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The Solar Trifecta: A Path to Smart Utility-Scale Solar

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Contents

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Executive Summary

"Traditional" utility-scale solar creates operational challenges at high penetrations.

- Traditional utility-scale solar is designed and operated to generate and deliver the maximum amount of electricity in real time. At high penetrations, these systems create significant operational challenges for the electric grid operators (e.g., California duck curve).
- A common response to this challenge is to simply pair traditional utility-scale solar with flexible natural gas generation. However, this is not the only option as utility-scale solar has the potential to become smarter and provide significant value to the electric grid.

In the near term, "controllable" utility-scale solar may emerge as a near-term resource to support electric grid operations.

- A controllable utility-scale solar system uses existing technology to provide additional value and flexibility through targeted curtailments, smoother output, and expanded ancillary services.

Over the long term, "smart" utility-scale solar could emerge as a flexible and dynamic grid asset.

- Smart utility-scale solar is capable of cost competitively offering operational attributes that are comparable to conventional generation assets. By leveraging smart inverters and battery storage, smart utility-scale solar can be optimized for the grid, not just maximum output.

Smart utility-scale solar could become a reality and may behave more like a dispatchable resource with the convergence of three important market requirements, which we call the "solar trifecta." The three pillars of the solar trifecta are:

- ***Value from Good Grid Citizenship*** – With smart inverters, utility-scale solar PV systems provide smoother, more predictable output; a broad suite of ancillary services; and targeted curtailment.
- ***Energy When You Need It*** – Utility-scale solar PV plus storage (PV+S) allows a system to dispatch energy and capacity to meet evening and nighttime load.
- ***Cost-Competitive Resource*** – Advances in operating intelligence coupled with declines in the cost of utility-scale PV and batteries bring promise for cost-performance competitiveness with other options.

How Utility-Scale Solar Evolves to Meet Solar Trifecta Requirements*

Type of Solar	Value from Good Grid Citizenship	Energy When You Need It	Cost-Competitive Resource**
Traditional	✘	✘	✓
Controllable	✓	✘	✓
Smart	✓	✓	✓

* Table reflects requirements met by each type of solar; not necessarily current state of market.
** Cost competitiveness is dependent on location and available solar resource.

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Traditional Utility-Scale Solar: Growing Penetrations, Growing Challenges

Utility-scale solar has become an important and growing part of the electric generation portfolio in the Unites States. However, operational challenges for grid operators are becoming evident in markets with high penetrations of utility-scale solar. While the historical trend has been marked by growing operational challenges, this does not have to be the future for utility-scale solar.

- Existing installed utility-scale solar capacity can be categorized as “traditional” utility-scale solar. ScottMadden defines traditional utility-scale solar as a system designed and operated to generate and sell the maximum amount of electric output. Key features of traditional utility-scale solar include:
  - System is oriented toward the south to maximize potential electricity generation.
  - Generation output is maximized and delivered in real time to the electric grid.
  - Battery storage is not integrated into the utility-scale solar system.
  - Some systems may be providing dynamic voltage and power factor regulation based on bulk power system interconnection requirements.
- As a result of the design, traditional utility-scale solar has the following operational attributes:
  - Variable output – Electricity generation is dependent on solar irradiance and can vary significantly with passing cloud cover.
  - Lack of robust ancillary services – Systems do not provide a broad suite of ancillary services and reduce inertia on electric system.
  - Dispatch limitations – Unless curtailed, generation output is constantly maximized rather than set by grid operators. Further, generation output is limited during evening load and nonexistent during nighttime load.
  - Cost competitiveness – While this is changing quickly and varies by region, utility-scale solar has historically been more expensive than conventional generation assets, the most notable being natural gas-fired generation.
- At high-penetration levels, the design features and operational attributes of traditional utility-scale solar create significant operational challenges for electric grid operators.
  - The California duck curve is the most pronounced example of operational challenges. The California ISO faces oversupply risk during mid-day from utility-scale solar production followed by steep ramps in evening hours as solar production declines.
  - Further, increasing penetration of utility-scale solar to less developed solar markets (i.e., non-California markets) could create new and extreme operational challenges to electric systems unaccustomed to high amounts of solar power generation.
- A common response to this challenge is to simply pair traditional utility-scale solar with flexible natural gas generation. However, this is not the only option as utility-scale solar has the potential to become smarter and provide significant value to the electric grid.

