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The economics of **solar power**

Don't be fooled by technological uncertainty and the continued importance of regulation; solar will become more economically attractive.

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Article at a glance

Solar energy is becoming more economically attractive as technologies improve and the cost of electricity generated by fossil fuels rises.

By 2020, hundreds of billions of dollars of investment capital will probably boost global solar-generating capacity 20 to 40 times higher than its current level.

As the new sector takes shape, producers of solar components must drive their costs down, utilities must place big bets despite enormous technological uncertainty, and regulators must phase out subsidies with care.

The actions these players take will determine the solar sector's scale, structure, and performance for years to come.

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A new era for solar power is approaching. Long derided as uneconomic, it is gaining ground as technologies improve and the cost of traditional energy sources rises. Within three to seven years, unsubsidized solar power could cost no more to end customers in many markets, such as California and Italy, than electricity generated by fossil fuels or by renewable alternatives to solar. By 2020, global installed solar capacity could be 20 to 40 times its level today.

But make no mistake, the sector is still in its infancy. Even if all of the forecast growth occurs, solar energy will represent only about 3 to 6 percent of installed electricity generation capacity, or 1.5 to 3 percent of output in 2020. While solar power can certainly help to satisfy the desire for more electricity and lower carbon emissions, it is just one piece of the puzzle.

What's more, solar power faces challenges that are common in emerging sectors. Several technologies are competing to win the lowest-cost laurels, and it's not yet clear which is going to win. Rapid growth has created shortages and high margins for early players, such as the silicon refiners Dow Corning, REC Solar, and Wacker, as well as the component manufacturers First Solar, Q-Cells, and SunPower. Fueled by ever-increasing flows of new equity from venture capital and private-equity firms—$3.2 billion in 2007—innovative new competitors are entering the sector, and with them the potential for excess supply, falling prices, and deteriorating financial performance for some time.

With competition heating up, the companies building the equipment that generates solar power must relentlessly cut their costs by improving the processes they use to manufacture solar cells, investing in research and development, and moving production to low-cost countries. At the same time, they must secure access to raw materials without tying themselves to the wrong technology or partner.

The evolution of technology looms large for utilities as well. If they hesitate to undertake large long-term investments until the dust clears, they risk losing customers to players such as panel installers willing to put up and finance solar units on the roofs of buildings in return for a share of the savings the owners enjoy. As always in the utility sector, it will be essential to deploy smart regulatory strategies, which in some regions might mean including solar investments in the capital base used to set rates for consumers. Government policies will also continue to influence the sector's development heavily. Deciding when and how to phase out subsidies will be critical for creating a vibrant, cost-competitive sector.

Even in the most favorable regions, solar power is still a few years away from true "grid parity"—the point when the price of solar electricity is on par with that of conventional sources of electricity on the power grid. The time frame is considerably longer in countries such as China and India, whose electricity needs will require large amounts of new generating capacity in the years ahead and whose cheap power from coal makes grid parity a more elusive goal.

The birth of a sector

The solar sector includes a diverse set of players, including the manufacturers of the silicon wafers, panels, and components used to generate much of today's solar power, as well as the installers who put small-scale units on individual roofs, utilities and other operators setting up enormous solar collection systems in deserts, and start-up companies striving for breakthroughs such as lower-cost thin-film technologies. All are operating in a dynamic environment in which long-held assumptions—subsidies, the primacy of incumbents, and the predominance of silicon-wafer-based technology—are being eroded.

Beyond subsidies

Government subsidies have played a prominent role in the growth of solar power. Producers of renewable energy in the United States receive tax credits, for example, and Germany requires electricity distributors to pay above-market rates for electricity generated from renewable sources. Without such policies, the high cost of generating solar power would prevent it from competing with electricity from traditional fossil-fuel sources in most regions.

