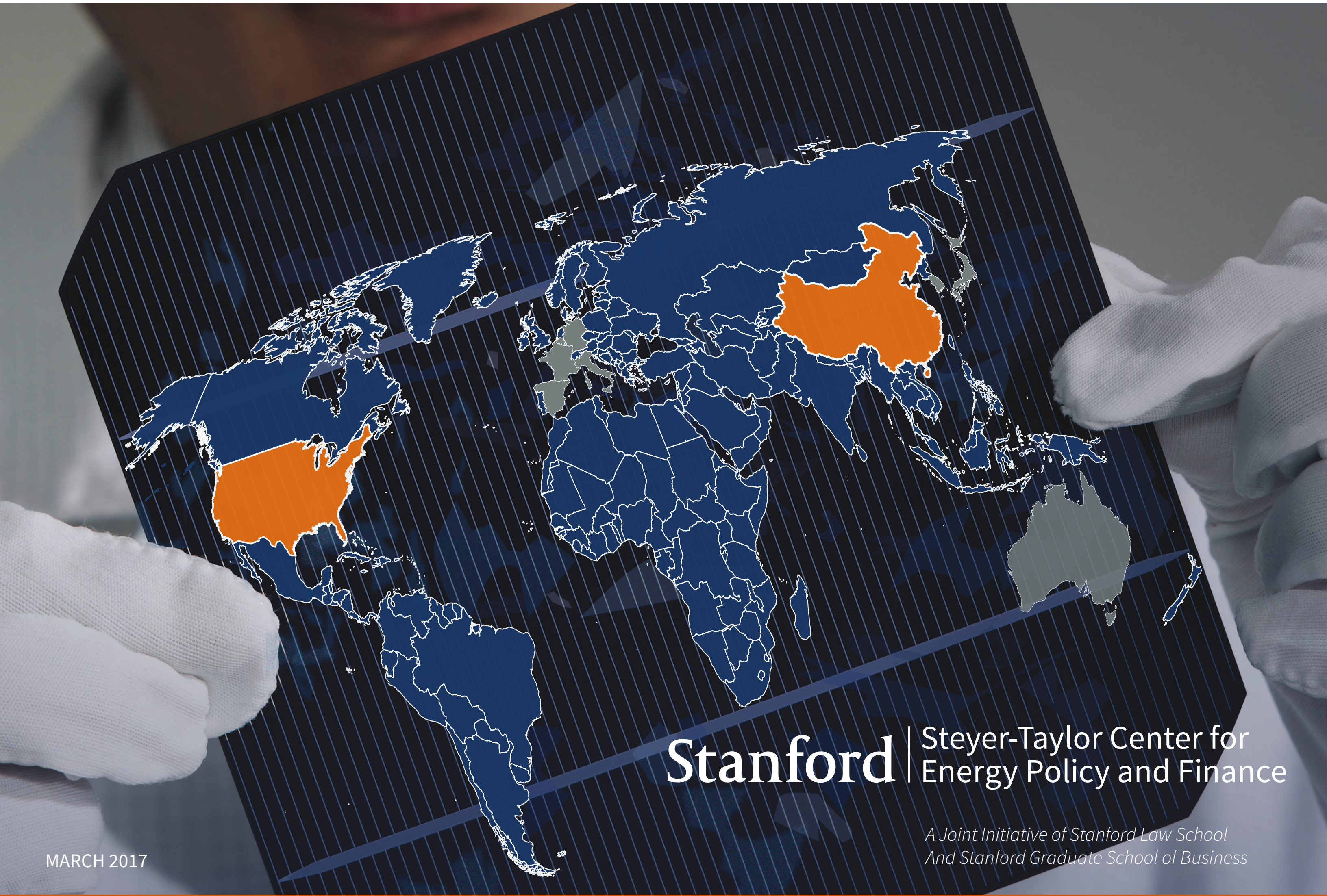
THE NEW SOLAR SYSTEM

CHINA'S EVOLVING SOLAR INDUSTRY AND ITS IMPLICATIONS FOR COMPETITIVE SOLAR POWER IN THE UNITED STATES AND THE WORLD

JEFFREY BALL | DAN REICHER | XIAOJING SUN | CAITLIN POLLOCK



Stanford | Steyer-Taylor Center for Energy Policy and Finance

A Joint Initiative of Stanford Law School And Stanford Graduate School of Business

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About the Authors

Jeffrey Ball led this project from its conception through its research and writing. He is the primary author of *The New Solar System*. A writer on energy and the environment, he is the scholar-in-residence at Stanford's Steyer-Taylor Center for Energy Policy and Finance and is a lecturer at Stanford Law School. His writing has appeared in The Atlantic, Foreign Affairs, Fortune, the New Republic, Slate, and The Wall Street Journal, among other publications. He came to Stanford in 2011 from The Wall Street Journal, where he worked for 14 years as a reporter, a columnist, and the environment editor.

Dan Reicher helped frame the research for, and collaborated in the writing of, this study. He is executive director of Stanford's Steyer-Taylor Center for Energy Policy and Finance and holds faculty positions at Stanford Law School and Stanford Graduate School of Business. He has more than 30 years of experience in energy and environmental policy, finance and technology, having served three presidents, including as assistant secretary of energy for energy efficiency and renewable energy under President Bill Clinton. He came to Stanford in 2011 from Google, where he directed the company's climate and energy initiatives.

Xiaojing Sun worked as co-manager of research for this study. She coordinated research on the research-and-development chapter and on the supply-chain component of the manufacturing chapter. She received her PhD in public policy from the Georgia Institute of Technology in 2016, specializing in energy and climate policy with a minor in international affairs. She wrote her dissertation about the solar industry in China and the United States. She is chief technology officer at The Greenlink Group, a clean-energy consulting and analytics company based in Atlanta.

Caitlin Pollock worked as co-manager of research for this study. She coordinated research on the finance and deployment chapters and on portions of the manufacturing chapter dealing with the evolution in the Chinese solar industry's manufacturing footprint. She has more than 11 years' experience in analyzing the renewable-energy and energy-efficiency industries, including having worked as an analyst at IHS Emerging Energy Research overseeing the firm's Asia-wind-industry analysis. She is a senior energy efficiency and policy and strategy analyst at Pacific Gas and Electric Co.

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Several solar experts at the DOE's Solar Energy Technologies Office—some still at the department and some now elsewhere—answered questions throughout the research for this report: David Danielson, assistant secretary for the Office of Energy Efficiency and Renewable Energy as of the start of this research and through May 2016; Minh Le, director of the Solar Energy Technologies Office (SETO) as of the start of this research and through October 2015; and Lidija Sekaric, deputy director of the SETO during this research, and Charlie Gay, the current director of the SETO, were particularly helpful. In addition, Daniel Stricker, technical project officer at the DOE, and Garrett Nilsen, technical advisor to the DOE during much of the research for this project and, starting in January 2017, the manager of the SETO's Technology to Market Program, were extremely helpful in the administration of the DOE grant.

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Benjamin Bai, an intellectual-property lawyer in China with expertise in the patent system, offered insight into China's technology-patent system that was instrumental in framing this study's analysis of Chinese solar patents. He was a partner at Allen & Overy's Shanghai office at the start of this research; he is now vice president and chief intellectual-property counsel at Ant Financial in Hangzhou, China.

Eicke Weber, a veteran solar researcher who was, through the end of 2016, the director of Germany's Fraunhofer Institute for Solar Energy Systems, provided extremely helpful context about the solar industry in several discussions.

Ruiying Zhang, for many years the deputy chief representative of the Energy Foundation China's Beijing office, provided helpful insight during several discussions.

The Stanford research team held three half-day workshops—two in Beijing and one in Washington—as part of this project. The attendees at all of the workshops were generous with their time and were extraordinarily helpful with the insight they offered during the discussions.

One Beijing workshop focused on investment in the solar industry. Attendees included Zhipeng Liang, deputy director general China's National Energy Administration; Qi Lu, director of strategy and research at Tsing Capital; Qiongying Ma, project officer for the program on Sino-German Cooperation on Renewable Energies for Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ); Peng Peng, policy research director at the Chinese Renewable Energy Industries Association; Sandra Retzer, at the time the head of energy in the China office of GIZ; Teresa Tan, at the time chief financial officer of Trina Solar; Shijiang Wang, deputy secretary-general of the China Photovoltaic Industry Association; Sicheng Wang, senior researcher at China's Energy Research Institute; Xiaoting Wang, solar research associate for Bloomberg New Energy Finance; and Bin Zhu, a strategy-management researcher at Hanergy.

The other Beijing workshop focused on technological innovation in China's solar sector. Attendees included Benjamin Bai, at the time a partner at Allen & Overy's Shanghai office; Jing He, an intellectual-property lawyer and senior consultant at the Anjie Law Firm; Yongfang Li, professor at the Chinese Academy of Sciences' Institute of Chemistry; Feng Liu, of the Chinese Academy of Science and Technology for Development; Wenjing Wang, photovoltaic group leader for the Chinese Academy of Sciences' Institute of Electrical Engineering; Honghua Xu, chief photovoltaic scientist of the China Ministry of Science and Technology and researcher at the Chinese Academy of Science's Institute of Electrical Engineering; and Rui Zhu, associate professor of physics at Peking University.

The Washington workshop was a broad discussion about all aspects of this research. Participants included Guido Agostinelli, senior solar industry specialist at the International Finance Corporation; Peter Aschenbrenner, executive vice president for strategy and business development for Sunpower; Michael Bolen, at the time an adviser to the DOE's Solar Energy Technology Office; Tonio Buonassisi, associate professor of mechanical engineering at the Massachusetts Institute of Technology; Andy Coulouris, U.S. area vice president of public affairs for Dow Corning; Charlie Gay, a longtime solar technologist; Robert Margolis, senior energy analyst at the U.S. National Renewable Energy Laboratory; Robert Olsen, global marketing director for DuPont Photovoltaic Solutions; Rhone Resch, at the time chief executive officer of the Solar Energy Industries Association; Lidija Sekaric, at the time deputy director of the DOE's Solar Energy Technologies Office; Varun Sivaram, a fellow at the Council on Foreign Relations; John Smirnow, a lawyer then representing the Solar Energy Industries Association; Daniel Stricker, technical project officer at the DOE; and Gregory Wilson, director of the U.S. National Renewable Energy Laboratory's Materials Applications and Performance Center and co-director of the National Center for Photovoltaics.

On research trips to China that various members of the Stanford research team made in conducting this study, executives at a broad range of Chinese solar companies provided time and insight. Those companies include Advanced Solar Power, Canadian Solar, GCL, Hanergy, JA Solar, Jinko Solar, Shunfeng International Clean Energy, Trina Solar, and Yingli Green Energy. The Stanford team's discussions with these executives and visits to their facilities were crucial to this report.

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Executive Summary

Solar power is undergoing a revolution. Over the past decade, an energy source as old as the planet and theoretically all but limitless has plummeted in cost and begun in some places to be harnessed in large volume. This dynamic is disrupting the modern energy system and, as energy disruptions always do, rattling the geopolitical order. In the process, the industry that produces the equipment to convert sunlight into electricity is simultaneously reeling, consolidating, and surging. These twin transformations—one of the global energy system, one of the global solar industry—carry profound implications for national economies and for the planet. At the center of both transformations sits China.

The New Solar System illuminates key and little-understood changes that are remaking the solar enterprise—in China and thus in the world. Based on this analysis, it recommends changes in U.S. solar policy—particularly timely with a new U.S. administration and Congress—that would put solar power on a more economically sensible path toward environmentally significant growth.

A Global Solar Strategy: Harnessing Comparative Advantage to Cut Solar's Cost

Solar power has grown massively in recent years and yet it still represents only about 1% of global electricity generation. Mainstream observers now predict that solar photovoltaic could provide 16% of global electricity by mid-century, and credible sources predict even higher levels.

Whether solar power grows this significantly, and whether in the process it makes much environmental difference, will depend in large part on whether governments approach it with a new level of economic efficiency. Many of the solar policies that countries have adopted thus far have been inefficient. They have achieved, to varying degrees, their stated goals of boosting domestic solar manufacturing or deployment in the near term, but often they have done so in ways that are unable to be sustained—for political or economic reasons or both.

The result, in much of the world, has been wild swings in solar policy, ranging from unnecessarily generous support to unreasonable neglect. That has contributed to a boom-bust pattern in the solar industry that has benefited no one: not investors, solar-technology entrepreneurs, ratepayers, taxpayers, or citizens around the world who could benefit from an energy system decarbonized sooner rather than later. Enabling solar power to scale to a level that can help curb fossil-fuel emissions requires governments to find smarter means of policy and financial support. One key predicate for making smarter policy is taking into account a country's relative comparative advantage in the rapidly globalizing solar industry: what it does well and what it does not.

The New Solar System does not seek to enable any country to beat another in the global solar industry. It seeks instead to help all countries find their most effective places. By better understanding and playing to their comparative strengths in the solar business, countries would achieve two key objectives. They would reduce the cost for the world of scaling up solar power. And they would be better positioned to fashion policies that maximized the long-term benefit to their own economies from solar's global growth.

It is important to be clear: This notion of comparative advantage is no rose-colored vision of borderless global harmony. It is the increasing reality of the cutthroat international solar market today. It does not ignore very real tensions between China and the United States, including an ongoing dispute in which each country has imposed solar tariffs on the other, doubts about the protection of intellectual property in China, and concerns by both the U.S. and Chinese governments about national security. Rather, it puts those concerns into perspective, which is something that investors, corporations, and governments try to do every day.

The Chinese solar industry is likely to remain, for the foreseeable future, the major driver of the global solar industry. But this does not mean that China as a country will remain as dominant in the solar industry as it is now. This distinction—China as the leader of the global solar industry but with declining dominance—is crucial in clarifying the roles that other countries could sustainably play in the global solar industry of the future.

This emphasis on economic efficiency in the globalizing solar industry is particularly relevant during the administration of U.S. President Donald Trump, who has talked approvingly of tariffs against China and who has questioned the desirability of U.S. support for renewable energy and of U.S. action to curb carbon emissions.

The New Solar System is based on some two years of work by Stanford University's Steyer-Taylor Center for Energy Policy and Finance, an initiative of Stanford Law School and Stanford Graduate School of Business. The research was funded by a research grant from the U.S. Department of Energy's (DOE's) Solar Energy Technologies Office. Stanford's Steyer-Taylor Center proposed the research and initiated the grant application to the DOE. The grant provided the center with full independence and authority to frame the inquiry, conduct the research, draw conclusions, and write this report.

Busting Myths About China's Solar Sector

The New Solar System busts five key myths about China's solar industry that have prevailed in the West. Clarifying the reality behind those myths is crucial to charting a more economically efficient path forward for solar power:

Myth**:** China's solar industry is a financial bubble about to burst.
Fact**:** Chinese solar companies are reforming their capital structures to make them more economically efficient.

Myth**:** China doesn't innovate.
Fact: China is innovating significantly in solar—not only in manufacturing processes, China's traditional strength, but also increasingly in underlying solar R&D.

Myth**:** The global solar industry is centralizing in China.
Fact: The global solar industry, led by Chinese companies, is showing early signs of decentralizing geographically.

Myth**:** Tariffs imposed by the United States and the European Union are hobbling the Chinese solar industry.
Fact: Tariffs imposed by the United States against imported Chinese solar products are forcing the Chinese solar industry to get leaner and stronger and are failing to achieve a goal articulated strongly by their Western supporters: to catapult the United States into the ranks of the world's major solar manufacturers. Moreover, the U.S. tariffs have prompted China to impose its own tariffs on U.S.-made polysilicon, the solar-manufacturing sector in which the United States traditionally has been most dominant.

Myth**:** China's solar market is largely closed to foreign investment.
Fact: Top Chinese government officials and corporate executives have concluded that China needs both capital and sophisticated investment structures from the West in order to scale up solar to the point where it would help achieve China's climate targets. Their interest presents a profitable opportunity for players in the West.

The Maturation of China's Solar Enterprise

China's solar enterprise has encompassed three broad stages. First, China commoditized the manufacture of vast quantities of solar equipment. Next, it deployed vast quantities of that equipment within its borders. Now, China is attempting something more subtle and, if it succeeds, more far-reaching: to reform both its solar-R&D effort and its massive solar-deployment apparatus to make them more economically efficient. The R&D reform represents an acknowledgment by the Chinese government that its solar-R&D efforts thus far have been insufficiently productive. The attempt to reform solar deployment is about financial innovation—both in government policy and in private-investor practice. The success of both these shifts will be crucial if the world is to ramp up solar deployment to levels that contribute meaningfully to global climate reductions.

The New Solar System details how the Chinese solar enterprise is evolving across four key dimensions: its financial status, its research-and-development capabilities, its manufacturing prowess, and its deployment of solar projects.

Financial Status

In the near term, the major China-based solar manufacturers are struggling with the repercussions of a strategy they have used essentially since their inception: aggressively expanding manufacturing capacity to increase their global market share. Longer-term, however, the financial condition of the Chinese solar industry, as a group, appears to be improving. Corporate consolidation in the Chinese solar industry is in full swing, yielding a smaller number of larger, stronger, and globalizing players.

Corporate profit margins, though still thin, are rising. Debt, though still high, is becoming less of a concern, both because the extent of leverage of China's major solar manufacturers is lower than it was during the last major industry downturn, in 2012, and because debt is shifting to forms that the Chinese companies are better equipped to shoulder. Government policy support—which initially was, by the admission of top Chinese government officials themselves, wasteful—is being tightened with an eye toward producing more solar deployment for every yuan's worth of subsidy.

Research and Development

The widespread assumption in the West has been that the United States and certain European countries, notably Germany, produce the major technological advances in solar, and that China picks up those technological advances and then figures out how to drive down the cost of manufacturing them at scale. *The New Solar System* largely upends that view. It finds that the Chinese solar industry is producing more underlying technological innovation than the conventional wisdom suggests.

Some of this innovation has put China ahead of the U.S. in certain key solar technologies. In one example, Trina Solar, one of the world's largest solar manufacturers, has become the first China-based firm to be recognized on the U.S. National Renewable Energy Laboratory's well-known chart of solar-cell-efficiency world records. Trina has achieved the world record in the efficiency of a research-scale version of the type of solar cell that dominates the global market: the multicrystalline-silicon cell. China's solar industry is making less, though still notable, progress in several other solar-technology areas.

The New Solar System maps China's solar-R&D ecosystem, providing what the Stanford research team believes is a newly comprehensive picture of the way that solar R&D in China is organized and funded. This analysis, which the report presents in both a diagram and words, draws from an extensive review of Chinese government documents, scholarly studies, and conversations with dozens of Chinese government officials, academics, and solar-industry executives. It shows the extent to which China's solar-R&D activities depend on a relationship between the government and domestic companies far closer than the relationship that typically prevails in countries in the West.

The New Solar System also provides new details about China's spending on solar R&D, though this assessment remains limited, because China is far more opaque about its level of solar-R&D spending than are most countries active in solar research. The study clarifies the path by which the Chinese government funds its solar scientists. And it finds both that the average China-based solar manufacturer spends significantly less on R&D than does its U.S.-based counterpart—a comparison partially offset by the fact that R&D is cheaper in China than in the United States—and that Chinese solar R&D spending is rising.

China, as reflected in its latest broad economic-planning document, the Thirteenth Five-Year Plan, is intent on upgrading its solar enterprise from one that merely manufacturers and installs technology developed by others to one that also innovates and develops technology. China is systematically restructuring its government support for solar R&D in an effort to make it more effective and efficient.

Manufacturing

China dominates global solar manufacturing. In 2016, China accounted for 52% of polysilicon manufacturing capacity, 81% of silicon-solar-wafer manufacturing capacity, 59% of silicon-solar-cell manufacturing capacity, and 70% of crystalline-solar-module manufacturing capacity in the world, according to IHS Markit. The United States, by contrast, accounted for 11% of the world's polysilicon production capacity, 0.1% of wafer manufacturing capacity, 1% of cell manufacturing capacity, and 1% of module manufacturing capacity.

The New Solar System finds that Chinese solar supply chain is strong in producing materials and durable goods that require extensive labor, small to medium capital investment, and few advanced technical skills. The Chinese solar supply chain is at this point weaker in producing more technologically advanced goods but is steadily improving.

The commonly understood picture of Chinese solar production is of a global industry all but totally centralized in one country. A key conclusion of *The New Solar System* is that this picture is quickly changing. In two closely related shifts, the solar industry is consolidating in a corporate sense and decentralizing geographically. The industry is consolidating around a smaller number of players, each of which is spreading its operations—from R&D, to manufacturing, to deployment—across the globe. This is an important sign of industry maturation. It resembles transformative stages in the growth of other global manufacturing sectors, from automobiles to electronics. One result is that, more and more, the geographic footprints of leading solar companies look similar—whether those companies are based in China, in the United States, or elsewhere.

Precisely how this decentralization of the solar industry will play out—which parts of solar manufacturing will happen in which countries—is impossible to predict. But the fact that the decentralization has begun signals that countries that previously considered themselves uncompetitive as a locus for solar manufacturing now have reason to reassess that assumption. Importantly, this does not mean that every country will be globally competitive in every segment of solar manufacturing. What it does mean is that the question of national comparative advantage in the global solar industry—the question of which countries do what well—now is extraordinarily relevant and nuanced.

The New Solar System finds that Chinese solar manufacturing is maturing in four fundamental ways:

- The industry is integrating up and down the value chain—from polysilicon to wafers, cells, modules and balance-of-system components—with fewer bigger companies dominating the entire global solar enterprise.
- The industry is expanding its Chinese production capacity, but, increasingly, it is doing so by upgrading assembly lines and not only by building additional ones.
- The industry is ramping up manufacturing outside of China, in large part a response to tariffs imposed by the United States and the European Union on Chinese-produced solar goods.
- Solar-product manufacturers from outside China are entering China, though thus far on a small scale. So far, China-based solar manufacturers have not put factories of any scale in the United States.

China's solar industry is a textbook lesson in the power of manufacturing "clusters." The epicenter of the Chinese solar industry—and thus of the global solar industry—is the Yangtze River Delta, an area that includes Shanghai and parts of two provinces to its west. *The New Solar System* details the growth of the Yangtze River Delta solar-manufacturing cluster, including, notably, the role of government subsidies and of a key feature of China's manufacturing prowess: the industrial park.

Government subsidies are probably the aspect of China's solar enterprise most hotly disputed in the West. They are a chief driver of trade complaints that Western solar companies have launched against their Chinese competitors. Those complaints have led to U.S. and European tariffs—measures that sparked Chinese tariffs in response. All levels of government in China—national, provincial, and local—provide a range of subsidies to the Chinese solar industry. (And China, for its part, has complained to international trade authorities about the subsidies that the United States and European countries provide to their solar firms.) Quantifying China's solar subsidies is extraordinarily difficult, owing to a lack of transparent Chinese government data. But *The New Solar System* paints a newly detailed picture of these subsidies using a range of available information. Importantly, China now is redesigning its solar-deployment subsidies, restructuring them for more economic efficiency and learning from past policy-design mistakes both in China and in other countries that have heavily subsidized solar deployment.

Deployment

At the end of 2010, China had just 800 megawatts of solar capacity installed within its borders. By the end of 2016, Chinese officials estimate, the country had installed approximately 76,500 megawatts. To put this into perspective, China in five years added more solar capacity than Germany, previously the world's solar leader, deployed over a period of two decades.

China is widely expected to remain by far the world's largest solar-deployment market for many years to come. China's Thirteenth Five Year Plan for Solar Energy Development, issued in December 2016, calls for cumulative solar-capacity deployment in China of some 110,000 megawatts by 2020, though senior Chinese government officials believe actual deployment by then will total closer to 150,000 megawatts. That would amount to approximately half of all the solar capacity estimated to have been deployed globally as of the end of 2016.

One significant problem impeding solar deployment in China has been what is known as curtailment: the rejection by China's grid operators of a portion of the electricity that China's solar projects generate. China's solar deployment is concentrated overwhelmingly in a handful of provinces, many of them in rural areas located far from population centers that need electricity and in areas where transmission development has not kept pace with renewables deployment and there is little storage capacity. In some of those provinces, solar-curtailment rates have approached 30%.

The Chinese government has concluded that, to deploy solar capacity at the massive levels it has targeted, China will have to get more efficient in the way it spends its solar-deployment capital. So China is moving to develop more-efficient solar-deployment tools—through government policy and through private investment mechanisms. Three aspects of this attempt to increase the efficiency of solar-deployment capital are particularly noteworthy: reform of China's "feed-in tariff," the country's main solar-deployment incentive; reform of China's solar-project approval process; and the introduction of a variety of new solar-deployment financing mechanisms.

Recommendations for U.S. Policy

Framework

The best way for any country—including the United States—to derive lasting economic gain from the growing solar industry is to help maximize the industry's efficient global growth. This framework suggests three overarching priorities for U.S. policymakers:

- **Seek above all else to reduce solar power's costs.** Solar power, despite significant cost cuts over the past decade, remains too expensive to scale to the level that would make a meaningful environmental difference, particularly when its intermittency is taken into account. In 2016, the DOE announced the solar industry had achieved 70% of cost-cut targets that the DOE had set five years before—and so it unveiled more-aggressive unsubsidized-cost targets for 2030: $0.03 per kilowatt-hour for utility-scale solar, $0.04 per kilowatt-hour for commercial rooftop solar, and $0.05 per kilowatt-hour for residential solar. Reducing the cost of solar energy to this extent would require maximizing international R&D cooperation, manufacturing in the most-cost-effective locations, and improving solar-project permitting and deployment. And it would require significant advances in two enablers—energy storage and transmission—that will be crucial to overcoming solar's intermittency and its varying availability across regions including North America.
- **Embrace the reality of a globalizing solar industry.** U.S. policy bearing on solar should reorient fundamentally so that it seeks to leverage, not defeat, China. More than ever before, the solar industries in China and the United States are intertwined: Shareholders across the globe invest in both of them, capital moves between them, many of the same companies are active in both of them, and market dynamics in one influence fortunes in the other. Key players in both countries increasingly believe that they will profit more if each country focuses on exploiting its comparative advantages in the globalizing solar industry than if it orients policy around trying to beat the other. That conclusion marks a major shift from the thinking that prevailed just five years ago, when the solar sector was more a patchwork of small and distinct national industries than the interconnected, international force it is becoming today.
- **Focus U.S. federal support for solar primarily on R&D and deployment and only secondarily on manufacturing.** Certain types of solar manufacturing in the United States seem increasingly feasible. But U.S. policymakers should regard manufacturing as a subordinate, not a primary, policy goal. Solar manufacturing is unlikely to produce large numbers of U.S. jobs, because it is an increasingly automated process. The majority of solar jobs are in areas other than manufacturing: in sales, installation, operation and maintenance, and R&D.

R&D *Recommendations*

The United States remains a leader in many aspects of solar R&D. This leadership has been backed by significant U.S.-government funding, and it will be important to solar's global growth. The United States should:

- Significantly increase U.S. spending on R&D for solar and for solar-enabling technologies such as storage and transmission, in both the public and private sectors, to help propel solar's global growth and to ensure that the United States remains a leader in it.
- Broaden international solar-R&D efforts to include China so that China's increasing solar innovation informs efforts elsewhere. For the United States, cooperating with China on solar R&D poses real and important challenges, including concerns about the protection of intellectual property and about national security. But not cooperating with China on solar R&D also presents significant risks, including reduced relevance in the silicon-based solar technologies that command the majority of today's market.
- Reform a federal policy that requires that those who accept federal R&D funding, including for solar R&D, promise to manufacture "substantially" in the United States any technologies that they develop through that R&D. According to a wide range of U.S. solar executives, scientists, and even government officials involved in implementing it, this provision is outdated and counterproductive. In its effort to maximize U.S. solar-manufacturing jobs, it risks weakening U.S. solar R&D, an activity with potentially greater long-term economic value to the United States than solar manufacturing.

Manufacturing Recommendations

U.S. solar manufacturing is rising significantly but from an extremely small base. As noted above, the United States in 2016 accounted for 0.1% of global wafer manufacturing capacity, 1% of global cell manufacturing capacity, and 1% of module manufacturing capacity. Several new or expanded U.S. solar-cell and -module factories are under construction or expected to be built over the next two years. Yet predictions are that, at least in the near term, U.S. solar manufacturing will remain small in the global context. The key opportunity for the United States is to identify those sorts of solar manufacturing that are likely to be economic absent significant government subsidy.
The New Solar System concludes that U.S. solar manufacturing is likely to prove economically viable for three categories of solar products:

- products for U.S. consumption that are expensive to import;
- export-oriented goods that the United States can competitively produce at large scale because of cheap U.S. natural gas;
- and export-oriented goods developed with U.S. R&D talent that the United States is well-positioned to manufacture in relatively small quantities in initial factories but that may shift to cheaper manufacturing locations overseas as they scale up.

Around the world, solar manufacturing, like manufacturing in many other sectors, has centered on particular geographic clusters that leverage well-developed supply chains, established transportation infrastructure, abundant low-cost energy, and often partnerships with local R&D institutions such as universities or government-affiliated labs. The United States has focused on developing two solar-manufacturing clusters: California's Bay Area and New York's upstate region near Buffalo. One way to grow the upstate New York solar cluster, in particular, would be to expand an existing solar-R&D effort there to include companies beyond U.S.-based firms.

An important element of China's buildup of its solar-manufacturing enterprise has been the financing that Chinese lenders have provided to China-based solar firms for their international expansion. The U.S. Export-Import Bank is the subject of ongoing political disagreement but has played, and could continue to play, an important role in exports by U.S.-based solar firms.

Deployment Recommendations

Certain areas of the United States—particularly the Southwest, Mountain West, and California—have some of the best solar resources on the planet. Largely in those regions, U.S. solar deployment is surging. In 2015, the United States was the third-largest deployer of solar modules in the world, behind China and Japan. It installed 7,200 megawatts of solar capacity in 2015, up 16% from 2014. Cumulatively, the United States installed 25,600 megawatts of solar capacity as of 2015, placing it fourth globally, behind China, Germany, and Japan. And in 2016, new U.S. solar deployment increased hugely to 14,600 megawatts, essentially twice the figure for 2015. Yet despite this growth, the United States still ranks 25th globally in the percentage of its electricity—just under 1%—that it generates from solar.

In scaling up solar power for itself and for the world, the United States could do much more. It should focus on two broad categories.

The first is U.S. domestic energy policy. U.S. solar deployment would benefit from:

- establishing a significant U.S. price on carbon, the single most important policy step the country could take in incentivizing private enterprise to develop and deploy technologies, such as solar, that curb climate change;
- continuing the Clean Power Plan, a federal rule finalized in 2015 that would cut greenhouse-gas emissions from U.S. power plants; though the plan is the subject of current legal challenge, and analysts differ as to how significantly it would drive solar deployment, it would help propel the shift from higher-carbon to lower-carbon electricity sources, and so, if it survives in the courts, the federal government and the states should implement it;
- achieving an equitable outcome to intensifying disputes over "net energy metering," a state-level policies that require utilities to pay consumers for electricity—generally solar power—that the consumers generate and feed into the power grid;
- supporting state renewable-portfolio standards (RPSs), which have been key drivers of solar deployment in the United States and remain important because solar power is, in most places, more expensive than conventional power;
- extending to solar energy—in the wake of a 2015 Congressional decision to phase down the federal investment tax credit (ITC) for solar—certain tax benefits enjoyed by fossil-fueled energy projects, including the master limited partnership (MLP);
- learning lessons from successes and failures of federal loans and loan guarantees provided by the DOE's Loan Programs Office (LPO);
- and ensuring that U.S. federal agencies adhere to the requirements of a 2015 law that requires them to collaborate much more than before in the way they conduct environmental reviews and permitting of a host of large-scale developments, including renewable-energy projects.

The second area ripe for U.S. federal action is to facilitate engagement by U.S. investors and financial institutions in the Chinese solar market.

Several leading U.S. solar-technology firms have sold large stakes or their entire businesses to Chinese investors. U.S. investment banks have been active in helping China-based solar firms tap the public markets for capital for manufacturing, both through initial public offerings and through follow-on offerings. And China-based solar manufacturers are beginning to invest significant sums in developing solar projects in the United States. So far, however, neither U.S. lenders nor U.S. solar developers have been active in China's burgeoning solar-deployment market.

Now is the time for that to change. U.S. solar companies, investors, and policymakers have pioneered innovative methods of solar-deployment financing. In what may prove to be one of its most significant findings, *The New Solar System* points up rising interest among high-ranking government officials in China in deploying in China certain U.S.-developed financial structures. Those structures could facilitate both debt and equity financing in China by institutions beyond banks, whose capital tends to be expensive and which have dominated the Chinese market so far. The hope in China is that more-innovative financing methods would reduce the cost of capital, helping expand solar deployment in the largest solar market in the world.

Increasing U.S. financiers' involvement in China's solar market inevitably will raise complex issues, including questions about China's electricity-market regulations—regulations that currently make it difficult for foreign investors to participate. But the prize is substantial: China plans by 2030 to spend ¥41 trillion ($5.95 trillion) on low-carbon technologies, including solar.

The U.S. government could act as a powerful facilitator of increased involvement by U.S. investors and solar developers in the Chinese solar-deployment market. Doing so could help unleash private capital to combat carbon emissions—as study after study has concluded that private capital will be far more important than direct government spending in cleaning up the global energy system. Amid continuing animosity between Beijing and Washington on many fronts, including on the issue of solar tariffs, the possibility of increased involvement by U.S. investors in China's solar-deployment market is a significant opportunity.

Conclusion

China and the United States find themselves at an unprecedented moment in the growth of solar power. How they proceed will do much determine whether solar energy emerges as a mainstream energy source and, in the process, as an engine of significant economic growth and carbon reductions. There are many reasons to be skeptical that the world's two largest energy consumers and carbon emitters will find the will to work more closely together to scale up solar power to meaningfully address the climate challenge. Yet *The New Solar System* concludes that each of them has an even more-compelling reason to do so: economic self-interest.

Methodology

The idea for the project that became *The New Solar System* emerged from a workshop that Stanford's Steyer-Taylor Center for Energy Policy and Finance convened at Stanford Law School in 2013. Some 20 senior executives from solar companies based around the United States and across the world met for a day to probe a crisp but complex question: What will the globalizing solar industry look like in a decade? Which sorts of companies, and which countries, will do what?

At the workshop, which the Steyer-Taylor Center convened in partnership with the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, the executives broke into groups and mapped out their view of the solar industry's plausible future under four scenarios.

The result of the workshop was a report published in November 2013. That report, Avoiding Sunstroke: Assessing National Competitiveness in the Global Solar Race, was only 17 pages long.* But in framing a fundamental challenge for solar energy's future as the assessment and pursuit of comparative advantage, the document spurred extensive discussion among solar leaders across the United States. From the report's 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 the 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 discussion sparked by *Avoiding Sunstroke* made clear that the notion of national comparative advantage in the globalizing solar industry was one that needed to be more deeply explored. That led the Steyer-Taylor Center in 2014 to submit a proposal to the U.S. Department of Energy (DOE) for a research grant to assess and analyze China's rapidly changing solar industry, already the world's largest, and its impact on the world. *The New Solar System* is the result of the ensuing research.

Behind *The New Solar System* is some two years of work involving the analysis of multiple data streams and extensive on-the-ground interviews in China.

The on-the-ground work included four research trips to China by members of the Stanford team. On those trips, the Stanford researchers interviewed dozens of industry executives, government officials, scientists, and financiers—all of them expert in the China-based solar industry. Also on the trips, Stanford researchers made site visits to China-based solar facilities. By the end of the research period, the researchers had spoken to many of the China-based solar industry's most experienced leaders and had visited many of the major China-based solar manufacturers' facilities.

The on-the-ground research also included two half-day workshops that the Stanford research team conducted in Beijing with China-based experts: one workshop focused on investment and one focused on R&D. The research also included a half-day workshop in Washington with U.S.-based experts.

*Jeffrey Ball and Jonas Meckling, "Avoiding Sunstroke: Assessing National Competitiveness in the Global Solar Race," Stanford Steyer-Taylor Center for Energy Policy and Finance and German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, November 4, 2013. http://law.stanford.edu/wp-content/uploads/sites/default/files/publication/443568/doc/slspublic/2013-10-31%20Final%20solar%20report.pdf

A description of data sources and data-analysis methods follows, arranged according to the four chapters of this report that focus on China's changing solar industry: its financial status and its R&D, manufacturing, and deployment activities.

Information about the China-based solar industry's financial status, the focus of Chapter 3, came from Bloomberg New Energy Finance's solar-research stream, to which the Stanford research team bought a subscription during the research for this report; publicly available financial filings from solar firms; and interviews in China with senior executives of leading solar firms. The financial data itself was widely available. What distinguishes *The New Solar System*'s analysis of the financial status of the China-based solar industry is the way that information the Stanford team gleaned through extensive on-the-ground discussions with those inside the China-based solar industry framed conclusions from the data.

The analysis of China's solar-R&D efforts that constitutes Chapter 4 involved a variety of work streams.

In the assessment of China's progress improving solar-cell efficiencies that occupies Section 4.2, data on record solar-cell efficiencies by non-Chinese entities came from the U.S. National Renewable Energy Laboratory's record-efficiency chart, and data on record efficiencies by Chinese entities came from an extensive literature search of academic papers in English and in Chinese.

The patent analysis in Section 4.3 rests primarily on data from China's State Intellectual Property Office (SIPO). The SIPO patent database is publicly available, but in raw form it is difficult to categorize and thus to analyze. With assistance from Chinese-patent-system experts at Evalueserve, a global data and analytics firm, the Stanford team grouped solar-related "invention" patents—the most innovative of the three grades of patents issued by the Chinese government—that are in the SIPO database according to a range of criteria. The criteria included the specific solar technology for which the patent was granted, the specific institution that was awarded the patent, and the type of institution (company, government agency, or academic institution) that was awarded the patent.

The number of patents granted to Chinese entities over time provided an indication of patent quantity. The "patent-lapse rate"—the percentage of patents that are not renewed by their owners, who are required to pay an annual fee for the renewal—provided insight into patent quality. To be sure, lapse rates are an imperfect measure of patent value; other factors, such as a financial squeeze, could lead a patent holder not to renew a patent. Still, lapse rates are widely used as an indicator of patent value.

The diagram of China' solar-R&D ecosystem that is the focus of Section 4.4 reveals important relationships among government institutions, and between government institutions and industry, in setting China's solar-R&D strategy and in funding it. The diagram is the result of an extensive review of the websites of the various Chinese entities and discussions with dozens of experts in industry, government, and research institutions in China. To the knowledge of the Stanford research team, it represents a newly comprehensive picture of the way that solar R&D in China is organized.

The account of the evolution of solar policy in China's five-year plans that forms Section 4.5 comes primarily from analyzing the relevant portions of the plans in the original Chinese. The account is informed by extensive discussions with experts in China in government, industry, and research institutions.

The New Solar System, in Section 4.6, goes beyond previous analyses in detailing some of the Chinese government's solar-R&D spending. This detail is based on extensive reviews of publicly available documents and on interviews with dozens of informed people in China. But it is crucial to emphasize that *The New Solar System*'s assessment of solar-R&D spending in China nevertheless remains significantly incomplete. That is because of the difficulty of obtaining accurate data on Chinese-government solar-R&D spending.

The one solar-R&D funding source in China for which a complete database of funding awards is publicly available is the National Natural Science Foundation of China (NNSFC). Section 4.6.1.2 explains the results of that database analysis. But, as the report explains, NNSFC funding is small compared to that in other solar-R&D programs in China. For those other programs, the funding information provided in the report—information that is incomplete, and almost certainly significantly so—comes from interviews, financial filings, and other publicly available documents. U.S. solar-R&D spending is, by comparison, disclosed in public documents, though categorizing it can be difficult, because it is often not listed as being primarily solar-related. For this reason, an analysis of U.S. federal solar-R&D funding conducted by DOE and NREL researchers, and provided to the Stanford research team, was extremely helpful. Yet even this analysis likely does not include some federal funding related to solar R&D; deciding what research is related to solar is to some extent subjective, dependent on how broadly one defines solar-related technologies.

The Stanford research team used third-party data, primarily from Bloomberg and IHS Markit, to provide the explanation in Section 5.1 of China's rise to its current status as the dominant global solar manufacturer.

The analysis in Section 5.2 of the main engine of China's solar-manufacturing industry—the Yangtze River Delta—emerges from extensive on-the-ground research buttressed by third-party data. The assessment in Section 5.3.1 of China's solar-manufacturing subsidies comes from a detailed examination of publicly available filings in the tariff dispute between the United States and China. As the section notes, this examination was complicated by the fact that government officials have redacted large portions of those documents. The analysis throughout the remainder of Section 5.3 of various types of government assistance to China-based solar firms comes from corporate filings, detailed searches of news reports, and discussions with industry officials and experts.

The exploration of the strengths and weaknesses of China's solar-manufacturing sector comes from three main sources. The first is a database from ENF, a China-based solar-information company. As the report explains, the ENF data is seriously flawed in that it dates to 2012. Nevertheless, despite its age, ENF's data is particularly granular in its representation of the Chinese solar-manufacturing supply chain, according to experts who are well regarded in Chinese solar circles and are affiliated with Chinese solar-research institutes. As such, the ENF data is relevant because it describes a baseline landscape from which to assess more-recent changes in the China-based solar industry, which *The New Solar System* does in Section 5.5. The second source of the assessment of the industry's strengths and weaknesses is extensive on-the-ground discussion with manufacturing experts at China-based solar firms. The third is a detailed report that the China Photovoltaic Industry Association, a trade group directly affiliated with the country's Ministry of Industry and Information Technology, issued in 2015. That report examined the status of various parts of China's solar supply chain, assessing both the progress that the Chinese industry has made over time and how each segment of the Chinese industry compares to its competitors in other countries. It is important because it shows how leaders of the China-based solar industry see the industry's strengths and weaknesses and how they intend to address them.

The examination in Chapter 6 of the evolution of solar deployment in China relies in part on third-party data to chart numerical trends. It also benefits from discussions that the Stanford research team had with experts involved in solar-deployment policy in China, including at China's National Energy Administration. One important conclusion from the deployment analysis—and an area ripe for further research—is the significant and rising interest on the part of leaders of the China-based solar industry in learning from more-efficient solar-financing mechanisms pioneered in the West.

Chapter 1: Introduction: A Charged Moment for Solar Power

Solar power is undergoing a revolution. Over the past decade, an energy source as old as the planet and theoretically all but limitless has plummeted in cost and begun in some places to be harnessed in large volume. This dynamic is disrupting the modern energy system and, as energy disruptions always do, rattling the geopolitical order. In the process, the industry that produces the equipment to convert sunlight into electricity is simultaneously reeling, consolidating, and surging. These twin transformations—one of the global energy system, one of the global solar industry—carry profound implications for national economies and for the planet. At the center of both transformations sits China.

> *Twin transformations—one of the global energy system, one of the global solar industry—carry profound implications for national economies and for the planet.*

The New Solar System seeks to illuminate China's solar path and, based on it, to chart an economically sensible course for solar power in the United States and the world.

Today, solar power remains a negligible energy source globally, contributing only about 1% to worldwide electricity production.[1] But that 1% represents a massive increase over the past decade, and during those years solar has achieved major technological and business-model advances—advances that have led many sober-minded observers to predict that solar is destined to become a cost-competitive mainstream energy source.

Yet it is no forgone conclusion that solar will become cost-competitive at a scale necessary to meaningfully curb carbon emissions. Making that happen would require reducing the cost of much more than the equipment that turns solar power into electricity. It also would require radically modernizing the system that brings that electricity to customers—including slashing the cost of energy storage and increasing the availability and sophistication of the electricity-transmission grid.

Charting a course for a rise of solar at this scale is the purpose of *The New Solar System*, and doing so involves considering several crucial issues. Among them:

- The effect of intensely challenging financial conditions for solar manufacturers around the world, including China-based firms and the two largest U.S.-based firms, First Solar and SunPower. The challenge for each leading global company is to maintain and grow both its profitability and its market share in an extraordinarily competitive global solar market that is facing overcapacity in the near term but the likelihood of significant growth in the long term.
- Disagreement among policymakers about the focus and depth of U.S. and Chinese cooperation in future global research-and-development (R&D) efforts designed to scale up solar power to a level that would meaningfully curb carbon emissions. Although the United States traditionally has led global solar R&D, *The New Solar System* finds that China is rapidly and significantly improving its solar R&D, and

[1] International Energy Agency Photovoltaic Power Systems Program's "Trends 2015 in Photovoltaic Applications" report, available at http://www.iea-pvps.org/fileadmin/dam/public/report/national/IEA-PVPS_-_Trends_2015_-_MedRes.pdf

in certain key areas China now leads the world.

- The viability of solar manufacturing in the United States. As a result of a five-year-old trade fight between the United States and China, each country has imposed tariffs on solar products that it imports from the other. The tariffs are blunt instruments that fail to resolve the most important question in charting a course for U.S. solar manufacturing: What sort of solar products is the United States well-positioned to cost-competitively manufacture and what sort of solar products is it not?
- The defining impact on the global solar industry of increasing corporate ties between Chin-based and U.S.-based companies—financial ties that are intensifying despite political tensions between Beijing and Washington and that are evidenced by a number of R&D, manufacturing, deployment investments in the United States by China-based solar firms.
- Donald J. Trump's election in November 2016 as U.S. president. Mr. Trump has raised questions about U.S. government support for renewable energy sources—and, more broadly, for efforts to curb climate change—including solar power. And he has expressed support for tariffs against China. Nevertheless, it remains unclear what steps the Trump administration will take on a number of policies specifically affecting solar power.

The New Solar System is based on some two years of work by Stanford University's Steyer-Taylor Center for Energy Policy and Finance, an initiative of Stanford Law School and Stanford Graduate School of Business. The research was funded by a research grant from the U.S. Department of Energy's (DOE's) Solar Energy Technologies Office. Stanford's Steyer-Taylor Center proposed the research and initiated the grant application to the DOE. The grant provided the center with full independence and authority to frame the inquiry, conduct the research, draw conclusions, and write this report.

1.1: A Global Solar System Centered Around China

Six decades ago, the United States developed the first photovoltaic cells.[2] A decade later, it moved them beyond the laboratory, deploying them in space. Starting in the late 1990s, Japan and Germany launched consumer markets for solar modules, installing unprecedented, though still relatively small, volumes on rooftops. However, not until the past decade did solar power begin to advance from a niche business into a mainstream electricity source. In a turn of events that not long ago would have been unthinkable, solar power today generates a several-digit share of electricity in a handful of relatively small countries around the world—countries with particularly generous solar incentives, or particularly high conventional power prices, or particularly strong sunshine, or some combination of those factors.[3] [4] The International Energy Agency announced in October 2016 that two firsts had occurred in 2015: More than half of all the power capacity that was added globally in 2015 came from renewable sources, and the cumulative amount of installed global electrical-generating capacity from all renewables—hydropower, wind, solar, geothermal and other sources—surpassed that from coal.[5]

[2] An explanation of the different components in solar manufacturing—including cells and modules—is in Section 5.1.1.
[3] In 2014, the latest year for which statistics are available, solar provided 8% of total electricity generation in Italy, 6.7% in Germany, 3.8% in Spain, and 3.6% in Belgium.
[4] Op. cit., International Energy Agency's Photovoltaic Power Systems Program, "Trends 2015 in Photovoltaic Applications."http://www.iea-pvps.org/fileadmin/dam/public/report/national/IEA-PVPS_-_Trends_2015_-_MedRes.pdf
[5] International Energy Agency, "Renewable Energy Medium-Term Market Report 2016 Executive Summary," issued October 2016. https://www.iea.org/Textbase/npsum/MTrenew2016sum.pdfhttps://www.iea.org/Textbase/npsum/MTrenew2016sum.pdf

Still, it is crucial to put this growth of solar and other renewables into perspective. The two firsts identified by the IEA relate only to renewable energy installations' generating capacity, not to the amount of electricity that they actually generated. Globally, coal still accounts for 41% of electricity generation, and all fossil fuels—coal, oil, and natural gas—together account for 67%. Solar, as noted above, provides just 1%; renewables together constitute 22%, with the vast majority of that coming from hydropower.[6] China has more solar installations than any other country, yet all its solar installations together produced just 39.2 million megawatt-hours of electricity in 2015[7]—45% of the 87 million megawatt-hours of electricity that was produced that year by China's Three Gorges Dam, which was commissioned in 2003 and remains the largest power plant in the world. The Three Gorges Dam's output, indeed, amounted to one-third of the 253 million megawatt-hours of electricity produced in 2015 by all of the solar installations on the planet combined.[8]

China, more than any other player, is driving the global rise of solar power.

China, more than any other player, is driving the global rise of solar power. Through a combination of aggressive government support and rough-and-tumble entrepreneurialism—both of which have created friction with the West—China over the past decade has trained its formidable manufacturing supply chain and banking system on capitalizing on the solar opportunity. Not only has it come to dominate and transform the business of making solar modules; more recently, it has developed some of the world's largest solar projects and it is developing world-class capabilities in solar R&D. In the process, China has built sophisticated solar companies that operate across more and more segments of the solar value chain, from R&D to manufacturing to deployment. Those companies are investing in the full range of solar activities across the world—including, as explained in Section 3.4, in the United States, where China-based solar manufacturers have bought innovative U.S. solar-technology firms, have been assessing whether to build solar-cell and solar-module factories, and are increasingly investing in developing solar-power projects. The manufacturing scale that China has brought to the solar industry is the main reason that, over the past decade, the cost of making solar modules used on rooftops and in solar farms around the globe has plummeted by between 60% and 80%.

In 2016, China produced 71% of the world's solar modules, IHS Markit estimates.[9] China installs the majority of them within its borders—mainly in large solar farms in a handful of Chinese provinces. The result confounds stereotypes: China, the world's largest coal burner and biggest carbon emitter, also is the world's leading producer of solar power equipment and deployer of solar energy. The United States produced just 1.3% of solar modules in 2016, IHS Markit estimates.[10] The United States in 2015 was third globally in cumulative solar capacity deployed, behind China and Japan.[11]

[6] International Energy Agency, World Energy Outlook 2016.
[7] BP Statistical Review of Energy 2016, data workbook. http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html)
[8] China Three Gorges Corp.'s 2015 annual report. http://www.ctgpc.com/en/_304039/_304171/index.html
[9] IHS Markit
[10] Ibid.
[11] Renewable Energy Policy Network for the 21st Century (REN21)'s Renewables 2016 Global Status Report. http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report_REN21.pdfhttp://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report_REN21.pdf

China's dominant role in the solar industry has sparked a heated debate in the West. To some, it is salutary: a reduction in the cost, and an expansion in the deployment, of solar energy for the world. To others it is threatening: a significant concentration of solar manufacturing far from the West, and a concentration that, these people contend, has been driven in significant part by government support and corporate behavior that are unfair or even illegal. The resulting global trade fight over solar is discussed in Sections 1.5 and 5.3.1 and in Appendix B. The purpose of The New Solar System is neither to promote nor to undermine China's position as the world's major solar power. Rather, it is to assess how China's preeminent position is evolving, how that evolution is likely to shape the future of a global solar industry that is at a crucial stage in its growth, and what the United States and China might do to play to their respective comparative advantages in the solar sector in a way that reduces the cost of scaling up solar energy for the world.

The purpose of The New Solar System is neither to promote nor to undermine China's position as the world's major solar power.

1.2: The Global Solar Challenge: Making Solar Bigger By Making It Cheaper

Solar power provides only about 1% of the world's electricity.[12] That may seem negligible, but in crossing that 1% threshold during the past two years, solar power reached a milestone, a sign of massive growth over the past five years from an infinitesimal base. Mainstream analyses now predict that solar is on its way to becoming a significant energy source. The International Energy Agency projects that solar photovoltaic power will account for 16% of the world's electricity production by 2050.[13] Others predict an even bigger role for solar. Thomson Reuters, for example, predicts that by 2025, less than a decade from now, "methods of harvesting, storing and converting solar energy [will be] so advanced and efficient that it becomes the primary source of energy on our planet."[14] Whatever specific percentage of the global energy mix solar ends up providing, the reality is that solar has now reached the point where it is here to stay. Nations around the world have decided to support solar energy's development and deployment so they can reap its economic, security, and environmental benefits. The United States, which, as noted in Section 1.1, developed solar cells more than 60 years ago, can and should remain in the pack of leading solar powers.