Controllable Utility-Scale Solar: A Major Step Forward

The past is not always indicative of the future. Rather than the unabated deployment of traditional utility-scale solar, "controllable" utility-scale solar may emerge as a near-term resource to support electric grid operations.

- ScottMadden defines controllable utility-scale solar as a utility-scale solar system that trades some energy output to cost competitively offer operational attributes comparable to conventional generation. Key features of controllable utility-scale solar include the following:
  - Consists of utility-scale solar PV
  - Leverages smart inverters and operating intelligence to provide:
    - Targeted curtailments to better manage evening ramping of conventional generation
    - Smoother, more predictable output by withholding a portion of output ramping blocks of inverters up and down to achieve desired output
    - Suite of grid reliability services, such as regulation (both up and down) and frequency response
  - Competes on cost with new natural gas generation and other conventional generation

"Traditional" Utility-Scale Solar

Utility-scale solar systems designed and operated to generate and deliver the maximum amount of electricity in real time. At high penetrations, these systems create significant operational challenges for the electric grid operators.

"Controllable" Utility-Scale Solar

Utility-scale solar systems that use existing technology to provide additional value and flexibility through targeted curtailments, smoother output, and expanded ancillary services.

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Smart Utility-Scale Solar: An Even Better Way

Controllable utility-scale solar becomes "smart" utility-scale solar with the addition of battery storage. Smart utility-scale solar is a dynamic grid resource that could become a significant asset on the grid over the long term.

- ScottMadden defines smart utility-scale solar as a utility-scale solar system capable of cost competitively offering comparable operational attributes to conventional generation. Key features of smart utility-scale solar include the following:
  - Consists of utility-scale solar PV plus battery storage (PV+S)
  - Provides controllability through targeted curtailments, smoother output, and expanded ancillary services
  - Leverages battery storage to provide grid reliability services and offers dispatchable energy around the clock
  - Competes on cost with new natural gas generation and other conventional generation
  - Becomes a dynamic and desired grid asset, rather than a growing challenge like traditional utility-scale solar—optimized for the grid, not just maximum output

"Traditional" Utility-Scale Solar

Utility-scale solar systems designed and operated to generate and deliver the maximum amount of electricity in real time. At high penetrations, these systems create significant operational challenges for the electric grid operators.

→

"Controllable" Utility-Scale Solar

Utility-scale solar systems that use existing technology to provide additional value and flexibility through targeted curtailments, smoother output, and expanded ancillary services.

→

"Smart" Utility-Scale Solar

Utility-scale solar systems capable of cost competitively offering comparable operational attributes as conventional generation assets. Smart utility-scale solar consists of PV+S.

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The Solar Trifecta: The Path to Get There

There are three market requirements that, when delivered, give a generation asset a competitive advantage:

Value from Good Grid Citizenship
With smart inverters, utility-scale solar PV systems provide smoother, more predictable output; a broad suite of ancillary services; and targeted curtailment.

Energy When You Need It
Utility-scale solar PV plus storage (PV+S) allows a system to dispatch energy and capacity to meet evening and nighttime load.

Cost-Competitive Resource
Advances in operating intelligence coupled with declines in cost of utility-scale PV and batteries bring promise for cost-performance competitiveness with other options.

In combination, these requirements address the constraints of traditional utility-scale solar and advance the deployment of smart utility-scale solar. We call the convergence of these three pillars and emergence of smart utility-scale solar the "solar trifecta."

TRADITIONAL SOLAR

CONTROLLABLE SOLAR

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Value from Good Grid Citizenship: Grid-Friendly Capabilities

A common view is traditional utility-scale solar has not been a good grid steward because the resource is variable and the generation asset does not provide a broad suite of ancillary services. As a result, other resources are required to respond to solar-related grid integration challenges.

- Passing cloud cover can create significant variation in the net output of a traditional utility-scale solar system.
- In addition, unlike conventional generation which has rotating machines synchronized to the electric grid that can naturally provide reactive power and voltage control, utility-scale solar plants are connected to the grid through an inverter which converts DC to AC energy (non-synchronous), and the traditional inverter setting cannot provide a suite of ancillary services.
- So traditional utility-scale solar is dependent upon the grid to provide electrical support, flexibility, and reliability. Increasing penetration of traditional utility-scale solar generation increases the need for additional support from the grid—potentially limiting future utility-scale solar deployments.
- The support provided to the grid by typical inverters and controls in today's traditional utility-scale solar systems is rudimentary (e.g., disconnecting solar systems during grid disturbances) and does not provide a net positive effect to the grid—not good "grid citizenship."

