US Solar Power Growth through 2040

Exponential or inconsequential?

Deloitte Center *for* Energy Solutions

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Contents

Executive summary

This paper provides perspectives on the long-term growth trajectory for solar power in the US. Our goal in writing it is to provide managements of solar and electric companies, as well as companies in related industries and their stakeholders, with insights to inform their strategies related to solar power in the US. In the context of the evolving US electric power industry and ecosystem, this paper provides a perspective on one of several exponential technologies that are transforming the industry.

Key takeaways:

1. Projections for long-term US solar power growth vary widely, and while most foresee growth moderating from recent exponential rates, the potential for continued exponential growth is worth consideration, as it has happened with other technologies. Solar power growth may continue to outpace most conventional projections.

2. Many factors may constrain or enable solar growth, such as the cost of solar and enabling technologies; the rate of technological advances; the evolution of policies such as fiscal incentives and carbon reduction programs; utility rate reform; and evolving financial structures, business models, and customer sentiment.

3. Regardless of the rate of solar growth in coming decades, solar power and other exponential technologies are already penetrating the traditional electric value chain and driving change throughout that value chain. How it plays out is uncertain, but what is certain is that now is the time for electric utilities and other electric value chain participants to embrace these technologies and the operating models and business ecosystems they imply.

This paper is informed by interviews and discussions with a number of experts from across the solar power industry, government research labs, solar industry associations, academic faculty devoted to energy research, and other stakeholders. A list of interviewees is provided at the end of the paper.

Introduction

Projecting the path of a rapidly growing technology like solar power more than a few years forward is dicey at best; many unpredictable variables inject a large dose of uncertainty into the equation. Evolving cost structures, new business models, developing technologies, policies and customer attitudes are just a few pieces of the puzzle that may determine solar power's future. So it's not surprising that forecasts for US solar power penetration by 2040 do, indeed, range from almost inconsequential levels to an exponential progression in which solar accounts for nearly all US power generation by 2030.

Energy industry analysts and executives discount the exponential scenario almost without exception, labeling it naïve and unrealistic. While a US powered almost exclusively by the sun within 15 years is highly doubtful, we'll take a look "under the hood" of the exponential scenario in addition to the others explored in this paper for the following reasons: First, solar power has already been growing exponentially in the US and globally for at least a decade, and there are some important trends underlying that growth. While such rapid growth is common for successful new technologies, and it's natural for growth to plateau and then slow, technological change in general is accelerating faster, and history tells us that sudden disruptive and largely unpredictable technology shifts do occur. We have only to look back at the adoption of the automobile, the cell phone, or electricity itself to find other examples of technologies whose growth followed an exponential progression for an extended period of time. In each of these cases, analysts in the original core industry were taken by surprise at the speed with which these innovations displaced prior technologies.

"In 2016, 75 percent of all new generation will be solar."

Jigar Shah, Co-Founder Generate Capital Inc. and Founder SunEdison

Whether solar power follows those trajectories or not, its growth has been outpacing conventional projections for some time and will likely continue to do so, especially given the recent breakneck speed of residential and commercial solar installations. For example, in 2000, the US Energy Information Administration (EIA) projected US solar generation would total about 2.6 billion kilowatt hours (kWh) in 2015.[1] Fast forward to 2014, and the country generated nearly 29 billion kWh of solar power, with EIA projecting more than 36 billion kWh in 2015, roughly 15 times the amount projected 15 years earlier.[2] Most other sources also failed to anticipate the rapid growth seen in recent years. Likewise, it's challenging to project how long this exponential growth will continue and when, or if, the US will reach a point where the majority of electric power is generated from the sun.

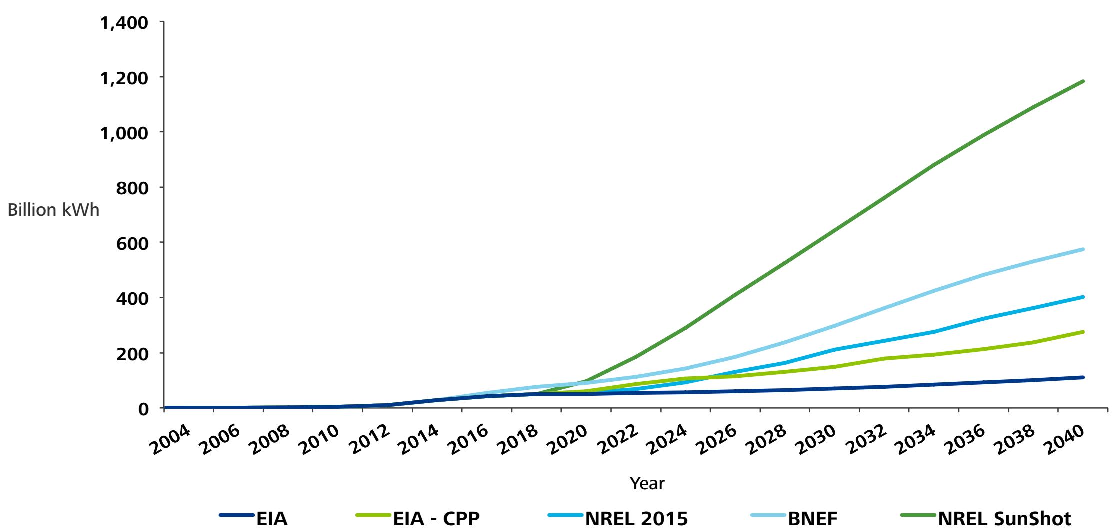
This paper will explore several projections for US solar power growth, including two scenarios from the EIA, two from the National Renewable Energy Laboratory (NREL), one from a leading renewable energy data provider, and, finally, the picture painted by those who contend that recent exponential growth rates will continue unabated. We'll examine the enablers and constraints for solar growth and the most promising technologies, innovations, and trends that could promote continued exponential growth.

Lend me your crystal ball

To explore projections for US solar power growth through 2040, we'll start with the last 10 years history and compare government and private energy data providers' projections for the next 25 years, through 2040. Then we'll add a more aggressive scenario, from those who expect continued exponential growth, in a separate graph, since it changes the scale considerably. We chose 2040 because it is consistent with the 25–30 year utility planning horizon for major capital expenditures such as power plants. We'll focus on total US solar power generation, in billion kWh.

In the solar power generation scenarios depicted in Figure 1, the EIA and others project a slower growth rate beyond 2014. For example, the compound annual growth rate (CAGR) of US solar generation in billion kWh in the last 10 years (2004–2014) was 43 percent, climbing to 59 percent in the last five years (2009–2014). The lines in Figure 1 do not appear to be advancing very rapidly before 2015 because the absolute amounts were so small, but it was actually more than doubling every two years. Between 2014 and 2040, however, the EIA projects the CAGR will slow to about 5 percent.[3] Bloomberg New Energy Finance (BNEF) pegs growth at about 12 percent from 2014–2040,[4] and NREL's SunShot scenario, the most aggressive, projects a CAGR above 15 percent.[5] The Department of Energy's (DOE) SunShot Initiative aims to make solar energy cost-competitive with other forms of electricity by 2020.[6] The pace of growth in all of these scenarios is well below the 43 percent CAGR witnessed in the last decade.

Figure 1: Total historical and projected US solar power generation, 2004–2040



Source notes:
EIA — EIA's "Reference Case" scenario from 2015 Annual Energy Outlook
EIA-CPP — EIA's "Base Policy" scenario models the impact of EPA's proposed Clean Power Plan
NREL 2015 — The "Central Scenario" from NREL's 2015 Standard Scenarios Annual Report assumes utility-scale solar PV costs fall to $1.50/Watt by 2020 and to $1/Watt by 2030
NREL SunShot — The NREL SunShot Vision Study projection from 2011 assumes utility-scale solar costs meet the SunShot Initiative's target of $1/Watt by 2020 and stay there.
BNEF — Bloomberg New Energy Finance, 2015 New Energy Outlook — Americas

Note: Historical data through 2014 is from EIA. NREL's near term data for 2015-2018 is adjusted to match the EIA Reference Case, as NREL is updating its database with new plant information. NREL projections are biannual, so data points for odd-numbered years were provided by calculating the midpoint between adjacent years.

Exploring the exponential scenario

The many factors that impact these projections will be discussed further in the next section. But first, let's engage in a thought experiment by exploring a final scenario, which is a bit more controversial, both because it is difficult to envision, and because it is largely espoused by thought leaders outside the energy industry. This scenario shows global and US solar power continuing to grow at the recent exponential pace until solar power becomes the predominant source of electricity by about 2030.

Those who imagine this scenario include inventor and futurist Ray Kurzweil; engineer, physician, and innovator Peter Diamandis; and entrepreneur, educator, and business consultant Tony Seba, among others. None of them have roots in the traditional electric power industry, which may prompt some to discount their projections. But in the past they have projected with some accuracy the rapid spread of other technologies, such as the internet and mobile phones, when others foresaw more moderate growth. In the case of solar power, the scenarios they describe sometimes lack specific details, although not in the case of Seba, who has written a book that discusses solar disruption.

These theorists point to solar's exponential growth in the last 20 years and suggest a similar pace will continue due to exponentially advancing technologies. Diamandis wrote in 2014 that seven more doublings of solar capacity are required to meet all global energy needs and this would occur in about 20 years.[7] Kurzweil suggested in 2011 that it would take eight more doublings, which would happen in 16 years (by 2027).[8] When we extrapolate the 2004–2014 US growth rate forward from 2014, it takes about 15 more years for US solar generation to equal total projected US electricity generation, as we will demonstrate below. The technological advances they suggest will underpin this scenario include continuing progress in solar panel, battery storage, and electric vehicle (EV) technologies (i.e., rising EV production would help reduce battery costs, enabling wider use of electricity storage to mitigate solar intermittency, and spurring solar growth). "The convergence of solar, batteries, and EVs will democratize energy production and offer billions of people access to cheap, carbon-neutral energy," Diamandis writes.[9] They also mention satellite-earth imaging, nano-technology, and digital technologies as enabling technologies for solar growth.