Speed and size are crucial if low-carbon energy technologies such as solar power are going to grow large enough to meaningfully curb climate change. In a striking illustration of the extent of this challenge, an April 2016 paper by researchers at the Massachusetts Institute of Technology (MIT) and the U.S. National Renewable Energy Laboratory (NREL) estimates that, given current global solar-manufacturing capacity and a rate of growth similar to that of recent years, the world is on track to have installed 1,000 gigawatts of cumulative global solar-power capacity by 2030.[15] [16] However, to meaningfully contribute to

[12] Op. cit., International Energy Agency's Photovoltaic Power Systems Program, "Trends 2015 in Photovoltaic Applications." http://www.iea-pvps.org/fileadmin/dam/public/report/national/IEA-PVPS_-_Trends_2015_-_MedRes.pdf

[13] International Energy Agency Technology Roadmap, 2014: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdfhttps://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf

[14] "The World in 2025: 10 Predictions of Innovation," Thomson Reuters, 2014. http://sciencewatch.com/sites/sw/files/m/pdf/World-2025.pdfhttp://sciencewatch.com/sites/sw/files/m/pdf/World-2025.pdf

[15] David Needleman, Jeremy Poindexter, Rachel Kurchin, I. Marius Peters, Gregory Wilson, Tonio Buonassisi,, "Economically sustainable scaling of photovoltaics to meet climate targets," Energy & Environmental Science, April 21, 2016.

[16] One gigawatt is equal to 1,000 megawatts. The cumulative capacity of installed solar projects around the world stood at 227,000 megawatts at the end of 2015—up 50,000 megawatts, or 28%, from 2014, and up 187,000 megawatts, or 468%, from 2010, according to the Renewable

significantly cutting global greenhouse-gas emissions, total global solar capacity by 2030 would have to be massively more than that. In such a world, installed solar capacity would be measured in the thousands of gigawatts instead of, as today, in the thousands of megawatts. Specifically, total global solar capacity would have to be between 2,000 gigawatts and 10,000 gigawatts, these researchers estimate. [17] The wide range between these two figures reflects uncertainty about the extent to which low- and zero-carbon energy technologies other than solar might expand over the same period.

If global solar capacity reached 10,000 gigawatts by 2030, solar power would supply some 44% of global electricity in that year, according to the MIT and NREL researchers, who based their calculation on current projections of global electricity demand in 2030. The precise quantity of carbon emissions that would be avoided if global solar deployment reached 10,000 gigawatts by 2030 has not been calculated; all that is clear, the researchers say, is that solar deployment at that level would have a substantial impact on curbing greenhouse-gas emissions.

Scaling up solar to this massive level would entail increasing global solar installations approximately 25% every year between now and 2030, according to a working draft of a second paper now under development by researchers who include several of the authors of the April 2016 paper.[18] [19] In other words, according to these calculations, in order for solar to substantially help meet global climate targets, annual global solar-project installations would have to continue growing over each of the next 15 years at approximately the same torrid rate at which they grew over the past few years. Maintaining that rate of growth gets harder every year, as solar's installed base—now sizeable—expands.

Even assuming that the cost of manufacturing solar equipment continued to decline, the capital investment required to increase global-manufacturing capacity enough to reach these solar-capacity numbers would be huge. Global manufacturing capacity will stand at roughly 78,000 megawatts per year for solar cells and 77,000 megawatts per year for silicon solar modules by the end of 2016, IHS Markit, a global analyst of the energy world, including of the solar sector, projected as of December 2016.[20] [21] Building a cumulative 3,000 gigawatts of solar capacity by 2030 would require some $265 billion in investment in new manufacturing capacity, according to one estimate, and building a cumulative 10,000 gigawatts by 2030 would require approximately $817 billion in investment in new manufacturing capacity.[22]

For context on how large an undertaking it would be to achieve a global installed solar capacity of between 2,000 gigawatts and 10,000 gigawatts, consider that, in 2013, the last year for which statistics are available, total electricity-generating capacity from all sources was 5,884 gigawatts globally, of which 1,286 gigawatts was in China and 1,134 gigawatts was in the United States.[23] The reason that such a massive amount of installed solar capacity would be necessary is that solar

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Energy Policy Network for the 21st Century (REN21)'s Renewables 2016 Global Status Report. http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report_REN21.pdfhttp://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report_REN21.pdf

[17] Op. cit., D. Needleman, J. Poindexter, R. Kurchin, I. Peters, G. Wilson, T. Buonassisi.

[18] Nancy Haegel et. al., "Terawatt-Scale Photovoltaics: Trajectories and Challenges," under review September 2016. Note: One terawatt is equal to 1,000 gigawatts.

[19] A draft copy of this second paper was made available to the Stanford Steyer-Taylor Center for Energy Policy and Finance research team to help inform *The New Solar System*. The second paper is based largely on a two-day workshop held in spring 2016 in Freiburg, Germany, that addressed ways to scale up solar power significantly. The workshop was organized by the U.S. National Renewable Energy Laboratory, Germany's Fraunhofer Institute for Solar Energy Systems, and Japan's National Institute of Advanced Industrial Science and Technology.

[20] Op. cit., IHS Markit

[21] The fact that module-manufacturing capacity exceeds cell-manufacturing capacity means that a greater percentage of module-manufacturing capacity is sitting unused.

[22] Communication with Gregory Wilson, Director, National Center for Photovoltaics, U.S. National Renewable Energy Laboratory, September 2016.

[23] International Energy Agency, World Energy Outlook 2015.

energy is intermittent. It produces power only to the extent that the sun shines, and the amount of power that it produces at any given moment when the sun is shining depends on myriad and complex factors, from temperature to cloud cover to dust in the air. As a result, a collection of solar modules that is rated by its manufacturer to have a capacity of, say, 1,000 megawatts, produces only a fraction as much electricity as a coal-, gas-, or nuclear-fueled power plant that is rated by its manufacturer as having the same 1,000-megawatt capacity. That fraction for solar differs among locations around the world. On average, a utility-scale solar installation generates on average approximately 20% of its rated capacity over the course of a year, according to NREL, though that percentage varies significantly depending on location.[24]

Realizing the massive increases in installed solar capacity that solar advocates are envisioning would require a range of technological innovations—innovations that would increase the productivity and reduce the capital cost of all of this solar-generating equipment. Among the technologies widely seen as particularly promising: so-called "epitaxial" technology, in which a very thin layer of photovoltaic material is created on a substrate and then pulled off and used, a process that drastically reduces the amount of such material that is required; and solar-wafer-production technologies that entirely eliminate "kerf," the waste material generated when a block, or ingot, of silicon is sliced into individual wafers.[25]

Importantly, technological innovation is influenced by many forces beyond the lab. *The New Solar System* argues that technological innovation is likelier to emerge to the extent that governments set solar-energy policies with the clear goal of minimizing solar's cost rather than with more-parochial goals that many of them have embraced thus far—goals such as maximizing solar-manufacturing jobs within their national borders.

1.3: A Global Solar Strategy: Harnessing Comparative Advantage to Cut Solar's Cost

Whether solar power grows this significantly, and whether in the process it makes much environmental difference, will depend in large part on whether governments—nations as well as sub-national states, provinces, and municipalities—adopt a more economically efficient approach to it than they have thus far. This economic efficiency would involve governments making thoughtful and nuanced assessments about the sort of benefits that solar energy is—and is not—likely to bring their economies over the long term. Today, governments fashion certain solar policies largely for short-term economic gain—in many cases, to induce a relatively small number of highly subsidized domestic manufacturing jobs. A more effective and efficient approach would involve governments assessing, and then fashioning policies that played to, their jurisdictions' specific comparative advantages in solar manufacturing.

A more effective and efficient approach would involve governments assessing their jurisdictions' comparative advantages.

As Chapter 7 argues, the best way for the United States to support the sort of solar manufacturing that is likely to be economically viable over the long term is not by direct solar-manufacturing subsidies but rather by support for solar R&D and for solar deployment. R&D acts as a push for solar manufacturing; deployment acts as a pull for it.

The New Solar System does not seek to enable any country to beat another in the global solar industry. It seeks instead to help all countries find their most effective places. Idealistic as this objective may sound, it is, in fact, practical. By better understanding and playing to their

[24] "Utility-Scale Energy Technology Capacity Factors," U.S. National Renewable Energy Laboratory. http://www.U.S. National Renewable Energy Laboratory.gov/analysis/tech_cap_factor.htmlhttp://www.nrel.gov/analysis/tech_cap_factor.html

[25] Op. cit., D. Needleman, J. Poindexter, R. Kurchin, I. Peters, G. Wilson, T. Buonassisi.

comparative strengths in the solar business, countries would achieve two key objectives. They would reduce the cost for the world of scaling up solar power, a technology that has dropped significantly in price and grown significantly in penetration but that still accounts for only a tiny fraction of global electricity generation and, according to U.S. government targets issued in November 2016, still needs to cut costs by about half.[26] And they would be better positioned to fashion policies that maximized the long-term benefit to their own economies from solar's global growth. In short, a more considered view of comparative advantage in the growing global solar industry would benefit not just the planet but also the pocketbooks of the players involved.

This notion of long-term—what also might be called "sustainable"—economic benefit is crucial. *The New Solar System* argues that many of the solar policies that countries have adopted thus far have been inefficient. They have achieved, to varying degrees, their stated goals of boosting domestic solar manufacturing or deployment in the near term, but often they have done so in ways that are unable to be sustained—for political or economic reasons or both. The result, in much of the world, has been wild swings in solar policy, ranging from unnecessarily generous support to unreasonable neglect. That, in turn, has contributed to a boom-bust pattern in the solar industry that has benefited no one: not investors, solar-technology entrepreneurs, ratepayers, taxpayers, or citizens around the world who could benefit from an energy system decarbonized sooner rather than later. Enabling solar power to scale to a level that can help curb fossil-fuel emissions requires governments to find smarter means of policy and financial support. One key predicate for making smarter policy is taking into account a country's relative comparative advantage in the rapidly globalizing solar industry: what it does well and what it does not.

The New Solar System envisions the global solar industry as a jigsaw puzzle, with each piece representing a different country or sub-national jurisdiction. In this puzzle, the optimal shape of each piece represents a jurisdiction's comparative advantage. The puzzle as a whole—one in which the pieces fit together—reflects an economically efficient arrangement for solar power's global growth. Today, the pieces are not shaped optimally; as a result, in certain places they overlap with each other and in other places they leave gaps in the puzzle. *The New Solar System* explores two underlying questions about this puzzle:

- What would be the optimal shape of each piece—optimal in the sense of lowering the cost of solar power for the world and, in the process, maximizing the long-term economic benefit that the solar sector delivered to each country, state, or province?
- What policies and financial tools would maximize the chance of producing these optimally shaped puzzle pieces? In other words, what policies and financial tools would help countries play to their comparative advantages in the solar sector in a way that benefited them domestically and that scaled up solar globally at the lowest possible cost?

As the global solar industry matures, and in the process consolidates around a smaller number of increasingly large international companies, those companies are likely to look increasingly similar in the parts of their operations that they carry out in particular spots around the world. China is by far the biggest piece in the global solar puzzle; in 2016, 53% of the polysilicon, 60% of the silicon solar cells, and 71% of the silicon solar modules produced in the world were made in China, IHS Markit estimates.[27] Moreover, for reasons that *The New Solar System* will detail, major non-China-based players in the solar industry are likely to become increasingly involved in the Chinese market.

[26] The U.S. Department of Energy in November 2016 announced new targets for the cost of solar power without subsidies by 2030; those targets seek to reduce the cost of solar power by another roughly 50% beyond the price targets that the DOE in 2011 established for 2020. The cost targets are explained in Section 7.3.2.

[27] Op. cit., IHS Markit

Therefore, the shape of China's puzzle piece will increasingly influence the shapes of all the other national and sub-national pieces. So *The New Solar System* focuses on the Chinese piece of the puzzle, and, in turn, it implications for the U.S. piece. What companies do in China will increasingly influence what they do elsewhere.

Many companies and investors are ahead of governments in rationally analyzing their comparative advantage in the solar sector; their profits depend on it. Yet the speed at which the solar industry is growing and globalizing means that business models can grow stale quickly. In just one example, U.S. venture capitalists lost hundreds of millions of dollars in solar-sector investments between 2010 and 2015 because, fundamentally, they misjudged the technological, financial, and political challenges of scaling up an immature energy technology that is vastly different from the information technologies that many of those investors cut their teeth on. The next stage of solar's growth will require new types of partnerships among companies and between companies and governments, more-innovative financing, and, underlying it all, a broader global view.

Solar energy is likely to continue to grow even if governments and the private sector do not calibrate their strategies to minimize its cost. But it almost certainly will grow faster and larger if they pivot to this more rigorous approach.

1.4: A Moment in Time

The New Solar System seeks to illuminate a long-term economic strategy for the significant scale-up of solar power. The time is right to provide that clarity.

1.4.1: Momentum for Solar Globally

The December 2015 Paris climate agreement codified commitments from many of the world's largest nations—including China and the United States—to dramatically scale up the development of low-carbon energy sources including solar power. In one potentially significant example, China, the United States, and many other nations agreed at the Paris climate talks to double their spending on global clean-energy research and development under an initiative called Mission Innovation. Their pledges raise both the possibility for significant solar-technology advances and the crucial question of whether Western nations will welcome China's more-significant participation in an expanded global solar-R&D game.

The New Solar System seeks to illuminate a long-term strategy for the scale-up of solar power. The time is right to provide that clarity.

Myriad forces have been converging in both China and the United States that suggest a moment of unprecedented opportunity to fashion a workable global strategy for the economically efficient growth of solar power.

In China, air pollution that in cities often far exceeds the levels that the World Health Organization has defined as safe has created a groundswell in support of cleaner energy sources. President Xi Jinping has pledged that, by 2030, China's carbon-dioxide emissions will peak and non-fossil energy sources, including renewables, will constitute 20% of the country's total energy supply.[28] China's Thirteenth Five-Year Plan, the government document that will shape the Chinese economy through 2020, stipulates a massive increase in China's solar manufacturing and deployment—both areas in which China already leads the world. And China's solar industry is consolidating, following a period of torrid growth fueled by generous government subsidies around the world that in many cases have been or are being reduced. This consolidation is creating in

[28] "U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation," White House press release, Nov. 11, 2014. https://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c

China a handful of sophisticated global solar players, companies with increasingly international operations. These companies and their diversifying foreign markets are coming to depend on each other as both seek to promote solar power's rise. That interdependence is leading these China-based companies and prominent solar players in other countries to a similar conclusion: that the nationalistic outlook that has tended to define government policies toward the solar industry in China, the United States, and much of the world is outdated, increasingly counterproductive, and ripe for reform.

Recent developments give conflicting signals about the future of protectionist policies that tend to inflate the price of solar power, as explained further in Sections 5.3.1 and 5.3.2. Policies in many countries that have required that solar products sold there also be manufactured there are being ruled illegal by international trade authorities. And various international solar-industry groups are meeting together to try to broker an easing both of these domestic-content requirements and of tariffs that the United States and China each have imposed on solar products manufactured by the other. Yet, despite these legal and diplomatic moves against protectionist barriers broadly, the reality is that solar tariffs—levied by the United States on solar cells manufactured in China and levied by China on polysilicon manufactured in the United States—show little indication of easing anytime soon.

U.S. support for solar power also has been rising. The U.S. Congress voted in December 2015 to extend for five years and then phase down the federal investment tax credit (ITC), the chief U.S. subsidy for solar deployment. California and New York, the nation's first and third most-populous states, have mandated that, by 2030, half their electricity come from renewable sources including solar.[29] [30] Thus, despite the oft-repeated and incorrect notion that the United States has no energy policy, evidence has been mounting that the United States indeed is inclined to make decisions on both the federal and state levels that dramatically affect the future of energy, including of solar power.

1.4.2: Uncertainty About U.S. Solar

Yet several recent events underscore that, at least in the near term, the U.S. solar industry faces significant uncertainty.

In November 2016, Americans elected as president Mr. Trump, who has disputed the link between human activity and climate change and who has characterized efforts to scale up solar and other forms of renewable energy as uneconomic because of the subsidies involved.

In his 2015 book, "Crippled America: How to Make America Great Again," Mr. Trump wrote that solar energy did not make commercial sense though it might prove more economic in the future:

> The most popular source of green energy is solar panels. They work, but they don't make economic sense. They don't provide enough energy savings to cover the cost of installing and using them. They are the most highly subsidized form of green energy in America.
>
> Some estimates claim it takes as long as several decades after installing solar panels to get your money back. That's not exactly what I would call a sound investment.
>
> Even if that number is only half right, what kind of investment do you make that takes 20 years before you break even? I understand solar energy is eventually going to become more efficient and maybe even cost-effective. Maybe. When it

[29] California Energy Commission, "Tracking Progress," Oct. 11, 2016. http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdfhttp://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf

[30] New York Governor's Press Office, "Governor Cuomo Announces Establishment of Clean Energy Standard That Mandates 50 Percent Renewables by 2030," Aug. 1, 2016. https://www.governor.ny.gov/news/governor-cuomo-announces-establishment-clean-energy-standard-mandates-50-percent-renewableshttps://www.governor.ny.gov/news/governor-cuomo-announces-establishment-clean-energy-standard-mandates-50-percent-renewables

> proves to be affordable and reliable in providing a substantial percent of our energy needs, then maybe it'll be worth discussing. Meanwhile, we have to keep our cars and trucks running and our homes and buildings heated. There are much more efficient, cost-effective, and reliable ways of doing that.[31]

In a plan for his first 100 days in office that he released in May 2016, Mr. Trump pledged to "cancel the Paris Climate Agreement and stop all payments of U.S. tax dollars to U.N. global warming programs."[32] He explained in the plan that his environmental goals "are very simple: clean air and clean water." His plan added: "Any future regulation will go through a simple test: is this regulation good for the American worker? If it doesn't pass this test, the rule will not be approved." The Trump plan expresses support for "all forms of energy. This includes renewable energies and the technologies of the future. It includes nuclear, wind and solar energy—but not to the exclusion of other energy. The government should not pick winners and losers."[33]

In an interview with The New York Times on Nov. 22, 2016, approximately two weeks after he was elected president, Mr. Trump said he believes "you can make lots of cases for different views" as to the relationship between human activity and climate change. "I have a totally open mind," he said. He added: "I think there is some connectivity. There is some, something. It depends on how much. It also depends on how much it's going to cost our companies. You have to understand, our companies are noncompetitive right now."[34] In a section of the interview that dealt with renewable energy—focusing on wind turbines rather than on solar panels—Mr. Trump said, "I don't think they work at all without massive subsidy," and that "I wouldn't want to subsidize it."[35]

Mr. Trump also has indicated opposition to the Clean Power Plan, a federal regulation promulgated in the Obama Administration that seeks reductions in carbon-dioxide emissions from U.S. power plants. The Clean Power Plan faces challenges in federal court from opponents who argue it is a misuse of federal authority. If it survives, the plan will add pressure and financial momentum for more renewable energy including solar power. The Trump administration's "America First Energy Plan," published on the White House website, reiterates Mr. Trump's commitment "to eliminating harmful and unnecessary policies such as the Climate Action Plan"—a broad suite of federal policies that includes the Clean Power Plan.[36]

Mr. Trump also has criticized China and called for a tougher trade stance with the country. During his candidacy for president, he pledged to "bring trade cases against China" because of "China's unfair subsidy behavior," and he wrote that he will employ "every lawful presidential power to remedy trade disputes if China does not stop its illegal activities, including its theft of American trade secrets…."[37]

It is unclear to what extent Mr. Trump will move as president to scale back recent federal support for solar power. Over the past five years, the politics of solar energy have grown increasingly complicated. The industry's growth has won it bipartisan support in many locations from policymakers who see it—and federal subsidies

[31] Donald J. Trump, "Crippled America: How to Make America Great Again," Simon & Schuster, November 2015, page 65.http://www.ontheissues.org/2016/Donald_Trump_Energy_+_Oil.htm
[32] "An America First Energy Plan," Donald J. Trump website, https://www.donaldjtrump.com/press-releases/an-america-first-energy-planhttps://www.donaldjtrump.com/press-releases/an-america-first-energy-plan
[33] Ibid.
[34] "Donald Trump's New York Times Interview: Full Transcript," New York Times, Nov. 23. 2016. http://www.nytimes.com/2016/11/23/us/politics/trump-new-york-times-interview-transcript.html?_r=0http://www.nytimes.com/2016/11/23/us/politics/trump-new-york-times-interview-transcript.html?_r=0
[35] Ibid.
[36] "An America First Energy Plan," White House website. https://www.whitehouse.gov/america-first-energy
[37] "Donald J. Trump's 7 Point Plan to Rebuild the American Economy By Fighting For Free Trade," Donald J. Trump website, https://www.donaldjtrump.com/policies/trade/

that undergird it—as helping their local economies with locally significant job creation.

It is similarly unclear to what extent the Trump administration will intensify trade barriers against China. Some of Mr. Trump's key cabinet nominees have staked out positions much more supportive of free trade than has Mr. Trump. Terry Branstad, whom Mr. Trump nominated in December 2016 as U.S. ambassador to China, spent his tenure as governor of Iowa pursuing a close trading relationship with China. In a statement he issued accepting the nomination as ambassador, Mr. Branstad described Chinese President Xi as a friend, saying this: "During our 30-year friendship, President Xi Jinping and I have developed a respect and admiration for each other, our people and our cultures. The United States-Chinese bilateral relationship is at a critical point. Ensuring the countries with the two largest economies and two largest militaries in the world maintain a collaborative and cooperative relationship is needed more now than ever."[38]

Coincident with, but unrelated to, the U.S. presidential election, the two largest solar manufacturers based in the United States, First Solar Inc. and SunPower Corp., announced significant cost-cutting programs, including broad layoffs, in late 2016, at or around the time that they released their third-quarter-2016 financial results. The restructurings are designed to trim the companies' operations at a moment when the prices of solar modules—largely as a result of market conditions in China—are dropping. First Solar's restructuring is expected to cut some 1,600 jobs, more than one-quarter of the company's worldwide workforce.[39] First Solar said it expects a 2016 operating loss of between $210 million and $445 million and that it will incur charges in 2016 of between $500 million and $700 million as part of its restructuring.[40] SunPower too announced in December 2016 that it would lay off up to 2,500 workers, some 25% of its total workforce, and would close a factory in the Philippines that has a capacity of approximately 700 megawatts. It said it expects restructuring charges of at least $150 million in the fourth quarter of 2016 and between $75 million and $125 million in 2017. "This comprehensive restructuring program will enable us to successfully navigate the current challenging industry conditions while positioning us for success over the long term," the company said in a press release announcing the restructuring.[41]

The "push" of R&D investment and "pull" of deployment support are likely to be more effective than direct aid for U.S. solar factories.

The New Solar System argues that it would be a mistake for the United States to abandon federal support for solar R&D and deployment in the United States. Such support, provided over decades and in varying degrees by both Republican and Democratic administrations, has been one reason among others that the price of solar power has fallen significantly and continues to drop.

It is time, however, for the U.S. federal government to reform its approach to solar power to make it more economically efficient—both to increase the reach of solar globally and to improve the competitiveness of the U.S. solar industry in that global expansion. As *The New Solar System* explains in detail, the "push" of R&D investment

[38] Statement by Office of Iowa Gov. Terry Branstad, Dec. 7, 2016. https://governor.iowa.gov/2016/12/gov-branstad-issues-statement-on-being-nominated-to-serve-as-the-us-ambassador-to-china

[39] Eric Wesoff, "First Solar Restructures," Greentech Media, Nov. 17, 2016. https://www.greentechmedia.com/articles/read/First-Solar-Restructures-Faster-New-Module-Rollout-But-25-Workforce-Layof?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+GTM_Solar+(GTM+Solar) https://www.greentechmedia.com/articles/read/First-Solar-Restructures-Faster-New-Module-Rollout-But-25-Workforce-Layof?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+GTM_Solar+(GTM+Solar)

[40] "First Solar Announces Acceleration of Series 6 Solar Module Production to 2018; Restructures Operations; Updates 2016 Guidance & Provides 2017 Guidance," First Solar press release, Nov. 16, 2016. http://investor.pP.com/releasedetail.cfm?ReleaseID=999827

[41] "SunPower Announces Restructuring Program," SunPower press release, Dec. 7, 2016. http://newsroom.sunpower.com/2016-12-07-SunPower-Announces-Restructuring-Programhttp://newsroom.sunpower.com/2016-12-07-SunPower-Announces-Restructuring-Program

and the "pull" of deployment support are likely to be far more effective in cost-effectively helping to scale up solar power than direct government aid for domestic U.S. solar factories. A refined federal approach to solar would help scale up this energy source and, in doing so, would deliver important economic value to the United States: in global technological leadership, in domestic low-carbon power, and, to a lesser extent, in manufacturing jobs. How the government could reform its solar support in this way is explained in detail in The New Solar System.

1.5: An Entrenched International Trade Fight

Solar power's rapid growth makes it a disruptive force. One sort of disruption is economic. Solar power is challenging the business models of traditional electric utilities in a number of major economies, including parts of the United States and several European countries. And it is following a familiar path of industrial maturation, with a declining number of increasingly large and global firms coming to dominate the sector. Another aspect of the disruption wrought by solar energy is political. The governments of many large countries have identified solar-technology research as a strategic priority.

The geostrategic stakes of solar power are nowhere clearer than in a long-running trade battle between the United States and China over Chinese-made solar products. That trade dispute started in 2011, a time when major China-based solar firms were beginning to sell solar modules in the West at prices so low that many Western firms found it difficult to compete. One of those firms, SolarWorld AG, a German-based solar manufacturer with a factory in the U.S. state of Oregon, filed complaints with the U.S. Department of Commerce and International Trade Commission alleging that the low prices at which major China-based solar firms were selling solar modules in the West were a result of predatory pricing by those firms and of subsidies by the Chinese government—pricing and subsidies so aggressive that they violated World Trade Organization rules. The commission validated the charges, and today, five years later, the United States continues to levy tariffs on Chinese-made solar panels imported into the United States.

As *The New Solar System* explains in Sections 2.4 and 7.4.1.3 and in Appendix B, the tariffs have significantly redrawn the global solar industry—and in ways far different than their advocates in the West intended. The tariffs that the United States imposed on imports of Chinese-made solar products led China to impose tariffs on imports of the one solar product of which the United States was a major global manufacturer: polysilicon. Those Chinese tariffs have significantly reduced U.S. exports of polysilicon to China. Meanwhile, the tariffs the United States imposed on Chinese solar products have failed to catapult the United States into the ranks of leading manufacturers of solar cells and solar modules.

A similar trade dispute over Chinese-made solar cells and solar modules continues in the European Union, which, like the United States, imposed tariffs on imports of Chinese-made solar products after concluding that the Chinese government was unfairly subsidizing China-based solar manufacturers and that China-based solar manufacturers were dumping their products onto the European market.

Many solar advocates in both the United States and Europe are pressing for an end to the tariffs, arguing that the tariffs, in artificially propping up the price of solar modules, are slowing the penetration of solar power. Nevertheless, solar tariffs appear likely to shape the global solar industry for the indefinite future.

Beyond tariffs, some countries have instituted requirements that solar products be manufactured domestically in order to qualify for certain government subsidies. However, as explained in Section 5.3.2, these domestic-content mandates increasingly are being challenged and invalidated under international trade rules.

The prospects for solar power, in short, are promising in the long term and challenging in the short term. The fundamentals argue for solar's rise: Interest in low-carbon energy sources is rising along with concern about climate change; the cost of solar power continues to fall; and a lengthening list of countries have decided that pursuing solar is in their economic, geopolitical, and environmental interests. Yet solar remains a tiny slice of the global energy pie. And recent political developments—notably trade barriers, which were designed to protect domestic solar industries—are making it more expensive to harness energy from the sun. Amid this complexity, one thing is clear: It is now more important than ever that the pursuit of solar proceed in an economically efficient way. *The New Solar System* seeks to map that path.

Chapter 2:
Busting Myths About China's Solar Sector

The New Solar System examines changes in China's solar industry in its overall financial condition and across its three major operational areas: R&D, manufacturing, and deployment. The conclusions of this analysis contradict a number of long-held beliefs about the global solar industry that have been prevalent in the United States and Europe and that have guided solar policy and investment decisions there. In other words, they bust some myths. And in busting those myths, they frame recommendations The New Solar System will make for a more economically efficient set of policies and investment approaches.

The New Solar System challenges at least five key myths about the Chinese solar industry that are prevalent in the West:

2.1: Myth: China's Solar Industry Is a Bubble About to Burst

The roller-coaster financial history of China's major solar manufacturers has led many observers in the West to conclude that the solar industry is a financial bubble about to burst. In fact, China-based solar companies are reforming their capital structures to make them more economically efficient. The industry's finances are strengthening—spottily. China-based solar companies remain highly leveraged—a couple of them dangerously so—but, industry-wide, finances are improving. The Chinese central government is reforming its solar policies and financial support (across R&D, manufacturing, and deployment). And the Chinese solar industry is strengthening its domestic supply chain—notably in the production of polysilicon and in the equipment used to manufacture solar cells.

2.2: Myth: China Does Not Innovate

There is a widespread view in the West that China doesn't innovate—that it merely manufacturers, at low cost, technologies perfected in the West. In fact, China is innovating significantly in the solar sector—not only in manufacturing processes, its traditional solar-industry strength, but also increasingly in underlying solar R&D. That innovation is occurring across the full spectrum of solar technologies, *The New Solar System* finds. But it is playing out differently across three broad solar-technology categories:

- China's leading solar-cell manufacturers are catching up with and, in the case of certain cell technologies, overtaking their foreign competitors in a key metric of solar-industry prowess: the efficiency with which their cells convert sunlight to electricity. A strong sign of this progress is that one of China's leading solar-cell makers, Trina, has set the world efficiency record for a laboratory version of a multicrystalline solar cell, as verified by the U.S. National Renewable Energy Laboratory. The multicrystalline solar cell is the type most commonly used in solar modules.
- China is narrowing the gap with the West in a subgroup of technologies that are on the market in smaller quantities—technologies such as heterojunction-with-intrinsic-thin-layer (HIT) solar cells and copper-indium-gallium-selenide (CIGS) cells.
- Little gap exists between China and the West in emerging technologies that are not yet in the marketplace—technologies such as perovskite and organic solar cells.

An important aspect of China's improving solar R&D is a move by the Chinese government to restructure the way it organizes and funds its solar-R&D ecosystem—the ministries, laboratories, and companies that make up China's solar-R&D effort—because the government has concluded that the prior structure failed to achieve enough technological innovation for the money the government spent. This reform will put China in an even stronger position to move ahead in solar R&D.

An important aspect is a move by the Chinese government to restructure the way it organizes and funds its solar-R&D ecosystem.

2.3: Myth: The Global Solar Industry Is Centralizing In China.

For much of the past decade, the global solar industry centralized in China. Between approximately 2007 and 2013, China-based solar manufacturers came to dominate the global market for solar modules, exporting virtually all those modules, initially mostly to Europe and gradually to a variety of markets around the world. Since then, the Chinese government has rolled out an array of domestic deployment subsidies that have made China itself the world's largest market for solar-module installations.

Now, however, after this stage of centralizing in China, the global solar industry, led by China-based companies, is showing early signs of decentralizing geographically. China-based solar manufacturers are expanding globally in all three major aspects of the solar business.

First, they are intensifying R&D efforts in the West, both by working with research institutes in the United States and Europe and by establishing R&D outposts of their own in the West.

Second, although they expect to continue to produce the majority of their products in China, they are launching factories elsewhere, primarily in an effort to circumvent tariffs on Chinese-made solar goods imposed by Western countries. The vast majority of this non-mainland manufacturing capacity is at this point in Southeast Asia. But several large China-based solar manufacturers report exploring the possibility of opening factories in the United States, both to avert the tariffs and because local manufacturing makes increasing economic sense as foreign markets such as the United States grow.[42]

Third, several China-based solar manufacturers are beginning to develop solar-deployment projects abroad—notably in the United States, South America, and Europe—in an attempt to ensure a larger and more-diverse range of markets for their products. As with manufacturing, deployment outside of China remains small compared to that inside the country, but it is growing quickly. The upshot of all of three of these forms of geographic expansion is significant: China is the key player in a budding decentralization of the global solar industry. This decentralization is just beginning, and so China-based solar companies' activities outside China remain small in the context of their domestic operations. But the decentralization is likely to intensify—and to redefine the global solar industry in coming years.

2.4: Myth: Western Tariffs Are Hobbling the Chinese Solar Industry.

The tariffs absolutely are making business more difficult for China-based solar manufacturers. They are squeezing their margins and forcing them to innovate new business strategies to succeed.

[42] Executives at Trina and GCL, for instance, reported looking at possible U.S. factories.

As a result, however, the tariffs are forcing the Chinese solar industry to grow leaner and stronger. They are strengthening the Chinese solar industry in ways that are profound and that the tariffs' promoters did not intend. Just as the human body develops antibodies to resist the threat of an infection and in the process becomes stronger, the Chinese solar industry is developing strategies to resist the threat of Western tariffs and in the process is becoming better positioned for long-term success.

business for the foreseeable future—and that, as a result, the world's leading solar manufacturers, most of which are based in China, are adapting to this reality. To the extent that the architects of the Western tariffs intended them as a tool to quash the Chinese solar industry, events on the ground have shown the tool to be blunt and clumsy. Not surprisingly, China-based solar manufacturers have developed multiple surgical strategies in response. In developing these strategies, China-based solar manufacturers are becoming more sophisticated global players. Moreover, as *The New Solar System* will explain, China-based companies are not the only ones adapting adroitly to avoid the tariffs' impacts. Aiding the China-based firms are a number of U.S.- and European-based firms, particularly polysilicon producers at the industry's upstream end. These Western firms are doing so purely in their own economic interests.

Tariffs are forcing the Chinese solar industry to grow stronger, strengthening it in ways the tariffs' promoters did not intend.

The tariffs are driving the consolidation and vertical integration by China-based solar manufacturers in two ways. First, companies need healthier balance sheets to fund the global diversification that will allow them to circumvent the tariffs by building factories in other countries whose exports are not subject to the U.S. tariffs. Second, a suite of policies implemented by the Chinese government are accelerating consolidation among China-based solar manufacturers—consolidation designed to produce companies that are sufficiently large and globally diversified to thrive in an industry that many expect to remain driven by tariffs for years to come.[43]

This is not to say that the tariffs are helpful for the cost-effective growth of solar power; studies suggest the tariffs are raising the price of solar power for consumers in the West, though by how much is unclear.[44] It is to say that most solar firms, wherever in the world they are based, regard the tariffs as a reality of

2.5: Myth: China's Solar Market Is Largely Closed To Foreign Investment.

Western observers, particularly Western policymakers, often criticize what they describe as Chinese resistance to investment in China by foreign entities. Recently, however, Chinese renewable-energy regulators and China's leading solar manufacturers have decided they will have to enlist on a grand scale both financing innovation and capital from the West.

[43] These policies are explained in Sections 3.3.2 and 5.5.3.

[44] A Greentech Media study in 2014 projected that the price of China-made solar modules imported into the United States would rise an average of 14% as a result of the tariffs. (Mike Munsell, "New Tariffs on Chinese Solar Modules Will Raise U.S. Prices by 14%," Greentech Media, June 20, 2014. https://www.greentechmedia.com/articles/read/New-Tariffs-on-Chinese-Solar-Modules-Will-Raise-US-Price-by-14) Several U.S. solar-industry experts said they have seen no credible analysis of how much the tariffs have, in fact, pushed prices up recently. That is a potential area for future research.

The biggest funder of China's solar expansion, from manufacturing to deployment, has been the country's web of state-run "policy banks"—the banks whose primary purpose is to finance the implementation of Chinese government policy. Chief among those solar lenders has been the China Development Bank (CDB). But that financing, while plentiful, has been relatively expensive, as is explained in The New Solar System. Chinese regulators and solar executives have concluded that, in order to be able to afford to increase the deployment of solar energy both inside China and globally to the levels they are projecting, they will need to develop lower-cost financing alternatives, in particular alternatives that have been pioneered in the United States.

Some of this interaction has been occurring for years: Leading China-based solar manufacturers hired U.S.-based investment banks, such as Morgan Stanley and J.P. Morgan, to coordinate their initial public stock offerings, and since then they have rehired these banks repeatedly to raise subsequent rounds of capital. From that fairly rudimentary base, however, financial interaction between China and the United States in solar appears poised to grow significantly in the next few years, motivated in large part by growing interest in China in adopting financial tactics used in the U.S. solar industry, such as consumer leasing of rooftop solar arrays.

China's National Energy Administration, the government entity that heads China's solar-deployment strategy, has identified as a key priority working more closely with U.S. institutions to develop a variety of innovative ways to finance a massive expansion of solar deployment in China. In recent months, the potential for this solar-financing cooperation has reached the level of U.S.-China diplomatic discussions.[45] This is a significant opportunity for mutually profitable interaction between solar firms and financiers in China and those in the United States—interaction that could help dramatically scale up solar power.

[45] These discussions have occurred under the auspices of the U.S.-China Renewable Energy Partnership, a bilateral organization established by the two countries in 2009, as explained in Section 7.5.2.

Chapter 3:
Financial Status of the Industry

3:1: Overview

Among those in the West who monitor the global solar industry, there is a widespread view that China's solar industry is economically unsustainable. This view holds that China-based companies are groaning under government-issued debt, saddled with inefficient factories, and, as a result of both situations, unable to afford the next stage of expansion that the global solar industry will have to undertake if solar power is to become a truly mainstream source of electricity.[46] [47]

The notion of China as the global solar leader but with declining dominance clarifies the roles other countries could sustainably play.

The New Solar System finds that these concerns, while important, are overblown.

In the near term, the major China-based solar manufacturers are struggling with the repercussions of the strategy they have used essentially since their inception: aggressively expanding manufacturing capacity to increase their global market share. That strategy is particularly perilous at moments, such as now, when governments are restructuring their policy support for solar to trim public costs.

Longer-term, however, the financial condition of the Chinese solar industry, as a group, appears to be improving. Corporate consolidation in the Chinese solar industry is in full swing, yielding a smaller number of larger, stronger, and globalizing players. Corporate profit margins, though still thin, are rising. Debt, though still high, is becoming less of a concern, both because the extent of leverage of China's major solar manufacturers is lower than it was during the last major industry downturn, in 2012, and because debt is shifting to more-sustainable forms. Government policy support—which initially was, by the admission of top Chinese government officials themselves, wasteful—is being tightened with an eye toward producing more solar deployment for every yuan's worth of subsidy. Geographically, the Chinese solar industry remains centered in China, but it is meaningfully expanding both its manufacturing and its deployment into other countries. Broadly speaking, the Chinese solar industry, though still facing financial challenges, is maturing and diversifying.

The financial veins of the Chinese solar industry that this chapter explores are further analyzed, with respect to R&D, manufacturing, and deployment, in subsequent sections of *The New Solar System*. The upshot, however, is that the Chinese solar industry is likely to remain, for the foreseeable future, the major driver of the global solar industry. This does not mean that China as a country will remain as dominant in the solar industry as it is now. Indeed, this distinction—China as the leader of the global solar industry but with declining dominance—is crucial in clarifying the roles that other countries could sustainably play in the global solar industry of the future. It is a distinction that *The New Solar System* explores in detail.

What follows is a brief assessment of the financial condition of nine major China-based solar manufacturers according to three key metrics: profit, debt, and geographic diversification. This assessment provides the quantitative foundation

[46] Wall Street Journal, "Debt Cloud Hangs Over Chinese Solar Industry"; August 30, 2012. http://www.wsj.com/articles/SB10000872396390444914904577621083934245866
[47] Reuters, "China solar expansion needs billions from wary investors"; April 29, 2015. http://www.reuters.com/article/china-solar-financing-idUSL4N0XP2FD20150429

that subsequent sections of *The New Solar System* will build on to analyze China's comparative advantages and the implications of those advantages for the future of the global solar industry.

Crucial to understanding the current financial situation of the Chinese solar industry is understanding its history. The industry emerged roughly a decade ago with a relatively simple role: to harness China's manufacturing economy, notably its low worker wages, to manufacture solar modules that the Chinese industry exported for sale in Europe and, to a lesser extent, in the United States. The impetus for the industry was a raft of generous solar-deployment incentives offered by Western governments, particularly by Germany, which in 2000 implemented a feed-in tariff that guaranteed that those who invested in solar projects could sell the electricity that they generated into the country's grid for a price set significantly higher than that of conventional electricity. The feed-in tariff, soon adopted by other European countries, sparked a surge in demand for solar modules—a demand that enterprising Chinese entrepreneurs decided they could competitively tap by ramping up a solar-manufacturing industry in China, where the cost of production was significantly less than that in the West.

The stampede to export solar modules into the heavily subsidized European market led to a ballooning of China-based solar manufacturers—and Chinese solar-manufacturing capacity. Between 2008 and 2012, China's annual solar-cell and solar-module manufacturing capacity each grew nearly eight-fold, from roughly 3,200 megawatts, or 30% of the global market, to roughly 27,000 megawatts, or roughly 60% of the global market.[48] That stampede produced a glut of solar modules in the global market—a glut that depressed prices, hurt margins, and started a wave of consolidation among China-based solar manufacturers. The consolidation intensified as several European governments rolled back their generous solar incentives in the wake of the global financial crisis, deciding they no longer could afford such high subsidies. The consolidation currently underway within the Chinese solar industry marks a continuation of this trend.

An important result of this consolidation is that the China-based solar manufacturers that began as mere assemblers of Western components using Western tooling have grown into significantly more sophisticated global players. As manufacturers, they have integrated vertically: many of them today make everything from polysilicon, to wafers, to cells, to modules.[49] Beyond manufacturing, the large China-based solar manufacturers now operate up and down the entire solar value chain: They conduct extensive R&D to improve their products, and they invest heavily in deployment—both within China and around the world—to ensure direct markets for the modules they manufacture. And beyond the China-based solar manufacturers themselves, China's now-world-leading solar-deployment market has attracted the country's largest power generators. Chapters 3, 4, and 5 of *The New Solar System* explore in detail the country's R&D, manufacturing, and deployment activities, respectively.

3.2: Profit

Most major China-based solar companies reported a positive net income for 2015, as shown below in Figure 1. That was an improvement from two or three years earlier, when many were in the red. The sole exception to the profitability of China's large solar manufacturers in 2015 was Yingli, which posted a net loss for the year of approximately $900 million—the largest net loss yet for a company that has been in the red for the past five years.

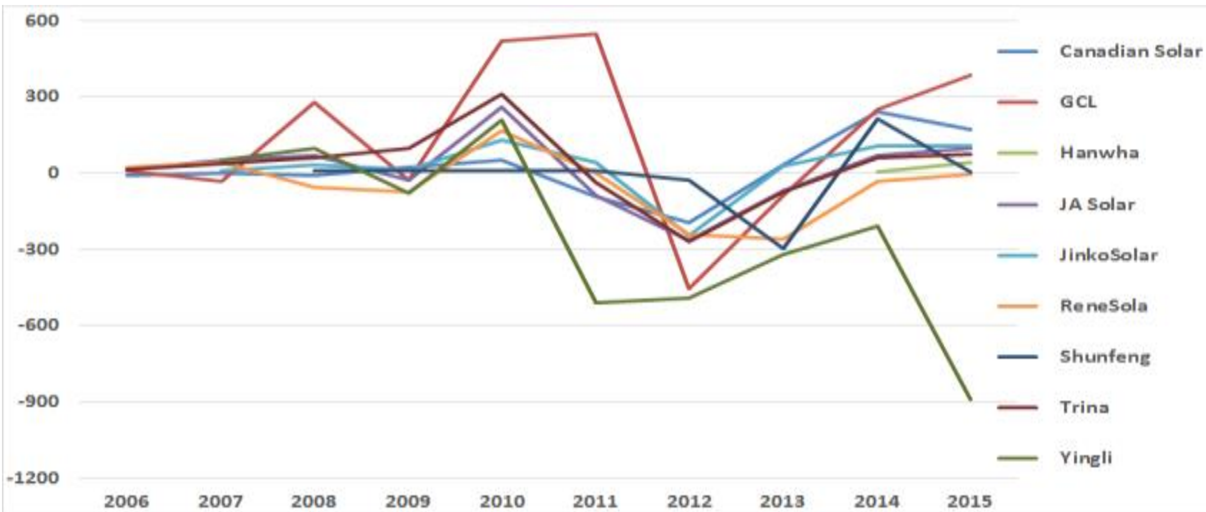
The next several years are widely expected to be difficult for global solar players—leading China-based firms among them. One analyst, ACMR-IBISWorld, projects that, although annual revenue for the Chinese solar-manufacturing industry will

[48] "Americas: Clean Energy: Solar: 2016 Outlook: Growth To Value," Goldman Sachs Equity Research, Jan. 5, 2016.
[49] An explanation of the different components in solar manufacturing—including polysilicon, wafers, cells, and modules—is in Section 5.1.1.

grow to $62.4 billion in 2021, an 11.7% annual growth rate, excess manufacturing capacity and the resulting competition among companies for market share will push profitability over the five-year period down.[50]

Long-term, however, the Chinese solar industry appears likely to emerge from these pressures financially stronger. Ultimately, those companies able to successfully weather the current industry consolidation should be more sustainably profitable.

Figure 1: Net Income For Nine Major China-Based Solar Manufacturers



Source: Bloomberg

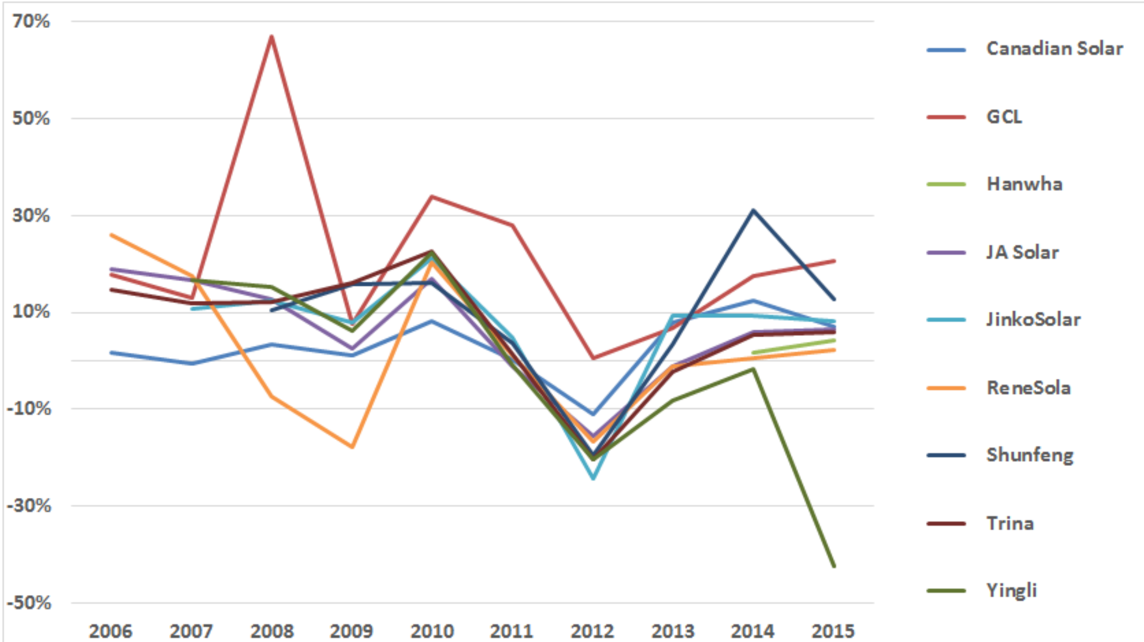
More telling than absolute profit as an indicator of a company's financial health is its profit margin. Operating-profit margins—operating profits divided by sales—at most leading China-based solar manufacturers were, as shown below in Figure 2, up markedly in 2015 from 2012, a time of particular global solar-module overcapacity.

Nevertheless, though profit margins at top China-based solar manufacturers are improving, they remain thin. Financial data for the first half of 2016 showed that profit margins at the world's leading solar manufacturers were flattening. And concern is mounting about the Chinese solar market in 2017. Analysts broadly predict a decline in solar-module selling prices—a decline borne of a manufacturing oversupply driven in part by a slowdown in the growth of the Chinese solar-deployment market.

Conditions are difficult not just for China's major solar manufacturers but also, as indicated below in Figure 3, for the two biggest U.S.-based ones, First Solar and SunPower. Both these U.S.-based firms announced in late 2016 significant layoffs and restructuring plans intended to help the companies ride out a fiercely competitive period in a global industry dominated by China-based companies. Those restructuring efforts are explained in Section 1.4.2.

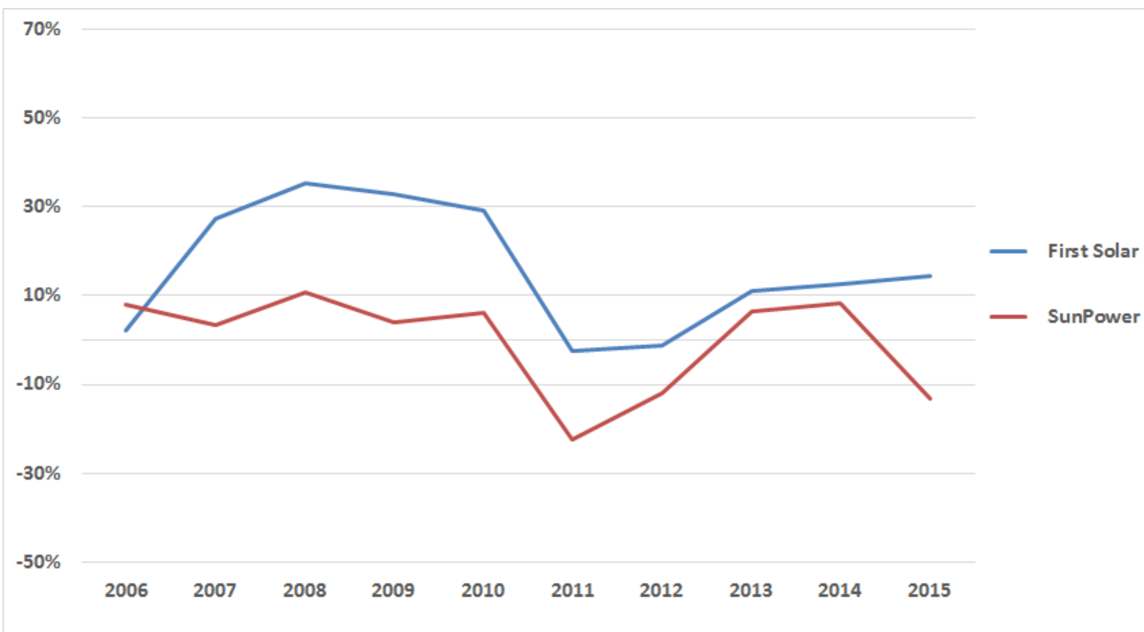
[50] "Solar Manufacturing in China," IBISWorld, May 2016. Obtained under Stanford University subscription.

Figure 2: Operating-Profit Margins for Nine Major China-Based Solar Manufacturers



Source: Bloomberg

Figure 3: Operating-Profit Margin for Two Largest U.S.-Based Solar Manufacturers



Source: Bloomberg

In the first quarter of 2016, manufacturers globally announced plans to add 22,300 megawatts of solar-manufacturing capacity, a quarterly expansion rate second only to the fourth quarter of 2015, when manufacturers announced plans for 27,000 megawatts of new solar-manufacturing capacity, according to PV Tech, an industry analyst.[51] More of these planned capacity expansions were for China than for any other country: 7,100 megawatts in total solar-manufacturing capacity, representing 32% of the global total. India was No. 2, with 5,700 megawatts of planned capacity expansion, or 26% of the global total.[52] However, the bulk of the capacity expansions planned by China's largest solar manufacturers are for factories outside China. Those overseas factories—further explained in Sections 3.4 and 5.6.3—are intended to produce solar modules for foreign sales.[53] They are positioned abroad in large part as an effort by China-based manufacturers to circumvent tariffs imposed on them by the United States.