With smart inverters and operational intelligence, utility-scale solar can become much more grid friendly by performing new functions and providing new grid services which improve stability and reliability rather than reducing it—potentially setting the stage for future large-scale integration of utility-scale solar into the electric grid.

- Solar PV is capable of providing nearly constant output. This is done by designing an additional capacity and controlling the system to meet the interconnection limit (e.g., operating below maximum capacity). When this is done, blocks of inverters can be ramped up to mitigate passing cloud cover, resulting in nearly constant net output. In a sense, this makes solar dispatchable within a range of operation. Targeted curtailments can also allow grid operators to better manage ramps in net load.
- Demonstrations have also shown the capability to provide a suite of ancillary services by trading energy output in favor of regulation (both up and down) and frequency response. In many instances, utility-scale solar is already providing dynamic voltage and power factor regulation based on bulk power system interconnection requirements.

Smart Utility-Scale Solar Capabilities*	Description
Regulation up and down (i.e., following reserves)	Minute-to-minute balancing during normal conditions with faster ramping resources
Frequency response and inertial response	Fast response following a contingency (loss of load/generator) to reduce area control error (ACE), or the difference between scheduled and actual generation

Note: *Services commonly provided by conventional thermal generation, but generally not provided by solar generation.

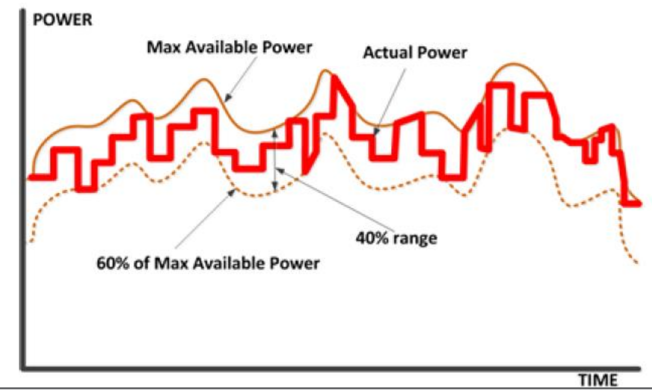
Sources: EPRI, NREL

Value from Good Grid Citizenship: Demonstrating Potential

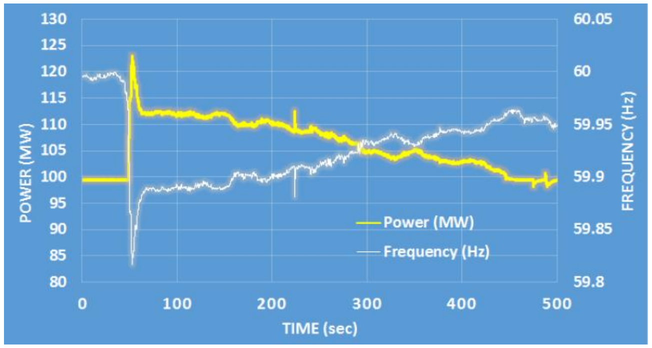
Three recent demonstrations have shown the potential capabilities and have provided tangible evidence that smart utility-scale solar is capable of delivering multiple grid services, thereby making smart utility-scale solar a better grid steward.

- The first two demonstrations were included in a study designed to prove the ability of utility-scale solar plants to provide various types of active and reactive power control with the implementation of new controls in two different wholesale markets with varying characteristics.
  - **Puerto Rico (Jul–Aug 2015)** – Ilumina PV Plant (AES)
    - Objective: Demonstrate possibilities/benefits of Active Power Control (APC)
      - Participation in frequency regulation
      - Fast inertia-like frequency response
  - **Texas (Sept 2014 and Aug 2015)** – Pecos Barilla PV Power Plant (First Solar)
    - Objective: Demonstrate range of grid services currently provided in the ERCOT market, including some services planned for the market in the future
      - Balancing energy services and reserve energy services
      - Dynamic voltage and power factor regulation
- The third demonstration represents a potential step-change advancement toward smart utility-scale solar by demonstrating the technology's ability to combine and provide multiple advanced reliability services from a single large solar plant in California.
  - **California (Aug 2016)** – 300-MW Solar Plant (First Solar)
    - Objective: Demonstrate how multiple advanced inverter functions, combined with plant control features, can address a range of grid challenges
    - Distinct feature: Plant-level controller (PPC) designed to regulate real and reactive power output so that it behaves as a single large generator, coordinating and communicating catered instructions to multiple different inverters at the plant to optimize plant output to the grid

Solar Plant Up and Down Regulation



Solar Plant Response to Under-Frequency Event



By providing an enhanced suite of reliability and flexibility services, smart utility-scale solar's operating characteristics look more like those of conventional generation—potentially upending assumptions about utility-scale solar's value as a grid citizen.