Similarly, Tony Seba writes "Should solar continue on its exponential trajectory, the energy infrastructure will be 100 percent solar by 2030," and follows by suggesting "the solar growth rate could actually accelerate (beyond that rate)."[10] We will explore the reasoning behind these statements further in the upcoming sections. First, let's do the math.

To start, we'll define the term "exponential." As many readers will remember from math class, if a quantity changes (increases or decreases) by a fixed fraction per unit time, (for example, 25 percent per year), the quantity is said to be changing exponentially. An example would be a population that increases (or decreases) by 5 percent each month.[11] Solar power generation for the last 10 years did not grow by a precisely constant percentage. But in Figure 2, you can see that while the pace accelerated during the period, the numbers roughly doubled every two years, at a CAGR of about 43 percent.

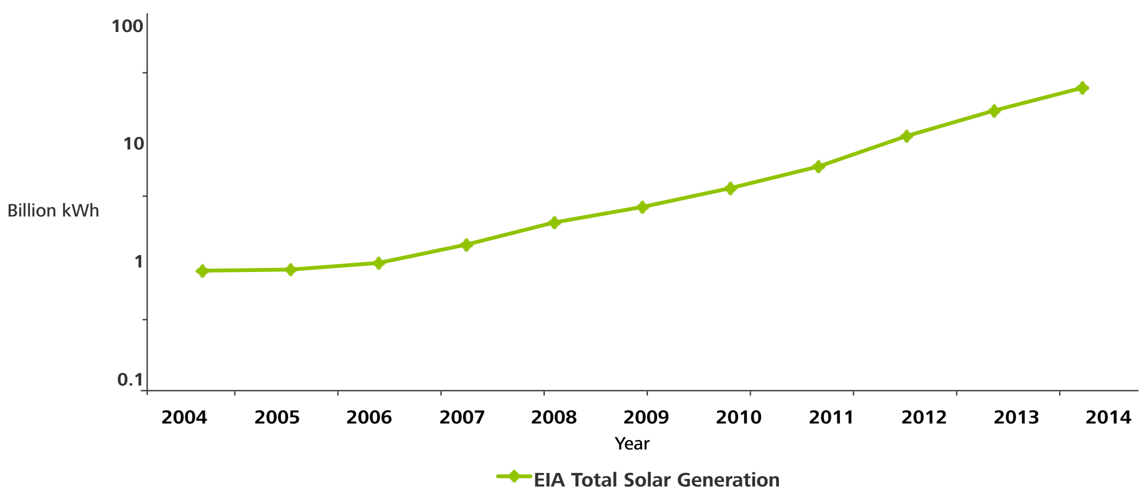
When charted at logarithmic scale (base 10) in Figure 3, it's almost a straight line, which is an indicator of an exponential progression. To project these exponential growth rates forward, we will use the CAGR for US solar generation from 2004–2014 (43 percent) from Figure 3.

Figure 2: US solar generation growth, 2004–2014

US Solar Generation (Billion kWh)	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EIA Total Solar Generation	.81	.83	.95	1.35	2.08	2.83	4.06	6.24	11.23	18.54	28.87

Source: EIA Annual Energy Outlook 2015 Reference Case

Figure 3: US solar generation growth, logarithmic scale



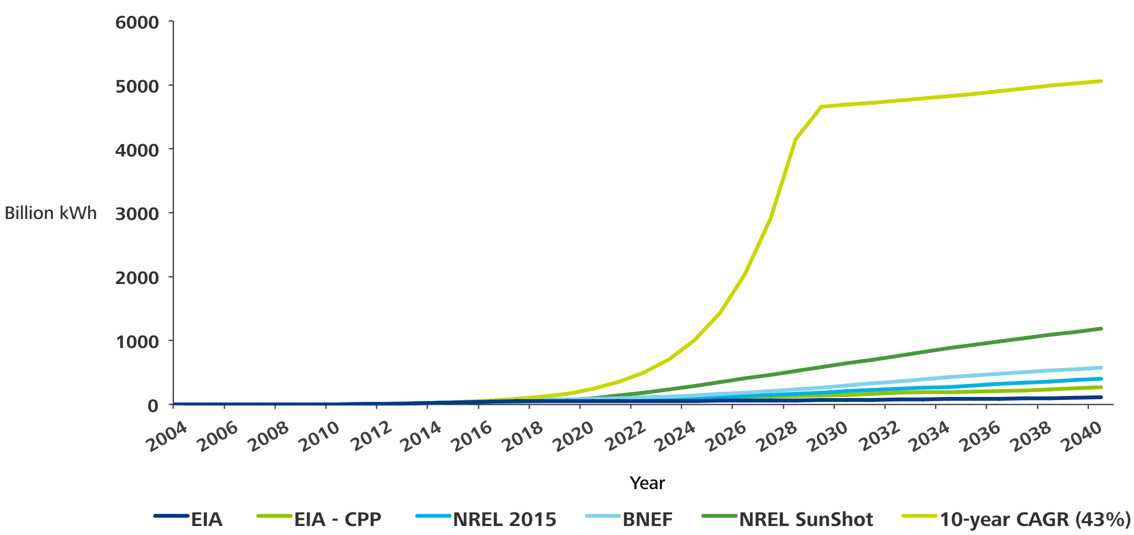
Source: EIA Annual Energy Outlook 2015 Reference Case

As you can see in Figure 4, projecting this historical growth rate forward yields a dramatic increase in solar generation, intersecting with the EIA's projection of total US generation by about 2029 (the exponential trajectory would extend higher, but we leveled it off when it surpassed EIA's total US electricity generation projection for each year). Of course, one should always be skeptical of any such "hockey stick" projections.

As noted earlier, many government and energy industry analysts do not see this growth trajectory as realistic, nor do many solar industry executives, even in their best case scenarios. We'll explore some of the assumptions behind this scenario in a later section, so you can evaluate them yourself.

But first, let's look at two underlying trends that have contributed to solar power's accelerating growth—exponentially declining costs and rapidly improving efficiency of solar panels. The conviction that these trends will continue is at the foundation of some of the more aggressive projections for solar growth.

Figure 4: Total historic and projected US solar power generation, 2004–2040



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NREL SunShot — The NREL SunShot Vision Study projection from 2011 assumes utility-scale solar costs meet the SunShot Initiative's target of $1/Watt by 2020 and stay there
BNEF — Bloomberg New Energy Finance, 2015 New Energy Outlook — Americas
The 10-year curve is extrapolated using the CAGR of US solar power generation from 2004-2014 (43%) and leveled off when it reached EIA's total generation projections

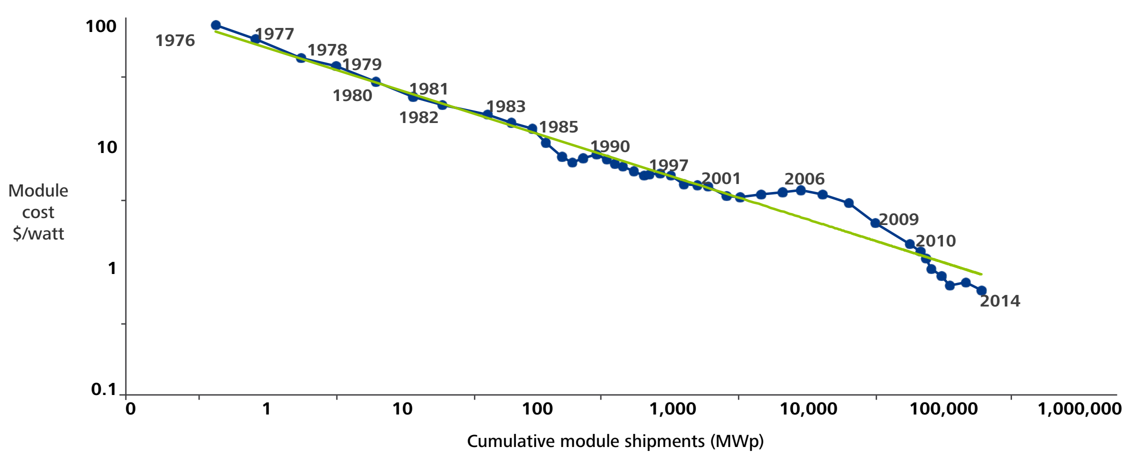
Note: Historical data through 2014 is from EIA. NREL's near term data for 2015-2018 is adjusted to match the EIA Reference Case, as NREL is updating its database with new plant information. NREL projections are biannual, so data points for odd-numbered years were provided by calculating the midpoint between adjacent years.

Solar photovoltaic (PV) costs are declining exponentially due to scale and efficiency gains

As illustrated in Figure 5, solar PV costs have fallen sharply as solar installations have increased. This is due to an experience curve that some have equated with the well-known "Moore's Law" in the semi-conductor industry. However, the experience curve observed in solar PV production is commonly known as "Swanson's Law." Moore's Law was an observation by Intel's Gordon Moore in 1965 that the number of transistors on an integrated circuit would double every two years, increasing processing power.[12] Swanson's Law was an observation by Richard Swanson, the founder of SunPower Corporation, that since the 1970s, for every doubling of global shipments of PV cells, the module cost drops by about 20 percent.[13] These cost reductions result from the benefits of experience; for example materials costs fall with scale and labor costs decline through manufacturing automation.

