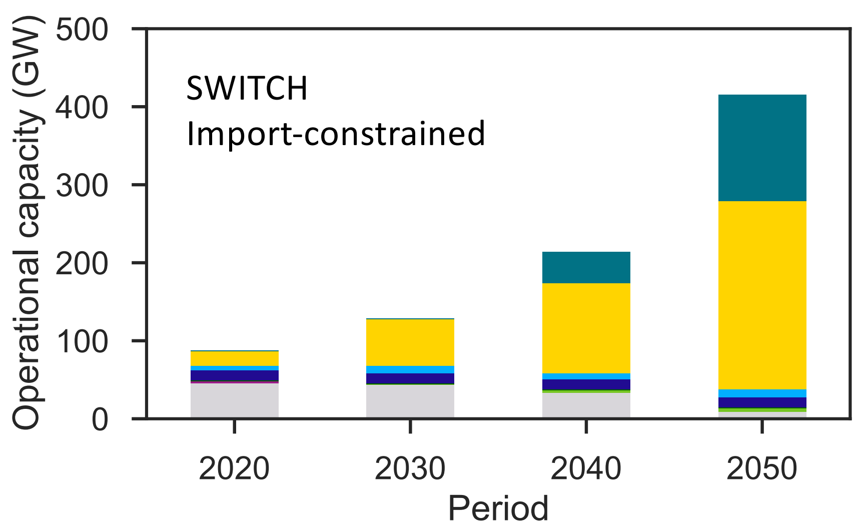
UNIVERSITY OF CALIFORNIA MERCED

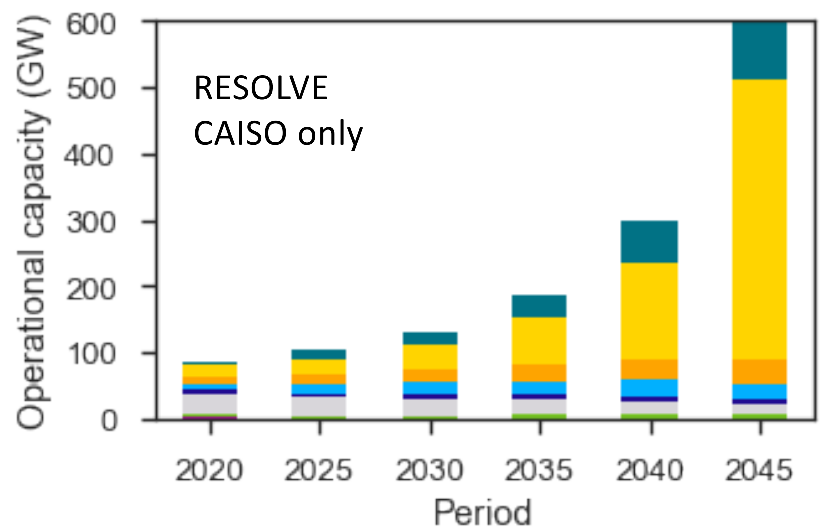
Preparation of SWITCH Baseline

Baseline development

- Updated all inputs (*e.g*. EIA list of generators, NREL ATB costs, regional costs for new expansion of transmission lines)
- Set up database access at UC San Diego and UC Merced
- Selected configuration – (*e.g*. zero emissions in 2045, WECC config.)
- Began study of best strategy for selecting time points to optimize trade off between run time and accuracy of calculation
- Implement baseline run (shown on next slide)

Comparison of SWITCH and RESOLVE baselines





Reflects restriction to CAISO (no imports) and increased load for hydrogen and EVs

UNIVERSITY OF CALIFORNIA MERCED

Agenda

1. Introductions (5 min)
   a. Presenters and Attendees
   b. Team Members and Project Partners
2. Project Overview & Status (30 min)
   a. Project Timeline and Goals
   b. Results from the Introductory Public Workshop and Baseline Development (Task 2)
3. **Project Approach (25 min)**
   a. **Approach to Storage and Energy Technology Summaries**
   b. **Plans for the Scenario Selection Public Workshop**
   c. **Challenges and Opportunities**
4. **Questions (30+ min)**
5. **CPR Determination April 8, 2021**

Where are we? What's next?

