Avoiding Sunstroke

Assessing National Competitiveness in the Global Solar Race

Results from a Scenario-Planning Workshop at Stanford University

Jeffrey Ball
Scholar-in-Residence
Steyer-Taylor Center for Energy Policy and Finance
Stanford University

Jonas Meckling
Senior Adviser
German Federal Ministry for the Environment

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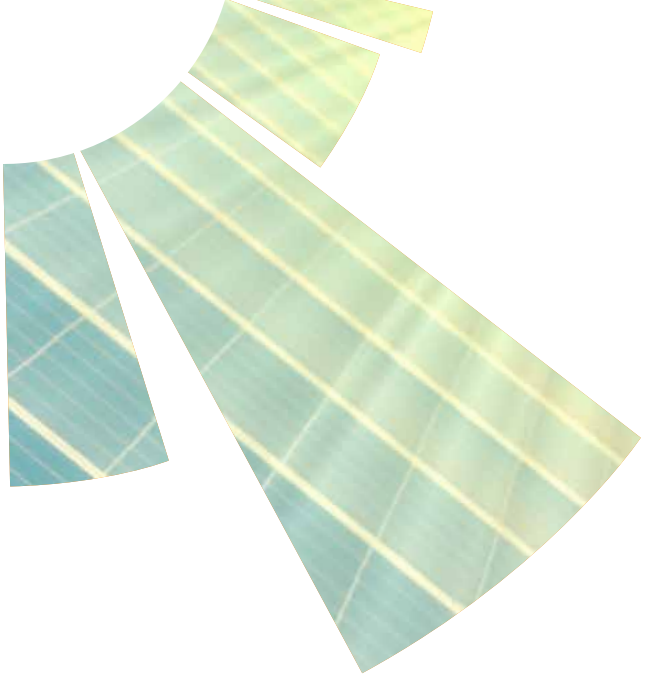

About the Authors

Jeffrey Ball, formerly *The Wall Street Journal*'s environment editor, is scholar-in-residence at Stanford University's Steyer-Taylor Center for Energy Policy and Finance, a joint initiative of Stanford's law and business schools. His recent writing about energy and the environment has appeared in such publications as *Foreign Affairs* and *Slate*. He heads a Stanford project exploring the relationship among countries, particularly between China and the U.S., in scaling up cleaner energy. Before coming to Stanford in 2011, he spent 14 years at *The Wall Street Journal* as a reporter, columnist and editor, focusing on energy and the environment. He is a member of "The Experts," a *Journal* panel of energy experts who write on WSJ.com, and he speaks frequently about energy and environmental issues. He graduated from Yale University. He can be reached at jeffball@stanford.edu. Follow him on Twitter @jeff_ball.

Jonas Meckling is Senior Advisor to the German Federal Ministry for the Environment, the lead agency for Germany's clean-energy policy. He advises on international clean energy and climate cooperation. Before working in government, he was a Research Fellow at Harvard University's John F. Kennedy School of Government for five years, most recently with the Geopolitics of Energy Project at Harvard. He is the author of various articles and two books, the latest of which is *Carbon Coalitions: Business, Climate Politics, and the Rise of Emissions Trading* (MIT Press, 2011). He previously worked at the European Commission and the Allianz Group. He holds a Ph.D. in International Political Economy from the London School of Economics and Political Science. He can be reached at jonas.meckling@bmu.bund.de.

More information about Stanford University's Steyer-Taylor Center for Energy Policy and Finance is at energyfinancecenter.stanford.edu.

More information about the German Federal Ministry for the Environment is at bmu.de/en.

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In addition, the authors thank the approximately 20 solar-industry executives who participated in the workshop. Many of them flew in from other states and countries to take part in the Stanford discussion. The broad range of their experiences and views — and their straightforwardness in expressing them — was crucial to the workshop's insight.

This report, however, remains the work of the two authors. They intend it not as an expression of their own views but as an accurate picture of the wide-ranging discussion at the Stanford workshop. They alone bear responsibility for its contents.

Executive Summary

Stanford University's Steyer-Taylor Center for Energy Policy and Finance and the German Ministry for the Environment brought together some 20 top global solar executives for a day-long workshop at Stanford in summer 2013 to probe a crucial but little-explored question about the economic competitiveness and impact of this small but rapidly growing energy sector. At issue: What will the globalizing solar industry look like in 2025? Which sorts of companies, and which countries, will do what?

The industry leaders, many of them chairmen or chief executives of major solar firms, sketched out the sector's plausible future under four scenarios. They reached several conclusions, all of them subject to wild cards detailed in the report:

"Glocalization": The solar industry started with small, nationally focused companies. In the future, it will follow a pattern of what might be called "glocalization": a handful of dominant global players, each doing different things in different end markets around the world. Which countries and companies will do what in this "glocal" model varies depending on the scenario. Those differences are crucial. They will, to a large extent, dictate who in the industry makes money and who doesn't.

Countries' comparative advantages: Different countries will play different roles in the global solar industry than they do now. The participants generally felt that, in a global market in which goods are allowed to trade freely, companies headquartered in the U.S. and Germany are likely to manufacture only the most sophisticated solar components in their home markets, and that companies headquartered in China and in even-lower-cost countries will dominate the production of commodity goods. Participants disagreed, however, about where in the world those companies would do their manufacturing.

Solar beyond subsidies: The solar industry has grown based overwhelmingly on government incentives. Those subsidies will subside, participants agreed. Though solar power's costs have fallen sharply in recent years, workshop participants felt strongly that the costs need to fall much more for solar to become a sizeable slice of the total global energy pie.

Problems plugging in: As the cost of solar power falls, political and technical difficulties connecting solar installations into power-transmission grids are emerging as major challenges to solar's growth.