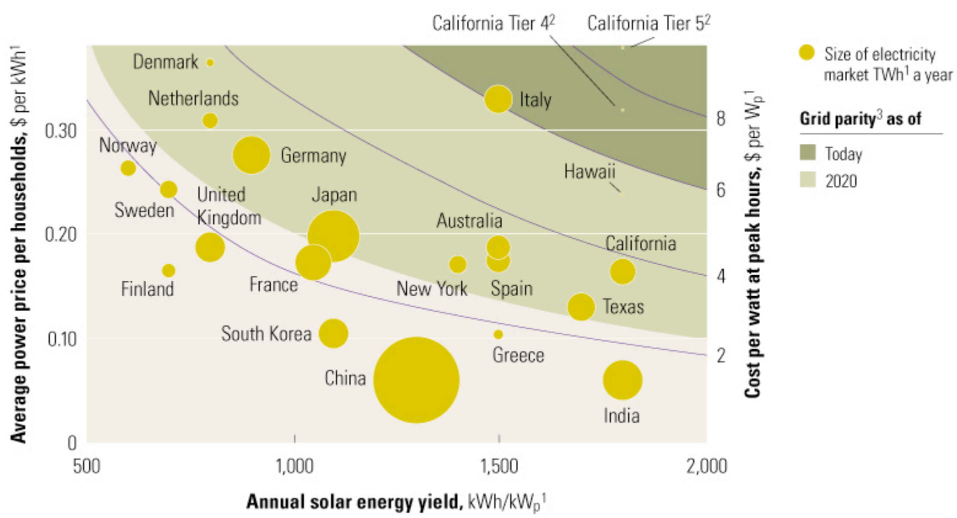
But the sector's economics are changing. Over the last two decades, the cost of manufacturing and installing a photovoltaic solar-power system has decreased by about 20 percent with every doubling of installed capacity. The cost of generating electricity from conventional sources, by contrast, has been rising along with the price of natural gas, which heavily influences electricity prices in regions that have large numbers of gas-fired power plants. These regions include California, the Northeast, and Texas (in the United States), as well as Italy, Japan, and Spain.

As a result, solar power has been creeping toward cost competitiveness in some areas. California, for example, combines abundant sunshine with retail electricity prices that, partly as a result of the state's policies, are among the highest in the United States—up to 36 cents per kilowatt-hour for residential users.[1] Unsubsidized solar power costs 36 cents per kilowatt-hour. Support from the California Solar Initiative [2] cuts the price customers pay to 27 cents. Rising natural-gas prices, state regulations aiming to limit greenhouse gas emissions, and the need to build more power plants to keep up with growing demand could push the cost of conventional electricity higher.

During the next three to seven years, solar energy's unsubsidized cost to end customers should equal the cost of conventional electricity in parts of the United States (California and the Southwest) and in Italy, Japan, and Spain. These markets have in common relatively strong solar radiation (or insolation), high electricity prices, and supportive regulatory regimes that stimulate the solar-capacity growth needed to drive further cost reductions (Exhibit 1). These conditions set in motion a virtuous cycle: growing demand for solar power creates more opportunities for companies to reduce production costs by improving solar-cell designs and manufacturing processes, to introduce new solar technologies, and to enjoy lower prices from raw-material and component suppliers competing for market share.

EXHIBIT 1

The growing competitiveness of solar power



[1]kWh = kilowatt hour; kWp = kilowatt peak; TWh = terawatt hour; Wp = watt peak; the annual solar yield is the amount of electricity generated by a south-facing 1 kW peak-rated module in 1 year, or the equivalent number of hours that the module operates at peak rating.
[2]Tier 4 and 5 are names of regulated forms of electricity generation and usage.
[3]Unsubsidized cost to end users of solar energy equals cost of conventional electricity.

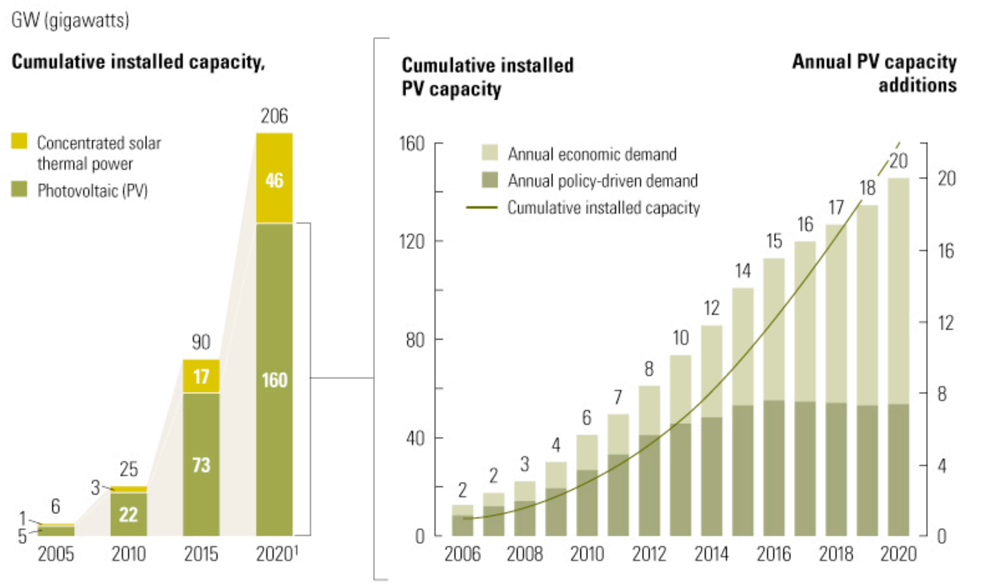
Source: CIA country files; European Photovoltaic Policy Group; Eurostat; Pacific Gas & Electric (PG&E); Public Policy Institute of New York State; McKinsey Global Institute analysis