One snag some analysts point to is that Swanson's Law applies only to solar module costs, which are a shrinking portion of total system costs. As a result of falling module costs, balance of system (BOS) costs now comprise more than half of the total cost of a solar installation.[14] These costs include equipment such as inverters and racking, plus soft costs like installation, labor, permitting, financing, and customer acquisition costs. The DOE's SunShot initiative is focused on decreasing BOS costs, and a Berkeley Lab study suggests BOS costs will continue falling as the US market achieves scale, similar to Germany, where solar system installed costs are roughly half those in the US.[15]

Figure 5: Swanson's Law—module costs decline as shipments increase



Source: SEMI (the global industry association serving the manufacturing supply chain for the micro- and nano-electronics industries, including PV); International Technology Roadmap for Photovoltaic (ITRPV)

Solar cell efficiency is improving rapidly with technological progress

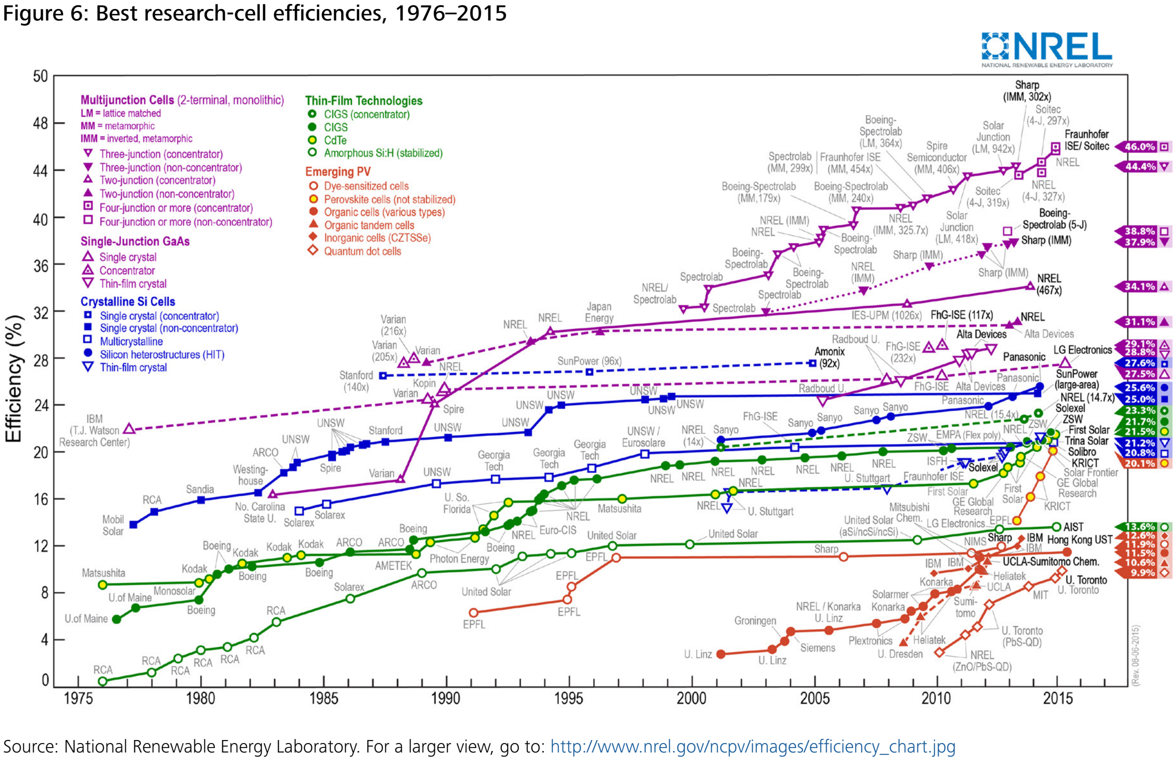
Another contributor to fast declining solar PV system costs is the increasing efficiency of the cells themselves. Advances in solar cell technology mean the same square foot of solar panels now captures more power from the sun, providing greater energy output and thereby reducing the cost of each watt of electricity produced.[16] Figure 6 shows the best results researchers have achieved in solar cell efficiencies for various PV technologies since 1976, and the trend is clearly moving upward.

As solar costs decline, residential system sales increase exponentially

As solar system costs have declined across US residential markets, it's no surprise that sales have accelerated accordingly. In fact, the US solar industry's largest residential installer, SolarCity Corp., has highlighted its own exponential sales trajectory and publicized its goal to reach one million customers in the five year period from 2013–2018.[17] So far, the company appears to be close to its goal of roughly doubling its customer base annually; it grew by 96 percent year-over-year in 2014, to nearly 190,000 customers, and by almost 40 percent in the first half of 2015, to 262,000.[18]

So, what is a realistic scenario for US solar generation growth over the next 15 to 25 years? In the next sections, we'll discuss some of the key technology, cost, and consumer trends enabling the growth of the solar industry, as well as those factors that could potentially constrain that growth.

Figure 6: Best research-cell efficiencies, 1976–2015



Source: National Renewable Energy Laboratory. For a larger view, go to: http://www.nrel.gov/ncpv/images/efficiency_chart.jpg

Two sides of the same coin:
Enablers and constraints for US solar power growth through 2040

Projecting the path of US solar growth in the short or long-term is a matter of weighing the impact of many factors that will likely enable or constrain growth during the period. Frequently, enablers and constraints are two sides of the same coin, and will impact solar power growth positively or negatively depending on how the issues evolve. Figure 7 outlines the variables that impact solar power's future in the US, followed by further discussion of each one.

Figure 7: Enablers and constraints for US solar power growth

Enablers	Constraints
Costs	
Solar system costs are declining fast	Total system costs still a deterrent in many areas
Technological progress	
Technological advances are spurring additional cost reductions and rapid growth	Research funding may be declining and barriers are high for new solar technologies
Grid integration	
Experience and new solutions are enabling integration of increasing volumes of variable renewables like solar	Variable solar must be balanced with other resources to avoid unanticipated voltage fluctuations or circuit overload
Enabling technologies	
Other rapidly advancing technologies, like storage, can enable further solar growth	Technologies such as battery storage may be uneconomical for large-scale solar back-up
Cost of capital	
Financial innovations are reducing the cost of capital for solar systems	Solar growth can be limited by the high cost of capital
Addressable market	
New business models are enhancing solar power's reach and value proposition	Not everyone owns their rooftop, has good credit, or access to capital
Policies	
New policies may support solar growth and existing incentives may be extended	Key incentives are expiring and new policies are evolving that may add costs
Carbon	
Rising cost of carbon emissions could make solar increasingly attractive	Other existing and emerging low carbon technologies could compete with solar
Competition	
Natural gas and electricity prices are projected to rise, which may make solar more competitive	Natural gas prices are relatively low and it often out-competes solar as a source for new generation
Adoption	
Customer sentiment increasingly favors solar power and falling costs may spur future adoption	Scant need for new generating capacity and stagnant electricity demand may slow future adoption

Costs: Will solar costs decline fast enough to continue supporting rapid growth?

Sharp cost declines have been a primary driver of growth and will likely continue to spur adoption, though some suggest costs may not fall fast enough to offset the effects of pending policy changes. "There's a high degree of price elasticity and unfettered growth based on economics. The decrease in costs is amazing and there's no end in sight," said Dan Shugar, chief executive officer (CEO) of NEXTracker, which provides tracking systems to help PV installations follow the sun's path.[19] Indeed, the industry is ahead of schedule to meet the DOE's SunShot Initiative goals, which aim to reduce the total installed cost of solar systems to $.06 per kWh by 2020, which the DOE considers "grid parity."[20] Three years after the program's inception, SunShot is already 70 percent of the way there, as the average price of a utility-scale PV project has dropped from about $0.21 to about $0.11 per kWh.[21]

"I think solar will easily get to 10 percent of generation within a decade—if not more. It took 40 years to get the first 1 percent—we could get to 10 times that in the next 10 years—it's doable."

Rhone Resch, President and CEO, SEIA

In some cases, large solar developers have already reached the SunShot goal. Speaking at an industry conference in June 2015, First Solar CEO Jim Hughes said, "I don't remember the last time I saw pricing that had a 7- or 8-cent price in front of it...we're regularly bidding in at... 5- and 6-cent power. We're beginning to see 4- to 5-cent power. I fully believe that within 10 years we'll be talking about low-3-cent power on a peak basis."[22]

As discussed earlier, the solar industry is focusing on reducing BOS costs in the near future, since module costs have already fallen sharply.[23] "Balance of system costs continue to decline; inverters are becoming more efficient and cheaper, and in particular the cost of acquisition is coming down. Companies are deploying technology and sophisticated sales techniques to lower acquisition costs,"[24] said Rhone Resch, president and CEO of the Solar Energy Industries Association (SEIA).

Despite continuing cost declines, analysts point out that the variable nature of solar power means systems must be backed up by additional generation, transmission, storage, or other resources, all of which can add significant costs. In addition, today's declining costs still depend heavily on incentives such as the investment tax credit (ITC), net metering, and other federal and state policies, some of which are scheduled to expire or are under review. All of these issues will be discussed further below.

Another potential constraint in the cost category is that as solar penetration increases in specific locations, the market prices for solar power will likely be depressed during the sunniest part of the day, since competition will be higher from a growing number of solar generators.[25] At the same time, other sources of generation will face the same issue during peak solar hours in these locations.

Technology: Is a solar technology break-through on the horizon, or do we need one?

The solar industry can cut costs and support widespread deployment by continuing to improve current crystalline silicon based solar cell technology and developing other attractive alternatives, specifically polycrystalline thin film and low-cost III-V PV technologies,* according to Gregory Wilson, National Center for Photovoltaics (NCPV) director at NREL. To back that effort, he says there are three key areas researchers are working on and "breakthroughs in any one of them could take us down the experience curve much faster."[26] These include:

1. Finding more cost-effective ways of manufacturing high efficiency silicon PV cells. Examples of this work include the development of low cost silicon tandem cells (i.e., adding a second PV cell to a silicon bottom cell) and developing high efficiency silicon cells that can be produced without using a wafer cut from a silicon ingot.

