EXECUTIVE BRIEFING:
THE FUTURE OF U.S. SOLAR
Getting to the Next Order of Magnitude

Shayle Kann, Senior Vice President, GTM Research

gtmresearch

November 2015

CONTENTS

ABOUT THE AUTHOR

Shayle Kann, Senior Vice President | GTM Research

Kann@gtmresearch.com
@shaylekann

Shayle Kann directs GTM Research, the market analysis, advisory and consulting division of Greentech Media. GTM Research provides deep, analytical insight into the state and future of solar power, energy storage, and the transformation of the electric grid at the edge. An expert on distributed energy markets, he has presented at conferences around the world, been featured in publications such as *The Economist, The New York Times, Wall Street Journal, Washington Post, Forbes, Bloomberg, Reuters* and *Financial Times,* and has spoken at Harvard, Yale, MIT and Columbia. He has also testified in front of the U.S. House of Representatives Natural Resources Committee on the state and future of the U.S. solar market.

Prior to joining GTM, Shayle was a U.S. Fulbright scholar in Australia, studying the impacts of the global financial crisis on wind project finance. He has a bachelor's degree cum laude, Phi Beta Kappa from Pomona College.

1. EXECUTIVE SUMMARY

Solar power is on an impressive growth streak in the U.S., having gone from 2 gigawatts of cumulative capacity at the end of 2010 to a likely 26 gigawatts at the end of this year. More importantly, costs have fallen enough to make it clear that solar will play a meaningful role in the future of electricity in the U.S.

For the solar industry, it is time to start thinking about the next order of magnitude. Solar generates approximately 1% of all electricity in the U.S. today, but there is a realistic path toward 10% over the next 10-15 years. That path is by no means guaranteed; solar faces both advantages and disadvantages as it begins to truly scale. This report highlights the key forces likely to push, or impede, solar growth in the coming years and identifies opportunities for the solar industry to ensure its future.

Catalysts for Growth

- Rising Electricity Prices will continue to make solar more competitive in comparison
- Falling Solar Costs should continue for the foreseeable future, albeit at a more moderate pace than the past five years
- The Clean Power Plan could open up new state markets to solar and diversify the demand landscape
- Electricity Market Reinvention through initiatives such as New York's Reforming the Energy Vision carries the promise of new revenue streams for solar as a grid asset

Risk Factors

- Investment Tax Credit Expiration is looming and likely to generate the first down year for the U.S. solar market in well over a decade
- Solar's Value Deflation Effect, through which the marginal value of solar power decreases as solar penetration grows, means that grid parity will be a moving target
- Electricity Rate and Net Energy Metering Reform can still erode the economics of distributed solar through the introduction of higher fixed charges, higher or new demand charges, or lower export rates for solar generation

Market Opportunities

- Investing in energy storage and load control can make solar a better long-term citizen of the grid
- Testing radical cost-reduction opportunities will leave the door open for step-function reductions in solar costs
- Participating in market reinvention will ensure that distributed solar receives its full value as the electricity market becomes increasingly distributed

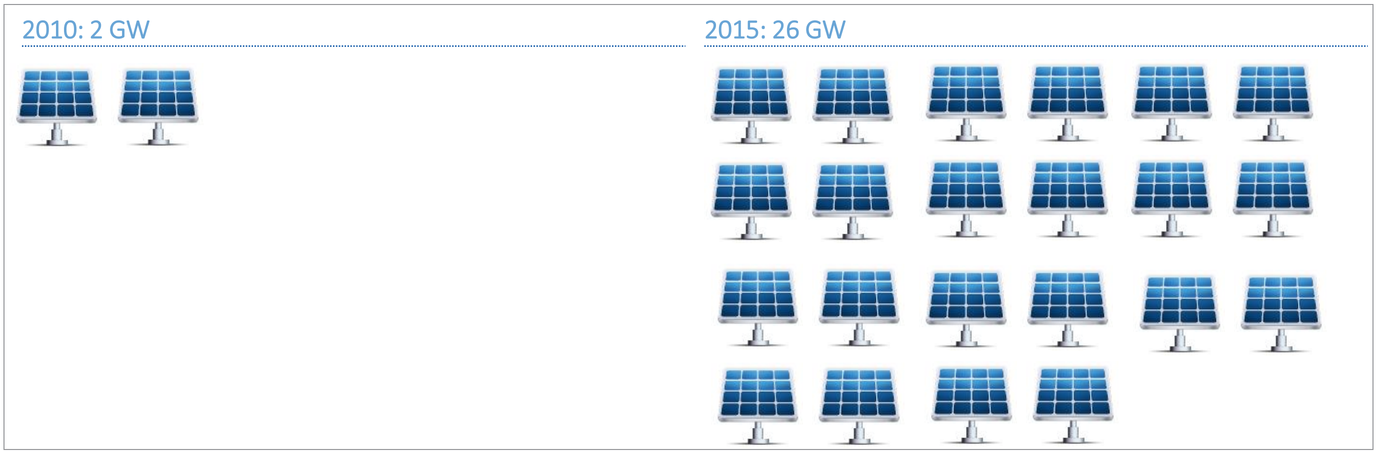
2. SOLAR HAS COME A LONG WAY IN THE U.S.

The Anatomy of a Booming Market

Five years ago, as 2010 came to a close, the U.S. was home to a total of 151,000 solar installations that provided 2.0 gigawatts of generation capacity. Thanks to a 2008 extension of the federal Investment Tax Credit, and a 2009 stimulus-package-driven program to enable the conversion of the tax credit to a cash grant (much needed in the wake of the ongoing financial crisis), the U.S. installed 852 megawatts (MW_{dc}) of solar photovoltaics (PV) that year alone. Solar costs were falling precipitously; utility-scale solar installations were constructed that year for an average of $3.58/watt ($W_{dc}$), down from 63% from a decade prior. At the time, all of these numbers seemed impressive.

My, how times have changed. This year, we forecast that the U.S. will install 7.7 GW of solar PV, more than nine times the 2010 total. By the end of this year, the U.S. will have 26 GW of solar PV operating. Total capacity has increased by an order of magnitude in just five years.

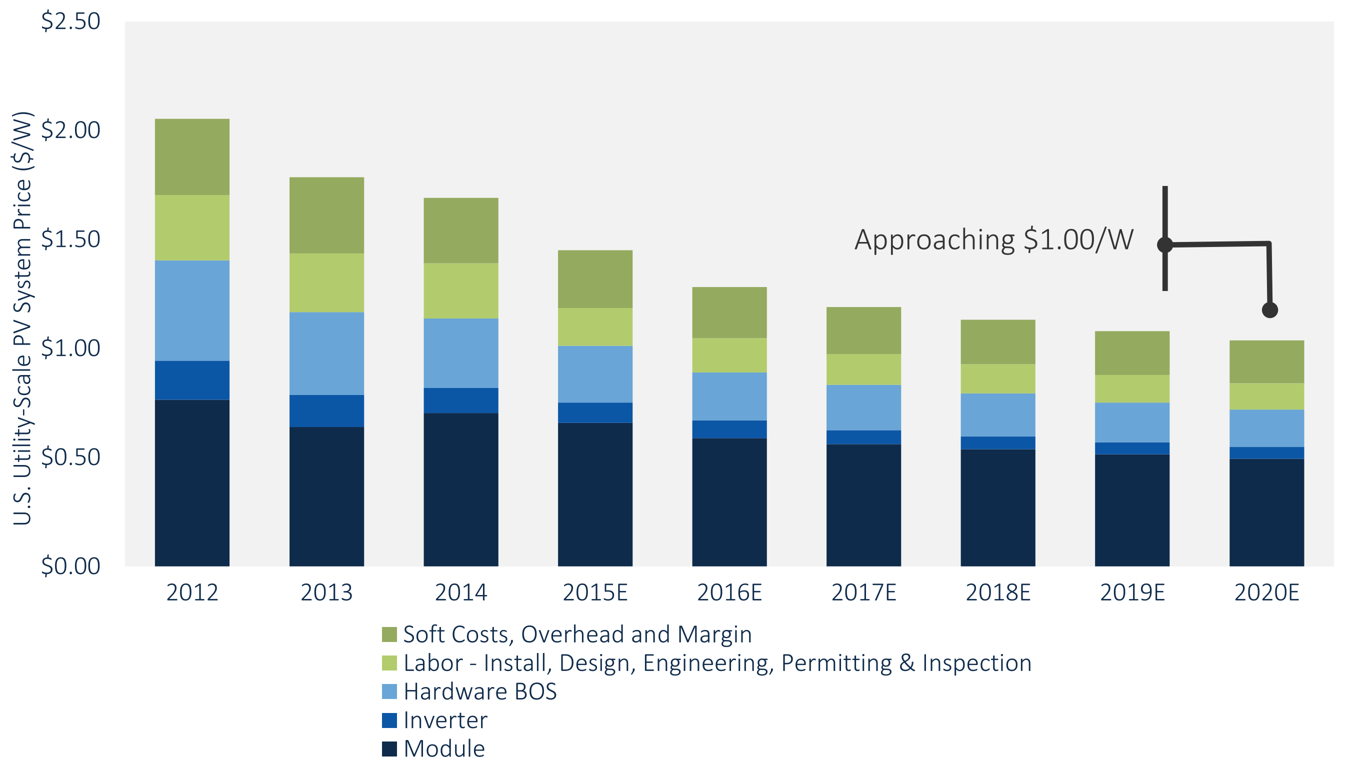
Figure 2.1 Cumulative Solar Capacity, 2010 vs. 2015



Source: GTM Research/SEIA *U.S. Solar Market Insight* report

Meanwhile, costs have continued to plummet. Today, the average cost to install a utility-scale fixed-tilt solar project in the U.S. is around $1.45/W all-in (including developer margins). We have even heard quotes for best-in-class projects in the Southeast U.S. planned for completion in 2016 at nearly $1.00/W. And average costs shouldn't be far behind; we forecast that fully loaded average prices will hit $1.04/W by the end of the decade.