We forecast global solar demand by estimating the payback period for customers in different countries and regions. (Payback estimates rest on projected system costs and power prices, as well as local sunlight and incentive schemes.) Our analysis suggests that by 2020 at least ten regions with strong sunlight will have reached grid parity, with the price of solar electricity falling from upward of 30 cents per kilowatt-hour to 12, or even less than 10, cents. From now until 2020, installed global solar capacity will grow by roughly 30 to 35 percent a year, from 10 gigawatts today to about 200 to 400 gigawatts[3] (Exhibit 2), requiring capital investments of more than $500 billion. Even though this volume represents only 1.5 to 3 percent of global electricity output, the roughly 20 to 40 new gigawatts a year of installed solar capacity would provide about 10 to 20 percent of annual new power capacity over that period.

This level of installed solar capacity would abate some 125 to 250 megatons of carbon dioxide—roughly 0.3 to 0.6 percent of global emissions in 2020.

EXHIBIT 2

The global solar market in 2020



¹Estimate uses base-case scenario. Aggressive scenario predicts 400 GW in 2020.

Evolving technologies

Our demand and capacity forecasts assume continued improvement in solar-cell designs and materials but neither a radical breakthrough nor the emergence of a dominant technology. At present, three technologies—silicon-wafer-based and thin-film photovoltaics and concentrated solar thermal power—are competing for cost leadership. Each has its advantages for certain applications, but none holds the overall crown. Major innovations and shifts in the relative cost competitiveness of these technologies could occur.

Companies that use either of the current photovoltaic technologies, which generate electricity directly from light, are striving to reduce costs by making their systems more efficient. In power conversion, efficiency means the amount of electrical power generated by the solar radiation striking the surface of a photovoltaic cell in a given period of time. For each unit of power generated, more efficient systems require less raw material and a smaller solar-collection surface area, weigh less, and are cheaper to transport and install.

Silicon-wafer-based photovoltaics. Although 90 percent of installed solar capacity uses silicon-wafer-based photovoltaic technology, it faces two challenges that could create openings for competing approaches. For one thing, though it is well suited to space-constrained rooftop applications (because it is roughly twice as efficient as current thin-film photovoltaic technologies), the solar panels and their installation are costly: larger quantities of photovoltaic material (in this case, silicon) are required to make the panels than are to make thin-film photovoltaic solar cells.[4] Second, companies are starting to approach the theoretical efficiency limit—31 percent—of a single-junction silicon-wafer-based photovoltaic cell; several now achieve efficiencies in the 20 to 23 percent range. To be sure, there is still room for improvement before the limit is reached, and clever engineering techniques (such as concentrating sunlight on solar cells or adding a number of junctions made of different materials to absorb a larger part of the light spectrum more efficiently) could extend it, though many of these ideas increase production costs.

Thin-film photovoltaics. The other important photovoltaic approach, thin-film technology,[5] has been available for many years but only recently proved that it can reach sufficiently high efficiency levels (about 10 percent) at commercial production volumes. Thin film trades off lower efficiencies against a significantly lower use of materials—about 1 to 5 percent of the amount needed for silicon-wafer-based photovoltaics. The result is a cost structure roughly half that of wafer-based silicon. This technology also has significant headroom to extend the cost gap in the long term.

But challenges abound. The lower efficiency of thin-film modules[6] means that they are currently best suited to large field installations and to large, flat rooftops. Furthermore, the longevity of these modules is uncertain; silicon-wafer-based photovoltaics, by contrast, maintain their output at high levels for more than 25 years. Of the most promising thin-film technologies, only one—cadmium telluride—has truly reached commercial scale, and some experts worry about the toxicity of cadmium and the availability of tellurium. A final complicating factor is that a new generation of nanoscale thin-film technologies now on the horizon could significantly increase the efficiency and reduce the cost of producing solar power.

