PROGRESS REPORT for EPC-19-060

November 2022

Recipient Project Manager: Sarah Kurtz

Commission Agreement Manager: Jeffrey Sunquist

What we planned to accomplish this period

1. We will finalize our approach for the final phase of the work
2. We will continue to meet with stakeholders and community representatives to gather inputs and request feedback
3. We will prepare a draft of a paper describing our results on the critical time steps approach.
4. We will complete the revision of "Draft proposed electricity generation scenarios summary"
5. We will return to preparing for the submission of the final storage technology summary in December
6. We will be presenting four conference papers that have contributed to our understanding the details of our modeling

What we actually accomplished this period

1. We will finalize our approach for the final phase of the work.

We have been working with our manager on finalizing this – we propose to use a definition based on Tables 1 and 2. We expect to receive the final letter defining our approach shortly – we will then be ready to move forward with the analysis.

Table 1. Baseline scenarios for final analysis

Software	Description
RESOLVE	Use the Preferred System Portfolio with 2021 IEPR loads[1] and additional modifications described in the Grid Scenario Analysis, Table 2.1
SWITCH	As defined in Grid Scenario Analysis, Table 2.3.

[1] https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2021-integrated-energy-policy-report

Table 2. Sensitivity scenarios to be studied

Topic	Description	Software
EV Charging	Evaluate the effect of increased EV charging on the need for long-duration energy storage using scenarios D-1, D-8 and D-11 taken from California studies like the AB 2127 EVI PRO report[2]	RESOLVE
Generation profiles	Evaluate the impact of using solar and wind generators designed for higher output during the winter (as shown in Fig. 3.3 and 3.4 of "Generation Scenarios summary Task 3.4") on the need for long-duration energy storage	RESOLVE
Transmission	Explore key transmission corridors[3] for decarbonized WECC and California by capping the expansion of transmission (varying the cap). This will enable us to understand how different transmission corridors should be prioritized for their expansion.	SWITCH
Electrolyzers as flexible loads	Evaluate the potential for electrolyzers to reduce the need for long-duration storage by acting as a flexible load while supplying hydrogen for transportation, industrial and other applications	TBD
Oxycombustion	Evaluate the long-duration storage potential of using a closed combustion system with carbon dioxide as the working fluid (eliminating criteria pollutants) using biomass as a fuel source	RESOLVE

2. Stakeholder and collaborator meetings: During the month of November, we met with:

- Roderick Go of E3
- Priya Sreedharan of Gridlab
- At Catalyst H2: Erin Childs of Strategen, John Flory of Alliance, Victor Cervates of SDGE, Dino Barajas of Baker Botts, Kendal Asuncion of Bloomenergy, Sal Dicostanzo of International Longshore and Warehouse Union, Aaron Guthrey of Department of Water & Power, LA, Adrienne Farrar Houel of the Green Team, Dave Tamayo of SMUD, Bill Leighty of the Leighty Foundation
- Adam Goff and Jennifer Diggins of 8 Rivers to discuss their oxycombustion approach

3. We will prepare a draft of a paper describing our results on the critical time steps approach. Finalizing this approach is critical before starting the Phase 2 calculations

We made substantial progress. We have been debating about the benefits of using more than 2 time points per day (one tied to sunrise, and one tied to sunset). We thought that it would be better to use 4 time points per day (2 for the energy and 2 for the power), but we find that we can explain the 2 points well and haven't identified a logical strategy for selecting additional points.

The critical hours of each day are identified based on the sunrise and sunset times corresponding to the extrema for the state-of-charge of the storage. Using just the two selected hours each day (nominally one hour after sunrise and one hour before sunset) we find that the selected energy build is surprisingly accurate as shown in Fig. 2 that compares our "critical time step" (CTS) approach with the more conventional approach of using uniform step sizes.