2. Reducing production costs for much more efficient solar technologies, such as III-V multi-junction materials, which are used on the international space station. "We need space cells at earth prices," added NREL's Strategic Energy Analysis Center Director, David Mooney.[27]

3. Developing the next generation of polycrystalline thin film PV technologies, which can compete with silicon PV in terms of efficiency and durability, but require as much as 100 times less semiconductor material and can be manufactured using a roll-to-roll method similar to newspaper printing.[28]

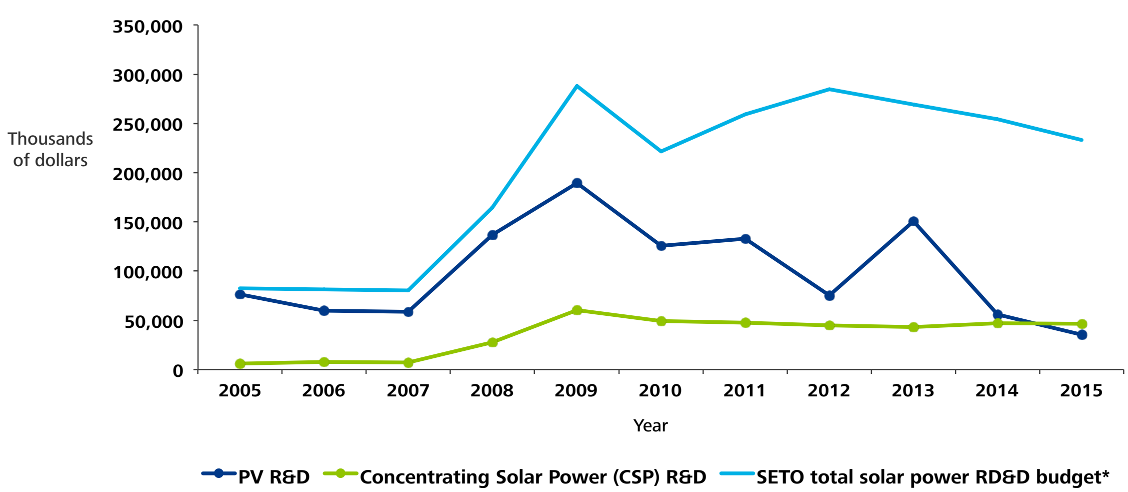
*For further information on polycrystalline silicon and III-V PV technologies, see endnotes.[29]

> "PV could be much larger than most people in the US think. The ultimate fraction of electricity generation from PV will depend on the price of carbon and the cost of storage. In the US, I think PV could supply as much as 50 percent of our electricity needs by mid-century."
>
> Gregory Wilson, Director, National Center for Photovoltaics, NREL

One factor that may limit progress, however, is the lack of adequate research funds in nearly every nation where major PV research institutions exist, according to NREL's Wilson. Even here in the US, "the entire PV research community, research universities, and national labs, are dealing with reduced funding," Wilson said.[30] MIT researchers suggest the variation in US federal government spending on solar research, development, and deployment (RD&D) over time reduces the efficiency of the research because it makes it difficult to assemble and retain the necessary talent to develop breakthrough solar technologies.[31]

The US federal government has been supporting solar RD&D since the 1970s, and manages that support largely through the Solar Energy Technologies Office (SETO) within DOE's Office of Energy Efficiency and Renewable Energy (EERE).[32] Figure 8 traces SETO's research budget for solar power technologies from 2005–2015, including a spike in 2009 when $116 million in additional funding was authorized under the American Recovery and Reinvestment Act of 2009 (the Stimulus Act).[33] SETO funding devoted specifically to PV research and development (R&D) declined more than 75 percent from 2013 to 2015, as the department increasingly focused resources on reducing BOS costs and pursuing innovations in manufacturing, in an effort to accelerate deployment. In another move to boost deployment, the DOE made $1 billion in additional loan guarantee authority available in August 2015 for innovative distributed energy projects, including solar projects. At the same time, DOE expanded a previously announced $10 billion loan guarantee solicitation to include distributed energy projects.[34] The DOE's FY 2016 budget includes a 76 percent increase in SETO funding for PV R&D, but it is not clear whether the budget will be approved by Congress.[35]

Figure 8: US Solar Energy Technologies Office budget for solar power RD&D, 2005–2015[36]



* SETO total above excludes funding allocated to solar heating, cooling and lighting research, and funding for Fuels from Sunlight Energy Innovation Hub. See endnotes for further details on categories included in this chart.[37] Totals also exclude funding through DOE's Office of Science and Advanced Research Projects Agency—Energy (ARPA-E), which is often targeted toward individual projects.

In the private sector, venture capital and private equity investment in the solar industry rose from $379 million in 2013 to $1.2 billion in 2014,[38] and Bill Gates recently pledged to donate $2 billion for alternative energy research.[39] But it's not clear how much of these sums will be devoted to solar power research and development.

In addition, there are high barriers for new technologies trying to beat silicon, according to Mooney. "A technology will have to be a lot better than silicon for banks to finance it—you'd have to beat it on performance, cost, and reliability," he said.[40] SunEdison founder Jigar Shah confirms "There's little funding for technologies that have been in the field for less than five years; the state of solar technology won't change much in the near future. There will be 4–5 percent cost reductions annually; the 20 percent reductions won't go on forever."[41]

However, according to Shah and other solar experts, we don't need a breakthrough in solar cell technology to drive continued rapid solar deployment. That can be largely driven, especially in the near term, by reduced BOS costs, new business models, and access to lower cost capital, which will be discussed further below. First, let's examine another technology issue related to solar—grid integration.

Grid integration: Will grid integration challenges hinder solar growth?

An often discussed constraint to widespread solar adoption is its intermittent nature, since the sun doesn't always shine when you need it. Variable resources like wind and solar must be integrated into the grid and balanced with demand and supply from other sources to avoid unanticipated voltage fluctuations or circuit overload that could trigger blackouts or brownouts. According to NREL's Mooney, the amount of variable renewable energy the grid can handle depends on the local footprint, or mix, of generation, transmission and distribution resources, but "in general there's a lot of headroom for continued renewables development. Five years ago they were reluctant to have more than 10 percent, but with experience they've figured it out. Now it's 20 percent and the margin will grow significantly."[42] Mooney mentions a utility that has integrated periods of as much as 50 percent wind power on its system, starting up and stopping without a problem. Haresh Kamath, an energy storage and distributed generation expert with the Electric Power Research Institute says "We know we can get to at least 35–40 percent. Now that we're getting to those numbers, people are pushing them up again."[43]

An NREL study suggested variable generation levels of up to 50 percent could be accommodated using a broad portfolio of supply and demand side flexibility resources and options.[44] Storage is often the first solution that comes to mind, but the list also includes grid automation, sensors, advanced analytics, forecasting, energy efficiency, demand response, traditional generation resources, and transmission over greater distances to smooth out variations and meet load with remote generation. "The key is flexibility," said Mooney. "Now they can dispatch on a sub-hourly basis, which makes it easier."[45]

Germany, Australia, and Hawaii, locations that can experience peak load solar penetration of 25 percent or more, are at the front edge of finding solutions to integrate solar power, and are generating some important learnings for the industry. Through collaborative research with NREL and SolarCity, the Hawaiian Electric Companies (Hawaiian Electric) found that high traffic circuits could absorb twice as much solar energy as they had thought. Specifically, after asking solar installers to upgrade software for inverters connecting solar systems to the grid, Hawaiian Electric was able to increase circuit thresholds from their current levels of 120 percent of daytime minimum load (DML) to 250 percent of DML, more than doubling the hosting capacity of circuits to integrate rooftop solar.[46]

Enabling technologies: Will storage and other emerging technologies enable faster solar growth?
The impact of cost-effective electricity storage on the electric power industry could be transformative. Traditional storage technologies, such as pumped hydro and compressed air, have limited applicability and are losing market share to emerging battery technologies, according to a Deloitte report.[47] "For PV to quickly grow to the terawatt scale that we need, it must be dispatchable; therefore low cost energy storage is critical," said NCPV's Wilson.[48] And that goal is getting closer. In 2014, a report prepared for an electric utility calculated grid-scale batteries' benefits would surpass costs if batteries were priced at $350 per kWh of capacity.[49] In the spring of 2015, grid-scale batteries were offered at $250 per kWh of capacity,[50] which is several years ahead of most industry forecasts for battery prices.[51]

"If residential solar adoption is like air conditioning, where 50 years later they had 80 percent saturation, solar on buildings could follow a similar path."
Dan Shugar, CEO, NEXTracker

While the cost-benefit ratio of grid-scale battery storage may not always make sense yet for a single application—like solar back-up—batteries can efficiently provide multiple services, yielding multiple revenue streams, such as ancillary services, for the same investment.[52] This makes battery storage increasingly viable on US electric grids, particularly as markets evolve to allow system owners to capture all the value streams created. For example, "As utilities and system operators continue pulling batteries onto the grid to improve reliability, they can use them to back up solar as well," Shah observed.[53]

In the residential market, solar systems with batteries make sense only in the markets with the highest retail electricity rates, such as Japan, Germany, Hawaii, and parts of California. But that is changing fast as solar and battery technologies travel down the experience curve and prices fall rapidly. "Storage is a big enabling technology," said SEIA's Rhone Resch. "In time, every solar system installed will have storage, which will act as a backup generator for the home. Then residential and small commercial customers' ability to sell excess electricity back to the grid will be less significant, as they will be able to store it for use later."[54] Currently, a 10 kWh capacity battery designed for residential and small commercial customers is priced at $350 per kWh, and that price is expected to decline below $200 per kWh of capacity by 2020.[55] The 10 kWh battery is described as sufficient to power most homes during peak evening hours, and multiple batteries may be installed together for homes with greater energy needs.[56]

In addition to storage, another technological advance that supports solar power's growth is the increasing deployment of digital technology, communications, and advanced analytics on the grid. As networked devices begin to monitor systems and physical conditions—such as cloud cover patterns, solar intensity and output across the grid—and feed data into applications that aggregate, analyze and learn from it, the whole system will become smarter, more predictive, and efficient. "The integration of solar generation and digital communications interfacing with the grid will increase stability and lower costs for consumers," said Resch.[57] Such technologies are part of what is known as the "Internet of Things," or alternatively by some in the power industry, the "Grid of Things."