At the same time, solar-project installations in China, which were feverish through the first part of 2016, are expected to fall. Developers rushed during the first half of 2016 to bring their projects online before a government-mandated reduction in China's solar feed-in tariff took effect June 30, 2016.[54] According to IHS Markit, China installed almost 13,000 megawatts of solar capacity during the first half of 2016, ahead of the feed-in tariff reduction; IHS Markit predicts solar installations in China will have fallen by as much as 80% in the third quarter—a temporary dip triggered by the feed-in-tariff reduction—before recovering later.[55]

Trina CEO Jifan Gao said in spring 2016 that he anticipated "downward pressure on pricing for the entire industry value chain caused by China's reduced subsidy in the second half, ongoing curtailment in Western China, and the possible oversupply brought by the capacity expansion of tier-one manufacturers."[56] The serious issue in China of curtailment—the rejection by China's grid operators of a portion of the electricity that China's solar projects generate—is discussed in Section 6.3.

Trina executives predicted in spring 2016 that solar-module prices across the industry could drop 10%, though the Trina officials did not specify a timeframe for that drop.[57] IHS Markit has projected that gross margins of solar-module suppliers, approximately 20% for the first half of 2016, may end up having dropped to less than 10% for the second half

of 2016, results of which will be reported in early 2017. That, IHS Markit notes, could prompt further industry consolidation.[58]

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[51] Of the 22,300 megawatts in newly announced capacity additions, approximately 12,000 megawatts were for module-assembly plants, approximately 7,000 megawatts were for cell-production plants, and approximately 3,500 megawatts were for integrated cell-and-module factories.

[52] PV Tech, "Global solar manufacturing capacity expansion plans top 22gw in Q1," April 19, 2016. http://www.pv-tech.org/news/global-solar-manufacturing-capacity-expansion-plans-top-22gw-in-q1http://www.pv-tech.org/news/global-solar-manufacturing-capacity-expansion-plans-top-22gw-in-q1

[53] PV Tech, "Trina Solar warns of overcapacity in 2016. Should the industry panic?" March 4, 2016. http://www.pv-tech.org/editors-blog/trina-solar-warns-of-overcapacity-in-2016-should-the-industry-panichttp://www.pv-tech.org/editors-blog/trina-solar-warns-of-overcapacity-in-2016-should-the-industry-panic

[54] See Section 5.2 for a fuller explanation of the evolution of China's feed-in tariff.

[55] IHS Technology, "Solar Industry Set for New Overcapacity and Shake-Out Cycle, as Outlook for the Second Half of 2016 Deteriorates," June 1, 2016. https://technology.ihs.com/579238/solar-industry-set-for-new-overcapacity-and-shake-out-cycle-as-outlook-for-the-second-half-of-2016-deterioorateshttps://technology.ihs.com/579238/solar-industry-set-for-new-overcapacity-and-shake-out-cycle-as-outlook-for-the-second-half-of-2016-deteriorates

[56] PV Tech, "Trina Solar warns of overcapacity in 2016. Should the industry panic?" March 4, 2016. http://www.pv-tech.org/editors-blog/trina-solar-warns-of-overcapacity-in-2016-should-the-industry-panichttp://www.pv-tech.org/editors-blog/trina-solar-warns-of-overcapacity-in-2016-should-the-industry-panic

[57] Ibid.

[58] IHS Technology, "Solar Industry Set for New Overcapacity and Shake-Out Cycle, as Outlook for the Second Half of 2016 Deteriorates," June 1, 2016. https://technology.ihs.com/579238/solar-industry-set-for-new-overcapacity-and-shake-out-cycle-as-outlook-for-the-second-half-of-2016-deterioorateshttps://technology.ihs.com/579238/solar-industry-set-for-new-overcapacity-and-shake-out-cycle-as-outlook-for-the-second-half-of-2016-deteriorates

What is clear is that, when companies report full-year 2016 results in early 2017, those results are likely to reflect a financially challenged industry.

This situation helps explain why these companies' stocks are out of investor favor. As of December 2016, the stocks of most of these firms were trading near their 52-week lows. Those depressed stock prices, in turn, are spurring another trend: delisting from stock exchanges and privatization. Trina announced on Dec. 16, 2016, that its shareholders had approved an agreement to take the company private through a buyout by an investor consortium led by Mr. Gao, Trina's chief executive and chairman.[59] Trina previously said it expected its shift from a publicly traded to a privately held company to take place in the first quarter of 2017.[60] Similarly, JA Solar created in summer 2015 a special committee to consider an offer to take the company private by an investor group led by JA's chief executive and chairman, Baofang Jin. However, as of November 2016, JA had not announced any actual decision to take the company private.[61]

But these difficulties today may yield a stronger industry tomorrow—an industry dominated by fewer, but financially healthier, global solar firms. China's recently-trimmed feed-in tariff, explained in Section 6.4.1, should incentivize more-efficient solar projects, which would further drive consolidation, ultimately helping leading players to compete abroad. Ultimately, given the importance to many provincial economies of China's leading solar manufacturers, it is reasonable to expect government policies that will help those top manufacturers find a market for oversupply.

It is worth noting that China has a history of revamping its deployment incentives for renewable energy in an effort streamline them. China's experience with its wind-power industry is instructive. In the mid-2000s, times were challenging for China's then-young wind industry. Chinese grid operators were curtailing significant amounts of wind power amid concerns that the variable source of electricity would wreak havoc with the grid. In 2008, the country undertook a "Wind Power Base Initiative," mapping out the development of large amounts of wind power across seven selected regions. China structured this wind development in tranches ranging in size from 10,000 megawatts to 20,000 megawatts each, aiming for a total of more than 138,000 megawatts by 2020.[62]

Difficulties today may yield a stronger industry tomorrow—
one dominated by fewer but financially healthier global solar firms.

3.3: Debt

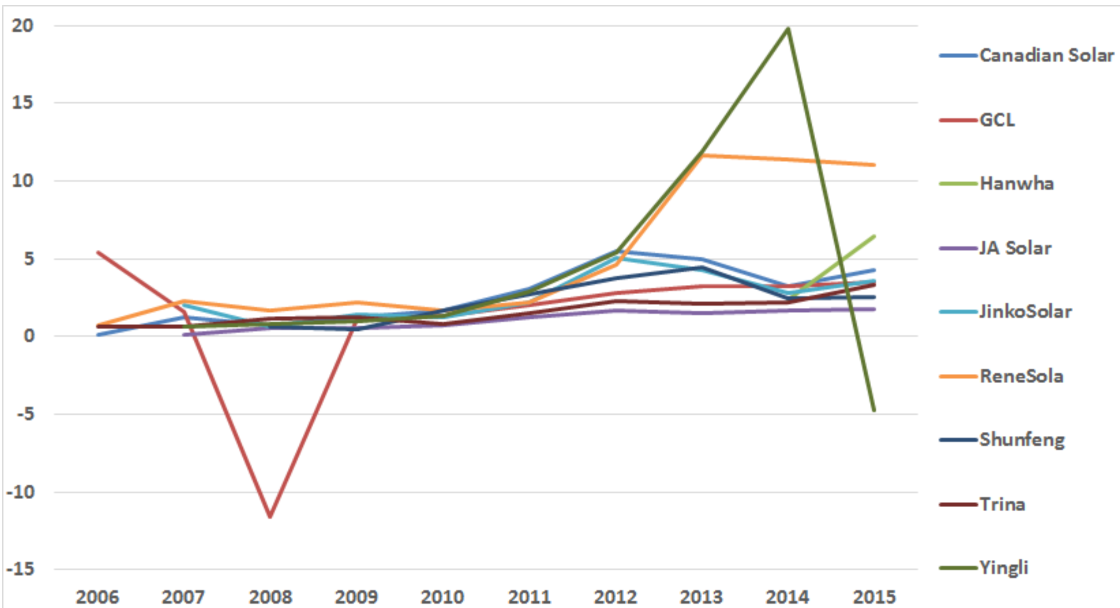
Leverage among leading China-based solar manufacturers is rising. As shown below in Figure 4, the debt-to-equity ratios at, for example, Trina, Canadian Solar, and Jinko were higher at year-end 2015 than at year-end 2014. Indeed, for at least three major China-based solar manufacturers, the ratio

was higher at year-end 2015 than it was in 2012, the previous peak of debt-funded solar-manufacturing expansion in China. The most financially troubled top-tier China-based solar-

[59] Trina Solar press release, Dec. 16, 2016, "Trina Solar Announces Shareholders Vote to Approve Going-Private Transaction," http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-newsArticle&ID=2230297
[60] Trina Solar press release, Aug. 1, 2016, "Trina Solar Enters into Definitive Agreement for Going Private Transaction," http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-newsArticle&ID=2191453
[61] JA Solar press release, July 29, 2015, "JA Solar's Special Committee Retains Financial Advisor and Legal Counsel," http://investors.jasolar.com/phoenix.zhtml?c=208005&p=irol-newsArticle&ID=2072196http://investors.jasolar.com/phoenix.zhtml?c=208005&p=irol-newsArticle&ID=2072196
[62] IRENA-GWEC, "30 Years of Policies for Wind Energy: Lessons from 12 Wind Energy Markets," 2012; pp. 47-49. https://www.irena.org/DocumentDownloads/Publications/IRENA_GWEC_WindReport_Full.pdf

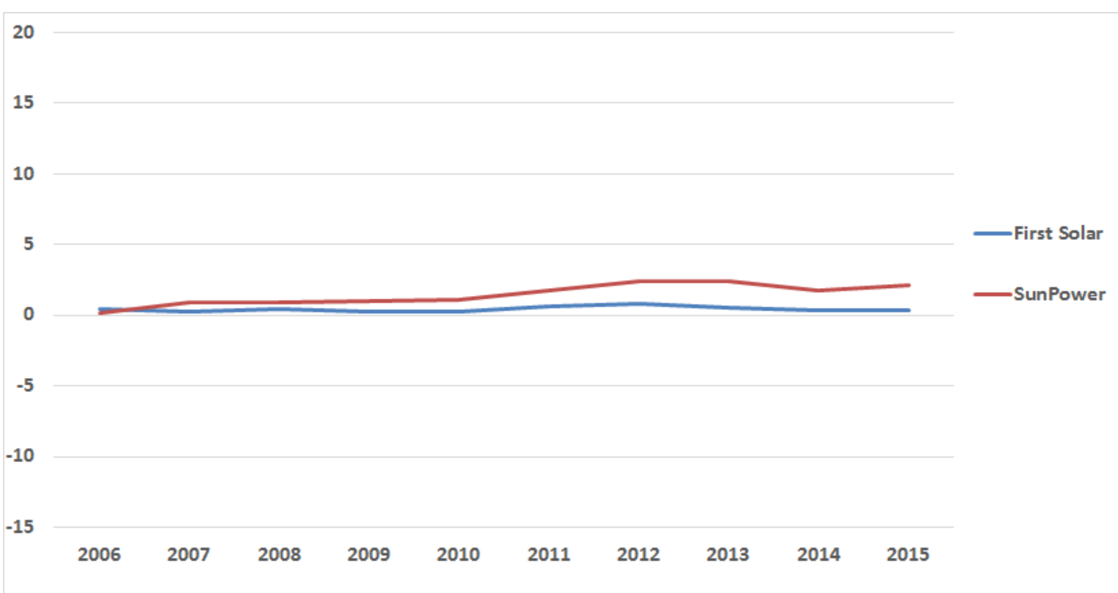
equipment producer is Yingli, which faces particular financial problems that are discussed later in this section. Moreover, as shown below by a comparison of Figure 4 with Figure 5, the debt-to-equity ratios of most large China-based solar manufacturers are higher than those of the two largest U.S.-based solar manufacturers, First Solar and SunPower. Debt-to-equity ratios for the first three quarters of 2016 are broadly in line with the full-year-2015 numbers for most of the companies depicted in Figures 4 and 5.

Figure 4: Debt-to-Equity Ratio For Nine Major China-Based Solar Manufacturers



Source: Bloomberg

Figure 5: Debt-to-Equity Ratio For Top Two U.S.-Based Solar Manufacturers



Source: Bloomberg

3.3.1: History of Debt: Plentiful But Not Cheap

Conventional wisdom is that cheap debt has been a main driver of China's solar-industry boom. That conventional wisdom is, in the main, wrong. Extensive debt has indeed fueled China's solar boom. But that debt has not, by international standards, been cheap. Two realities are important to grasp.

The China-based companies' advantage was not cheap debt. It was, rather, that they were able to access plentiful debt at all.

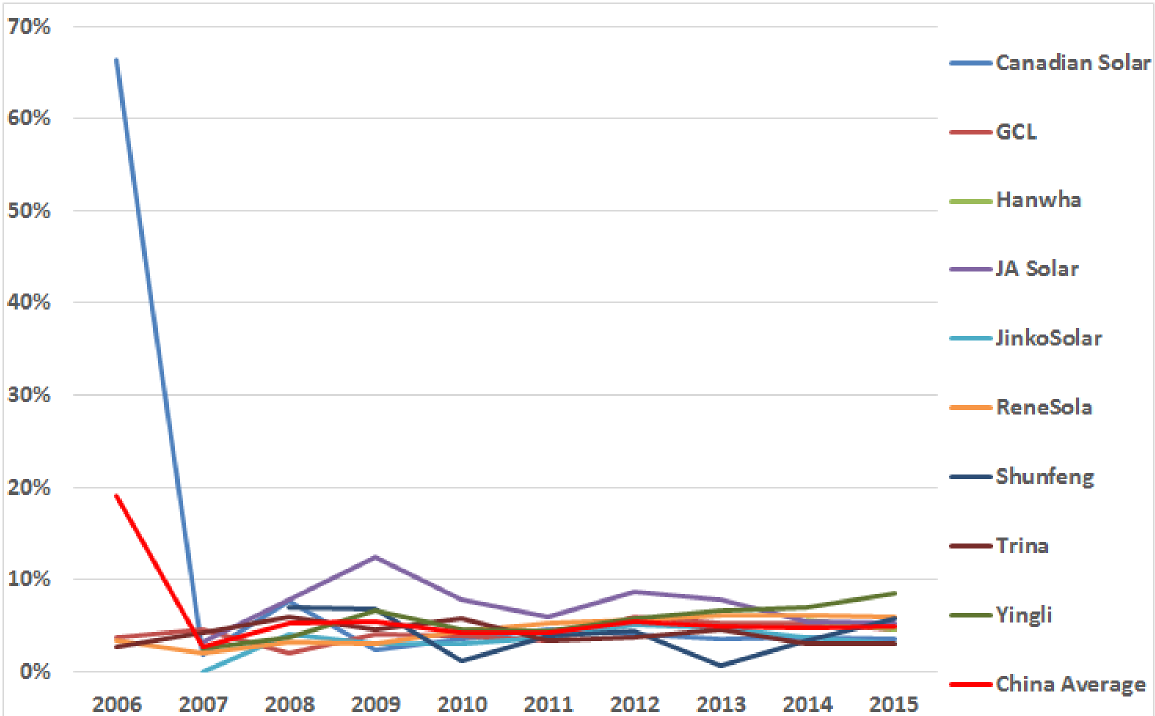
First, during the height of China's solar-manufacturing expansion, between roughly 2008 and 2012, China-based solar companies appear to have paid market rates for the majority of the debt they received—market rates that in China tend to be higher than in the West. The China-based companies' advantage was not, therefore, cheap debt. It was, rather, that they were able to access plentiful debt at all at a time when, in the midst of the global financial crisis, most Western solar manufacturers were unable to do the same. In the words of Teresa Tan, who until mid-2016 was Trina's chief financial officer, "access to money is more important than the cost of money."[63]

Second, since 2013, Chinese banks have grown increasingly conservative in their solar-manufacturing lending. Chastened by what leading officials of Chinese banks and of the Chinese government now acknowledge was a solar-manufacturing bubble that their easy liquidity helped create, both China's government and its leading banks have significantly toughened requirements for companies seeking debt to expand their solar-manufacturing capacity.

A comparison below of Figure 6 with Figure 7 points up the reality that China-based firms have not been paying markedly less for debt than U.S. firms have been paying, based on figures reported in corporate financial filings. Figure 6 depicts, by company, the total amount of money spent annually on interest as a percentage of total debt outstanding in that year. That percentage is an indicator of the relative rate of interest that a company is paying across all its debt. Figure 7 provides the same information for leading U.S. solar manufacturers. The data shows that the levels prevalent among U.S. and China-based firms tracked relatively closely between 2007, the start of the large-scale Chinese solar industry, and 2014. That in itself calls into question the Western assumption that China-based solar firms were paying significantly lower interest rates. Moreover, in 2015, a significant gap emerged between China-based and U.S.-based firms. In that year, the level of interest paid as a percentage of debt outstanding for China-based solar manufacturers (4.79%) was 79% higher than the average level for U.S. solar manufacturers (2.67%). This is consistent with the notion of increasing conservatism among Chinese lenders to the solar industry, a point that is explained later in this section.

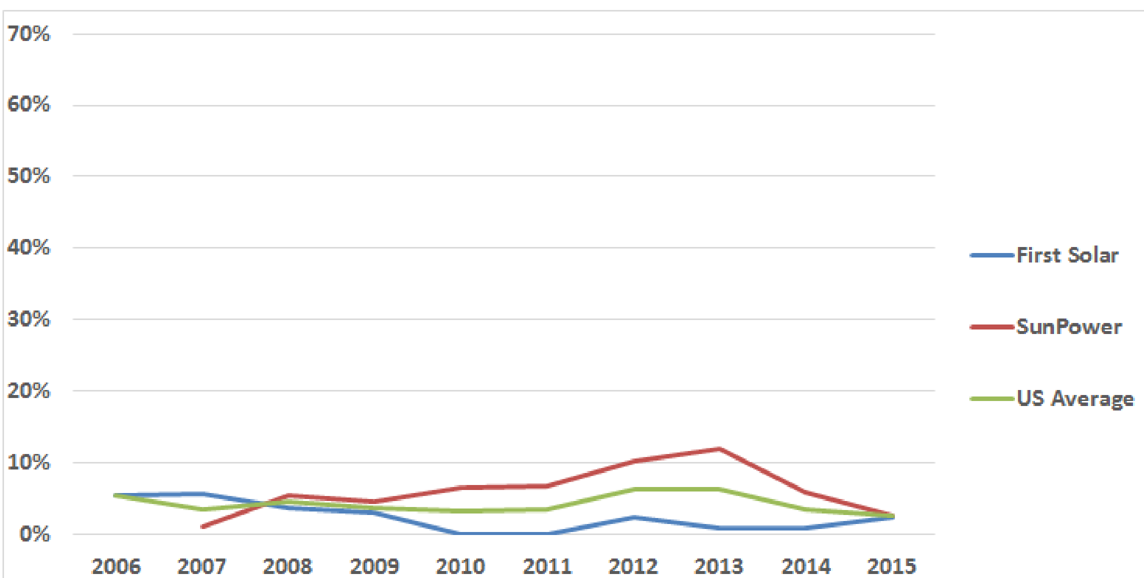
[63] Discussion with Teresa Tan, at the time Trina's chief financial officer, May 2015.

Figure 6: Interest Expense as a Percentage of Total Debt for Nine Major China-Based Solar Manufacturers



Source: Bloomberg

Figure 7: Interest Expense as a Percentage of Total Debt for Two Largest U.S. Solar Manufacturers



Source: Bloomberg

Note: Average in 2006 is First Solar number because no number was available for that year for SunPower.

The main player in financing China's solar-manufacturing expansion has been the China Development Bank (CDB). The CDB is controlled by the Chinese government and is a creature of Chinese-government policy. The CDB, the Export-Import Bank of China, and the Agricultural Development Bank of China, are China's three "policy banks." These three banks are intended by the Chinese government to ensure adequate financing of initiatives that are key to the Chinese government and that commercial banks might see as unattractive, in particular large infrastructure projects both within China and abroad.[64]

In 2010 alone, the CDB authorized an unprecedented $30.41 billion in total credit facilities to five top domestic manufacturers: LDK Solar, Suntech Power, Yingli, JA Solar, and Trina.[65] That represented the vast majority of some $31.35 billion in credit facilities that the CDB extended to China's major solar manufacturers between 2005 and 2013.[66] And those CDB facilities represented well over 70% of the total publicly disclosed credit facilities extended to China-based solar manufacturers during that period.[67]

This extension of credit generated criticism in the West. "The Chinese are eating our lunch," Rep. John Dingell, the Michigan Democrat, said, referring to Chinese spending on the solar industry, during a November 2011 hearing by the a subcommittee of the House Energy and Commerce Committee. The hearing addressed solar competition between the United States and China.[68]

Nevertheless, it is important to emphasize two ways in which the CDB's credit facilities have been widely misunderstood in the West.

First, China-based solar companies actually borrowed only a small portion of the $31.35 billion that, on paper, the CDB made available to them. A senior CDB official involved in the bank's solar business estimated that China-based solar firms borrowed only about ¥30 billion ($4.4 billion) of the credit facilities the bank authorized them to draw down.[69] [70] Discussions with executives of China-based solar manufacturers support that assessment. Investment bankers with deep expertise in China say that, across industries, it is typical for Chinese banks to extend credit lines far in excess of what China-based manufacturers actually will use. In doing so, the Chinese banks are seen as providing significant help to nationally important sectors. But often the manufacturers—particularly in the case of industries, such as solar, where manufacturing overcapacity has been a long-running problem—decide it would hurt financial returns for them to expand capacity as quickly and extensively as the credit lines would allow.

Second, on the CDB debt that the China-based companies did borrow, they paid what, by international standards, was relatively high interest. The senior CDB solar official said the CDB typically charged China-based solar manufacturers a base interest rate of 6.5%, plus additional rates that depended on the bank's assessment of the financial condition of the company that was assuming the debt, plus a variety of CDB fees.[71]

[64] "China Approves Reforms to Three Policy Banks," Xinhua, April 12, 2015. http://english.gov.cn/policies/latest_releases/2015/04/12/content_281475087560462.htm

[65] Customized data set generated from Bloomberg New Energy Finance database.

[66] Customized data set generated from Bloomberg New Energy Finance database. Companies include LDK Solar, Suntech Power, Yingli, Trina, JA Solar, Sunergy, Canadian Solar, Renesola.

[67] The CDB was not the only Chinese bank to have extended debt to the country's solar manufacturers. Other banks that did so during that period include another policy bank, the Export-Import Bank of China; commercial banks including the Bank of China, the Bank of Beijing, and the Bank of Communications; and local banks in certain Chinese provinces where significant solar manufacturing takes place.

[68] Steven Mufson, "China's Growing Share of Solar Market Comes At a Price," Washington Post, Dec. 16, 2011. https://www.washingtonpost.com/business/economy/chinas-growing-share-of-solar-market-comes-at-a-price/2011/11/21/gIQAhPRWyO_story.html?utm_term=.fe1088ad1582

[69] Discussion with CDB executive with authority over CDB's solar-deployment lending, August 2014.

[70] Throughout *The New Solar System*, the ¥ symbol refers to the Chinese currency, the yuan, which also is known as the renminbi, or RMB.

[71] Ibid. The main fee, the executive said, was what the bank calls a "financial consulting fee."

Corporate financial filings by China-based solar manufacturers, and discussions that the Stanford Steyer-Taylor Center's research team had with CDB officials in China, support the conclusion that China-based solar manufacturers typically paid market rates for the CDB debt they assumed. Notably, the rate charged by the CDB was higher than the benchmark lending rate imposed by the People's Bank of China (PBOC), the country's central bank. (Since the financial crisis, the PBOC's lowest benchmark rate has been 5.1%.)[72]

Solar manufacturers in China had a bank willing to lend them billions when financial markets in much of the world had seized up.

One point is important to underscore: China-based solar manufacturers had a bank willing to lend them billions of dollars, even at higher rates than were common for corporate debt in the West, and at a time when the financial markets in much of the world had seized up. That gave the China-based firms a significant advantage over their competitors in the United States and Europe.

China-based companies benefited from this liquidity because of the CDB's position as a policy bank for the Chinese government, which had articulated the expansion of China's solar-manufacturing industry as an important plank of the country's industrial policy. At the time, in much of the world, bank lending to finance solar and other renewable-energy projects had slowed considerably. For instance, global investment in renewable-energy, which rose in 2007 and early 2008, fell significantly in the second half of 2008 and in early 2009, and debt provided by banks to renewable-energy companies was among the most notable sources of capital to dry up.[73]

The continuing liquidity for solar manufacturers in China during the financial crisis stands in stark contrast to the lack of liquidity for solar-project developers in the United States at that time. The financing that enables U.S. renewable-energy developers to take advantage of the U.S. federal government's renewable-energy tax credits—financing known as "tax equity"—fell markedly during the 2008-2009 financial crisis. This tax equity funds a variety of U.S. renewable-energy projects, including solar. According to the U.S. Partnership for Renewable Energy Finance, and industry group, the number of U.S. tax-equity investors fell from 20 in 2007 to 12 in 2009, and the tax-equity market dropped from $6.1 billion in 2007 to $1.2 billion in 2009. This difference between high liquidity in China and low liquidity in the United States is, at least in part, a result of a fundamental difference in the structure of renewable-energy support in the two countries. In China, much of that support is provided directly by government-controlled banks. In the United States, much of that support comes only indirectly from the government and relies much more significantly on private investors. Times of financial crisis—precisely the times when liquidity is most needed—are the times when those investors are in the least position to provide that funding. The reason: Those are the times when the investors' taxable income wanes, thus limiting the tax liability that they have to make use of, or "monetize," the U.S. federal tax credits in support of renewable-energy projects.

In China, given the disproportionate leverage that some major solar manufacturers carried at the time they received additional loans from Chinese banks, it is quite conceivable that they would have been unable to persuade Western banks to provide such debt to them—even if there had been no global financial crisis underway at the time. In other words, the CDB's willingness, at the

[72] The rate was as high as 7.41% before the financial crisis. It dipped to 5.31% by October 2010 in an attempt by the PBOC to stimulate the economy. It rose back to 6.31% by July 2012 but then fell again as the Chinese economy entered a period of medium growth. Regardless of the downward adjustments, the cost to borrow money in China today remains high. During the same time period, interest rate in the U.S. was kept at 0%.

[73] "The Global Financial Crisis and its Impact on Renewable Energy Finance," United Nations Environment Program, April 2009. http://www.unep.org/pdf/dtie/Study_Financial_Crisis_impact_on_RE.pdf

government's urging, to lend large sums to China-based solar manufacturers constituted a form of government support for the industry, even though evidence strongly indicates that China-based solar firms typically paid relatively high interest rates for the debt they received.

Nevertheless, as is explained in Section 3.3.2 below, the liquidity that allowed China-based solar manufacturers to expand also sowed the seeds of their current financial difficulties, because the liquidity made it easier for the companies to expand, essentially all at the same time, thus contributing to industry overcapacity.

3.3.2: Changing Uses of Debt

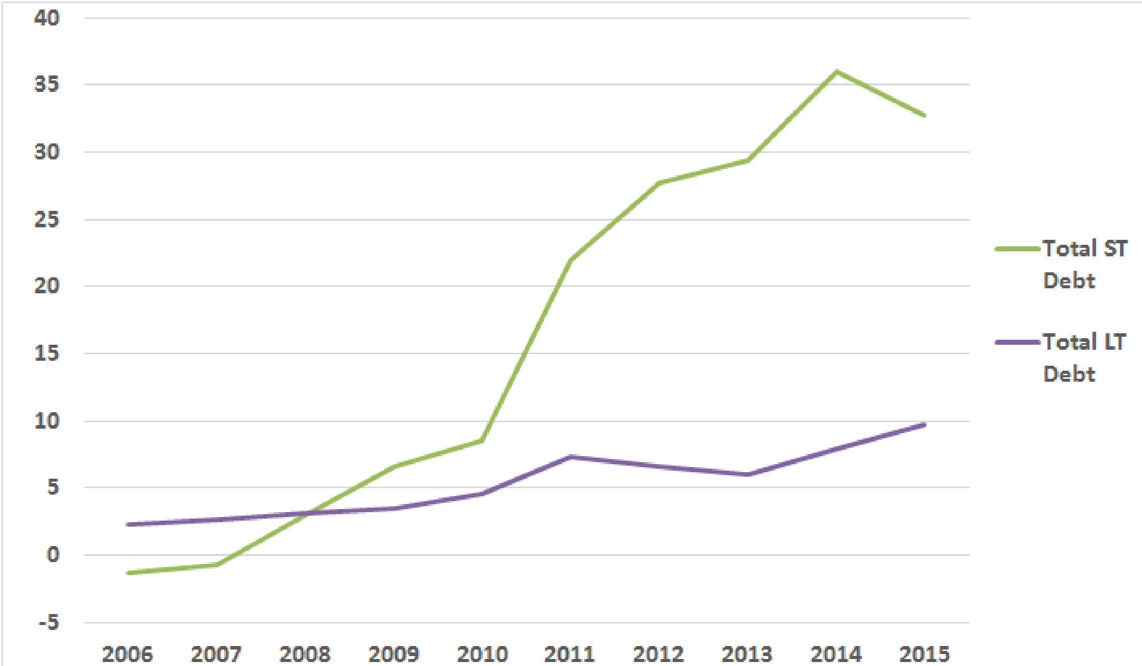
An important change is underway in the way China-based solar companies use their debt. The change mitigates some of the concern about the companies' high debt levels.

What got many China-based solar companies into trouble earlier this decade was that they used their debt mostly to expand manufacturing capacity. That was problematic for three reasons.

First, China's major solar manufacturers firms undertook these debt-financed factory expansions essentially simultaneously. That herd-like behavior, a result of expectations that Europe's generous solar subsidies would continue, contributed beginning in 2011 to a global glut in the supply of solar cells and modules that quickly eroded profit margins from the manufacturing activities on which companies had based their projected repayment of their debt.

Second, as is shown in Figure 8 below, most borrowing that China-based solar firms undertook involved short-term, rather than long-term, debt. The China-based companies had little choice: Chinese banks tend to be conservative and thus typically were unwilling to extend large amounts of long-term debt. Short-term debt generally carries lower interest rates and fewer stipulations on usage, making it a more flexible medium. But it was particularly ill-suited to financing factory expansions given how long after investing in construction of a new factory it takes to realize revenue from the facility. That was particularly true given the worsening overcapacity, and the consequently thin margins, prevalent in Chinese solar manufacturing. As a result, it became common practice for many leading China-based solar firms to secure repeated bank extensions of their short-term debt or to take on new rounds of short-term debt to repay rounds that were coming due. The result of both these practices was that the short-term debt ended up functioning much like long-term debt. Strong competition for market share, boundless availability of Chinese debt, and the difficulty of meeting debt-repayment schedules ensnared companies such as Yingli in cycles of ever-increasing leverage.

Figure 8: Annual Short-Term and Long-Term Debt Aggregated Across Top China-Based Manufacturers (Billions of Dollars)



Source: Bloomberg

Note: Includes aggregated data from the same nine China-based module manufacturers as are featured in Figures 1,2, 4, and 6 above.

This unveils a third key problem with the debt assumed by China's solar industry: Chinese banks provided it too easily—at virtually limitless volumes, and with minimal guidance or criteria for access—to fuel industry growth. Although that liquidity helped the China-based companies boost their share of the global market during the critical moment of the global financial crisis, it ultimately fueled industry overcapacity—overcapacity that now is cutting into the companies' profits.

Chinese lenders are becoming increasingly conservative.
Guidelines for accessing debt are becoming more stringent.

Ultimately, this constituted a lesson in unsustainable finance. Now, however, conditions are changing.

Chinese lenders are becoming increasingly conservative. This does not imply that less debt is available now in China. Rather, it implies that guidelines for accessing debt are becoming more stringent, in large part because the Chinese government, in an effort to consolidate and strengthen the industry, is requiring China-based solar manufacturers to meet detailed performance standards in order to qualify for a variety of important government financial benefits—benefits widely seen as important in enabling a company to service its debt.

A significant early example of this conservatism was a collection of standards issued in 2013 by China's Ministry of Industry and Information Technology (MOIIT).[74] The standards made it more difficult for smaller China-based solar firms to compete, thus helping to launch a wave of

[74] China Ministry of Industry and Information Technology, Solar PV Manufacturing Industry Standards (2013). http://www.gov.cn/zwgk/2013-07/15/content_2447814.htm (Content in Chinese). The MOIIT standards are explained in Section 4.5.3 and are enumerated in Appendix C.

corporate consolidation within the Chinese solar industry that continues today. One of the MOIIT standards, for example, requires all solar-manufacturing companies annually to spend 3% of their revenue or ¥10 million ($1.5 million), whichever is lower, on research and development. Another standard set a minimum capacity level of 200 megawatts for any new solar cell manufacturing company that seeks to enter the industry. The MOIIT standards are detailed in Section 5.5.3—including an explanation of why the R&D-spending requirement had a significant impact on the Chinese solar industry despite the apparently small minimum sum that it mandated that companies spend.

More recently, China's major banks have tightened their lending requirements. For instance, the CDB increasingly has been directing its loans toward solar-deployment projects; in 2014 it spent approximately ¥25 billion ($3.6 billion) on solar-project deployment, a figure that represented an approximately 50% increase from its solar-deployment lending two years before.[75] In addition, the CDB, like China's two other policy banks, has in practice been shifting from a policy bank to a commercial bank, making lending decisions based increasingly on considerations of financial returns.[76] However, that shift is controversial within the Chinese government, and in 2015 the government issued a ruling that, according to Xinhua, the government news agency, the CDB must "stick to its positioning as a `development financial institution,'" meaning a bank whose emphasis is on lending in areas the government deems in the country's interest.[77]

As a result of this new lender conservatism, many China-based solar companies are assuming and allocating significant portions of new debt and credit lines to expanding solar-project deployment, including in overseas markets. They are doing so based on the belief that deployment typically will produce higher profit margins than manufacturing will. Now as before, the majority of the debt that the Chinese solar industry is taking on is short-term. But short-term debt is considerably less risky in today's Chinese solar industry than it was. New solar-deployment projects yield revenue more quickly—and at more reliable levels over time—than new solar factories do. As a result, solar-deployment projects generate—more quickly and with more stability than solar-manufacturing projects—revenue that can be used to pay off a given tranche of short-term debt, allowing the company to take on a new one while keeping its leverage levels relatively steady. That is particularly true given deployment-support policies, discussed in Section 6.2, that have been rolled out at multiple governmental levels in China.[78] China now is trimming those subsidies in an effort to make them more financially efficient, but even the reformed versions of the subsidies remain important drivers of China's deployment.

There would appear to be one glaring exception to this narrative of increasing restraint on the part of Chinese banks in flooding China-based solar manufacturers with debt—an exception so significant that it questions the underlying narrative. That exception is Yingli. Yingli, based in the Hebei Province city of Baoding, has posted steep annual losses since 2011, as shown above in Figure 1. Nonetheless, Yingli was, until its financial problems deepened significantly in 2014, China's largest solar-module manufacturer. Yingli reported total debt of $1.9 billion at the end of the third quarter of 2015, and its public financial filings indicate that this high debt load imperils its ability to remain in business. In a move unprecedented at this scale, the China Banking Regulatory Commission reportedly asked the CDB in spring

[75] Op. cit., CDB executive, August 2014.
[76] Discussion with senior MOIIT official, May 2015.
[77] Op. cit., Xinhua, April 12, 2015.
[78] As an example, in the Jiangsu Province city of Jiaxing, one of the Chinese cities that is most aggressively supporting the deployment of solar energy, five different types of deployment subsidies, provided by multiple level of governments, are available, according to discussions with government officials in Jiaxing.

2016 to "ensure" that Yingli receives $1.16 billion in new loans.[79]

Even if Yingli received new debt of that magnitude, the loans would not invalidate the notion of increasing conservatism toward solar lending by China's state-affiliated banks. Previously, Chinese banks lent vast amounts to solar companies so that those companies could rapidly expand their manufacturing capacity. It was that behavior that created what amounted to a Chinese solar-manufacturing bubble. The situation with Yingli is different. Yingli already is among the largest solar companies in the world. According to many analysts, the company's products and distribution network are no less desirable than those of Yingli's competitors. The company's problem is financial, not structural.[80] Yingli's goal is to use new debt not primarily to expand its production capacity but rather to pay off debt that is coming due and to ramp up production in factories that it already has built. Those factories have been running well below capacity as Yingli has been forced to divert large portions of its revenue to debt service.[81] Producing and selling more solar modules would resuscitate Yingli's cash flow.

In other words, in recommending a liquidity lifeline for Yingli, Chinese officials have concluded that Yingli is too big to fail, in broadly the same way that U.S. officials decided to bail out General Motors Corp. following its 2009 bankruptcy. The decision to help Yingli clearly amounts to a form of government support for the troubled solar manufacturer; some observers see that as problematic and some do not. Either way, the particular context of the Yingli situation is worth taking into account when assessing the broader question of the Chinese banking industry's attitude toward solar lending.

3.4: Chinese Investments Abroad

The Chinese solar industry began in the mid-2000s as an entirely export-focused business in which most manufacturing occurred in China and most sales occurred elsewhere—largely in Europe and the United States. Now, both manufacturing and deployment are globalizing, with China-based firms in the lead. China-based solar manufacturers' global expansion is explored in detail in Chapters 4 and 5. But a summary is provided here as context to round out the financial picture of the Chinese solar industry.

Large China-based solar manufacturers are expanding their factory production beyond China largely for artificial policy reasons. Countries that are profitable places to deploy solar projects, primarily because of subsidies by their governments, also have imposed protectionist manufacturing policies, in the form of either import tariffs or domestic-content requirements, as explained in Section 5.6.3. In the case of tariffs imposed by the United States and the European Union, China-based manufacturers are not shifting significant manufacturing to those end markets, as some tariff advocates in those countries had hoped. Rather, they are scaling up regional manufacturing bases elsewhere. These countries are free from the tariffs; according to the calculations of China-based solar companies, their manufacturing costs are lower than those in the Western end markets. Several Southeast Asian countries, such as Malaysia, India, Thailand, and Vietnam, are or will be key beneficiaries of this tariff-driven shift in manufacturing away from China.

In the case of domestic-content requirements, China-based manufacturers are compelled to set up factories in the country in which their products will be installed. (This has been the case, for example, in Canada, India, and South Africa.) As

[79] Bloomberg News, April 8, 2016, "China Said to Push for $1.16 Billion in Loans for Yingli." http://www.bloomberg.com/news/articles/2016-04-08/china-said-to-push-for-1-16-billion-in-loans-for-yingli-imri0khzhttp://www.bloomberg.com/news/articles/2016-04-08/china-said-to-push-for-1-16-billion-in-loans-for-yingli-imri0khz

[80] Trefis Team, "Why Is The Chinese Government Stepping In To Help Yingli Green Energy?" Forbes, Feb. 29, 2016. http://www.forbes.com/sites/greatspeculations/2016/02/29/why-is-the-chinese-government-stepping-in-to-help-yingli-green-energy/#569ce14277ee

[81] Ibid.

explained in Section 5.3.2, however, domestic-content rules are being successfully challenged legally, on the basis that they violate World Trade Organization rules.

At the same time, these large China-based solar manufacturers are aggressively expanding downstream into project development. They are deploying most of their solar modules in China, which, as a result of Chinese-government policy, has become the world's largest and fastest-growing solar market, with some 76,500 megawatts of cumulative capacity installed as of the end of 2016. But they also are increasingly pursuing deployment in select other countries. One China-based company, Canadian Solar, accounts for the bulk of Chinese foreign deployment so far, and its foreign deployment has occurred mostly in Canada, a country to which the company's founder has strong ties. But other China-based firms also are starting to develop project capacity outside China. They are doing so in South Africa, the United Kingdom, the United States, Germany, and certain countries in Eastern Europe.

There is another significant way in which China-based solar manufacturers are globalizing—a way that often draws little attention, that typically is politically controversial when it does get noticed, and that is a strong sign that the global solar industry is maturing. China-based companies are investing in or buying, often at discounted prices, U.S. firms that have developed interesting solar technologies but that lack the capital to commercialize them. In some cases, these U.S. companies have received direct government support. Among the most recent of these deals: The sale to GCL, a fast-growing China-based solar manufacturer that produces everything from polysilicon to modules, of $150 million in polysilicon assets of SunEdison, the U.S. solar firm that entered bankruptcy proceedings in 2016.[82] [83] Several of these investments are explained more

deeply in later sections. Table 1 below lists several of the most prominent deals.

Table 1: Examples of Chinese Corporate Investments In U.S. Solar-Technology Firms

Chinese Investor/Buyer	U.S. Company	Year	Deal Value	Description	U.S. Government Assistance
Hanergy	MiaSole	2012	$30 million	California-based MiaSole, a developer of CIGS thin-film technology, was bought by China's Hanergy.[84]	MiaSole received $101.9 million in manufacturing tax credits through the American Recovery and Reinvestment Act of 2009.[85]

[82] "Bankruptcy Court Approves GCL Purchase of SunEdison FBR Polysilicon Tech," PV Magazine, Oct. 31, 2016. http://www.pv-magazine.com/news/details/beitrag/bankruptcy-court-approves-gcl-purchase-of-sunedison-fbr-polysilicon-tech_100026711/#axzz4SXyggyLwhttp://www.pv-magazine.com/news/details/beitrag/bankruptcy-court-approves-gcl-purchase-of-sunedison-fbr-polysilicon-tech_100026711/ - axzz4SXyggyLw

[83] The GCL-SunEdison deal is explained more fully in Section 5.1.2.

[84] Eric Wesoff, "MiaSole Sold to China's Hanergy for $30 Million," Greentech Media, Sept. 29, 2012. https://www.greentechmedia.com/articles/read/MiaSol-Sold-to-Chinas-Hanergy-For-30-Million

[85] "Tax Credits Give Thin-Film Solar a Big Boost," U.S. Department of Energy website. https://energy.gov/articles/tax-credits-give-thin-film-solar-big-boost

Table 1 (cont.): Examples of Chinese Corporate Investments In U.S. Solar-Technology Firms					
Chinese Investor/Buyer	**U.S. Company**	**Year**	**Deal Value**	**Description**	**U.S. Government Assistance**
Various China-based venture-capital investors were among Silevo's investors	Silevo		$55 million[86] [87]	California-based Silevo received funding from Chinese venture-capital investors; it has a factory in Hangzhou, China; SolarCity bought Silevo for about $200 million in 2014.[88]	Received $4.9 million grant from U.S. Department of Energy in 2014 to develop a thin-film manufacturing tool.[89]
Shunfeng	Suniva	2015	$57.8 million	Shunfeng, a China-based company moving rapidly into the solar sector, acquired 64% of Suniva, an Atlanta-based developer of high-efficiency solar modules.[90]	Received, from U.S. Department of Energy, $4.5 million grant in 2013 and $2.3 million grant in 2014 to improve manufacturing of high-efficiency solar cells.[91] [92]
GCL	SunEdison	2016	$150 million	GCL, a China-based solar manufacturer, bought certain polysilicon assets of SunEdison after SunEdison entered bankruptcy	Received a $1 million award from the U.S. Department of Energy and received $1.87 million in grants through the American Recovery and Reinvestment Act.[93]

Source: Stanford Steyer-Taylor Center research

[86] The $55 million includes funding from various investors, among them China-based venture-capital firms.

[87] Ucilia Wang, "Silevo Unveils Hybrid Solar Cell Tech, Chinese Factory," GigaOm, Oct. 12,2011. https://gigaom.com/2011/10/12/silevo-unveils-hybrid-solar-cell-tech-chinese-factory/

[88] Herman K. Trabish, "SolarCity Buys Silevo To Become 4th U.S. Vertically Integrated Solar Giant," UtilityDive, June 18, 2014. http://www.utilitydive.com/news/solarcity-buys-silevo-to-become-4th-us-vertically-integrated-solar-giant/275819/

[89] "Solar Manufacturing Technology 2," U.S. Department of Energy website, https://energy.gov/eere/sunshot/solar-manufacturing-technology-2

[90] Ehren Goossens, "Solar Billionaire-Backed Shunfeng Buys Majority Share of Suniva," Bloomberg, Aug. 12, 2015. https://www.bloomberg.com/news/articles/2015-08-13/solar-billionaire-backed-shunfeng-buys-majority-share-of-sunivahttp://investors.jasolar.com/phoenix.zhtml?c=208005&p=irol-newsArticle&ID=2072196http://investors.jasolar.com/phoenix.zhtml?c=208005&p=irol-newsArticle&ID=2072196

[91] "Suniva Awarded $4.5 Million for Innovations in Solar Manufacturing," Suniva website, Dec. 12, 2013. http://www.suniva.com/documents/DOE%20Grant%20Press%20Release-%202013%2012%2012.pdf

[92] "Suniva Selected for Second SunShot Award from U.S. Department of Energy," Suniva website, Oct. 22, 2014. http://www.suniva.com/documents/Suniva%20Awarded%20SunShot%20Initiative%20Grant%202014%2010%2021.pdf

[93] Rob Nikolewski, "SunEdison Files For Bankruptcy Protection," Los Angeles Times, April 21, 2016. http://www.latimes.com/business/la-fi-sunedison-bankruptcy-20160421-story.html

Chapter 4:
Research and Development

4.1: Overview

The widespread assumption in the West has been that the United States and certain European countries, notably Germany, produce the major technological advances in solar, and that China picks up those technological advances and then figures out how to drive down the cost of manufacturing them at scale. Both these achievements constitute innovation. But, according to conventional wisdom, the Western sort is about the underlying technology, and the Chinese sort is about the manufacturing process. Prior studies have generally supported this view.[94] [95] [96] Some have relied largely on an analysis of patents awarded in China to conclude that the Chinese solar industry isn't producing much in the way of deep solar-technology innovation.

The New Solar System largely upends that view. It finds that the Chinese solar industry is producing more underlying technological innovation than the conventional wisdom suggests. Some of this innovation has put China ahead of the U.S. in certain key solar technologies. The implications for the United States of this finding are discussed in Chapter 7. One implication is that it would behoove the United States to engage with China in certain areas of solar R&D.

The New Solar System analyzes China's solar-R&D effort by exploring both what that effort is producing and how it is producing it. To assess the results of China's solar R&D effort, *The New Solar System* assesses solar-cell-efficiency gains and patent registrations by Chinese companies and laboratories. To assess how the structure of China's solar R&D effort is changing, *The New Solar System* maps China's solar-R&D ecosystem, charting key government entities and programs, research institutions, and individual researchers in a variety of solar sub-technologies; tracks the evolution over the past 15 years in China's solar-R&D policies, as codified in the country's crucial five-year plans; and tries to quantify China's solar-R&D spending, though it does so only incompletely, given that comprehensive data is unavailable.

The Chinese solar industry is producing more technological innovation than the conventional wisdom suggests.

This R&D research yields two conclusions that have significant implications for the future shape of the global solar industry:

- China's solar industry is putting steadily more effort into technological innovation. In part, that is a result of broad dynamics in the global solar industry. In significant part, though, it is a result of concerted reforms being implemented by the Chinese government in an attempt to improve the effectiveness of the country's R&D spending.
- China's solar enterprise—which includes government agencies and institutes, universities, public-private research labs, and companies—is making significant R&D progress in certain, particularly market-relevant, technological areas. China's leading solar-cell manufacturers are narrowing the innovation gap and, in the

[94] Jonas Nahm, & Edward Steinfeld, (2014). "Scale-up Nation: China's Specialization in Innovative Manufacturing." World Development, 54, 288–300. doi:10.1016/j.worlddev.2013.09.003
[95] Yuan Li, Yi Liu, & Feng Ren (2006). "Product Innovation and Process Innovation in SOEs: Evidence from the Chinese Transition." Journal of Technology Transfer, 32, 63–85. doi:10.1007/s10961-006-9009-8
[96] Arnaud de la Tour, Matthieu Glachant, & Yann Ménière (2011). "Innovation and International Technology Transfer: The Case of the Chinese Photovoltaic Industry." Energy Policy, 39(2), 761–770. doi:10.1016/j.enpol.2010.10.050

case of certain cell technologies, overtaking their foreign competitors in cell efficiency, a key technological metric.

China has been developing an increasingly specific and nuanced national strategy for the solar industry, chiefly through the government's overarching five-year plans. The government, through its main research-and-development arm, the Ministry of Science and Technology (MOST), uses multiple programs to implement the development goals laid out in the five-year plans. These programs have established solar-specific labs and research centers to work in concert with the five-year-plan goals.

China's solar-R&D effort has been, in fundamental ways, inefficient.

The MOST, which is further explained in Section 4.4.1.2, aims for a comprehensive strategy that covers the entire solar value chain and a variety of solar technologies at different R&D stages. For example, the MOST has underway research on an array of leading solar-cell technologies: high-efficiency adaptations of conventional silicon-based solar cells, such as heterojunction with intrinsic thin layer (HIT) and multi-junction technologies; thin-film technologies such as copper-indium-gallium-selenide (CIGS) and cadmium-telluride (CdTe); and other technologies, including amorphous silicon and perovskite. There are also projects dedicated to solving what Chinese government planning documents call "bottleneck" issues: a range of key materials and equipment needed for solar-cell and -module manufacturing that the country is unable to manufacture at high quality domestically. Among those, according to the MOST: silver and aluminum paste, which conduct the electricity generated by the solar cell; back sheet, the multi-layer barrier that protects a solar module's electrical components from the elements; ethylene vinyl acetate (EVA), one of the layers of the back sheet; and certain cell- and module-manufacturing equipment. The MOST also is researching downstream system optimization and grid integration.

Chinese government and university research labs focus mainly on next-generation technologies—particularly those the MOST has determined are sufficiently immature that they allow China room to become a global technological leader. Chief among those technologies are perovskite and organic solar. One piece of evidence of the effort that China is putting into perovskite and organic-solar innovation is the number of patents that the government has granted to Chinese researchers in these two areas. Another is the amount of R&D money that the MOST and another important Chinese-government R&D catalyst, the National Natural Science Foundation of China (NNSFC), which is further explained in Section 4.4.2.1, are spending on these two technologies.

In contrast with China's government and research labs, China's private solar companies work mostly on current-generation technologies. The most striking illustration of progress in this area comes from Trina, which over the past approximately two years has announced a string of world records in efficiency in p-type and n-type silicon solar cells. Trina's world records are an indication that a strategic push by the Chinese government to improve solar-technology innovation is starting to bear fruit. They also reflect the effectiveness of a strategy increasingly common at Chinese companies and research institutions that focus on solar energy: hire experienced solar researchers who were trained overseas.

Despite these public and private efforts, China's solar-R&D effort has been, in fundamental ways, inefficient. By the admission of top Chinese officials, the MOST-led effort has failed to commercialize adequate technological advances to justify China's related R&D spending. As a result, China's government is undertaking a restructuring of MOST.[97] [98] The restructuring affects the full range of technologies the MOST oversees, one of which is solar. Of particular relevance, the MOST is shifting to a more strategic and less tactical role. Rather than managing most of the research itself, it plans to restrict its involvement to planning the research and selecting outside entities to manage the actual research. The MOST is replacing its two leading solar-research-spending programs, known as the 863 and 973 programs, with five specialized programs, a move that is further detailed in Sections 4.4.1.1 and 4.5.4. The new programs are intended to better shepherd technology across the technology-development-and-commercialization cycle, and to devote more money and effort to basic research. This shift, if successful, could have far-reaching implications for the global solar industry, especially vaulting China into the top ranks of countries pursuing solar R&D.

4.2: Solar-Cell Efficiency

The New Solar System divides solar technologies into three groups for the purpose of assessing the efficiency of Chinese R&D.

The first group is the one that represents the vast majority of the current global market: silicon-based technologies. This group includes traditional multicrystalline-silicon and monocrystalline-silicon cells as well as amorphous-silicon cells. It also includes cell technologies that result from relatively basic modifications to traditional silicon structures: passive-emitter rear-contact (PERC) cells; interdigitated back-contact (IBC) cells; and HIT cells. All three of these second-generation silicon-based technologies—PERC, IBC, and HIT cells—are attracting increasing manufacturer interest for their ability to deliver relatively significant efficiency improvements with relatively minor modifications to conventional silicon-cell assembly lines. These technologies are widely available on the market and are growing rapidly.