Introduction

A Different Question

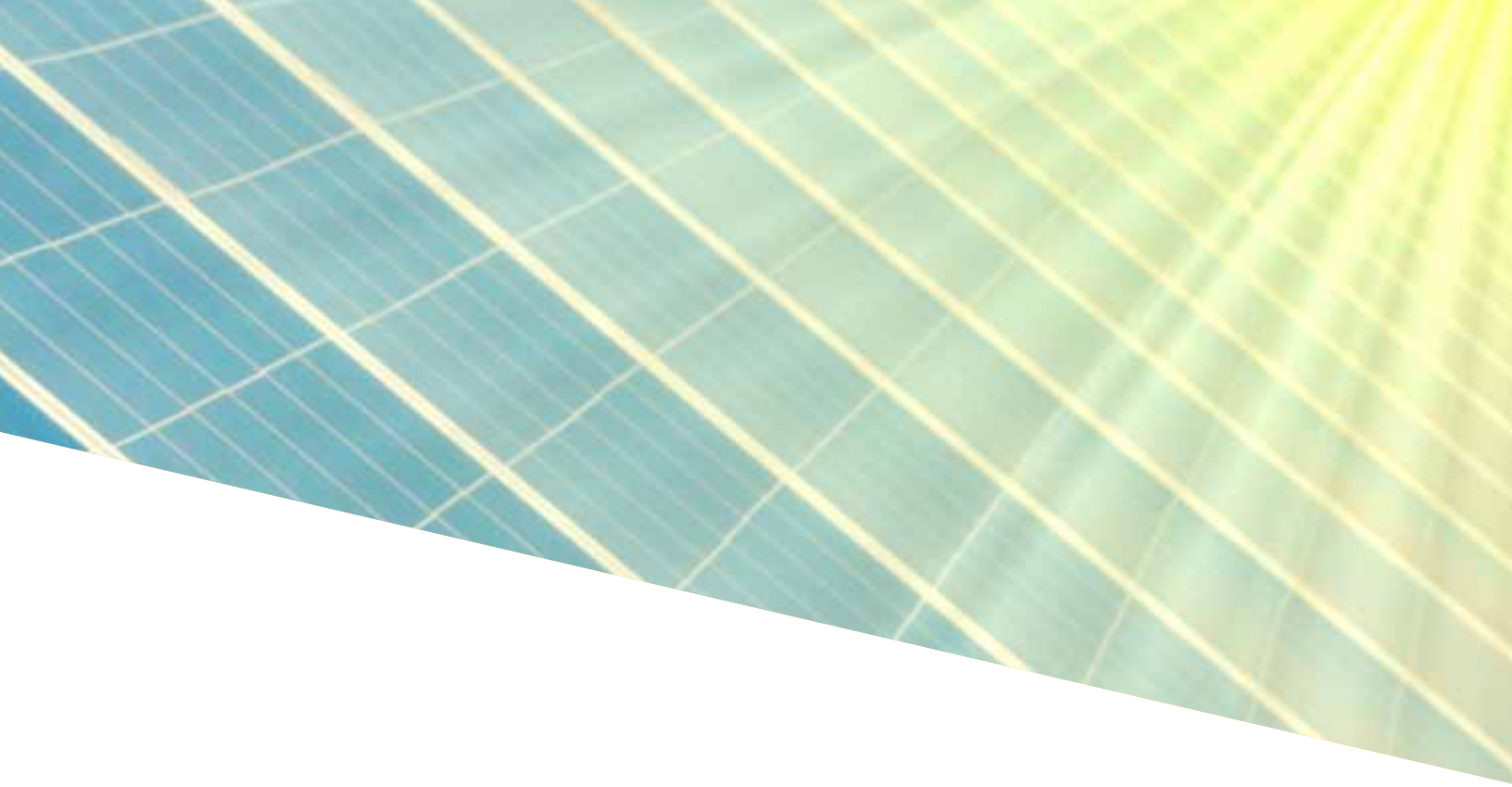
The globalizing solar industry is at a transformative point, benefiting from big technological gains and beset by big geopolitical fights. As the industry develops over the next decade and beyond, who will win, who will lose and how will those shifts play out — among companies across the solar industry, among companies in other industries and among nations?

To illuminate the potential contours of tomorrow's global solar industry, Stanford University's Steyer-Taylor Center for Energy Policy and Finance and the German Federal Ministry for the Environment brought together some 20 top global solar executives in summer 2013 for a daylong workshop at Stanford. We probed a critical but little-asked question: As the solar industry continues to globalize, which parts of it will occur in which parts of the world?

To answer it, we conducted what we believe is a first-of-its-kind exercise: a tightly structured yet freewheeling discussion with industry leaders that sought to chart in detail how, in four different scenarios, the solar industry might develop between now and 2025. The scenarios differ sharply among each other. Each paints a plausible picture of what the solar industry might look like 12 years from now.

The question at the center of the workshop — Who will do what in the solar industry of the future? — carries increasingly high stakes both for the industry and, as solar power grows, for the world. Today, solar power is a tiny slice of the global energy pie. Yet its costs are falling, and its penetration in many parts of the world is rising. That is prompting investors, business executives and policymakers to consider the prospect that solar energy could start to meaningfully affect both their corporate bottom lines and their national energy mixes. But how?

The group at the workshop included executives from around the world and across many sub-sectors of the industry. They lead companies based in China, Germany, Italy, Korea and the U.S. They lead companies that produce polysilicon, solar panels, inverters and other components; that lease solar systems to consumers; that finance solar installations; and more.



The world has no shortage of solar-power conferences and reports. The Stanford workshop was designed to be different.

It was different, first, in intent. Its goal was not to predict how big solar power might get. Nor was it to advocate — not for any policy and not for more solar power. Its goal was to take a realistic, unbiased look at the way that comparative advantage might play out in the globalizing solar industry. Participants considered all parts of the solar enterprise: research and development; the production of polysilicon, wafers, cells and modules; the integration of various components into full systems that supply solar energy; and the development, financing, assembly and operation of solar projects.

The charge to the industry leaders who participated in the workshop was to chart, in as much detail as possible, how the industry might develop in four different scenarios: Global Sun, Solar Systems, Sunblock and Total Eclipse. As this report will detail, the workshop framed those scenarios to take into account various economic trends now transforming solar energy. The workshop aimed to flesh out, within each scenario, how the industry's players might position themselves to maximize both their own financial strengths and solar energy's overall cost-competitiveness. In short, with solar power now growing rapidly enough to be taken seriously as a global energy sector, the workshop sought to assess how the sector might evolve between now and 2025 — that is, which players in the industry might do what.

The Stanford workshop was different, too, in structure. Several of the companies whose executives took part in the workshop compete head-to-head with each other every day. Many of the participants noted that they never had been in a room with so many top solar executives from around the world, let alone spent a day debating scenarios and strategies with them. Many said it was the chance to interact so deeply with such a varied group of industry insiders that led them to travel to Stanford for the workshop.

To encourage honest discussion and debate, the workshop was held under the Chatham House Rule: Though the workshop's discussion would be reported publicly and in detail, specific statements wouldn't be attributed to specific people. Thus, though this report includes many quotes from the workshop, it doesn't identify who said what.

This report, like the workshop on which it's based, is qualitative rather than quantitative. It also is speculative, with all the messy uncertainties that define speculation. It is intended to provide a snapshot of what one influential and representative slice of the global solar industry thinks about the industry's future — nothing more, nothing less. That thinking, of course, may prove right and it may prove wrong. Yet each of the scenarios it explores is a plausible future. Scenario-planning long has proven a useful tool for companies and policymakers to assess both what's coming at them and what they'd need to do to shape the outcome. Today, things are changing fast in the global solar industry. Against that backdrop, this report, and the Stanford workshop on which it's based, marks an attempt to look into four very different but equally instructive crystal balls.

Solar's Status, Bottom Lines and Wild Cards

Solar power today

Solar, also known as photovoltaic, or PV, power, accounted for just 0.3% of global electricity generation in 2011, according to the International Energy Agency (IEA). It represented somewhat larger slices of total electricity production in a few countries: Italy generated 3.6% of its electricity from PV; Germany, 3.2%; and Spain, 2.5%, according to IEA figures for 2011.

Even those small numbers represent significant growth for solar power in recent years. Behind them are massive changes transforming the industry — changes that raise the possibility that solar power could become a significantly bigger portion of the global energy mix.

Solar-panel prices fell by between one-half and two-thirds in the two years ending September 2012, according to the International Renewable Energy Agency. That price drop, moreover, is quickening, because the bulk of reduction came in the single year ending September 2012, when panel prices fell between 30% and 40%, the International Renewable Energy Agency says. The drop in prices has occurred largely because the industry built too much manufacturing capacity too quickly; that produced a glut of solar panels on the global market, forcing manufacturers to cut both the prices they were charging for their panels and their internal costs in order to stay competitive. The price drop is producing two very different results. For consumers, at least in sunny places with high conventional-electricity prices, it is making solar more economical. For the solar industry, particularly for solar-equipment manufacturers, it is causing an uproar: Many companies are going bankrupt, and those still around are having to scramble to get more efficient. So the future contours of the global solar industry are very much in flux.