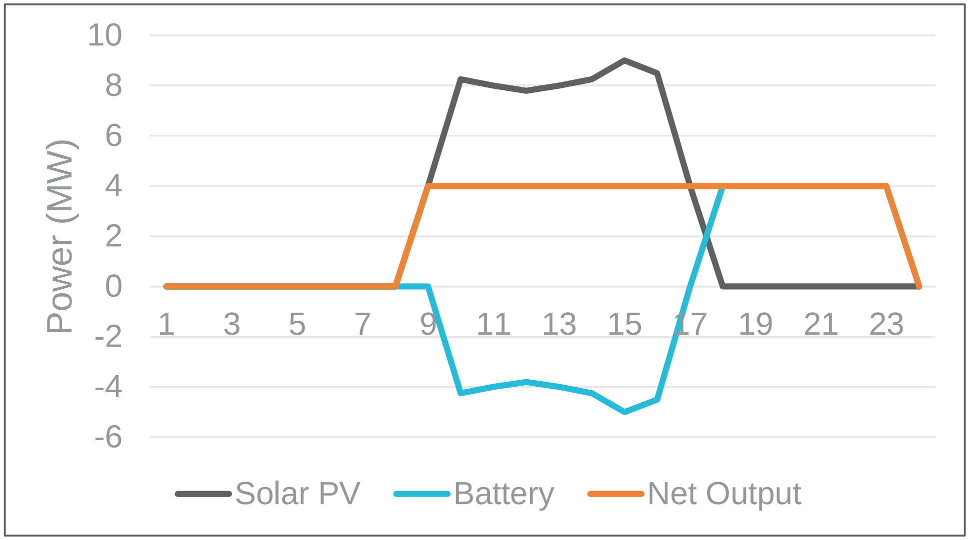
Sources: NREL, CAISO, First Solar, AES, PV Tech, Regulatory Assistance Project

Energy When You Need It: Extending Net Output

Without the sun, traditional utility-scale solar is unable to generate and deliver electricity. Smart utility-scale solar will rely on battery storage to ensure delivery of energy and capacity during evening and nighttime hours.

- By exporting generation only in real time, traditional utility-scale solar is often unavailable during evening load periods.
  - As a result, conventional generation must follow changes in solar output and be available to serve evening load.
  - The most extreme example of this dynamic is the California duck curve.
    - Conventional generation is limited mid-day during high solar production, but must ramp exceedingly fast to meet evening load.
- Smart utility-scale solar addresses these operational challenges by using PV+S to provide energy and capacity during evening and nighttime hours.
  - A PV+S system would be capable of serving evening load by using excess generation to charge battery storage during the day (see chart).
  - As solar production declines in the evening, the battery storage would switch from charging to discharging at a constant output level.
  - The result is less strain on the system during noon and more solar power for the system to serve evening load.
  - In wholesale markets, battery storage would allow system owners to benefit from higher prices often available during evening hours.
  - Depending on market needs, a PV+S system could be designed to meet a variety of operational specifications by altering solar capacity, battery capacity, battery discharge, and system configuration.

Illustrative Net Output from PV+S System



PV+S vs. Standalone Grid Storage

A PV+S system has multiple advantages over standalone grid storage. A PV+S system allows sharing of fixed costs (e.g., site), soft costs (e.g., EPC), and O&M costs. Further, a PV+S system may reduce system complexity by creating one dynamic asset rather than multiple assets to be managed by the electric grid operator.

Sources: First Solar, Alevo, ScottMadden

Energy When You Need It: Targeting Evening Load

The unique advantage of battery storage becomes clear when modeling a PV+S system over the long term.

- First Solar recently modeled a 10 MW-ac PV plant in the desert Southwest with four hours of energy storage.
- The tables represent the average hourly production over the 20-year life of the plant.
  - The analysis accounts for weather variations and production degradation.
  - The target period highlighted represents a summer evening peak.
- The PV+S system is capable of "smartly" using the energy storage to nearly double the capacity factor during the target period.
  - The standalone solar PV system maintains a 50% capacity factor during the target period.
  - ***The PV+S system maintains a 98% capacity factor during target period.***
  - The PV+S system is capable of offering energy and capacity during a specific peak period.

