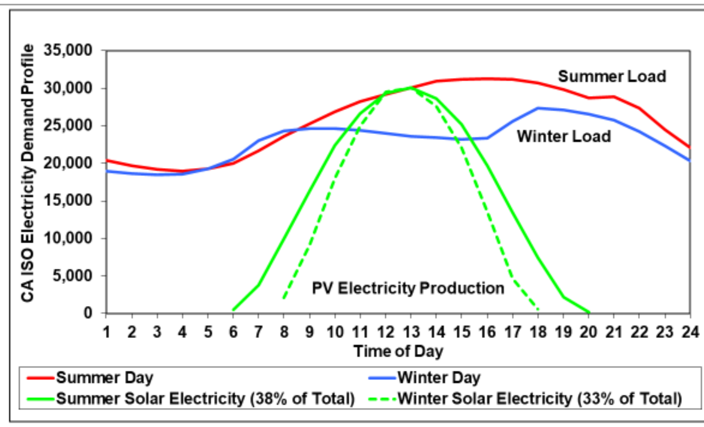
ASAP

PV with Utility-Scale Battery Storage

ASAP, May 2020

Battery technology is emerging as a solution to variable solar PV electricity production due to variation in sunlight conditions. Sunlight (insolation) available for PV electricity production is low in the early morning and late afternoon hours with peak sunlight during the middle of the day. The daily electricity production profile of a PV plant on a cloudless day is shown in Fig. 1. Solar PV technology converts sunlight into electricity, and clouds reduce the sunlight available for PV electricity production, which further complicates PV electricity production levels. In other words, electricity storage is essential to smooth PV electricity supply.

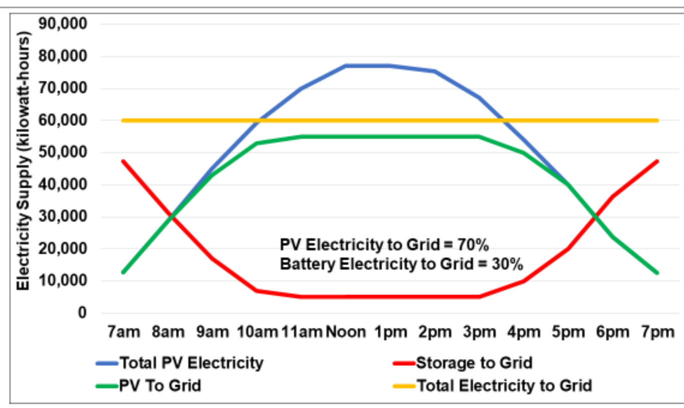
Figure 1. PV Electricity Supply Profile



The objective is to create a PV electricity system that provides dependable, on-demand (dispatchable) peak period electricity supply (refer to Fig. 2). This requires PV electricity storage, and batteries are a storage option. At present, battery storage is applied for peak load shaving with current facilities having two to four hours of storage (refer to Fig. 3).

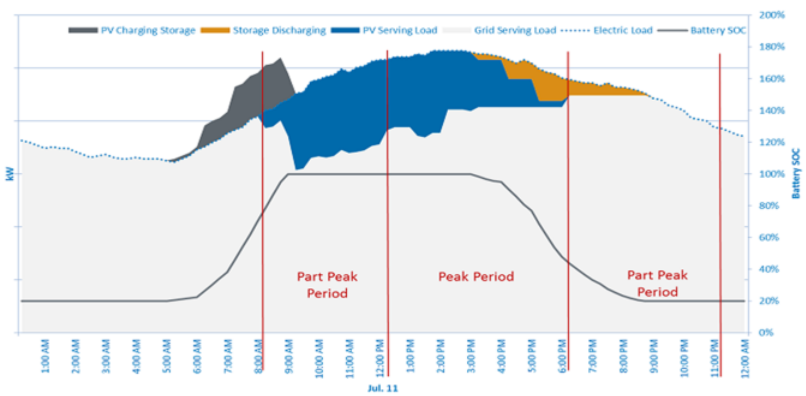
Battery storage for PV electricity is attractive on several scores. The advantages of batteries are dependability, fast responding, low maintenance cost and require only a few acres of land. Battery storage facilities can be located at PV sites to optimize PV transmission to market centers. The process of storing PV dc-electricity is efficient since batteries receive

Figure 2. 60 MW of Peak PV Electricity Supply (100 MW PV and 60 MW Battery Storage)



dc-electric current, which negates the need for inverters on the charging side. The modularity of battery storage systems allows the simultaneous charging and discharging of electricity.