[2] Electric Vehicle Charging Infrastructure Assessment – AB 2127 – Analyzing Charging Needs to Support Zero-Emission Vehicles in 2030 (Commission Report). https://www.energy.ca.gov/programs-and-topics/programs/electric-vehicle-charging-infrastructure-assessment-ab-2127 with tables in https://efiling.energy.ca.gov/getdocument.aspx?tn=238851.

[3] See Fig. 2.1-1 in http://www.caiso.com/InitiativeDocuments/Draft20-YearTransmissionOutlook.pdf.

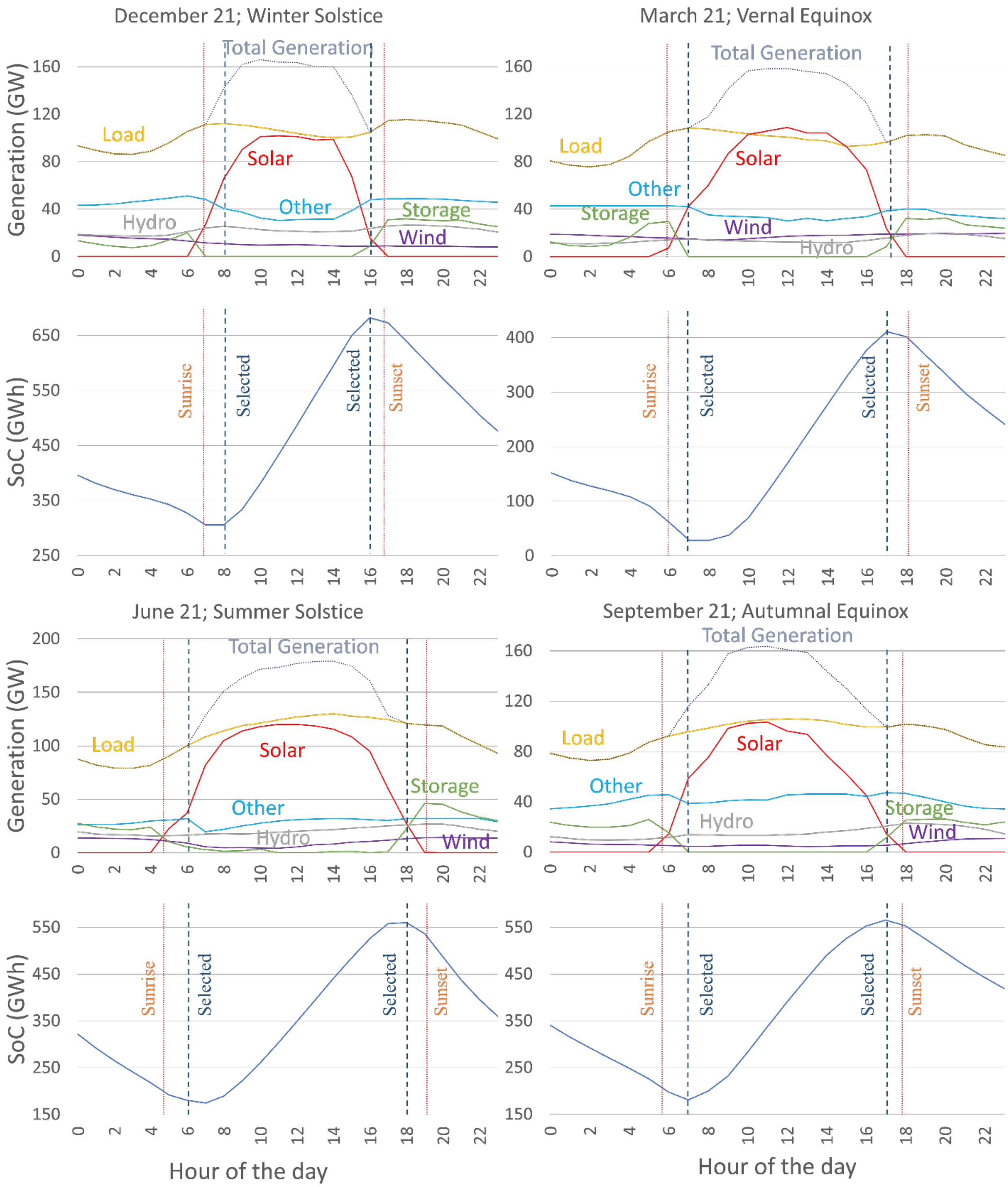


Fig. 1. Generation profiles vs hour of the day for the 2045 baseline scenario for solstices and equinoxes