10-MW Solar PV: 20-Year Average Energy Delivered

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.9	5.0	5.4	5.2	5.1	5.2	5.4	5.4	3.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.3	5.6	6.0	5.9	5.8	5.6	5.8	5.2	4.3	2.1	0.0	[illegible]	[illegible]	[illegible]	[illegible]	0.0
Mar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	5.7	6.8	6.7	6.6	6.6	6.5	6.6	6.6	5.7	3.3	0.4	0.0	0.0	0.0	0.0	0.0
Apr	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.6	6.9	7.5	7.7	7.5	7.5	7.7	7.5	7.2	6.4	4.6	1.2	0.0	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0	0.0	0.0	2.7	6.1	7.3	7.8	7.8	7.7	7.8	8.0	7.6	7.6	7.0	5.6	2.3	0.1	0.0	0.0	0.0	0.0
Jun	0.0	0.0	0.0	0.0	0.0	0.0	3.2	6.2	7.3	7.7	7.8	7.9	7.8	7.8	7.7	7.5	7.0	5.9	3.0	0.3	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0	0.0	2.2	5.2	6.4	6.8	7.3	7.5	7.4	7.6	7.5	7.4	6.5	5.1	2.4	0.2	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.8	5.8	6.6	7.4	7.2	7.4	7.3	7.5	7.1	6.6	5.0	1.5	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.4	3.9	6.2	6.8	6.9	7.0	6.8	6.9	6.7	6.2	5.5	3.0	0.3	0.0	0.0	0.0	0.0	0.0
Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.8	5.7	6.1	6.3	6.1	6.2	5.8	6.5	6.2	4.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Nov	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	4.8	5.9	5.5	5.2	5.1	5.2	5.2	5.0	2.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.1	4.9	5.0	4.9	4.6	4.8	5.1	4.4	2.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Target Period

10-MW PV+S with Four Hours of Storage: 20-Year Average Energy Delivered

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.9	5.0	5.3	5.2	5.0	5.1	5.4	5.4	3.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.3	5.6	6.0	5.9	5.8	5.6	5.8	5.2	4.3	2.1	0.0	[illegible]	[illegible]	[illegible]	[illegible]	0.0
Mar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	5.7	6.8	6.7	6.6	6.6	6.5	6.6	6.6	5.7	3.3	0.4	0.0	0.0	0.0	0.0	0.0
Apr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.2	5.1	6.4	6.6	7.2	7.5	10.0	10.0	10.0	9.8	0.0	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	7.3	7.6	7.7	8.0	7.6	10.0	10.0	10.0	10.0	0.1	0.0	0.0	0.0	0.0
Jun	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	7.6	7.9	7.8	7.8	7.7	10.0	10.0	10.0	10.0	0.3	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	5.1	6.7	7.4	7.5	7.5	10.0	10.0	10.0	9.8	0.2	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.6	5.4	6.8	7.2	7.5	10.0	10.0	10.0	9.9	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	4.3	5.8	6.4	6.7	9.9	9.7	9.6	9.0	0.0	0.0	0.0	0.0	0.0
Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.3	5.0	6.5	9.9	9.5	9.2	8.7	0.0	0.0	0.0	0.0	0.0
Nov	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	4.8	5.9	5.3	5.0	4.9	5.0	5.0	4.9	2.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.1	4.9	5.0	4.9	4.6	4.8	5.1	4.4	2.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Target Period

Smart utility-scale solar will leverage a battery storage (or PV+S system) to provide reliable energy and capacity during evening and nighttime hours.