The second technology group comprises so-called thin-film cell technologies—those containing one or multiple layers of photovoltaic material applied atop a substrate made of a material that is less expensive than silicon. The most common thin-film technologies are CIGS and cadmium-telluride cells. Thin-film cells typically convert sunlight into electricity at lower efficiencies than do silicon-based cells but are less expensive to produce. The traditional market distinction between silicon-based and thin-film cells is blurring, however, as, simultaneously, silicon prices have fallen and thin-film efficiencies have risen.

The third group of solar cells comprises a range of emerging technologies now under research in multiple laboratories around the world. Among these technologies are organic, perovskite, dye-sensitized, quantum-dot, and copper-zinc-tin-sulfide solar cells. Because of low efficiencies and high production prices, they are far from market-ready. But they offer the potential for significant improvements over time in efficiency and cost.

This section analyzes China's efforts to improve the efficiency of each of these three technology groups. The analysis occurs in two steps. First, Sections 4.2.1, 4.2.2, and 4.2.3 explain what China is doing to try to improve the cell efficiencies of silicon-based cells, thin-film modules, and perovskite and organic cells. Those subsections focus on the major laboratories and researchers active in each of the three identified technology groups. Second, Section 4.2.4 analyzes the progress that China is achieving as a result of these efforts to improve the efficiencies of these different classes of solar technologies. The section makes this assessment by comparing efficiency results among Chinese research groups to those among non-Chinese research groups for laboratory-scale cells in each of five solar-cell technologies: HIT, CIGS, cadmium-telluride, perovskite, and organic. The comparison is based on a literature review.

[97] National Science Foundation. "China Announces Major Reform of Competitive S&T Funding." https://www.nsf.gov/od/oise/beijing/perspectives/china_reforms_st_funding.jsp
[98] Christina Larson. "Overhaul of Chinese Science Spending Looms." Sciences. Oct. 23, 2014. http://www.sciencemag.org/news/2014/10/overhaul-chinese-science-spending-looms

4.2.1: Silicon-Based Cells

4.2.1.1: Conventional Silicon Cells

China-based firms have made steady progress in improving the efficiency of their silicon-based solar cells, particularly their multicrystalline-silicon cells, which command the overwhelming share of the global solar market. Of particular note are a string of efficiency improvements over the past two years at Trina Solar. The improvements have occurred under the direction of Pierre Verlinden, a Belgian-born scientist and longtime solar expert who helped create SunPower, the U.S.-based solar giant, and who joined Trina in 2012 as its chief scientist. As a result of these improvements, Trina has become the first China-based solar manufacturer to be recognized on the U.S. Renewable Energy Laboratory's well-known chart of solar-cell-efficiency world records, shown below in Figure 9. Trina holds the world record for a research-scale multicrystalline-silicon solar cell, at an efficiency of 21.3%.[99] Trina announced the result in November 2015; it broke the previous multicrystalline-silicon solar cell record of 20.76%, which Trina had announced in 2014.[100] Before that, the world record for the efficiency of a multicrystalline-silicon solar cell had been held by Germany's Fraunhofer Institute for Solar Energy Systems, one of the world's foremost solar-research labs. "To the best of our knowledge, this is the first time ever that a multi-crystalline silicon solar cell has been able to achieve a conversion efficiency of over 21%," Trina said in its press release announcing the 21.3% record.[101]

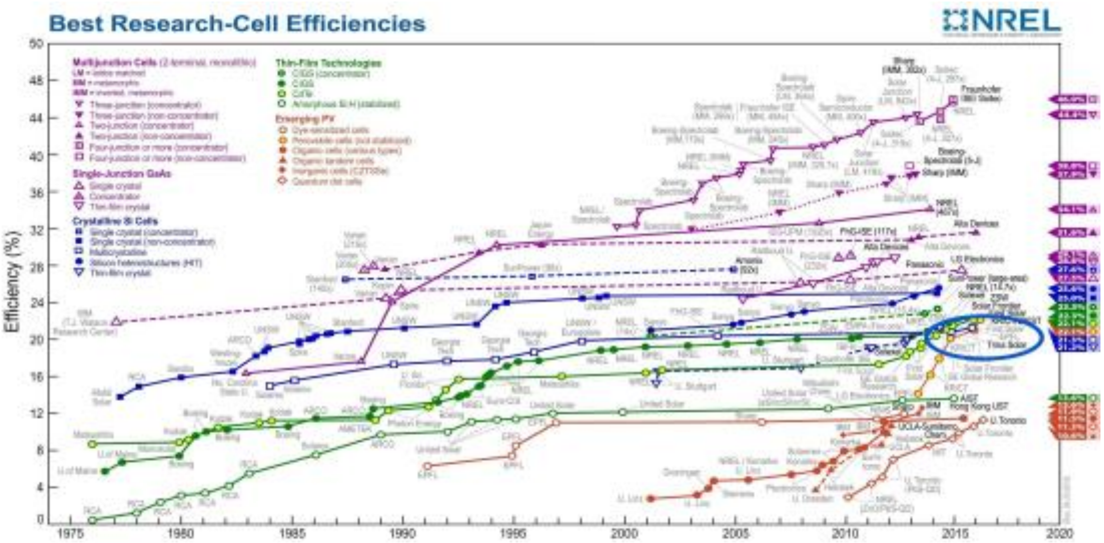
A China-based solar manufacturer has been recognized on the U.S. National Renewable Energy Laboratory's cell-efficiency chart.

[99] Trina press release, "Trina Solar Announces New Efficiency Record of 21.25% Efficiency for Multi-crystalline Silicon Solar Cell," Nov. 9, 2015. http://www.trinasolar.com/us/about-us/newinfo_978.htmlhttp://www.trinasolar.com/us/about-us/newinfo_978.html

[100] Trina press release, "Trina Solar Announces New R&D Breakthrough," Dec. 13, 2014. http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-newsArticle&ID=2002414

[101] Op. cit., Trina press release, Nov. 9, 2015.

Figure 9: World Record Research-Solar-Cell Efficiencies, 1975-2015 [102]



Source: U.S. National Renewable Energy Laboratory

In addition to the multicrystalline-silicon cell that won Trina a spot on the NREL chart, Trina also claims a series of other world records in silicon cells and modules over the past two years.[103]

4.2.1.2: HIT

HIT is an adaptation of traditional crystalline-silicon-cell technology that offers improved efficiency because it sandwiches a thin silicon wafer between two amorphous-silicon layers. Two research groups are leading China's HIT work. The most advanced is led by Zhengxin Liu, who grew up in China, did his doctoral work in Japan, the country that pioneered the technology and has led global HIT work since then, and in 2009 was recruited to return to his native country and ramp up HIT work there through China's Thousand-Talent Program.[104][105] The program—a government initiative that recruits China research experts from around the world, attracting them with a variety of financial perks—is explained in Section 4.4.2.7. Dr. Liu is based at the Chinese Academy of Sciences' Shanghai Institute of Microsystem and Information Technology and works in collaboration with Trina. In 2013, his research group produced a laboratory HIT cell with a 22% efficiency. Trina announced in 2015 that it had produced this HIT cell on a pilot line at 21% efficiency.[106]

The other major Chinese HIT research group is led by Wenjing Wang, who is based at the Chinese Academy of Sciences' Institute of Electrical Engineering, in Beijing. Dr. Wang's research group

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[102] U.S. National Renewable Energy Laboratory cell-efficiency chart, http://www.U.S. National Renewable Energy Laboratory.gov/ncpv/images/efficiency_chart.jpg

[103] Among them, according to Trina press releases: In February 2014, Trina announced a laboratory-scale IBC cell, developed by the Australian National University under a research contract with Trina and involving the Solar Energy Research Institute of Singapore (SERIS), tested at an efficiency of 24.4%. In December 2015, Trina announced a p-type monocrystalline-silicon PERC cell tested at an efficiency of 22.13%. In April 2016, Trina announced an n-type monocrystalline-silicon IBC cell with a total-area efficiency tested at 23.5%. These press releases are available at http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-news&nyo=0http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-news&nyo=0

[104] Kentaro Wakisaka, Masao Taguchi, Takuya Sawada, Masayuki Tanaka, Takashi Matsuyama, Toshifumi Matsuoka, Shinichiro Tsuda, Shunsuke Nakano, Yudai Kishi, Yasuhiko Kuwano, "More than 16% Solar Cells with A New `HIT' (doped a-Si/nondoped a-Si/crystalline Si) Structure," Photovoltaic Specialists Conference. 1991; 2: 887 – 892.

[105] Throughout *The New Solar System*, all names are written in the Western style, with the first name preceding the last name. That is contrary to the convention in China, in which the last name precedes the first name. *The New Solar Sy*stem employs this single naming style in the interest of uniformity among Western and Chinese names.

[106] Trina State Key Lab, 2015, Trina and CAS Hold HIT Research Workshop. http://www.sklpvst.com/industry_view.asp?id=234

has been working on HIT technology for nearly a decade. Supported first by China's 863 program and later through a collaboration with Shanghai Chaori Solar, a mid-sized China-based solar manufacturer, Dr. Wang's group produced an HIT cell with 20.25% efficiency in 2013—a less-stellar result than Liu's group.[107]

4.2.2: Thin-Film Modules

4.2.2.1: CIGS

CIGS is a type of thin-film solar cell made by depositing on a substrate a photovoltaic layer of copper, indium, gallium, and selenide. Many research groups in China are working on CIGS technology. The leader is a group in Shenzhen headed by Xudong Xiao. Dr. Xiao grew up in China and then went to graduate school in the United States, where he received his doctoral degree from the University of California, Berkeley, and did post-doctoral work at Lawrence Berkeley National Laboratory. In 2004, he was recruited back to China under the Thousand-Talent Program. Initially he took a faculty position at the Hong Kong University of Science and Technology; in 2008 he moved to the Shenzhen Institutes of Advanced Technology's Solar Research Institute. In 2013, Dr. Xiao's group produced a CIGS cell with a 19.42% efficiency, about two percentage points lower than the then-world record.[108] [109]

A variety of other research groups in China are working on CIGS cells. Most involve alliances between academic researchers and solar companies. Tsinghua University has worked with Lanxing Terra Co., based in the Shandong Province city of Weihai, and with Dikai, a solar company in Guangxi Province. Peking University, working with the solar firm BESC, built a pilot HIT production line in Henan Province. Similarly, Nankai University, located in Tianjin, worked with Taiyang Co., a solar firm located in the same city, to build a pilot HIT production line. None of these efforts has yielded large-scale production.

China's best-known CIGS effort was undertaken by Hanergy, a Beijing-based company that got started in the hydroelectricity business. Between 2012 and 2014, Hanergy launched a mergers-and-acquisition strategy to dominate the global CIGS market, buying, among other companies, and as indicated above in Table 1, U.S.-based MiaSole and Germany-based Solibro, two CIGS companies that had developed sophisticated technologies but needed capital and a market to scale them up. Hanergy announced that it was building large factories in China to manufacture the MiaSole and Solibro CIGS modules. But those plans now are on hold, in the wake of an investigation by authorities in Hong Kong, where Hanergy's stock is traded, into the company's financial practices.

4.2.2.2: Cadmium-Telluride

Cadmium-telluride solar cells use as their photovoltaic material thin layers of cadmium and telluride that are applied to a substrate. China has at least two efforts underway on cadmium-telluride. Neither stands as a legitimate competitor to the global cadmium-telluride solar leader, U.S.-based First Solar.

China's only producer-at-scale of cadmium-telluride cells is Advanced Solar Power, based southwest of Shanghai in the Zhejiang Province city of Hangzhou. The company was founded and still is led by Xuanzhi Wu, who grew up in China and then worked for several decades at the U.S. National Renewable Energy Laboratory before returning to China in 2008 to found Advanced Solar Power. During his lengthy time as a senior scientist at NREL, Dr. Wu set the then-world record for efficiency for a cadmium-telluride thin-film solar module. His company currently produces 40 megawatts of cadmium-telluride modules annually, mostly with equipment that Advanced

[107] The 863 program is explained in Sections 4.4.2.3 and 4.6.1.
[108] Laboratory website of Xudong Xiao, Shenzhen Institutes of Advanced Technology. http://sourcedb.siat.cas.cn/zw/zjrc/gdxs/201508/t20150826_4415385.html
[109] Yafen Song, "CIGS Solar Cell Efficiency Reaches 21.7%," China News, Oct. 16, 2014. http://www.chinanews.com/ny/2014/10-16/6687067.shtml

Solar Power designed itself.[110] Advanced Solar Power's commercial modules have an efficiency of about 13%.[111] That is approximately two percentage points lower than the efficiency of First Solar's modules—a significant difference.

The second major cadmium-telluride effort in China is under the direction of Xiangxin Liu, based in Beijing at the Chinese Academy of Sciences' Institute of Electrical Engineering. Like Dr. Wu, Dr. Liu was born in China and then spent significant time in the United States—in Liu's case, earning his doctoral degree from the University of Toledo, one of the world's leaders in cadmium-telluride research—before returning to China. Dr. Liu was lured back through a scientist-recruitment program, the Chinese Academy of Sciences' Hundred-Talents Program. In 2014, Dr. Liu's lab produced a laboratory research cell that had an efficiency of 14.4%.

A few smaller cadmium-telluride research efforts also are underway in China. Nevertheless, China is not at this point a serious competitor to First Solar. Opinions differ as to why. Some in China argue that the technology is generally uninteresting because of two factors that appear to limit its commercial appeal: Cadmium's potential for water contamination presents concerns about environmental regulation, and tellurium's status as a rare element raises concerns about its availability and thus about its future cost. Others, however, say Chinese scientists and companies simply have been unable to compete thus far with the technology of the global cadmium-telluride leader, First Solar.

4.2.3: Emerging Technologies

4.2.3.1: Organic

In China as around the world, interest in organic solar cells is surging, though the technology remains far from ready for commercialization. Two research groups in China are competing against each other for efficiency gains. Both are led by scientists who spent time at leading organic-solar laboratories at universities in California. One of the Chinese groups focusing on organic solar cells is at the Chinese Academy of Sciences' Institute of Chemistry. The lab's leader, Yongfang Li, was educated during the 1970s in China and spent stints later in his career in the United States. From 1997 to 1998, he worked at a lab at the University of California, Santa Barbara, run by Alan Heeger, a Nobel laureate in chemistry. Dr. Heeger's lab has set multiple world records for the efficiency of laboratory-scale organic solar cells. In 2000, Li worked at the University of California, Los Angeles, lab run by Yang, another leading organic-solar-cell researcher. Working with a research group at China's Suzhou University, Dr. Li produced an organic solar cell with an efficiency of about 8%.

China's neck-and-neck organic-solar efficiency gains are a result of competition between two research groups.

The other major organic-solar research effort in China is headed by Yong Cao, of the South China University of Technology. Dr. Cao received his doctoral degree from Tokyo University. From 1988 to 1990, he was a visiting scholar at Dr. Heeger's lab in Santa Barbara. Then, from 1990 to 1998, he worked as a senior researcher at UNIAX, a company that Dr. Heeger co-founded.

China's neck-and-neck organic-solar efficiency gains are almost entirely a result of competition between Dr. Li's and Dr. Cao's research groups. Nevertheless, despite that domestic rivalry, Chinese researchers working on their own

[110] Another noteworthy cadmium-telluride player in China, Chengdu China National Building Materials Group Solar PV and Material Corp., is building a 300-megawatt cadmium-telluride production line. See (in Chinese): http://coeapollo.cn.china.cn/

[111] China Stock Times, May 06, 2016 (Content in Chinese): http://kuaixun.stcn.com/2016/0509/12707958.shtml

remained behind research groups that involved non-Chinese scientists as of 2014, the latest year for which the Stanford Steyer-Taylor Center for Energy Policy and Finance team analyzed these statistics. As shown below in Figure 14, the record as of that year from Chinese researchers was 9.28%, from the South China University of Technology. The record that year beyond China was 11.5%, from a team of researchers from both the Hong Kong University of Science and Technology and North Carolina State University.

4.2.3.2: Perovskite

The perovskite solar cell has captured enormous interest among solar researchers over the past four years; efficiencies for laboratory-scale perovskite cells have soared from less than 15% in 2013 to 22.1% in 2016, an extraordinarily rapid rise.[112] "Perovskite" refers to the structure of the crystals in the photovoltaic layer of the perovskite cell; the layer is applied to a substrate, commonly glass.[113] Perovskites promise higher efficiencies and lower production costs than silicon-based solar cells.[114] One significant concern is the cells lack of what scientists call "stability"—the cell's tendency to degrade in a relatively short time.

Perovskite enthusiasm has been as pronounced among Chinese researchers as among their counterparts elsewhere in the world. Hong Kong Polytechnic University produced the first Chinese-made perovskite solar cell, with an efficiency 4.87%, in 2013. Since then, research groups at Tsinghua University, Peking University, Huazhong University of Science and Technology, the Chinese Academy of Sciences' Institute of Physics, and the Chinese Academy of Science's Institute of Applied Chemistry all have begun working intensively on perovskite cells.

A notable recent development in China's perovskite work came in April 2016, when Hong Kong Polytechnic University announced that a research group there produced a laboratory-scale solar cell using a perovskite-and-silicon tandem architecture—a design different from a pure perovskite cell—that achieved an efficiency of 25.5%. The university described the result as a world record, though the result does not appear on the NREL chart, in large part because the NREL chart does not include records for cells that use perovskite-and-silicon tandem architecture. The research team, led by Charles Chee Surya, a professor at the university, produced three innovations that contributed to the efficiency breakthrough, the university said: a new chemical process that reduces efficiency losses in the solar cell as a result of perovskite defects; a new design of the perovskite layer said to improve its ability to transfer light to the silicon substrate; and a new film said to trap more light.[115]

Some of the leading perovskite work in China has involved collaboration with preeminent Western research labs. For example, Hongwei Han, leader of the perovskite research group at Huazhong University of Science and Technology, has maintained a long-term collaboration with Michael Graetzel's group at the Ecole Polytechnique Federale de Lausanne (EPFL) in Lausanne, Switzerland, among the world's top perovskite research facilities, where Dr. Han received his PhD degree.

4.2.4: Cell-Efficiency Conclusions: Mind the Gap

With this description of the relevant technologies as a backdrop, what follows is an analysis assessing the R&D progress that China-based entities are making in a broad array of solar technologies beyond multicrystalline-silicon cells, the cells that dominate today's global market.

Figures 10, 11, 12, 13, and 14, based on original research by the Stanford Steyer-Taylor Center for

[112] U.S. National Renewable Energy Laboratory, "Best Research-Cell Efficiencies." http://www.U.S. National Renewable Energy Laboratory.gov/ncpv/images/efficiency_chart.jpg
[113] The perovskite crystalline structure is named for Lev Perovski, a Russian mineralogist who worked in the 19th century.
[114] Martin Green, Anita Ho-Baillie, and Henry Snaith. "The Emergence of Perovskite Solar Cells." Nature Photonics. June 27, 2014. doi:10.1038/nphoton.2014.134 http://www.nature.com/nphoton/journal/v8/n7/full/nphoton.2014.134.html#ref1
[115] Science Daily. 2016. Perovskite-silicon tandem solar cells with the world's highest power conversion efficiency.https://www.sciencedaily.com/releases/2016/04/160412104814.htm

Energy Policy and Finance research team, compare record efficiencies reported by Chinese and non-Chinese researchers for laboratory-scale solar cells in a variety of solar technologies.

Two caveats are crucial to keep in mind about these figures and the analysis that underpins them.

The first has to do with the verifiability of the data. The plots in Figures 10, 11, 12, 13, and 14 that represent reported cell-efficiency results from non-Chinese entities come from NREL's cell-efficiency chart, described in Section 4.1.[116] [117] The plots in the figures that represent reported cell-efficiency results from Chinese entities, by contrast, come from a Stanford Steyer-Taylor Center for Energy Policy and Finance review of scientific journals, most of them written in Chinese. Importantly, some of these Chinese results were verified by third parties and some were not.

The second caveat has to do with the quantity of data. Figures 10 and 12 each include just four data points for Chinese entities. Those are the data points that the Stanford Steyer-Taylor Center research team was able to find. The comparison would be significantly more robust if it included more data points on Chinese research results. That is a potential avenue for further research.

With these caveats in mind, the data reflected in the figures below underscores China's intensifying focus on improving the efficiency of a range of types of solar cells. More particularly, and as explained further in the text and figures below, the efficiency analysis shows that China is making more progress on certain types of cell technologies—including, as mentioned above, achieving the world record in the efficiency of a multicrystalline-silicon cell—and less progress on others. Why that is the case cannot be determined for certain. However, discussions with solar researchers in China and elsewhere suggest some reasons for the differing gaps between researchers in China and in other parts of the world.

China is making particular progress on certain cell technologies—including world-record efficiency for a multicrystalline-silicon cell.

4.2.4.1: HIT and CIGS: Narrowing the Gap

As Figures 10 and 11 below show, in technologies that already are on the market, notably HIT and CIGS, Chinese researchers are narrowing the cell-efficiency gap with researchers elsewhere in the world. This stands to reason. Researchers outside China were working on these technologies long before China ramped up its solar effort; by the time China did so, Western researchers had a significant efficiency lead. However, as China has put more effort into these technologies, it has narrowed that gap.

[116] Op. cit., U.S. National Renewable Energy Laboratory

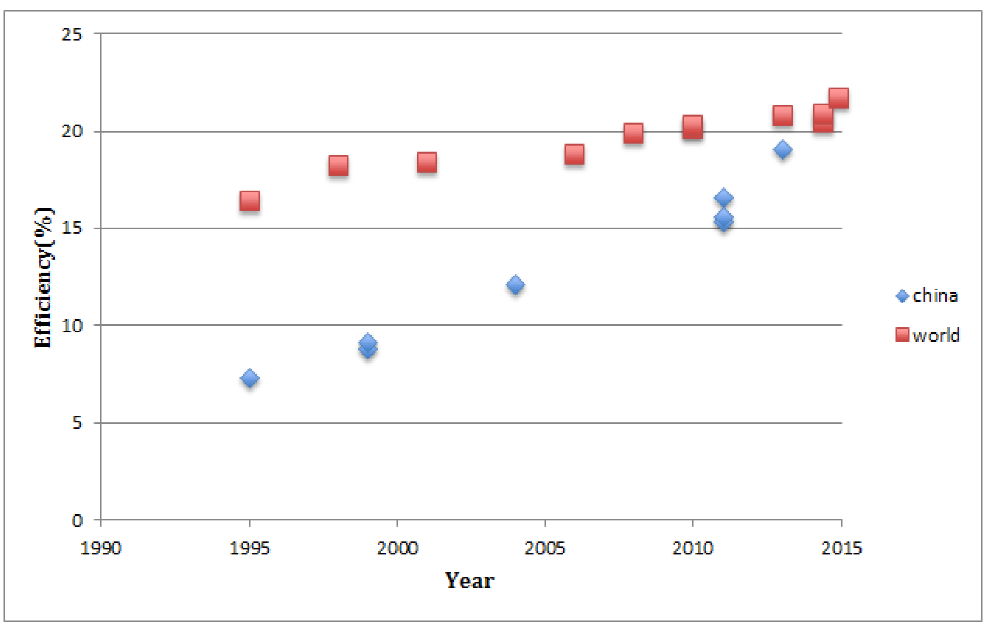
[117] As explained in Section 4.2.1.1, the U.S. National Renewable Energy Laboratory chart recognizes one Chinese solar manufacturer, Trina, for a laboratory-cell-efficiency world record.

Figure 10: HIT Laboratory-Scale Cell Efficiency

Source: Literature review; NREL laboratory-cell efficiency chart

Note: This figure shows four data points for Chinese entities although it appears to show only three. Two of the data points, both for 2013, are so close in their efficiency numbers that their blue diamonds in the chart overlap. For details on the four data points, see details for the HIT Laboratory-Scale Cell Efficiency results in Appendix A.

Figure 11: CIGS Laboratory-Scale Cell Efficiency



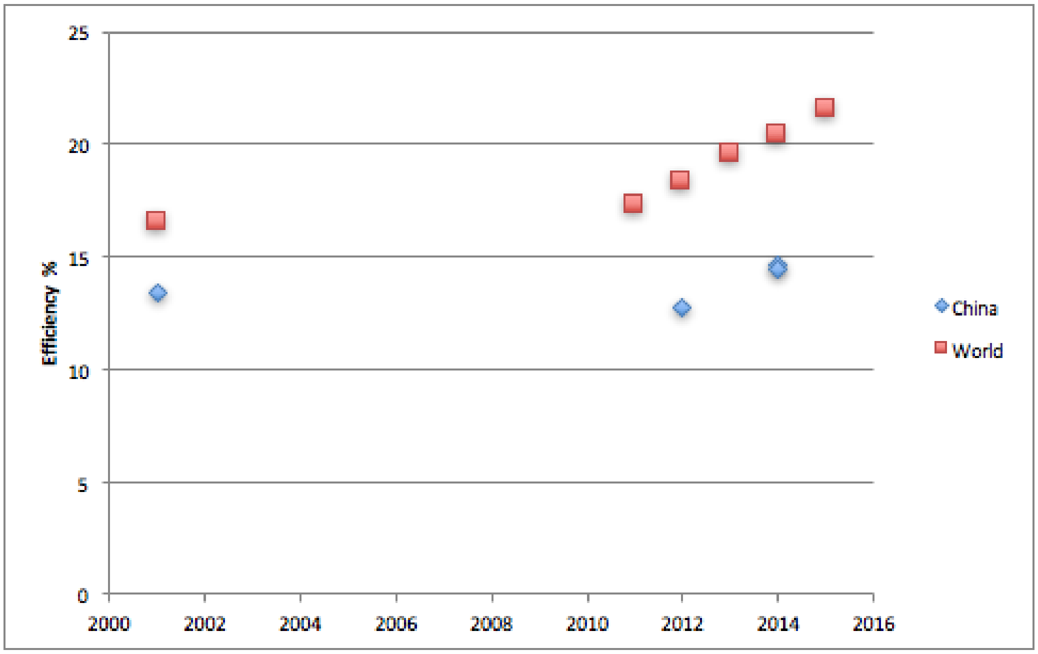
Source: Literature review; NREL laboratory-cell efficiency chart

Note: This figure shows eight data points for Chinese entities although it appears to show only six. Two of data points for 1999 and two data points for 2011 are so close to each other in their efficiency numbers that their blue diamonds in the chart overlap. For details on the four data points, see details for the CIGS Laboratory-Scale Cell Efficiency results in Appendix A.

4.2.4.2: Cadmium Telluride: A Wide Gap

As indicated in Figure 12 below, there appears to be no narrowing over time of the gap between cell efficiencies reported by Chinese researchers and by those elsewhere in one cell technology: cadmium telluride, a popular form of thin-film solar cells. Some in China speculated that the reason for the gap is a lack of interest in China in the technology—a lack of interest based on concerns about cadmium's impact on water quality and tellurium's supply constraints.[118] Others, however, argue that China appears further behind in cadmium telluride not because of a lack of effort but because of a lack of success.

Figure 12: Cadmium Telluride Laboratory-Scale Cell Efficiency



Source: Literature review; NREL laboratory-cell efficiency chart

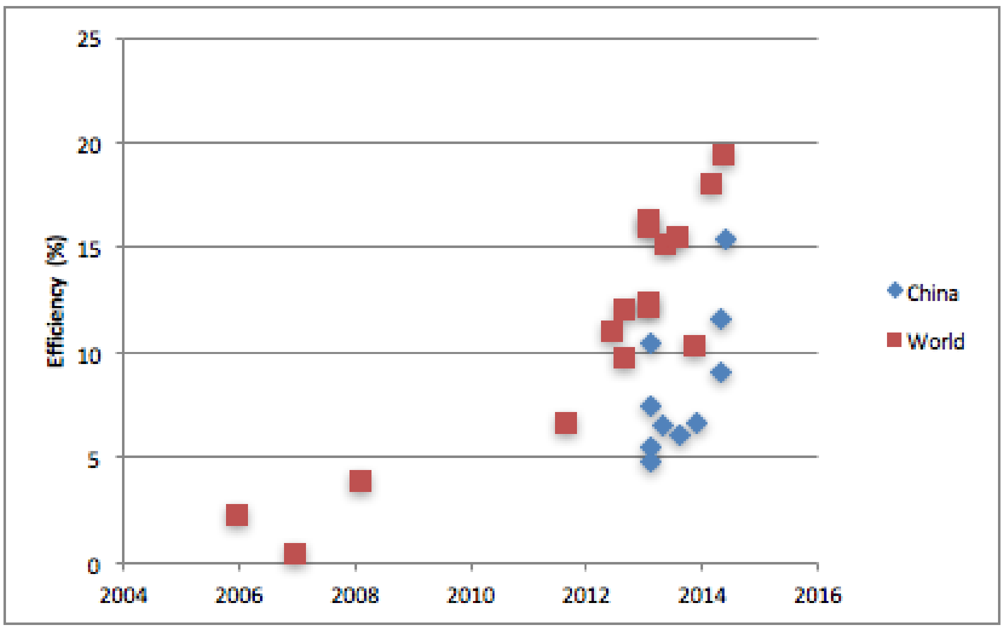
Note: This figure shows four data points for Chinese entities although it appears to show only three. Two of the data points, both for 2014, are so close in their efficiency numbers that their blue diamonds in the chart overlap. For details on the four data points, see details for the Cadmium Telluride Laboratory-Scale Cell Efficiency results in Appendix A.

[118] Discussion with senior solar scientist at Chinese Academy of Sciences' Electrical Engineering Institute in Beijing.

4.2.4.3: Emerging Cell Technologies: Less Gap

Chinese researchers appear from the literature to be tracking the progress of Western scientists at least somewhat more closely in perovskite and organic solar cells than they are in, for instance, in cadmium-telluride cells. As Figure 13 below shows for perovskite cells and Figure 14 shows for organic cells, the literature indicates that, though Chinese researchers still remain behind their counterparts in other parts of the world in these two technologies, the gap is smaller than it is in the case of other solar-cell technologies. Discussions with a wide range of solar researchers suggest that the reason is one of timing. Globally, research into organic solar cells has intensified over the past decade, and research into perovskite solar cells has shot up during just the past few years. In other words, the boom in research into these two technologies has occurred during the time when China has been aggressively building up its domestic solar enterprise—including solar-R&D. Chinese researchers, therefore, have been racing alongside their counterparts in other parts of the world to try to improve organic and perovskite cells.[119]

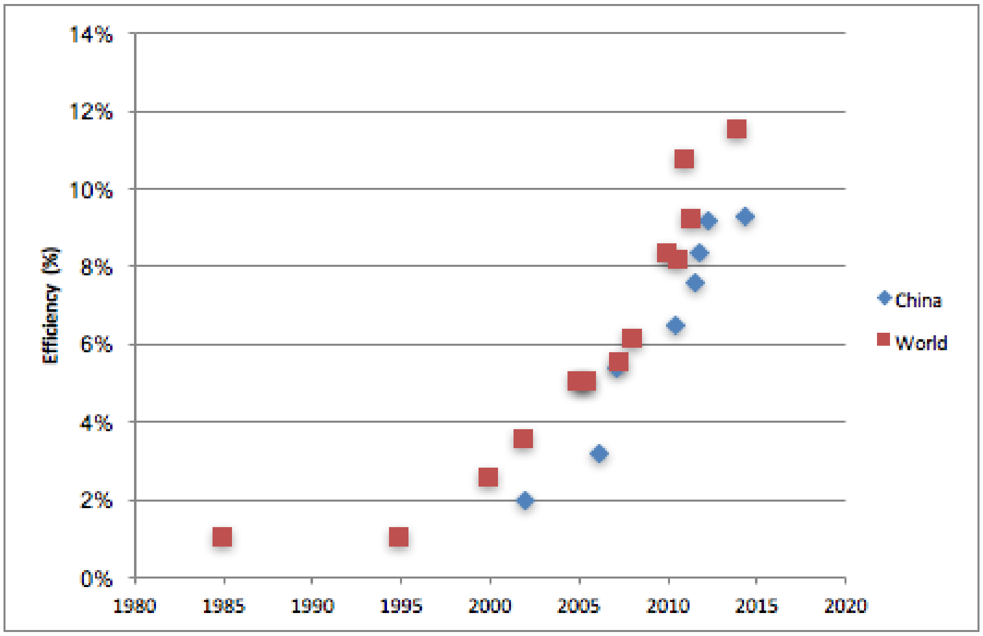
Figure 13: Perovskite Laboratory-Scale Cell Efficiency



Source: Literature review; NREL laboratory-cell efficiency chart

[119] Note that, in Figures 10, 11, 12, and 13, each vertical line represents a change of five percentage points from the one next to it, whereas, in Figure 14, the difference between each vertical line is two percentage points.

Figure 14: Organic Laboratory-Scale Cell Efficiency



Source: Literature review; NREL laboratory-cell efficiency chart

Note: This figure shows three data points for World (non-Chinese) entities in 2005 although it appears to show only one. The three 2005 World data points are so close in their efficiency numbers that their red squares in the chart overlap. For details on the three data points, see details for the Organic Laboratory-Scale Cell Efficiency results in Appendix A.

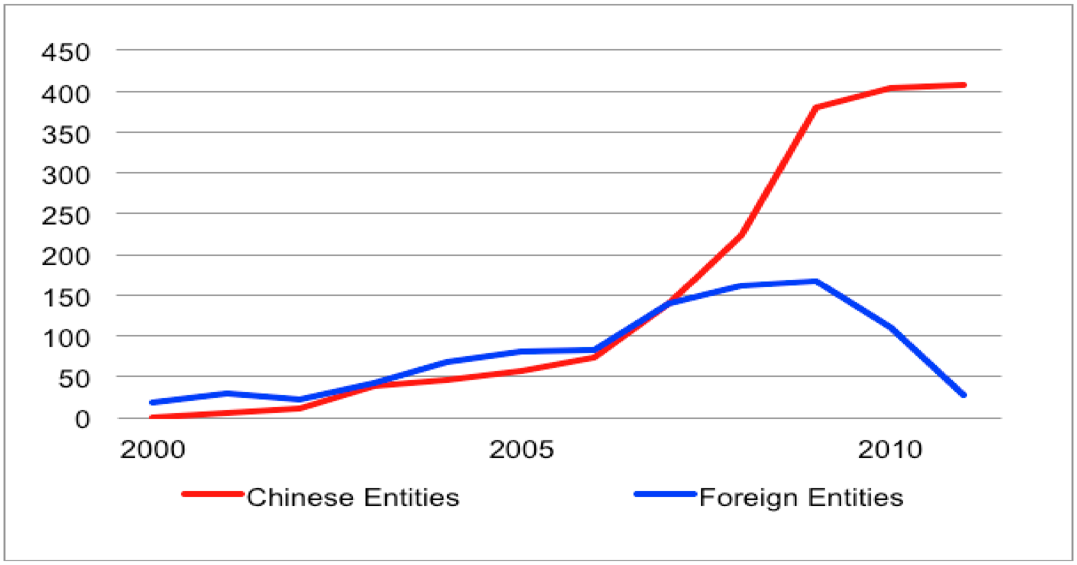
4.3: Patents

4.3.1: Patent Numbers

The Stanford Steyer-Taylor Center for Energy Policy and Finance research team undertook a comprehensive assessment of solar patents granted by the relevant Chinese government authority, the State Intellectual Property Office (SIPO), between 2000 and 2014. The Chinese government issues three grades of patents, the most innovative of which are known as “invention” patents, and it was this grade of solar patent the Stanford team assessed. The SIPO patent database is publicly available, but in raw form it is difficult to categorize and thus to analyze. With assistance from a Chinese patent-search firm, Evalueserve, the Stanford team grouped solar-related invention patents in the SIPO database according to a range of criteria, including the specific solar technology for which the patent was granted, the specific institution that was awarded the patent, and the type of institution (company, government agency, or academic institution) that was awarded the patent.

The results of this analysis are far from determinative, but they are directionally revealing. As Figures 16 and 17 below show, the number of solar patents granted by the Chinese government soared between 2000 and 2014.

Figure 15: Solar-Related Innovation Patents Granted by China To Chinese and Non-Chinese Applicants



Source: State Intellectual Property Office of China; data compiled with assistance from Evalueserve, a data-consulting company with expertise in Chinese patent statistics

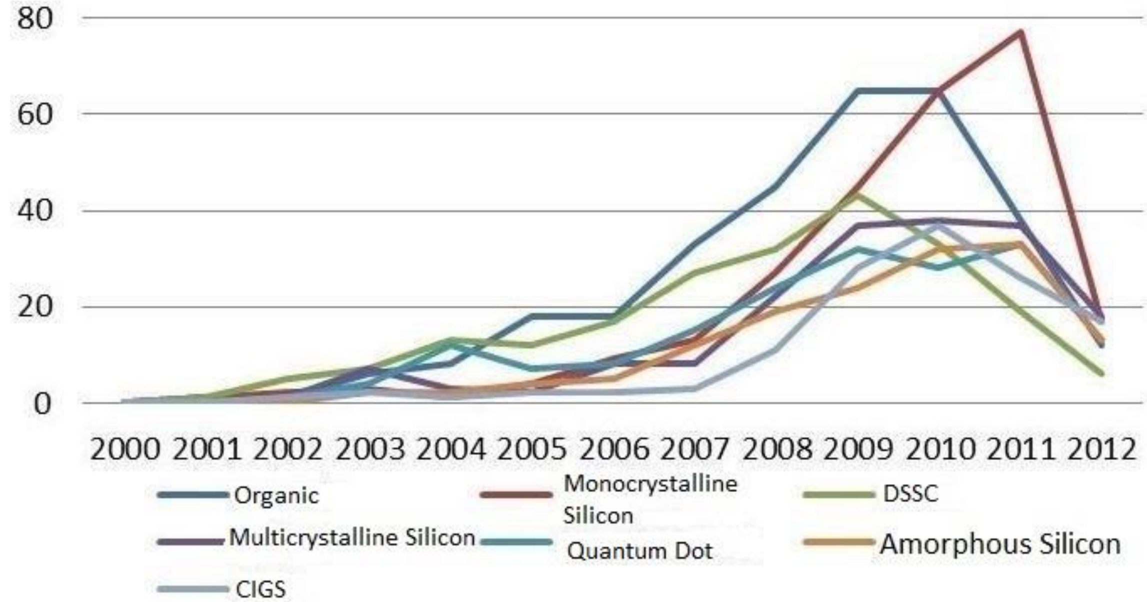
The question that matters most, of course, is to what extent that surge in patents indicates a surge in underlying technological innovation. It is possible that Chinese entities, encouraged by Chinese government policy, simply are applying more often for patents as a way to portray themselves as having achieved technological gains—and a Chinese system that grants patents more readily and for less actual innovation than the governments of many other countries do.

A detailed analysis of the quality of individual patents was beyond the scope of *The New Solar System*. What this study is able to conclude about patents are two things, both of which are discussed below. First, Chinese solar researchers across a range of technologies and institutions are working harder to innovate than ever before.

Chinese solar researchers across a range of technologies and institutions are working harder to innovate than ever before.

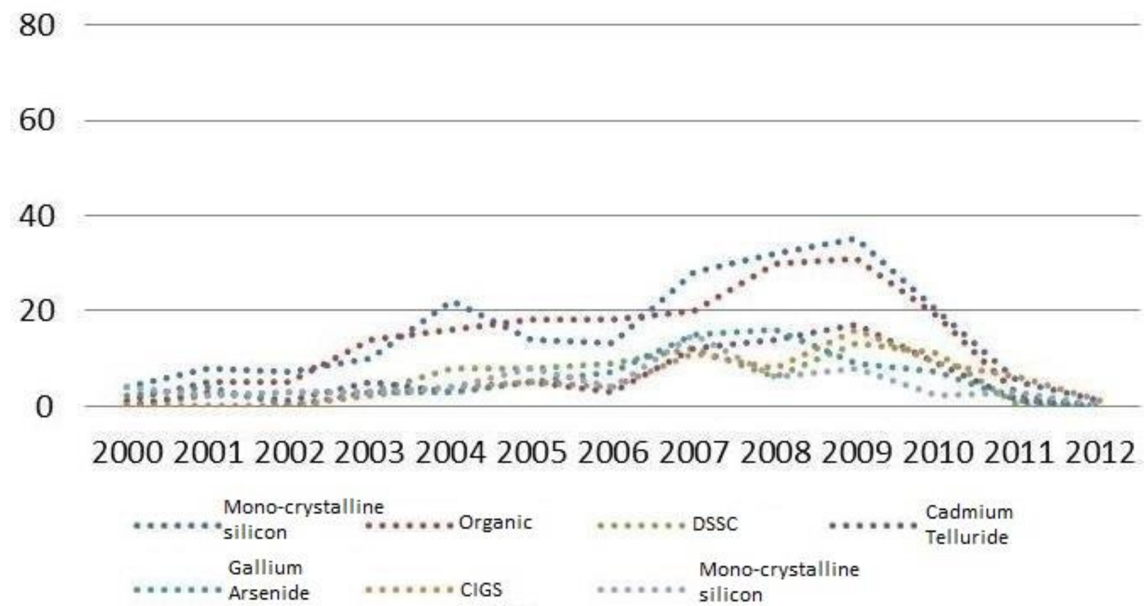
Second, at least according to one metric that patent experts widely consider relevant in assessing patent quality, and as discussed in Section 4.3.2, China's solar-research community appears to value patents on more-conventional technologies more than patents on more-advanced ones.

Figure 16: Top Seven Solar Technologies in Number of Patents Granted by China



Source: State Intellectual Property Office of China; data compiled with assistance from Evalueserve, a data-consulting company with expertise in Chinese patent statistics

Figure 17: Top Seven Solar Technologies in Number of Patents for Foreign Players



Source: State Intellectual Property Office of China; data compiled with assistance from Evalueserve, a data-consulting company with expertise in Chinese patent statistics

Part of the rise in the number of solar patents granted appears clearly to be the result of changes in Chinese policy—changes that have incentivized solar companies and academic solar researchers to rack up patents regardless of the patents' quality. One example of those policy changes was an Outline of National Intellectual-Property Strategy that the SIPO issued in 2008. It sought, as a way to demonstrate to the world that China was improving in technological innovation, to raise both the number of invention patents granted by the SIPO to Chinese applicants and the number of patent applications filed by Chinese nationals to overseas governments. The outline made clear that patents would be one criterion that the government would use in awarding research support. And it listed solar energy as a key area that the government was prioritizing for patent creation.[120]

Another example of Chinese policy changes that have promoted patent applications are a number of MOST-run programs that require research projects to have racked up a certain number of patents in order to qualify for MOST research grants. Indeed, several Chinese solar researchers who received MOST funding reported to the Stanford research team that they applied for and received patents that they themselves viewed as lacking in true innovative merit. Instead, they filed for the patents, they said, because doing so was a requirement for getting the MOST research funding. It is little wonder that, according to United Nations statistics, by 2012 China processed more patent applications than did any other country.[121] In China, said Benjamin Bai, a leading intellectual-property lawyer in China who assisted the Stanford Steyer-Taylor Center for Energy Policy and Finance research team in analyzing the patent data, "patents are a numbers game."

The Chinese research community values patents on near-term technologies more than on emerging ones.

4.3.2: Patent Lapse Rates

One way that patent value is often measured in the business world is the patent "lapse rate"—the percentage of patents that are not renewed by their owners, who are required to pay an annual fee for the renewal. The theory is that patent holders are likely to pay to renew the patents they regard as financially valuable and not to renew those they regard as less valuable. To be sure, lapse rates are an imperfect measure of patent value; other factors, such as a financial squeeze, could lead a patent holder not to renew a patent. Still, lapse rates are widely used as an indicator of patent value.

The New Solar System analyzed patents awarded by China's State Intellectual Property Office in 16 solar sub-technologies. Some of those Chinese patents were awarded to Chinese entities; some were awarded to non-Chinese entities. Table 2 below shows how patent-lapse rates differed among the 16 solar sub-technologies. In six of the sub-technologies, the Chinese patents awarded to Chinese entities had a higher lapse rate than those awarded to non-Chinese entities. In eight of the sub-technologies, the Chinese patents awarded to Chinese entities had a lower lapse rate than those awarded to non-Chinese entities.

What is interesting is the nature of the sub-technologies that fell on either side of that divide. The sub-technologies that had a higher lapse rate among Chinese entities were, generally, emerging ones: organic, perovskite, dye-sensitized, and quantum dot, in addition to CIGS and cadmium-telluride. Those that had a lower lapse rate among Chinese entities were, generally, those for which there is now a commercial market: polysilicon, monocrystalline-silicon, PERC, IBC, HIT, and multi-junction (a technology in which the cell has multiple interfaces between p-type and n-type

[120] State Intellectual Property Office of China. 2008. Outline of the National Intellectual Property Strategy.
[121] United Nations. "China's Patent Office Now the World's Biggest, U.N. Innovation Report Finds." Dec. 11, 2012. http://www.un.org/apps/news/story.asp?NewsID=43744#.VkTeEa6rSRt

semiconductor material), in addition to amorphous-silicon and gallium-arsenide (another thin-film technology). That suggests that the Chinese research community values patents on near-term technologies more than it values patents on emerging ones.

Table 2: Patent-Lapse Rate By Solar Technology

Technology	Lapse Rate By Chinese Patent Holders	Lapse Rate By Non-Chinese Patent Holders
Technologies with Higher Patent-Lapse Rate By Chinese Patent Holders		
Organic	15.2%	7.4%
Dye-Sensitized	18.1%	10.3%
Quantum Dot	19.8%	12.2%
CIGS	13.8%	6.5%
Perovskite	20.0%	15.4%
Cadmium Telluride	14.8%	10.6%
Solar Technologies with Lower Patent-Lapse Rate By Chinese Patent Holders		
Gallium Arsenide	7.8%	9.1%
PERC	6.0%	7.7%
HIT	16.0%	18.9%
Monocrystalline Silicon	10.0%	14.4%
Amorphous Silicon	11.6%	16.7%
Multi-junction	8.0%	13.2%
Multicrystalline Silicon	11.0%	17.0%
IBC	0.0%	12.0%

Source: State Intellectual Property Office of China; data compiled with assistance from Evalueserve, a data-consulting company with expertise in Chinese patent statistics

4.3.3: Future Patent Analysis

Further work exploring solar patents, in China and in other countries, would be useful. A key question is why scientists choose to seek or not to seek patents for solar and other energy technologies they are pursuing. This examination would benefit from both geographic and temporal comparisons. Do scientists in China differ from those in, for instance, the United States or Germany in their calculations about when it does and does not make sense to patent a solar or other energy technology? And, for scientists in any given country, has that calculation changed over time? Answering these questions is particularly crucial at a time when, as will be explored further in Chapter 6, the governments of China, the United States and many other countries have pledged under a December 2015 agreement called "Mission Innovation" to double their spending on clean-energy R&D over the next five years in an effort to speed the spread of technologies, including solar. Assessing the extent of underlying innovation embodied in each Chinese patent becomes more important as, with increased R&D spending, the number of those patents would be expected to rise. Moreover, as is discussed in detail in Chapter 6, China's increasing solar-R&D effort and output increases the importance for the United States to assess the areas in which it wants to work with China in solar R&D and the areas in which it does not. Greater insight into the significance of each Chinese patent would help frame both what the United States stands to learn from China in any such research relationship and areas in which U.S.-based and China-based companies are commercially competing and therefore would want to avoid collaborating and might seek increased R&D support from their respective governments.

4.4: Mapping China's R&D Ecosystem

China's modern R&D system was created in the 1980s, a time when the country was rebuilding its intellectual infrastructure in the wake of the Cultural Revolution. Starting then and continuing since, the Chinese R&D system's underlying goal has been evolutionary rather than revolutionary: to execute carefully engineered and incremental steps in an attempt to catch up to the scientific leadership of the West.[122]

This historical context is important in understanding China's solar enterprise. It helps explain why, for most Chinese solar researchers, the goal traditionally has not been to invent a new type of solar cell or to break a world cell-efficiency record. Rather, it has been to gradually close the gap between China and the West. In an interview, one leading Chinese solar-cell researcher—a man who, like many of his colleagues, grew up in China, received his graduate training overseas, and returned to China to start his lab—explained that the goal of his research group was "not necessarily to develop new world efficiency records but to ensure China has the ability to mass-produce" two solar technologies that were invented in the West: CIGS and HIT.[123] This mindset helps explain why no Chinese research group set a cell-efficiency world record until two years ago, when Trina did so under the leadership of Mr. Verlinden, the Belgian-born scientist whom Trina recently had hired to head its solar R&D work.

For most Chinese solar researchers, the goal has not been new invention. It has been to close the gap with the West.

It also helps explain why China's solar-R&D ecosystem has been structured the way it is—although, as is explained below, China is beginning to change that structure in a stated attempt to improve its innovative prowess. The ecosystem is arranged in a rigorously hierarchical fashion, with China's central government setting a research

[122] State Council of People's Republic of China. "The Mid- to Long-Term Plan for Science and Technology Development in China. 2006." (Content in Chinese). http://www.gov.cn/jrzg/2006-02/09/content_183787.htm

[123] Discussion with leading solar researcher at the Chinese Academy Sciences' Shanghai Institute of Microsystem and Information Technology, November 2014.

agenda that is carried out by a range of labs. And the ecosystem has, by central-government design, relied heavily on collaboration between scientists in China and leading solar researchers in the West. Only very recently, having cemented its dominance of global solar manufacturing, has China begun to establish itself as an R&D leader as well.

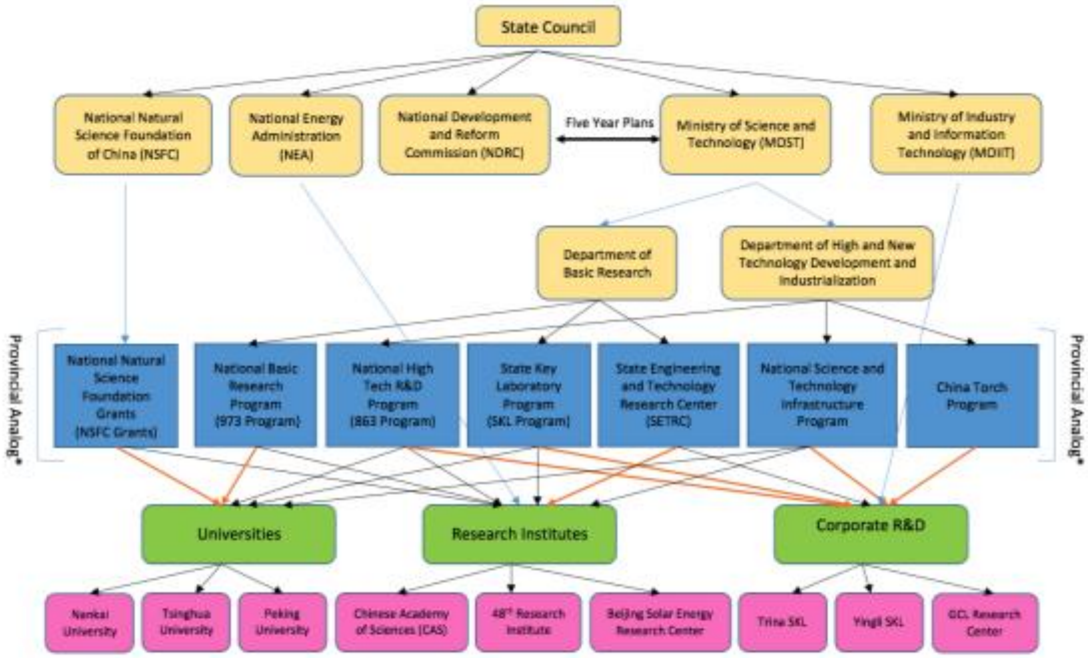
Figure 18 below charts China's solar R&D ecosystem. The figure draws from an extensive review of Chinese government documents, scholarly studies, and conversations with dozens of Chinese government officials, academics, and solar-industry executives. To the knowledge of the Stanford Steyer-Taylor Center for Energy Policy and Finance research team, it represents a newly comprehensive picture of the way that solar R&D in China is organized.