Two approaches were used for the uniform-step calculations: one in which the data for the selected time point is used without modification – we call this the "snapshot" approach and the other in which the average values for the time interval are used, called "average." The first bar in Fig. 2 shows results from the full model for the total battery energy build.

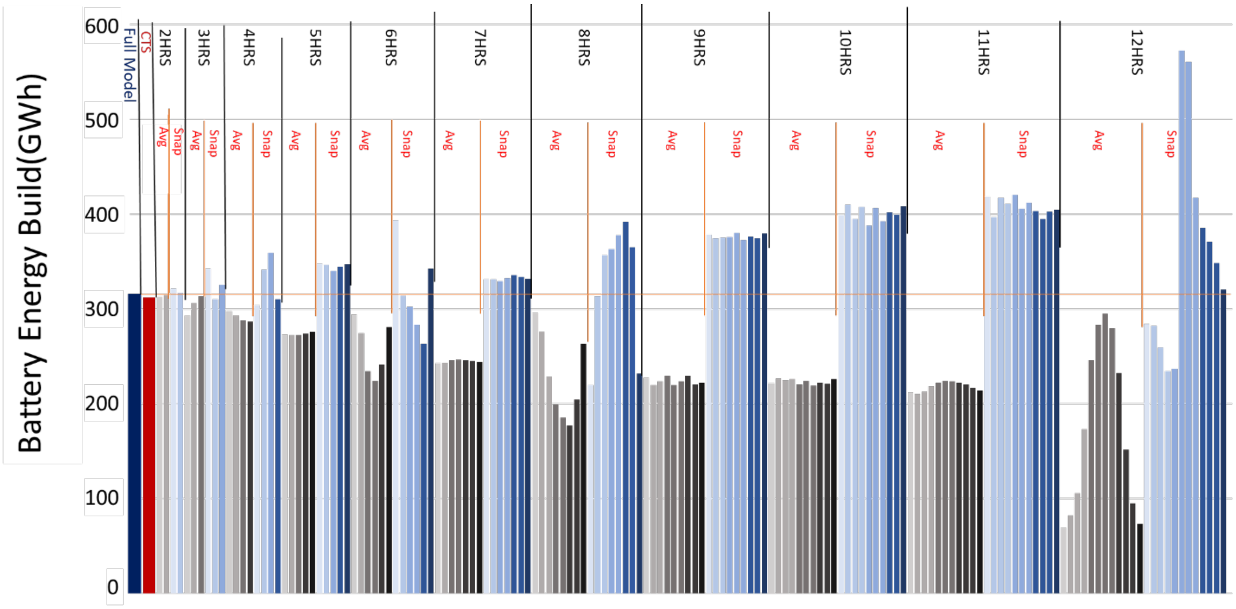


Fig. 2. Battery energy storage build selected for a comprehensive set of optimizations for the 2045 baseline scenario. The top row indicates the time interval (in hours) for each calculation. “Avg” or “Snap” indicate the data sampling.

The accuracy of each calculation as a function of the number of timepoints used in each optimization can be assessed in Figs. 3 and 4. The Snapshot approach tends to systematically overestimate the energy storage needed while the Average approach systematically underestimates it, though individual calculations may over- or underestimate the value depending on the starting hour. The selected power builds show somewhat similar behavior.