- Identified baselines, but still need to implement baseline in new version of RESOLVE (after received from E3)
- In the meantime, there is a lot we can learn:
- Note that results often reflect the resources given to the model:
  - We can study the energy balance without the full cost model
  - This can enable us to understand the effects of overbuild on needed storage
  - Can use this to differentiate storage applications as a function of the overbuild and generation source

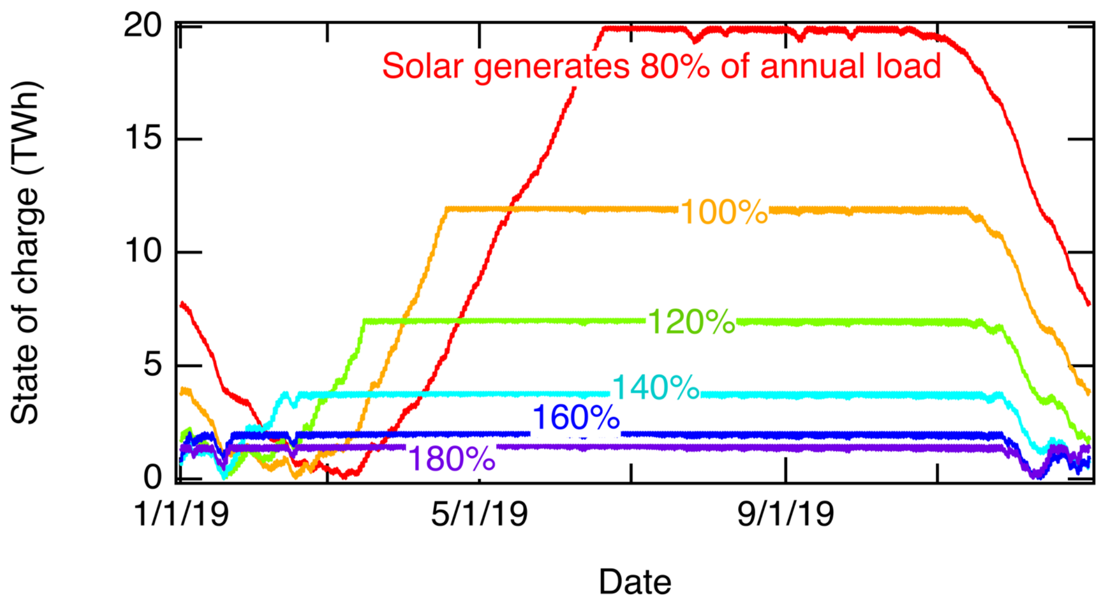
UNIVERSITY OF CALIFORNIA
MERCED

Simple model definition

- Use historical generation-profile data (from CAISO)
- Scale relative generation (remove thermal, add solar and wind, etc.)
- Calculate the generation minus the load and charge or discharge a large storage reservoir accordingly
- Assumptions:
  - No issues with transmission
  - No attempt to consider cost
  - Select relative generation for each technology as a set of input values and consider hundreds of scenarios
  - No calculation of reserve – just calculate energy balance, quantifying:
    - Size of storage needed
    - Cycle times/year for the storage if storage is divided into bins that provide 40 GWh each
    - Surplus electricity (can be used for something else or curtailed)