Figure 2.2 Average Utility-Scale Fixed-Tilt PV System Price Forecast Through 2020



Source: GTM Research

Over the next few months, the U.S. solar market will reach two symbolic milestones. First, early next year, the millionth solar installation will begin operation. Second, around the end of this year, solar will begin generating over 1% of all electricity in the country.

These milestones can be viewed through two different and equally appropriate lenses. On one hand, solar's transformation from a tiny blip on the radar of the expansive electricity sector to a $15B+ annual industry with an ever-growing coalition of supporters is remarkable. The market has proven resilient in the face of incentive reductions, import tariffs, and many other roadblocks; solar clearly is here to stay. On the other hand, for all its growth, solar remains a bit player in the electricity sector. The industry has yet to fundamentally change the generation mix, or to significantly impact U.S. greenhouse gas emissions. There remains a long way to go.

3. GETTING TO THE NEXT ORDER OF MAGNITUDE

What Will 250 GW Look Like?

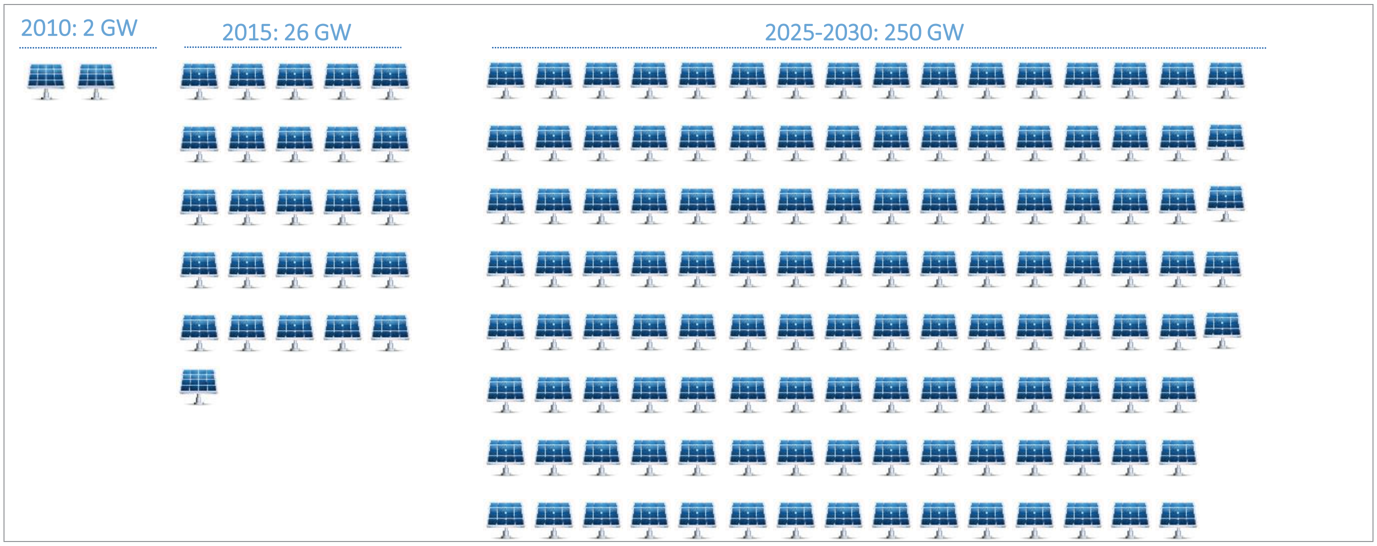
The past five years of growth have made it clear that solar is an enduring market. There was a time when one could easily make a compelling argument that solar would see period of promise, but ultimately fade away due to lack of economic competitiveness, intermittency, or technological limitations. That time has passed. While there will certainly be ups and downs as the solar market matures, the long term will include a dramatic expansion of solar generation in the U.S.

As it stands today, the solar industry in the U.S. is primarily focused on the near term, and for good reason. Every quarter brings a new spate of business models, regulatory skirmishes, financing innovations (or woes), and overarching change. The solar market moves fast, and there is little time to invest resources beyond the next few years.

But it is worth considering the next order of magnitude for solar in the U.S. What does that really mean? How long will it take to get there? And how can the industry bring it closer?

Let's use 250 GW as a rough benchmark. Assuming incremental increases in solar performance, this should equate to around 10% of all electricity generation in the U.S. And if average system sizes hold steady, this means nearly 10 million individual installations.

Figure 3.1 Cumulative Solar Capacity: The Next Order of Magnitude

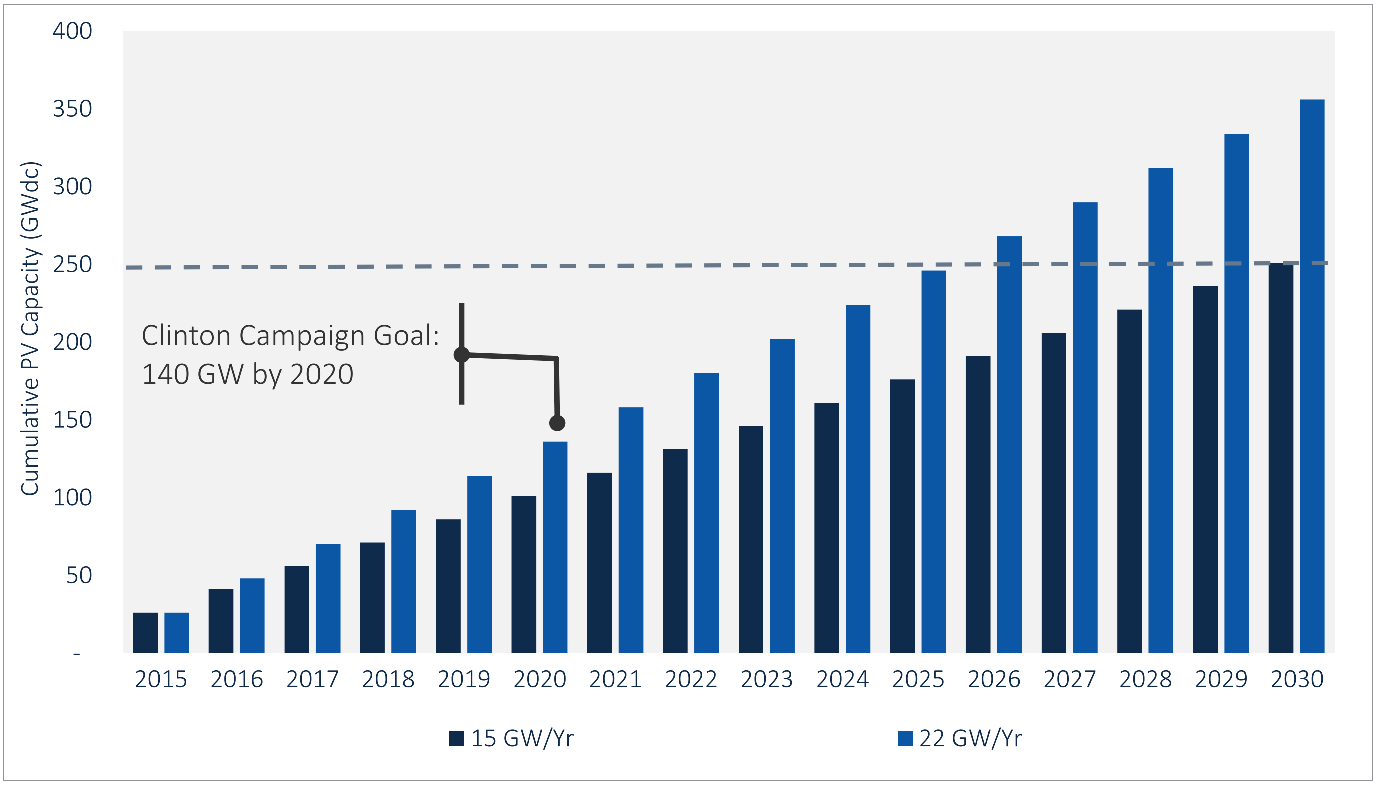


Source: GTM Research

A reasonable, if ambitious, timeframe for this achievement is 10 to 15 years. If the U.S. averages 15 GW of new solar per year from 2016-2030, the goal will be reached at the end of next decade. And if the market grows faster, averaging 22 GW per year from 2016-2025, it would hit 250 GW in the middle of the decade.