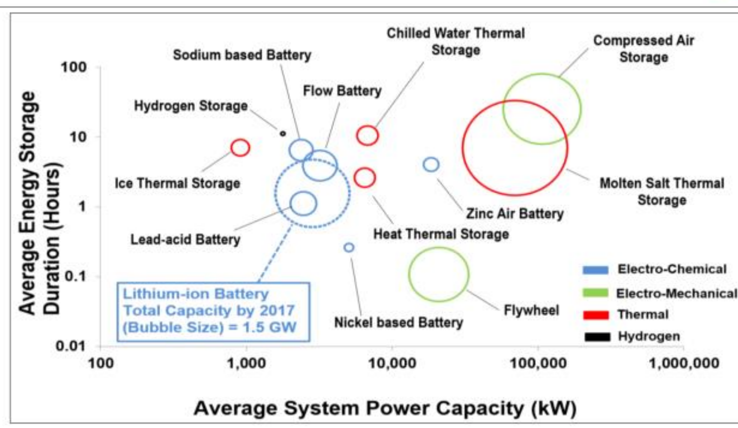
Figure 3. NREL (Nov. 2018) Evaluation of PV plus Battery Storage at a California Military Base



Most importantly, battery storage enables PV to become a zero carbon dioxide emissions source of on-demand electricity. The major concern with utility scale battery storage is battery operating life. The median reported battery life expectancy estimate is 15 years (NREL, 2018). The NREL battery life expectancy estimate may be low by five to ten years based on recent analyses of electric car battery performance. Rapid advances are being made in lithium-ion and other battery technologies, and it is expected that a 20-plus year battery life expectancy will be realized.

The goal of PV+battery systems is to replace peak natural gas power plants. To date, PV+battery systems have been successful at peak load shaving (refer to Fig. 3). Peak load shaving is the supply of electricity to meet electricity demand (load) over the hours 3-9pm, which are the hours when daily load is greatest (peak). PV+battery systems use early morning and weekend PV electricity to charge the batteries and then discharge the batteries during the premium priced peak load period, 3-9pm. The largest battery systems installed to date are designed for 2-4 hours of electricity storage capacity.

Figure 4. DOE Energy Storage Database (2018)



ASAP research indicates that 30-plus hours of storage capacity in needed for PV+storage to actually replace natural gas power plants. Can battery storage systems be scaled to 30-plus hours of storage capacity? The familiar schematic of storage options in Fig. 4 places battery storage as a relatively small-scale 0.5-6 hours of storage capacity. The large-scale battery options with 30-plus hours of storage capacity are molten salt and compressed air. ASAP estimates a $200 million capital cost for either a 60 MW molten salt or compressed air storage facility with 30-plus hours of storage capacity. Pumped hydro plants are another large-scale storage technology but siting opportunities are limited.

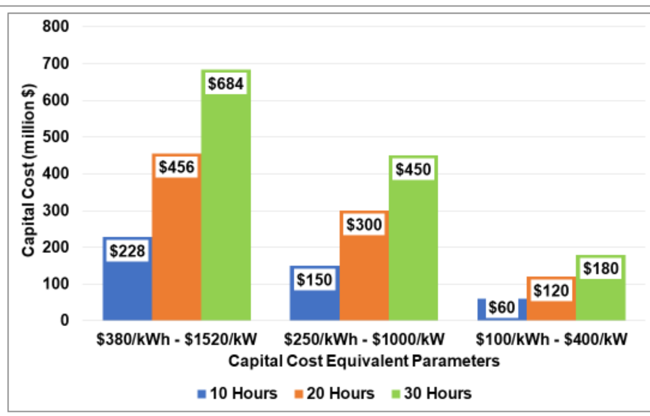
Using NREL data (refer to references), the cost characteristics of a 60 MW battery storage facility are explored. These are not definitive cost estimates but are presented to stimulate discussion and additional research. As previously stated, storage is important to stabilize PV and wind electricity supply, and the potential of battery storage needs to be fully explored.