Globally, Germany, the United States, Italy and China, in that order, had the most solar-power capacity at the end of 2012, according to REN21, a global public-private network that monitors renewable-energy trends. China, though, is adding solar capacity faster than any other major country. China's solar-power capacity doubled in 2012, and China is widely expected soon to become the world's largest solar-power generator. The Chinese government announced earlier this year that the country intends to increase its installed solar-power capacity more than fivefold, to 35 gigawatts, by 2015. (Capacity represents the amount of electricity that the installed base of solar equipment could generate under optimal conditions; generation, the metric in the IEA figures at the start of this section, is the amount of electricity that installed equipment actually produced.)

The dollars pouring into solar power also are rising. In 2012, according to REN21, $140.4 billion of what the group calls "new investment" poured into solar energy — far more new investment than any other renewable energy source received. Between 2004 and 2012, according to REN21, new investment in solar power increased more than 11-fold — a significantly steeper increase than for any other renewable energy technology.

Bottom lines

This report details the Stanford workshop's methodology, its scenario discussions and its conclusions. The bulk of the report sketches — in the narrative format that the participants were asked to lay out — the way these industry insiders think each of the four scenarios might develop. These scenario sketches are crucial, both because they point up big disparities in how the industry might develop and because they underscore key uncertainties that the participants flagged. Still, the workshop participants reached several top-level conclusions that they believe are likely to define the industry's next stage of growth:

"Glocalization": The solar industry started with many small companies, each focused on the national market in which it sat. It has grown around a number of multinational players shipping their centrally produced wares around the world. In the future, the workshop participants believe, the industry will follow a pattern of what might be called "glocalization": a handful of dominant global players, each doing different things in different end markets based not on any national allegiance but on its own corporate views of what's economically efficient. (Importantly, as the scenario descriptions explain, what a company sees as economically efficient depends greatly on what rules governments impose.) This "glocal" model of the solar industry would resemble the structure of the auto industry: a small number of multinational players that differentiate their products and business models in different markets based on differing regulatory models and consumer preferences. In short: global brands, local manufacturing.

Countries' comparative advantages: Different countries will play different roles in the global solar industry than they do now. Those roles will depend on which of the scenarios plays out, and in what order. In particular, the roles of the three countries that now dominate the global industry — China, the U.S. and Germany — will change, with potentially significant ramifications for the sort of solar companies that are and aren't competitive in each country. The participants generally agreed that, in a global market in which goods are allowed to trade freely, companies headquartered in the

U.S. and Germany will manufacture only the most sophisticated solar components in their home countries, and that companies headquartered in China and in even-lower-cost countries will dominate the production of commodity goods. Notably, however, workshop participants disagreed about exactly where in the world those companies would do their manufacturing. Some thought manufacturing would shift continually to whatever countries had the lowest labor and manufacturing costs. Others thought significant parts of solar manufacturing — particularly module assembly — would occur wherever around the world solar demand had grown large enough to justify a factory. Interestingly, at a time when tariff disputes among the world's solar-panel makers dominate headlines, workshop participants from various countries believed these trade disputes would grow less important. Most said the solar industry already has become so global that most countries have more to lose than to gain by such tariffs. Moreover, they predicted, where such barriers exist, companies will circumvent them, for instance by manufacturing in third countries.

Solar beyond subsidies: The solar industry has grown based overwhelmingly on government incentives. Those subsidies will subside, participants agreed, though exactly how and when isn't clear. That will put more pressure on the industry to slash costs. Participants said that, in a number of markets around the world, typically sunny places with high conventional electricity prices, solar power is nearing price competitiveness with conventional electricity — at least when government subsidies for solar power are taken into account. The electricity market calls this "grid parity," and the specter that solar might reach grid parity in more places raises the possibility that solar energy one day might be able to thrive without subsidies. (What constitutes a subsidy and how subsidies for solar power compare with subsidies for other energy sources are questions on which people strongly disagree.) Yet although the solar industry has achieved major cost reductions, participants in the workshop felt adamantly that their industry still needs to wring out significant excesses in cost. As one participant put it, the industry is "in its infancy — very inefficient."

Problems plugging in: As the cost of solar power falls, what's emerging as a major challenge to high solar penetration is the technical and political — and therefore economic — difficulty of connecting solar installations into power-transmission grids. "Markets have learned how to deal with financial volatility. Energy markets now need to learn to deal with physical volatility," one executive said. The economic implications of larger-scale solar use are prompting battles around the world between established utilities and newer solar providers, in such places as China, the U.S. and Germany.

Wild cards

Just as important as the main trends that the workshop participants identified are several key uncertainties that could shift the solar industry's trajectory in big ways. Among these wild cards, according to the workshop's participants:

The price of money: The solar industry is proportionally more capital-intensive than traditional energy industries, workshop participants noted. That's because it's still installing its foundational infrastructure and because its fuel is effectively free. Particularly in some parts of the world, such as the U.S., the solar industry has paid a premium for capital, in part because it gets much of its capital through a tax-equity market whose funders get significant returns. Nevertheless, workshop participants agreed, today's historically low interest rates have been a boon for solar's growth, and an uptick in interest rates probably would be particularly problematic for the industry. "Money is free right now," said one participant, and higher interest rates would be, for solar even more than for many other energy sources, "a headwind."

The price of coal and gas: Low natural-gas prices in the U.S. already are making it harder for solar power to compete. What happens to gas prices will bear significantly on solar's prospects, workshop participants said. If governments impose a price on carbon emissions, coal and, to a lesser extent, gas, likely will be disadvantaged, and solar likely will be given a leg up. On the other hand, if technologies to capture and safely store carbon dioxide emitted from coal- and gas-fired power plants prove economical at scale, solar will have a harder time competing. One participant dubbed this potential a "coal black swan."

The pace of technology: Several participants said the efficiency gains solar panels have made have been incremental, albeit cumulatively significant. Solar's future, they said, will depend in large part on how quickly new technologies — from radically more efficient solar panels to energy-storage systems — become economical. Though controllable factors such as government research-and-development spending can influence the pace of technological development, ultimately it's impossible to predict whether, when and how technological breakthroughs might happen. In particular, participants said, slow progress toward viable energy storage could seriously stymie solar.

The Four Scenarios

The workshop's four scenarios revolve around two key factors likely to significantly influence the structure of the global solar industry over the next decade and beyond. One is the level of penetration of solar energy in overall power markets. The other is the extent to which national markets in the solar industry are open or closed — both to the participation of foreign-based companies and to the integration of solar power, regardless of who produces it, into the national energy mix.

The level of penetration of solar energy in power markets depends on a number of factors, such as the extent of government subsidy, the price of fossil fuels, the price of solar modules and the nature of regulations governing solar deployment. Those factors, in turn, depend on various sub-factors, such as regulation around fossil-fuel production, improvements in the efficiency of solar cells and constraints on carbon emissions.