An aggressive interim target was recently set by former Secretary of State Hillary Clinton on the presidential campaign trail, when she called for 140 GW of cumulative solar capacity by 2020. This would exceed even the 22 GW/year pace.

Figure 3.2 Scenario-Based Cumulative PV Capacity Growth, 2015-2030



Source: GTM Research

4. CATALYSTS FOR GROWTH

Solar’s Tailwinds Are Strong

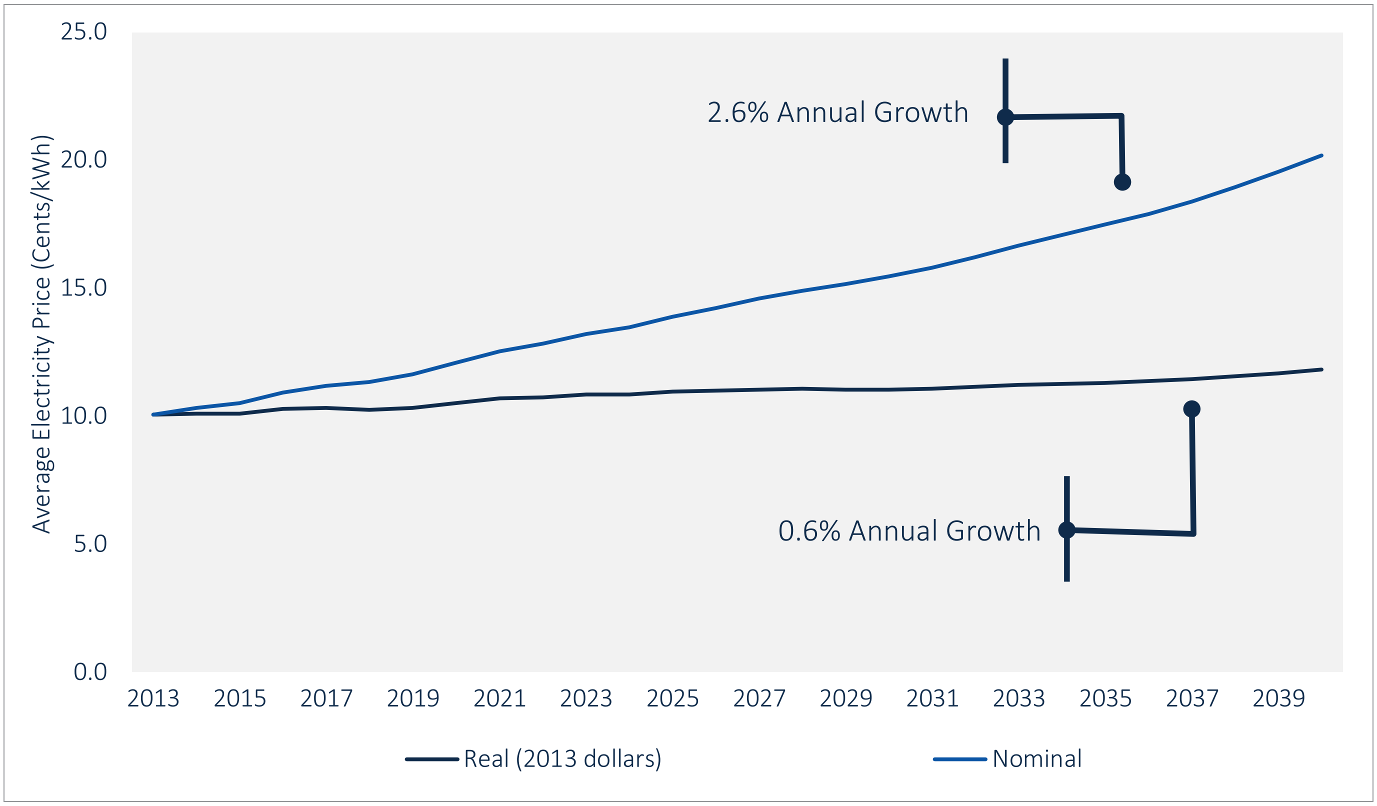
In order for solar to reach 10% of U.S. electricity generation in the next 10 to 15 years, the market must continue to surpass the expectations of most grid planners, regulators and policymakers. Fortunately for the solar industry, there are a number of ongoing drivers to support continued long-term growth.

Electricity Prices Will Probably Continue to Rise

Every time retail electricity prices increase, distributed solar becomes more attractive for two reasons. First, solar looks better to the customer in an immediate sense – solar providers can offer greater savings, shorter payback periods, and better returns. Second, solar’s value proposition as a hedge against continually rising electricity prices becomes more apparent with each electricity price hike.

So rising electricity prices will only help solar reach its next order of magnitude. And it seems likely that prices will indeed continue to climb throughout most of the country. Even in a scenario characterized by perpetually low natural-gas prices, utility investment in infrastructure, communications, equipment replacement and new services will keep propping prices up. The Energy Information Administration’s base-case forecast calls for 2.6% annual growth in electricity prices through 2040 in nominal terms, and around 0.6% annual growth in real terms. In other words, electricity prices will likely continue to outpace inflation, making solar ever more competitive in comparison.

Figure 4.1 EIA Retail Electricity Price Forecast Through 2040

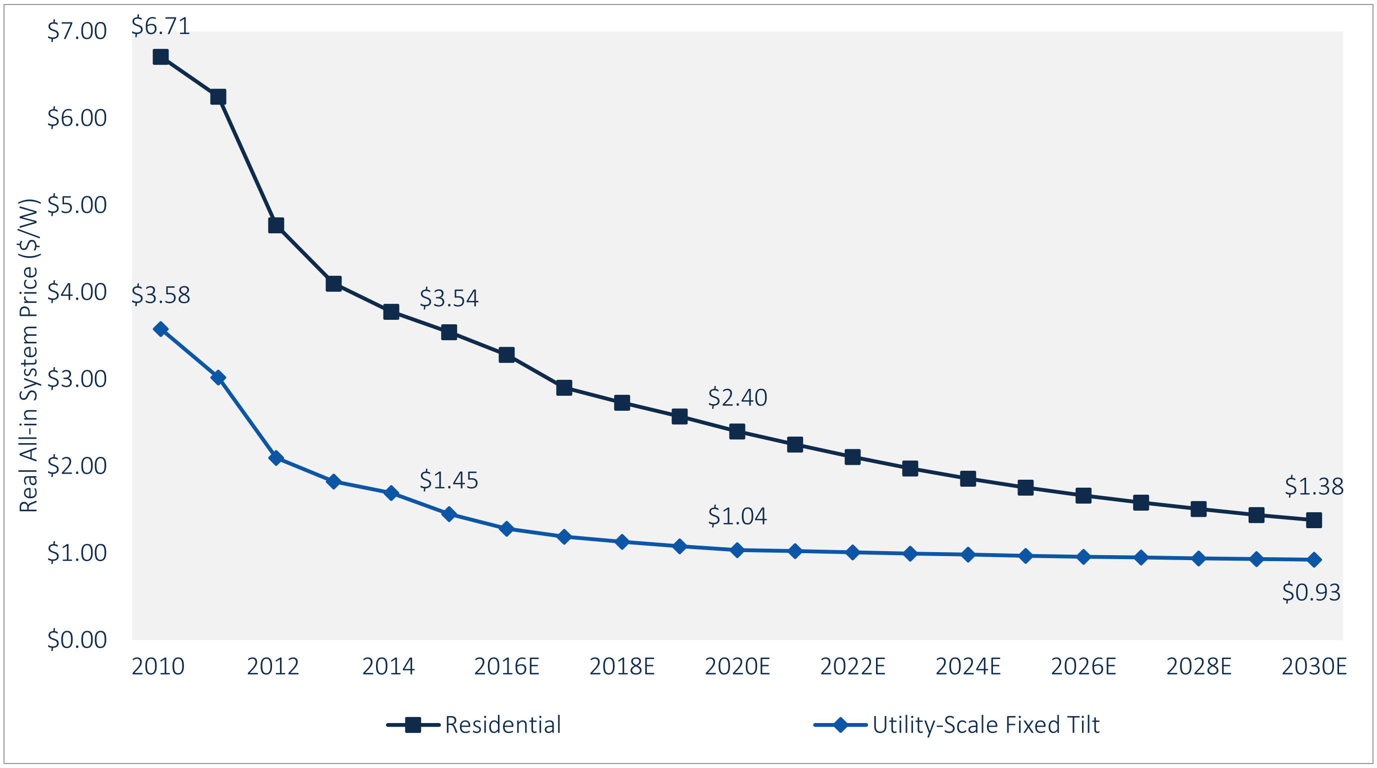


Source: EIA, GTM Research

Solar Prices Will Probably Continue to Fall

While electricity prices are likely to keep rising over the coming decades, solar prices will continue to fall. To be clear, it would be unrealistic to expect the cost of solar to decline over the next decade at the same rate it has over the past decade. But there is still plenty of headroom in system prices – hardware can still be optimized and made more efficient, while a variety of "soft cost" reductions remain unrealized. This is particularly true of distributed solar, where costs in the U.S. remain high relative to more mature markets such as Germany. Using a highly conservative methodology based on known cost reductions and learning rates from similar markets, we forecast a 61% reduction in average residential solar costs between now and 2030, and a 36% cost decline for utility-scale solar.

