White Paper

Solar + Battery Is the Next Power Couple

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Shareables

- Looking at certain cost measures and predicted revenues, solar-plus-battery systems are predicted to become cost-competitive, versus "CTs", on an LCOE basis in 5–10 years.
- Areas with bigger price spreads and better solar resources will see bigger impacts sooner.
- As solar-plus-battery gains market competitiveness, it could begin to threaten certain technologies in the current generation mix.

Executive Summary

The dawn of an integrated solar-plus-battery system as the next "power couple" could be on the horizon as high intermittent renewables penetration drives the need for fast ramp capacity and as decreasing technology costs and chances at new revenue streams converge. ICF's levelized cost of electricity (LCOE) assessment indicates that the LCOE of solar-plus-battery is already competing with simple cycle generators (CT or "peakers") in some areas of the country.[1] When we add revenue analysis on top of those findings, two regions of the country, namely California Independent System Operator (CAISO) and the NERC Southeast region SERC East (SERC-E), will provide economic opportunities for solar-plus-battery due to great solar potential and greater price spreads. This initial analysis could indicate that battery storage is moving toward becoming a viable technology in the energy industry if tied with solar.

[1] This applies to areas of the country that see a summer peaking more so than a winter peaking system due to the resource availability for solar in these regions during the time of peak requirements.

As costs continue to decline at a faster rate than the market has predicted for the past several years, the LCOE, and eventually the levelized cost of capacity, of solar-plus-battery storage will make this the energy pairing to watch.

The Need for Peaking Capacity

Currently, peakers constitute approximately 15% of the capacity mix across all the independent system operators (ISOs). Looking forward, the U.S. Energy Information Administration's 2018 Annual Energy Outlook projects a need of around 20 GW of peak capacity in the next decade to meet peak demand. This requirement of peaking capacity and fast ramping capacity will only increase as more intermittent, largely renewable, resources join the capacity mix. However, as this capacity need increases, rising plant age, run-time limitations, and environmental regulations pose a threat to the traditional plants that are used to meet peak demand today.

Battery and Solar a Feasible Solution to Replace Peakers

Battery systems have already been paired with solar systems in a number of projects.[2] By replacing the traditional types of generating plants currently used, utility-scale storage integrated with solar has the potential to revolutionize the energy space. Making an intermittent resource a "dispatchable" resource will impact the price-setting, marginal resources that currently exist only to serve the grid's brief moments of peak demand.

To assess the current and future potential of battery buildout, ICF considered three lithium-ion battery system configurations. Batteries in these systems are used for energy arbitrage and to provide capacity services[3] :

- **Standalone Battery**: a battery directly charging from and discharging to the grid
- **Independent (non-integrated) solar and battery system ("independent system"):** battery and solar systems installed separately, meaning they don't share the same inverter and the battery doesn't charge from solar
- **Integrated solar-plus-battery system ("integrated system"):** battery and solar systems installed with one another, which means that they are co-located and share the same inverter. The battery is DC coupled to the system and is charged exclusively by solar, which allows the battery to capture the 100% investment tax credit (ITC). The ratio of solar capacity to battery capacity is assumed to be 5-to-1. The battery will have only one cycle per day and is charged and discharged for four continuous hours at a time.

[2] For example, in May 2016, Tucson Electric Power and NextEra Energy signed a $45/MWh PPA. https://www.utilitydive.com/news/how-can-tucson-electric-get-solar-storage-for-45kwh/443715/

[3] ICF assumes these batteries will be charged and discharged for a continuous 4 hours.

Savings with Integrated Solar-Plus-Battery

- **Financing:** The solar federal investment tax credit (ITC) can be applied to storage technologies that are charged by at least 75% renewable energy. Furthermore, a battery charged with over 50% solar energy qualifies for a five-year (as opposed to seven-year) Modified Accelerated Cost Recovery System (MACRS). When both benefits are applied in the PJM market, the LCOE of an integrated system decreases by approximately $31/MWh.
- **Design:** Prices become more competitive when we consider strategic system design. The larger the portion of solar capacity in the system, the less expensive the integrated system is on a $/MWh basis. For example, a system in PJM with a 50/10 solar/storage capacity split has a LCOE that is approximately $33/MWh lower than a system with a 50/20 split.