UNIVERSITY OF CALIFORNIA MERCED

Buildout of solar reduces needed storage



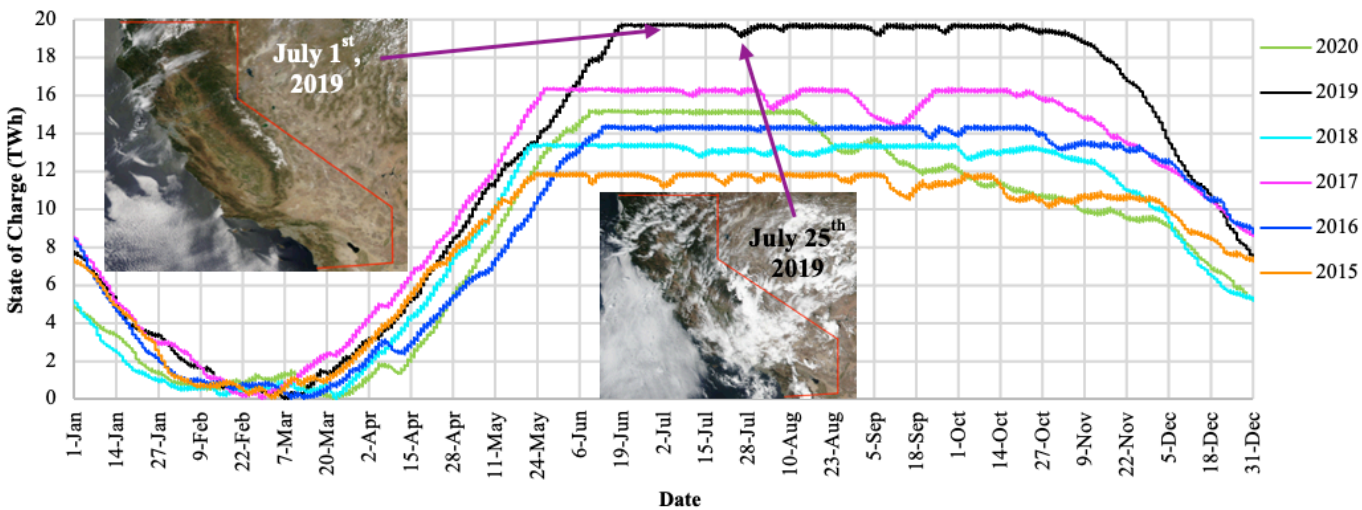
Mahmoud Abido
Abstract submitted to PVSC
Manuscript is being developed

Simple model is applied

- Start with CAISO generation data, but remove thermal and imports
- Build solar to compensate for the removed generation
- Size of seasonal storage decreases 10-fold as solar is increased 2-fold
- Time of year for minimum stored energy shifts as solar is added

UNIVERSITY OF CALIFORNIA
MERCED

Overbuild of solar reduces needed storage



Mahmoud Abido
Abstract submitted to PVSC
Manuscript is being developed

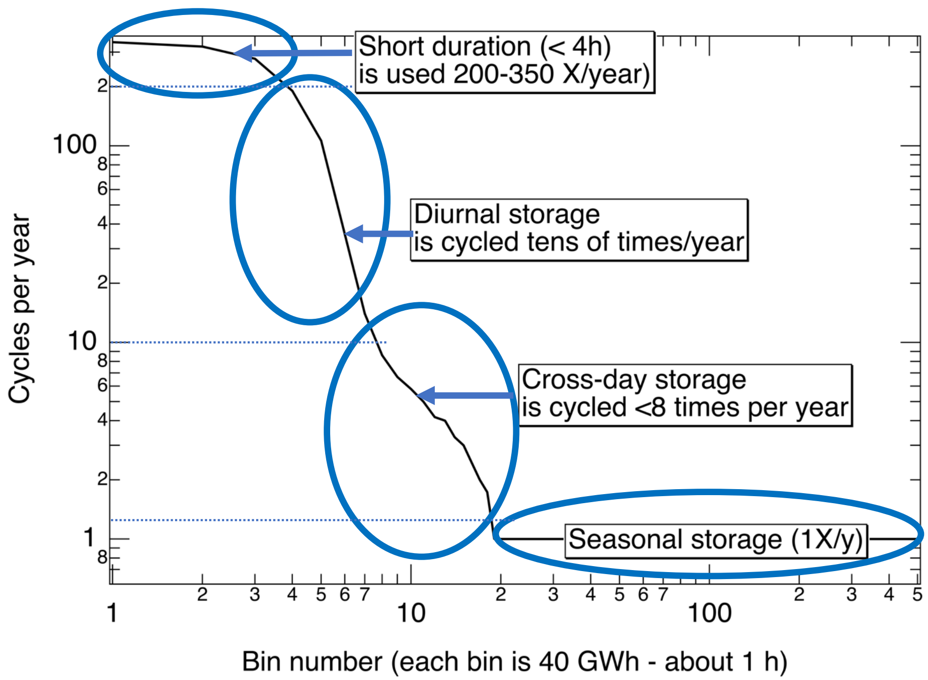
- Time of year for minimum stored energy shifts

Question: When do we need to be concerned about resource adequacy?