Figure 4.2 Solar PV System Price Forecast Through 2030



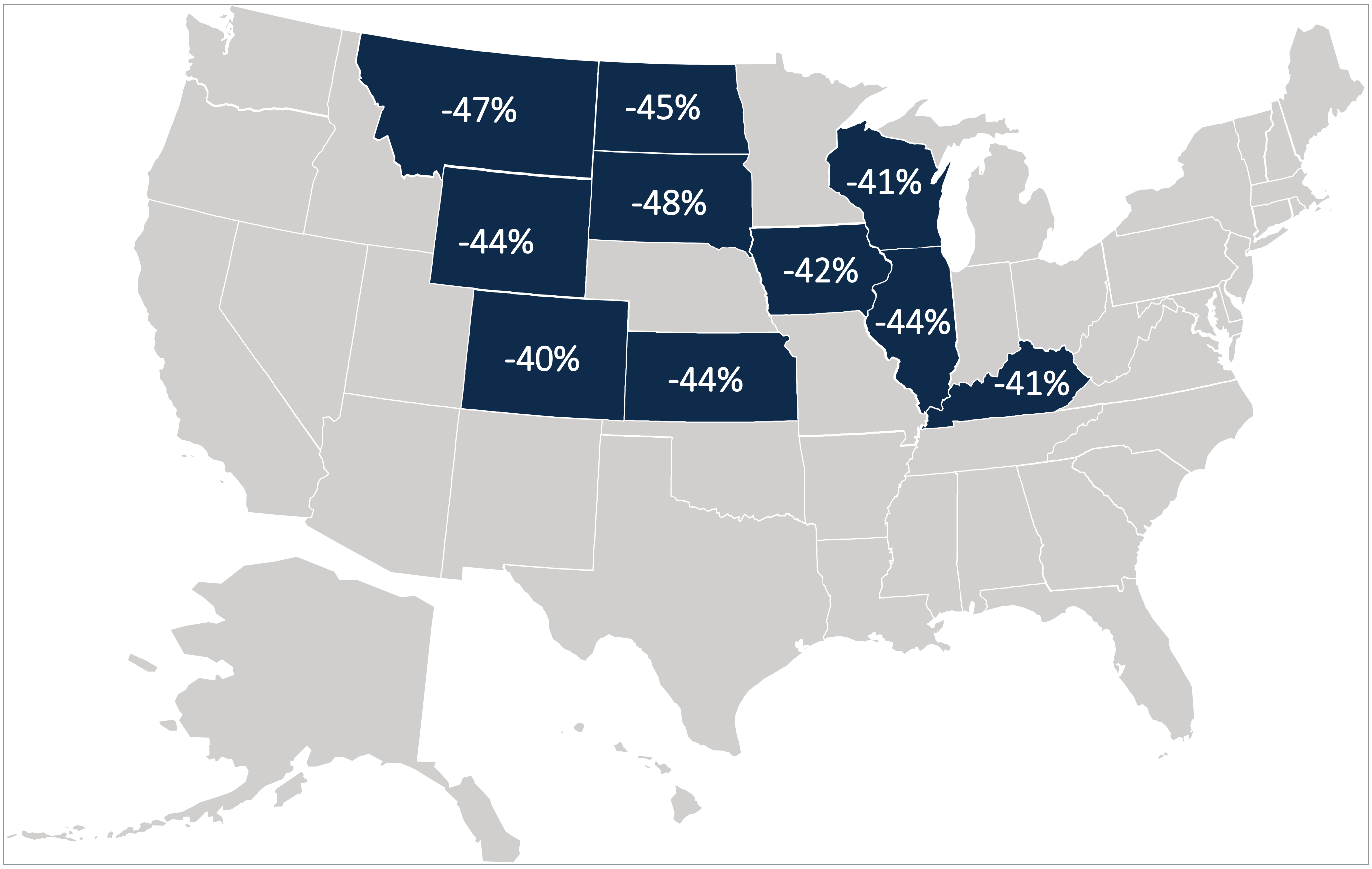
Source: GTM Research

The Clean Power Plan Could Open Up New Markets

The Clean Power Plan is a bit of a mixed bag for solar. The first compliance date for the CPP is 2022, but the rule issued by the EPA includes a Clean Energy Incentive Program intended to support renewable energy installations in 2020 and 2021. One unintended consequence of this program, if it is left unchanged, is that states may design their policies to support solar/wind installations in those years, even at the expense of earlier years (2017-2019), since those earlier installations won't receive the same credit. So counterintuitively, the CPP may dampen solar growth through 2019.

But in the long term, the CPP provides enormous potential to support the expansion of solar in the U.S. While the ultimate impact won't become clear until states begin crafting and submitting their compliance plans, one interesting dynamic to monitor is the relationship between the states with the largest greenhouse-gas reduction targets and today's state solar markets. The 10 states with the largest GHG reduction requirements by 2030 under the CPP account for a cumulative total of just 1.4% of operating solar in the U.S. In other words, these states (with the exception of Colorado) have virtually no solar market today, and solar may be an attractive component of their aggressive GHG-reduction compliance requirements.

Figure 4.3 States With the Largest GHG Reduction Targets Under the Clean Power Plan



Source: GTM Research, E&E Publishing

This will be important because the U.S. solar market cannot remain as geographically concentrated as it is today if it is to reach 10% of national generation. This year, five states – Arizona, California, Massachusetts, Nevada and North Carolina – will account for 68% of all solar capacity placed in operation. And while a number of new state markets are already gaining steam, diversification is still in its early stages. The Clean Power Plan will provide many benefits for solar, but this is certainly a key one.

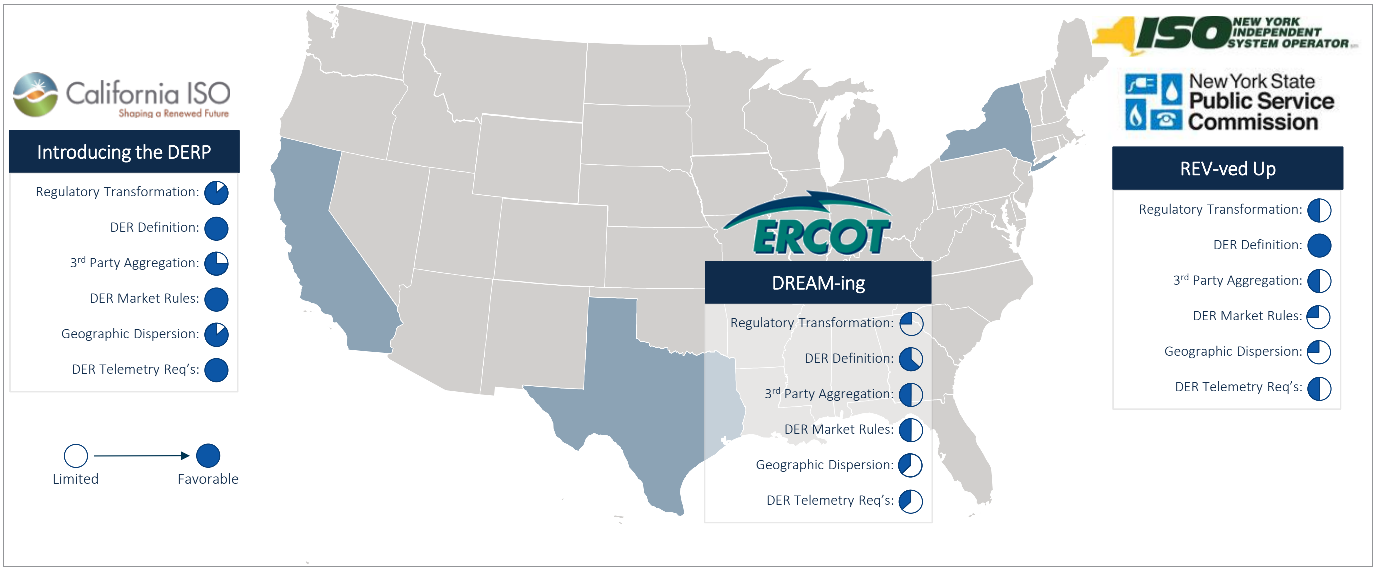
Market Reinvention May Open Up New Revenue Streams

A final tailwind for solar could come in the form of new sources of revenue, particularly for behind-the-meter (distributed) projects. Today, these projects essentially receive a single value stream – the reduction of a customer's bill via a combination of self-consumption of solar power and net energy metering for power fed back into the grid. But solar ultimately has greater value – specifically, its value to the grid. Especially when paired with energy storage, load control and other distributed energy resources (DERs), solar can be a crucial component of tomorrow's grid-responsive buildings.