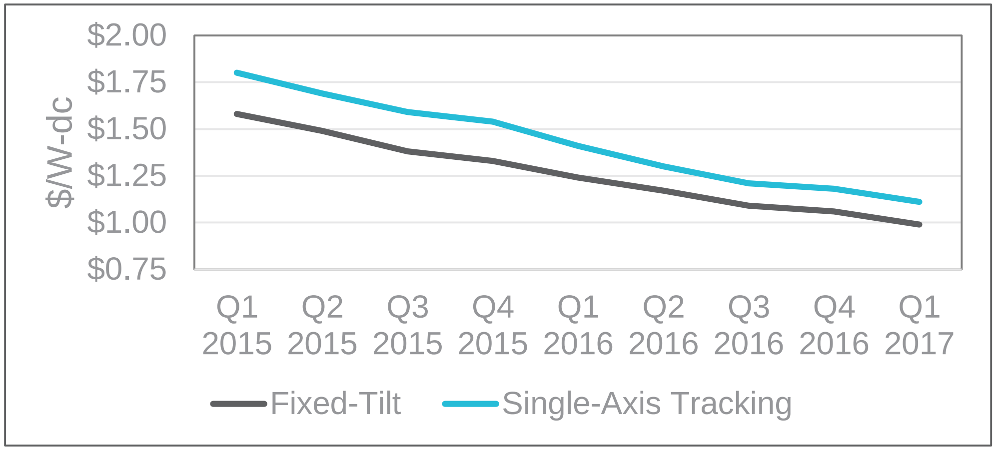
Source: First Solar

Cost-Competitive Resource: Solar PV and Battery Storage

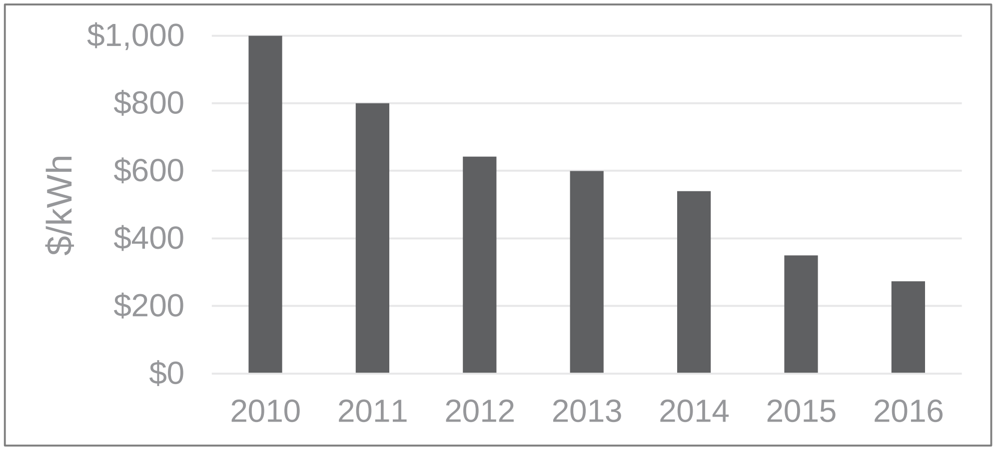
The third pillar of the solar trifecta is smart utility-scale solar as a cost-competitive generation asset. This depends on the installed cost of utility-scale solar and battery pack costs.

- The installed costs of utility-scale solar continue to fall with declining hardware costs being the primary driver.
  - The modeled national average installed cost for fixed-tilt utility-scale solar dropped below $1/W-dc in Q1 2017.
    - This record price follows a 37% drop in installed costs since Q1 2015.
  - The installed costs of single-axis tracking utility-scale solar has also declined significantly with the premium over a fixed-tilt system shrinking over time.
  - The majority of the declines in installed costs come from falling hardware costs (e.g., modules).
  - Operating below maximum capacity in order to provide other services is also reaching financial parity in some regions.
- The cost of battery storage packs is rapidly declining, driven by emerging grid storage markets and electric vehicle growth.
  - Battery storage costs declined 73% from 2000 to 2016.
  - Emerging grid storage markets include fast frequency regulation and state-driven battery storage requirements (e.g., California).
  - In addition, the growth of electric vehicles is expected to accelerate the learning-curve effect as the battery storage industry expands to meet demand (e.g., Tesla Gigafactory).

U.S. Utility-Scale Solar Installed Cost, Q1 2015–Q1 2017



Global Lithium-Ion Battery Pack Cost, 2010–2016



Sources: GTM Research, SEIA, BNEF

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Cost-Competitive Resource: PV+S Systems

Declining technology costs—coupled with increasing PV+S system size and the federal investment tax credit—have resulted in a rapid decline in power purchase agreement (PPA) prices for PV+S systems. In September 2015, a PV+S system in Hawaii signed a PPA for 13.9 cents per kWh. In May 2017, a PV+S system in Arizona signed a PPA for less than 4.5 cents per kWh.