Is Solar-Plus-Battery Economic Today?

For a few specific areas of the United States, integrated solar-plus-battery systems should be a cost-competitive by 2020. We calculated and compared the three different systems' respective LCOE, which considers the capital, fixed, and variable costs from 2020 to 2040 in different markets across the United States (Exhibit 3).[4] ICF is using the LCOE as an initial screening tool that shows the revenue level a technology needs to have in order to be profitable. With the implementation of a solar module tariff by the US in early 2018 and the policy changes in China limiting available solar subsidies, potentially creating a module oversupply, the capital costs for solar have become somewhat volatile. However, we have chosen to reflect the state of capital costs based on the first half of 2018 in this analysis. Therefore, it was assumed the tariff will increase capital costs by roughly 10% in the next year, with decreasing impacts until 2021. ICF understands the repercussions of current changes in global policy may impact this assumption, however we expect that it will likely lower the solar capital costs.

EXHIBIT 1: COMPETITIVENESS OF SOLAR & BATTERY SYSTEMS ACROSS PRIME MOVERS (LCOE$/MWH)

Region/ Prime Mover	Combined Cycle	CT (10% CF)	CT (30% CF)	Wind	Solar	Stand-Alone Battery[1]	Independent Solar & Battery	Integrated Solar & Battery
CAISO	$69	$188	$104	$75	$55	$618	$82	$68
Arizona	$56	$157	$91	$85	$52	$400	$78	$66
ERCOT	$55	$154	$91	$55	$67	$455	$100	$86
MISO	$54	$151	$89	$54	$89	$451	$128	$113
PJM	$49	$142	$79	$64	$82	$323	$114	$104
ISO-NE	$69	$177	$107	$69	$93	$495	$133	$117
NYISO	$75	$174	$102	$88	$97	$756	$140	$119
SERC-E	$54	$150	$89	$60	$69	$313	$100	$90

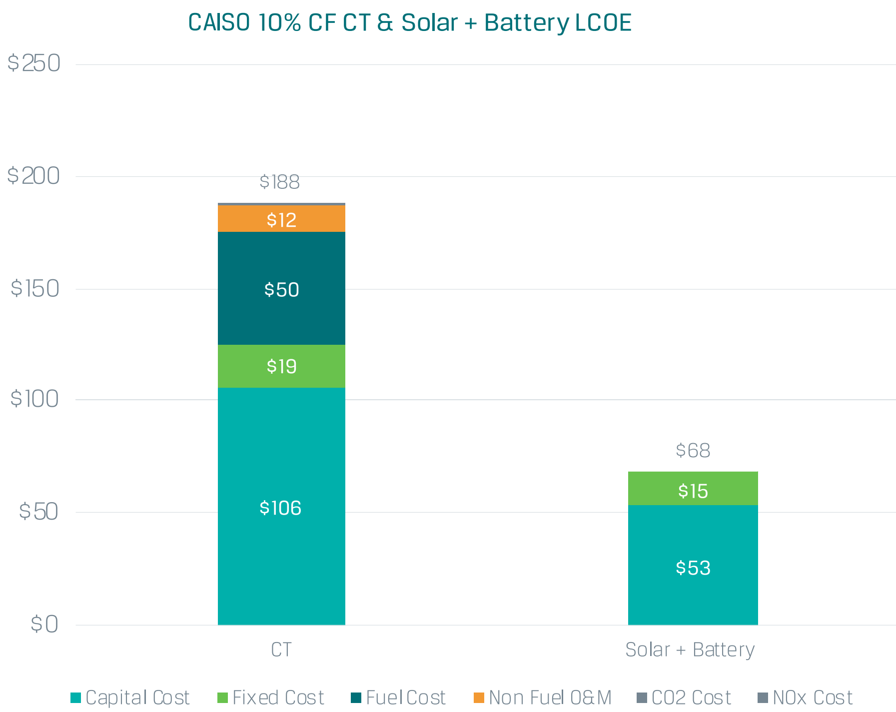
Notes(1) We include the standalone battery in this comparison for illustrative purposes. However, in reality, since it is not an energy source, it is more comparable to a CT on a $/kW-mo basis. (2) Combined costs are calculated using a generation-weighted average of solar and battery costs.