The development of a peak PV+storage electricity supply system is required if PV is to replace over 200 GW of peak natural gas power plants and if the U.S. is to achieve zero emissions electricity supply. The goal is to increase storage hours from the current 4 hours to 30 hours to enable peak period PV electricity supply for as much as fourteen hours per day.

The battery storage of low cost nighttime wind electricity is another means of achieving peak period electricity demand (load). Hawaii is the first state to apply the storage of wind electricity for peak shaving. ASAP's study of wind electricity production profiles indicates that the storage of nighttime wind to supply 10-plus hours of daytime peak period electricity will also require about 20 to 30 hours of storage capacity. Therefore, the PV battery storage estimates are also applicable for wind electricity storage.

To move beyond PV+battery for peak shaving, the objective becomes the design of battery or underground compressed air energy storage (CAES) systems to supply peak electricity up to 14 hours per day as shown in Fig. 2. Based on measured variability in sunlight conditions (solar insolation), ASAP research indicates that PV storage should provide at least 30-hours of electricity supply without recharging to deliver on-demand electricity when taking into account daily variations in sunlight conditions. Scaling up the storage capacity of a 60 MW battery from 4 hours to 30 hours of storage requires a corresponding increase in battery capacity to 450 MW to maintain a constant 60 MW of power output. An explanation of the relationship between battery power output and energy storage time is provided in the Appendix.

Figure 5. Capital Cost of a 60 MW Battery Storage (10-30 Hours of Electricity Storage Capacity)

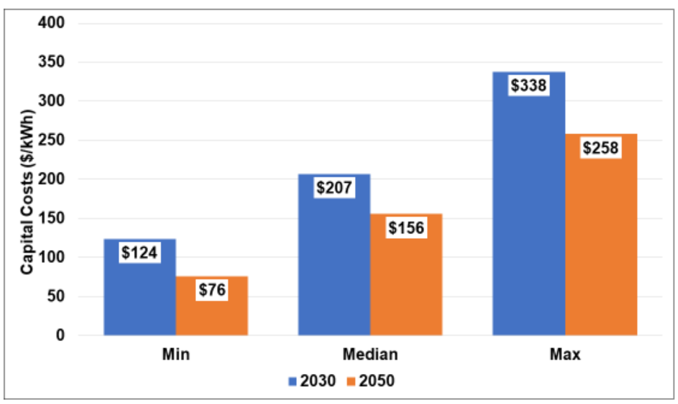


The capital costs of a 60 MW battery facility with 10, 20 and 30 hours of storage and with capital cost reductions are presented in Fig. 5. The initial $380/kWh - $1,520/kW battery cost pairing is NREL's cost estimate for a 2018 U.S. utility-scale (60 MW), lithium-ion, standalone battery with four hours (240 kWh) of storage. The lower estimates to the right in Fig. 5 are ASAP selected values to demonstrate expected battery system cost reductions.

With the low capital cost pairing, the capital cost of a 60 MW battery storage facility with 30 hours of storage is $180 million, which is competitive with molten salt or compressed air energy storage systems. ASAP estimates a $200 million capital cost for a 60 MW molten salt or compressed air storage facility with 30+ hours of storage capacity. Now the question becomes whether the battery $100/kWh - $400/kW capital cost pairing can be achieved.

NREL's Cole and Frazier examined over 25 utility-scale battery cost studies and organized the cost projections of the studies into minimum, median and maximum categories for the years 2030 and 2050. The Cole and Frazier battery cost projections are presented in Fig. 6, and the minimum prices in 2030 and 2050 are $124/kWh and $76/kWh respectively. These battery cost estimates suggest that utility-scale battery costs can compete with molten salt and compressed air storage technologies in the long run.

Figure 6. Utility-Scale Battery Cost Projections ($/kWh) - NREL, Cole and Frazier Study, 2019



All battery manufacturers have large R&D budgets with cost reduction and extending battery life targets. A project to watch is the proposed Tesla and CATL (Contemporary Amperex Technology Ltd.) collaboration on the "million-mile battery" project. It is reported that Tesla is in advanced talks to use CATL's lithium iron phosphate batteries, which use no cobalt, the most expensive metal in EV batteries. CATL also has developed a simpler and less expensive way of packaging battery cells, called cell-to-pack, that eliminates the middle step of bundling cells. Tesla is expected to use the technology to help reduce battery weight and cost. Tesla's goal is to develop low cost, long life batteries that not only will benefit the automotive market but also the utility-scale electricity storage market.