Some expect a rapid increase in EV adoption as lower-priced models hit the market in the next few years. Of course, competition becomes tougher if gasoline prices stay low. But if EV adoption increases, it could feed solar adoption in several ways. First, an increase in battery production for EVs will accelerate battery technology's journey down the experience curve and reduce battery costs, which will in turn make them a more economically viable solution for solar intermittency. Second, if more EVs with batteries are connected to the grid, they too can act as storage for excess grid capacity and as a source for grid power when needed, which would help mitigate solar power's variability. Finally, EV purchasers who are interested in reducing their carbon footprints further may consider installing solar panels to charge their cars. Research suggests that approximately one in three EV owners already have solar panels to generate electricity at home,[58] which far exceeds the 3 percent found in an overall sampling of US consumers in the Deloitte Resources 2015 Study, an annual survey that provides insight into consumer and business attitudes and practices regarding energy management.[59] In view of this trend, homebuilders are already teaming with auto companies to integrate EV management systems and solar power into new "net-zero energy" homes.[60]

Cost of capital: Will solar's cost of capital continue falling?

One of the biggest contributors to solar system costs for utility-scale, commercial, and residential installations is the cost of capital. The solar industry has been introducing financial innovations at a furious pace to bring these costs down. One of the first breakthroughs was the introduction of "solar-as-a-service," which brought the concept of power purchase agreements and leasing to residential and commercial markets. This model requires customers to pay nothing upfront, as the installer designs, installs, owns, and maintains the system. Customers sign a power purchase agreement for a fixed period (typically 10–25 years), which covers the aforementioned costs and usually reflects savings compared with the customers' current and projected future electricity bills.[61] The developer/installer monetizes any applicable tax credits, while the customer benefits from net metering payments, if available. These incentives are still a critical component of solar economics in most states, and are explained further in the policy discussion below. That may change as solar system costs fall further and as storage becomes more widespread. Most customers continue to use the grid for back-up power.

> "Conventional projections have a poor track record; they often don't account for the rapid pace of innovation. At the same time, continued 45 percent growth breaks down due to constraints such as costs and variability."
>
> Ramez Naam, Energy Analyst and Faculty Member, Singularity University

Today, across high penetration solar markets in the US, this third-party ownership model represents about 80 percent of solar installations," said Resch.[62] From 2010–2015, the industry also saw the introduction of innovative financial tools to fund the growing number of solar installations including solar securities; green bonds; YieldCos; online crowd-funding sites like Mosaic; and new solar-optimized loans, which are making direct ownership a more attractive option for customers in some areas of the country.

"The solar industry is just catching up to other industries; these tend to be financial structures developed by other industries. We also expect to see new rule changes coming up, such as the ability to include solar assets in Real Estate Investment Trusts" said SEIA's Resch.[63]

In the commercial market, developers sell multi-site portfolios to retailers, standardize contracts to streamline financing, and now offer energy storage as an add-on to maximize solar's benefits by reducing demand charges.[64] Demand charges are based on commercial and industrial customers' peak electricity usage during a billing period, and that peak usage can be reduced by using solar power or storage.

These financial tools help the solar industry tap into capital from both large and small investors. But to keep reducing the cost of capital, the industry must attract broader capital market participation. In order to do this, they must continue to work toward providing a liquid, tradable product priced by the market. NREL's Solar Access to Public Capital working group is pursuing solutions through measures such as standardizing documents, recording best practices and promoting their adoption by the industry, and expanding access to data and tools to conduct due diligence necessary to build market confidence in the asset class.[65]

Addressable market: Not everyone owns their homes—doesn't that limit the addressable market?
Some cite limits to the addressable solar market as a long-term barrier to rapid growth in the US. But new business models, like community solar programs, may be able to address more of the market. "Not all roofs are suitable for solar and not all customers are homeowners, have good credit scores, available capital or even the desire to put systems on their own property," said Tanuj Deora, chief strategy officer, Solar Electric Power Association.[66] According to these criteria, only between 10–20 percent of US residential households would likely acquire or lease rooftop solar PV systems, Deora added. But a new and increasingly popular alternative is community solar, a market segment that could have the largest growth rate in the US in the next three to four years, Deora said.[67] (see sidebar)

Policies: Will utility rate restructuring or potential changes to net metering slow solar growth?
Utilities across the country have expressed concern that customers with solar installations are not paying their share of the cost of maintaining the grid. As these customers' usage of utility-provided electricity declines, utilities receive less revenue to cover the fixed costs of maintaining the grid and access to generation, and these costs must then be spread across all customers' bills. Some utilities say that customers who do not install solar panels are in effect subsidizing the solar customers' access to and usage of the reliability provided by the integrated electric grid and associated generation capacity. Electric companies in more than 20 states have asked their regulators to help them recover such costs through rate restructuring. A variety of rate revisions have been proposed and some have been implemented. The net effect of most of these revisions for solar customers would be to raise costs. This will likely cut into solar sales, depending on the extent of the additional cost.

Community Solar
The term "community solar" refers to community-shared solar projects that are not physically connected to the customer's property. It includes a wide spectrum of offerings, ranging from utility-owned projects offered through rate-based programs, to "virtual net-metered" installations that customers buy shares of according to their needs.[68] Credits are applied to customers' bills in accordance with their ownership stakes. These facilities average in the 1–2 megawatt (MW) range, which is large enough to access utility-scale benefits such as project financing and more efficient sources of capital. The larger scale and more attractive financing can help bring the cost of shared residential solar systems down 30–50 percent compared with individual rooftop solutions.[69] There are currently more than 50 shared solar programs across 19 states and dozens of cooperative, municipal and investor-owned utilities, exceeding 170 MW of capacity.[70] NREL projects community solar installations could total as much as 11 gigawatts (GW) of capacity by 2020, but growth will depend in part on how many states adopt community solar or virtual net metering legislation.[71]

Utility-owned programs require the approval of state utility commissions, which may be less difficult than passing legislation, as these programs can reduce costs for consumers and help states meet Renewable Portfolio Standard (RPS) goals. The federal government has also joined the effort to increase access to solar energy, particularly in low to moderate income communities through new initiatives like its National Community Solar Partnership, which aims to unlock access to solar for the nearly 50 percent of US households and businesses that rent or do not have adequate roof space.[72]

In addition, most states have net metering programs that require electric companies to buy the excess energy produced by various types of distributed energy, including rooftop solar, from customers at retail rates. Since electric companies could generally produce this power themselves or buy it on wholesale markets from other electricity providers at lower cost, they are calling for net metering policies to be revised. One suggestion is that net-metered customers be compensated using the wholesale price for the electricity they produce, similar to other electricity providers.[73] There will be different outcomes across utility territories, and some of them could potentially pose big challenges for solar companies, according to solar industry executives.

It will likely take more time for commercial and residential solar systems to become economically viable in areas that impose or increase grid charges or alter net metering programs. But in the meantime, the cost of solar systems will likely continue to decline in many parts of the country, and installers will focus on these areas. Many suggest as storage prices fall in the next few years, more solar systems will include storage so customers will not have to rely on net metering to make their systems economic; they would just store excess energy and use it later, thereby saving further on electric bills. Regarding net metering policies, Resch says, "Until low cost storage becomes available, net metering will remain an important policy; it has been foundational for creating markets for the last 10 years. But if we get storage technology right, then solar will become cost competitive in all 50 states without it. And most experts feel that this is less than five years away."[74]

Policies: What does pending expiration of the federal ITC mean for solar?

Another policy that has been foundational to the solar industry is the ITC, which is scheduled to step down from 30 percent to 10 percent after 2016 for utility-scale solar projects, and to zero for installations directly owned by residential and small commercial customers.[75] The solar industry is still lobbying for an extension of the ITC or a change in the ruling to include projects that begin construction by the deadline rather than go in service. If that doesn't happen, "After expiration, solar will probably take a hit, but the 20–30 percent increase in costs will be made up for in about two to three years by price declines. There may be some loss in 2018–19, but then it will bounce back," said Ramez Naam, energy analyst and faculty member at Singularity University.[76]

One view is that expiration of incentives will allow the solar industry to focus more on the value proposition of the services they are selling. Solar energy companies are beginning to sell a suite of products that includes not just solar panels and storage, but other products like energy management and microgrids. For example, SolarCity offers a turnkey microgrid service that combines solar panels, battery storage and a monitoring and control system to manage the mix.[77] The service, targeted at municipalities, remote communities, campuses and military bases, can be financed with no upfront costs in a pay-as-you-go "microgrid as a service" model, or it can be purchased.[78] "The vision you're selling companies is microgrids, more reliability, power quality. Now you're just selling solar because of the ITC, but when the ITC goes away, it becomes broader than solar. Now solar has a 6 percent return, but the overall package after adding these other services may have a 9 percent return" for customers, said Shah.[79]

Carbon: How will environmental considerations and initiatives impact solar growth?