[4] LCOE reflects a simplistic assessment of the all-in cost of generation but does not capture higher / lower value of generation on the basis of the timing of this (e.g. greater value when dispatched at peak vs. off-peak).

The model shows that while a standalone battery would cost $400/MWh in the Arizona market, a system containing independent solar and battery components would cost significantly less at $78/MWh, and one containing integrated components would cost $66/MWh.

Peaker costs include capital, fuel, fixed, non-fuel operations and maintenance (O&M), and emissions costs. Independent and integrated solar-plus-storage systems gain an advantage over peakers by avoiding fuel and emissions costs while benefiting from financing, design strategies, and technology improvements. The integrated solar-plus-battery configuration is also advantageous since it qualifies for the ITC. In certain markets, CAISO and Arizona for example, the LCOE of an integrated system approaches that of a combined cycle.

EXHIBIT 2: COE COMPONENT COST COMPARISON IN CAISO FOR CT VS. INTEGRATED SOLAR + BATTERY SYSTEM



Looking Forward: The Next 5–10 years

The fuel dominating the U.S. power market has shifted over time, first from coal to nuclear, then from nuclear to natural gas. Rising environmental concerns and more ambitious Renewable Portfolio Standards (RPS) have supported renewable generation growth. As of January 2018, wind and solar assets constitute 8.1% and 2.6% of the U.S. capacity mix respectively. ICF anticipates that these numbers will increase as states meet and increase RPS requirements, as consumer demand for renewables continues to grow, and as overall cost competitiveness improves.

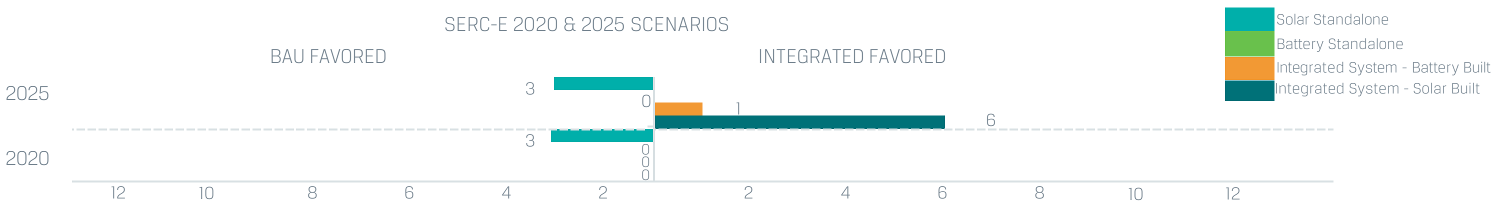
Battery storage deployment is still small compared to renewables but has increased substantially in the last two years from 46 MW in 2014 to 600 MW at the end of 2017. Much of this increase has been driven by state mandates (notably California) and pilot programs. While utility-scale battery systems are still technologically immature compared to CTs, decreasing costs and growing mandates position them for continued growth and potential system disruption in the next few years. Battery prices have been declining more rapidly than even many optimistic projections. Since 2005 lithium-ion battery pack prices have fallen from $1,000–1,500/kWh to less than $400/kWh. Vistra's recently announced battery project in California is estimated to have an LCOE in the $300-$350/kWh range. In the future, provider competition will cause prices to fall even more rapidly, and the integration of solar-plus-battery offers better returns than batteries alone, creating a system that could be financially competitive with other technologies including peakers.