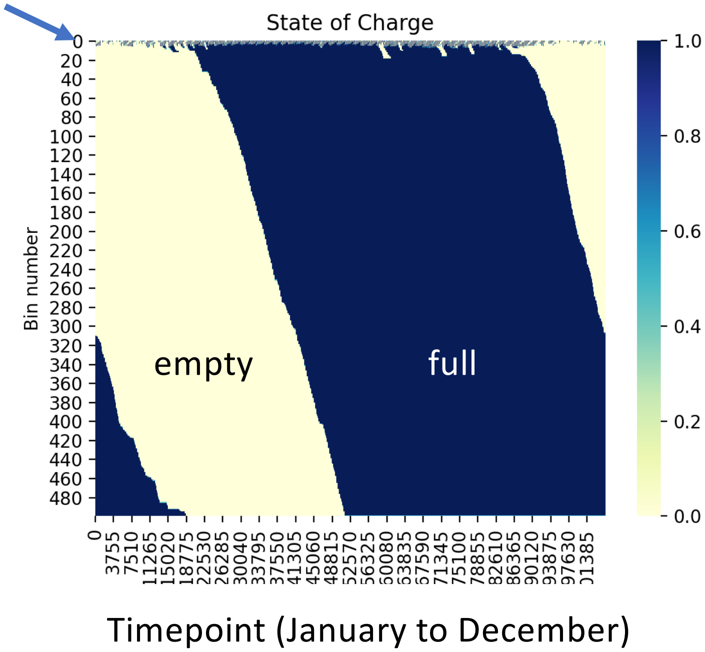
Answer: It depends on the design of our energy system, but may be quite predictable (or may be unpredictable)