One rationale in picking a metric as broad as solar's total power-market penetration was that it gave workshop participants the latitude to take into account their views on all of these — and other — factors. Another rationale was that this workshop's goal wasn't to assess what level of power-market penetration solar might achieve. (Plenty of market analysts are trying to do that.) Rather, as noted above, the workshop's goal was to assess what the structure of the global solar market might look like under different potential levels of overall solar penetration.

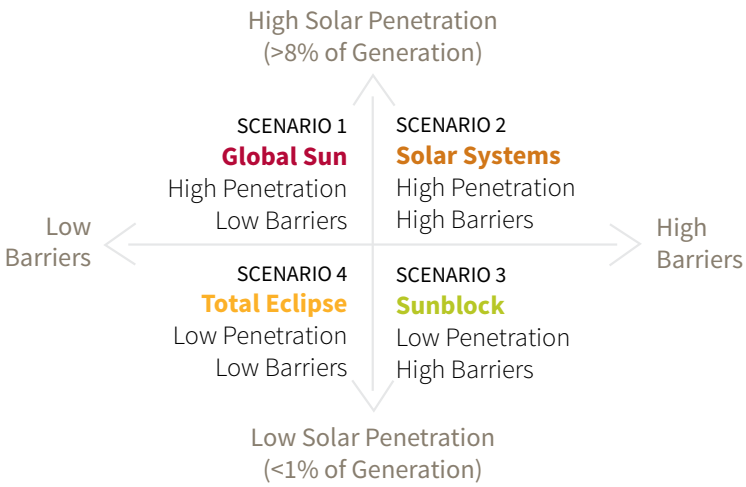
The extent to which global trade and national markets in the solar industry are open or closed takes into account such specific issues as tariffs, local-content rules and other restrictive trade policies imposed by governments. It also considers differing levels of government subsidization of the solar industry, since differences in subsidy levels across geographies tend to skew the global market (for good or for ill, depending on one's point of view). And it includes regulatory requirements within individual countries that act as international barriers to the solar trade; some countries, for instance, have costlier requirements for local-government approval of solar projects than other countries do. The goal in this workshop was not to pass judgment on whether such policies are good or bad. As with the first metric, the goal was to assess what the global solar market would look like under different potential levels of market openness.

The intersection of those two factors — the level of market penetration and the extent to which markets are open or closed — produced the workshop's four scenarios: Global Sun, Solar Systems, Sunblock and Total Eclipse.

As workshop participants divided into four groups, each of which sketched one of the scenarios, they were asked to consider a number of key cross-cutting questions:

- What roles do the major industry players — notably the U.S., China and Germany — play in each of the scenarios? As technological innovators? As manufacturers? As deployers? And within each scenario, how does each country's role change between now and 2025?

The Global Solar Industry in 2025: 4 Views



- How is innovation likely to differ across the different scenarios? How is it likely to change over time?

- Who are the key industry players in each scenario: Incumbent utilities? Incumbent solar firms? Oil and gas majors? Electronics companies? Any entirely new entrants — and if so, who?

- How do companies in the solar industry organize themselves across scenarios? Do they integrate vertically and globally? Or are there lots of local players?

- What happens to the price of solar power under each scenario?

- Between now and 2025, does the world stay in one scenario? Or does it move from one to another — and, if so, in what sequence?

What follows in this report is a sketch of what the group thought the global solar industry would look like in 2025 under each of these four scenarios. For each scenario, this report seeks to tell a story: the broad economic and political forces that would be necessary for the scenario to occur; the results of the scenario for companies in the solar industry; and the results of the scenario for individual countries that play in the global solar industry.

SCENARIO 1

Global Sun

High Penetration, Low Barriers

This is nirvana for the solar industry — "our dream scenario," as one of the participants said. It's a scenario that many of those at the workshop said they're skeptical will come about.

Drivers

In this scenario, a variety of factors combine to push solar power to generate more than 8% of global electricity — roughly 25 times what the International Energy Agency says is today's level. First, natural-gas prices rise from today's historic lows in the U.S., and they remain high in both Asia and Europe. The shale-gas revolution loses steam, as reserves prove technically harder to produce and as environmental regulations impede shale-gas development. Second, public concerns about climate change reach a groundswell, as severe weather events are linked in the public mind to climate change and thus boost the political push for policies to promote renewable-energy sources such as solar. Together, those factors move governments around the world to impose, in the coming years, a range of policies aggressively subsidizing solar power and spurring energy users to adopt it. Most important, the U.S. imposes a price on carbon, and the world's other major economies follow suit. At the same time, governments impose long-term requirements on their power producers to generate higher percentages of their electricity from renewable sources.

As policymakers push hard to help solar along, scientists produce major technological breakthroughs in solar power's efficiency — step changes of the sort that workshop participants agreed haven't happened in the past. "In the last five years, we haven't really seen a technological breakthrough," one participant said. "All we've seen is efficiency [improvements] and cost reduction in manufacturing." Participants said that, to increase the chances of such breakthroughs — that is, to move beyond today's incremental gains with polysilicon-based solar panels — governments would have to significantly ramp up research-and-development spending on solar electricity. Said one attendee: "We need other forms of PV that haven't seen big adoption yet."

Absent any one of these requirements — a rise in gas prices, a major government policy push or major technological breakthroughs — this rosy-for-solar scenario won't come to pass, participants agreed. "If gas is cheap and there's no public policy to coerce the development of renewables, this is not happening," one participant said. It will require "a radical shift in U.S. sentiment and politics. And if that's not possible," said another, "I don't think this scenario is going to play out."

As governments increase their support for solar, the solar industry itself matures. It adopts uniform reliability standards for solar equipment — standards that the capital markets believe to be credible. That, in turn, gives investors confidence to finance a massive solar expansion.

Results for companies

Solar is, in a word, big. It grows in the form of both large-scale solar farms and rooftop solar systems.

That draws new large players into the solar business. Global oil companies enter the market in a significant way, focusing not on the business of solar panels but on the business of producing solar-based transportation fuels. Commercializing work previously underway in labs, they use sunlight to produce such fuels as hydrogen and methane, and then they refine those fuels into higher-density liquid transportation fuels. The established players have the benefit of existing infrastructure; in producing these solar-based transportation fuels, they exploit the liquid-fuel pipeline network. Global chemical and electronics makers also enter the solar business aggressively. So do regional electricity producers; they're motivated by concern that, if they don't start selling solar systems themselves, they'll lose material numbers of customers. "For utilities, you're either smart and you adapt, or you're going to die," said one participant, reflecting a sentiment voiced to varying degrees by a number of workshop attendees — none of whom, it should be noted, represents a utility. According to one participant, unless this happens — unless a few very large firms from established industries emerge as solar leaders — solar power won't achieve the innovation necessary to expand it into a significant energy source.

The solar-equipment industry, meanwhile, undergoes a massive consolidation. One participant described the upshot this way: "There will be a few global players that dominate the world." Another said that trend already is developing, with an oligopoly of perhaps three dominant international players in the making.

But those global leaders each manufacture in many countries. Unimpeded by protectionist barriers, these companies build their

Global Sun continued

factories in consumer markets according to a solar-industry rule of thumb: Once a company is selling about 1 gigawatt of solar panels annually in a market, it decides that building a factory in that market makes sense. “At the end of the day,” one participant said, “PV still needs to be assembled locally. The weight and the transportation costs are really high.” This arrangement of a handful of dominant global manufacturers with factories in local markets around the world resembles another industry: “The comparison to the auto industry is very clear,” one participant said.