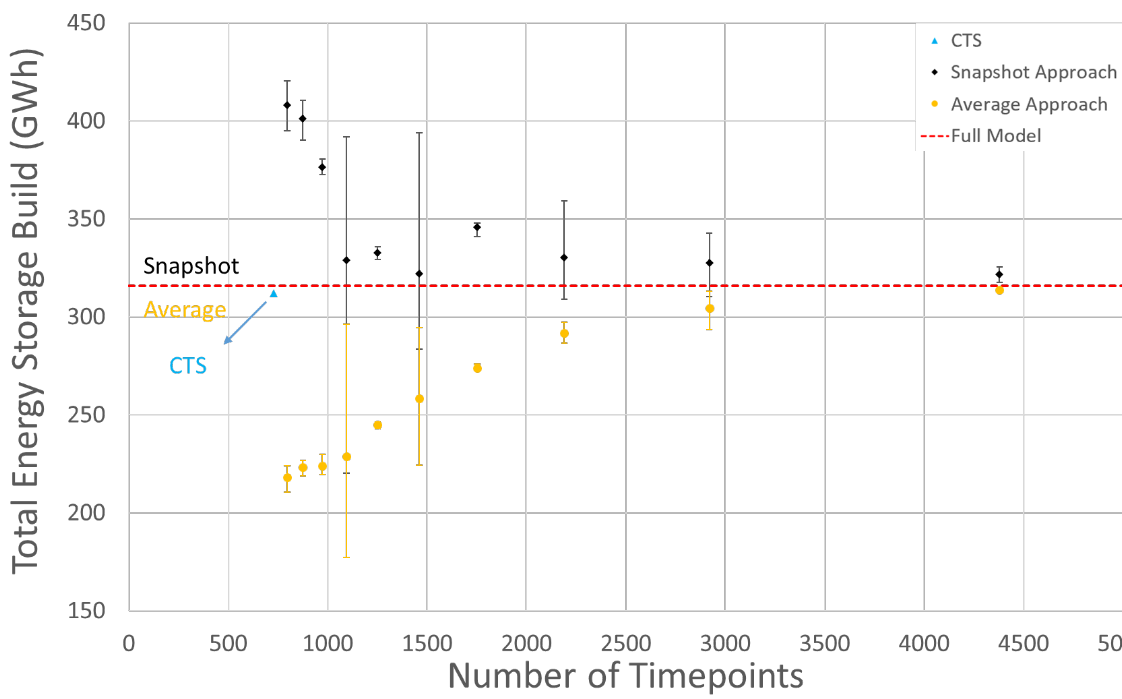


Fig. 3. Total Energy Storage Build (GWh) versus number of timepoints.