Concentrated solar thermal power. The third major solar technology, concentrated solar thermal power,[7] is the cheapest available option today but has two limitations. Photovoltaic systems can be installed close to customers, thereby reducing the expense of transmitting and distributing electricity. But concentrated solar thermal power systems require almost perfect solar conditions and vast quantities of open space, both often available only at a great distance from customers. In addition, the ability of concentrated solar thermal power to cut costs further may be limited, because it relies mostly on conventional devices such as pipes and reflectors, whose costs will probably fall less significantly than those of the materials used in semiconductor-based photovoltaics. Nonetheless, several European utilities now regard concentrated solar thermal power as the solar technology of choice.

The road ahead

The extent and speed of this diverse and complex emerging sector's growth will depend on its ability to keep driving down the cost of solar power. No single player or set of players can make that happen on its own.

• The necessary technological breakthroughs will come from solar-component manufacturers, but rapid progress depends on robustly growing demand from end users, to whom many manufacturers have only limited access.

• Utilities have strong relationships with residential, commercial, and industrial customers and understand the economics of serving them. But these companies will have difficulty driving the penetration of solar power unless they have a much clearer sense of the cost potential of different solar technologies.

• In some regions, regulators can accelerate the move toward grid parity, as they did in California and Germany, but they can't reduce the real cost of solar power. Poor regulation might even slow the fall in prices.

Although these considerations make it difficult to predict outcomes and to prescribe strategies, certain economic principles do apply.

Solar-component manufacturers

The fundamentals are clear for photovoltaic-component manufacturers that hope to remain competitive: there's no escaping significant R&D investments to stimulate continued efficiency improvements, as well as operational excellence to drive down manufacturing costs. Furthermore, in view of the technological uncertainty, established silicon-wafer-based companies should hedge their bets by investing in advanced thin-film technologies.

Some manufacturers have considered establishing partnerships or vertically integrating—approaches that could give them access to supplies, customers, and financing but might also lock them into the wrong technology. To make the right trade-offs, the manufacturers of components for silicon-wafer-based and thin-film technologies should focus on fundamentals, such as manufacturing costs, efficiency improvements, and the movement of prices for raw materials.

Raw materials. Polysilicon is the main raw material for silicon-wafer-based solar-cell manufacturers, which now consume more of it than the semiconductor industry does. Over the last two years, shortages and price spikes have been the result.

Cell manufacturers shouldn’t overreact to this tight environment by making big bets on supply and demand contracts for polysilicon or by forging onerous partnerships with suppliers. High margins have encouraged incumbents to add capacity and have attracted new entrants. Many observers have therefore been predicting that global polysilicon production capacity will at least triple from 2005 to 2010, and our forecasts indicate that demand for the material will only double during the same period. This mismatch suggests that the spot price of polysilicon wafers could drop from over $200 a ton to the variable cost of production—as little as $25 to $50.

Production process technology. The way companies manufacture solar cells has the largest impact on the cells' efficiency and their cost. Many incumbents have invested heavily in developing proprietary manufacturing processes. Some start-up cell manufacturers, by contrast, buy entire manufacturing lines from equipment companies such as Applied Materials.

Cell manufacturers are valuable partners for equipment companies hoping to tap into the growth of the solar sector. The equipment companies need formal partnerships that will allow them to retain ownership of the intellectual property associated with their manufacturing processes—a difficult trick that these vendors tried (and failed) to pull off in the semiconductor sector. The same thing could happen again unless equipment providers can figure out how to make their offerings extremely cost competitive and difficult for operators to imitate or enhance.

Producing in low-cost regions. Many leading silicon-wafer-based photovoltaic solar companies are located in high-wage countries. These manufacturers produce cells that are typically more efficient than those produced in lower-wage countries; for example, many German and US cells achieve an efficiency of 20 percent or more, compared with 15 to 16 percent for Chinese ones. Yet countries like China and India will inevitably gain an overall cost advantage by developing the skills needed to produce more efficient cells. Companies in regions with high labor costs should therefore constantly monitor the benefits and risks of locating their next plant in an area that offers lower-cost labor and generous subsidies.

Utilities

Although the distributed nature of solar power might seem to clash with the utilities’ business model of centralized electricity generation, these companies do have assets in the solar era, starting with strong customer relationships. They are also in a good position to integrate electricity generated at large numbers of different locations (such as rooftops) into the existing network. Many utilities could use their advanced metering infrastructure to calculate the full value of solar power during peak times.

One way of leveraging these assets would be to form partnerships with component manufacturers. Building profitable partnerships will require utilities to develop new skills, such as installing and managing solar-generation capacity, as well as deciding which solar technologies best suit their service territories.