Global players emerge, too, in the business of designing and building large-scale solar farms. Project-management firms that already today have global reach could move significantly into solar, particularly given their access to institutional investment. But important developments in solar industry differ country-by-country. Among them: innovation in business models, particularly in new ways to market and finance solar installations. The techniques that the solar industry uses to deploy its technology in different markets around the world vary, in large part because tax structures — key drivers in a capital-intensive business such as solar — vary regionally. In certain markets new distribution channels emerge for rooftop solar systems: do-it-yourself stores, electric-equipment dealers, plumbers and providers of cable and telecommunications services.

Results for countries

China is a dominant global solar-panel manufacturer. Today its solar companies are struggling, though they have shown some recent signs of financial improvement. In this scenario, China intensifies a two-pronged solar-policy push that it’s now beginning to implement: developing a large domestic solar market and consolidating its fragmented solar-manufacturing industry into a few dominant players. The result: At least one or two very large Chinese solar manufacturers emerge as long-term global leaders. At first, they concentrate on the massively expanding Chinese domestic solar market — the world’s largest, buoyed by the Chinese government’s ambitious deployment targets. Then, they expand abroad. Importantly, in their international business they manufacture in end markets, building factories in places where the solar market has grown enough to justify it. In this, the growth of Chinese solar companies mirrors the expansion of Japanese auto companies into the U.S. and other international markets over the past 30 years. Meanwhile, in an effort to promote technological innovation among Chinese solar companies, China’s government-affiliated banks broaden their solar lending from manufacturing — their traditional focus— to research and development.

China is important to the global solar industry in two other ways. It invests massively in the rollout of electric vehicles — later prompting similar investment by the U.S. and Europe — and those vehicles boost demand for electricity from the sun. In addition, China becomes a leading innovator in solar-panel technology.

The solar industry becomes a complex global ballet. Chinese and Korean companies dominate solar-panel manufacturing; they produce their wafers and cells in low-cost countries and they assemble their modules in end markets around the world. (This plays to the strengths of Korean companies, which traditionally have focused on exporting rather than on selling into their comparatively small domestic market.) The U.S. and Germany dominate in innovation, and in limited types of manufacturing beyond panels, particularly of complex power-electronics components. They also excel in developing systems to integrate solar panels into the electrical grid; more economically efficient business models to deploy solar energy, such as solar-panel-system leasing; and transmission-and-distribution technology.

Workshop participants disagreed on a question now generating much discussion in policy circles in both the U.S. and Germany: whether these industrialized countries would need to push to grow solar-equipment manufacturing within their borders as a prerequisite for maintaining a position of global leadership in solar-technology innovation.

In sum, said one participant, this scenario is “economically rational globalization” for solar power.

SCENARIO 2

Solar Systems

High Penetration, High Barriers

This is a complicated world in which solar power grows significantly but does so within the confines of protectionist national policies. Solar blooms within "walled gardens," as one participant put it. The protectionist barriers mean that, as another attendee noted, "costs aren't optimized" globally, so the cost of scaling up solar under this scenario is higher than under Global Sun.

Drivers

The drivers for this scenario are similar to those for Global Sun: higher fossil-fuel prices; an aggressive suite of government-funded solar incentives; government restrictions on carbon emissions; and solar-technology breakthroughs in the lab.

The pro-solar policy moves are a response to a number of shifts in the energy landscape. Shale-gas development slows markedly, in part because of concerns that it is causing local environmental damage. Oil prices rise, due largely to conflict in oil-producing regions. Disruptive weather events increase, the public perceives them to be linked to climate change, and the weather events cause extensive economic damage.

An added driver in this scenario is a lackluster global economy and, in most countries, high unemployment. So governments push solar power largely in an attempt to create domestic jobs. That means the governments impose a variety of policies designed to maximize the number of jobs the solar industry creates specifically within their borders. Those policies include local-content rules, tariffs on imported solar equipment and, perhaps, equipment standards that vary from one country to another. For companies operating within their national borders, however, governments lower barriers for solar deployment by reforming rate structures and connection rules to increase solar installations' access to the transmission grid.

In addition, governments give solar power another economic leg up by levying some sort of price on carbon emissions. But in this scenario, unlike in Global Sun, that price varies widely across geographies, acting as a barrier to the free flow of solar goods.

"It's a struggle," one participant said.

Results for companies

As with the Global Sun scenario, established players in many industries — oil, chemicals and power — enter the solar market aggressively. Oil and gas producers are particularly active. That's in large part because their experience producing a global commodity in a variety of geographies, each with its own rules, has prepared them well to manage the regional barriers that, in this scenario, define the solar industry. "Oil companies are actually really good at operating with regional barriers," noted one participant. So they "enter the market big-time."

Again as in the Global Sun scenario, a handful of global players dominate the production of polysilicon-based solar panels, from refining polysilicon to making solar wafers and cells, to assembling solar modules. The polysilicon, wafer and cell production is concentrated in a few low-cost markets, particularly in Asia. But, over time, that production shifts from China to still-lower-cost Asian countries, such as Malaysia and Vietnam. Module assembly, however, is done across the world, wherever a local solar-panel market is large enough to justify a factory. Module assembly by the globally dominant companies is the main type of solar manufacturing that takes place in the U.S. As one participant said, module-assembly factories "will be like bakeries. Every market will have its own."

Although the companies that produce solar goods are global, the companies that install and operate solar systems are regional. In each large market, the engineering, procurement and construction — known in the business as EPC — of solar projects is done by what one workshop participant called "regional kings." That business consolidates, but that consolidation still is limited by national boundaries.

Photovoltaic capability is integrated into a range of products far beyond what consumers now recognize as solar panels. Companies make windows, exterior wall material and roof tiles that can convert sunlight into electricity. And energy-storage devices become economical at scale.

Results for countries

China emerges triumphant in this scenario. With its already globally dominant solar-panel-manufacturing industry, and with a domestic solar market that also is fast becoming the world's

Solar Systems continued

largest, China is, as one participant said, "big enough to do it all." Of all the global solar industry's walled gardens, China is by far the largest, able on its own to secure materials, make tooling, produce and install panels, and service solar installations. In short, though Western governments may intend to constrain China by erecting protectionist walls around their domestic solar markets, those protectionist measures constrain China less than they constrain those Western countries' own solar industries, workshop participants said.

Japan, too, does well in this scenario. What one participant called "very innovative, cool things" happen in Japan, which leads technological innovation in the solar industry. Japan ends up as the global "technology leader — the solution leader," one participant said. Japan's solar market remains one of distributed generation on rooftops rather than of utility-scale solar farms on the ground, because, as a workshop attendee noted, in Japan, "they have roofs but not land." If national barriers in the industry aren't too severe, Japanese and European solar-technology firms might work together, because, said one attendee, Japan is "a classic market for partnerships with European companies."

Yet, in this globally fragmented solar industry, some of the most interesting opportunities for international companies looking for expansion are in smaller sun-drenched economies.