This may sound overly futuristic and speculative, but it is already beginning to happen today. The technology for DER aggregation is quickly arriving, as are associated business models. And most importantly, the ground rules are being set by regulators and grid operators. At the independent system operator (ISO) level, there are at least three ongoing agendas that could open up markets for DER aggregation. In California, the ISO has approved a proposal for distributed resources (under the name Distributed Energy Resource Providers, or DERPs) to bid into ISO markets under certain conditions. In Texas, ERCOT introduced its Distributed Resource Energy and Ancillaries Market (DREAM) taskforce to examine and craft rules for participation. And in New York, the Reforming the Energy Vision (REV) initiative seeks to open a host of grid-service value streams to distributed resources under the guidance of the state ISO and the newly formed Distribution System Platform (DSP) providers.

This market reinvention clearly comes with no shortage of acronyms.

Figure 4.4 Near-Term Opportunities for DER Participation in ISO Markets



Source: GTM Research's *DER Participation in Wholesale Markets* report

This additional revenue could be used to open up otherwise-unattractive markets, or it could be passed on to the customer as savings. Regardless, DER aggregation for grid services may present the most significant new opportunity for distributed solar in years.

5. RISK FACTORS

The Headwinds Are Blowing

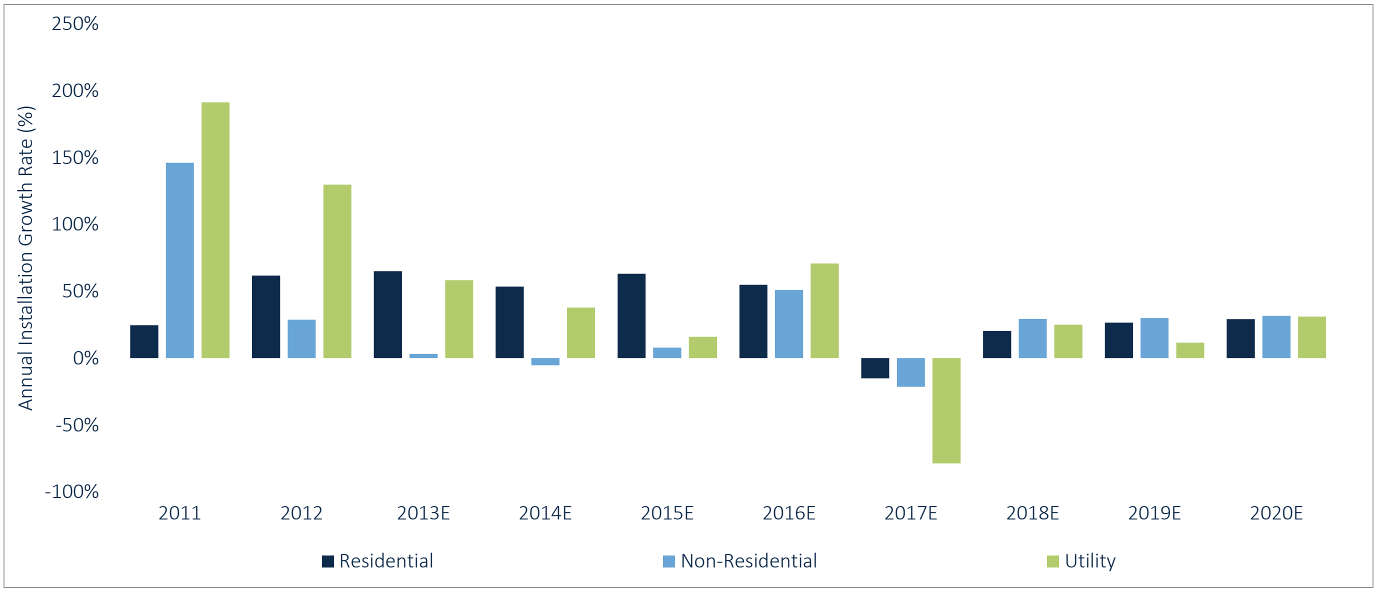
This vision of dramatic solar growth throughout the country for the next 15 years is no foregone conclusion. While the solar market does have momentum and the factors mentioned above on its side, there are a number of significant roadblocks that could threaten to derail its growth.

ITC Expiration Could Result in the First Down Year for Solar in Recent History

The most immediate risk to solar market growth is the impending expiration of the federal Investment Tax Credit (ITC), which is scheduled to step down from 30% to 10% (0% for direct-owned residential systems) on January 1, 2017. Today, project developers, installers and contractors are beginning a mad dash to complete as many projects as possible before the expiration hits. This will create a demand pull-in effect in 2016, and we will almost certainly see the largest solar market in history next year in every sector and most states.

If the ITC is not extended, the truth is that no one knows for certain how the expiration will impact the market. It is simply unprecedented; while the wind industry has a number of PTC expiration-driven cycles to look back on, solar has benefited from a consistent federal policy since 2008. Our granular examination of project economics at the state and segment level does, however, suggest one likely outcome: the ITC expiration will lead to the first year-over-year downturn in the U.S. solar market in more than 15 years.

Figure 5.1 Annual U.S. Solar Growth by Sector, 2011-2020E



Source: GTM Research

This will make it more difficult to reach the market-size targets discussed here (and render it nearly impossible to achieve Hillary Clinton's 2020 goal). But it may also have wider-reaching impact of slowing down investment in the sector, the full impact of which might not be made manifest for years afterward.

In the long term, ITC expiration certainly will not bring about the end of solar growth in the U.S. But the timing of expiration (2017), combined with the Clean Power Plan waiting game (2018-2019), could push the industry's goals further into the distance.

Rate and Net Energy Metering Reform Could Still Erode Distributed Solar Economics

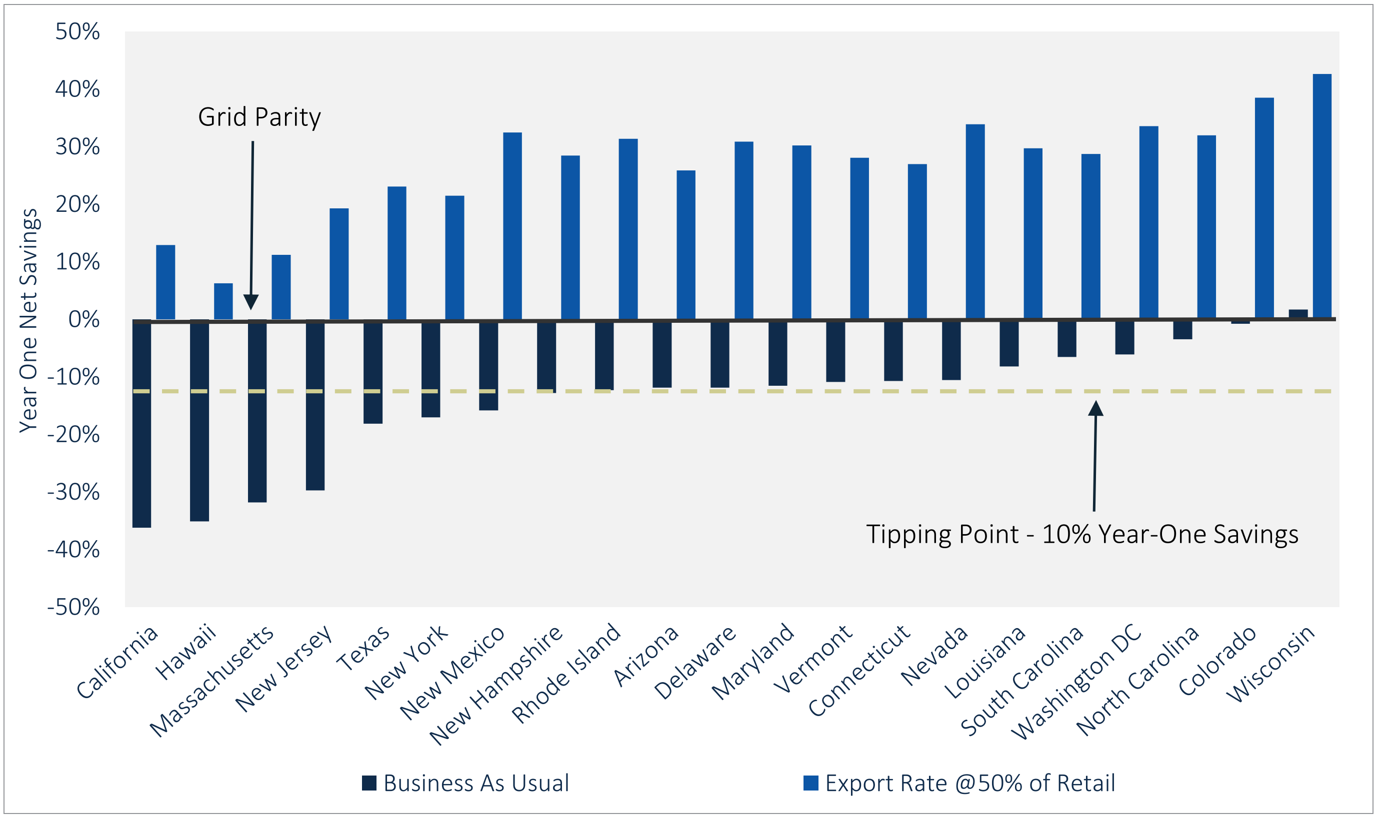
Virtually all customer-sited solar operating in the U.S. has been built (and financed) under the paradigm of full net energy metering (NEM), wherein customers offset the full value of their electricity exported to the grid by their solar system. Over the past few years, NEM has been at the center of regulatory disputes across more than 20 states. Utilities often argue that NEM customers do not pay their fair share of grid costs, resulting in a cost shift to non-solar ratepayers. Solar advocates counter that distributed solar has value to the grid for which utilities aren't fully accounting, such as capacity value, transmission and distribution (T&D) deferral, and T&D line-loss savings.