Major PV+S Announcements Timeline

2015	2016	2017

SEPT. 2015:
Kapaia Solar Array & Storage Facility

- Pricing: 20-year PPA for 13.9 cents per kWh
- System: 13 MW-ac solar with 13 MW/52 MWh energy storage
- Partners: Kauai Island Utility Cooperative and Tesla
- Purpose: Meet evening peak demand
- Timeline: Operational in March 2017

JAN. 2017:
Kauai Hybrid Solar Project

- Pricing: 25-year PPA for 11 cents per kWh
- System: 20 MW-ac solar with 20 MW/100 MWh energy storage
- Partners: Kauai Island Utility Cooperative and AES Distributed Energy
- Purpose: Reduce evening peak demand and provide consistent night-time power
- Timeline: Operational by late 2018

MAY 2017:
Tucson Solar Project

- Pricing: 20-year PPA for less than 4.5 cents per kWh
- System: 100 MW-ac solar with 30 MW/120 MWh energy storage
- Partners: Tucson Electric Power and NextEra Energy
- Purpose: Integrate renewable resources
- Timeline: Operational by December 2019

Declining technology costs—including utility-scale solar and battery storage—are critical for smart utility-scale solar to become cost competitive with conventional generation assets.

Sources: Company web sites, Utility Dive, SNL

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The Dawn of Smart Utility-Scale Solar

The solar trifecta provides a clear pathway for smart utility-scale solar to offer tremendous benefits to consumers, the environment, and grid management. However, advancements within all three pillars of the trifecta will be needed to ensure scalable deployment of smart utility-scale solar:

- The opportunity and potential for smart utility-scale solar would be dampened if advancements in any one of the pillars of the trifecta fail to materialize.
  - Utility-scale solar must begin providing a broad suite of ancillary services in regular operations, not just in demonstration settings.
  - PV+S systems must become cost competitive and in broad use. The National Renewable Energy Laboratory recently estimated that PV+S systems would become cost competitive with standalone PV by 2020.
  - Utility-scale solar and battery storage costs must continue to decline in order to compete with conventional generation.

However, a critical intermediate step will be the emergence of controllable solar.

- Controllable solar will be achievable by increasing the value from being a good grid citizen (i.e., smoother output, robust ancillary services, and targeted curtailment).
- The addition of cost-effective storage will allow the transition from controllable to smart utility-scale solar.

How Utility-Scale Solar Evolves to Meet Solar Trifecta Requirements*

Type of Solar	Value from Good Grid Citizenship	Energy When You Need It	Cost-Competitive Resource**
Traditional	✗	✗	✓
Controllable	✓	✗	✓
Smart	✓	✓	✓

* Table reflects requirements met by each type of solar; not necessarily current state of market.
** Cost competitiveness is dependent on location and available solar resource.

Sources: NREL, GTM, ScottMadden

The Dawn of Smart Utility-Scale Solar (Cont'd)

Several market developments and regulatory decisions could either hamper or accelerate advancement of the solar trifecta and ultimately the deployment of controllable and smart utility-scale solar. Key sign posts to watch include:

- Recognition of good grid citizenship – Most utilities do not compensate or set minimum requirements for solar assets to provide broad ancillary services. As a result, traditional utility-scale solar systems do not leverage these potential capabilities. New and innovative PPA structures and market rules could accelerate the learning curve and encourage future utility-scale solar systems to be model grid citizens.
- Success of early PV+S systems – For evening and nighttime dispatchable solar to gain broad industry acceptance, early PV+S systems must prove their ability to reliably and consistently deliver energy and capacity during evening load periods.
- Continued learning-curve impacts – With increasing installed capacity, both solar PV and battery storage costs have benefited from learning curves as installed capacity grows. Continued declines in technology will be important if smart solar is to become cost competitive.

Are we there yet? So what are the key milestone that will mark the dawn of smart-utility solar and a new era for the electric grid?

- An initial milestone will be controllable utility-scale solar becoming commonplace, supplanting the deployment of traditional utility-scale solar.
  - For example, solar output could be curtailed in the late afternoon to mitigate steep ramps for conventional generation.
  - In many markets, leveraging the full potential of existing technology may require new PPA constructs, as well as regulatory changes.
- Longer term, a critical milestone will be a PV+S system outcompeting a new natural gas peaking plant and successfully providing energy, capacity, and a broad suite of ancillary services.

"Post-2020, there may never be another peaker built in the United States – very likely you'll be just building energy storage instead."

– Jim Robo, CEO of NextEra (2015)

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