Low carbon energy sources like solar are gradually becoming more valuable as policies like the Environmental Protection Agency's (EPA) Clean Power Plan (CPP) are proposed and implemented. The CPP seeks to lower carbon dioxide emissions from the US power sector by 19.2 percent from 2012 levels by 2030.[80] While there are legal challenges to the EPA ruling, if it goes forward "it will be a major driver for solar in all markets—residential, commercial, and utility scale. The demand for solar from the CPP could be an order of magnitude bigger than all of the RPS combined," according to Resch.[81]

Most industry observers see the future of carbon policy as an important driver for solar growth. NREL's Wilson suggests "any discussion about future terrawatt-scale growth for solar depends on whether there's an appropriate price on carbon. Once we have a global climate change policy framework that addresses carbon emissions costs, PV industry growth will accelerate."[82] Even while the policies are still uncertain, the issue is impacting corporate decisions about energy use. An energy manager for a large technology company told us companies like his are beginning to address carbon dioxide reduction sooner rather than later because they expect a price to be put on carbon eventually, so it's probably cheaper to reduce carbon now. In the Deloitte Resources 2015 Study, 57 percent of companies surveyed reported having carbon emissions reduction goals in 2015 compared with 46 percent in 2014 and 49 percent in 2013.[83]

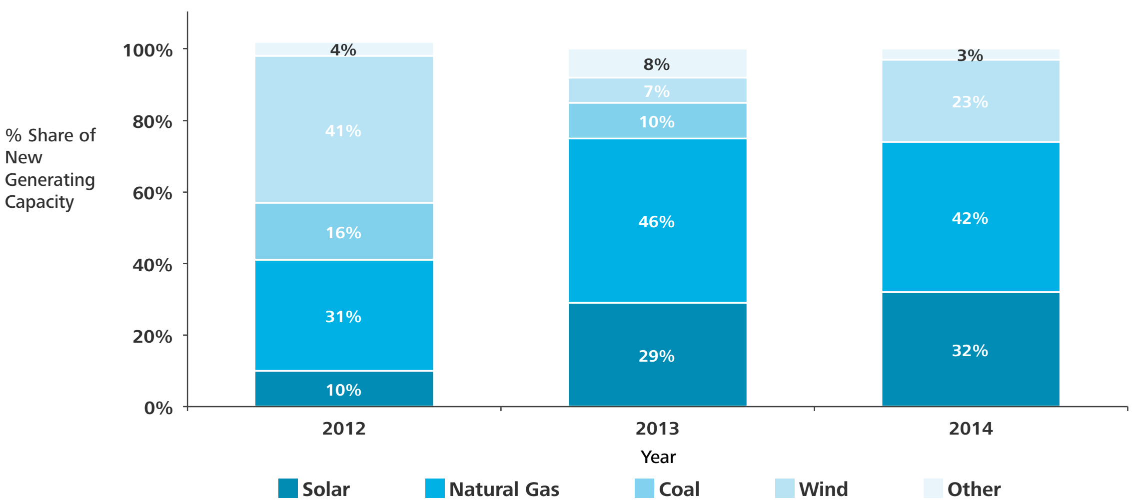
Competition: Will competitive electricity sources slow or complement solar's growth?

Competition from existing and future power generation technologies will likely impact the rate of growth of solar power in the US, as will continued advances in energy efficiency. At the same time, all of these sources can be complementary to solar, helping to serve load when the sun isn't shining. For example, the wind tends to blow strongest in the evening, while solar power is obviously diurnal, creating convenient synergies between the two power sources. Natural gas peaker plants, with their ability to start and stop quickly, are also a good complement to solar power.

These three technologies have been the leading sources of new generation in the US in recent years and will likely continue to lead in the near term (see Figure 9).

Natural gas plants' key advantages are their lower cost to construct and relatively short time to build compared with other dispatchable sources like coal and nuclear, plus availability of abundant US shale gas supplies. Wind and solar boast falling costs to build plants and no fuel costs, providing generators with valuable price certainty over the long term. Figure 10 provides EIA estimates of levelized cost of energy (LCOE) for various technologies.

Figure 9: Share of new US generating capacity by energy source



Source: GTM Research, Federal Energy Regulatory Commission

Figure 10: US average levelized cost of energy (LCOE) for plants entering service in 2020 (in 2013 $/mWh)[1]

Plant type	Capacity factor	Levelized capital cost	Fixed Operations & Maintenence (O&M)	Variable O&M (including fuel)	Transmission investment	Total system LCOE	Subsidy[2]	Total LCOE including subsidy
Dispatchable								
Coal-fired								
Conventional coal	85	60.4	4.2	29.4	1.2	95.1		
Advanced coal	85	76.9	6.9	30.7	1.2	115.7		
Natural gas-fired								
Conventional combined cycle	87	14.4	1.7	57.8	1.2	75.2		
Advanced combined cycle	87	15.9	2	53.6	1.2	72.6		
Advanced nuclear	90	70.1	11.8	12.2	1.1	95.2		
Non-dispatchable[3]								
Wind	36	57.7	12.8	0	3.1	73.6		
Solar PV	25	109.8	11.4	0	4.1	125.3	-11	114.3
Solar thermal	20	191.6	42.1	0	6	239.7	-19.2	220.6

Source: US Energy Information Administration, Annual Energy Outlook 2015

[1]LCOE represents cost of building and operating a generating plant over an assumed financial life and duty cycle. Costs for advanced nuclear technology reflect an online date of 2022
[2]The subsidy component only reflects subsidies available in 2020, which include a permanent 10 percent investment tax credit for solar technologies
[3]Non-dispatchable energy sources like wind and solar cannot be directly compared with dispatchable sources like natural gas, coal and nuclear. Refer to EIA's LCOE/LACE analysis for further information http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf

Energy efficiency technologies are advancing fast as well, and costs to save energy are below those for building most types of new generation.[84] The average total cost of saving electricity by US utility efficiency programs from 2009–2013 was 4.6 cents per kWh across 20 states, according to a Berkeley Lab study.[85] Increasing adoption of systems to manage and reduce energy usage across homes, buildings, and cities is reducing the need for new generation overall, which could constrain solar growth.

While solar power is gaining value for its attractive environmental profile, other emerging low carbon technologies may also be advancing. Two technologies being researched and tested are carbon capture and storage, which would dramatically cut carbon emissions from coal-fired and natural gas-fired generation by capturing and storing them, and small modular nuclear reactors designed to be built faster and more cost effectively than today's reactors. Breakthroughs in these technologies or others could create competition that could potentially slow the growth trajectory of solar power, depending on the timing of commercialization.

Adoption: New energy technologies don't just take hold overnight

Energy analysts make the point that large scale-deployment of new energy technologies doesn't happen fast; new technologies have historically grown exponentially until they reach about 1 percent of the energy mix, which solar is approaching now, and then growth slows to a linear pace.[86] This is due partly to limitations related to manufacturing capacity and investment dollars. And importantly, analysts argue that "unlike consumer goods, which may become obsolete in a few years, the capital goods of the energy system have a lifetime of 25–50 years, so only 2–4 percent of existing technology needs replacement in a given year."[87] The economic barrier to replacing existing power plants with solar plants is high, they would argue, because the total cost of new solar plants (capital and operating costs) would have to fall below the operating costs of existing plants. And that is unlikely to happen, even with rapidly declining solar costs.

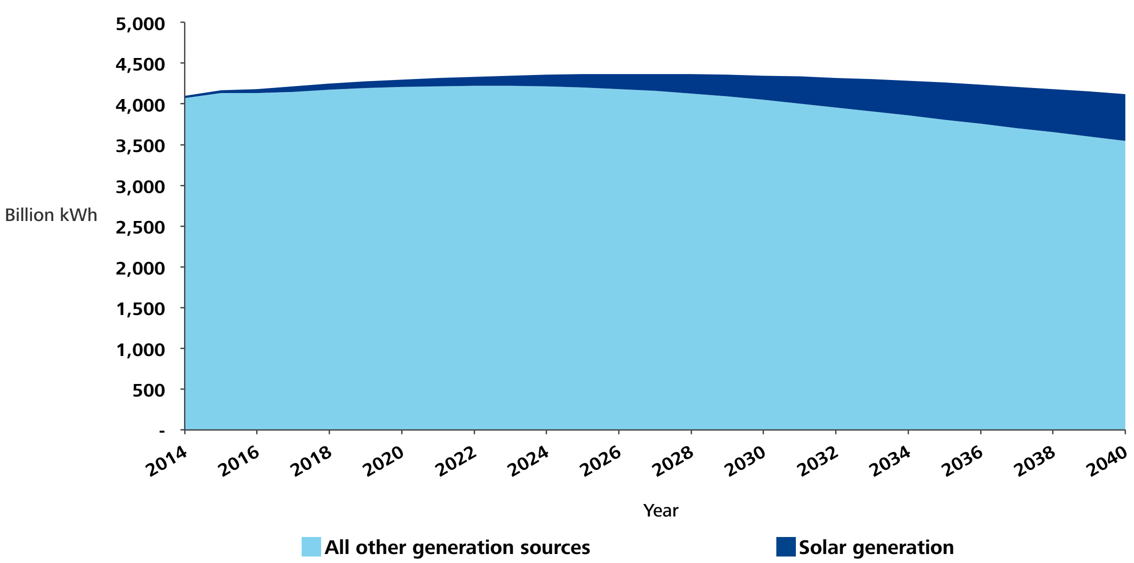
So, if a shift toward solar dominating the US generation mix depends on traditional utility-scale generation deployment (through electric companies and independent power producers) it will likely happen gradually. But does it depend only on traditional utility-scale deployment? Those who envision continued exponential solar growth in the US leading to its dominance within as little as 15 years do not think so. They believe it will come as a combination of utility and customer-initiated deployment. Some suggest that at the end-user level, solar systems have already become a consumer good, like a refrigerator, a furnace, or a car, so solar adoption may no longer be subject to the previous "laws" of energy technology adoption. They suggest this shift will happen because of customer choices and sentiment, which is on the verge of, or already at, the "tipping point" for solar power. These concepts will be explored further in the next section.