The diagram illustrates the way that different government, academic, and corporate entities interact in China to carry out R&D in a model that involves rigorous central planning. The figure is arranged thusly:

- Each yellow rectangle represents a central-government agency or department with direct impact on China's solar-R&D activities.
- Each blue rectangle represents a major central-government program that bears on solar R&D. (These programs have analogs on the provincial level; because of the large number of such provincial programs across China, this figure details only the central-government programs.)
- Each green rectangle represents a category of entity that receives central-government funding and uses that funding to carry out solar R&D.
- Each pink rectangle is an example of actual entities that receive such funding and carry out such R&D. These entities are listed here only as examples; there are dozens of entities that receive central-government solar-R&D funding in China.
- Arrows depict the most direct administrative and funding relationships between the entities and programs shown on the chart. Regarding the arrows between the blue and green rectangles, the orange arrows point to the primary type of funding recipients under a given program, and the black arrows point to secondary types of funding recipients under that program.

Following the diagram, the remainder of this section explains the players in China's solar-R&D ecosystem and traces the development of that ecosystem over the past roughly two decades through the evolution of the key central-government planning documents that frame the ecosystem: China's five-year plans.

Figure 18: China's Solar-R&D Ecosystem



Source: Stanford Steyer-Taylor Center for Energy Policy and Finance research

*Similar science and technology programs are available at the provincial level

4.4.1 Government Ministries

4.4.1.1: National Development and Reform Commission (NDRC)

The NDRC is in charge of drafting China's overarching national economic policies, including, crucially, its five-year plans. The five-year plans set top-level goals, including for technological R&D. The NDRC also oversees the National Energy Administration (NEA), the central government's chief energy-policy-making body. In solar, the NEA is in charge of deployment policy, notably the nation's feed-in tariff and its rules regarding the connection of solar arrays to the electrical grid.[124] The NEA also directly funds certain solar R&D, particularly that dealing with integrating solar energy into the grid.[125]

4.4.1.2: Ministry of Science and Technology (MOST)

China's science and technology policy-making body, the MOST, is the main architect of solar R&D in the country. It is in charge of setting a national vision for science-and-technology development, designing policies and strategies to promote the vision, and building—through funding—a framework to carry out the vision. The MOST codifies that vision in subordinate five-year-plans that it writes for individual technology areas, one of which is solar. And the MOST coordinates its financing and administrative efforts with other government agencies, introduced below.

The Chinese government announced in late 2014 that it was restructuring the MOST because of a widespread sense in China that the MOST has been inefficient in coordinating R&D across a broad suite of technologies—including solar.[126] The Chinese government called the previous technology-

[124] Yongxiu He, et al. "A Regulatory Policy to Promote Renewable Energy Consumption in China: Review and Future Evolutionary Path." Renewable Energy 89 (2016): 695-705.
[125] Sufang Zhang and Yongxiu He. "Analysis on the Development and Policy of Solar PV Power in China." Renewable and Sustainable Energy Reviews 21 (2013): 393-401.
[126] Discussion with Honghua Xu, senior solar scientist at the MOST

spending arrangement wasteful and inefficient, and it said its reorganization of innovation spending is designed to put its public dollars to better use.[127] [128] As part of the change, the MOST intends by 2017 to replace its two leading solar-research-spending programs—the 863 and 973 programs, which have been in place since 1986 and 1997 respectively and are explained in Sections 4.4.2.2 and 4.4.2.3—with five specialized programs. The new programs are intended to better shepherd technology across the cycle of technology development and commercialization, and to devote more money and effort to basic research.

More broadly, as part of the reforms the MOST is shifting to a more strategic and less tactical role. Rather than managing most research itself, it plans to restrict its involvement to planning the research and selecting outside entities to manage it. A key motive for this shift is concern on the part of Chinese government officials that the traditional system has created a conflict of interest in which advisers whose input the MOST solicited in helping decide whom to fund were themselves frequent applicants for MOST funding. Under the new system, the MOST intends to engage outside consultants who have expertise in a given technology but who, at least in theory, have no interest in recommending one grant applicant over another.[129] If this reorganization succeeds in making Chinese solar R&D more effective, it could have far-reaching implications for the global solar industry.

4.4.1.3: Ministry of Industry and Information Technology (MOIIT)

As China's industrial-policy-making body, the MOIIT seeks primarily to promote Chinese industry. The MOIIT has been closely involved in the development of China's solar policies, with an eye toward promoting R&D, manufacturing, and exports by China's solar industry. In particular, the MOIIT has been instrumental in guiding the consolidation of the Chinese solar industry, largely by issuing standards that China-based solar firms must meet in order to qualify for various sorts of industrial assistance, including loans from China's state-affiliated banks. Those standards have had the effect of weeding out smaller and less-competitive firms, as is explained in more detail in Section 4.7. These standards have been particularly focused on strengthening the Chinese solar industry in the wake of the tariffs imposed by the United States and the European Union—that is, on ensuring that the industry is headed by firms with balance sheets and global operations large enough to withstand the bite of those tariffs.[130] That was the rationale, for instance, behind the MOIIT's issuance in 2013 of China's Solar PV Manufacturing Industry Standards.[131] They set specific requirements for levels of corporate R&D spending, factory size, factory energy intensity, cell and module efficiency, and other metrics. The MOIIT also conducts periodic comprehensive studies of the Chinese solar industry; the studies are issued only in Chinese. Both the 2013 standards and the 2015 edition of the MOIIT's Chinese-industry study are discussed in detail later in *The New Solar System*.

[127] Ibid.; op. cit., National Science Foundation
[128] China Daily, "New Science and Technology Policy: From Segmented Organization to Systematic Planning," Oct. 22, 2014. http://scitech.people.com.cn/n/2014/1022/c1007-25882909.html
[129] Op. cit., Honghua Xu
[130] The tariffs are explained in Sections 1.5 and 5.3.1 and in Appendix B
[131] Op. cit., Ministry of Industry and Information Technology

4.4.1.4: Ministry of Finance (MOF)

Key to the MOST's promotion of solar R&D are a range of tax breaks and other subsidies distributed by China's central government. The MOF is the agent that administers those financial incentives. For example, in 2007, the MOF and two other central-government offices, the Administration of Customs (AOC) and the Administration of Taxation (AOT), exempted 13 categories of equipment used at Chinese scientific research institutes from import tax and import-related Value Added Tax (VAT) if the equipment was imported, and from domestic VAT if the equipment was bought from domestic Chinese producers. The exemptions lasted until the end of 2010.[132] In 2009, the government extended most of these exemptions to foreign research institutes conducting research in China.[133] [134] In 2011, the government further extended the VAT exemption until the end of 2015 for Chinese research institutes that purchase equipment from domestic suppliers.[135] [136]

Key to China's promotion of solar R&D are a range of tax breaks and other subsidies.

4.4.1.5: Ministry of Education (MOE)

The MOE oversees universities, which are important R&D actors. In the past, it also shared with the MOST the responsibility for overseeing those state key laboratories (SKLs) and state engineering and technology-research centers (SETRCs) that are based at universities. (The role of SKLs and SETRCs is explained in Section 4.4.2.4.) However, in one change that results from a broad reform in China's R&D system, in August 2015 the MOE lost its authority to choose and fund SKLs. Now, all SKLs are designated by and funded by the MOST, an effort by the Chinese government to streamline R&D spending and reduce redundancy.

4.4.2: Government Solar-R&D Programs

Government funding for solar R&D in China comes through a range of programs. The programs fund work at a variety of types of institutions, including universities, research institutes, and companies. Funding levels differ among the programs. In all of them, solar is just one of many targeted technologies. Some of the programs now are undergoing significant reform—the result, as explained in Sections 4.1 and 4.4.1.2, of a determination by the Chinese government that they have proven insufficiently effective. What follows is a description of the most important programs, ordered from those that fund basic research to those that fund applied research.

4.4.2.1: National Natural Science Foundation of China (NNSFC)

The NNSFC, much like the U.S. National Science Foundation, supports early-stage and novel research conducted in universities and research institutes. It is the one Chinese government program that funds solar research whose complete funding record is publicly available and thus lent itself to analysis. The NNSFC's public funding database is available back to 2000. NNSFC grants typically range between $75,000 and $100,000. Individual researchers are allowed to apply on their own for NNSFC grants versus other Chinese-government R&D funding programs that require

[132] Central Government of the People's Republic of China, "Temporary Rule on the Exemption of Import Tariffs for R&D Equipment." http://www.gov.cn/ziliao/flfg/2007-02/05/content_517808.htm (Content in Chinese:)

[133] One component of the tax breaks accorded Chinese research institutes was not accorded foreign research institutes in China, however: rebates on import-related VAT.

[134] China Ministry of Finance, http://www.chinatax.gov.cn/n8136506/n8136593/n8137537/n8138502/9309334.html (Content in Chinese)

[135] China Administration of Taxation, "Administrative Rules on Tax Returns for Research Institutes that Purchase Domestically-made Equipment," 2011. http://www.most.gov.cn/kjzc/gjkjzc/kjjryss/201308/P020130823579847815179.pdf

[136] There is no evidence in the Chinese regulatory record that this exemption was extended after it expired in 2015.

researchers to work in teams or with solar companies.

According to NNSFC data, in 2000, the NNSFC funded research regarding the two solar technologies that then were most prominent in the market: polysilicon and cadmium-telluride.[137] Starting in 2007, the NNSFC broadened the suite of solar technologies it funded. Since then, the NNSFC has invested in a wide portfolio of technologies, including polysilicon, monocrystalline silicon, and amorphous silicon; thin-film technologies including cadmium-telluride and CIGS; and emerging technologies including organic, perovskite, and dye-sensitized solar. Notably, since 2007, the majority of NNSFC solar funding has gone to organic, perovskite, and dye-sensitized solar research. That indicates a push by NNSFC into emerging technologies.[138]

4.4.2.2: National Basic Research (973) Program

The National Basic Research Program was designed to support large-scale basic-research projects: those that appear likely to significantly affect China's national economy. The program is known colloquially in China as the 973 Program—a reference to its launch date of March 1997, which, when written in Chinese fashion, with the year preceding the month, is 97-3. The program funded early research into amorphous-silicon technology between 2001 and 2005, and it funded research into high-efficiency "black silicon" between 2011 and 2015.[139]

4.4.2.3: National High Tech R&D (863) Program

The National High Tech R&D Program focuses on more-mature technologies. It is known colloquially as the 863 program, a reference, again, to the fact that it was created in March 1986, or 86-3. It was designed to fund projects judged likely to be commercialized if one or two remaining research problems could be solved. The 863 program got a significant boost during the Eleventh Five-Year Plan, which ran from 2006 through 2010, when MOST began officially to encourage companies to participate in the program. Research proposals that are jointly developed by private companies and academics receive priority in the grant-application process—a nod to the program's intent to move technologies from the laboratory to commercialization. Solar research funded through the 863 program includes work on developing and manufacturing HIT cells, designing and manufacturing PERC cells with efficiency greater than 20%, commercializing amorphous-silicon cells, and next-generation inkjet printing of solar cells.[140]

4.4.2.4: State Key Lab (SKL) and State Engineering and Technology Research Center (SETRC) programs

Through these programs, the MOST provides long-term funding for research institutions that have demonstrated strong capacity in certain science or engineering areas deemed important to the Chinese economy. The institutions may be located at universities, research institutes, or companies. The initial MOST funding term for an SKL or SETRC is typically five years, but recipients often are renewed for second or third terms. Funding under the SKL and SETRC programs often is used to build, equip, and operate a research institution, including

[137] China National Natural Science Foundation Internet-based Science Information System https://isisn.nsfc.gov.cn/egrantweb/ (Content in Chinese)
[138] Ibid.
[139] Black-silicon solar cells are similar to crystalline-silicon solar cells, but their surface is treated with special techniques to increase the cells' ability to absorb sunlight. After the treatment, the surface of the cell turns darker, hence the name black silicon.
[140] Data provided by Chinese Renewable Energy Industries Association, an industry group affiliated with China's central government, and through Stanford Steyer-Taylor Center for Energy Policy and Finance research.

paying for salaries. Institutions must re-apply for funding at the end of each five-year period.

China has two solar-related SKLs. The first is the State Key Laboratory of PV Science and Technology, located west of Shanghai in the Jiangsu Province city of Changzhou, at Trina's headquarters. The second is the State Key Laboratory of Photovoltaic Materials and Technology, located southwest of Beijing in the Hebei Province city of Baoding, at Yingli's headquarters. Trina and Yingli executives run their respective SKLs, and the companies, supported by the MOST SKL funding, employ the people who work in the labs.

China has three solar-related SETRCs. LDK is home to the State Photovoltaic Engineering and Technology Research Center. China Electronic Technology Group Corp., a state-owned firm, houses the State PV Tooling Engineering and Technology Research Center at the company's 48th Research Institute, an entity in the Hunan Province city of Changsha that has been key to the development of an indigenous Chinese solar-tooling industry. The Chinese Academy of Sciences' Material Structure Research Institute in Fujian houses the State Photo-Electronic Crystalline-Material Engineering and Technology Research Center.

In addition to these SKLs and SETRCs, various Chinese provinces, working in concert with the central government, operate their own key labs and engineering and technology research centers. Discussions with technology experts in China suggest that the quality of research at these provincial-level labs and research centers is lower than at the national entities.[141] According to the China Renewable Energy Industries Association (CREIA), a trade group that is closely affiliated with the central government, two provinces, Liaoning and Henan, have key labs focusing on solar, and there are six provincial-level engineering-and-technology-research centers, located in Jiangsu and Hubei provinces and in Beijing.[142]

The SKLs and SETRCs are crucial to China's technology-R&D effort, and they differ from the U.S. approach to solar R&D, in at least two respects.

A close relationship between the government and companies in China goes far beyond the one typical in the West.

First, they are built around a close cooperative relationship between the government and companies. That relationship goes far beyond the one that typically prevails in the West, in which, in simple terms, a government provides grants, often on a competitive basis, for certain corporate R&D and then receives reports about the progress of that research that are often made public. In the case of China's key labs and technology-research centers, the government and company work closely together to shape the underlying goals of the research. Moreover, the lab itself is located at the company's headquarters and staffed by company employees. Although the government typically funds each key facility for an initial period of five years, the significant investment that both the government and the company have made in the facility and its operations means that both sides hope and expect that the funding will be renewed repeatedly into the future. Both parties understand that the research is intended to accomplish objectives seen not just as nationally relevant but as nationally crucial. The results of the research are communicated in reports to the government; in meetings among Chinese government officials, business executives, and scientists; and in scientific conferences both in China and abroad. China's state key facilities amount to the scientific proving grounds for the country's industrial policies.

Second, China's state key labs and engineering-research centers are focused squarely on applied

[141] Op. cit., Honghua Xu; discussion with solar scientist at Chinese Academy of Sciences' Electrical Engineering Institute.
[142] Op. cit., Chinese Renewable Energy Industries Association and Stanford Steyer-Taylor Center for Energy Policy and Finance research

rather than basic research. Consistent with their roles as enablers of China's industrial policies, the scientists who work in the key facilities focus on research likely to yield products in a relatively short period of time. In solar, this explains why China's state key facilities focus more on iterating improvements in today's commoditized silicon-based technology than on blazing new trails in emerging technologies that are likely to take many years or decades to commercialize. More particularly, it explains the string of improvements in silicon-cell efficiencies that, as explained in Sections 4.1 and 4.2.1.1, have been announced over the past two years by Trina's state key lab. This contrasts with the situation in the United States, in which the relationship between government R&D funders and any one company is more attenuated and in which government-funded research typically focuses on technology at the pre-competitive stage.

4.4.2.5: National Science and Technology Infrastructure Program

This program funds work to industrialize and commercialize technologies. Within the solar industry, manufacturers of tooling are particularly common recipients of funding under this program. For example, China Silicon Corp., which both processes silicon and makes the equipment that it uses to do so, received funding under this program for five silicon-equipment-development projects.

4.4.2.6: China Torch Program

This program supports ancillary activities that contribute to the industrialization of solar projects. It funds such things as industrial parks and solar-product quality testing. It appears to be little valued by China's companies, largely because the sums it provides are small.

4.4.2.7: Thousand-Talent Program

Through the Thousand-Talent Program, more than 20 central-government agencies seek to recruit to China research experts from around the world, attracting them with a variety of financial perks. Launched in 2008, the program had, through mid-2014, recruited to China 4,180 research experts from abroad. Most of them had grown up in China and then left to be trained overseas before being attracted back.[143]

The program provides the experts it recruits with a job at a Chinese research institute or company, an annual salary generally in the range of ¥1 million ($145,043) to ¥5 million ($725,217), a research budget, and administrative support. Those recruited under the Thousand-Talent Program usually receive, on top of this central-government package, local support that typically includes free or subsidized housing and additional research funding.

Initially, the program recruited mostly senior scholars and placed them in R&D positions at Chinese universities and research institutes. But many of those people ended up living in China only part-time, maintaining ties to their overseas institutions and declining to move permanently back to China because they wanted their spouses and children to continue to work and go to school in the countries where they had been living.

Since 2012, the program has shifted to focus to younger researchers who are earlier in their careers and thus are more open to moving their families permanently back to China. Among that cohort, the program targets people who own intellectual property bearing on certain technologies and are looking to start businesses based on those technologies.

The development of R&D in China on several solar technologies has depended deeply on collaboration between researchers in China and those abroad. Because the people recruited to China under the Thousand-Talent Program tend to be fluent in English and to have established

[143] Data collected by the Thousand-Talent Program. Data communicated in May 2015 discussion with government officials who oversee the Thousand-Talent Program.

networks with researchers around the world, they have proven instrumental in building these R&D ties between China and other parts of the world.

Among the prominent solar leaders recruited back to China under the Thousand-Talent Program are Zhengxin Liu, China's leading expert in HIT solar cells, whose work is explained above in Section 4.2.1.2; Xudong Xiao, who received his doctoral degree at the University of California, Berkeley, who is leading the CIGS research at the Chinese Academy of Sciences' Shenzhen Institutes of Advanced Technology, and whose work is explained above in Section 4.2.2.1; and Deliang Wang, who received his doctoral degree from Goettingen University in Germany is a prominent figure in cadmium-telluride research.

Solar R&D in China has depended on collaboration between researchers in China and those abroad.

4.5: Solar in China's Five-Year Plans

Modern China is a rigorously planned economy. Every five years, the government lays out its economic intentions for the country in a massive document known as a five-year plan. For industries or technologies that the government believes are particularly important, it fleshes out the vision in the main five-year plan with more-granular sector-specific five-year plans. China's five-year plans are only guides to the economy; in practice, things often work out differently than the government had intended. Yet these documents are crucial windows into the government's economic strategy, and in the case of solar, as in other industries, scientists and investors alike report exploiting the five-year-plan system in two mutually reinforcing ways. First, they try to influence the government, as it is writing a new five-year plan, to promote their favored technology. Second, when a new five-year plan is published, they use it as a guide, putting their research focus and investment capital into the areas that the plan makes clear the government will most heavily support.

Solar in particular, and renewable energy more broadly, first became a focus in a Chinese five-year plan in 2001. The succession of four five-year plans since then—the Tenth Five-Year Plan from 2001-2005; the Eleventh Five-Year Plan from 2006-2010; the Twelfth Five-Year Plan from 2011-2015; and the Thirteenth Five Year Plan, which starts this year and runs through 2020—have guided the Chinese economy to advance solar from an entirely export-focused manufacturing sector based on technology developed abroad to a more-sophisticated enterprise whose every activity—from R&D, to the manufacture of the full gamut of solar components, to extensive solar-project deployment—takes place on Chinese soil. The Thirteenth Five-Year Plan is particularly ambitious in terms of solar R&D; it enunciates a fundamental restructuring of China's technology-innovation structure, and it articulates ambitious goals for the efficiency of Chinese-made solar cells.[144] What follows is a detailed description of how China's solar strategy has evolved between the Tenth Five-Year Plan, issued in 2001, before China had much of a solar industry, and the Thirteenth Five-Year Plan, which launched this year, with China indisputably dominating the global solar industry.

4.5.1: Tenth Five-Year Plan (2001-2005)

This was the era in which China first articulated plans to ramp up a renewable-energy industry. At the start of this five-year period, China had essentially no domestic solar industry, and the global industry itself was tiny. In a document called the Tenth Five-Year Plan for New- and Renewable-Energy-Industry Development, China's State Economic and Trade Commission, the predecessor of the country's current economic-planning agency, the NDRC, laid out a vision to industrialize

[144] China National Energy Administration. 2015. Thirteenth Five Year Plan for Solar Energy Utilization (Draft) http://www.nandudu.com/article/17744

renewable-energy industries by building in China economies of scale.

The plan treated solar as an industry first and a research area second—in many ways the opposite of the U.S. federal government's approach. It called for China to scale up solar-cell and -module production, and in so doing to develop a robust solar supply chain. Specifically, it targeted 15 megawatts of annual solar-cell-manufacturing capacity, and a fully developed solar supply chain, in China by 2005. It mentioned the need for technological innovation as a way to make a Chinese solar industry competitive, but it provided no substantial details about solar R&D, merely calling on industry to collaborate with universities to produce solar-technology advances that it could then commercialize.[145]

The plan treated solar as an industry first and as research second—in many ways the opposite of the U.S. approach.

History proved the plan far too tame. By 2005, China's solar-cell-manufacturing capacity was 500 megawatts, 33 times the Tenth Five-Year Plan's goal.

4.5.2: Eleventh Five-Year Plan (2006-2010)

Written at a time when China's solar-manufacturing industry was growing massively faster than the government had anticipated, the Eleventh Five-Year Plan put an increased emphasis on augmenting factory production with better R&D and more-extensive solar deployment within China. The plan acknowledged the rapid growth of solar manufacturing and the lackluster progress of Chinese solar R&D. It proposed more effort to solve technical issues such as how to produce high-purity polysilicon, a key ingredient in solar cells, and how to more seamlessly connect large solar farms to the country's electrical grid.

The Eleventh Five-Year Plan discussed solar not just as an energy source but as an opportunity for technological leadership, listing it alongside areas such as aerospace, biotechnology, and information technology. It called for more R&D in China on polysilicon material production, high-efficiency solar and its application in large-scale electricity generation, and solar cells that are built into the cladding of buildings—a technology known as building-integrated PV (BIPV).

The plan emphasized the need for China to develop a stronger solar-manufacturing supply chain. It identified, as mentioned in Section 4.1, what it called "bottleneck" issues: the country's inability to manufacture at home a range of key materials and equipment needed for solar-cell and -module manufacturing. Among them: high-purity polysilicon; the back sheet of a solar module; EVA; silver paste (the conductive material that ferries the electricity that a solar cell generates from the silicon wafer itself to the wires that will take the power into the electrical grid); and fully automated versions of screen-printing machines (the devices that engrave on a silicon solar cell the channels through which the electricity they produce will travel). More importantly, having stipulated in the five-year plan that these areas were bottlenecks, the Chinese government began funding R&D projects to address them.

The growth of China's solar industry during the period of the Eleventh Five-Year Plan was extraordinary. The country's solar-module manufacturing capacity skyrocketed more than 17 times, from 500 megawatts in 2005 to 8,700 megawatts in 2010.[146] Seven China-based solar-module makers went public during these years. China-based manufacturers were, by the end of

[145] State Council of People's Republic of China, "Tenth Five-Year Plan's New Energy and Renewable Energy Industries Development Plan," 2001. http://edu.mayortraining.org/WebSite/leader/Upload/File/201202/20120210101829917125.pdf

[146] China National Energy Administration, "Twelfth Five-Year Plan's Special Plan for Solar Electricity Generation Technology Development," 2012. This was a solar-specific plan accompanying the general Twelfth Five-Year Plan. http://182.92.181.100/uploadfile/2014/1016/20141016015752531.pdf

the Eleventh Five-Year Plan period in 2010, supplying more than one-third of all solar modules sold globally.[147]

Also during these years, China significantly bolstered its domestic solar-manufacturing supply chain. Whereas in 2005 China produced at home only 10% of the polysilicon it needed for solar production, by 2010 that portion had risen to 50%—a higher portion of a vastly larger market.[148] Similarly, whereas in 2005 China-based solar manufacturers bought essentially all of their tooling from abroad, by 2010 they were buying the majority of it at home.

4.5.3: Twelfth Five-Year Plan (2011-2015)

China's Twelfth Five-Year Plan, which governed the period from 2011 to 2015, pushed forward the country's goals of improving domestic solar R&D, supply-chain production, and project deployment. In greater detail than any previous five-year plan, and as reflected below in Table 3, it articulated specific R&D goals across the entire solar value chain, from materials, to cells and modules, to systems, to the tooling used in manufacturing. The plan also laid out ambitious deployment goals. It targeted 21,000 megawatts of cumulative solar deployment—including 10,000 megawatts of distributed solar—in China by 2015.

[147] Ibid.
[148] Ibid.

Table 3: Twelfth-Five-Year Plan's Solar-Innovation Goals for Full Value Chain

Focus Area	Innovation Topics	Innovation Goals
Materials	New high-efficiency, low-emission ways to mass produce polysilicon	Improve the "modified Siemens process" for mass, low-cost, clean production of silicon; achieve mass production using the silene method; explore new low-cost production methods.
	Auxiliary materials used in solar-module production	Master the techniques to produce the following materials: silver paste; aluminum paste; TPT back-sheet material; EVA; and TOC glass substrate for thin-film
Cell and Module	Cell-efficiency improvement and/or pilot-line production for seven types of solar-cell technologies and concentrated solar power (CPV)	(See subsequent table, on Twelfth Five-Year Plan)
System	Grid integration of utility-scale solar	Master power-station designs and grid-integration techniques required for 100-megawatt solar-plant grid integration
	Microgrid with solar	Master techniques related to microgrid stability and quality-control system
	High-voltage inverter for microgrid	Master the design and production of self-controlled synchronous voltage-source inverter and its application in microgrid operation
	10-megawatt level CPV	
	Large scale solar power grid integration with other renewable sources	Master system design and operation techniques required in grid integration of large-scale multi-renewable-energy sources
	Silicon-based building-integrated solar	Build a BIPV module-production industry and its tooling supply chain
	Distributed CPV	Master 100-kilowatt distributed concentrated solar power technologies and the power-electronic technologies required to operate the system
	Solar thermal storage	Improve thermal storage materials; master thermal-energy transmission and distribution technologies
Tooling	Required in all of the above areas	(See subsequent table, on Twelfth Five-Year Plan)

Source: Twelfth Five-Year Plan's Special Plan for Solar Electricity Generation Technology Development, a solar-specific plan accompanying the general Twelfth Five-Year Plan.

In addition, for the whole gamut of solar technologies, from silicon-based to thin-film to emerging technologies to concentrated solar, the Twelfth Five-Year Plan laid out specific goals both for cell efficiency and for pilot-line production. Not content to goad the creation of prototype solar cells, China's government also pressed companies and government-affiliated solar-research institutions to figure out how to begin scaling up production of those cells. Furthermore, for a few technologies—cadmium-telluride, amorphous-silicon, and tandem cells—the Twelfth Five-Year Plan specified production-cost targets. This emphasis on manufacturability, detailed in the following table, was and is a key feature of China's solar-R&D strategy. Even recognizing the fundamental differences between the way the Chinese and U.S. governments approach and carry out R&D, the Chinese emphasis on the manufacturability of technologies such as solar is worth studying as the United States mulls how to improve the economic effectiveness of its own R&D. This idea is explored in Section 7.3.2.

Table 4: Twelfth Five-Year Plan's Solar-Innovation Goals for Cells and Modules

Technology	Innovation Goals	Commercialization Goals
Monocrystalline silicon	19% and above average commercial efficiency	Domestic supply of key tooling equipment; 100-megawatt production capacity of high-efficiency silicon solar
Multicrystalline silicon	20% and above average commercial efficiency	
CIGS	Master key CIGS tooling design and manufacturing techniques; electrochemical deposition method	5-megawatt roll-to-roll flexible substrate CIGS production line; flexible-substrate CIGS pilot production line of at least 1-megawatt capacity
Cadmium Telluride (CdTe)	10% and above average commercial efficiency; 100% self-designed and self-produced tooling for 30-megawatt production line	30-megawatt CdTe production line; CdTe turnkey solutions; ¥5/watt ($0.73/watt) or lower production cost
Amorphous silicon	10% and above average commercial efficiency; 100% self-designed and self-produced tooling for 40-megawatt production line	1-megawatt roll-to-roll flexible subtracted a-Si pilot production line; 40-megawatt production line; turnkey solutions; ¥5/watt ($0.73/watt) production cost or lower
Dye-sensitized (DSSC)	8% and above average commercial efficiency; master materials and tooling required in mass production	5-megawatt level production line
Heterojunction with intrinsic thin layer (HIT)	18.5% pilot-line efficiency	2-megawatt pilot production line
Amorphous-silicon/crystalline-silicon tandem solar cell	8% and above average commercial efficiency; a-Si materials; tooling for mass production	50-megawatt production line; ¥5/watt ($0.73/watt) or lower production cost
Gallium-indium-phosphide/Gallium-indium-arsenide/Germanium multijunction cell	Master multi-junction cell design and production techniques	5-megawatt pilot production line
Concentrated solar PV (CPV)	35% commercial efficiency; master CPV power-plant control system and inverter design	5-megawatt capacity pilot production line

Source: Twelfth Five-Year Plan's Special Plan for Solar Electricity Generation Technology Development, a solar-specific plan accompanying the general Twelfth Five-Year Plan.

4.5.4: Thirteenth Five-Year Plan (2016-2020)

China's Thirteenth Five-Year Plan names solar as one of several renewable-energy technologies that the government will prioritize through 2020. Others include wind, biomass, geothermal, and ocean energy. The plan sets out ambitious capacity-expansion, cost-reduction, and R&D goals for solar in the country. It implements a general restructuring of the country's fundamental approach to technology R&D—including solar R&D—seeking both to bolster basic research and to funnel the results of innovation into large-scale commercialization. In the case of solar, that restructuring reflects disappointment on the part of top Chinese officials that, although the country has attempted to produce steadily more innovation throughout the past 15 years, it has failed so far to distinguish itself as a leader in breakthrough innovation.

China seeks large-scale production of "advanced crystalline-silicon" solar cells with efficiencies of at least 23% by 2020.

In addition to the overarching five-year-plans, the Chinese government issues a variety of more-detailed five-year-plans for specific sectors and industries**.** A final version of the Thirteenth Five Year Plan that focuses on solar, called the Thirteenth Five Year Plan for Solar Energy Development, was issued by China's National Energy Administration in December 2016. Among other objectives, it lays out China's goal of achieving large-scale commercial production of "advanced crystalline-silicon" solar cells with efficiencies of at least 23% by 2020.[149] [150] That would represent a significant efficiency increase from today.

To understand the challenge in reaching that goal, consider the record that won Trina placement on the NREL world-record chart: an efficiency of 21.3% for a multicrystalline silicon cell. What is important to appreciate is that Trina's record is for a laboratory version of the cell. Turning a laboratory cell into a commercialized cell, and then into a solar module, is no small feat. Among solar manufacturers based in China as among those based in the United States and around the world, that commercialization process involves a reduction in efficiency. The modules that Trina sells using multicrystalline-silicon solar cells, for instance, are rated at a maximum efficiency of between 16.2% and 16.8%.[151]

According to the Thirteenth Five-Year Plan, China will pursue technological R&D through five overarching programs. The five are listed below, roughly in order from basic to applied R&D, although it is important to reiterate that one of China's goals in this restructuring is to organize technology R&D more by scientific topic and less by technology stage.

- The National Natural Science Foundation of China, explained in Section 4.4.2.1, will remain essentially unchanged.
- China's main technology-R&D programs—including the 973, 863, and China Torch programs, explained in Sections 4.4.2.2, 4.4.2.3, and 4.4.2.6, respectively—will be folded into a new mega-R&D basket called, collectively, the National Key Research and Development Projects. Procedurally, its goal is to integrate the variety of R&D programs administered by the MOST. Substantively, it seeks to integrate the entire technology-development continuum, from basic research all the way to deployment.
- In a deeper effort to fix what China has identified as its "bottleneck" problems—in solar, as explained in Sections 4.1 and

[149] China National Energy Administration, "Thirteenth Five Year Plan for Solar Energy Development," December 2016. http://zfxxgk.nea.gov.cn/auto87/201612/t20161216_2358.htm
[150] A December 2015 draft of this document—a draft called the Thirteenth Five Year Plan for Solar Energy Utilization—cites a 23% efficiency goal for "monocrystalline silicon" cells. But the December 2016 final plan pegs the goal to "advanced crystalline-silicon" cells.
[151] Trina Solar webpage. http://www.trinasolar.com/us/product/index.htmlhttp://www.trinasolar.com/us/product/index.html http://www.trinasolar.com/us/product/index.html

4.5.2, the ability to produce key materials, components, and tooling that it still mostly imports—the government is launching what it calls the National Key Science and Technology Special Program. The program is designed to restructure the way that China funds R&D into these high-priority objectives. Traditionally, China has organized this R&D funding by technology stages, with different government offices focusing their grants on specific stages of development. But the government has concluded that that stage-based arrangement is suboptimal because it has failed to advance some of these high-priority bottleneck technologies from one stage to another. As a result, with the National Key Science and Technology Special Program, the government will organize funding by technology type rather than by technology stage.

- The Technology-Innovation Guiding Program will provide money to companies, especially small and medium-sized ones, to help them commercialize novel technologies. This marks a continuation of China's attempt in recent years to shift money from universities, which historically received the bulk of Chinese-government R&D grants, to companies, on the theory that companies are better equipped to commercialize technologies for the benefit of the Chinese economy.
- China is attempting to produce truly world-class research facilities, and to attract more of the world's best researchers, through a new effort called the Innovation Base and Talent Program. The goal is to create what amount to technology-innovation hubs in various parts of China—hubs centered on an existing or to-be-built scientific research institute.

4.5.4.1: Capacity Increases and Cost Cuts

The Thirteenth Five Year Plan for Solar Energy Development was issued in December 2016, as noted in Section 4.5.4. The plan stipulates that, by 2020, China should have 110,000 megawatts of solar capacity installed in the country. It says the vast majority of that total, 105,000 megawatts, should be solar photovoltaic, and that a much smaller slice, 5,000 megawatts, should be solar thermal.

A draft version of the plan, which was issued in December 2015, articulated a more-ambitious solar-deployment goal for 2020. It sought by that year 160,000 megawatts of installed solar capacity in China, of which 150,000 megawatts would be solar photovoltaic and 10,000 megawatts would be solar thermal.[152]

Although China reduced its official solar-deployment goal between the December 2015 draft and the December 2016 final plan, Zhipeng Liang, deputy director-general of the Chinese National Energy Administration's department of new and renewable energy, said he believes China still will reach 150,000 megawatts of installed solar photovoltaic by 2020.[153] That amounts to approximately half of all the solar capacity estimated to have been deployed globally as of the end of 2016.[154]

The Thirteenth Five Year Plan for Solar Energy Development also sheds light on the country's intent to cut solar's costs. It says that, by 2020, the cost of solar-power generation should fall by half from its 2015 level. Beyond that, the document does not enumerate specific cost targets. But Mr. Liang estimated that solar-generation costs in parts of China with the best solar resources,

[152] The December 2015 draft of the solar plan said that, by 2020, solar power should account for 7% of China's total electric-generating capacity and 2.5% of its electricity generation. The December 2016 final version of the document lacks these percentage targets.

[153] Conversation with Zhipeng Liang, deputy director general of the China National Energy Administration's department of new and renewable energy

[154] Joshua S. Hill, "Global Solar Installations To Reach 76 GW In 2016, According To Mercom," CleanTechnica, Nov. 30, 2016. https://cleantechnica.com/2016/11/30/global-solar-installations-reach-76-gw-2016-mercom/

particularly the western region of the country, should fall from approximately ¥0.8 ($0.12) per kilowatt-hour in 2015 to ¥0.4 ($0.06) per kilowatt-hour in 2020, and that solar-generation costs in parts of China with less-advantageous solar resources, particularly in the country's highly populated East, should fall from approximately ¥1 ($0.15) per kilowatt-hour in 2015 to approximately ¥0.6 ($0.09) per kilowatt-hour in 2020.[155]

4.5.4.2: R&D Gains

As noted in Section 4.5.4, China's Thirteenth Five Year Plan for Solar Energy Development sets the goal of achieving large-scale commercial production of "advanced crystalline" solar cells with efficiencies of at least 23% by 2020. In addition, the plan specifies certain solar technologies to which the Chinese government will, through 2020, give preferential support. They include PERC solar cells, n-type monocrystalline solar cells, next-generation thin-film solar technologies, and the commercialization of these of solar products, including the domestic production of materials and tooling needed to mass-produce them in China.[156]

Further insight into China's solar-R&D agenda through 2020 comes from two other sources. One is the December 2015 draft version of the solar plan. The other is a presentation given a year before even that draft was released—a November 2014 presentation at a Beijing conference by Honghua Xu, chief solar scientist for China's Ministry of Science and Technology. Providing context for the draft solar plan that then was in development, the conference presentation categorized China's solar-R&D priorities into six general areas: high-efficiency and low-cost silicon-based solar cells, thin-film solar cells, new and emerging solar cells, grid integration of large-scale solar plants, grid integration of distributed solar, and solar-system testing. The research agenda articulated in the December 2015 draft and the November 2014 presentation is detailed in Table 5 below.

[155] Op. cit., Zhipeng Liang

[156] Op. cit., Thirteenth Five Year Plan for Solar Energy Development

Table 5: Thirteenth Five-Year Plan's Expected Solar-Innovation Goals

Technology	Innovation Goals
Monocrystalline silicon	Commercialized cells with efficiency of at least 23%
Multicrystalline silicon	Commercialized cells with efficiency of at least 20%
Thin-film	Commercialize various emerging thin-film technologies
Solar production equipment and materials	Ability to domestically produce equipment needed to manufacture high-efficiency solar cells; improvements in production equipment through automation and other techniques. 90% of equipment used by commercial solar-product manufacturers in China is made in China
Solar grid-integration and energy-storage technologies	Overcome technical barriers for: grid integration of large-scale solar and distributed-solar systems; solar-connected smart grids and microgrids; and balance-of-system
Solar-cell and -system testing and efficiency verification	For example, test, to improve, solar-system performance at high elevations

Source: Thirteenth Five Year Plan for Solar Energy Utilization (Draft Plan Soliciting Comments), December 2015; presentation by Honghua Xu, chief solar scientist for China's Ministry of Science and Technology, in Beijing, at the 14th China Photovoltaic Conference, November 2014; "Six Innovation Topics for Solar PV in the 13th Five-Year Plan," (Content in Chinese), Information, April 2016 http://news.ttjkrb.com/cjdyfsdyy/1760.html

4.6: R&D Spending

China is far more opaque about its level of spending on solar R&D than are most countries active in solar research. In one indication of that opacity, a 2015 assessment by the International Energy Agency's Photovoltaic Power Systems (IEA PVPS) Program of government spending on solar R&D in most major economies lists no spending figures for China.[157] [158] [159]

China is more opaque than most countries about its spending on solar R&D.

According to the report, whose findings are detailed in Section 4.6.3, the United States spends far more public dollars on solar R&D than any other country: $439 million in 2014, the latest year for which the IEA PVPS report lists statistics that are comparable across countries.[160] The second-highest-spending country, Korea, spent less than half as much as the United States: $202.4 million. Japan and Germany, both of which are widely regarded as international solar-R&D leaders, spent

[157] The IEA PVPS program is one of the foremost aggregators of information about the global solar industry.

[158] International Energy Agency, 2015, "Trends 2015 in Photovoltaic Applications, Survey Report of Selected IEA Countries between 1992 and 2014." http://www.iea-pvps.org/fileadmin/dam/public/report/national/IEA-PVPS_-_Trends_2015_-_MedRes.pdf

[159] A country-specific report by Chinese researchers—the report on which the IEA PVPS report bases its China-solar-R&D assessment—also lists no spending figures for China.

[160] See Section 4.6.3 below for a more-detailed discussion of U.S. federal solar-R&D spending, including U.S. spending numbers for 2015.

significantly less: $97.2 million and $54.7 million, respectively.[161] [162]

4.6.1: Chinese Central-Government Solar-R&D Funding

4.6.1.1: Overview

The New Solar System goes beyond previous analyses in detailing some of the Chinese government's solar-R&D spending. This detail, reflected in Table 6 below, is based on extensive reviews of publicly available documents and on interviews with dozens of informed people in China. But it is crucial to emphasize that the report nevertheless remains significantly incomplete, a function of the difficulty of obtaining accurate data on Chinese solar-R&D spending. It underestimates—almost certainly by a large amount—China's solar-R&D spending. The sub-categories of spending that it quantifies cover varying time periods, further complicating efforts to tease overarching trends from the data. However, people in China who are deeply involved in solar R&D said that, because the solar R&D effort is so fragmented in China, the Chinese central government itself may not know the total amount of public money being spent on solar R&D.

This weakness in the data points up an important priority: Particularly given China's participation in the global push for more international clean-energy R&D cooperation—a push exemplified by the December 2015 Mission Innovation announcement, explained in Section 7.3.1—China should release fuller and clearer data about its solar-R&D spending.

Even assuming the total amount of solar R&D spending by China's national and provincial governments is significantly larger than the amount *The New Solar System* is able to quantify, it almost certainly is smaller than what the U.S. government is spending.[163] However, R&D costs less in China than in the United States—largely because wages, including for researchers, are lower in China. So, even if total solar-R&D spending in China is lower than total R&D spending in the United States, the gap between the two countries' actual solar-R&D effort almost certainly is not as great as the gap between their solar-R&D spending.

This is not to suggest that the United States should pull back on its solar-research effort. Solar is hardly the only example of a sector in which the United States developed the initial technology and then saw other countries ramp up their R&D in an effort to surge ahead. Semiconductors are another example, as explained in Section 7.4.1.2. But now—explained throughout *The New Solar System*—is a critical time for the future of solar power and of the United States' role in this burgeoning industry. Maintaining, and indeed increasing, U.S. solar R&D will be crucial to continuing the cost reductions and rapid deployment that have led more and more mainstream observers to predict that solar will become a significant energy source globally. Moreover, a robust U.S. solar-R&D effort will be crucial to ensuring that the United States derives meaningful economic benefit from solar's growth.

Maintaining, and indeed increasing, U.S. solar R&D will be crucial.

The New Solar System identifies several buckets of solar-R&D spending in China. It found $74 million in solar-R&D spending between 2000 and 2015 by governments in China at both the central and

[161] Op. cit, International Energy Agency.

[162] Of the 17 countries whose solar-R&D strategy is addressed in the IEA PVPS Program, four provided no information on the amount of money they spend on solar R&D: China, Malaysia, Switzerland, and Thailand.

[163] Informed officials in China, including those close to MOST and in the Chinese solar industry, said they are convinced that total government and corporate spending on solar R&D in China remains significantly smaller than in the United States. This was a consensus among Chinese government officials, Chinese solar-manufacturer executives, and Chinese solar scientists who attended workshops in Beijing in summer 2015 that the Stanford Steyer-Taylor Center for Energy Policy and Finance team held as part of this research. And this conclusion would be consistent with the message from the IEA PVPS Program report that the United States is by far the world's largest spender on solar R&D.

provincial levels. It found another $223 million in solar R&D spending from a mixture of government and corporate sources spanning roughly the decade between 2005 and 2015; the data was not sufficiently detailed to parse how much came from each source.[164]

It is important to note, as is explained in Section 4.6.4 below, that both of these figures pale beside the $1.44 billion that, according to Bloomberg data, China's top-tier solar manufacturers reported in their financial filings having spent on R&D between 2006 and 2015. Large China-based solar manufacturers are increasing their spending on R&D, but the largest U.S.-based solar companies still spend far more on solar R&D than China-based firms do.

Table 6: Traceable Examples of Public and Private Solar-R&D Spending in China*

Program	Spending
NNSFC (complete; only government spending; 2001-2014)	$26 million
973+863 (incomplete; only government spending; 2001-2015)	$48 million
SKL & SETRC (incomplete; government and corporate spending; 2009-2015)[165]	$190 million[166]
Provincial Key Lab & Provincial ETRC (incomplete; government and corporate spending; 2005-2014)	$33 million[167]
China-based top-tier solar companies (complete, corporate spending; 2006-2015)[168]	$1.44 billion

Source: NNSFC database; government ministries; government-grant recipients; BNEF; press releases; news coverage; Chinese Renewable Energy Industries Association, an industry group affiliated with China's central government

*: As explained above, this table is significantly incomplete. It includes only those amounts of public and private solar-R&D spending in China that the Stanford Steyer-Taylor Center for Energy Policy and Finance research team was able to verify. It almost certainly underestimates by a large amount the total sum of solar-R&D spending in China.

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164 Discussions with corporate executives and government officials suggest the majority of that $223 million came from companies rather than from government sources.

165 Includes information only on Yingli's SKL, approved by the government in 2010, and on LDK's SETRC, approved by the government in 2009. Information on spending on Trina's SKL and on the two other SETRCs—one at the 48th Research Institute and on at the Chinese Academy of Sciences' Institute of Material Structures—was unavailable.

166 These figures include both (1) direct cash expenditures by the government and companies and (2) the declared value of certain solar-R&D assets used by the companies.

167 These figures consist entirely of the declared value of certain solar-R&D assets used by the companies. This financial data was available only for the university-based PKLs in Liaoning and Henan provinces and for the Trina PETRC. Information on spending at other PKLs and PETRCs was unavailable.

168 Includes R&D spending by China's nine largest solar manufacturers—those listed Section 4.6.4 in Table 10. Spending goes back only to 2006 because 2006 was when the first Chinese solar company went public. The $1.44 billion may include some of the same corporate dollars that are included in the $190 million and the $33 million noted elsewhere in Table 6. Publicly available information does not make it possible to determine whether the corporate spending embodied in the $190 million and $33 million is some of the same spending embodied in the $1.44 billion.

4.6.1.2: National Natural Science Foundation of China (NNSFC)

A persuasive indicator of the gap in information about Chinese solar-R&D spending is the one Chinese-government solar-R&D funding program whose complete funding information is publicly available: the NNSFC. According to its database, the NNSFC spent just $26 million between 2000 and 2015 on solar-related R&D. By comparison, the U.S. National Science Foundation, the U.S. entity whose funding similarly focuses on basic research, spent $27.7 million on solar R&D in 2015 alone, according to figures gathered by researchers at the U.S. National Renewable Energy Laboratory and U.S. Department of Energy and detailed in Section 4.6.3.[169] Beyond this sum, the NSF spends significant money on R&D into other areas that bear indirectly on solar—areas such as materials science.

4.6.1.3: 973 and 863 programs

Particularly difficult to quantify is the Chinese government's spending on solar R&D through its 973 and 863 programs. Data on these programs' spending prior to the Twelfth Five-Year Plan was particularly lacking. *The New Solar System* quantifies a total of $48 million in combined spending by these two programs from 2000 to 2015. Roughly half—$23.2 million—of that amount came during the Twelfth Five-Year Plan. It is unclear whether that accurately points to a rise in spending over the years or whether it reflects particularly incomplete data for earlier years. Despite this uncertainty, analysis of public records and discussions with informed officials in China illuminate the following characteristics of solar-R&D spending by these two programs:

- Typical 973 grants range from about ¥20 million ($2.9 million) to ¥30 million ($4.4 million). They usually cover three to five years of research.
- For the 863 Program, a small-scale project usually receives between about ¥1 million ($145,043) and ¥3 million ($435,130); a "key" project receives about ¥20 million ($2.9 million) to ¥50 million ($7.3 million); and a "crucial" project receives about ¥50 million ($7.3 million) to ¥150 million ($21.8 million).
- The MOST attempts through these two programs to set up innovation networks covering the full range of major solar technologies prioritized in the five-year plans. That range includes conventional silicon-based solar, multi-junction solar, HIT, CIGS, cadmium-telluride, amorphous silicon, and perovskite. The MOST also funds work through these two programs on improving China's ability to manufacture at home certain products that it has identified as necessary to fill out the country's solar-manufacturing supply chain. Among them: silver and aluminum paste, back sheet, EVA, and tooling to make cells and modules.

4.6.1.4: State Key Labs and State Engineering and Technology Research Centers

A crucial part of China's solar-R&D effort are its state key labs and state engineering and technology research centers, which are described in Sections 4.4.2.4 and 5.4.2. Each of these labs is a joint initiative between the Chinese government and the company that hosts the lab. "Hosting," in this context, means that the company locates the lab on its property and that the people who work in the lab are employees of the company. Funding for these facilities too comes both from the government and from the company hosting the facility.

Data on funding for these state key research facilities is extremely difficult to find. The MOST publishes a list of state key labs but does not detail the labs' funding. As shown in Table 7 below, the Stanford Steyer-Taylor Center for Energy Policy and Finance research team was able to find funding data on only one of the two state key labs

[169] David Feldman; Daniel Boff; Robert Margolis. Unpublished spreadsheets quantifying U.S.-solar-R&D spending that these U.S. National Renewable Energy Laboratory and DOE researchers provided to the Stanford Steyer-Taylor Center for Energy Policy and Finance research team.

and on only one of the three state key engineering and technology research centers. In both cases, it is all but certain that this funding data is incomplete, meaning that spending on each of these facilities exceeded the amount shown below. Further complicating matters, this funding data comingles two sorts of support: (1) direct cash expenditures by the government and the company hosts and (2) the value of certain assets used in the facilities as declared by the company hosts. Discussions with corporate officials at several of these labs suggest that funding by the companies that host the labs far outweighs funding by the Chinese government. But comprehensive information on each lab's funding proved unavailable.

Taking into consideration all of these caveats, the Stanford Steyer-Taylor Center for Energy Policy and Finance research team found $90 million in such partial and comingled support for the state key lab at Yingli and $100 million for the state key engineering and technology research center at LDK.

Table 7: Traceable R&D Spending on State Key Labs And State Key Engineering and Technology Research Centers

Lab/Research Center	Home Entity	Year Established	Investment[170]
State Key Labs			
PV Material and Technology SKL	Yingli	2010	At least $90 million in 2010, the year construction started on the lab. Funding was from MOST and Yingli collectively^
PV Science and Technology SKL	Trina	2010	Not available
State Engineering and Technology Research Centers			
National PV Engineering and Technology Research Center	LDK	2009	At least $100 million investment in 2009, the year construction started on the lab. Funding was from both National Energy Agency and LDK^
National PV Equipment Engineering and Technology Research Center	48th Research Institute of CETC	2011	Not available
National Photo-Electronic Material Engineering and Technology Research Center	Chinese Academy of Sciences' Fujian Institute of Material Structure Research	2007	Not available

Source: Company press releases; new reports; Chinese Renewable Energy Industries Association, an industry group affiliated with China's central government

^: These figures include both (1) direct cash expenditures by the government and companies and (2) the declared value of certain assets used in this research by the companies.

170 Funding data for subsequent years was unavailable.

4.6.2: Chinese Provincial-Government Solar-R&D Funding

Provinces across China fund key labs and engineering-and-technology research centers of their own. As described above with regard to China's state—or central-government-funded—key R&D facilities, funding data for China's provincial-level key labs and engineering-technology centers is extraordinarily difficult to find. The Stanford Steyer-Taylor Center for Energy Policy and Finance research team found funding for only three of the provincial facilities, and, even for those facilities, the funding data found is almost certainly incomplete. That said, *The New Solar System* identifies $33 million in funding for provincial-level solar-R&D facilities: provincial key labs in Liaoning and Henan provinces and a provincial engineering-technology research center at Trina. That funding, and the other Chinese provincial key solar-R&D facilities for which no funding data was found, are shown in Table 8 below.

Table 8: Traceable Financial Information On Provincial Key Labs And Provincial Key Engineering and Technology Research Centers

Lab/Research Center	Home Institute	Year Established	Investment
Provincial Level Key Labs			
Liaoning Province Key Lab for Solar PV System	Dalian University of Technology	2008	$2 million in asset value
Henan Province key Lab for PV Materials	Henan Normal University, Henan University	2008	$0.8 million in asset value
National Energy Administration PV Technology Key Lab	Yingli		Not available
Provincial Level Engineering and Technology Research Centers			
Jiangsu Engineering and Technology Research Center for PV Vertical Integration	Trina	2008	$30 million in asset value
Jiangsu Engineering and Technology Research Center for High Efficiency Silicon PV	Altusvia Energy (Hareon Solar Affiliated)	2013	Not available
Engineering and Technology Research Center for PV High Efficient Solar Cell	Chinese Academy of Sciences Material Institute and Xinyou Solar	2011	Not available
Hubei Engineering and Technology Research Center for Solar PV	Wuhan Rixin Technology, Co. LTD	2005	Not available
Hubei Engineering and Technology Research Center for Invertor and Energy Storage	Hubei Zhuiri Electric	2014	Not available
Beijing Engineering and Technology Research Center for PV Manufacturing Equipment	Beijing Jingyi Century Electronics Co. LTD	2011	Not available

Source: Company press releases; news reports; Chinese Renewable Energy Industries Association, an industry group affiliated with China's central government

Note: These figures consist entirely of the declared value of certain solar-R&D assets used by the companies. This financial data was available only for the university-based PKLs in Liaoning and Henan provinces and for the Trina PETRC. Information on spending at other PKLs and PETRCs was unavailable.