Thus far, NEM has survived most of these debates intact. But as solar penetration grows across more states, this may not always remain true. Just last month, Hawaii (which many call a "postcard from the future" when it comes to solar penetration issues) instituted new interim rules for customer-sited solar in which exported generation will be credited at roughly half the retail electricity rate. California's three investor-owned utilities all proposed something similar for the next iteration of NEM in that state (the rules of which will be determined in the next two months).

This has a significant impact on the economics of residential solar, in particular. Using the GTM Research PV Economic Model, which incorporates real hourly load profiles, rate structures, state incentives and region-specific solar costs, we modeled the economics of residential solar today in all 50 states. We found 20 states currently at "grid parity" given all available incentives, where customers can be offered savings from day one on new residential installations. And 14 states have exceeded the tipping point of 10% year-one savings.

But if every state were to change its NEM rules in a similar fashion to Hawaii, where exported generation is credited at 50% of the retail rate, only Hawaii would remain near grid parity, and every other state would immediately become unattractive for residential solar.

Figure 5.2 Residential Solar Economics, Full Retail NEM vs. 50% Export Rate, Top 20 States



Source: GTM Research *Residential Solar Grid Parity Monitor*. Contact GTM Research for more information on methodology and assumptions, or for additional sensitivities including the impact of fixed and demand charges.

Just as important as NEM to the economics of residential solar is the structure of electricity rates. The majority of residential rates today are highly volumetric, with small fixed monthly charges and no peak demand charges. This lies in contrast to commercial rates, which often have a demand component. And while solar can have an impact on customer peak demand, it is often minimal and can't be guaranteed. So, solar economics are most attractive with today's residential rates. But as with NEM, rate structures are beginning to shift. According to EQ Research, 20 utilities have received approval for residential fixed-charge increases since July 1, 2014, with increases as large as 38% (Kentucky Power) and new charges as high as $24/month (Central Hudson Gas & Electric). Moreover, utilities are beginning to seek the addition of demand charges to residential bills, an idea for which Arizona's Salt River Project received approval earlier this year.

Not all rate-structure revisions are negative for solar, however. Time-of-use rates, for example, generally improve distributed solar economics in the near term. And locational pricing can help solar installers target their customers in locations that best serve the needs of the grid. But drastic revisions to today's largely solar-friendly rate structures can serve to erode project economics and thus impede solar growth.

As Solar Penetration Grows, Its Value to the Grid Shrinks[1]

As solar grows as a share of the total generation mix, its value to the electricity system (and thus the revenue it can generate) begins to decrease. Solar is a zero-marginal-cost resource, which means it will bid into wholesale power markets at zero dollars and take any price it can receive. Add an increasing amount of solar to that market and prices decline overall, leading to lower revenue for each solar project. Since solar is non-dispatchable, project operators cannot strategically sell into the market at times of higher pricing – solar is purely a price-taker (unless paired with energy storage, as discussed below). In fact, the more solar is placed on the grid, the less the grid needs power when solar production is highest – causing solar's value to decline as its penetration increases.

In the short term, this has little impact on solar's competitiveness for two reasons. First, solar penetration in most locations is low enough that it has virtually no impact on wholesale electricity prices. Second, most solar projects are insulated from wholesale market prices because they have long-term, fixed-price power-purchase agreements (utility-scale solar) or compete via net energy metering with retail electricity prices (distributed solar).

However, in the long run, as solar becomes a mainstream power source, regulators and utilities are more likely to align solar compensation more closely with wholesale market pricing. Just as importantly, solar on its own will deliver less value to the grid as its penetration increases by providing power during times of over-generation rather than times of particularly acute demand. As solar adoption takes off, if compensation tracks solar's value, then solar owners will experience declining revenues.

Researchers first identified the value deflation effect in the 1990s, and it has continued to inform planning studies for increased renewable penetration (for example, in those conducted by the National Renewable Energy Laboratory). But over the last two years, a number of high profile studies using wholesale price predictions as proxies for the future value of solar have quantified a similar effect with increasing precision in disparate geographical contexts. One relevant example comes from Lawrence Berkeley National Laboratory, which modelled a proxy for the California grid and estimated solar value to be 38% lower when solar is at 10% penetration than at zero penetration.

---

[1] Credit for this section should be shared with Varun Sivaram, Douglas Dillon fellow at the Council on Foreign Relations, with whom I have been collaborating to study the value deflation effect and its impact on solar cost targets.

Figure 5.3 Marginal Value of Solar: California

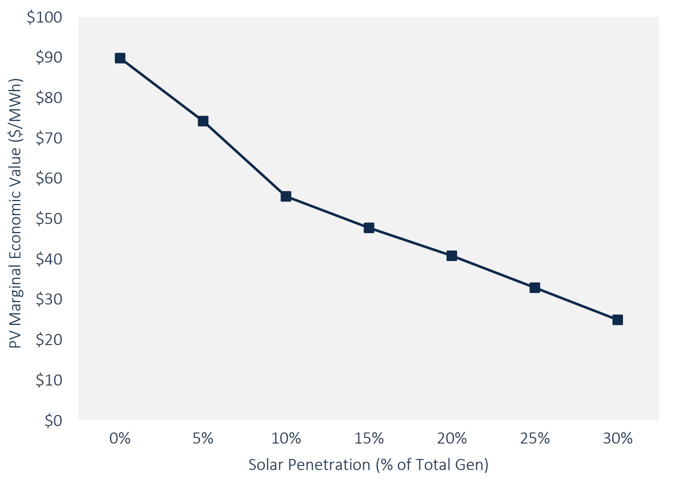
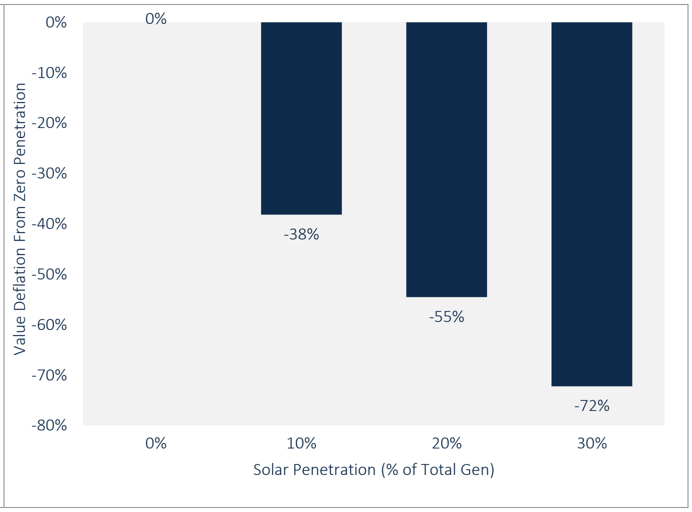


Figure 5.4 Value Deflation Effect: California



Source: Mills and Wiser, LBNL 2014

California's high electricity prices may make solar attractive even if it becomes subject to this effect – at least for the next decade or so – but imagine the value-deflation impact in states that begin with lower wholesale costs. Can solar compete in 15 years if it is compensated at $30/MWh or less?