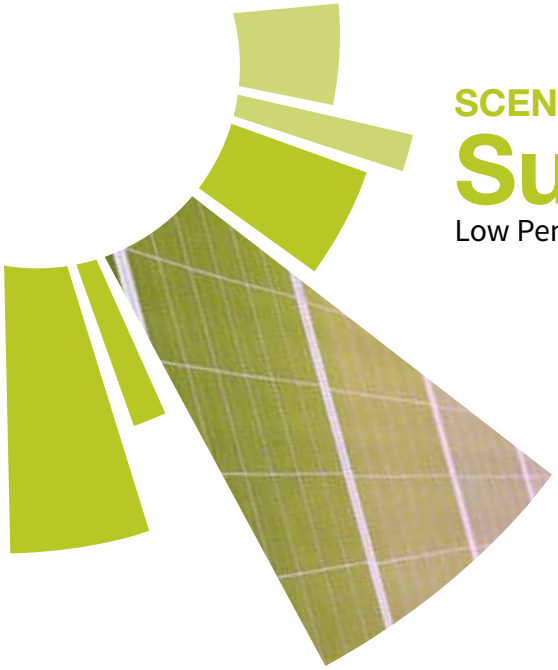
Middle Eastern countries emerge as particularly vibrant solar deployers. They do so by buying technological know-how and building factories within their borders. "They have the cash, they're buying [intellectual property], they're buying module manufacturing, they're doing production too," explained one participant. They see solar power both as a way to curb domestic consumption of oil, allowing them to sell more of their oil on the global market, and as a technology to desalinate water, an increasingly precious resource.

Still smaller countries also become promising solar markets. One is Jamaica, a sunny island with a population of 2.8 million people who today depend overwhelmingly on imported diesel fuel to generate electricity.

Many of the workshop participants described the U.S. and Germany in this scenario as largely fields on which solar manufacturers that either are based or conduct most of their operations in other countries play. The U.S. and Germany are large markets for investment by the companies that dominate the world's "glocal" solar market. Solar modules are assembled in the U.S. and Germany, and that produces jobs in those countries. But the companies that employ those workers — the global solar-manufacturing oligarchs — might be headquartered elsewhere. One question raised by participants in the workshop is whether the U.S. and Germany might lose even many of the module-assembly jobs to lower-cost countries on their borders: Mexico instead of the U.S. and countries in Eastern Europe instead of Germany.

In the U.S., the military is a major player in solar, both in research and development and in deployment. Even with fossil fuel cheap, the military looks to solar both as a hedge against potential future hikes in natural-gas prices and, more immediately, because it's concerned about the reliability of the U.S. electricity grid.

The bottom line in Solar Systems, according to workshop participants: The only countries that manufacture significant amounts of solar equipment are those that have robust domestic markets for solar power.



SCENARIO 3

Sunblock

Low Penetration, High Barriers

This is a dog-eat-dog world in which solar power has to get scrappy. The broad economic and political drivers pushing solar's expansion in 2013 have, in most places, slowed down, in part because of a backlash by interests that felt threatened by solar. Yet pockets of vibrant solar markets remain. The only companies that succeed in this scenario are those that are nimble and innovative, able to understand and exploit a patchwork of limited and varied local markets.

Drivers

Very little is sunny for the solar industry. Interest rates rise, a colossal problem for this young, capital-intensive industry. There is, explained one participant, "no more cheap debt." Countries impose a range of domestic regulatory barriers that drive up the cost of deploying solar power.

The shale-oil and shale-gas revolution playing out in the U.S. expands to other parts of the world — notably to China and Eastern Europe. As a result, natural-gas prices remain low in the U.S., and they decline elsewhere. That's a boon for consumers and for energy-intensive manufacturers, but it's a hurdle for an industry trying to peddle an alternative energy source.

Climate-change concerns no longer act as a key driver for solar power's expansion. That's because one of two things happens. In one instance, global temperatures dip, and while scientists argue about whether that's just a short-term respite from a long-term trend of human-induced global warming, the cooling keeps climate change far down on the political agenda. In the other instance, curbing carbon emissions is widely seen as a political priority, but techniques other than solar — particularly carbon capture and storage, and geoengineering — offer cheaper and more consequential solutions.

In addition, the global economy slows. As a result, governments around the world — notably in China, the U.S. and Europe — dial back solar subsidies, which for years were the major impetus for the industry's growth.

Results for companies

The global solar industry retrenches from a $100 billion market, its estimated value in 2013, to an industry one-third that size. "It's companies fighting over scraps," one workshop attendee said.

Large numbers of solar panels installed around the world start to fail, and the industry's reputation takes a hit. This confirms concerns that the solar industry grew too fast. It also makes solar installations increasingly difficult to finance.

With the spoils so scarce, spending on research and development for new solar-power technologies dries up. The companies that win are those that develop economically efficient business models — in particular, ways to grab significant shares of the dwindling number of solar-power customers who remain. "Cheap customer access becomes really important," one participant explained.

In the world's major energy markets, including China, the U.S. and Europe, established utilities succeed in enacting policies that many consumers perceive as contributing to solar energy's costs. In particular, they support requirements that consumers pay fees for connecting solar arrays to the electrical grid – fees that, rightly or wrongly, dissuade many consumers from switching to solar.

The financial difficulty of connecting solar systems to the grid increases the importance of technological improvements in energy storage as a way to compensate for the variability of solar power. But in this scenario, big advances in energy storage don't materialize, and energy storage isn't financeable at large scale. As one workshop participant said: "Storage has the potential to be the unicorn of the industry."

Results for countries

In the U.S., solar manufacturing remains insignificant. It's "not big enough to matter," one attendee said. Manufacturing throughout the industry occurs in countries with labor costs far lower than in the U.S.

U.S. solar deployment also slows. U.S. utilities, concerned that an early expansion of rooftop solar systems threatens to materially erode their paying customer base, fight back. In key solar states around the country, notably Arizona, they succeed in blocking so-called "net-metering" rules, which provide a financial boost to solar-panel owners by letting them sell back into the grid power that they generate but don't use. The prevailing argument, one

Sunblock continued

attendee said, is that "every PV system takes a utility's customer." The U.S. solar market shrinks to focus on a small number of places where prevailing electricity prices are so high, and the solar resource is so good, that the financial argument for solar power remains compelling. Exhibit A: Hawaii.

Across the Atlantic, the Eurozone splits apart. That political shakeup helps solar in the continental market that has long been solar's biggest booster: Germany. Freed by the Eurozone fissure from the need to send money to other European economies, Germany has plenty of political will — and thus cash — to maintain its chief solar subsidy, the feed-in tariff. As a result, Germany, hardly Europe's sunniest place, regains its role as Europe's solar bright spot. "The guys who have 500 sun-hours a year" — that is, comparatively little sun — "come out looking the best," one workshop participant said.

Though Germany installs plenty of solar panels, its companies don't make much in the way of solar equipment. The solar panels deployed in Germany are made by companies whose home offices are elsewhere — primarily in China. Germany is an export-driven economy, and with global solar demand so stagnant, German panel manufacturers decide it makes little economic sense for them to expand their operations at home. As one participant asked: "Who do you sell them to?" The installation of solar panels, though, continues in Germany, and the German solar industry's project developers and system integrators thrive in their subsidized domestic market.

Asia remains a low-cost manufacturer of solar panels to the handful of niche markets around the world that remain. Among them: Germany, Chile and South Africa. China's central government promotes consolidation of the Chinese solar industry in an effort to maintain a competitive edge in the increasingly cutthroat global market. Yet lower-cost Asian countries, such as Vietnam, grab solar-manufacturing share from China. Meanwhile, China's push to deploy solar energy domestically loses momentum, as China aggressively develops its massive shale-gas resources as a cleaner supplement to its domestic coal supplies.