4.6.3: U.S.-Government Solar-R&D Spending

As noted at the start of Section 4.6, the IEA PVPS report for 2015 concludes that the United States spends significantly more on solar R&D than does any other country.

The precise amount of government money spent on solar R&D in the United States has varied over the past few years. The most detailed analysis comes from researchers at the U.S. National Renewable Energy Laboratory and the U.S. Department of Energy.[171] As Table 9 below details, U.S. federal solar-R&D funding totaled $385.5 million in fiscal 2015, the most recent year for which the NREL and DOE researchers have computed the numbers.[172] [173] Yet even this analysis likely does not include some federal funding related to solar R&D; deciding what research is related to solar is to some extent subjective, dependent on how broadly one defines solar-related technologies.

The total annual federal solar-R&D allocation numbers reported vary in part because of shifts in actual allocations by certain agencies but also in part because of the researchers' difficulty in tracking certain funding streams from one year to the next. Given those methodological difficulties, in analyzing U.S. federal spending on solar R&D, what is more important than year-to-year fluctuations in the funding numbers reported by those researchers is the relative distribution in funding among U.S. government agencies. That distribution has remained roughly constant in each of the past few years that the researchers have tracked.

Two offices of the U.S. Department of Energy accounted for nearly 90% of the total federal solar-R&D spending in fiscal 2015: the Solar Energy Technologies Office, which spent $233 million, and the Office of Science, which spent $118.9 million.[174] Far smaller amounts were spent, in declining order of size, by the Department of Energy's Advanced Research Projects Agency - Energy (ARPA-E), the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST), the Department of Defense (DoD), the Department of Agriculture's (USDA's) National Institute of Food and Agriculture (NIFA), other parts of the USDA, and the National Aeronautics and Space Administration (NASA).

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[171] David Feldman; Daniel Boff; Robert Margolis. 2015. "National Survey Report of PV Power Applications in the United States 2014." IEA PVPS. Available at: http://www.iea-pvps.org/index.php?id=93&no_cache=1&tx_damfrontend_pi1[pointer]=1

[172] Op. cit., David Feldman; Daniel Boff; Robert Margolis. Unpublished backup spreadsheets quantifying U.S.-solar-R&D spending.

[173] The $385 million in fiscal 2015 solar-R&D spending estimated by the U.S. National Renewable Energy Laboratory and DOE researchers is significantly less than the researchers' fiscal 2014 estimate. The 2014 estimate as reported in the IEA PVPS report was $439 million. In fact, however, the U.S. National Renewable Energy Laboratory and DOE researchers estimated fiscal 2014 U.S. solar-R&D spending at $466.8 million. The difference between the two fiscal-2014 estimates was approximately $27 million in funding for "demonstrations and field tests"–a category that was counted as R&D by the U.S. National Renewable Energy Laboratory and DOE researchers but not in the IEA PVPS report. As for the difference between the $466 million in fiscal 2014 spending and $385 million in fiscal 2015 spending reported by the U.S. National Renewable Energy Laboratory and DOE researchers, three main factors explain the gap. First, the annual allocation for the DOE's Solar Energy Technologies Office dropped from $257 million in fiscal 2014 to $233 million in fiscal 2015. Second, the 2014 figure included $42 million in Department of Defense research-lab-response allocation that the U.S. National Renewable Energy Laboratory and DOE researchers were not able to verify for 2015. Third, although the 2014 figure included $11 million in NASA money for research into the propulsion of solar-powered vehicles, the researchers excluded that line item from their 2015 estimate because they decided that program was related only tangentially to solar-energy technology itself .

[174] As noted in Chapter 1, the U.S. Department of Energy's Solar Energy Technologies Office provided Stanford University with the research grant that funded *The New Solar System*; the grant provided Stanford's Steyer-Taylor Center for Energy Policy and Finance with full independence and authority to frame the inquiry, conduct the research, draw conclusions, and write *The New Solar System*.

Table 9: Estimated U.S.-Government Solar-R&D Allocation in Fiscal Year 2015

Agency	Estimated Spending	Explanation
DOE Solar Energy Technologies Office	$233 million	SunShot Initiative (includes programs in tech-to-market, concentrated solar power (CSP), system integration, and balance-of-system, and photovoltaics.
DOE Office of Science	$118.9 million	Includes scattering and instrumentation research, photochemistry and biochemistry research, fuel-from-sunlight research, and Energy Frontier Research Centers
DOE ARPA-E	$24.1 million	Micro-Scale Optimized Solar-Cell Arrays with Integrated Concentration (MOSAIC), which aims to develop low-cost photovoltaic power systems developing micro-scale PV cells that incorporate concentrating technology.
NSF	$27.7 million	Various solar R&D grants
NIST	$3.1 million	National Nanotechnology Initiative
DOD	$2.3 million	National Nanotechnology Initiative
NIFA	$400,000	National Nanotechnology Initiative
NASA	$700,000	National Nanotechnology Initiative
USDA	$400,000	National Nanotechnology Initiative
U.S. government total	**$385.5 million**	

Source: Op. cit., David Feldman; Daniel Boff; Robert Margolis. Unpublished spreadsheets quantifying U.S.-solar-R&D spending.

4.6.4: R&D Spending by China-Based and U.S.-Based Solar Manufacturers

Table 10 and Figures 19 and 20 below show annual R&D spending by the nine companies that have dominated solar manufacturing in China over roughly the past decade. The nine companies' total R&D spending between 2006 and 2015 totaled $1.44 billion. The two largest U.S.-based solar manufacturers, First Solar and SunPower, together spent approximately the same amount, $1.38 billion, on R&D over the same period. Clearly, the average China-based solar manufacturer spends significantly less on R&D than does its U.S.-based counterpart.

The average China-based solar manufacturer spends less on R&D than does its U.S.-based counterpart.

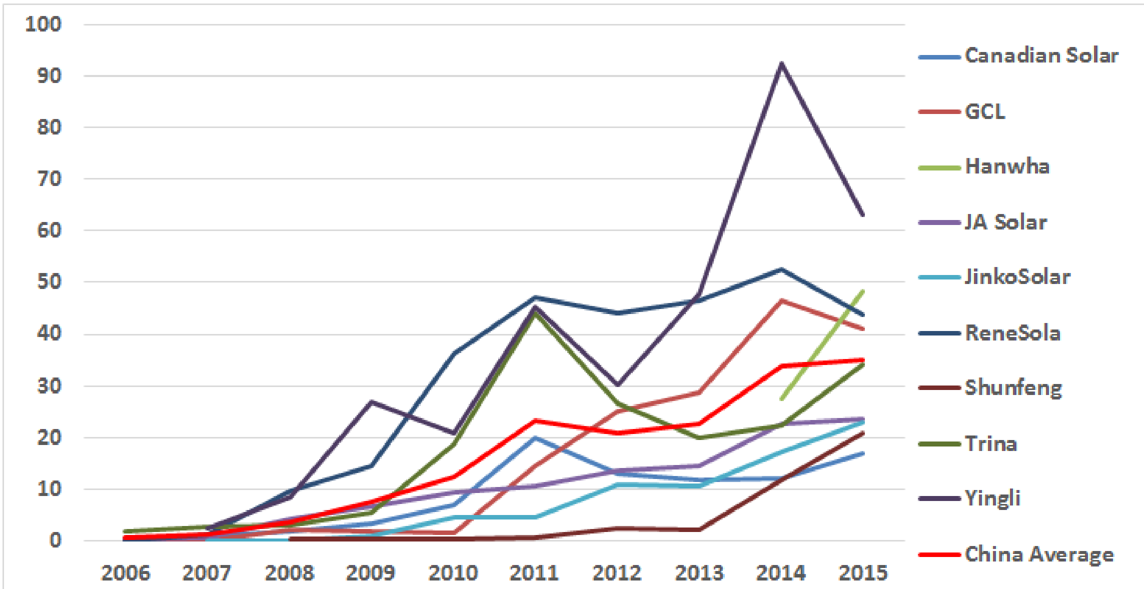
Two caveats to this data are important to keep in mind. First, definitions of R&D vary among companies; it appears from discussions with executives of solar manufacturers in both countries that China-based firms typically define R&D to encompass a broader range of activities than U.S. firms do. To the extent that is true, China-based firms may be spending even lower percentages of their revenue on the sorts of activities that U.S. firms would classify as R&D. Second, as noted in Section 4.6.1.1, R&D costs less in China than in the United States, given, in particular, China's lower labor costs. So the fact that a China-based company spent, for instance, half as much on R&D as a U.S. company almost certainly would not mean that the China-based company was conducting only half as much R&D.

Table 10: China-Based and U.S.-Based Solar Manufacturers' R&D Spending, Ranked by 2015 Amount (Millions of Dollars)

Company	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Canadian Solar	0.58	0.33	0.26	0.50	0.46	1.04	1.00	0.71	0.41	0.49
GCL	0.00	0.00	0.43	0.29	0.07	0.44	0.87	0.88	1.33	1.18
Hanwha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.54	2.68
JA Solar	0.19	0.16	0.52	1.19	0.54	0.64	1.29	1.23	1.24	1.10
Jinko	0.00	0.01	0.02	0.38	0.68	0.41	1.44	0.93	1.07	0.89
ReneSola	0.04	0.46	1.45	2.84	3.01	4.78	4.55	3.06	3.37	3.42
Shunfeng	0.00	0.00	0.19	0.40	0.43	0.21	1.47	0.91	1.26	1.86
Trina	1.66	0.93	0.37	0.64	1.00	2.15	2.04	1.12	0.97	1.12
Yingli	0.00	0.43	0.76	2.54	1.10	1.94	1.65	2.15	4.44	3.98
China Average	0.50	0.33	0.50	1.10	0.91	1.45	1.79	1.37	1.96	1.86
First Solar	6.89	5.85	4.28	10.17	9.05	5.68	11.11	9.24	9.17	8.38
SunPower	4.09	1.75	1.49	2.08	2.21	2.43	2.62	2.32	2.42	6.28
U.S. Average	5.49	3.80	2.89	6.12	5.63	4.06	6.87	5.78	5.80	7.33

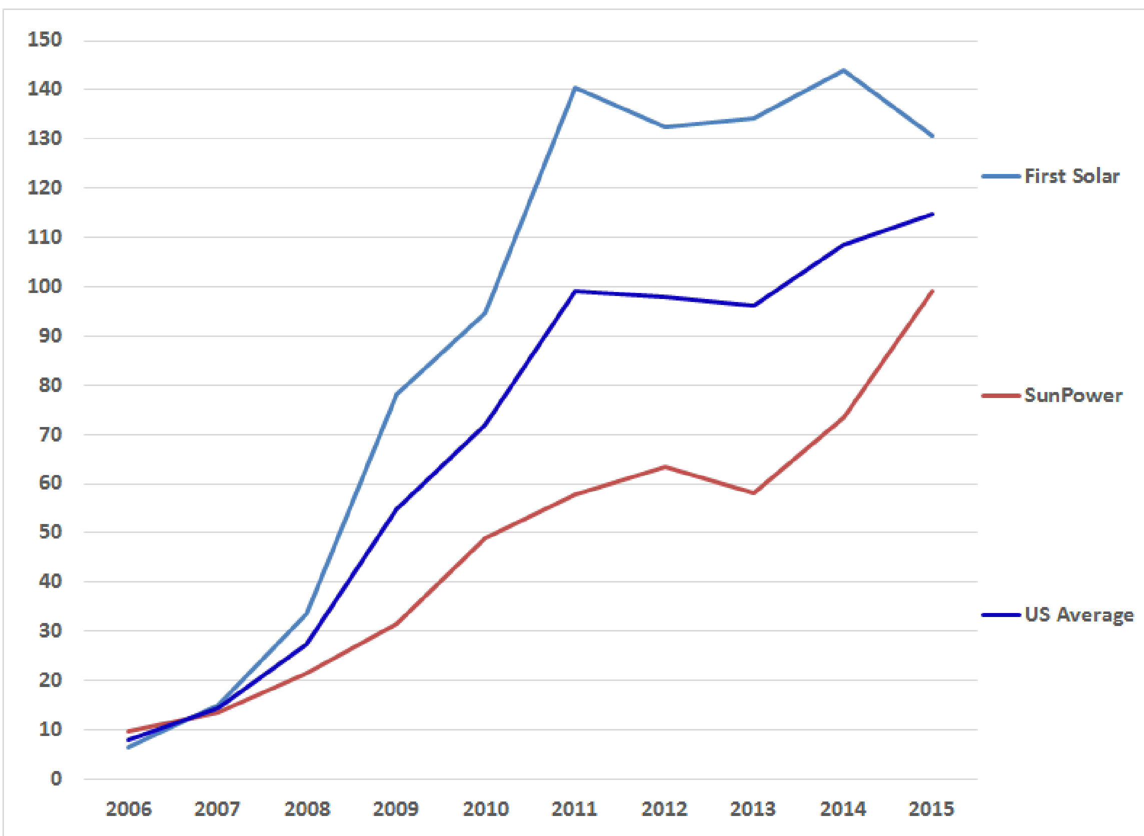
Source: Bloomberg

Figure 19: China-Based Manufacturers' R&D Spending, Ranked by 2015 Amount (Millions of Dollars)



Source: Bloomberg

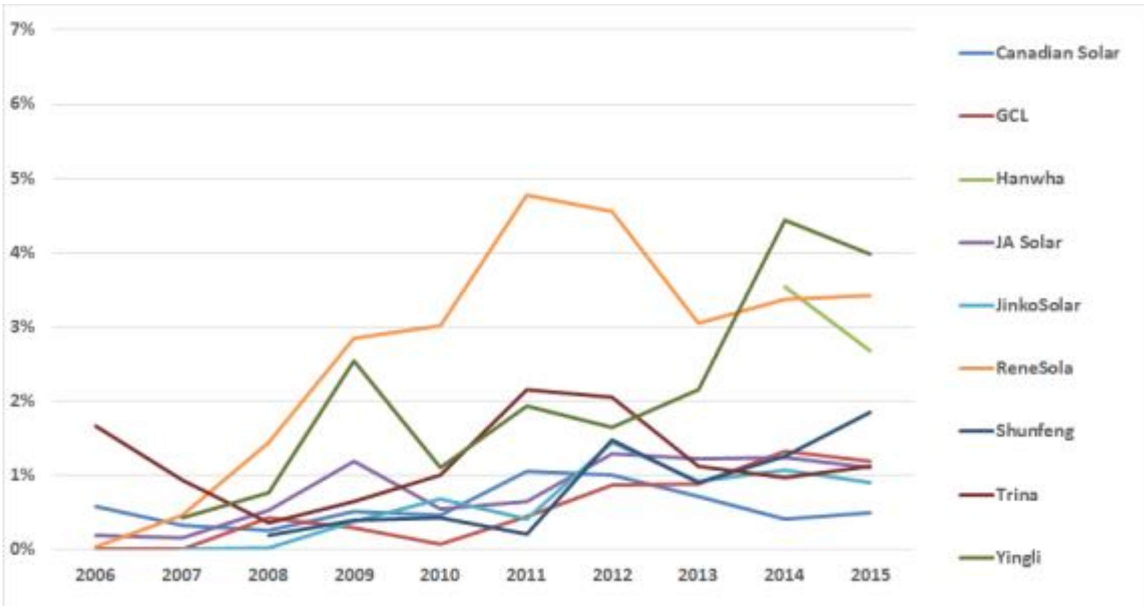
Figure 20: U.S.-Based Solar Manufacturers' R&D Spending, Ranked by 2015 Amount (Millions of Dollars)



Source: Bloomberg

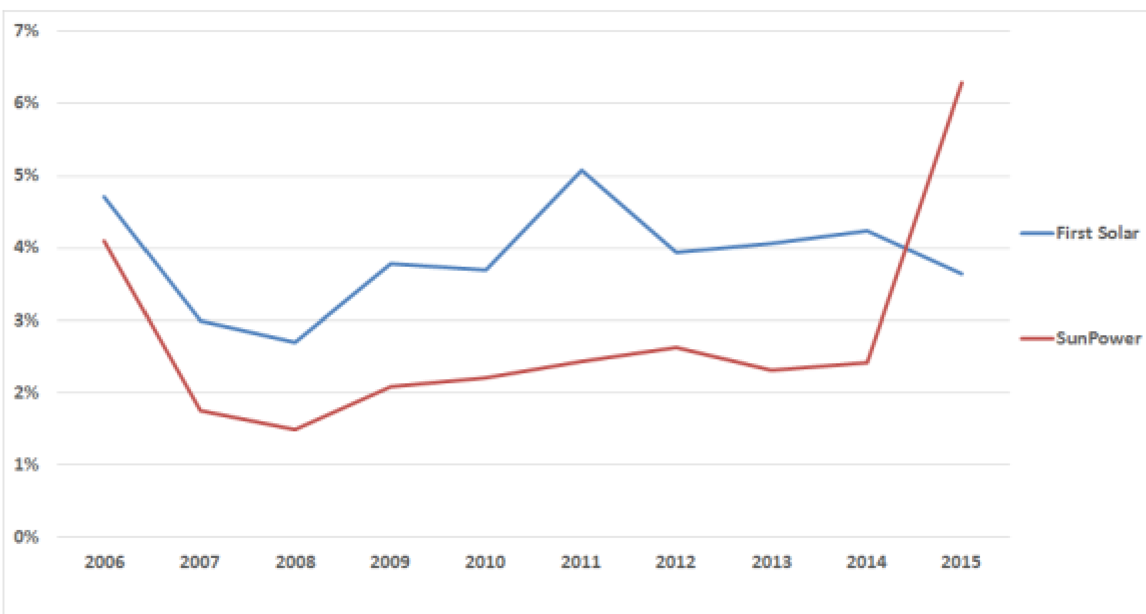
An even clearer picture of relative corporate-R&D effort comes from examining the percentage of its total sales that a company spends on R&D. Figure 21 below shows that metric over time for leading China-based solar manufacturers; Figure 22 below shows it for leading U.S. solar firms. As a group, leading China-based solar manufacturers spend approximately 1% of their revenue on R&D. For the two largest U.S. solar manufacturers, First Solar and SunPower, the level in 2015 was approximately 4% and 6%, respectively.

Figure 21: Total R&D to Total Sales for China-Based Companies



Source: Bloomberg

Figure 22: Total R&D to Total Sales for U.S. Companies



Source: Bloomberg

4.7: Upshot of Solar R&D in China

This analysis of solar R&D in China shows that China is intent on upgrading its solar enterprise from one that merely manufacturers and installs technology developed by others to one that also innovates and develops technology—both incremental changes in already-commercialized technologies and more fundamental work on emerging technologies. China is systematically restructuring its government support for solar R&D in an effort to make it more effective and efficient. It is recruiting top solar researchers from around the world, and those researchers are working with their counterparts around the globe. One early, albeit imperfect, indication that China's solar-R&D effort is beginning to bear fruit is the broad range of gains that researchers at China-based solar companies and at other Chinese solar institutions are reporting in the efficiencies of their laboratory-scale solar cells.

China is systematically restructuring its government support for solar R&D to make it more effective and efficient.

These improvements in China's approach to solar R&D are likely to have significant impact on the shape of the global solar industry—including on the United States' position in it. The implications for the United States—and suggestions about how the United States might respond—are discussed in Section 7.3.

In particular, the analysis in Section 4.6.4 above about R&D spending by major U.S. and China-based solar manufacturers reveals three important insights:

- Individually, each of the two leading U.S. solar manufacturers has been spending, and continues to spend, significantly more on R&D, both in absolute and in percentage terms, than any of the leading China-based solar manufacturers.
- As a group, China's leading solar manufacturers are coming to rival the United States' leading solar manufacturers in total R&D spending. That spending is distributed among more companies in China than it is in the United States. Nevertheless, the emergence of China's solar industry as a serious R&D player represents a significant shift from just a few years ago, when collective R&D spending by the leading China-based solar companies was a fraction of that by the major U.S.-based firms. This shift reflects both the maturation of the leading China-based solar firms and the increasing priority that the Chinese government is placing on R&D as a determinant of success for the nation's economy.
- The fact that R&D spending as a percentage of revenue has remained relatively constant for leading China-based solar manufacturers obscures another way in which solar R&D in China is intensifying. In 2013, China's MOIIT issued its Solar PV Manufacturing Industry Standards, which required companies to spend a minimum amount on R&D in order to qualify for a variety of important government support. The standards are explained in Sections 3.3.2, 4.4.1.3, 5.5.3, and 5.5.4.2 and in Appendix D. Specifically, the standards required China-based solar firms every year to spend on R&D either 3% of their revenue or ¥10 million ($1.5 million)—whichever was lower.[175] That requirement meant little for China's larger solar companies, which, as shown in Table 10 above, were spending several times the $1.6 million minimum even in 2012, the year before the new rules took effect. Nevertheless, the standards represented a significant requirement for the majority of solar manufacturers operating at the time

[175] State Council of the People's Republic of China, "Solar PV Manufacturing Industry Standards," 2013. http://www.gov.cn/zwgk/2013-07/15/content_2447814.htm (Content in Chinese)

in China—manufacturers that were far smaller than the leading firms. Indeed, as mentioned above in Section 4.4.1.2, the standards were intended to consolidate the Chinese solar industry around a handful of increasingly large and global firms—and, in so doing, to boost the quality of Chinese solar modules. The standards succeeded in helping to force out of business a number of smaller firms that did not have the financial wherewithal to devote that much spending to R&D. One indication of that is that, between 2012, the year before the MOIIT rule was promulgated, and 2013, the year the rule was promulgated, the number of China-based companies in three solar segments—silicon-cell manufacturing, silicon-module manufacturing, and thin-film-module manufacturing—dropped by 32%, 33%, and 36%, respectively. Today, the average China-based solar manufacturer—even beyond the largest companies shown in Table 10—spends significantly more on R&D than it did at the start of this decade.

Chapter 5: Manufacturing

5.1: Overview

Manufacturing has been and remains the backbone of the Chinese solar industry. At its inception, some 15 years ago, the Chinese solar industry did essentially nothing but manufacture. China-based solar companies bought turnkey assembly lines and the vast majority of their materials from established suppliers in the West.[176] And they sold their finished solar modules to buyers in the West. Their play was in the middle: They harnessed China's structural advantages as a manufacturing economy—advantages that included low labor costs, lax environmental standards, and ready government support for establishing factories—to scale up the production of solar modules, a commodity that, despite its high-tech image, is relatively straightforward to manufacture. In other words, the companies that began producing solar modules in China harnessed the country's manufacturing base much in the same way that companies that produced everything from t-shirts to televisions had done before. Chinese entrepreneurs recognized a profitable foreign market; they recognized China's strengths as a global factory floor; and, with enthusiastic help from various levels of government in China, they got down to business.

Chinese solar-module producers harnessed the country's manufacturing base like companies that produced everything from t-shirts to televisions had done before.

Low manufacturing costs give a country a particularly salient advantage in a renewable-energy sector such as solar—a much greater advantage, indeed, than in a conventional-energy sector such as oil, natural gas, or coal. For electricity generated by burning fossil fuels, the cost of the fuel accounts for a significant portion of the cost of the electricity. However, for electricity generated from solar power, the fuel is free, and so the cost of manufacturing equipment that converts sunlight into electricity accounts for a much larger percentage of the cost of the delivered electricity.

5.1.1 The Solar-Manufacturing Process

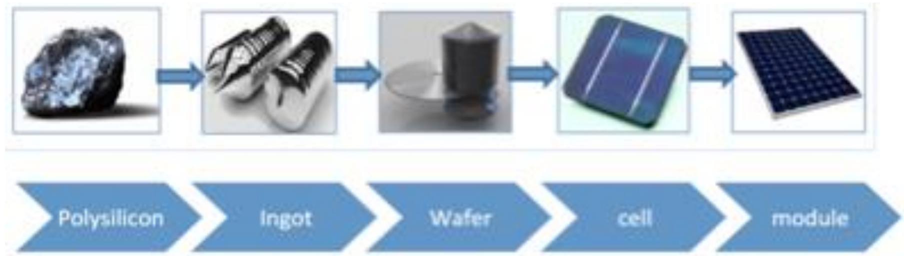
Manufacturing polysilicon solar modules, the technology that dominates today's global solar market, involves five major steps, which are described below and then shown below in Figure 23:

- processing metallurgical-grade silicon into *polysilicon*;
- casting the polysilicon into cylindrical *ingots*;
- slicing the ingots into thin, generally square-shaped pieces called *wafers*;
- processing the wafers, mostly by applying a variety of chemical coatings, into photovoltaic devices called solar *cells*;
- and packaging the solar cells, generally in bunches of 60 or 72, into rectangular-shaped, glass-covered assemblies known to industry insiders as solar *modules* and typically to the public as solar *panels*. In a module, the solar cells are sandwiched between two external layers—on the front of the module, glass, and on the back of the module either another layer of glass or an opaque layer called backsheet. When

[176] The term "turnkey" here refers to solar-equipment assembly lines bought from assembly-line manufacturers and installed in Chinese factories in ready-to-use form.

installed, multiple modules are strung together by wire to form a solar *array*.

Figure 23: Steps in manufacturing silicon-based solar modules



Source: Stanford Steyer-Taylor Center research

5.1.2: By the Numbers: China's Role in Global Solar Manufacturing

Today, as shown below in Figures 24, 25, 26, and 27, China dominates global solar manufacturing. In 2016, IHS Markit estimates, China accounts for 52% of polysilicon manufacturing capacity, 81% of silicon-solar-wafer manufacturing capacity, 59% of silicon-solar-cell manufacturing capacity, and 70% of crystalline-solar-module manufacturing capacity in the world.[177] The United States, by contrast, accounts for 11% of the world's polysilicon production capacity, 0.1% of wafer manufacturing capacity, 1% of cell manufacturing capacity, and 1% of module manufacturing capacity, according to IHS.[178] The United States and Europe accounted for a significant share of solar manufacturing prior to the mid-2000s, an era in which the solar industry was fledgling. But neither is a globally significant solar manufacturer today, a time when China is the world's undisputed solar manufacturer.

That is not expected to change in the next couple of years, despite plans to build a handful of high-profile solar factories in the United States. Among those plans, which also are discussed in Sections 7.4.1.1 and 7.4.2.3:

- California-based SolarCity is building in in upstate New York a solar-module factory that it has said ultimately will have an annual capacity of 1,000 megawatts—a size that, if it materializes, will make it one of the largest solar factories in the world.
- Massachusetts-based 1366 Technologies is building, also in upstate New York, a solar-wafer factory with an initial annual capacity of 250 megawatts and, the company says, an expected ultimate annual capacity of 3,000 megawatts.
- Atlanta-based Suniva now has a 200-megawatt plant in Georgia and is doubling its U.S.-manufacturing capacity to 400 megawatts with the addition of a 200-megawatt factory in Michigan.[179]
- German-based SolarWorld has said it is increasing the annual capacity of its Oregon module-manufacturing plant from 380 megawatts to 530 megawatts.

China, moreover, has moved well beyond the assembly of solar cells and modules. China now manufactures many, though not all, of the materials, components, and tooling necessary to construct a solar-power system.

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[177] As Sections 5.6.3 and 5.6.4 explain, most of that capacity is in China, though China-based solar manufacturers recently have begun intensifying their efforts to expand manufacturing abroad, particularly in Southeast Asia.

[178] Op. cit., IHS Markit

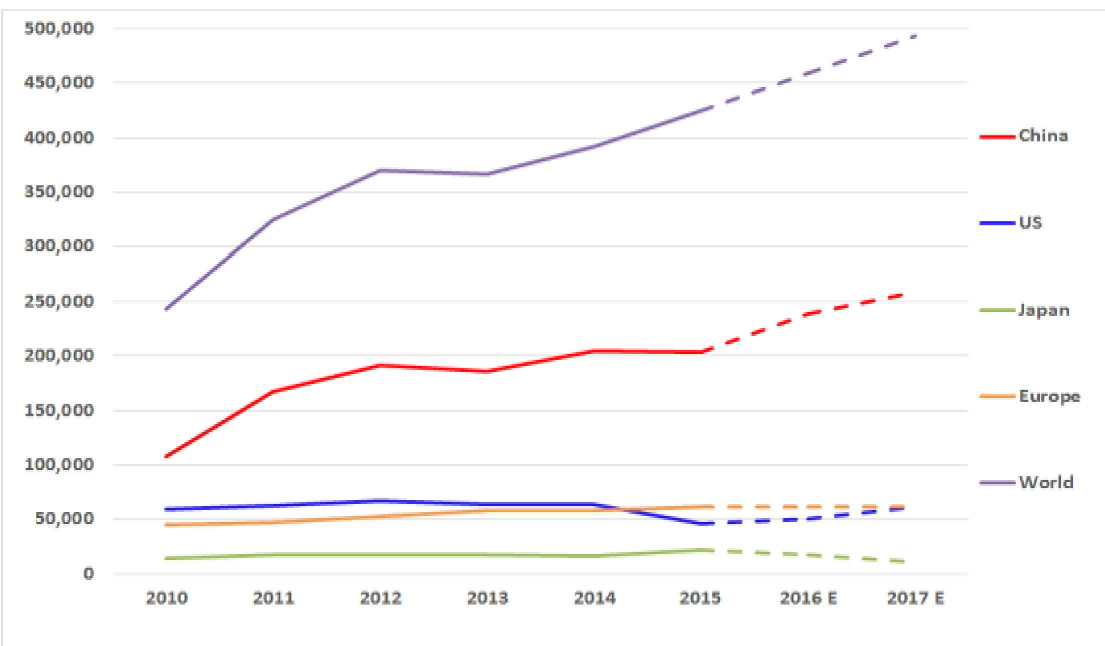
[179] Ehren Goossens, "Solar Billionaire-Backed Shunfeng Buys Majority Share of Suniva," Bloomberg, Aug. 12, 2015. http://www.bloomberg.com/news/articles/2015-08-13/solar-billionaire-backed-shunfeng-buys-majority-share-of-suniva

Particularly significant is the rise in the manufacturing in China of polysilicon, the material on which the vast majority of today's solar cells and solar modules are based. As shown below in Figures 24, 25, 26, and 27, polysilcon processing is the only one of the four major steps in solar-module manufacturing in which the United States had a significant share as of 2008, roughly the time when the global solar industry began growing rapidly. As explained further in Section 5.5.4.1 below, the global solar-tariff fight had the unintended effect of cementing Chinese dominance of global polysilicon manufacturing. After the United States imposed tariffs in 2012 on Chinese-made solar cells sold in the United States, China imposed tariffs of its own on U.S.-made polysilicon sold in China, a move that created an advantage for companies that produce polysilicon in China. That advantage has proved decisive in the global market.

Particularly significant is the rise in Chinese manufacturing of polysilicon, the material on which most solar cells are based.

In one recent example of China's leadership in the global polysilicon industry, as noted in Chapter 1, GCL, now the world's largest polysilicon producer, was finalizing in late 2016 the purchase for $150 million of polysilicon assets of SunEdison, a U.S.-based company that entered bankruptcy proceedings in 2016. GCL won bankruptcy-court approval in October 2016 for the deal, which includes a SunEdison facility in Pasadena, Calif., that produces polysilicon through what is known as the fluidized-bed-reactor (FBR) process, a process of polysilicon manufacturing that is less energy-intensive, and thus potentially less expensive, than the traditional method. GCL in late 2016 still was waiting for approval for the deal from the Committee on Foreign Investment in the United States (CFIUS), a U.S. government panel.[180]

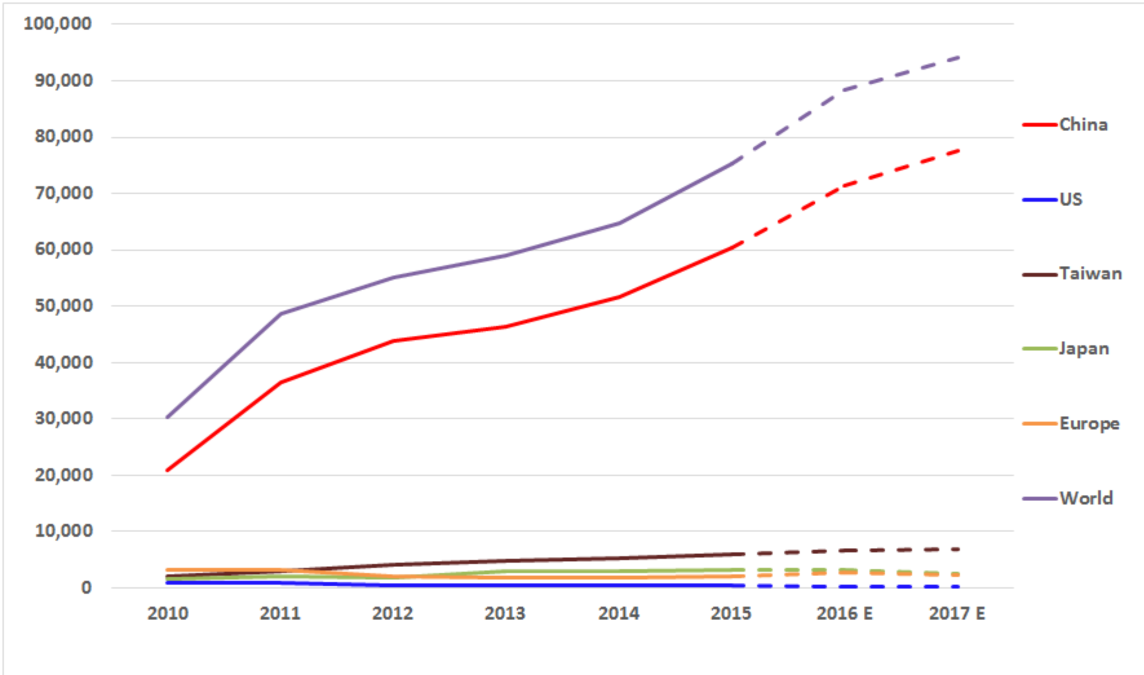
Figure 24: Global Manufacturing Capacity: Polysilicon (Tons)



Source: IHS Markit

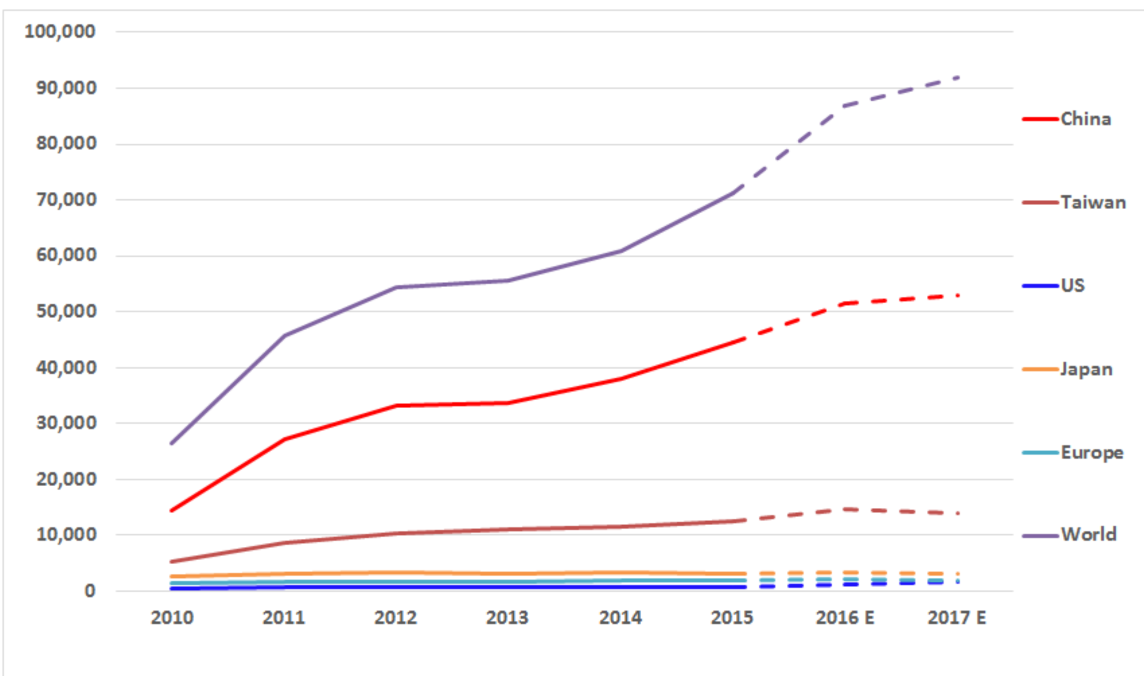
[180] Op. cit., PV Magazine, Oct. 31, 2016.

Figure 25: Global Manufacturing Capacity: Wafers (Megawatts)



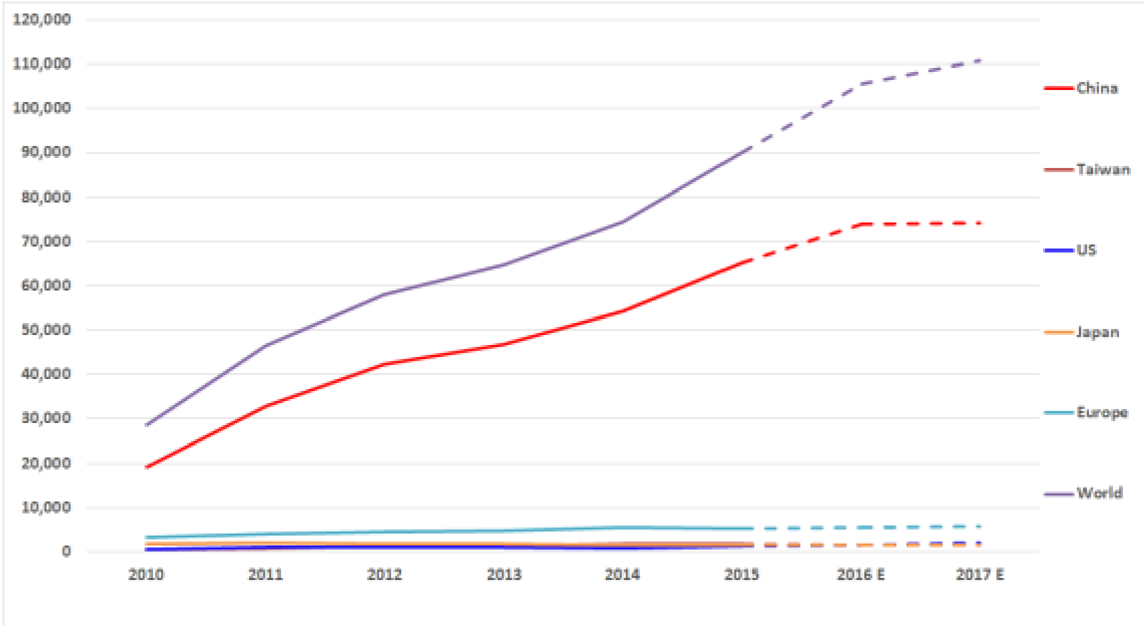
Source: IHS Markit

Figure 26: Global Manufacturing Capacity: Cells (Megawatts)



Source: IHS Markit

Figure 27: Global Manufacturing Capacity: Crystalline Modules (Megawatts)



Source: IHS Markit

Yet although China-based firms dominate global solar manufacturing, they do not do all their manufacturing in China. The commonly understood picture of Chinese solar production is of a global industry all but totally centralized in one country. A key conclusion of *The New Solar System* is that this picture is quickly changing. In two closely related shifts, the solar industry is consolidating in a corporate sense and decentralizing geographically. The industry is consolidating around a smaller number of players, each of which is spreading its operations—from R&D, to manufacturing, to deployment—across the globe. This is an important sign of industry maturation. It resembles transformative stages in the growth of other global manufacturing sectors, from automobiles to electronics. One result is that, more and more, the geographic footprints of leading solar companies look similar—whether those companies are based in China, in the United States, or elsewhere.

Countries that considered themselves uncompetitive for solar manufacturing now have reason to reassess that assumption.

Precisely how this decentralization of the solar industry will play out—which parts of solar manufacturing will happen in which countries—is impossible to predict. But the fact that the decentralization has begun signals that countries that previously considered themselves uncompetitive as a locus for solar manufacturing now have reason to reassess that assumption. Importantly, this does not mean that every country will be globally competitive in every segment of solar manufacturing. What it does mean is that the question of national comparative advantage in the global solar industry—the question of which countries do what well—now is extraordinarily relevant and nuanced.

More specifically, *The New Solar System* finds that Chinese solar manufacturing is maturing in four fundamental ways, all of which will be detailed later in this chapter:

- The industry is integrating up and down the value chain—from polysilicon to wafers, cells, modules and balance-of-system components—with fewer bigger companies dominating the entire global solar enterprise.

- The industry is expanding its Chinese production capacity, but, increasingly, it is doing so by upgrading assembly lines and not only by building additional ones.
- The industry is ramping up manufacturing outside of China, in large part a response to tariffs imposed by the United States and the European Union on Chinese-produced solar goods.

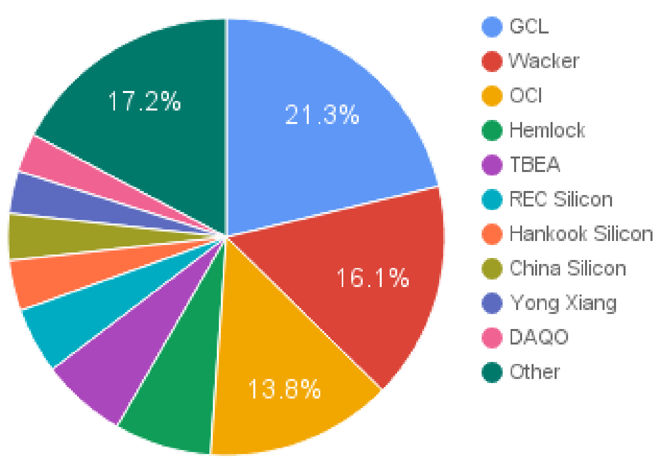
Solar-product manufacturers from outside China are entering China, though thus far on a small scale. So far, China-based solar manufacturers have not put factories of any scale in the United States.

One important conclusion from the foregoing bears repeating: The geographic footprints of leading solar companies look increasingly similar, regardless of whether those companies are based in China, the United States, or elsewhere.

5.1.3: By the Numbers: The World's Leading Solar Manufacturers

Figure 28 below shows the ten largest global polysilicon manufacturers, based on 2015 production. Five of them manufacture solely or largely in China. Two—Hemlock Semiconductor and REC—are based in the United States. Two—OCI and Hankook—are based in South Korea. And one, Wacker Chemie, is based in Germany. Half of all polysilicon made in the world is made in China, up from virtually zero in 2008, the result largely of tariffs imposed by China on imports by China-based solar-wafer manufacturers of polysilicon made in the United States.

Figure 28: World's 10 Largest Polysilicon Manufacturers, 2015

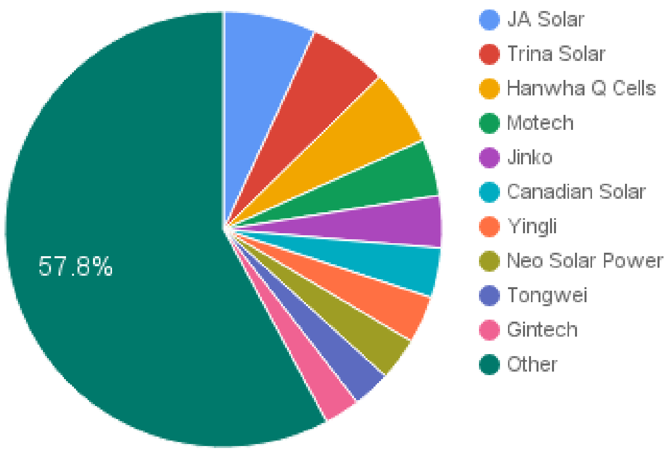


Source: Bloomberg New Energy Finance

Note: Global polysilicon production in 2015 totaled 348,000 tons.

Figure 29 below shows the 10 largest global solar-cell manufacturers, based on 2015 production. Seven of them manufacture solely or largely in China. Three—Motech, Neo Solar, and Gintech—manufacture in Taiwan. The rise of Taiwan as a solar-manufacturing center has been largely a result of an attempt by China-based solar-module manufacturers to obtain cells that, because they are manufactured off of the Chinese mainland, are do not trigger import tariffs when assembled into modules that are sold in the United States. As Appendix B explains, the United States later moved to thwart what critics described as this Taiwan "loophole" by imposing tariffs even on solar cells manufactured in Taiwan. The large size of the "other" category in Figure 29 is an indication of how fragmented, and thus probably ripe for further consolidation, the global solar-cell sector is.

Figure 29: World's 10 Largest Solar-Cell Manufacturers, 2015

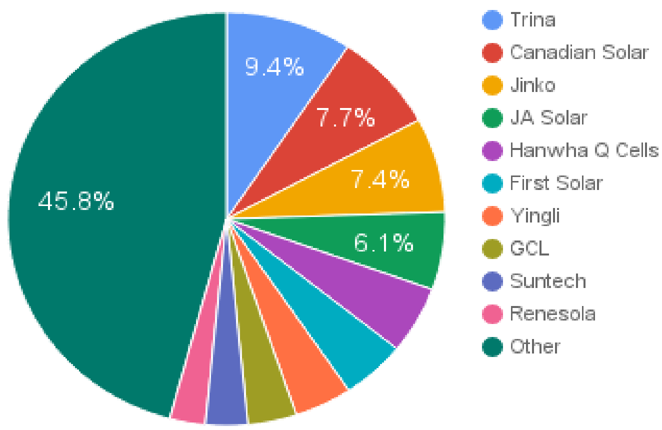


Source: Bloomberg New Energy Finance

Note: Global solar-cell production in 2015 totaled 56,900 megawatts.

Figure 30 below shows the 10 largest global solar-module manufacturers, based on 2015 production. Nine of them manufacture solely or largely in China. One, First Solar, is based in the United States and manufacturers largely in Malaysia. The 11th-largest global solar-module manufacturer by production is SunPower, the other major U.S.-based solar manufacturer. SunPower, like First Solar, manufacturers largely in Malaysia. As explained above with regard to the solar-cell sector, the large size of the "other" category in Figure 30 is an indication of how fragmented, and thus probably ripe for further consolidation, the global solar-module sector is.

Figure 30: World's 10 Largest Solar-Module Manufacturers, 2015



Source: Bloomberg New Energy Finance

Note: Global solar-module production in 2015 totaled 60,900 megawatts.

This chapter explores key aspects of China's solar-manufacturing enterprise. It analyzes China's globally dominant solar-manufacturing supply chain, a key to the country's solar leadership, tracing how that supply chain grew, where it stands today, and how it is changing. It examines the nature of manufacturing-process innovation that leading China-based solar companies have achieved. It assesses government subsidies for solar manufacturing in China (an assessment severely constrained by lack of data). And it analyzes how China-based solar companies are expanding manufacturing operations abroad.

5.2: China's Solar Supply Chain

China's main advantage in the global solar industry has been its robust supply chain. In a September 2013 paper, "Assessing the drivers of regional trends in solar photovoltaic manufacturing," researchers at the U.S. National Renewable Energy Laboratory assessed data from the first six months of 2012 and concluded that a representative Chinese factory produced solar cells at a 23% lower selling price than a representative U.S. factory.[181] The vast majority of the Chinese price advantage, they concluded, was due not to "indigenous factors" such as labor costs, or to "regional incentives" such as government subsidies, but rather to "scale and supply-chain" advantages—the fact that the typical Chinese factory was four times the size of the typical U.S. factory and thus could buy materials and equipment less expensively and could realize other economies of scale. The upshot of their study, the NREL analysts suggested, was that the United States could produce solar cells as inexpensively as China if the United States decided to push to replicate the manufacturing scale that China has achieved. "The competitive advantage that has led to the regionalization of the PV industry…is not inherent; it is built and therefore might be equalized," the NREL researchers wrote in the paper. Moreover, the NREL analysts argued that the United States should not let solar-module manufacturing move entirely offshore; they suggested that to do so would erode U.S. public and political support for research-and-development spending that they argued is necessary to realize technology improvements that would further reduce the price of solar power.

[181] Alan Goodrich, Douglas Powell, Ted L. James, Michael Woodhouse, & Tonio Buonassisi, "Assessing the Drivers of Regional Trends in Solar Photovoltaic Manufacturing. Energy & Environmental Science," 6(10), 2811. 2013. doi:10.1039/c3ee40701b

The fundamental reason that the supply chain is so crucial to China's comparative advantage in solar manufacturing is that materials and equipment account for such a high proportion of the cost of making a solar module. According to Bloomberg New Energy Finance, using 2014 numbers, materials account for 65% of the cost of producing a solar cell in China and for 78% of the cost of producing a finished solar module.[182] [183] Manufacturing equipment represents an additional 20% of the cost of cell production and another 5% of the cost of module production. In other words, materials and equipment constitute 85% of the cost of producing a solar cell and 83% of the cost of producing a solar module. By comparison, materials constitute about 47% of the cost of a car, according to one analysis.[184]

Given their outsized importance, reducing material and equipment costs—precisely what China's extensive supply chain does—is a powerful way for the Chinese solar industry to ensure its continued competitiveness and leadership. The economic advantage that accrues to China from its extensive solar-manufacturing supply chain outweighs, at least today, the disadvantage the industry is starting to experience as China's traditionally low labor rates rise. (According to Chinese government statistics, between 2004 and 2014, the decade of the Chinese solar industry's most-intense growth, the country's average annual wage tripled.[185]) This explains why executives of China-based solar manufacturers report that, as tariffs on Chinese-made solar products induce them to shift some of their manufacturing to other countries—even to Southeast Asian nations where the average wage today is lower than it is in China—the China-based companies' total production costs rise. The significant benefit of China's efficient solar supply chain dissipates the farther a large China-based company moves its manufacturing operations from the Chinese mainland.

Many China-based solar firms, as they shift manufacturing elsewhere, are working to bring their Chinese suppliers with them.

In an effort to counteract this impact, many China-based solar firms, as they shift manufacturing to countries whose exports to the United States are not penalized by U.S. import tariffs, are working to bring their Chinese suppliers with them. They are establishing in these countries what amount to satellite clusters of the supplier networks that they have assembled around the plants they operate back home on Chinese soil. (It is too early to judge whether this effort will succeed at a scale that will materially affect the industry's economics, but it is an important strategic move.)

Furthermore, the fact that production costs are higher in the countries in which these companies are ramping up production than costs are in China provides yet more impetus for them to wring cost out of their Chinese supply chain. "Cost-reduction is baked into the manufacturing culture in China," said a senior executive of GCL. "This unabashed chase for lower cost throughout the entire supply chain is hardly seen anywhere else in the world."

The New Solar System finds that:

- the solar-manufacturing supply chain is highly geographically concentrated within China;
- the Chinese supply chain is strong in producing certain materials and components and weak in producing others;
- and China-based companies and government officials acknowledge these weaknesses and are working to address them.