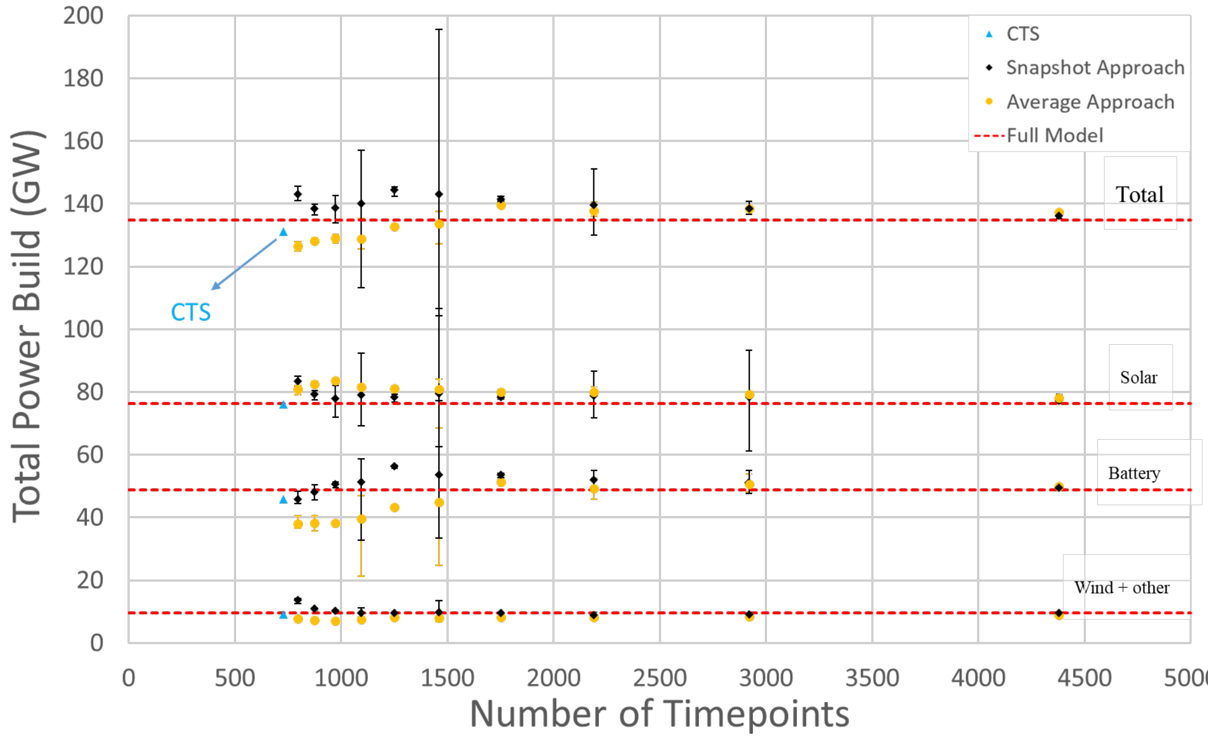


Fig. 4. Selected builds of candidate resources as a function of the number of timepoints.

The surprising accuracy of the 2-point CTS calculation can be explained by considering the sampling of the time points when the storage state-of-charge is at a maximum or minimum. Averaging the values during the time steps effectively gives an integral that allows the model to size the storage energy rating accurately. The power needed from wind and solar are also quite accurate. The success for the selection of the power of the batteries is not quite as good but is still excellent. Table 3 summarizes why each value can be obtained so accurately while sampling just two hours each day. We note that this approach relies on the final solutions being powered primarily by solar, enabling the wind and solar generation times to be easily differentiated. It also relies on our use of a fixed generation profile for hydropower. Also, our approach for studying the adoption of long-duration energy storage will fix the duration, resulting in the battery power as well as the battery energy being obtained accurately by capturing the extrema for the state-of-charge. The differentiation of durations of multiple lengths is not tested in the current assessment, but our plan to compare the adoption of long-duration storage with conventional lithium-ion batteries should be well aligned with this approach. Even though the CTS technique requires a solar-dominant grid, our study is definitely of a solar-dominant grid and we anticipate that the technique may be quite useful for many locations.

Table 3. Accuracy of 2-point CTS technique

Modeled element	Description
Diurnal energy storage capacity	Sampling minimum and maximum energy for each day sizes the diurnal batteries by comparing the difference between the state of charge in the morning and evening on adjacent days
Seasonal energy storage capacity	Sampling minimum and maximum energy for each day sizes the seasonal batteries by comparing the difference between the minimum and maximum over the entire year
Wind power capacity	Determined by the difference between the nighttime load and the average power needed from the diurnal storage
Solar power capacity	Determined by the energy needed to charge the storage during the day after accounting for the difference between the load and other generation
Power capacity of other components	Solar and wind dominate the grid, so the others have a relatively small effect and also tend to provide constant power during the day so are not very dependent on the choice of the time point sampling