Continued exponential growth—what would it look like?

To illustrate the dramatically different outcomes of the conventional, linear growth projections compared with the exponential growth scenario painted by analysts like Kurzweil, Diamandis, and Seba, we will plot solar's growing share of US electricity generation through 2040 in both cases. Going back to the linear projections depicted in Figures 1 and 4, let's use the BNEF projection for this exercise, since it sits about mid-way between the various government scenarios. In the BNEF projection, solar generation would grow from the 2014 level of 0.7 percent of US power generation to nearly 14 percent by 2040, shown in Figure 11.

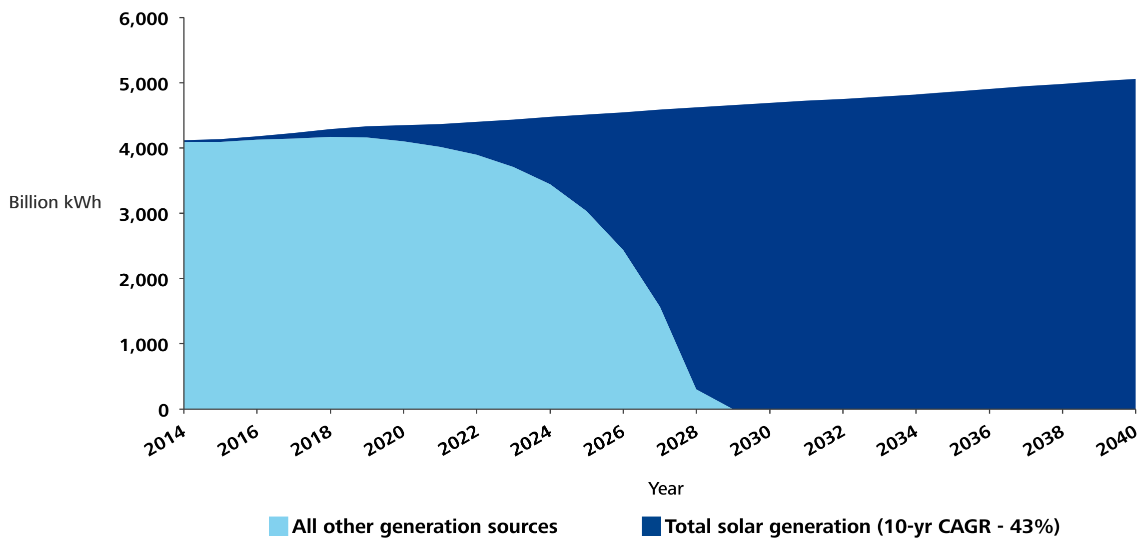
In contrast, a continuation of recent exponential growth rates, using the CAGR from the last 10 years (43 percent) would more closely resemble Figure 12, with enough solar power generated to meet all US generation requirements by about 2029.

Figure 11: Projected solar share of total US electricity generation through 2040 (BNEF)



Source: Bloomberg New Energy Finance, 2015 New Energy Outlook, Americas

Figure 12: Projected solar share of total US electricity generation through 2040 if exponential growth continues (using 2004–2014 CAGR of 43%)



Source: EIA, Deloitte analysis

Note: Total electricity generation differs slightly between Figures 11 and 12 because Figure 11 plots BNEF total US electricity projection, while Figure 12 plots EIA total US electricity projection. We cut solar generation growth when it intersected total US generation projections in this exercise, which implies use of storage, since solar generation is intermittent.

How could this possibly happen?

Once again, most analysts do not foresee this scenario, but since some have painted a picture similar to this, we will examine it more closely as a thought experiment. First, a major reason many think this scenario cannot happen is that the US already had about 1,077 GW of total installed electric generating capacity in 2014, and EIA projects electricity demand will grow at a relatively anemic 0.7 percent CAGR over the next 25 years as the US economy becomes more energy efficient.[88] So, the country will only require about 183 GW of net new generating capacity (accounting for projected plant retirements) to reach the 1,261 GW of installed electric generating capacity EIA projects for 2040.[89] Therefore, even if solar comprised 100 percent of all net new generating capacity, it would still be only about 16 percent of total electric generating capacity in 2040.

It would not make economic sense for utility planners to shutter thousands of megawatts of existing generating capacity before the end of its economic life and replace it with new solar generation. Even if solar costs continue to fall sharply, the cost to build and operate solar power plants is not likely to fall below the operating costs of existing plants.

So how could solar dominate the US generation mix in 15 years? Those who project this rapid transformation believe utilities will, in fact, choose solar for most new capacity and, importantly, end users in the commercial, industrial and residential sectors will continue to switch to solar at an exponentially growing rate. They contend that end users will choose to install solar panels when the cost of a solar system falls below what they are currently paying for electricity, which will increasingly be the case over time, according to some analyses. The question is how much time?

"The decision to switch to solar energy will not be about being green, but about saving green, as in dollars" said Tony Seba, author of *Clean Disruption of Energy and Transportation*. He suggests US solar power will continue to grow at a rate close to the 43 percent CAGR observed globally since 2000, and that it will displace most other power sources by 2030.[90]

So, how much do US residential and small commercial solar systems cost now, in which states are they currently at parity with retail electricity rates (sometimes called "socket parity"), and where are they expected to reach parity next? Figure 13 provides US average installed solar system costs as of Q2 2015.[91] GTM Research, a leading source of US solar data, provides both national average reported pricing as well as calculated, bottom-up "turnkey" pricing that reflects the price of system components plus margin. They include both indicators because they found that the timing and methodology of reported pricing, especially due to the high penetration of third-party systems, does not necessarily accurately reflect the turnkey price of installing a PV system.

Figure 13: US solar system costs as of Q2 2015

Installed solar system costs (in $ per watt)	National average reported pricing	National average turnkey pricing
Residential	$4.22	$3.50
Non-residential	$3.13	$2.13
Utility-scale: Fixed-tilt	—	$1.49
Utility-scale: One axis tracking	—	$1.71

Source: GTM Research is a division of Greentech Media, which partners with SEIA to produce the quarterly US Solar Market Insight Report.
Notes: A GTM analysis from late 2014 says that while these are average costs, you can get residential solar installed for under $3.00 per watt, commercial for under $2.00 per watt, and utility-scale for under $1.50 per watt.[92] *See endnotes for definitions of Wdc and modeled turnkey system.[93]

A GTM analysis from the same period suggests that rather than grid parity, we should consider the tipping point to be when customers could save 10 percent from their electric bills by going solar. GTM put three states in that category at year-end 2014 (CA, AZ, and HI), and four more at grid parity but not yet at the tipping point (NV, NM, NJ, and SC). Throughout 2015–2016, they expect more states to reach grid parity or the tipping point, such as the New England states, PA, CO, and possibly WY and MI. But if the ITC expires as scheduled in 2016, the industry will retreat back to 2014 levels, when just a few states were competitive.[94] GTM's analysis includes utility grid charges, but more charges may be added in the future and net metering rules could change, causing costs to effectively rise for consumers who implement solar. However, solar system costs will likely keep declining over time, which will tend to offset potential increases due to policy changes.

Costs may have to fall a lot further to trigger the number of installations needed to reach the scenario Seba describes, and installation logistics will also need to improve. There were about 734,000 residential solar installations in the US by mid 2015[95] and Seba calculates there will be 20 million by 2022.[96] This would result from about a 50–60 percent cost decline in the US by 2020, to levels he suggests are reachable since it would only entail catching up to today's system costs in Australia or Germany. Logistics are another consideration. To put Seba's 20 million installations by 2022 in context, SolarCity Corp, the largest US residential installer with nearly 40 percent of US market share, has a goal of installing its one millionth system by mid-2018.[97] To those who say the US solar industry can't physically install about 19 million systems in seven years, Seba recounts how DIRECTV installed its first 10 million customers for satellite TV in five years, and logistics technologies are far more sophisticated today than 20 years ago.[98] Coincidentally, SolarCity announced a new service relationship with DIRECTV in March 2015, which will enable DIRECTV technicians to offer its customers solar power service in every major market where SolarCity currently operates.[99] In addition, the leading solar companies are increasingly partnering with home builders to install solar power in new homes, which is far more cost-effective than retrofitting old homes.[100] "New homebuilders are building out the electrical structure and donating it to utilities; they will become microgrid operators," said Shah.[101]

Electricity disintermediation: Is Uber electricity in our future?

Seba thinks distributed solar costs will eventually fall below the cost of transmission, so that even if utilities could generate electricity for free, it would still cost more than distributed solar. Electricity will be generated from rooftops of commercial buildings, schools, parking lots, community solar gardens, warehouses, and other locations; and people and organizations will sell it in an online marketplace.[102] Analysts in both the electric power and solar industries foresee increasing disintermediation, like we've seen in other markets since the advent of widespread internet and cell phone use. Similar to other online marketplaces today, like eBay, many people would buy power, and a smaller number would be sellers.[103] Reliable power delivery would likely continue to be guaranteed by the electric utility, as it currently is in deregulated retail electricity markets. This vision of a potential retail online marketplace for electricity was described by an electric company president at a recent industry conference as "Uber electricity," referring to the technology company that has disrupted the taxi industry by connecting riders to drivers-for-hire through a cell phone application.[104]

Will consumers be the catalyst?