Other markets around the world turn their backs on the sun as an energy source. Japan, its 2011 Fukushima nuclear accident receding into memory, focuses anew on developing nuclear energy; it loses interest in solar and allows its solar feed-in-tariff to lapse. India and Africa, once seen as large potential markets for distributed solar generation, pivot toward centralized fossil-fuel power.

In Sunblock, any value that the solar industry adds to the economies of the current players is marginal. Even China risks losing its edge to neighboring economies. In this scenario, the industry's "glocalization" goes hand in hand with a downsizing: fewer global players and fewer local target markets.

SCENARIO 4

Total Eclipse

Low Penetration, Low Barriers

This is solar energy's doomsday situation. Solar power is utterly insignificant. It's too small to matter not just as an energy source but also as a matter of industrial policy. Companies and governments see solar as unworthy of their attention: not worth cooperating on and not worth fighting over. In this scenario, said one participant, "PV's value proposition just evaporated."

Drivers

Globally, economic growth is flat, depressing energy demand. Fossil-fuel prices stagnate or fall. Those places where energy demand continues to grow are confident that they can get the power they need from coal, oil and natural gas. A "coal black swan" materializes: Coal-powered generation grows significantly, both in developing economies such as China and India and in industrialized countries such as Germany and other European nations, where gas is relatively more expensive.

Focused on promoting economic growth, governments are loath to implement any policies seen as likely to drive up costs: energy research-and-development spending; carbon prices; renewable-energy mandates. Among the public, and therefore among politicians, climate change is of minimal concern, either because it's eclipsed by economic worries or because it's addressed by major advances in carbon-capture-and-storage technology. People are preoccupied with problems they agree are more immediate. Moreover, few people buy the idea that solar energy might provide a material number of new jobs. As solar falters, however, it's conceivable that wind power grows, because wind becomes cost-competitive with fossil-fueled energy in some parts of the world.

Results for companies

The momentum toward the growth of a global solar industry that was gathering in 2013 has long since stopped. Solar innovation falters; where once scientists were working on dozens of prospective technologies to capture energy from the sun, now they've scaled back to just one or two.

The prior push toward large utility-scale solar projects, from the southwestern U.S. to western China, has similarly slowed. Where solar panels are installed, they're installed on rooftops, by the same niche of people who did so back in solar power's infancy in the 1970s and 1980s: "greens," as one participant called them. These are environmentally interested people who are willing to pay the hefty premium that solar energy requires given the baseline of cheap fossil-fuel-powered electricity. At least in many developed countries, there's no rational economic proposition for solar power, so those who adopt it are doing so purely for environmental reasons. In short, as one participant described it, solar returns to being an "enthusiast's business."

Largely as a result, utilities have lost any interest they had in solar power. They no longer see it as either a threat or an opportunity. As one workshop participant said, they are "too bored to bother" with solar.

The upshot: The solar industry dries up. Companies across the industry — panel makers, component makers, installers, servicers — go bankrupt or move on to other, higher-margin, businesses. Firms that once did nothing but install solar panels on homeowners' roofs, for instance, move into other areas, such as installing roofing. Once a core business, solar becomes, in the words of one workshop attendee, merely an "add-on" in those rare cases where it finds a critical mass of customers.

Results for countries

In the U.S., with domestic natural gas still prolific and cheap and with climate change long since having receded to the periphery of public discussion, government subsidies for solar energy wither. America's preeminent solar subsidy, the federal investment tax credit, ramps down to 10% of a solar project's cost in 2017 from 30% today. There is no federal legislation to tax carbon emissions or to demand renewable-energy development. State policies similarly subside. Utility-scale solar projects in the U.S. don't much expand beyond their current footprint in the country's sunny southwest.

The U.S. consumer market for solar panels is anemic. The biggest viable market for solar energy in the U.S. is the military, which, as in Solar Systems, sees solar as strategic. And because the military has money, as one workshop participant said, it provides the solar industry, even in Total Eclipse, with a rare source of "good margin."

Total Eclipse continued

In China, the push for energy diversity takes a back seat to the push to fight poverty. Consolidation among Chinese solar-panel makers continues, and the survivors focus not on innovating new solar technologies but on producing the prevailing commodity polysilicon-based solar panels at incrementally lower cost. The emphasis is, as one workshop attendee put it, on "cheap, cheap, cheap, cheap, cheap."

Elsewhere in Asia, Japan embraces nuclear power again, which, said one participant, is "going to kill" the country's interest in solar. Korea achieves the 2015 target it has set for domestic solar deployment, and it's there that the country's solar foray effectively ends. Solar in Korea, one attendee said, is "dying out."

Solar does expand in a few places around the world: Countries where the conventional electricity system is so underdeveloped or overburdened that these countries see solar as an economic necessity — important for securing reliable electricity — even in an era of cheap fossil fuel. In such places, a mixture of government development aid and private financing fuels solar's growth.

One such market is India, which increasingly sees solar as a more reliable alternative than its blackout-prone power grid. An even bigger such market is Africa. Because much of Africa lacks a robust network of electric-transmission lines, installing distributed solar systems remains economically attractive across the continent. Here China emerges as a major player, with Chinese export-oriented banks financing the installation of Chinese-made solar panels throughout the African market. Though imported solar panels proliferate across Africa, Africa itself doesn't become a major solar-equipment maker. The continent, said one workshop participant, is "a consumer, not a producer."

In Total Eclipse, the solar industry isn't worth companies spending much effort to dominate. A few niche players reliant on either premium segments or public money suffice. Because governments don't care enough about solar to impose barriers to foreign firms' entry, these few players could be global. Given pressure to minimize costs, they might be based in Asia.

Several workshop participants said they were skeptical that this scenario would come to pass. They doubted the likelihood of the scenario's main drivers: stable fossil-fuel prices and a lack of escalation of concern about climate change. Said one participant, a solar-industry executive, reflecting at least the executive's own hope: "A lot of things could blow it away."

This is a transitional moment for the solar industry. Workshop participants spent a good deal of time considering what insights other industries' patterns of growth offer into the solar industry's future.

Solar in a Broader Light
Lessons from Other Industries

Autos:
Global economies of scale

"Solar is today what the auto industry was in 1936," one workshop participant said. Seeking to improve their manufacturing efficiency as the auto industry did decades ago, solar manufacturers are moving to a higher level of automation. They're also expanding abroad, developing global brands that make regionally differentiated products.

Semiconductors:
Consolidation and protectionist barriers

Decades ago, when the U.S. semiconductor industry felt threatened by Japanese competitors, U.S. companies and the U.S. government formed SEMATECH, an aggressive attempt, through industrial policy, to create U.S.-based global industrial champions. Some workshop participants suggested that China's current attempt to consolidate its solar industry is a comparable strategic push. The participants disagreed about whether other countries, particularly the U.S. and Germany, should try to adopt similar industrial policy for their domestic solar firms. And yet, though the semiconductor and solar industries share some technological underpinnings, the participants noted important differences between the two industries. Among them: The solar industry requires significant project financing to develop markets. So it's not clear that a country that invests heavily in solar research and development will end up the global winner.