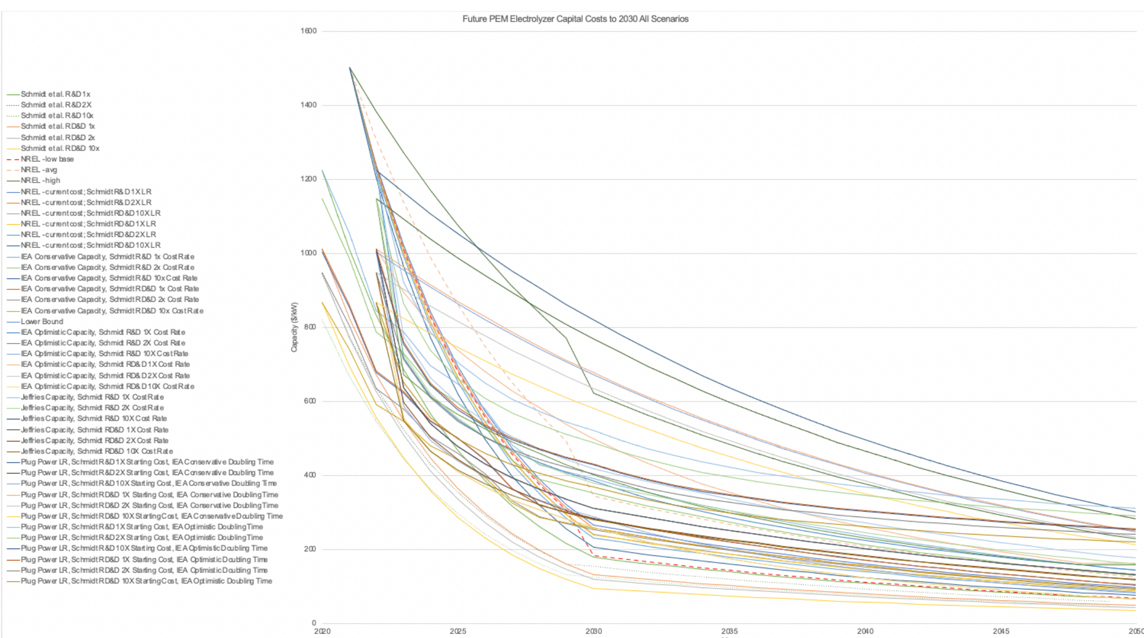
4. We will complete the revision of "Draft electricity generation scenarios summary"

This is attached. In parallel to preparing this, we have been assembling the needed files to be able to implement it as a clean package.

5. *We will prepare for completing the revision of "Storage Technology summary"*

We are updating this summary for completion in December based on feedback we obtained and new information that has been shared.

We have been developing a review and harmonization of learning curve cost projections for water electrolysis used to produce green hydrogen, which could be a critical competitor and component among the different storage technologies examined – see data graphed below.



By harmonizing different projections of future costs of water electrolysis with learning rates, we observe that by 2030 electrolyzers could reduce to $180-$820/kW dependent on global cumulative installed capacity. The probability of achieving this is explored with IEA scenarios and other features. The lower bound ranges for electrolyzer costs by 2045 hover near $300/kW in most scenarios, with aggressive learning and installations resulting in $50/kW in the most optimistic case. The implications of such a low cost for electrolysis are being explored currently in our research. For instance, the biggest question might not be how to reach the idealized DOE cost targets for green hydrogen, but the open question will be what happens once those cost targets are achieved and the interactions with long duration storage energy systems will be an important area.

6. We will be presenting four conference papers

The four papers are included as part of this package.

Pedro Sanchez-Perez presented "Effect of time resolution on capacity expansion modeling to quantify value of long-duration energy storage," at the 11th IEEE Electrical Energy Storage Applications and Technologies (EESAT), Nov. 7-9, 2022, in Austin, TX. Coauthors on the paper included: S. Kurtz, N. Gonzalez, M. Staadecker, and P. Hidalgo -Gonzalez.

> Long-duration energy storage (LDES) technologies have been recently included in capacity expansion models for long-term planning. Many of these models have a simplified temporal resolution to reduce the computation time to achieve faster scenario results. However, it is unclear if these simplifications change the optimal solution for LDES, especially when modeling grids dominated by variable renewable energy (VRE) generation. For this reason, we studied how such temporal simplification changes the modeled optimal power and energy capacity of LDES technologies. We formulated a capacity expansion problem for the California region using three different temporal resolutions. We obtained that decreasing the model complexity by using fewer time points yielded different configurations and utilization of LDES technologies.