UNIVERSITY OF CALIFORNIA MERCED

Differentiate use of the types of storage

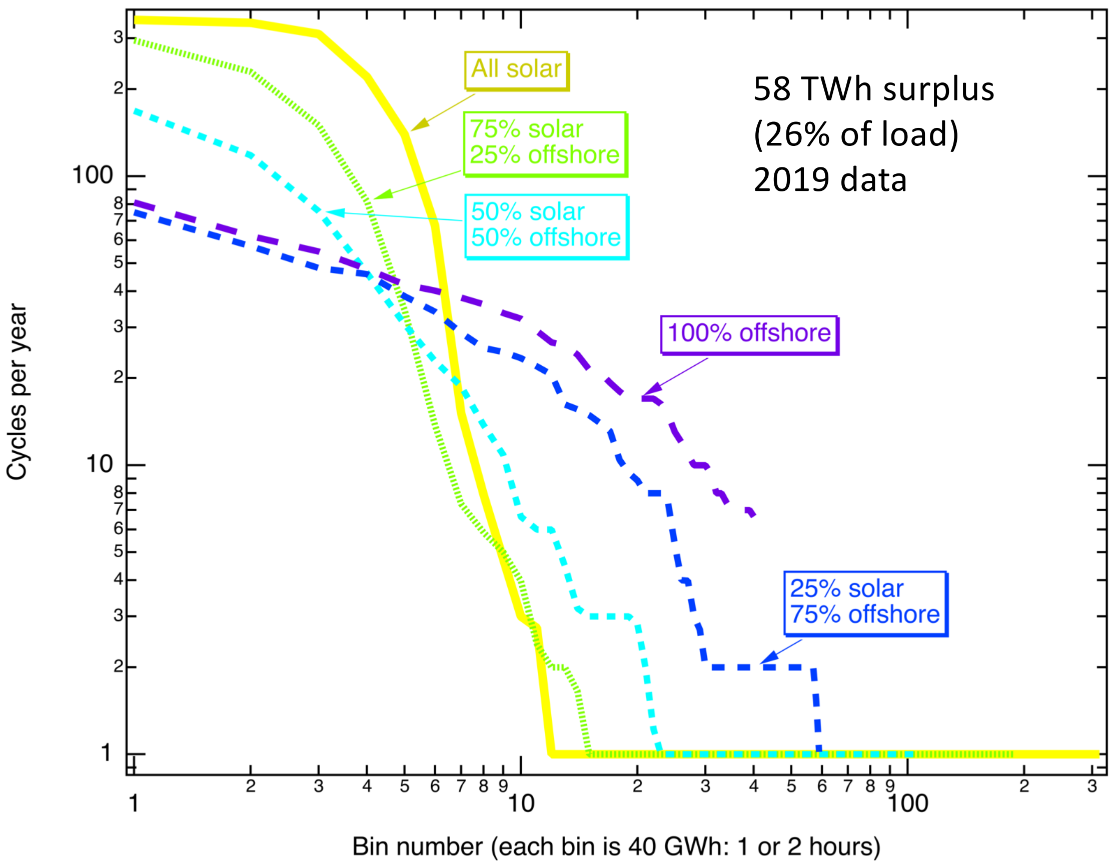


Always fill or empty bin 1 first



UNIVERSITY OF CALIFORNIA MERCED

How does offshore wind compare with solar?



"All solar" uses:

- 0.1 TWh short-duration (1-4 h) storage cycles every day
- 0.2 TWh diurnal (4-10 h) storage cycles 10-100X/year
- 12 TWh seasonal storage

"All offshore wind" uses:

- 0.1 TWh short-duration storage may only cycle 80X/year
- 1-2 TWh (4-100 h) storage cycles 10-50X/year
- No seasonal storage

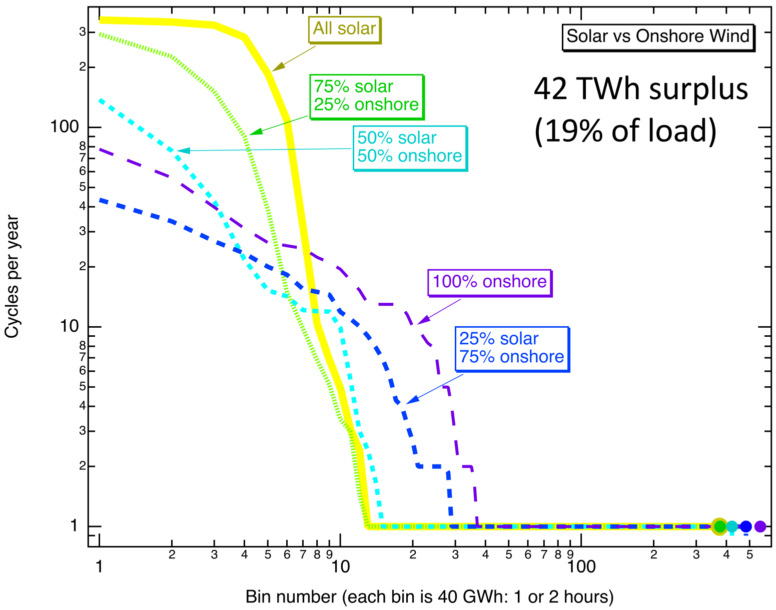
Shows how role of storage can change with choice of generators