The fundamental insight that the value of solar declines as its penetration on the grid increases holds true for distributed solar, as well as large-scale solar. This effect can be masked by the rate structure – for example, net energy metering that compensates distributed solar at a constant retail electricity rate will not reflect solar's value deflation. But one study of residential systems in California found that under a rate structure that compensates customers who own distributed solar for power exports to the grid at time-varying wholesale prices, customers lose 35 percent of their bill savings from solar at 15 percent solar penetration on the grid, compared with zero solar penetration and net energy metering.

Put another way, grid parity for solar is a moving target. As solar penetration increases, the value new projects can extract from the grid may fall, which will put further downward pressure on the cost of solar in order to remain competitive. As was discussed previously, we do expect solar costs to continue falling through 2030, but at a far more moderate rate than we have seen over the past decade (for example, our forecast calls for just 11% reduction in utility-scale system costs from 2020-2030). Will it be enough, or will economic competitiveness escape solar's grasp as the market grows?

6. ENSURING THE SOLAR FUTURE

The Solar Industry's Work Today Is Laying the Groundwork for the Next Decade or More

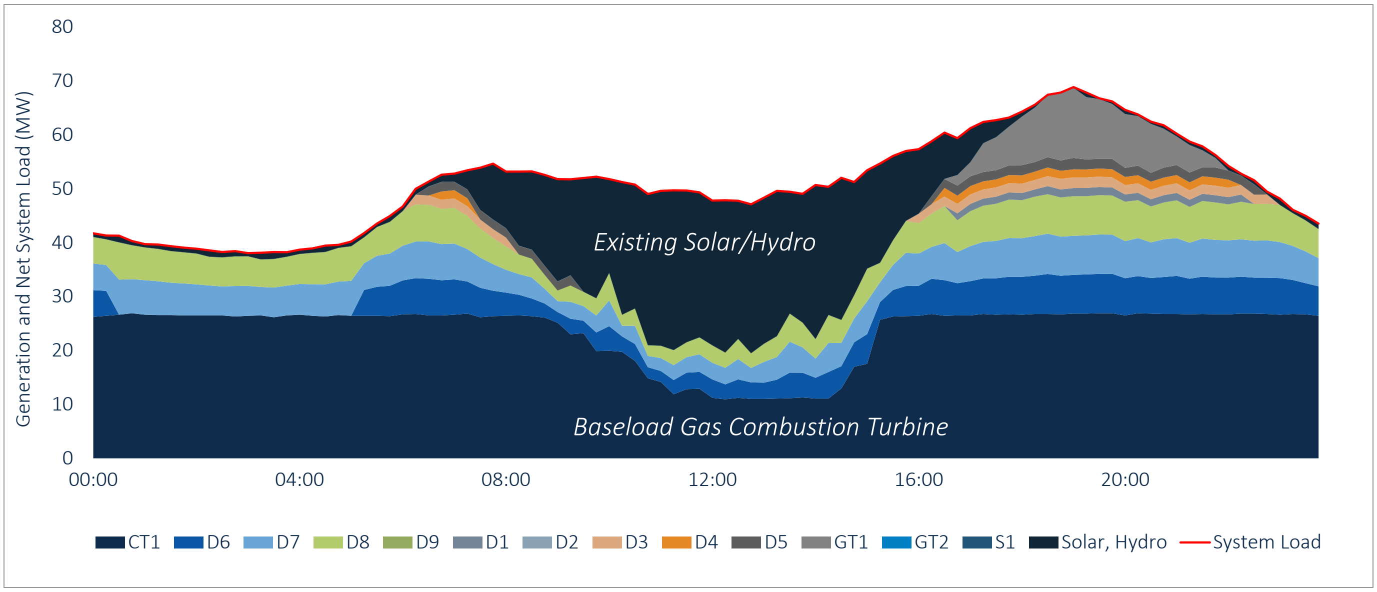
The factors mentioned above, both positive and negative, likely will not come as news to much of the solar industry. But many of these issues likely seem to be distant concerns, best dealt with after the next quarter, the next year, or the next business cycle. And while many solar-focused organizations do have a view toward the longer-term future, they would do best to focus their efforts around activities that can accelerate the tailwinds while combating the barriers.

Energy Storage Can Make Solar a Better Long-Term Citizen of the Grid

Energy storage has enormous promise on its own, but it can also serve the needs of a growing solar market. First, energy storage can help distributed solar owners navigate changing rate structures by maximizing self-consumption (and decreasing potentially lower-value grid exports), optimizing consumption vs. time-of-use rates, and mitigating demand charges. Second, at the system level, energy storage may be the factor that eases solar's value deflation effect before it truly takes hold.

Take the Hawaiian island of Kauai as an example, and the grid managed by Kauai Island Utility Cooperative (KIUC). Kauai already has a significant amount of solar generation, and on a representative day (in the example below, October 14, 2015), that solar covers the a large portion system load in the middle of the day, displacing expensive diesel generators as well as the primary baseload gas combustion turbine power plant.

Figure 6.1 KIUC Load and Generation Today

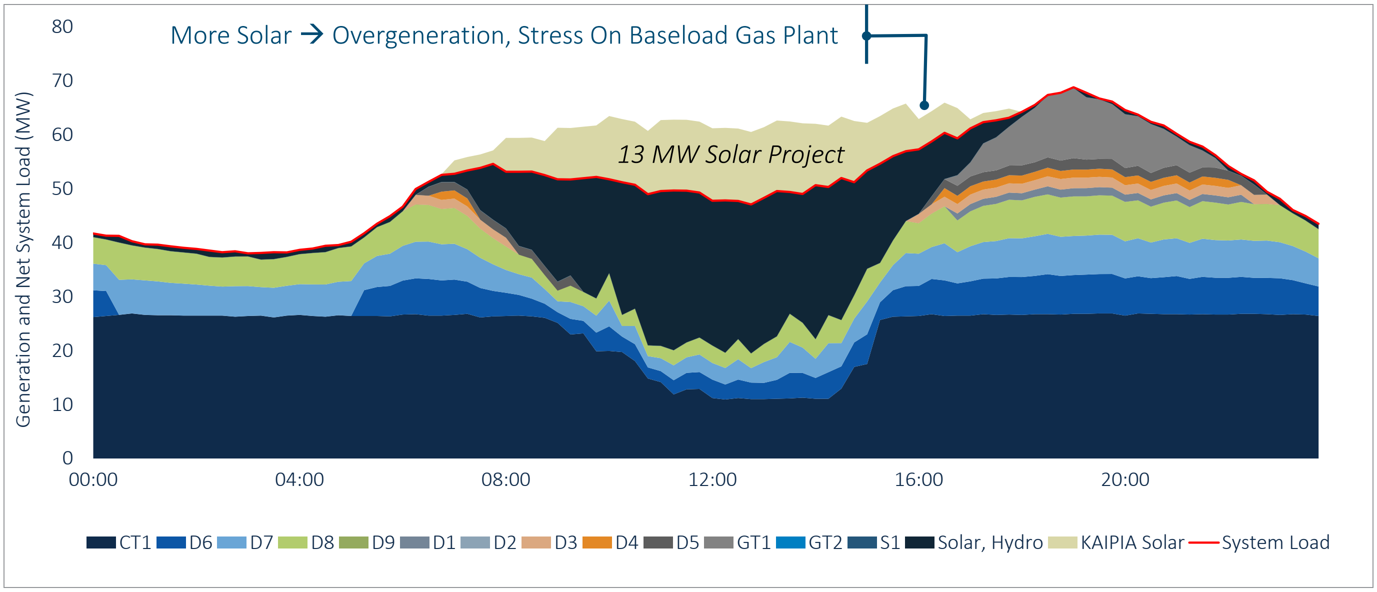


Source: KIUC, GTM Researc. Based on October 14, 2015 load/generation; CT=combustion turbine, D=diesel, GT=gas turbine, S=solar. Note: System load is net of distributed solar production (~21 MW of capacity currently in KIUC)

In September 2015, KIUC signed a contract with SolarCity for what it called the first "dispatchable solar storage system" in the country, consisting of a 13 MW_{ac} solar PV project tied to a 13 MW/52 MWh lithium-ion energy storage system. Why include the energy storage, which comes at a significant cost premium?

Imagine if KIUC had added the solar project alone (Figure 5.2). The resulting solar generation would have mirrored the already-operating projects, further depressing utilization of the baseload gas plant (and stressing its operation) without significantly improving the evening peak period when diesel and dirtier peaking gas generation play the biggest role. This new solar generation would have had low value, both economically and from a greenhouse gas reduction standpoint.