Two papers were presented at the 2022 IEEE Vehicle Power and Propulsion Conference in Merced, CA Nov. 1-4, 2022.

Farzan ZareAfifi presented "Analytical analysis of stationary Li-Ion-battery storage-system efficiency on a large scale" to help define the efficiency we should be using to model Li-ion batteries.

> In recent decades, Li-ion battery (LIB) technology has matured and is now the dominant battery technology for many mobile applications. Building on that success, LIBs are increasingly being adopted for stationary applications, as well. The Energy Information Administration (EIA) datasets show a huge increase in LIBs' use in the country, providing an opportunity to quantify their real-world performance. In this study, the reported efficiency of stationary LIBs units in storage plants in the USA is analyzed using the energy storage plants' data available in the EIA datasets. The plants are categorized according to the initial operating year; each group's efficiency is modeled as a function of the number of cycles/month. We found that 1) newer plants show higher efficiencies, 2) the efficiency typically increases with the LIBs' number of cycles/month, 3) the efficiencies are between 80-90 % for those that cycled more than five times in a month, 4) The combined efficiencies of battery and power electronics are observed to be 87-94%, and 5) the degradation of the efficiency is imperceptible from these data, even for the systems that have been operating for > 5 years. Finally, we discuss possible reasons for the lower reported efficiencies for those systems that cycle infrequently.

Zabir Mahmoud presented "Impact of EV Charging Schedule on Storage Requirements for a Renewable-driven Grid in California" to show the anticipated effect on the need for additional storage.

> California is going through a transition towards electric vehicles (EVs) as a pathway to its decarbonization goals. As the number of EVs on the road increases, the load profile will shift, and will affect the role of energy storage in a renewable-driven grid depending on whether the charging infrastructure enables EV charging to be a flexible or inflexible load. This paper considers daytime and nighttime EV charging profiles assuming the anticipated number of EVs and investigates the impact on different types of storage in a renewable-driven grid in California. A hierarchical-storage technique is used to understand the role of different charging profiles on the minimum number of cycles and size of energy storage required in a zero-carbon grid.

Noah Kittner gave a presentation in the Gridlab IRP Workshop with stakeholders from industry, national utility associations, and other academics.

Sarah Kurtz served on a panel at the Catalyst H2 event in Long Beach, as mentioned above.

How we are doing compared to our plan

We are working with the CEC to define our final scenario. This is behind, but it is almost completed, then work can proceed more quickly.

Significant problems or changes

The invoicing is still behind, but we have now completed the invoicing through June 2022. The no-cost extension is approved.

What we expect to accomplish during the next period

1. We will finalize our approach for the final phase of the work
2. We will continue to meet with stakeholders and community representatives to gather inputs and request feedback
3. We will prepare a draft of a paper describing our results on the critical time steps approach.
4. We will complete the revision of "Storage technology summary" in December

Status of Milestones and Products. (highlighted dates need to be modified still)

Task #	Task	Deliverable	Due date	Status
1.2	Kick-off meeting	Updated budget	9/18/2020	Complete
1.3	CPR Meeting #1	CPR Meeting #1	TBD	
	CPR Meeting #2	CPR Meeting #2	1/21/22	Complete
1.4	Final meeting	Final Meeting	11/11/23	
		Schedule for closeout	11/17/23	