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182 Bloomberg New Energy Finance, "2014 PV Manufacturing Theme: Efficient Use of Materials," 2015. Available by subscription only

183 Bloomberg New Energy Finance, "The Relentless Fall in Chinese PV Module Costs," 2014. Available by subscription only

184 Henry Kallstrom, "Raw Materials—The Biggest Cost Driver In the Auto Industry," Market Realist, Feb. 5, 2015. http://marketrealist.com/2015/02/raw-materials-biggest-cost-driver-auto-industry/http://marketrealist.com/2015/02/raw-materials-biggest-cost-driver-auto-industry/

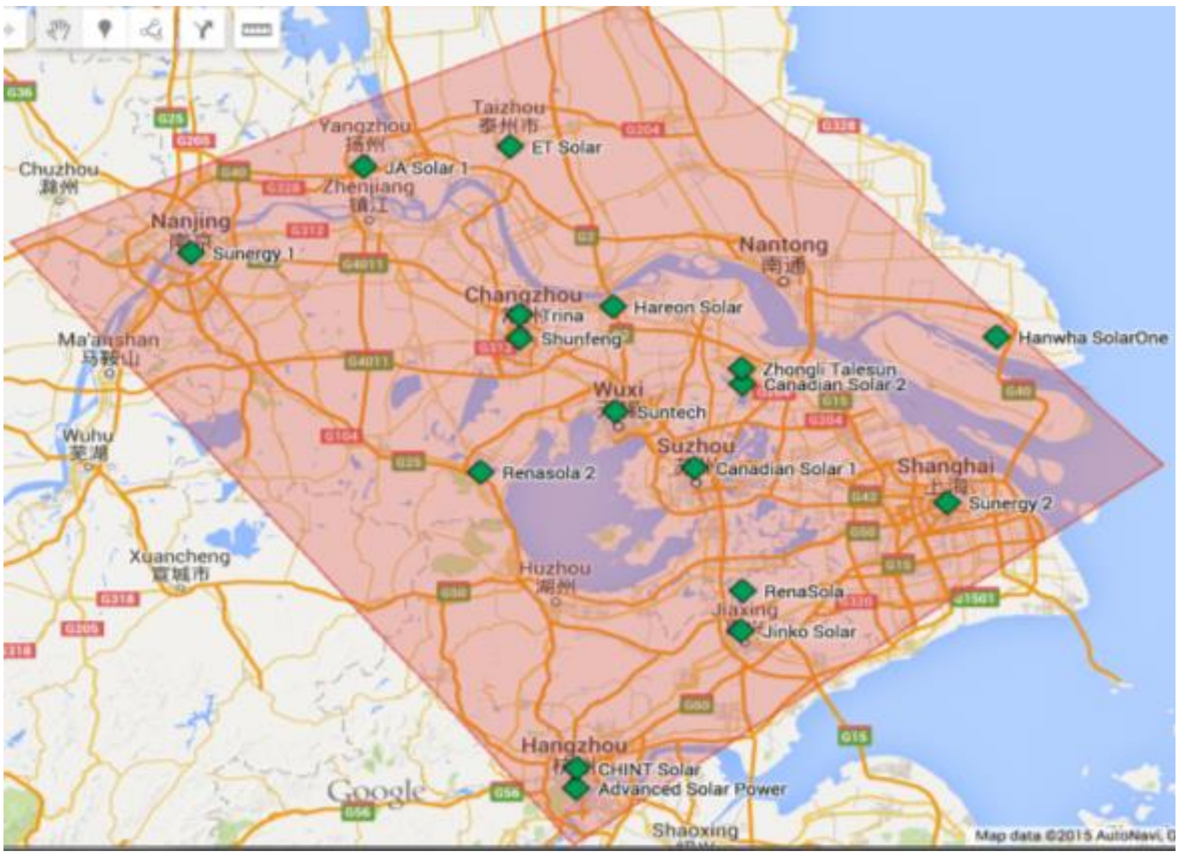
185 China Labour Bulletin. (2015). Wages in China. Retrieved November 8, 2015, from http://www.clb.org.hk/en/content/wages-china

All three of these conclusions have important implications for the future of the Chinese solar industry and, thus, for comparative advantage among the world's various solar players. These conclusions are detailed below.

5.2.1: Importance of the Yangtze River Delta Supply-Chain Cluster

China's solar industry is a textbook lesson in the power of manufacturing clusters. The epicenter of the Chinese solar industry—and thus of the global solar industry—is the Yangtze River Delta, an area that, as shown below in Figure 31, includes Shanghai and parts of two provinces to the west of the city: Jiangsu, which contains the leading solar-manufacturing cities of Suzhou, Wuxi, and Changzhou; and Zhejiang, which contains the prominent solar-manufacturing city of Jiaxing.

Figure 31: Solar Manufacturers in China's Yangtze River Delta



Source: BNEF; Google Maps

As shown by a comparison of Figure 31 above with Table 11 below, five of the world's six largest solar-module manufacturers have their headquarters in the Yangtze River Delta. They are: Jinko, Trina, JA, Canadian Solar, and GCL. The other company among the world's sixth-largest producers of solar modules, Hanwha Q Cells, also has its major module manufacturing located in the Yangtze River Delta, though the company's headquarters is in Korea. Strikingly, each of the six China-focused manufacturers shown in Table 11 has a level of module-manufacturing capacity and of actual module production that exceeds—by several times—the domestic module-manufacturing capacity and the domestic module production of the entire United States.

Table 11: Worlds Six Largest Silicon-Solar-Module Manufacturers, 2016

Global Ranking, By 2016 Silicon Module Production	Company	Silicon-Module Capacity (megawatts)	Silicon-Module Capacity As Percentage of Global Capacity	Silicon-Module Production (megawatts)	Silicon-Module Production As Percentage of Global Production
1	Jinko	6,500	6.2%	5,276	6.8%
2	Trina Solar	6,000	5.7%	5,172	6.7%
3	JA	5,650	5.3%	4,509	5.8%
4	Canadian Solar	5,830	5.5%	4,263	5.5%
5	Hanwha Q Cells	4,875	4.6%	4,263	5.5%
6	GCL	4,150	3.9%	3,503	4.5%

Source: IHS Markit

Note: Capacity and production statistics are based on actual data for the first three quarters of 2016 and IHS Markit projections for the fourth quarter of 2016. IHS Markit defines the Yangtze River Delta as including Jiangsu and Zhejiang provinces, Shanghai, and part of Anhui Province.

Table 12 underscores the extent to which the Yangtze River Delta is the single most important location for solar-cell and solar-module manufacturing in the world. According to IHS Markit estimates, the Yangtze River Delta in 2016 was home to approximately 74% of China's solar-cell production and 85% of its solar-module production. That equated to 45% of global cell production and 60% of global module production.[186]

[186] The IHS Markit estimates for 2016 use actual data for the first three quarters of 2016 and IHS Markit projections for the fourth quarter of 2016.

Table 12: Production Capacity for Solar Cells and Modules By Geography, 2016

Geography	2016 Silicon-Cell Capacity (megawatts)	2016 Silicon-Cell Production (megawatts)	2016 Silicon-Module Capacity (megawatts)	2016 Silicon-Module Production (megawatts)
Yangtze River Delta	37,825	34,618	59,990	46,231
China	51,366	46,721	74,026	54,599
World	86,922	77,732	105,668	77,434
Yangtze River Delta as Percent of China	74%	74%	81%	85%
Yangtze River Delta as Percent of World Total	44%	45%	57%	60%

Source: IHS Markit

Note: IHS Markit defines the Yangzte River Delta as including, in addition to the city of Shanghai and the provinces of Jiangsu and Zhejiang, part of Anhui Province.
Note: Capacity and production statistics are based on actual data for the first three quarters of 2016 and IHS Markit projections for the fourth quarter of 2016. IHS Markit defines the Yangtze River Delta as including Jiangsu and Zhejiang provinces, Shanghai, and part of Anhui Province.

5.2.2: History of Yangtze River Delta Supply-Chain Cluster

The growth of the Yangtze River Delta as the world's solar-manufacturing center occurred, broadly, in three stages.

5.2.2.1: First Stage: 2000-2005

Solar manufacturing began in the Yangtze River Delta in the early 2000s, with the founding of Suntech. The Yangtze River Delta long had been a center of Chinese manufacturing of other products. Suntech, followed soon by other solar manufacturers, notably Trina and Canadian Solar, located in the Yangtze River Delta in large part because of the region's already-existing industrial base.

The Yangtze River Delta was a good place for these companies to establish themselves because basic industrial infrastructure in the area—roads, power, industrial parks, labor—was robust. The Yangtze River Delta benefits from power prices that are relatively low compared to elsewhere in China. Power prices there are low both because, in certain parts of the Yangtze River Delta, local coal deposits are plentiful, and because of the Three Gorges Dam, which was commissioned in 2003.[187] In addition, provincial and municipal governments in the area were enthusiastic about attracting new industry, extending to the fledgling solar companies many of the same sorts of benefits and

[187]As noted in Section 1.1, the Three Gorges Dam, the largest power plant in the world, has a capacity of 22,500 megawatts and in 2015 produced 87 million megawatt-hours of electricity. (China Three Gorges Corp.'s 2015 annual report, at http://www.ctgpc.com/en/_304039/_304171/index.html.) That was 2.2 times the 39.2 million megawatt-hours of electricity generated in 2015 from all of China's solar projects combined. (BP Statistical Review of Energy 2016, data workbook, at http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html)

incentives that they previously had used to attract and expand other sectors.

Among these benefits was a Chinese institution that first emerged during modern China's industrial rise in the 1980s: the industrial park. A Chinese industrial park looks nothing like the mere handful of low-slung warehouse buildings that Westerners typically picture when they hear the phrase. Chinese industrial parks, generally created and operated by special arms of provincial or local governments, comprise massive tracts of land—often thousands of acres—and highways, train tracks, power plants, apartment buildings, shopping malls, and, of course, factories. Chinese industrial parks include essentially everything a company might need to set up shop—including housing and amenities for its workers. Crucially, industrial parks also boast what amount to government-employed industry consultants: staff of the government agencies that run the industrial parks, who are there to help corporate executives along the way, cutting through red tape and speeding the opening of the new plants that will employ local residents and boost the local tax base.

Chinese industrial parks comprise highways, train tracks, power plants, apartments, shopping malls, and, of course, factories.

5.2.2.2: Second Stage: 2005-2010

In the early years, China's first solar-module manufacturers had to import most of their materials and components. That began to change in the mid-2000s, when the early China-based solar companies grew torridly, fueled by generous government subsidies for solar deployment in Europe and, to a lesser extent, in the United States. The growth of these initial China-based solar manufacturers induced industrial suppliers in the Yangtze River Delta—companies previously engaged in other industries—to expand into the burgeoning local solar sector.

The development of China's polysilicon industry is a case in point. Over the past decade, the industry has grown from essentially nothing into the world leader.

Initially, Suntech and the other China-based solar-module makers imported most of their solar wafers; once they began making wafers, they initially imported most of the polysilicon they needed to do so. Producing wafers and the underlying polysilicon requires extensive capital as well as technical expertise; few China-based companies had enough of either. But when Suntech, Yingli and Canadian Solar went public on the New York Stock Exchange in 2005 and 2006, it sparked massive solar-manufacturing expansion in the Yangtze River Delta. Market demand for polysilicon and wafers soared; the spot price of polysilicon surged from less than $50 per kilogram in 2004 to approximately $475 per kilogram in early 2008. Sensing a huge opportunity, GCL, which has its main operations in the Jiangsu Province city of Suzhou and was engaged in the business of building power plants, entered the solar business by building its first polysilicon factory. (A polysilicon factory is, in important ways, part power plant and part refinery.) Over the ensuing decade, GCL has rapidly expanded its polysilicon business, moving vertically into the manufacture of solar wafers, cells and modules and, more recently, into the building of solar farms. Today GCL is the world's largest producer of polysilicon and a growing producer of silicon-based solar modules. In addition to its polysilicon production, GCL has 12 wafer factories—three around each of four major China-based global solar-module makers, all located in Jiangsu. Those four module makers are Trina, in the Jiangsu city of Changzhou; Canadian Solar, in Suzhou; GCL itself, in Suzhou; and Altusvia Energy, in the Jiangsu city of Taicang. By 2011, some three years after GCL entered the wafer-production business, it had become the world's largest wafer producer. That same year, GCL surpassed the production of the largest U.S.-based polysilicon maker, Hemlock. In 2013, GCL surpassed the production of the world's largest polysilicon producer, Germany's Wacker, rendering GCL the global leader.[188] GCL grew on the backs of the Jiangsu-based solar-cell-makers to which GCL sold its products: Between 2006 and mid-2015, those GCL customers saw their cell-manufacturing capacity grow 30-fold, from 500 megawatts to 17,000 megawatts.

The glass industry provides another important example of the growth of the Yangtze River Delta as a solar-manufacturing center. In the Zhejiang Province city of Jiaxing, a company called Flat Glass long made glass for China's construction industry. In 2006, as solar-module manufacturing was soaring in the Yangtze River Delta, Flat Glass branched out; it began making solar-grade glass for solar modules. By 2014—less than a decade later—Flat Glass had become the world's largest solar-grade-glass manufacturer.

5.2.2.3: Third Stage: 2010-Today

The build-out of the Yangtze River Delta supply chain base attracted a new wave of factory investments by players such as Jinko, JA Solar, and Renesola, as described in more detail in Section 5.1. This further reinforced the region's solar-manufacturing prowess. As shown above in Table 12, the Yangtze River Delta currently housed, in 2016, approximately 38,000 megawatts of silicon-solar-cell-manufacturing capacity and approximately 60,000 megawatts of silicon-module-manufacturing capacity, which accounted for 45% and 60%, respectively, of the global totals.[189] Escalating regional manufacturing capacity fueled strong demand for solar materials and tooling, which in turn offered ample market opportunities for existing regional suppliers, as well as newcomers.

5.3: China's Solar-Manufacturing Subsidies

Probably the most hotly disputed aspect of China's solar enterprise is the nature of the support that China's national, provincial, and local governments provide to the country's solar manufacturers. It is clear that all levels of government in China provide a range of subsidies to the Chinese solar industry. But much is unclear, as is explained throughout this section. One is the question of which governmental entities provide which types and quantities of incentives to which firms. Another is the legal issue of which subsidies are acceptable under international trade law and which are not.

In October 2011, a group of seven U.S. solar-cell and module manufacturers, led by the U.S. arm of Germany's SolarWorld AG, filed petitions with the U.S. Department of Commerce (DOC) and International Trade Commission alleging two categories of Chinese violations of international trade rules in the solar sector: "dumping," a practice in which a manufacturer, in a bid to gain market share, sells products abroad at less than the manufacturer's production cost; and solar-manufacturing subsidies by the Chinese government so excessive that, according to the allegations, they allowed China-based firms to underprice their foreign competitors in selling solar products in the United States.[190]

5.3.1: International Trade Dispute

China-based solar manufacturers and the Chinese government denied, and continue to deny, any illegal activity. Nevertheless, the U.S. government has, over the past four years, issued a series of decisions upholding the allegations and, based on those determinations, imposing tariffs on Chinese-made solar cells imported into the United States.

These tariffs take two forms: "anti-dumping" tariffs, intended to compensate for China-based

[188] Op. cit., Goldman Sachs Equity Research
[189] Op. cit., HIS Markit
[190] SolarWorld press release, "SolarWorld and Coalition of U.S. Solar Manufacturers Petition to Stop Unfair Trade by China's State-Sponsored Industry," October 19, 2011: http://www.solarworld-usa.com/newsroom/news-releases/news/2011/domestic-solar-manufacturers-petition-to-stop-unfair-trade-by-china.aspx

firms' alleged dumping; and "countervailing duties," intended to compensate for the Chinese government's allegedly unfairly large subsidies.

Moreover, U.S. authorities have, in response to the complaints by the SolarWorld-led consortium, issued two different rounds of each of these two types of tariffs. The first round occurred in response to the 2011 complaints; the second round occurred in response to a second round of complaints by the consortium in 2013, when the consortium complained that China-based solar firms were trying to circumvent the first round of tariffs by manufacturing solar products in Taiwan, off the Chinese mainland.[191]

The tariffs are discussed further in Sections 1.5. and 7.4.1.3. Taken together, the tariffs imposed by the United States in response to these complaints have had the effect of raising the price that U.S. consumers pay for solar power above the price that they would pay if the China-based firms were able to export their products into the United States tariff-free.[192]

5.3.2: Domestic-Content Rules

The concentration of solar manufacturing in China has led several countries to impose protectionist measures known as domestic-content rules in an attempt to boost solar manufacturing within their borders. Typically, governments have done this by promulgating solar-deployment subsidies and then stipulating that solar-project operators will qualify for the full subsidies only if their projects use solar cells or solar modules that contain a minimum threshold of domestically manufactured content. Increasingly, however, these domestic-content rules are being successfully challenged legally, on the basis that they violate World Trade Organization rules.

In May 2013, a WTO appellate body ruled impermissible a domestic-content requirement that was part of a feed-in tariff that Ontario, Canada, implemented in 2009 to incentivize solar power. The European Union and Japan had challenged the local-content requirement, saying it violated WTO rules.[193]

Similarly, in September 2016, the WTO appellate body stipulated that a domestic-content requirement in India's National Solar Mission, a government-sponsored solar-deployment program in that country, violates international trade rules. India's requirements apply to operators of solar projects selling electricity to the government. The ruling was in response to a claim against India that the United States filed in 2013 and that a variety of others, among them the European Union, Japan, China, and Brazil, later joined.[194]

5.3.3: Quantifying Chinese Solar Subsidies

The New Solar System's objective is not to assess legality—not of the price at which Chinese-made solar cells are sold in the United States, not of the level of Chinese-government solar subsidies, and not of the resulting tariffs imposed by the United States in response to those measures. The legality of those measures is for lawyers and courts to debate. *The New Solar Sys*tem's objective is, rather, to illuminate key types of subsidies that China has offered to its solar industry, ways in which this subsidy regime is changing, and

[191] For a detailed description of the chronology of the tariff dispute, see Appendix B.

[192] As explained above in a footnote to Section 2.4, a Greentech Media study in 2014 projected that the price of China-made solar modules imported into the United States would rise an average of 14% as a result of the tariffs. (Mike Munsell, "New Tariffs on Chinese Solar Modules Will Raise U.S. Prices by 14%," Greentech Media, June 20, 2014. https://www.greentechmedia.com/articles/read/New-Tariffs-on-Chinese-Solar-Modules-Will-Raise-US-Price-by-14) Several U.S. solar-industry experts said they have seen no credible analysis of how much the tariffs have, in fact, pushed prices up recently. That is a potential area for future research.http://www.greentechmedia.com/articles/read/New-Tariffs-on-Chinese-Solar-Modules-Will-Raise-US-Price-by-14http://www.greentechmedia.com/articles/read/New-Tariffs-on-Chinese-Solar-Modules-Will-Raise-US-Price-by-14

[193] "WTO Appellate Body Rules Against Canada in Renewable Energy Case," BioRes, International Centre for Trade and Sustainable Development, May 27, 2013. http://www.ictsd.org/bridges-news/biores/news/wto-appellate-body-rules-against-canada-in-renewable-energy-case-0http://www.ictsd.org/bridges-news/biores/news/wto-appellate-body-rules-against-canada-in-renewable-energy-case-0

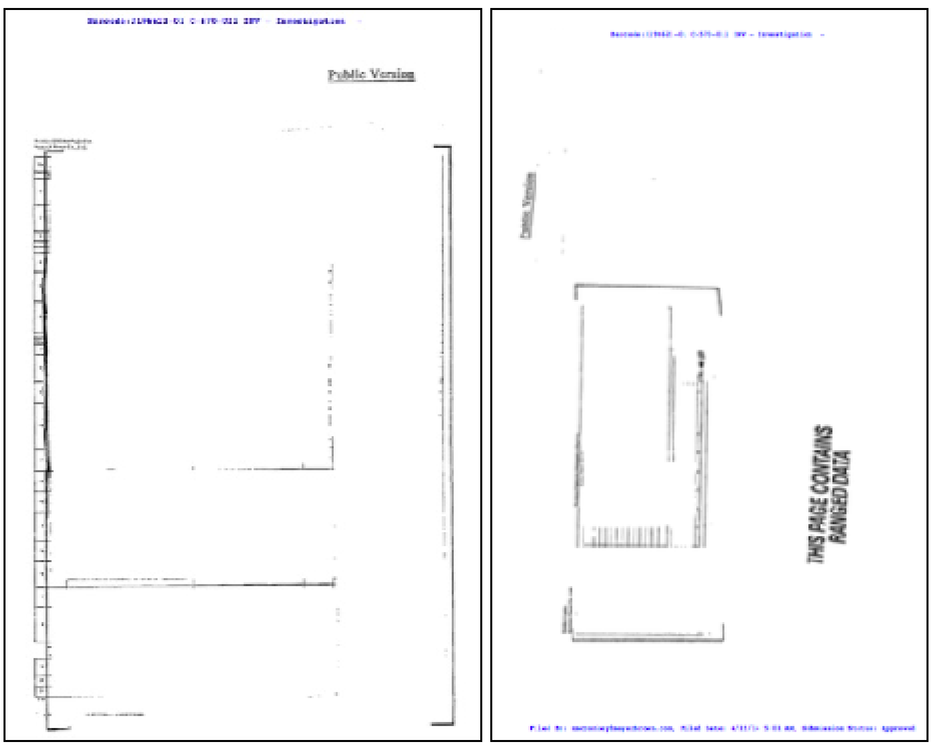
[194] "India: Certain Measures Relating to Solar Cells and Solar Modules," Dispute DS456, World Trade Organization, Oct. 14, 2016. https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds456_e.htm#bkmk456r

implications of those changes for China's comparative advantage in the global solar industry.

Quantifying China's solar subsidies is extraordinarily difficult. The most comprehensive effort to do so appears to have been the DOC investigation in the wake of the SolarWorld trade allegations. But that investigation is of limited value in an outside assessment of China's solar subsidies such as *The New Solar System*. While voluminous trade-case records are public, the U.S. federal government heavily redacted the vast majority of the investigation's findings about the details of China's subsidies. The U.S. government contended it is obligated to keep those details private because the details are company-specific business data.

For example, the publicly available versions of questionnaires completed by Trina, Suntech, and other China-based manufacturers that were investigated in the DOC's second countervailing duty case display nothing quantitative. Hundreds of pages are essentially whited-out; little more than a cursory introduction and final tariff numbers are visible, with no context on actual calculations.

Figure 32: Representative Sample of Heavily-Redacted U.S.-China Trade Case Content



Source: Suntech's response to the U.S. government's counterveiling-duty allegations as part of the solar trade case.

The New Solar System, therefore, bases its analysis of China's solar subsidies on extensive discussions and research. The discussions took place on the Chinese side, with officials at various levels of the Chinese government, executives of China-based solar manufacturing and deployment firms, and academics involved in China's solar enterprise. And the discussions occurred on the U.S. side, with relevant officials of the DOC and DOE and with executives of U.S.-based solar manufacturers. What emerges is a picture that is far from comprehensive but that nevertheless clarifies the nature of Chinese solar subsidies.

The United States and Germany have—much like China—provided a range of subsidies to their domestic solar firms.

Three points of context are important. First, other countries, including the United States and Germany, have—much like China—provided a range of subsidies to their domestic solar firms. Second, many of China's solar subsidies are structurally similar to the subsidies that the Chinese government has provided other industries whose growth it has prioritized as a matter of industrial policy. Third, Chinese government officials readily acknowledged in conversations with the Stanford Steyer-Taylor Center for Energy Policy and Finance research team that the country's early subsidies were often ill-designed, incentivizing solar-manufacturing growth so torrid that it proved unsustainable and ended up wasting large amounts of public and private investment.[195]

Key takeaways about China's solar subsidies include the following:

- Subsidies initially focused on manufacturing. Chinese manufacturing subsidies have included rebates on value-added tax and corporate income tax, and the provision of land and leased buildings for factories at below-market rates. Chinese solar executives report that their companies received generous subsidies to set up their manufacturing operations, though they add that those subsidies are similar to the sorts that a range of industries have received in China in the name of economic development.
- Many of these subsidies are administered by provincial and local governments rather than by the central government, and the size and breadth of these sub-national subsidies vary significantly depending on the locale. Provinces and cities often have competed against one another, offering increasingly large subsidies in an attempt to lure solar manufacturers to locate within their borders. They have done so, indeed, even when China's central government, fearing a resurgence of solar-manufacturing overcapacity, has advocated a reduction in this local-subsidy arms race. Not surprisingly, the manufacturing subsidies are strongest in provinces and cities where the presence of solar manufacturing is heaviest.
- Over the past two years, China's central government has been moving to redesign its solar subsidies in an effort to make them more economically efficient. Importantly, the Chinese central government has been shifting the focus of its solar subsidies from manufacturing to deployment. China now is redesigning its solar-deployment subsidies, restructuring them for more economic efficiency and learning from past policy-design mistakes both in China and in other countries that have heavily subsidized solar deployment.

Examples of Chinese solar-manufacturing subsidies are shown in Table 13 below and are discussed in the remainder of this section. It is

[195] Based on interviews with officials from the cities of Wuxi and Jiaxing; the policy director of the Chinese Renewable Energy Industries Association, an industry group affiliated with China's central government, and the director of Shanghai New Energy Industry Association, a trade group

important to underscore that this list of examples is neither comprehensive nor intentionally selective. It includes examples that emerged from discussions and research in the preparation of *The New Solar System*. It does not include specific examples of large loans that Chinese state-owned policy banks provided to China-based solar manufacturers during the global financial crisis, a time when solar manufacturers in the United States and elsewhere found it difficult to obtain loans for expansion. As Section 3.3.1 explains, those Chinese banks typically provided that debt at market rates. Opinions differ as to whether the provision of market-rate debt in large quantities in this situation constitutes a subsidy.

China is redesigning its solar-deployment in ways that seek to learn from past policy-design mistakes.

Table 13: Examples of Chinese Government Solar Subsidies Targeted at Manufacturers

Subsidy Type	Recipient	Provider/ Source	Timeframe	Details
Tax Incentives				
Revenue-tax exemptions	Suntech	Wuxi municipal government	Roughly 2015-2019	Granted for five years following the company's mid-2014 restructuring[196]
Local-tax reduction	PV producers in Wuxi	Wuxi municipal government	Unknown	Local industrial tax reduction for companies with large revenue.[197]
Input Subsidies				
Infrastructure support	LDK	Misc. local/ provincial governments	2005/2006 onward	Free or cheap land and electricity-grid extension[198]
Low electricity prices	DAQO	Shihezi municipal government (Xinjiang)	Q1 2014	Rate discounted by province through 2020[199]
	LDK	Xinyu municipal government	Misc.	Discounted rate approved by local government[200]
Equipment purchase	Multiple local PV manufacturers	Wuxi municipal government	Unknown	Government provided grants for companies to upgrade production equipment[201]
Cash Investments				
Manufacturing grant	E-Mei Semiconductor Corp.	Central government	Late 1990s	¥1.5 billion ($217.6 million) provided to build a polysilicon production line, based on imported Russian technology[202]

[196] "Creditors Dispute Details as Suntech Finds Buyer," Bloomberg New Energy Finance (China Solar Analyst Reaction); November 19, 2013: https://www.bnef.com/Insight/8856.
[197] Discussions with Wuxi officials
[198] NBD article; June 22, 2012: http://www.nbd.com.cn/articles/2012-06-22/662422.html.
[199] DAQO Q1 2014 earnings call (cited by Bloomberg New Energy Finance)
[200] Imeigu article; May 26, 2013: http://news.imeigu.com/a/1369576370859.html.
[201] Discussions with Wuxi officials
[202] Conversation with former Chinese government Energy Research Institute (ERI) official, May 31, 2015

Table 13 (cont.): Examples of Chinese Government Solar Subsidies Targeted at Manufacturers				
Subsidy Type	**Recipient**	**Provider/ Source**	**Timeframe**	**Details**
Cash Investments				
Project-development funds	CSI	Suzhou New District government	Q2 2009	¥7.5 million ($1.1 million) provided to match central-government renewable-energy stimulus funds, for CSI to develop projects locally[203]
R&D grants	LDK	Central government	Q4 2012	$419,000[204]
Purchase of shares	LDK	State-owned entity Heng Rui Xin Energy Co.	Q4 2012	$0.86/ordinary share cash injection, accounting for 19.9% of LDK's total issued and outstanding capital[205]
R&D grant	PV producers in Jiaxing	Jiaxing municipal government	Unknown	R&D grants from local government for local solar manufacturers[206]
R&D grant	LDK	Central government	Q4 2012	$419,000[207]
R&D grant	LDK	Central government	Q1 2013	$177,000[208]
R&D grant	Sunergy	MOST	2013	863 grant of ¥30 million ($4.4 million) to mass-produce PERC cells (with expectation that Sunergy would self-invest three times more)[209]

[203] Solar Daily article; May 4, 2009: http://www.solardaily.com/reports/Canadian_Solar_Announces_Funding_Agreement_With_City_of_Suzhou_999.html.
[204] LDK Q4 2012 earnings call (cited by Bloomberg New Energy Finance)
[205] LDK press release, "LDK Solar Signs Share Purchase Agreement with Heng Rui Xin Energy," Oct. 22, 2012. http://www.ldksolar.com/med_press_list.php?news_id=402.
[206] Discussions with Jiaxing municipal officials
[207] LDK Q4 2012 earnings call (cited by Bloomberg New Energy Finance)
[208] LDK Q1 2013 earnings call (cited by Bloomberg New Energy Finance)
[209] Discussions with Sunergy Power Science Technology executives.

Table 13 (cont.): Examples of Chinese Government Solar Subsidies Targeted at Manufacturers				
Subsidy Type	**Recipient**	**Provider/ Source**	**Timeframe**	**Details**
Cash Investments				
Purchase of subsidiaries	LDK	Affiliate of municipal government in Anhui Province city of Hefei.	Q2 2013	$19.3 million cash injection[210]
Loans				
Bank loan guarantees	LDK	Xinyu municipal government	2005/2006	¥200 million($29 million) in funding and bank loans provided at company's inception[211]
Other Financial Assistance				
Social welfare contribution	Local PV manufacturer	Wuxi municipal government	Unknown	Local government contributions for companies' social-security and pension funds[212]
Expert recruitment package	Recruited scientists and entrepreneurs	Wuxi municipal government	Unknown	Recruitment packages including an automobile, an apartment, and a research lab, provided for free or heavily subsidized by the local government [213]
Move-in-ready factory	PV manufacturers	Wuxi government & industrial park administration	Unknown	Pre-built standardized factory[214]

[210]LDK press release, "LDK Solar Provides Update on the Sale of LDK Hefei," April 16, 2013: http://www.ldksolar.com/med_press_list.php?news_id=452. A Hefei-city-government affiliate, Hefei High Tech Industrial Development Social Service Corporation, held the LDK subsidiary for four months before reselling it to Tongwei.
[211] Imeigu article; May 26, 2013: http://news.imeigu.com/a/1369576370859.html.
[212] Discussions with Wuxi officials
[213] Discussions with Wuxi officials
[214] Discussions with Wuxi officials

Table 13 (cont.): Examples of Chinese Government Solar Subsidies Targeted at Manufacturers				
Subsidy Type	**Recipient**	**Provider/ Source**	**Timeframe**	**Details**
Other Financial Assistance				
Public transit	Employees at local industrial park/PV production plants	Wuxi municipal government	Unknown	Public transit system for people who work at local industrial parks including employees of solar companies, provided for free or heavily subsidized by local government[215]
International school	International employees working at Trina Solar Industrial Park	Changzhou municipal government and Trina Solar	Unknown	International school located in Trina Solar Industrial Park, subsidized by local government and Trina Solar[216]

Source: Company filings and press releases; Stanford Steyer-Taylor Center research; BNEF

5.3.4: Tax Incentives

Since 2006, Chinese law has provided a framework for a range of policies encouraging renewable energy. China promulgated its 2006 renewable-energy law to help its then-fledgling solar industry grow; at the time, China's large solar manufacturers were just starting to go public on U.S. stock exchanges. Notably, the law has allowed "qualified" solar-component makers to apply for an exemption from half of the value-added tax they owe to the central government.[217] [218]

Solar developers also typically are exempted from 50% of China's value-added tax. The Chinese government first implemented that exemption in 2013 for two years.[219] Later, the government extended it through Dec. 31, 2018.[220]

On top of these central-government tax breaks, many local governments offer reductions in both value-added tax and income tax. These local tax breaks vary in their percentage and duration. As an example, in the Yangtze River Delta's Zhejiang Province, the city of Jiaxing, home to prominent solar-glass supplier Flat Glass and to solar-module makers Jinko and Renesola, the municipal government offers larger tax breaks to solar

[215] Discussions with Wuxi officials
[216] Discussions with Trina representatives
[217] National People's Congress of the People's Republic of China. 2005. Renewable Energy Law of the People's Republic of China. http://english.mofcom.gov.cn/article/policyrelease/Businessregulations/201312/20131200432160.shtml The law was passed in 2015 and took effect in 2016.
[218] Neither the law itself nor subsequent interpretations of the law issued by China's central government define what metrics qualify a manufacturer for this exemption.
[219] Chinese Ministry of Finance, "Notification On The Policy About Value-Added Tax Related to Solar Electricity Generation," Sept 23, 2013. http://szs.mof.gov.cn/zhengwuxinxi/zhengcefabu/201309/t20130929_994642.html
[220] Chinese Ministry of Finance, "Notification On Continuing The Policy About Value-Added Tax Related to Solar Electricity Generation," July 25, 2016. http://szs.mof.gov.cn/zhengwuxinxi/zhengcefabu/201608/t20160817_2392902.html

companies that generate more revenue and employ more people.

5.3.5: Subsidized Land

Chinese local governments historically allowed preferential land contracts for the construction of factories in industries that China's central and provincial governments promoted in their five-year plans. The solar industry is among them.[221]

Many local governments have provided access to discounted land to solar-equipment manufacturers that are large or that the governments regard in some other way as promising. In the late 1990s, China's Ministry of Electronic Industries issued a ¥1.5 billion ($217.6 million) grant to E-mei Semiconductor Corp., a state-owned enterprise, to build a polysilicon production line using imported Russian technology.[222][223] LDK, which built its factory in the Jiangsu Province city of Xinyu in 2005, reportedly received free or discounted land with local- and provincial-government support and a ¥200 million ($29 million) cash injection from the local government.[224] Both Suntech and Trina, in the facts they provided to the U.S. government as part of the companies' responses in the solar-tariff trade case, reported benefiting from the provision of subsidized land from local governments of their respective solar-manufacturing hubs, primarily for the purpose of building factories.[225]

5.3.6: Cash Investments

A handful of financially troubled tier-one China-based solar manufacturers have received cash injections from their local governments. The rationale behind these government outlays appears to be that these companies are too big to fail—that, because the companies are large employers and taxpayers, it is in the public interest for a local government to help carry them across their financial chasm. Prominent examples include Suntech and LDK.

A handful of financially troubled China-based solar manufacturers have received cash injections from their local governments.

Suntech, the company that essentially launched China's solar boom, became, in March 2013, the first Chinese company to default on publicly traded debt. Suntech subsequently filed for bankruptcy protection in both China and the United States. It was restructured through acquisition by Shunfeng International Clean Energy in April 2014. During this period, the municipal government of Wuxi, the Jiangsu Province city in which Suntech sits, supported the company in several ways. An investment arm of the Wuxi government provided a $150 million cash injection into Suntech's U.S.-listed holding company.[226] In addition, after the restructuring, the Wuxi government provided Suntech a conditional five-year exemption from revenue taxes.[227]

LDK, a solar manufacturer based in the Jiangxi Province city of Xinyu, encountered serious financial problems in 2013, was delisted from the New York Stock Exchange in 2014, defaulted on

[221] In multiple cities in the Yangtze River Delta, local-government officials and solar-company executives said the local governments historically provided subsidized land to solar companies as an economic-development tool. They said this practice is less prevalent now than it was before 2012.
[222] Conversation with former Chinese government Energy Research Institute (ERI) official on May 31, 2015.
[223] What previously was the Ministry of Electronic Industries is now a part of the Ministry of Industry and Information Technology.
[224] NBD article; June 22, 2012: http://www.nbd.com.cn/articles/2012-06-22/662422.html.
[225] Solar I Countervailing Duties Final Decision Memorandum; October 9, 2012; pp. 13-14 (http://enforcement.trade.gov/frn/summary/PRC/2012-25564-1.pdf). In the U.S. Department of Commerce trade investigation, both Suntech and Trina reported befitting from the "provision of land for LTAR," or "less than adequate remuneration," which according to the Commerce Department constituted a financial contribution from an authority in the form of goods or services and thus was "countervailable."
[226] The investment arm is called Wuxi Guolian Development Co.
[227] "Creditors Dispute Details as Suntech Finds Buyer," Bloomberg New Energy Finance (China Solar Analyst Reaction); November 19, 2013: https://www.bnef.com/Insight/8856.

debt, and sought bankruptcy protection. It exited bankruptcy proceedings in early 2016, but some of its subsidiaries remain in bankruptcy. Overall, LDK has received a variety of grants and subsidies. As an example, according to one LDK financial filing, those incentives in 2007 included $3.1 million in local electricity-rate reductions—equating to a 40% discount on prevailing local power prices—and $3.5 million in a direct payment "from the local government authority as an incentive for development of the wafer industry in Xinyu."[228]

Banks in China provide debt to solar companies whose balance sheets would make it difficult for them to secure loans elsewhere.

5.3.7: Preferential Lending

As in Section 3.3, the lender that has provided the majority of debt to China-based solar companies to build factories—the China Development Bank—appears to have done so at market rates. The financial filings of China-based solar manufacturers appear to support this conclusion. To the extent the filings report the companies' cost of debt, that cost appears to have been at prevailing market levels.

The U.S. Department of Commerce concluded in its tariff investigation that one Chinese policy bank, the Export-Import Bank of China, may have provided low-interest loans to buyers of solar products exported from China. Providing low-interest financing to foreign buyers of a domestic company's goods is, of course, a large part of the reason that export-import banks exist in many countries, including both China and the United States. The Department of Commerce said in documents that are part of the tariff investigation that the department was not able to verify whether the Ex-Im Bank of China actually did provide low-interest loans to foreign buyers of China-based solar companies' products. However, the department said, the Chinese government failed to provide enough information to the Department of Commerce to substantiate the Chinese government's contention that the Ex-Im Bank of China did not provide low-interest loans to foreign buyers of Chinese solar products. As a result, the Department of Commerce assumed for purposes of assigning penalties under the tariff investigation that the bank did indeed provide those preferential rates—and that those rates were evidence of unfair subsidies.[229]

Discussions with Chinese solar executives suggest that low-interest loans have been unusual in the industry. The more prevalent way in which debt has been provided to China-based solar manufacturers in a way that could be construed as a subsidy lies not in the rate of interest but in the amount of liquidity. Government-affiliated banks in China have continued to provide debt to China-based solar companies whose balance sheets would make it exceedingly difficult for them to secure new loans from non-Chinese lenders. Even assuming those companies are paying market rates for the debt, as their executives say they are, the issuance of new debt allows them to help pay off old debt. That amounts to significant government support, because it provides a company with a way to continue to generate cash flow that it otherwise would not have.

A good example of this phenomenon is Yingli, which has sustained losses since 2011 but was, until its financial problems deepened significantly in 2014, China's largest solar supplier. Yingli reported total debt of $1.9 billion at the end of the third quarter of 2015. In its public financial filings, the company has said that its high debt load imperils its ability to remain in business. In spring 2016, according to a report by Bloomberg News, the government body that oversees China's

[228] LDK Solar Co. Ltd. Form 2007 Form 20-F. https://www.sec.gov/Archives/edgar/data/1385424/000114554908000623/h02002e20vf.htmhttps://www.sec.gov/Archives/edgar/data/1385424/000114554908000623/h02002e20vf.htm

[229] U.S. Department of Commerce, Solar 1 Counterveiling Duties Final Decision Memorandum, http://enforcement.trade.gov/frn/summary/PRC/2012-25564-1.pdf.

banking industry, the China Banking Regulatory Commission, asked the China Development Bank to "ensure" that Yingli receives $1.16 billion in new loans.[230] This debt would support Yingli in two ways. First, it would help Yingli to repay its existing loans, thereby avoiding a potential debt default—the trigger that propelled both Suntech and LDK into bankruptcy. Second, it would help Yingli ramp up production in its factories, which despite healthy global demand for solar modules have been operating well below capacity as Yingli has been forced to divert large portions of its revenue—11% in the third quarter of 2015—to debt service. Producing and selling more solar modules would resuscitate Yingli's cash flow.[231]

5.3.8: Other Financial Assistance

Governmental entities in China, particularly municipal governments in cities with large solar-manufacturing clusters, have provided a variety of softer financial assistance to solar firms.

According to Wuxi municipal officials, the city helped cover some of Suntech's social-security and pension-fund costs. The Wuxi government also provided leading solar scientists at Suntech and other companies in the city with packages that included a free car, an apartment, and a budget for a company laboratory.

In Changzhou, home to Trina, the municipal government helped finance construction of an international school in the industrial park in which Trina's headquarters sit. The local government did so after Changzhou and Trina officials noticed that a common concern among foreign experts recruited by the China-based solar firm was their children's education.[232]

5.4: China's Solar-Manufacturing Priorities: Pragmatism and Cost

5.4.1: Limits on Technological Stretch

As Chapter 3 explains, Chinese scientists are working on essentially the same suite of emerging solar technologies as are scientists elsewhere in the world. However, when it comes to deciding which new solar technologies to manufacture, China-based companies typically are more conservative than Western firms. Their main hesitation is cost.

One example is the decision by many of top China-based solar-module manufacturers to choose PERC rather than HIT or IBC as the technology for their next-generation high-efficiency products. PERC cells typically are more efficient than conventional silicon cells but less efficient than HIT or IBC cells. However, reconfiguring a traditional silicon-cell assembly line to produce PERC cells requires only two basic changes, far fewer than reconfiguring that line to produce HIT or IBC cells. So PERC cells cost less than HIT or IBC cells to produce. The major exception to the Chinese solar industry's preference for PERC as the next-generation silicon technology is Trina, which, as explained in Section 4.2.1.1, is manufacturing IBC cells.

Another example is the way that Hangzhou-based Advanced Solar Power has chosen to manufacture its cadmium-telluride thin-film solar modules. As explained in Section 4.2.2.2, Advanced Solar was started and is led by Xuanzhi Wu, a longtime scientist at the U.S. National Renewable Energy Laboratory, where he set the then-world record for efficiency for a cadmium-telluride thin-film solar module. In an interview, Dr. Wu pointed out that Advanced Solar Power conducts only a few production steps in "clean rooms," expensive facilities that minimize contamination, whereas the global cadmium-telluride leader, U.S.-based

[230] "China Said to Push for $1.16 Billion in Loans for Yingli," Bloomberg News, April 8, 2016. http://www.bloomberg.com/news/articles/2016-04-08/china-said-to-push-for-1-16-billion-in-loans-for-yingli-imri0khz
[231] Ibid.
[232] Discussion with Trina tour guide

First Solar, conducts its entire production process in clean rooms. Dr. Wu called Advanced Solar Power's strategy "selective sophistication." He estimated that First Solar modules on average are about 2 percentage points more efficient than Advanced Solar Power's but cost about 25% more. Some in the solar industry argue that such an efficiency gain justifies the higher initial capital investment, given that the higher efficiency reduces the levelized cost of electricity that the First Solar cells produce. Dr. Wu said Advanced Solar Power has decided that its customers want to pay less for the modules they buy.

5.4.2: Manufacturing-Process Innovation

China's sprawling solar-manufacturing ecosystem yields a systemic outcome that is less tangible but no less significant than the lower prices of its materials and components: a deep and continuous innovation in the manufacturing process. The economic benefit of this process innovation is difficult to quantify. But its importance is evident in every visit to a Chinese solar factory and in every conversation with a Chinese solar executive.

Trina and Yingli, two of China's largest solar manufacturers, both have institutionalized their quests for manufacturing-process innovation. Each uses a slightly different approach, and both approaches are instructive.

Trina has created a specific pilot assembly line, which it calls the Golden Line, on the ground floor of the state key lab that it operates at its Changzhou headquarters.[233] The intent is to figure out how to commercialize the R&D innovations that the lab produces. Solar cells produced commercially almost never are as efficient as were the versions of those cells created in the lab. The goal of Trina's Golden Line is to tweak production to minimize cell-efficiency losses—a process that involves continuous communication, reevaluation, and reengineering between managers and technicians on the Golden Line and researchers upstairs in the lab. The company says that cells produced on the Golden Line are as much as 0.6% more efficient than comparable cells produced on Trina's conventional line—a significant gain given that improvements in solar-cell efficiency are measured in tenths of a percent.

Yingli has at its factories what it calls its "On-Line Research Program." This is an attempt to enlist all workers on conventional production lines in the process of improving the products they make. Also known inside the company as the "grassroots-innovation program," it is a campaign to encourage assembly-line workers to harness their daily experience to suggest and implement ways to improve the line's efficiency and Yingli's product quality. The program's slogan is: "Everyone is an innovator." In one example, the operator of one of a wire-saw machine on a Yingli line suggested an adjustment to the machine that allowed the machine to slice silicon wafers more thinly and more uniformly. Yingli says the shift increased both the number of wafers Yingli was able to produce from a polysilicon ingot and the photovoltaic efficiency of those wafers, since thinner wafers tend to present less electrical resistance than thicker ones. Dengyuan Song, Yingli's chief technology officer, estimated that the change saves the company about $1 million annually in production costs. That is a small sum—but nonetheless still a relevant one—in the context of Yingli's total business.[234]

Trina has created a pilot assembly line, called the Golden Line, on the ground floor of the state key lab at its Changzhou headquarters.

[233] The state key lab at Trina, and one at Yingli, are discussed in Sections 4.4.2.4 and 4.6.1.
[234] Discussion with Yingli's chief technology officer, Dengyuan Song

5.4.3: How Close Supplier Relationships Trim Costs

Module manufacturers typically work closely with their suppliers to diagnose problems and to develop new materials and parts. Trina is one example. Ten of its suppliers' factories sit in the same industrial park as does Trina itself. (A large plastic-encased model in Trina's main visitor's center in Changzhou shows that supply chain in detail, with the name of each Trina supplier inscribed on a flag planted atop the model of that supplier's facility.) The proximity allows engineers from Trina and its suppliers to meet to discuss their ongoing joint R&D projects on a weekly basis. When a piece of equipment breaks down, the equipment supplier commonly can send its maintenance team to diagnose the problem on the same day. The swift repair of equipment reduces machine downtime, which in turn increases the Trina factory's productivity.[235]

Module manufacturers also push their suppliers hard to slash costs. According to a former executive from a China-based solar company, large China-based solar manufacturers with strong bargaining power, such as Trina and Yingli, usually announce their detailed cost-reduction goals at annual suppliers' conventions that they hold.

Interviews with a wide range of solar-industry executives in China indicate that, for many machines used in the manufacture of solar cells and solar modules, the Chinese-made version sells for 50% to 65% less than the Western-made version. Often, leading China-based firms nevertheless prefer to by the Western versions of machines that are particularly technologically complex, reasoning that it makes sense to pay some degree of cost premium for those Western machines because the extra capital expense is justified by an even bigger economic advantage that the Western equipment brings the company in the form of efficiencies in the production process. Yet China-based module makers still benefit from the lower-priced machines sold by Chinese tooling makers; the module makers can use the existence of those lower-priced offerings as leverage to push Western suppliers to minimize the premium that they charge for their versions of these goods. The clear message from the China-based solar companies is that, if the foreign suppliers do not cut their prices significantly, the Chinese customers may decide it makes more financial sense for them to opt for the cheaper Chinese version.[236]

A telling example comes from the China Electronic Technology Group's 48th Research Institute. The institute is primarily an R&D facility that, in the solar realm, focuses on developing equipment used to manufacture solar cells and modules. The institute also manufacturers some equipment that it develops.[237] In an interview, the institute's deputy director recalled that, after the institute began producing what it believed was a high-quality version of a wire saw—a machine used to slice a silicon ingot into thin silicon wafers—it priced the machine at about $250,000, less than one-third of the $800,000 for which leading Western wire-saw makers were selling their machines. In response, several Western firms reduced by about half—to approximately $400,000—the price for which they were selling their machines.

"The ability to produce tooling domestically is the most important reason why solar modules made in China are so much cheaper than everywhere else," the institute's deputy director said.

5.4.4: Flexibility of Chinese-Made Tooling

In the case of solar manufacturing that is less technologically sophisticated and complex, China-based solar-product manufacturers tend to express a stronger preference for Chinese-made versions, and not just because of their lower purchase prices. Some examples from the Stanford Steyer-Taylor Center for Energy Policy and Finance team's visits to Chinese solar factories:

[235] Discussions with Trina executives

[236] Discussions with JA Solar's supply-chain director and China Sunergy's R&D director

[237] The 48th Research Institute also manufactures small volumes of solar cells and modules. It uses them primarily to test equipment, though it sells the cells and modules too.

- Advanced Solar Power, a Hangzhou-based solar-module maker, was able to quickly modify its Chinese-made assembly-line tooling to shift from making a parallel-circuit module to making a series-circuit module. Xuanzhi Wu, Advanced Solar Power's chairman, said reconfiguring the tooling machines to make this switch would have taken longer, cost more, and required more-difficult long-distance communications with the tooling manufacturer had Advanced Solar Power's tooling come from a foreign supplier instead of from a China-based firm.
- In Hunan Province's capital city, Changsha, an affiliate of the 48th Research Institute manufactures solar cells that it sells to several large China-based solar-module producers. The cell manufacturer has four firing furnaces that it uses to make cells. Three of the furnaces were made by the 48th Research Institute. One was made by a German company. The manager of the cell-production factory said the factory turns on the German furnace only if it has an order volume so large that it has maxed out the capacity of all three Chinese-made furnaces. The reason, the factory manager said, is that the factory's workers find it far easier to tweak the Chinese-made furnaces to increase the flexibility of production. By contrast, the German furnace, from a top supplier and of top quality, does not adjust to new production conditions easily, the factory manager said. For example, while the Chinese-made machine has its labels in Chinese, the German-made one has its labels in English, which many assembly-line workers do not read. And while the Chinese-made machine uses a green light to indicate that the machine is in operation—green being intuitive in China, as in much of the world, to mean "go"—the German-made machine uses a red light for the same purpose.
- China Sunergy, a solar-cell maker based in the Jiangsu Province city of Nanjing, had its PERC-cell production line on expensive pause during a recent visit by the Stanford Steyer-Taylor Center for Energy Policy and Finance research team to the factory. The reason: One of the assembly line's key pieces of equipment, an atomic-laser-deposition machine made by a Danish company, had been broken for three weeks. Sunergy's R&D director said he did not know when engineers from the Danish company would arrive to repair it—but that, until they did, Sunergy would remain unable to produce PERC cells.

The Chinese solar supply chain has been strong in producing goods that need extensive labor with few advanced skills.

5.5: China's Solar-Manufacturing Strengths and Weaknesses

China's solar supply chain has distinct strengths and weaknesses. China-based companies and the Chinese government are keenly aware of both and are trying to build on the advantages and address the shortfalls.

5.5.1: Overview of Strengths and Weaknesses

Evidence of this dichotomy of strengths and weaknesses in China's solar supply chain comes from interviews and factory visits in China.

The Chinese solar supply chain is strong in producing materials and durable goods that require extensive labor, small to medium capital investment, and few advanced technical skills. Those materials and goods include silicon wafers, glass, and aluminum frames; module accessories such as junction boxes, connectors, and cables;

and most of the machinery used to assemble modules.

The Chinese solar supply chain is at this point weaker in producing more technologically advanced goods: materials that require complex chemistry, such as silver paste and the solar-cell-encapsulating material known as EVA; and highly calibrated cell-manufacturing equipment such as wire saws, automatic welding machines, automatic screen-printing machines, plasma-enhanced chemical-vapor-deposition (PECVD) machines, and flash-, current-, and voltage-testing equipment.

There are companies in China that do manufacture these materials and machines. But it is a near-universal view among executives of top-tier China-based solar manufacturers that, for many of these materials and machines, the Chinese-made versions are of lower quality than the Western-made ones. Referring to equipment used to manufacture solar cells, Canadian Solar's R&D director said in an interview: "Although all equipment experiences down time, it happens to Chinese equipment more often than it does to German equipment."

As a result, many China-based solar companies rely primarily on imported equipment for those processes. However, many Chinese solar officials and R&D professionals said they expect Chinese-made tooling in these areas to improve over time —and that they will shift to that domestic equipment, which sells for markedly less than Western-made versions, when it does.