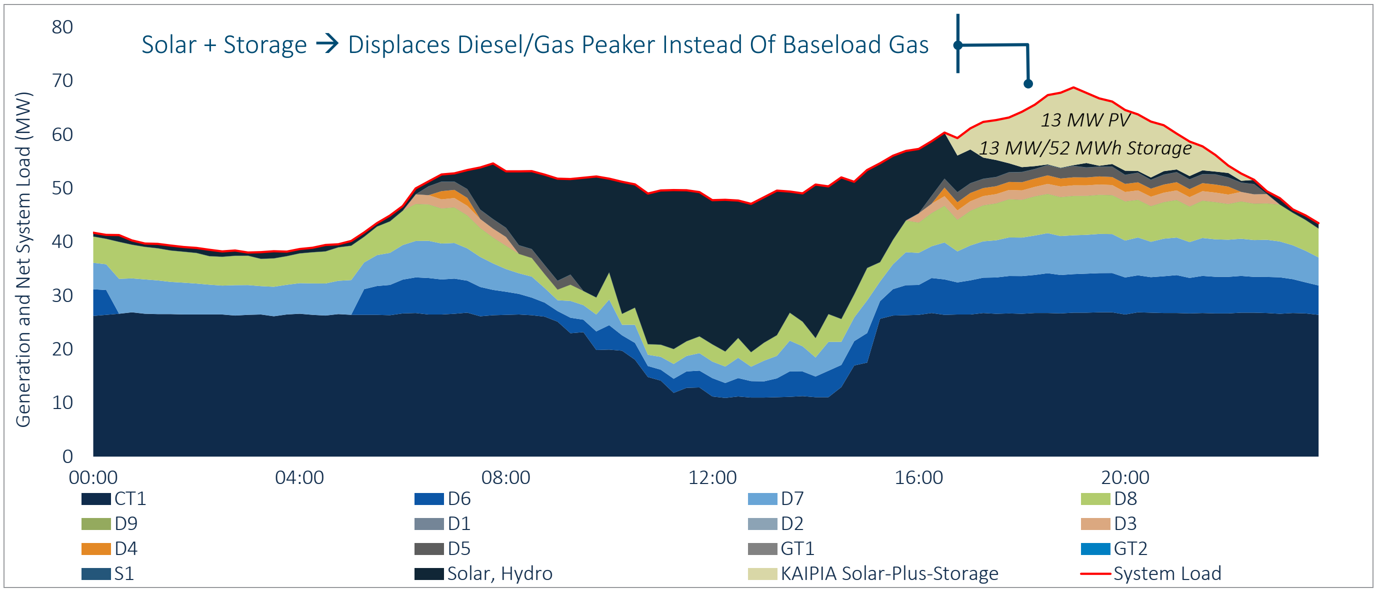
Figure 6.2 KIUC Load and Generation With New 13 MW Solar Project Alone



Source: KIUC, GTM Research, NREL PVWatts/SAM. Based on October 14, 2015 load/generation; CT=combustion turbine, D=diesel, GT=gas turbine, S=solar. Note: System load is net of distributed solar production (~21 MW of capacity currently in KIUC)

Instead, KIUC contracted for a solar-plus-storage combination. The batteries will be used to shift the PV generation into the 5 p.m. to 10 p.m. evening peak, displacing expensive peaking plants, providing more value during peak hours, and minimizing stress on the existing baseload plant.

Figure 6.3 KIUC Load and Generation With New 13 MW Solar, 13 MW/52 MWh Energy Storage Project



Source: KIUC, GTM Research, NREL PVWatts/SAM. Based on October 14, 2015 load/generation; CT=combustion turbine, D=diesel, GT=gas turbine, S=solar.
Note: System load is net of distributed solar production (~21 MW of capacity currently in KIUC)

Hawaii is, both literally and figuratively, an island unto itself, and the mainland U.S. is far from experiencing the stresses already facing the Hawaii grid. But as solar penetration grows, energy storage will increasingly become a vital resource to augment solar's value.

Energy storage is not the only resource that can help mitigate value deflation and manage evolving rates. While energy storage serves its purpose on the supply side of the equation, load control can provide additional support on the demand side. As more devices in the building become controllable, smart and networked, customers and services providers will gain the ability to shift load away from traditional peak periods and further toward periods of higher solar production. The Rocky Mountain Institute calls this "demand flexibility" or "flexiwatts" and has estimated that residential flexibility alone can reduce grid costs by $13 billion per year.

Solar Can Play a Vital Role in New Grid Edge Market Structures

The term "prosumer" has come into vogue over the past two years to describe tomorrow's electricity ratepayer, who both produces and consumes electricity. But that term may not be enough to describe the role that customers will play in the future of the grid. Regulatory overhauls such as that being proposed in New York under the Reforming the Energy Vision (REV) initiative have grander ambitions. In the ideal REV future, customer premises become grid-responsive assets, participating in a variety of new markets that reflect the true and full value of the customer's costs and her services to the system.

This customer of the future has all the trappings of the smart home – various controllable devices connected to high-energy-usage appliances, all operating in concert through a simple interface. But in order to maximize value, the customer needs some form of generation, and solar is often the best bet.

For the solar industry today, initiatives such as REV in New York or utility Distribution Resources Plans in California present small windows into the future of customer-sited solar. That future is hard to predict, but it almost certainly presents an array of new opportunities to extract value for customers and the grid from on-site solar.

The solar industry would do best to engage deeply with these proceedings, as well as seeking opportunities to expand beyond the few states that are ahead of the curve. Where will the next REV emerge, and what new prospects will it create for solar?

Solar Costs Could Fall Even Further

The final weapon that the solar industry has against an uncertain future is by far the most important, but also the most intractable: cost. Our long-term system cost forecasts are conservative, and it is possible that solar technology providers, developers and EPCs will find ways to wring more pennies out of each watt than we've projected.

In order to give itself the best shot of exceeding our cost reduction expectations, solar decision-makers, and policymakers, should expand their ambitions. Continued focus on near-term, incremental cost reduction opportunities is necessary, but should not come at the expense of basic research, development and commercialization efforts. While it may sometimes seem like today's solar technologies have already won the battle, step-function cost reductions may come only from a fundamental rethinking of solar technology and deployment. Some examples of areas worthy of consideration:

- **New Module Technologies:** Today, crystalline silicon (c-Si) solar modules represent 91% of all global production. The technology has clearly won the short-term battle. But there is a variety of other solar materials, such as perovskite solar cells, that have yet to be fully tested and commercialized but hold the potential for lower-cost, higher-efficiency production.[2]
- **New System Technologies:** Tomorrow's solar systems may be fully-integrated and plug-and-play. Harnessing innovations from power electronics and structural materials, modular and plug-and-play PV can be composed of fewer discrete components that require specialized labor to install. These systems will be able to efficiently and intelligently connect with the home or building's network and energy management controls, providing further value for the same costs.

[2] See the great writing from Varun Sivaram on the promise of perovskites

- **Customer Acquisition Strategies:** Though much attention has been paid to solar customer acquisition strategies over the past few years, these costs remain stubbornly high. Residential solar customer acquisition costs currently average $0.44/W and are staying steady, whereas acquisition costs for competitive retail electricity providers are around $150 – the equivalent of $0.02/W-$0.03/W for solar. Opportunities abound for better ways to identify, target and acquire solar customers.
- **New Form Factors:** Ideas such as building-integrated photovoltaics (BIPV) were popular a few years ago when thin-film solar (which can be lightweight and flexible) appeared ready to unseat crystalline silicon as the leading module technology. But as c-Si gained steam, BIPV has largely fallen by the wayside. But the technology still holds promise, particularly in its potential to lower the soft costs associated with design, engineering and installation.
- **New Deployment Models:** In the next decade, solar could become standard in new construction or even during roof replacement, reducing the soft cost burden on systems while accelerating deployment. Mechanisms such as community solar and crowdfunding could enable all citizens (regardless of homeownership, credit rating, and roof shading) to invest in solar projects and reap the benefits while driving down the cost of financing systems. And new models that are yet to be discovered could emerge to further depress system costs.

Programs such as the DOE SunShot initiative provide a promising bridge to examine the near-term opportunities in new technologies and deployment strategies. And the ARPA-E program offers support for earlier-stage technology with long-term promise. But the industry itself should also reserve both funding and resources to examine these possibilities.

7. CONCLUSION

Why the Future Is Bright, or Solar's Coming Dawn, or the Market's Day in the Sun

Traditional energy forecasters have always struggled to catch up with the solar market's growth. And while many of them have now awoken to the possibility that solar may account for a meaningful portion of the electricity market in the coming decades, few have truly considered the shape of the path between here and there. It will be bumpy; solar remains an incentive- and regulatory-driven technology, and its near-universal public appeal will not always translate to perfect policy. But I find it very difficult to conjure a realistic scenario that doesn't include solar achieving the next order of magnitude by 2030, if not earlier.

In the meantime, there is no shortage of work to be done by the solar industry, electricity regulators, utilities, and policymakers to ensure that the transformation at the edge of the grid produces a more affordable, efficient, resilient, and clean energy future.

THE FUTURE OF U.S. SOLAR

Getting to the Next Order of Magnitude

Shayle Kann, Senior Vice President, GTM Research