The exponential growth scenario depends to a large degree on strong consumer pull in the near future. We know that consumers in general view solar power positively, and many would like to install solar panels, but are still hesitating due to the perceived high cost. The Deloitte Resources 2015 Study found that 64 percent of consumers surveyed ranked "increasing the use of solar power" among the top three energy-related issues most important to them, up from 58 percent in 2014 and 50 percent in 2013.[105] In addition, more than one-fourth (28 percent) named installing solar panels as among the top five actions they could take to trim their electric bills, yet only about three percent reported having solar panels on their primary residences.[106] The top reasons making consumers pause were perceptions of solar power being expensive (40 percent) and fears of the panels not working as promised (25 percent).[107] This suggests that consumer demand for solar may be highly price-elastic. If prices continue declining rapidly, installations will likely increase accordingly. It's also possible that as adoption grows and consumers begin to see more panels on their neighbors' homes and become more familiar with how it works, particularly if it is saving their neighbors money, it would feed further adoption, which would lower customer acquisition costs and system costs, and boost adoption further, in a virtuous cycle. Reaching a "tipping point" through this type of scenario would likely be required for exponential growth rates to continue.

Will solar follow the path of other exponential technologies?

If we were to see a rapid shift to distributed solar power generation in the US, it would not be the first time one technology unexpectedly displaced another. An example that's often cited because it's fairly recent is cell phones. In the early 1980s, most people did not imagine an affordable mobile telephone. Even the developer of the first handheld cell phone, Martin Cooper, said in 1981, "Cellular phones will absolutely not replace local wire systems. Even if you project it beyond our lifetimes, it won't be cheap enough."[108]

A few years later, a technology consultant forecast that the total US market for cell phones would reach 800,000 by the year 2000.[109] There were, in fact, over 110 million cell phones in the US in 2000.[110] Some might point out that cell phones are a great deal less expensive than solar panels. But to consumers being offered "no money down" contracts under which they can begin saving on electricity bills in the first month, the "cost" may seem like a bargain compared with a cell phone. A comparison of the growth rate of US solar generation with cell phone subscriptions over a 10 year period in their respective early growth phases indicates that cell phone adoption was a bit faster than solar power. US cell phone subscriptions increased at a 58 percent CAGR in the ten year period from 1985–1995,[111] compared with US solar generation's 43 percent CAGR from 2004–2014.[112] Solar's pace accelerated to a 59 percent CAGR in the last five years (2009–2014), but how long such rapid growth will continue is unclear.[113]

Another technology whose fate initially seemed uncertain was the automobile on the verge of displacing horse-drawn vehicles in the early 20th century. "The horse is here to stay but the automobile is only a novelty, a fad," said a banker advising Henry Ford's lawyer not to invest in the Ford Motor Company in 1903.[114] But here's what happened in the first decade or so after introduction:

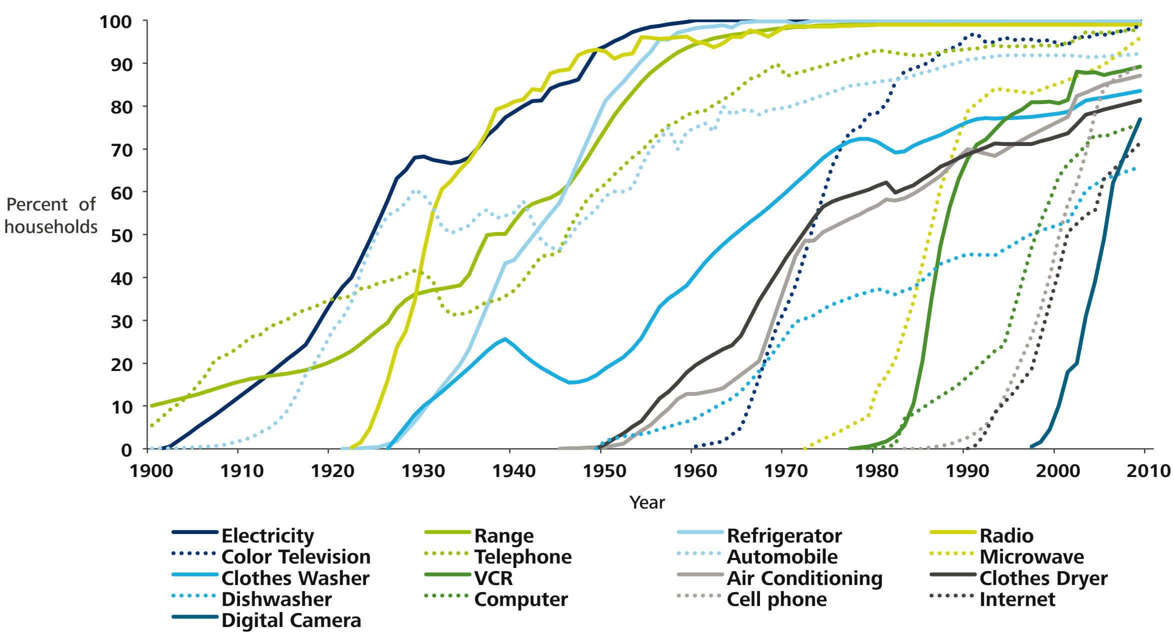
Figure 14: US auto sales increased at a 45 percent CAGR, 1900–1912

	1900	1912	CAGR
US auto sales	4,192	356,000	44.8%

Source: Eric Morris, "From Horse Power to Horsepower," Access, Vol 30, Spring 2007, p. 8

Similar to solar power, early automobile adopters calculated that car ownership cost less than horse-drawn vehicles.[115] In fact, the compound annual growth rate from the first dozen years of car sales, at 45 percent, is close to the 43 percent the US has experienced for solar power in the last 10 years. Cars went on to reach 50 percent ownership by 1929 and ownership by more than 90 percent of households by 1990. Figure 15 shows growth curves for various consumer goods throughout US history. Statistics suggest adoption rates for new technologies are accelerating—the question is whether the solar adoption curve will continue on its current trajectory or slow, and by how much and when?

Figure 15: US historical adoption curves for new technologies



Source: W. Michael Cox, founding director, O'Neil Center for Global Markets and Freedom; US Census Bureau

Concluding thoughts

Projecting solar power's growth trajectory is like predicting geomagnetic storms on the sun's surface, or any other weather phenomena. We have some idea of what might happen tomorrow, but next week, next year, or 20 years from now, it's far more challenging. Yet, it makes sense for companies involved in the solar industry or in adjacent or competing industries to develop a point of view on solar growth for long-term, strategic planning purposes. So here are some conclusions that may be helpful.

1. Continued exponential growth at a 43 percent CAGR may not be realistic, but conventional linear projections have almost all been outpaced by solar power's rapid growth and may well continue to be. It bears remembering that solar power has been growing like an exponential technology, and has so far been impacted by exponential cost declines. Cost declines may be beginning to slow as BOS costs become an increasing portion of overall system costs, but there's a sharp focus on reducing those costs and progress is being made.

2. The demand for solar power systems appears to be highly price-elastic, so as the cost of systems falls below retail electricity costs in more areas of the country, adoption will likely grow. Policy changes, incentive expiration, and electric rate restructuring may slow that growth in some areas, but that will likely be temporary as costs continue to fall.

3. For each scenario in your plan, update and re-evaluate solar costs often to keep up with cost declines. As NRG CEO David Crane tells business owners considering installing solar, "If you evaluated rooftop solar a year ago, or three months ago, your economics are way out of date."[116]

4. Remember that solar economics vary widely across US states and regions, so planners must take into account local electricity rates, solar system costs, insolation levels, economic incentives, availability and cost of other energy sources, consumer sentiment, and more as they make projections for solar growth.

5. Solar growth may be impacted by growth and adoption of enabling and adjacent exponential technologies, like electricity storage; the increasingly digital "grid of things;" and, potentially, electric vehicles if their costs fall significantly and range increases. These technologies and others represent wild cards in each planning scenario—and if that's not enough—many of them may impact each other.

6. Consumer sentiment may be one of the most important variables, because of its potentially accelerating effect on solar adoption. When costs fall below a certain threshold and adoption increases, reducing costs and boosting demand further in a virtuous cycle; a "tipping point" may be reached, beyond which adoption will accelerate. Increasing consumer awareness levels have played a significant role in solar growth in other countries like Germany and Australia.

7. In terms of technological breakthroughs, experts told us there is a possibility researchers may be able to develop the next generation of PV devices that are cheaper and will displace the entire industry over a couple of decades.

Mileposts to watch out for that could rapidly accelerate solar growth include a higher price on carbon emissions (which the CPP may effectively achieve); further declines in storage costs; and sharp declines in solar system costs, whether through technological advances, emerging business models, or new financial structures that dramatically lower capital costs. Policies that reduce or eliminate incentives such as the ITC and net metering, or add costs, such as utility rate restructuring, will potentially slow the growth rate, but the effect will likely be temporary as costs continue to fall.

For electric companies, even the most aggressive pace of solar growth would not necessarily trigger the so-called "death spiral." It would pose some challenging questions and require a substantial business model shift, but the future path appears to point to a critical and continuing role for the electric grid. Moreover, electric companies are taking an increasing stake in solar growth, from developing projects at the utility scale to installing, financing, and owning distributed solar—and that role will likely continue to grow. Community solar, in particular, opens a wide avenue for utility participation. In addition, as solar power deployment grows, the electric industry and the solar power industry could potentially converge. We've already seen several US and European electric companies acquire solar developers and installers, and some observers believe we may soon see a solar company acquire a small utility.[117]

In conclusion, whether your company is involved in developing or installing solar power; generating, transmitting or distributing electricity; or developing enabling or competing technologies, you should consider the following question: Does my company's planning include a full range of scenarios related to solar power growth, and have we developed strategies to address them?

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