Telecommunications:
New entrants and new market structures

In the U.S., the land-line telephone behemoth, AT&T, saw its monopoly toppled, ultimately by wireless carriers. Workshop participants saw a parallel in the way today's dominant electric utilities are being challenged by a panoply of solar-power producers, particularly homeowners with solar panels on their residential roofs. Increasingly, electricity companies, particularly in Germany and in certain parts of the U.S., are expressing concern about this. In addition, just as the telecommunications industry saw its early investment in satellite phones devalued by the advent of cellular handsets, workshop participants wondered whether today's solar companies will find their prevailing technology, polysilicon-based solar panels, displaced by some newer, more-efficient solar technology. Another potential telecom parallel: technology leap-frogging. Increasingly, developing countries are bypassing land-line phones and jumping straight to wireless networks. The question for the solar industry: Will emerging economies that today lack robust electricity-transmission infrastructures be able to bypass the need for power grids and jump straight to solar panels on rooftops, known in the industry as "distributed generation"?

Consumer electronics:
Commodification or market segmentation?

The story of digital cameras is of an expensive product getting better, growing cheaper and being integrated into other products such as cell phones. The solar industry could experience a similar evolution, with photovoltaic capability moving beyond today's solar panels and into roof tiles, paint and other products. Or not. If solar power remains a niche market, solar panels could, as a consumer product, more closely resemble digital single-lens-reflex cameras. In the mix of energy technologies, solar would be small but potentially high-margin – a premium segment.

Conclusion

The solar industry is quickly growing and globalizing; the fights over the industry now raging among companies and countries are plain signs of the high stakes. Today, the prevailing narrative of this industry transformation is that it's a zero-sum game: Some countries will win; others will lose; and the spoils will go to the ones that best guard their turf.

This report, and the Stanford workshop on which the report is based, suggests that, at this point, the prevailing narrative is too simplistic to be of much strategic use. The reality of the solar industry's transformation is less certain and more complex. The spoils in the globalizing solar industry are still very much up in air. They'll likely go to the companies and countries that are smartest about identifying their comparative advantages — and about structuring their policies and financial mechanisms to act on those strengths.

The workshop's core conclusion is that the global solar industry will develop based on a pattern of "glocalization." That conclusion belies a claim, heard often in industry and policy circles, that China has "won" the solar game and that other countries — the U.S., Germany and others — have "lost" it. Unquestionably, in solar energy as in many other industries, China has distinct advantages in manufacturing goods at low cost. China's low-cost manufacturing, indeed, has brought products to the world — among them, solar panels — that otherwise probably would have remained the pricey purview of a very niche consumer segment. Nevertheless, global solar-industry executives who participated in the workshop agreed that no one country has won this industry. The "glocal" view of the solar industry's growth suggests that many markets around the world have critical — and potentially profitable — roles to play in the industry as it progresses.

The "glocal" view of the solar industry's future suggests a number of takeaways:

- Manufacturing of solar panels is likely to concentrate among a handful of global players. Some workshop participants thought those global players would be headquartered either in China or in other Asian markets where manufacturing costs are even lower than in China. Other participants said that firms based in the U.S. or Europe might be among these dominant global solar manufacturers, but that if they were, they probably would do much of their manufacturing in less-expensive parts of the world.

- Wherever they're based, these solar-manufacturing oligarchs will conduct their business globally: doing whatever processes they decide are most efficient to do in whatever markets.

- Today, it appears the most efficient way for these companies to structure their global solar-panel-manufacturing operations is to do most of that work in low-cost markets, particularly those in Asia. In some cases, they then ship those components for final assembly in end markets, either because the companies have decided that those markets have enough solar demand to justify domestic module-assembly factories or because the governments of those countries have imposed rules requiring that solar modules be assembled within their borders if the modules are going to be sold there.

- A number of wild cards could change this calculus about where in the world it's most profitable for a global solar manufacturer to place its production. Among them: regional differences in energy prices, raw-material costs and wages; global transportation costs; and technological advances that reduce the need for factory-floor labor or that radically change the kind of photovoltaic device that the market wants.

- Manufacturing is today the most hotly debated piece of the solar industry. But it's only one piece. The business of turning sunlight into electricity involves a broad range of activities: research and development, early commercialization of new technologies, large-scale manufacturing, financing, marketing, and solar-project installation and maintenance. Each piece offers real opportunities for smart companies to make money — and for smart countries to play to their comparative advantages.

These conclusions raise several important questions for policymakers:

- What conditions in a particular country — solar market size, government regulations, cost and quality of labor, and others — might lead one of the global manufacturing behemoths to place some of its operations there?

- Which countries have advantages in which parts of the solar business beyond manufacturing — for instance, in parts of the industry that bear on technological innovation? How are countries' comparative advantages in innovation — whether early research and development or later manufacturing-process advancement — shifting? Who does what sort of innovation most economically efficiently? Who is likely to have what sort of innovation edge in a decade? How far do policymakers want to go to try to shape the answer?

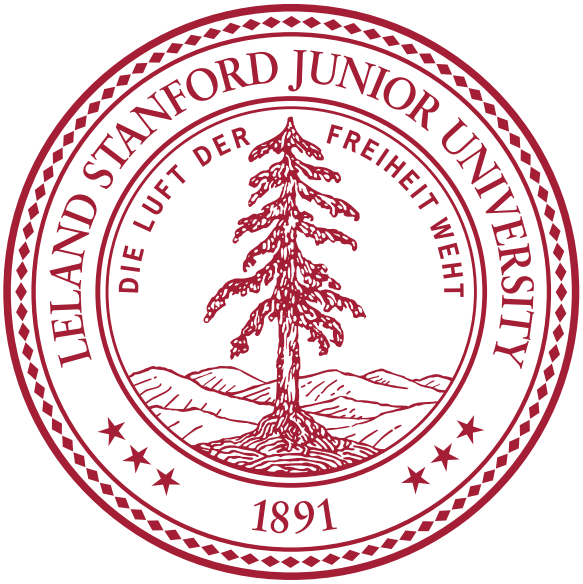
- If a country leads in parts of the solar industry other than manufacturing, how does it monetize that leadership? How, for instance, does it calculate the economic benefits of domestic solar work if that work doesn't produce domestic factory jobs?

These are fundamental and controversial questions. As they hang above the global solar industry, the industry continues to change.

As a parting exercise in the Stanford workshop, participants sketched out how they saw the industry changing over the next dozen years: whether the industry would move from one of the scenarios to another, and, if so, in what order. One conclusion expressed what the executives at least hope will happen to the sector on which their companies depend: They predicted big growth.

Beyond that, the wrinkles were instructive. The workshop participants decided the world today is in Sunblock. Solar power is a tiny portion of the global electricity mix, and it's facing high barriers to global growth.

By 2025, the participants said, solar power will account for more than 8% of global electricity generation — a massive jump from the 0.3% it represents today — regardless of whether countries maintain or lift the barriers that now constrain the industry. Most participants hoped for the low-barrier world of Global Sun rather than the high-barrier world of Solar Systems. And most predicted that, if significant barriers remain, the industry will find a way to work around them. But for the open access of Global Sun to emerge, countries will have to shift from today's game of erecting barriers to an approach in which they frame, develop and exploit their comparative strengths. That, the participants agreed, is a tall order.



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