The technology that currently seems most attractive for utilities is concentrated solar thermal power, because it involves centralized electricity generation—much as traditional coal, nuclear, and hydroelectric facilities do—and is today's low-cost solar champion. Its long-term cost prospects, though, are less favorable than those of some emerging photovoltaic technologies, so choosing it now is in effect a strategic bet on how quickly relative costs and local subsidy environments will change.

While the natural tendency might be to postpone investments until the technology picture becomes clearer, sitting on the sidelines could hurt the utilities. As the cost of solar energy decreases, the growing number of companies that will probably enter the business of installing solar equipment could cut off some utilities from their customers. Installers buy solar panels, mount them in homes and businesses, and then lease them in return for a stream of payments lower than prevailing electricity rates but still high enough to earn a healthy return on the panel investment. Since people who now pay the highest electricity rates would be the most likely to switch, utilities would lose their most valuable customers.

One way of coping would be to forge relationships with solar-cell and -module manufacturers that could help utilities claim a portion of this emerging business while they gain experience integrating distributed generating capacity into the grid. It should be in their interest to strike up such partnerships quickly, before disintermediation reduces their attractiveness as partners, since savvy manufacturers will pit them against installers in a quest for the most favorable financial arrangements.

Another approach for the utilities involves a regulatory strategy—for example, they could try to persuade regulators to add solar investments to their rate base (the expenses and capital investments that regulators use to calculate fair retail electricity prices). Although such a readjustment would raise electricity rates, utilities could argue that the long-term benefits would be significant: increasing their reserve margins while making conventional power generation investments unnecessary, dampening future rate increases from rising fuel prices, meeting environmental targets, and accelerating the decline in solar-power costs. This approach yields a fixed return on capital that might ultimately be lower than what would be possible if utilities bet successfully on the right technologies, but it also mitigates investment risk.

Governments and regulators

The decisions of regulators will affect not only utilities but also the entire solar sector. During the march to grid parity, well-understood and targeted subsidies will be critical to build the confidence of investors and attract capital. The impact of government policies in rapidly growing emerging markets such as China and India will be particularly important for the pace of the sector's growth. Our base-case forecasts do not include aggressive growth in these markets. But if China installed rooftop solar panels on, say, 13 percent of all new construction in 2020, the country would add 15 gigawatts of solar capacity a year, about 40 percent of the world's annual increase. Similarly, government policies encouraging the use of electric vehicles may also accelerate the growth of solar demand.

While the optimal regulations for different countries will vary considerably, all governments should focus on a few major factors.

- *Clarify objectives.* Before establishing policies, regulators must decide whether they want to increase energy security, lower carbon emissions, build a high-tech manufacturing cluster, create jobs for installers, or any combination of these goals. Once regulators have identified and prioritized them, appropriate policies can be developed to stimulate specific parts of the sector.

- *Reward production, not capacity.* Subsidizing capacity rewards all solar-power installations at the same rate, regardless of their cost-efficiency. Production-based programs, which reward companies only for generating electricity, create incentives to reduce costs and to focus initially on attractive areas with high levels of sunlight.

- *Phase out subsidies carefully.* In virtually every region of the world, solar subsidies are still crucial; in 2005, when they expired in Japan, capacity growth declined there significantly. But since solar power could eventually be cost competitive with conventional sources, regulators must adjust incentive structures over time and phase them out when grid parity is reached.

Solar energy is becoming more economically attractive. Component manufacturers, utilities, and regulators are making decisions now that will determine the scale, structure, and performance of this new sector. Technological uncertainty makes the choices difficult, but the opportunities—for companies to profit and for the world to become less dependent on fossil fuels—are significant. Q

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Notes

[1] Residential retail electricity prices in California increase with the end customer's usage.

[2] The California Solar Initiative provides $3.1 billion of subsidies to install 3 gigawatts, or 3 billion watts, of capacity by 2017.

[3] One gigawatt = one billion watts. As a point of reference, the capacity of a typical coal plant is about 0.6 to 1.0 gigawatts.

[4] Silicon absorbs light less well than the materials currently used to make thin-film photovoltaic solar cells, so they must be thicker to absorb the same amount of light.

[5] Leaving aside nanoscale materials and technologies, there are currently four promising thin-film technologies: cadmium telluride, copper indium gallium diselenide, amorphous silicon, and thin-film polysilicon.

[6] A module is a collection of cells that have been connected together to generate higher current and voltages.

[7] Photovoltaic systems use semiconductor materials to convert light directly into electricity. Concentrated solar thermal power uses mirrors to reflect sunlight onto fluids, which heat up and then pass through a heat exchanger to generate steam and drive a turbine. Such technologies include parabolic troughs, power towers, linear Fresnel reflectors, dish Stirling systems, and solar chimneys.

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