<u>References</u>

Fu, Ran, Timothy Remo, and Robert Margolis. 2018. 2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71714.

Cole, Wesley, and A. Will Frazier. 2019. Cost Projections for Utility-Scale Battery Storage. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-73222.

Appendix

A.1. Relationship between Battery Power Output and Hours of Electricity Storage

Battery system sizing is important if the goal is to transform variable PV electricity into an on-demand peak electricity supply. Battery system sizing is relatively complex and not easy to explain in words. The following explanation is made as simple and understandable as possible.

A 60 MW battery that stores 240 MWh of electricity can supply four hours of electricity at 60 MW of power (240 MWh / 60 MW = 4 hours). For a given battery capacity, which in our example is 60 MW, as the hours of electricity supply increases (storage time), the amount of power delivered must be lowered. For example, if ten hours of electricity supply is drawn from the 60 MW battery with 240 MWh of stored electricity, then the battery can only deliver 24 MW of power (240 MWh / 24 MW = 10 hours) as shown in Fig. A-1.

It follows that the sizing of a battery system is dependent on hours of electricity supply for given battery power and energy parameters, e.g., 60 MW of power and 240 MWh of electricity. To deliver a constant amount of battery power, e.g., 60 MW, for ten, twenty and thirty hours, the battery capacity must be increased by factors of 2.5, 5.0 and 7.5 respectively. The battery capacity required to supply 60 MW of power for ten hours is 150 MW, for twenty hours is 300 MW and for thirty hours is 450 MW.

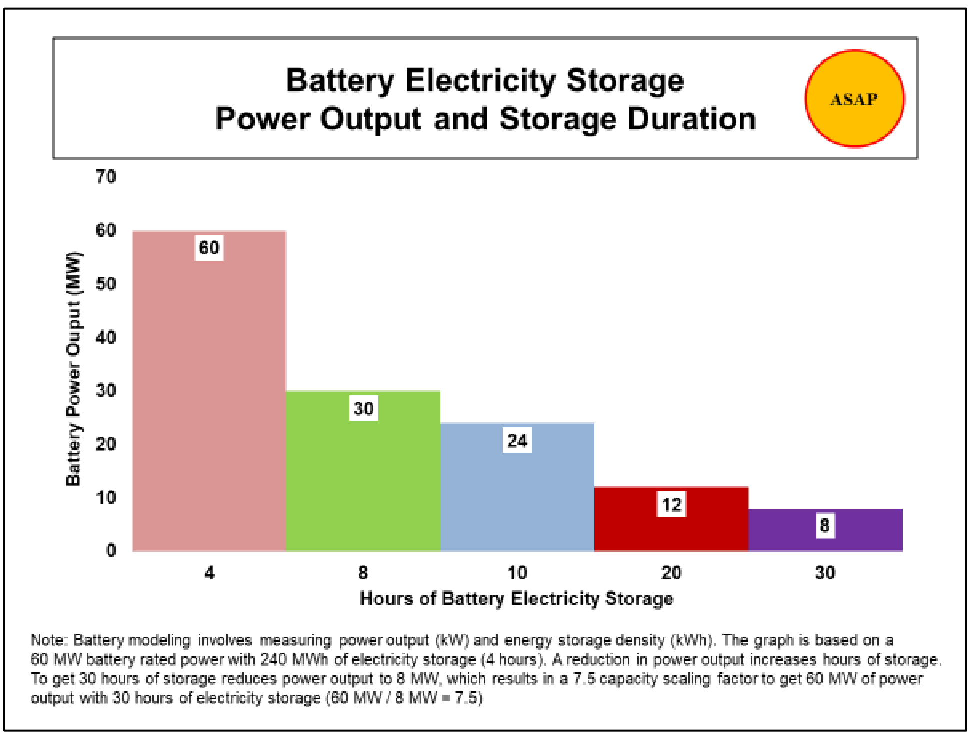


Figure A-1. Relationship between power output and hours of energy storage without recharging.