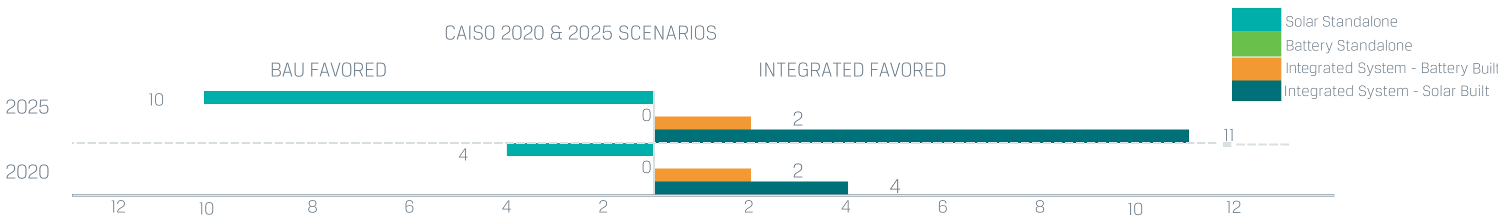
Batteries' unique capabilities inspired Order No. 841, which requires ISO and RTO markets to establish market rules that properly recognize all products of storage technology that should be eligible to receive revenue in the markets. As this process continues, new revenue opportunities should grow, especially when battery is combined with solar.

To fully consider the economics of the integrated solar-plus-battery systems and their potential impact on power markets within the next 5–10 years, we compared two market models: one with the integrated system ("integrated case") and one Business as Usual ("BAU") case. In the integrated case, the model has the choice to build standalone solar, standalone battery, and/or an integrated system. Both cases assume future declines in capital cost. The BAU case reflects the same market conditions, but no integrated system is available.

The analysis shows that only certain markets in the United States see disruptive impacts from the integrated system in the near-term. The integrated system has an advantage in markets with wider price spreads and greater amounts of solar resources, like the Southeast and Southwest markets. However, even those markets don't act the same way. For example, California starts to see the integrated system replacing standalone solar in 2020 due to the existing "duck curve" issue, while SERC-East (North Carolina and South Carolina) refrains from standalone solar builds until the integrated system's economics are more conducive to building the integrated system in 2025.

EXHIBIT 3: CUMULATIVE BUILDS DIFFERENCE BETWEEN "INTEGRATED" AND "BAU" CASES IN 2020 AND 2025





Our model results show that the standalone solar and battery systems are not economical in the integrated case; however, the total additions of solar, as a part of an integrated system, are greater in the integrated case, which contributes to a greater uptake of batteries as well. This effect is more prominent in SERC-East, with an increase from 3 GW in the BAU case to 6 GW in the integrated case, because it has a wider price spread than California.

The analysis also shows that the integrated system had a 10 to 20% higher return than the independent systems, largely due to the improved energy and capacity revenue capture and access to the ITC. As the integrated system gains market competitiveness and market penetration, it could begin to threaten the necessity of combustion turbines.

The Future Is (Having Effects) Now

The harbinger of power market disruption from renewables tied to storage is perhaps reflected in industry trends today, exemplified by recent changes GE and Siemens have made to their organizations and workforce. Although widespread deployment of solar + storage may be at least 5 years away, the disruptions it unleashes could be swift, affording little time for a period of calm transition. As companies such as GE and Siemens are demonstrating, energy firms need to begin devising and implementing their transition strategy before the looming transformation.

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About the Authors

David Gerhardt is a Principal and energy analyst with over 25 years of experience in energy economics and energy engineering issues. Most of his work in energy economics has been in areas such as power plant asset valuation, wholesale power litigation, resource planning, and PPA negotiations and recontracting. Mr. Gerhardt is the lead power generation engineer for ICF's Wholesale Power group. As the lead engineer, one of Mr. Gerhardt roles requires the review and development of all critical data required by the group including new power plant cost and performance characteristics by prime mover type, operation and maintenance estimates, forced and scheduled outage rates, uprates, and emission rates. Most recently this has included updating solar PV and battery storage construction cost data. Mr. Gerhardt is often the lead market consultant for private equity investors providing due diligence support.

Mr. Gerhardt has a BS in Mechanical Engineering, Rochester Institute of Technology and an MS in Energy Management and Policy, University of Pennsylvania.

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