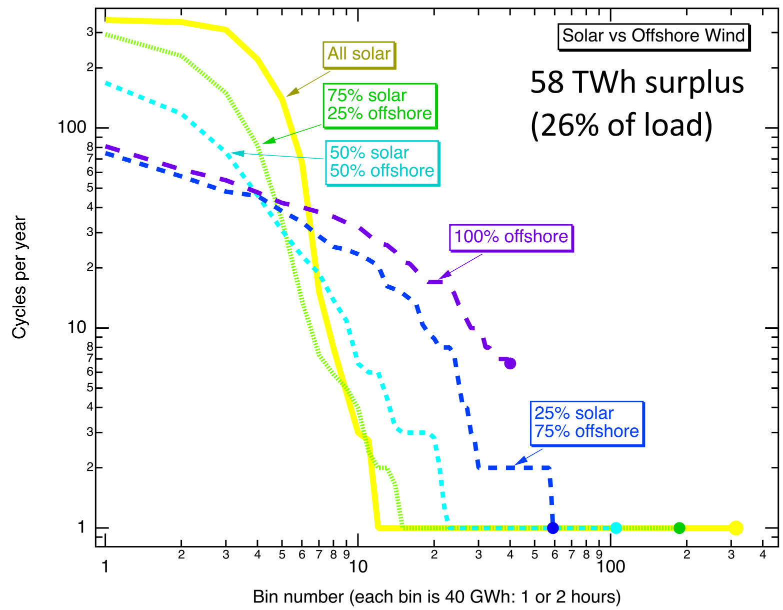
Zabir Mahmud

- Manuscript is being developed

UNIVERSITY OF CALIFORNIA
MERCED

Onshore and offshore wind differ for seasonal storage





Zabir Mahmud

- Manuscript is being developed

2019 data

Offshore wind decreases need for seasonal storage using 2019 data

UNIVERSITY OF CALIFORNIA MERCED

Surplus electricity can be used for generating hydrogen

- **Estimate potential supply of hydrogen from the surplus of renewable electricity with various generation mix scenarios in 2045**
- **Assess the size of grid services and long-duration energy storage that renewable hydrogen can provide using SWITCH-WECC model**

Kenji Shiraishi
Exploring how electrolyzers may use surplus electricity under guidance by Dan Kammen

UNIVERSITY OF CALIFORNIA MERCED

Time sampling for SWITCH

- **SWITCH has flexibility to define the time sampling, but the best strategy has not been explored for implementation with long-duration storage**
- **Example sampling strategies to study**
  - **4 representative days per month X 24 hours**
  - **14 consecutive days per month X 24 hours**
  - **31 consecutive days per month X 24 hours**
  - **365 days X 24 hours**
- **Will study run time vs accuracy of results related to understanding storage to select best strategies**

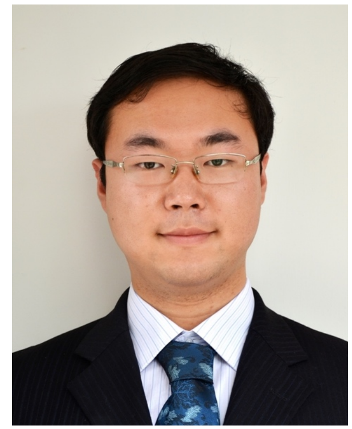
Pedro Sanchez
Studying the time-sampling strategy under guidance by Patricia Hidalgo-Gonzalez

UNIVERSITY OF CALIFORNIA MERCED

What candidate technologies may address long-duration storage needs?

Long duration energy storage technologies: candidates and use cases

- Pumped storage hydropower
- Other gravity-based solutions
- Compressed air energy storage
- Liquid air storage
- Thermal energy storage
- Flow batteries
- Power to gas



Rui Shan

Jeremiah Reagan

Manuscript is being developed under guidance by Noah Kittner

UNIVERSITY OF CALIFORNIA MERCED

Plans

Simple model
- Complete papers described in preceding slides
- Use intuition developed to guide use of RESOLVE and SWITCH

RESOLVE
- New version of RESOLVE from E3
- Implement baseline in new RESOLVE

SWITCH
- Define timepoint selection strategy and long-duration storage model
- Compare new RESOLVE and SWITCH baselines

Technology evaluation
- Finish initial review paper
- Identify paper results relevant to scenario

Define scenario

Public workshop

UNIVERSITY OF CALIFORNIA MERCED

Challenges and Opportunities
Questions to consider

- The challenge that the revised version of RESOLVE is not yet ready is an opportunity for orthogonal, but useful explorations
- The challenge of defining practical limits for each technology is an opportunity to explore which would be most useful

Questions:

- Target "California" vs "CAISO"? Include imports?
- Target zero emissions in 2045? For California? For WECC?
- Best way to add carbon sequestration (*e.g*. add hardware cost or carbon price)

UNIVERSITY OF CALIFORNIA
MERCED

UNIVERSITY OF CALIFORNIA
MERCED

For more information:
https://www.energy.ca.gov/event/workshop/2020-12/staff-workshop-initial-public-workshop-comments-long-duration-energy-storage

We welcome collaboration:

Sarah Kurtz – UC Merced (skurtz@ucmerced.edu)
Dan Kammen – UC Berkeley (kammen@berkeley.edu)
Noah Kittner – U North Carolina (kittner@unc.edu)
Patricia Hidalgo-Gonzales – UC San Diego (phidalgogonzalez@eng.ucsd.edu)
Sergio Castellanos-Rodriguez – UT Austin (sergioc@utexas.edu)

Thank you for your attention!

Special thanks to the California Energy Commission for supporting this project