		Draft and Final Written Products	11/17/23	
1.5	Progress Reports & Invoices	Progress Reports	Monthly	Ongoing
		Invoices	Monthly	Ongoing
1.6	Final Report	Draft Outline	6/30/23	
		Final Outline	TBD	
		Draft Report	8/30/23	
		Final Report	10/31/23	
		Written Responses to Comments on Draft Report	9/15/23	
1.7	Match funds	Status letter	9/9/20	Revision submitted
1.9	Subcontracts	Final subcontracts	TBD	Completed
1.10	TAC	List of potential members	9/9/20	Completed
		List of TAC members	TBD	Completed
		Documentation of TAC member commitment	TBD	Completed
1.11	TAC Meetings	Draft TAC meeting schedule	10/1/20	Completed
		TAC meeting 1	11/4/20	Completed
		TAC meeting 2	8/5/21	Completed
		TAC meeting 3	8/19/22	Completed
		TAC meeting 4	3/17/23	
		Note, each meeting need multiple actions		
		Final TAC meeting schedule	TBD	Completed
		Draft TAC meeting agenda	TBD	First one completed
		Backup materials	TBD	First one completed
		Final TAC Meeting agenda	TBD	First one completed
		TAC meeting summaries	TBD	First one completed
2.1	Data assembly	Draft baseline description	2/4/21	Completed
		Final baseline description	2/25/21	Completed
2.2	Confirmation of baseline data and approach	Draft modeling approach description	2/4/21	Completed

		Final modeling approach description	2/25/21	Completed
2.3	Implementation of baseline data into models to create initial baseline scenario	Summary of baseline model results	3/23/21	Completed
		CPR Report #1	15 days prior	Completed
3.1	Evaluate and document future energy storage technology alternatives	Draft storage Technology summary	7/2/21	Completed
		Final storage technology summary	12/12/22	
3.2	Define representative future energy storage technology alternatives	Draft proposed storage scenarios summary	6/1/22	Completed
		Final	1/2/23	
3.3	Evaluate and document future energy electricity generation technology alternatives	Draft electricity generation technology summary	8/2/21	Completed
		Final	10/12/22	Completed
3.4	Define representative future electricity generation technology alternatives	Draft proposed electricity generation scenarios summary	4/1/22	Completed
		Final	11/12/22	Completed
4.1	Multi-day model optimization	Summary of multi-day baseline model results	9/2/21	Completed
		CPR #2	**Summer**	Completed
4.2	Grid scenario selection	Draft grid scenario summary	2/8/22	Completed
		Final	3/7/22	Completed?
5.1	Preliminary Scenario Analysis	Draft preliminary analysis summary	7/1/22	Completed
		Final	8/26/22	In progress
5.2	Final scenario analysis	Draft final analysis summary	6/10/23	
		Final	8/13/23	
6.1	Initial public meetings	Opening workshop presentation materials	11/17/20	Completed
		Northern CA workshop	12/3/20	Completed
		Southern CA workshop	12/3/20	Completed
		Opening workshop summary	1/8/21	Completed
6.2	Public workshop for grid scenario selection	Agenda	11/2/21	Completed

		Presentation materials	11/2/21	Completed
	Public workshop with CEC and TAC to present proposed scenarios		11/16/21	Completed
		Workshop summary	11/23/21 Summarize public comments: 12/17/21	Completed
6.3	Public workshop for preliminary scenario analysis	Agenda	6/3/22	Completed
		Presentation materials	7/1/22	Completed
	Public Workshop with CEC and TAC to present preliminary analysis		7/12/22	Completed
		Workshop summary	8/9/22	In progress
6.4	Public Workshop for Final Scenario Analysis	Agenda	6/15/23	
		Presentation materials	6/15/23	
	Public workshop with CEC and TAC to present final analysis		6/30/23	
		Workshop summary	7/15/23	
7	Evaluation of Project Benefits	Kick-off meeting benefits questionnaire	9/18/20	Completed
		Final meeting benefits questionnaire	8/1/23	
8	Knowledge transfer activities	Draft initial fact sheet	7/23/20	Completed
		Final initial fact sheet	7/30/20	Completed
		Draft final project fact sheet	7/25/23	
		Final project fact sheet	8/1/23	
		Draft knowledge transfer plan	12/31/20	Completed
		Final knowledge transfer plan	2/26/21	Completed
		Draft knowledge transfer report	8/1/23	
		Final knowledge transfer report	10/1/23	