5.5.2: Quantification of Strengths and Weaknesses

Further evidence of this divide between the products that China's supply chain produces well and those it does not comes from a database collected by ENF, a China-based solar-information company. The ENF data has a serious flaw: It is current only through 2012. That is because ENF has not conducted a granular analysis of the Chinese solar supply chain more recently than the one that uses 2012 data. This is problematic given how much has changed in the Chinese solar industry over the past four years. Nevertheless, despite its age, ENF's data is particularly granular in its representation of the Chinese solar-manufacturing supply chain, according to experts who are well regarded in Chinese solar circles and are affiliated with Chinese solar-research institutes. So, even though it is four years old, the ENF data provides important insight into the structure of China's solar-manufacturing supply chain.

As noted throughout this chapter, discussions conducted by the research team from Stanford's Steyer-Taylor Center for Energy Policy and Finance suggest strongly that China's solar supply chain has deepened in the years since then.

As of 2012, the latest year for which the ENF database has granular statistics, China had more than 100 suppliers of each of the following components: slurry, ingot blocks and wafers, all of which are materials needed to make cells; junction boxes, crucibles, and connectors, required to make modules; and components such as inverters, charge controllers, and mounting systems, all of which are part of the "balance of system" of a solar project—that is, the equipment beyond the solar module itself.

However, although China had an extensive supply chain in those areas, the country had no domestic manufacturers of turnkey assembly lines to make silicon ingots or wafers, according to the ENF database. The 2014-2015 China Solar PV Industry Annual Report confirmed that the lack of domestic turnkey technology providers persisted as of 2014.[238]

The ENF data illuminates a collection of rising China-based solar-equipment producers: those that make cleaning machines, wire saws, EVA, diffusion furnaces, and cell-testing and cell-sorting

[238] Op. cit., China Photovoltaic Industry Association, 2015.

machines.[239] [240] [241] [242] [243] Table 14 below shows, for a variety of equipment types, whether each of China's major solar producers bought that equipment from manufacturers in China, from those outside China, or from a mixture of both China-based and non-China-based suppliers.

Table 14: Source of Solar Cell Manufacturing Equipment of Tier 1 China-Based PV Producers in 2012

Company/Process	Trina	Yingli	Suntech	JA Solar	Renesola	Hanwha
Cleaning	China	China	Foreign	China	Mixed	China
Diffusion Furnace	Foreign	N.A.	China	China	Mixed	China
Etching	N.A.	Foreign	Mixed	Mixed	Mixed	Mixed
PECVD	N.A.	Foreign	Foreign	Foreign	Mixed	Foreign
Screen Printer	Foreign	Foreign	Foreign	Foreign	Foreign	Foreign
Firing Furnace	N.A.	N.A.	Foreign	Foreign	Foreign	Foreign
Cell Tester/Sorter	China	China	China	Mixed	Foreign	Foreign

Source: ENF Chinese Cell and Panel Manufacturers Survey 4th, 5th and Continuous Edition Analysis Report, 2013

5.5.3: Chinese-Government Standards to Address Manufacturing Weaknesses

China's central government has concluded that the country's solar industry needs to improve the quality of its products to remain globally dominant. To force that improvement, the MOIIT, the agency of China's central government that oversees efforts to bolster domestic Chinese industry, has issued a detailed list of requirements for the industry. The MOIIT issued the requirements, called the Solar PV Manufacturing Industry Standards, in 2013, as the Chinese government was moving to restructure the Chinese solar industry to ensure its global competitiveness in the wake of tariffs imposed by the European Union and the United States on solar modules. Requirements as set by the MOIIT address a solar manufacturer's R&D spending, manufacturing scale, factory energy intensity, factory environmental performance, cell- and module-efficiency levels, module-efficiency-degradation rates, and module durability and quality.[244] The MOIIT standards are further explained in Sections 3.3.2, 4.4.1.3, 4.7, and 5.5.4.2 and in Appendix D.

The MOIIT requirements carry significant weight. Solar manufacturers that fail to meet the standards are ineligible for a range of important government subsidies. Their products are not certified for use in Chinese solar projects that qualify for the country's feed-in tariff, which essentially means their products are not be sold in the biggest solar-deployment market in the world. Their products also are ineligible for refunds on export taxes, meaning their products are severely disadvantaged in the global market.

[239] The companies that make cleaning machines include Sevenstar Electronics, based in Beijing; Rusitec Science & Technology, in Wuxi; Exact S.C., in Shenzhen; and China Electronics Technology Group Corp.'s 2nd Research Institute

[240] The companies that make wire saws include Jinggong Science and Technology, in Zhejiang Province.

[241] The companies that make EVA include SVECK Photovoltaic New Materials, based in Trina's hometown of Changzhou.

[242] The most prominent among the companies that make diffusion furnaces is the 48th Research Institute, a division of China Electronics Technology Group Corp., a state-owned conglomerate with ties to China's defense industry. Western companies continue to dominate the production of screen-printing machines and diffusion furnaces, but the 48th Institute has begun selling diffusion furnaces to one of China's top-tier producers.

[243] The companies that make cell-testing and cell-sorting machines include GSolar, in Xi'an, and HSPV Corp., in Shanghai.

[244] Op. cit., China Ministry of Industry and Information Technology

5.5.4: Chinese-Government Assessment of Strengths and Weaknesses

A particularly instructive window into the present and future of the Chinese solar industry comes from a report that the China Photovoltaic Industry Association, a trade group directly affiliated with the country's Ministry of Industry and Information Technology, issued in 2015.[245] The report examined the status of various parts of China's solar supply chain, assessing both the progress that the Chinese industry has made over time and how each segment of the Chinese industry compares to its competitors in other countries. The report's findings about the Chinese polysilicon and tooling industries are especially interesting. They underscore the Chinese government's intent to push the Chinese solar industry both to consolidate and to steadily improve the quality of its products in the face of an increasingly competitive global solar market where only the largest and most-sophisticated firms will have the wherewithal to thrive.

The trade fight over solar is remaking the global polysilicon industry.

5.5.4.1: Polysilicon

The China Photovoltaic Industry Association report contextualizes the increasing concentration in China of the global silicon market, a phenomenon explained above in Section 4.1.2. The four largest global polysilicon producers in 2014, the most recent year analyzed in the report, were China-based GCL, Germany-based Wacker, Korea-based OCI, and U.S.-based Hemlock. They collectively accounted for 60% of global production. Among China-based silicon producers, the report noted, the 10 biggest companies accounted for 91.9% of 2014 Chinese production.

Within China, the report explained, silicon production is moving to parts of the country where energy prices are lower, given that energy is by far the single biggest component in the cost of silicon production, accounting for between 39% and 46% of the cost. Small producers in China, as in other countries, are having difficulty surviving, the report noted; large firms continue to expand and to see profitability rise.

The report from the government-affiliated industry association also noted that the international trade fight over solar is remaking the global polysilicon industry. Hemlock, the top U.S. producer, has shifted its focus in the polysilicon market from the solar industry to the semiconductor sector after the Chinese government, responding to Western tariffs on Chinese-made solar cells, imposed tariffs of its own on Western-made polysilicon. Wacker remains strong in the solar-polysilicon industry after it reached a resolution in 2014 of the tariff dispute with the Chinese government. China still faces a shortfall in its ability to produce polysilicon, the report said; in 2014 the country produced 136,000 tons of polysilicon, well short of its 232,000 tons of demand. (In 2015, China produced more than 181,000 tons of polysilicon, and by the end of 2016 it is expected to have produced more than 221,000 tons of polysilicon, according to IHS Markit.)[246] The effect of the tariffs on the global polysilicon market is described further in Section 7.4.1.3.

In the future, the Chinese government said in its report, the Chinese polysilicon industry needs to innovate, improving its technology and reducing its energy consumption; it will continue to experience a shortfall of domestic supply; it will continue to consolidate; and it needs to improve the quality of the monocrystalline silicon that it produces.

[245] Op. cit., China Photovoltaic Industry Association
[246] Op. cit., IHS Markit

5.5.4.2: Solar tooling

For the Chinese solar-tooling manufacturing industry, too, the MOIIT report recommended consolidation and technological advancement. In findings largely consistent with those reflected in Appendix D, the MOIIT report noted that the Chinese solar industry buys the majority of the following types of machines from China-based makers: furnaces to produce silicon ingots, diffusion furnaces, dry-etching equipment, and tube-model PECVD machines.[247] The report said the following types of equipment are bought mostly from non-China-based companies: wire saws, wet-etching machines, high-quality equipment for making such advanced solar cells as PERC, HIT, and IBC ones; and flat-model PECVD machines, though the MOIIT report said China is making progress in domestic production of the latter.

The report advised China-based solar-tooling manufacturers to produce more-highly-automated equipment, particularly the sort with which solar-cell makers can produce higher-efficiency varieties such as PERC and HIT cells; to better tailor their machinery designs for the ways that China's solar-cell and solar-module manufacturers actually use this equipment in their factories; and to use more "smart-manufacturing" practices in the way they themselves build their equipment—practices that include "big data" and "the internet of things," the MOIIT report said.

5.6: China's Solar-Manufacturing Future

The Chinese solar industry is undergoing several fundamental structural shifts, which together have significant implications for the future of the global solar industry and for the roles that different countries are likely to play in it. An explanation of these shifts follows.

5.6.1: Corporate Consolidation

The industry is consolidating up and down the value chain—from polysilicon to wafers, cells, modules, and balance-of-system components. The consolidation is occurring in two ways. First, it is occurring within segments of the value chain: Polysilicon production, for instance, is concentrating in a handful of increasingly large players. Second, it is occurring among segments of the value chain: Companies previously focused on one segment are integrating vertically. All of this consolidation is a clearly and publicly articulated goal of China's central government, consistent with past efforts by the Chinese government to consolidate and strengthen emerging industries in the past. Consolidation also is an increasingly central strategy of China's leading solar-equipment manufacturers themselves. They see size—and the large balance sheet that size brings—as necessary to ensure themselves access to new, cheaper sources of capital and to markets both within China and beyond it.

Rather than just adding many new assembly lines, China-based solar manufacturers also are upgrading their existing lines.

5.6.2: Assembly-Line Upgrading

The industry is expanding its Chinese production capacity, but in a new way. Rather than merely adding many new assembly lines—the strategy that characterized China's solar-manufacturing growth for more than a decade—China-based solar manufacturers increasingly are upgrading their existing Chinese lines, switching out old machinery with new machinery to increase yield and efficiency. Compared to old equipment, newer equipment tends to be more energy-efficient, reducing electricity bills, which for industry in

[247] See Table 14

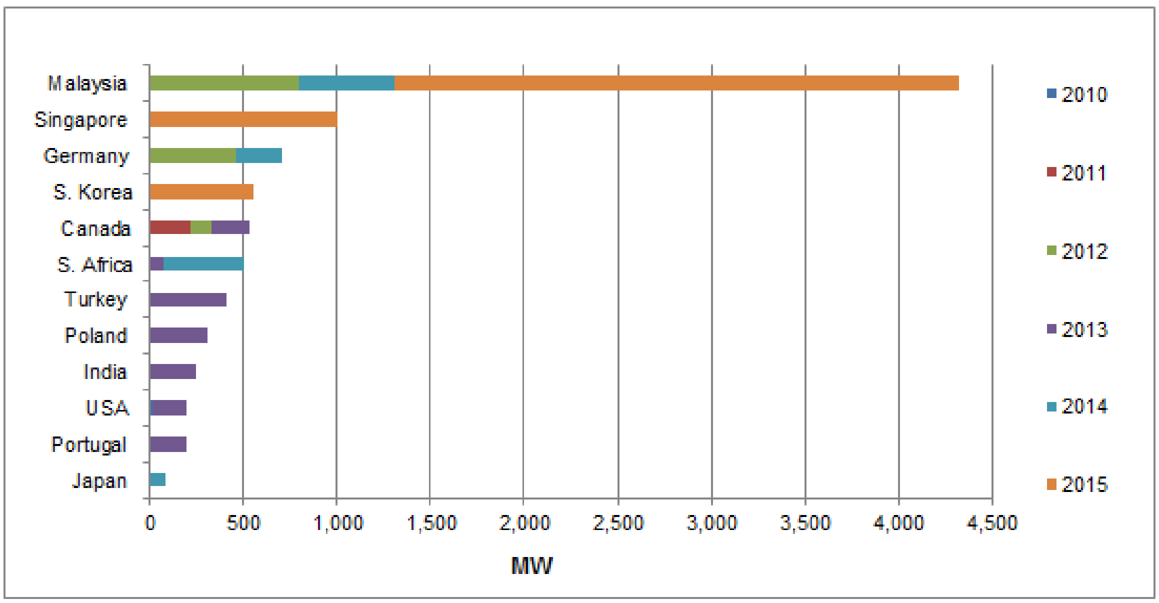
China are, by global standards, comparatively high. New equipment also is more automated and is designed for higher-capacity output, together reducing labor bills at a time when wages in China are rising. It also is more stable and precise, yielding a higher-quality finished product. This shift toward upgrading equipment in existing factories is being driven in large part by banks. These banks, chastened by past solar-market gluts, particularly a major one in 2013, have grown increasingly reluctant to finance a significant expansion of China's solar-manufacturing footprint.

5.6.3: Increased Manufacturing Abroad

China-based suppliers have begun investing aggressively in factory capacity abroad. The driver at this point is in large part market distortions created by government policy: chiefly tariffs and local-content requirements. Figures 33, 34, and 35 below trace China-based solar manufacturers' overseas production activities over time by overseas country, China-based manufacturer, and specific solar component, respectively.

As Figure 33 below shows, China-based solar manufacturers had roughly 9,100 megawatts of manufacturing capacity in operation abroad as of the end of 2015. Nearly half that amount—4,300 megawatts—was in Malaysia, a country whose generous manufacturing incentives, proximity to the Chinese mainland, and exclusion from Western tariffs make it an attractive place for China-based firms to manufacture solar equipment destined for export to the West. At least 60% of Chinese overseas manufacturing capacity as of the end of 2015 produced modules and roughly 30% produced cells.[248]

Figure 33: Annual Chinese Overseas Manufacturing Capacity Commissioned, by Country



Source: Companies; Bloomberg New Energy Finance

Note: Data excludes a 100-megawatt module factory that Suntech commissioned in 2004 in Japan and a module plant that it has decommissioned in Arizona.

[248] In addition to the overseas factory capacity that they had in operation, Chinese solar manufacturers had, as of mid-2015, announced plans to bring online another 5,700 megawatts of manufacturing capacity in Thailand, India, and Malaysia alone.

Trina's experience illustrates how tariffs are inducing China-based solar manufacturers to ramp up production abroad. In mid-2015, Teresa Tan, at the time Trina's chief financial officer, estimated that tariffs were adding approximately $0.03 per watt to the cost of modules that Trina made in China and exported to the United States. By contrast, she estimated, manufacturing outside China in countries that are not subject to the tariffs added only about $0.01 per watt to Trina's China-module-manufacturing cost.[249] As a result, Trina aims to have between 20% and 30% of its production capacity located abroad, and the company has committed $660 million to build 3,200 megawatts of factory capacity—some of it for modules and some of it for cells—in Thailand and India within the next few years.[250]

China-based solar manufacturers thus far have resisted putting factories of any scale in the United States.

Tariffs, however, are not the sole driver of the intensifying globalization of China-based solar manufacturers' operations. Several other factors are at play. One is that wages in China are themselves rising relative to those in certain other Asian countries.[251] Although manufacturing wages are five times to six times higher in leading Western markets than in China, those in Malaysia are equal to or slightly below China's, and those in India are three to four times lower than China's.[252] [253] [254] [255]

Another factor driving China-based solar manufacturers to ramp up factories abroad is the increasing automation in solar manufacturing, which makes China's traditional low-labor-cost advantage less relevant. Still another is the generous level of incentives offered in some Asian countries.[256] In addition, as described above, domestic-content rules in certain countries, though increasingly being invalidated by international trade authorities, drive China-based manufacturers to produce abroad to the extent that those rules remain in effect. Finally, the proliferation of sizable solar-deployment markets in countries around the world at some point makes it more economic to do some manufacturing in end markets beyond China. Executives at several of China's top solar-equipment manufacturers report continuing interest in relocating manufacturing to Southeast Asia, particularly Malaysia, Thailand, and Vietnam; to India; and to Central Europe.

5.6.4: Little Movement to Manufacture in the United States

China-based solar manufacturers thus far have resisted putting factories of any scale in the United States.[257] Herman Zhao, JA Solar's chief financial officer, estimated that the level of capital spending required to manufacture solar modules is between

[249] Op. cit., Teresa Tan

[250] "Trina Confirms 2 GW Indian Fab Plans"; PV Magazine; June 23, 2015: http://www.pv-magazine.com/news/details/beitrag/trina-confirms-2-gw-indian-fab-plans_100019915/#axzz4IsxYPP50http://www.pv-magazine.com/news/details/beitrag/trina-confirms-2-gw-indian-fab-plans_100019915/ - axzz4IsxYPP50

[251] The Chinese government's mandate that wages rise by 10% annually is one factor crimping its historical labor-cost advantage. Several German and Chinese equipment manufacturers have relocated to Vietnam and Malaysia.

[252] Conversation with Yingli chief financial officer in Beijing.

[253] Keith Bradsher, "Solar Rises in Malaysia During Trade Wars Over Panels," New York Times, Dec. 11, 2014.

[254] "India vs. China: The Battle for Global Manufacturing," Bloomberg Business Week; November 6, 2014: http://www.bloomberg.com/news/articles/2014-11-06/india-vs-dot-china-the-battle-for-global-manufacturing: "The hourly labor cost in India for manufacturing averages 92¢, compared with $3.52 in China, according to Boston Consulting Group."

[255] Harold L. Sirkin; Michael Zinser; Justin R. Rose. "The Shifting Economics of Global Manufacturing: How Cost Competitiveness is Changing Worldwide," Boston Consulting Group, August 2014: https://www.bcgperspectives.com/Images/The_Shifting_Economics_of_Global_Manufacturing_Aug_2014.pdf

[256] Malaysia offers a 10-year tax holiday and low-cost electricity to large foreign investors. Thailand offers a 5-7 year income tax holiday followed by a 50% tax rate for the subsequent five to seven years.

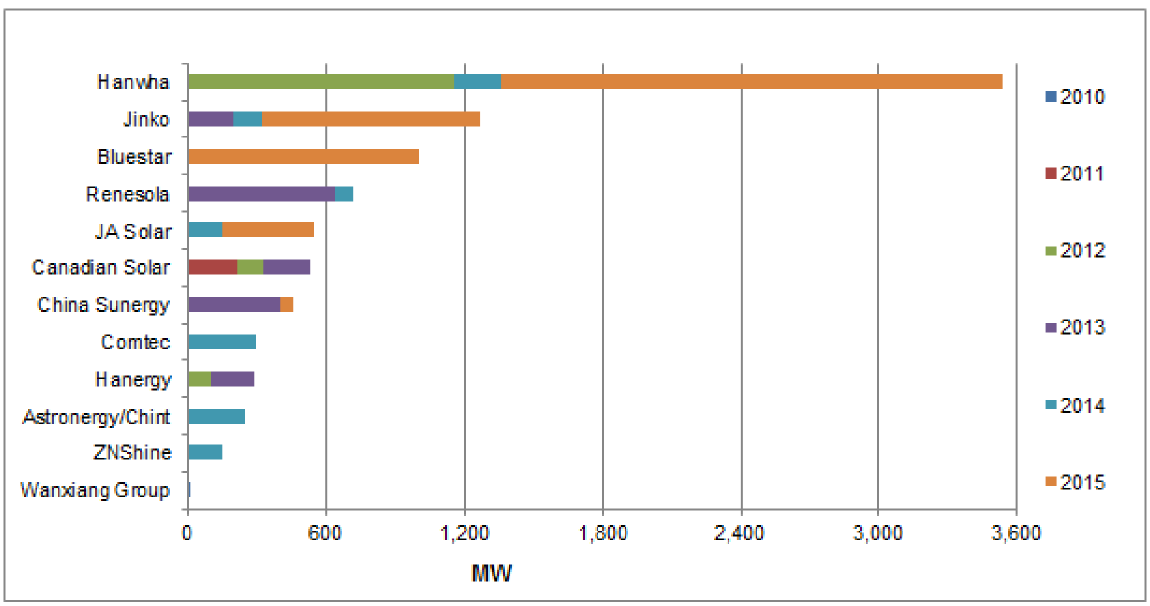
[257] Shunfeng is the only notable exception, which itself invested only $57.8 million. http://www.reuters.com/article/2015/08/13/suniva-ma-shunfeng-idUSL1N10N2X620150813http://www.reuters.com/article/2015/08/13/suniva-ma-shunfeng-idUSL1N10N2X620150813

15% and 20% higher in the United States than in China.[258] As a result, he said, "it never makes financial sense to produce anything except cells in the United States."[259] The fact that labor costs are higher and that the solar supply chain is less developed in the United States than in China further discourage Chinese investment in U.S. solar manufacturing.

Similarly, Peng Fang, the chief executive of GCL's U.S. unit, a San Francisco-based subsidiary of the firm that is engaged in developing solar projects in the United States, said that GCL over the last year explored the possibility of opening a cell and module factory in the United States but decided against the move. It rejected the move, he said, because it calculated that manufacturing in the United States would be economic only as a way to circumvent the tariffs the United States has imposed on imported Chinese-made solar goods. If GCL built a U.S. factory, and the United States then removed the tariffs at some point in the future, the price of solar modules sold in the United States would fall between 20% and 30%, he estimated. As a result, he said, GCL at that point would "lose money" on the products it was making in the United States. "It's a commercial decision," he said. "If there's no anti-dumping" tariff imposed by the U.S. government on Chinese imports, then manufacturing solar cells and modules in the United States is "not viable."[260]

Figure 33 above shows, by country, where China-based solar players are manufacturing abroad. Figures 34 and 35 below provide additional detail on China-based solar manufacturers' production outside China. Figure 34 traces overseas manufacturing activity by company. Figure 35 traces overseas manufacturing activity by component. An important explanatory note for both charts follows Figure 35.

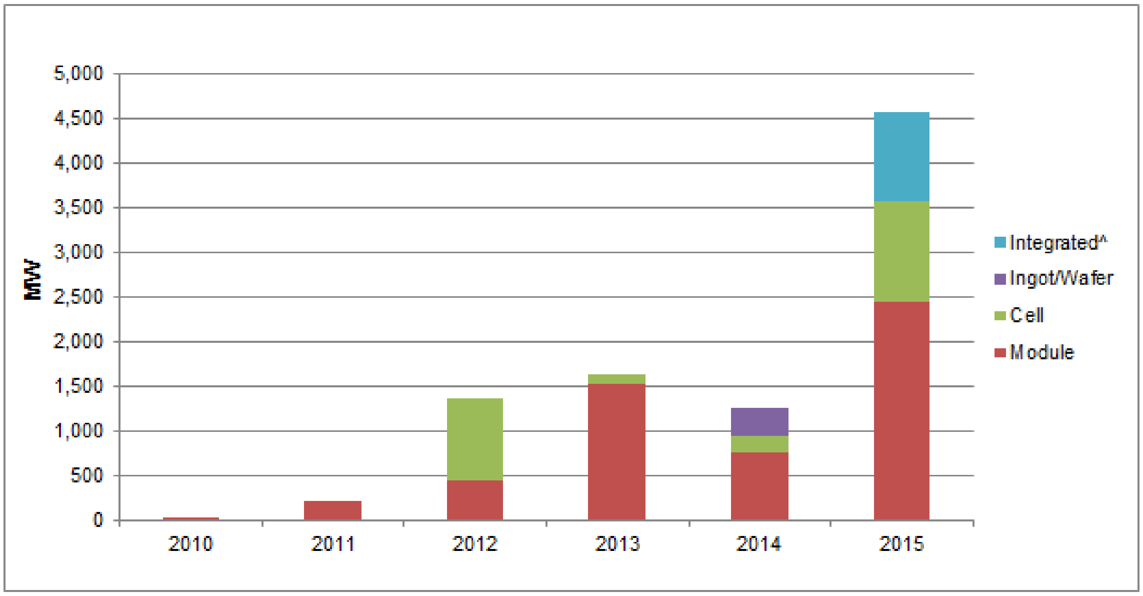
Figure 34: Annual Overseas Factory Capacity Commissioned By China-Based Solar Manufacturers at Year-End 2015, by Manufacturer



Source: Companies; Bloomberg New Energy Finance

[258] He estimated that capital spending in China ranges from ¥0.45 per watt to ¥0.50 per watt.
[259] Conversation with Herman Zhao, June 1, 2015.
[260] Conversation with Peng Fang, July 27, 2015.

Figure 35: Annual Overseas Factory Capacity Commissioned By China-Based Solar Manufacturers at Year-End 2015, by Component



Source: Companies; Bloomberg New Energy Finance

Note: Data excludes a 100-megawatt module factory that Suntech commissioned in 2004 in Japan and a module plant that it has decommissioned in Arizona. ^The '"integrated"' category encompasses a Singapore-based 1,000-megawatt wafer, cell, and module plant commissioned in 2010 by REC, which China National Bluestar (Bluestar) acquired in the first half of 2015; and 1,000 megawatts of cell and module capacity in the United States in which Shunfeng International Clean Energy acquired a 64% stake from Suniva in the third quarter of 2015.

5.6.5: Non-China-Based Companies' Involvement in the Chinese Solar Market

As China-based companies bolster manufacturing capacity overseas, select non-China-based solar players are seeking to manufacture in China. This typically occurs through joint ventures between non-China-based players and Chinese, state-affiliated firms.

This is most pronounced in the polysilicon segment. U.S. and European producers of the material are establishing factories in China. In one example, REC Silicon, the Washington State-based subsidiary of Norway's REC, has created a joint venture with China's Shaanxi Non-Ferrous Tian Hong New Energy Co. Ltd. to build a new polysilicon factory in the Shaanxi Province city of Yulin. REC reportedly undertook the joint venture to avoid tariffs imposed by China on polysilicon that REC manufactures in the United States.[261] The joint venture, called TianREC and capitalized at more than $1 billion, will produce polysilicon using fluidized-bed-reactor (FBR) technology, which consumes less energy than the traditional method of polysilicon production, known as the Siemens process. The factory was expected to have an annual capacity of more than 18,000 tons of polysilicon and to be operational by 2017.[262] [263]

To a lesser extent, U.S. firms also are investing in Chinese solar-module manufacturing. U.S.-based solar-module supplier SunPower has launched a manufacturing JV with a company in China's Inner Mongolia region. Under the arrangement, SunPower sells solar-cell packages to a joint venture with Huaxia CPV (Inner Mongolia) Power

[261] Mark Osborne, "Fluor to build REC Silicon's JV polysilicon plant in China," PV Tech, March 24, 2015. http://www.pv-tech.org/news/fluor_to_build_rec_silicons_jv_polysilicon_plant_in_china
[262] China Daily, "China-U.S. co-op to address climate change," Sept. 23, 2015. http://en.ccchina.gov.cn/Detail.aspx?newsId=55556&TId=103
[263] Sheila Barradas, "Polysilicon plant project, China," Engineering News, June 26, 2015. http://www.engineeringnews.co.za/print-version/polysilicon-plant-project-china-2015-06-26

Co., Ltd. Huaxia assembles, at a factory in Inner Mongolia, solar arrays that combine the SunPower cells with single-axis trackers and parabolic mirrors. The technology, which has been used in the United States, is being deployed at several projects in Inner Mongolia and in China's Sichuan Province. These projects in China have been developed jointly among SunPower, Apple and several China-based companies.[264]

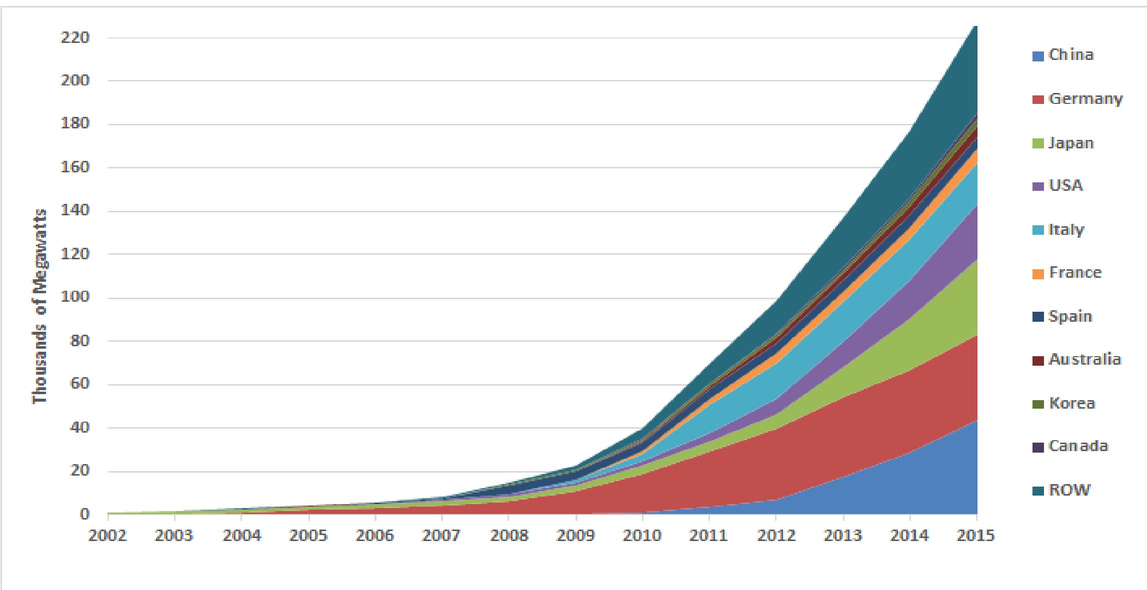
[264] "SunPower's China Joint Venture Partners with Apple to Provide Solar Power to the Environmentally-Preserved ABA Region," SunPower Corp. press release, April 16, 2015. http://newsroom.sunpower.com/2015-04-16-SunPowers-China-Joint-Venture-Partners-with-Apple-to-Provide-Solar-Power-to-the-Environmentally-Preserved-ABA-Region

Chapter 6: Deployment

6.1: Overview

Like the ramp-up of China's solar-manufacturing industry, the country's deployment of solar energy has occurred at breakneck speed. At the end of 2010, China had just 800 megawatts of solar capacity installed within its borders. By the end of 2015, that number had shot up 50 times—to 43,500 megawatts, the largest installed solar base of any country in the world.[265] In the first half of 2016, China installed an additional approximately 20,000 megawatts of solar capacity, pushing its total amount of installed solar capacity to some 63,500 megawatts.[266] In the second half of 2016, Chinese officials estimate, the country installed about 13,000 megawatts of solar capacity, bringing its total installed solar capacity to approximately 76,500 megawatts.[267] To put this into perspective, China in five years added more solar capacity than Germany, previously the world's solar leader, deployed over a period of two decades.[268] Figure 36 below illustrates China's emergence as the largest single solar market in the world.

Figure 36: Cumulative Solar Deployment Globally, By Country, 2002-2015



Source: 2002-14 data from op. cit, IEA PVPS; 2015 data from op. cit., Renewable Energy Policy Network for the 21st Century (REN21)

China's emergence as the world's leading solar-deployment market is a function of government policy that, in many cases, has driven private entrepreneurship. In that sense, China's solar-deployment model resembles its solar-manufacturing push and its increasing effort in solar R&D. That Chinese government policy began as a result of a change in policy in the countries

[265] Renewable Energy Policy Network for the 21st Century (REN21), Renewables 2016 Global Status Report.
[266] Kathy Chen, "China Installed 20 GW Of Solar Power in First-Half; Triple From a Year Ago," Reuters, July 22, 2016. http://www.reuters.com/article/us-china-solar-idUSKCN1020P7
[267] Op. cit., Zhipeng Liang
[268] Germany's cumulative installed solar capacity stood at 39,700 megawatts at the end of 2015.

that at the time were the world's leading solar deployers.

As discussed in Section 3.1, China's solar manufacturers emerged and grew by selling to solar developers primarily in Germany and other European countries. Over the past five years, however, those European countries—most notably Germany—have reduced their solar-deployment incentives, moves that have dramatically slowed solar deployment in those nations. The slowdown in deployment in Germany and a handful of other European nations, including Spain and Italy, deeply threatened China's solar-manufacturing industry. In response, the Chinese government began to ramp up a number of policies designed to build a sufficiently large domestic solar market to sustain and strengthen the Chinese solar-manufacturing industry. Those policies, as explained in Section 6.4.1, include a regionally tiered nationwide feed-in tariff, a requirement that China's grid operators buy a specified minimum amount of solar power at the feed-in-tariff premium, and renewable portfolio standards.

China has made major commitments over the past two years to reduce its greenhouse gas emissions by 2030.

In addition, China has made a series of major commitments over the past two years to reduce its greenhouse gas emissions by 2030. All of these commitments further incentivize the deployment of solar energy within China. In November 2014, Chinese President Xi Jinping began rolling out the commitments during an Asia-Pacific Economic Cooperation (APEC) meeting in Beijing with U.S. President Barack Obama. In December 2015, China reaffirmed and expanded the commitments at the global climate-change conference in Paris. China has pledged that by 2030:

- its carbon emissions will have peaked and begun to fall;
- the "carbon intensity" of its economy—the amount of carbon produced per unit of gross domestic product—will have fallen by 60% to 65% below 2005 levels;
- and "non-fossil" energy sources—essentially renewables and nuclear—will together constitute 20% of China's energy consumption. Given the vast size of China's energy system, this last commitment will require China, over the next 14 years, to deploy between 800 gigawatts and 1,000 gigawatts of non-fossil energy capacity—an addition that would be roughly the size of the United States' entire electrical capacity today.[269]

China is widely expected to remain by far the world's largest solar-deployment market for many years to come. An updated renewable-portfolio standard issued in March 2016 by China's National Energy Administration stipulates that, by 2020, 9% of China's electricity consumption should come from renewable sources other than hydropower.[270]

As explained in Section 4.5.4.1, China's Thirteenth Five Year Plan for Solar Energy Development, issued in December 2016, calls for cumulative solar-capacity deployment in China of some 110,000 megawatts by 2020, though senior Chinese government officials believe actual deployment by then will total closer to 150,000 megawatts. The wide variance among these numbers underscores the extent to which solar deployment over the next four years in China will depend on market and policy factors that are difficult for Chinese government officials to predict. Nevertheless, the high end of that range implies that China's installed solar capacity in 2020 could be roughly twice the approximately 76,500 megawatts that China had installed as of the end of 2016. Meeting that goal would require the

[269] ClimateNexus, China's Climate and Energy Policy, http://climatenexus.org/learn/international-actions/chinas-climate-and-energy-policy
[270] "China Announces Renewables Quota, But Is It Enough?" China Energy Storage Alliance, March 8, 2016. http://en.cnesa.org/featured-stories/2016/3/8/china-renewables-quota

country to add between 8,375 megawatts and 18,375 megawatts of solar capacity in each of the next four years.

Also as explained in Section 4.5.4.1, ambitious Chinese government goals target not just this increase in solar deployment but also a continued reduction in installed solar costs—a reduction of approximately half between the end of 2016 and 2020.

The surge in domestic Chinese solar deployment marks a fundamental change in the Chinese solar industry, with profound implications for the role that industries in various other countries will play. Among those implications: increased financial security for China-based solar manufacturers, who increasingly are pursuing deployment to boost profit margins; and increased opportunity for non-China-based solar players, particularly financiers, who already have entered the Chinese deployment market and are likely to do so in increasing numbers in the future. Both of these shifts are being facilitated by the Chinese government, which is adopting an increasingly sophisticated set of domestic solar-deployment incentives focused on improved economic efficiency.

China's solar enterprise has encompassed three broad stages. In the first phase, China commoditized the manufacture of vast quantities of solar equipment. In the second phase, it deployed vast quantities of that equipment within its borders. Now, in the third phase, China is attempting something more subtle and, if it succeeds, more far-reaching: to reform both its solar-R&D effort and its massive solar-deployment apparatus to make them more economically efficient. The R&D reform represents and acknowledgment by the Chinese government that its solar-R&D efforts thus far have been insufficiently productive. And China's latest attempt to reform solar deployment is about financial innovation—both in government policy and in private-investor practice. The success of both these shifts will be crucial if the world is to ramp up solar deployment to levels that contribute meaningfully to global climate reductions.[271]

6.2: History

When China entered the solar industry during the first decade of the 21st century, it operated almost entirely as a manufacturer of modules that it exported, as explained in Section 3.1. It sold them primarily to European countries in which demand for solar was rising on the backs of generous government incentives. Then the global financial crisis hit, and governments, particularly in Europe, dialed back their solar incentives as part of a reduction in spending. China-based solar manufacturers, which had massively increased their factory capacity in anticipation of a continuing rise in foreign demand, faced a crisis of overcapacity. It was then, largely to help support the Chinese solar-module-manufacturing industry, that the Chinese government began significantly incentivizing solar deployment on the mainland itself.

Initially, China's solar-deployment subsidies rewarded mere capital investment regardless of actual energy production. The country's Golden Sun Demonstration Program and its Solar Roofs Program, both launched in 2009, provided solar developers with a subsidy pegged at a set percentage of the developers' project investment. The Chinese government quickly determined that these subsidies, in rewarding mere investment, encouraged abuse and needed to be reformed.

In 2011, China shifted its focus to a different sort of solar-deployment subsidy: a national feed-in tariff. Much like feed-in tariffs already in place in Germany and other markets, China's guaranteed solar power producers a minimum price for the electricity they sold into the grid—a price above the prevailing government-set power rate.[272]

China set the feet-in-tariff rate at ¥1.15 ($0.17) per kilowatt-hour for solar projects in Tibet, an area of China in which the government wanted to

[271] Research on the extent of global solar expansion that would be necessary to meaningfully address global climate targets is explained in Sections 1.1, 7.2.1, and 7.3.1.

[272] China had implemented its first solar feed-in tariff six years earlier, in 2007. But that measure failed to spark much solar deployment.

encourage development, and for projects anywhere in the country that were approved before July 1 that year and completed by the end of the year. For those projects that fell into neither of those categories, the government set a lower feed-in-tariff rate of ¥1 ($0.15) per kilowatt-hour.

Just as China's feed-in-tariff was taking effect, seeding what would become a thriving domestic solar-deployment market, came the October 2011 filing by SolarWorld AG's U.S. arm and six other U.S. based solar manufacturers of formal complaints that China-based solar manufacturers were violating international trade rules.[273] Those tariffs against Chinese-made solar exports to the United States that resulted from those trade complaints underscored to Chinese officials how crucial it was for them to develop a domestic solar market as a way to preserve the profitability of China's solar manufacturers.

In 2013, China restructured its feed-in tariff in an attempt to equalize the rate of return that solar-project investors received regardless of the quality of the solar resource in the part of the country where they developed their project. The restructuring established three geographically focused tiers for the rates that solar-power producers would receive for their electricity. The new rates ranged from ¥0.90 ($0.13) per kilowatt-hour to ¥1 ($0.15) per kilowatt-hour. Investors received the higher rates for projects in less-sunny areas and received the lower rates for projects in sunnier areas. The Chinese government's goal in setting the feed-in tariff at these rates was to produce a minimum rate of return of 8% for investors in solar projects, regardless of where in the country the project was located.[274] Importantly, the restructuring also required the country's grid operators to buy all the solar power that solar generators produced.

Fueled by the feed-in tariff, China's solar-deployment market has surged. During 2015, China added 15,150 megawatts of solar capacity, raising the country's total installed capacity by year-end to the 43,500-megawatt level that surpassed Germany's installed solar base.[275] By comparison, the United States, which in 2015 also had a record-breaking year of solar-capacity installations, added during the year approximately half as much new solar capacity—7,300 megawatts—as China did. The United States ended the year with a cumulative installed solar capacity of 25,000 megawatts—58% of the level in China.

China's solar-capacity expansion continues at a rapid pace. As noted in Section 6.1, in just the first half of 2016, the country added 20,000 megawatts of solar capacity, pushing its total installed base to approximately 63,500 megawatts.[276] That first-half installation rate represented more than a doubling of China's full-year 2015 deployment pace—an increased spurred by developers' rush in the first half of 2016 to beat a reduction in China's solar feed-in tariff that took effect on June 30, 2016. And in the second half of 2016, Chinese officials estimate, China installed an additional 13,000 megawatts of solar capacity, bringing the country's installed base to some 76,500 megawatts.

6.3: Challenge: Curtailment

One significant problem impeding solar deployment in China has been what is known as curtailment: the rejection by China's grid operators of a portion of the electricity that China's solar projects generate. In some cases that rejection results from the fact that the electricity grid has failed to expand enough to accommodate the added power from new solar installations. In some cases it results from the fact that power demand in a given region has not expanded enough to use the added power from new solar installations. Curtailment tends to occur most in the afternoon when the sun is shining brightest.

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[273] The trade complaints and the resulting tariffs are explained in Section 5.3.1.
[274] Op. cit., Zhipeng Liang
[275] The 15,150-megawatt addition was below the 17,000-megawatt target that the Chinese government had set for 2015. Nevertheless, it marked a record one-year level of solar installations for any country ever.
[276] Op. cit., Kathy Chen, Reuters

Curtailment typically becomes a bigger problem on a grid as the amount of solar capacity connected to the grid increases.

China's solar deployment is concentrated overwhelmingly in a handful of provinces, many of them in rural areas located far from the population centers that need electricity and in areas where transmission development has not kept pace with renewables deployment and there is little storage capacity. In some of those provinces—notably Gansu, Xinjiang, and Jilin—solar-curtailment rates have approached 30%, according to several informed people in the Chinese power industry. Curtailment became a particular problem in 2014, when two unrelated forces conspired. On the one hand, the country's newly expanded feed-in tariff was incentivizing companies to build solar projects at a feverish pace. On the other hand, the Chinese economy was slowing, which meant that power demand was flattening in some parts of the country and actually declining in others. Nationwide, Chinese electricity demand grew less than 1% in 2015, down from annual growth rates of 5% or more a few years earlier. In one illustrative example, in Qinghai Province, a region in Western China with strong solar resources and a massive collection of solar projects, electricity demand in 2015 plummeted 8%. The reason: Due to the slowing Chinese economy, an aluminum plant, one of the province's biggest electricity consumers, shut down.[277]

In some provinces—notably Gansu, Xinjiang, and Jilin—solar-curtailment rates have approached 30%.

Today, Chinese electricity-grid officials seek to curtail no more than 5% of solar power produced in a given province.[278] [279] Nevertheless, some officials expect that it will be difficult for China to reduce curtailment below 10% in certain provinces in the next year or two.[280] Ultimately, reducing curtailment of solar power in China will require adding more high-voltage transmission and introducing storage at scale. China is working on both efforts.

With this as a backdrop, this chapter focuses on two aspects of solar deployment in China. One is the Chinese government's effort to reform its support structure for domestic solar deployment in an effort to make it more economically efficient. The other is the rapidly increasing deployment undertaken by China's solar-equipment manufacturers.

6.4: Goal: Increased Economic Efficiency

As noted in Section 6.1, China seeks by 2020 to grow its solar deployment significantly—according to some government officials, by a factor of more than three. Whatever the actual number is in 2020, reaching it will be a challenge even for China, a country accustomed to breaking records for industrial growth.

To deploy solar capacity at such levels, the Chinese government has concluded, China will have to get more efficient in the way it spends its solar-deployment capital. Developing more-efficient solar-deployment tools—through government policy and through private investment mechanisms—represents the latest and perhaps the most innovative stage in China's solar-deployment effort. Three aspects of this attempt to increase the efficiency of solar-deployment capital are particularly noteworthy: reform of China's feed-in tariff; reform of China's solar-project approval process; and the introduction of a variety of new solar-deployment financing mechanisms.

[277] Discussion with senior executive at State Grid's China Electric Power Research Institute, November 2015.
[278] Ibid.
[279] Op. cit., Zhipeng Liang.
[280] Ibid.

6.4.1: Feed-In-Tariff Reform

One key aspect of China's attempt to improve the economic efficiency of its solar deployment is its move to reform its major demand-side solar subsidy, the feed-in tariff. The attempted reform reflects solar-policy lessons that China has learned from other countries, including several in Europe and in Latin America. In a four-part move, the government is:

- Reducing the rate of the feed-in tariff—a recognition that the extent of the subsidy should shrink as solar's capital costs fall
- Increasing the pool of public money that funds the feed-in tariff—an effort to subsidize, at these newly reduced rates, the installation of a greater amount of solar capacity
- Increasing the amount of solar power that grid operators are required to buy from solar-power producers at the feed-in-tariff rate—an attempt to minimize the waste of feed-in-tariff funds that occurs when solar power subsidized by the feed-in tariff is curtailed
- Introducing a bidding procedure known as "auctioning" to pressure solar-power producers to sell their power into the grid at lower prices.

Each of these four aspects of China's feed-in-tariff reform is explained below.

6.4.1.1: Reducing China's Feed-In-Tariff Rate

As of June 30, 2016, China's solar feed-in tariff dropped from the previous range of between ¥0.90 ($0.13) per kilowatt-hour and ¥1 ($0.15) per kilowatt-hour to a lower range of between ¥0.88 ($0.13) per kilowatt-hour and ¥0.98 ($0.14) per kilowatt-hour.[281] This move cut the feed-in-tariff rate that solar-power producers receive by between 2% and 11%, depending on where in China's three solar-resource-pegged regions a company's project is located. This reduction in the feed-in tariff, moreover, is just a start.

The government in December 2016 announced further, and larger, cuts in the feed-in tariff. The new rates reduce feed-in-tariff prices for solar from the range of ¥0.88 ($0.13) per kilowatt-hour to ¥0.98 ($0.14) per kilowatt-hour to a range of ¥0.65 ($0.09) per kilowatt-hour to ¥0.85 ($0.12) per kilowatt-hour. These new feed-in-tariff rates represent a drop of between 13% and 26% and from the rates that were in effect in 2015—a significant decrease.[282] [283]

The planned reductions in the feed-in tariff produced torrid solar-project development in China in the first half of 2016 by developers who wanted to lock in the feed-in tariff before it fell. Many in China's solar industry predict a similar policy-driven rush to develop solar projects in China in the first half of 2017. That is because the lower feed-in-tariff rates announced by the government in December 2016 apply to solar projects on which construction finishes after in July 2017 or after. Projects on which construction finishes by the end of June 2017 will qualify for the previous, more-generous feed-in-tariff rates. Given the likelihood of this rush to develop projects before the lower feed-in-tariff rate takes effect, Mr. Liang, the deputy director-general of the National Energy Administration for new and renewable energy, predicted that solar

[281]Enerdata, Dec. 21, 2015. http://www.enerdata.net/enerdatauk/press-and-publication/energy-news-001/china-revises-solar-and-wind-feed-tariffs-2016_35469.html

[282] "National Solar PV Electricity Generation and Tariff Schedule," China National Development and Reform Commission, December 2016. http://www.sdpc.gov.cn/zcfb/zcfbtz/201612/W020161228326730780306.pdf

[283] The feed-in-tariff reduction announced in December 2016 was less aggressive than a reduction proposed by the government in a draft plan earlier in 2016. The draft plan envisioned reducing the feed-in-tariff from the range of ¥0.88 ($0.13) per kilowatt-hour to ¥0.98 ($0.14) per kilowatt-hour to a range of ¥0.55 ($0.08) per kilowatt-hour to ¥0.75 ($0.11) per kilowatt-hour. That would have represented a drop of between 25% and 38% from the 2015 rates.

deployment in China in the first half of 2017 will total some 15,000 megawatts.[284]

Like its solar feed-in tariff, China's wind feed-in-tariff also was reduced in 2015. The Chinese government has decided that it will reduce the wind feed-in tariff again in 2018. It has not yet decided whether it will reduce the solar feed-in tariff again in 2018.

The Chinese government will face a shortfall between what it collects and owes under the renewable-energy feed-in tariff.

6.4.1.2: Raising China's "Renewable-Energy Surcharge"

In January 2016, the government raised the country's "renewable-energy surcharge." The levy, assessed on electricity consumers in China, creates the pool of money that the government uses to pay renewable-energy producers what they are due under the country's feed-in tariff. The government raised the surcharge from 1.5 fen (0.23 cents) per kilowatt-hour of consumption to 1.9 fen (0.29 cents) per kilowatt-hour of consumption, a 27% increase.[285]

At the previous surcharge level, the government collected approximately ¥50 billion ($7.3 billion) annually to disburse under the feed-in tariff. Under the new, higher surcharge level, the government expects to collect ¥70 billion ($10.2 billion) to disburse each year.[286]

The rationale for raising the surcharge was that, historically, the pool of money created from surcharge revenue was not large enough to cover the government's obligations to renewable-energy producers under the feed-in-tariff. As a result, the government had to find money to cover the shortfall from elsewhere in the national budget. One consequence of that shortfall has been that the government has been slow in paying renewable-energy producers what they are due under the feed-in tariff. Solar firms in China widely complain about that slowness; although the government ultimately does pay what it owes, they say, the time it takes for the government to make those payments impedes corporate cash flow, which, given the time value of money, hurts the solar-deployment business. Chinese government officials concede that problem. Even with the 2016 increase in the renewable-energy surcharge, estimates Mr. Liang of China's National Energy Administration, the Chinese government will face an annual shortfall of about ¥30 billion ($4.4 billion) between the amount that it collects from electricity consumers under the surcharge and the amount that it owes renewable-energy producers under the feed-in tariff. "It's still a problem. Not enough money," he said. "We are now considering new models" to increase government revenue to cover feed-in tariff obligations, he added, "but we have not figured it out" yet. One strategy might be an additional increase in the renewable-energy surcharge, though officials at China's National Development and Reform Commission, the country's economic-planning agency, worry that an additional hike in the fee will spur public resistance.

6.4.1.3: Increasing Requirements for Grid Off-take of Solar

In summer 2016, in a potentially significant move for the expansion of solar deployment in China, the Chinese government announced that it was raising the minimum amount of electricity from renewable sources that China's grid operators will be required to buy at the feed-in-tariff rate. Each year, grid operators will be required to buy at the

284 Op. cit., Zhipeng Liang

285 Feifei Shen, "China to Increase Wind, Solar Power Capacity by 21 Percent in 2016," Bloomberg, as republished in Renewable Energy World, Jan. 1, 2016. http://www.renewableenergyworld.com/articles/2016/01/china-to-increase-wind-solar-power-capacity-by-21-percent-in-2016.html

286 Op. cit., Zhipeng Liang.

feed-in-tariff rate the equivalent of between 1,300 hours and 1,500 hours of a solar project's output at full capacity.[287] That equates to approximately 15% of the number of hours in a year—roughly the same percentage as the solar capacity factor that prevails on average in China. Under the new policy, if a grid operator fails to buy this minimum amount of feed-in-tariff-rate power from a solar project, then the solar project's operator will receive an amount of money equivalent to the difference between its revenue from the power that it did sell and the revenue that it would have received had it been able to sell the full minimum amount of power as specified by the government. The money to cover that gap will come from producers of non-renewable energy on the relevant power grid.

If, on the other hand, a solar project generates more electricity in a given year than the amount specified under the new government rule, the project will sell that power to the grid not at the feed-in-tariff price but at the prevailing market price.

This new policy, in effect, reduces the amount of premium-priced electricity that China's grid operators are required by the government to buy from China's solar producers. It comes in part in response to complaints from China's grid operators that the earlier policy—requiring the grid operators to buy all solar generation at the feed-in-tariff rate—was too expensive. The new policy is designed to reduce the price of solar power in two respects. First, the government believes that (1) the grid operators are likelier to adhere to the requirement that they buy a smaller number of hours' worth of premium-priced solar than grid operators did to the unlimited previous requirement; (2) that adherence should give banks that lend to solar projects greater confidence in the projects' future revenue stream; and (3) that confidence should induce the banks to lend to the projects at lower interest rates, thereby reducing the projects' financing costs and helping the Chinese solar industry grow. Second, the government reasons, the new policy ensures that solar power generated beyond the 1,300-to-1,500-hour threshold will be sold at conventional, not feed-in-tariff, prices.[288]

6.4.1.4: Introducing Auctioning to Trim Deployment Costs

In another potentially significant reform of the Chinese solar market that is intended to drive down costs, the government in 2016 introduced auctioning as a way to choose which companies will get the opportunity to develop solar projects across the country. The move toward auctioning is part of the Chinese government's broader push for consolidation of the solar industry. The theory is that bigger companies—that is, companies that have greater internal economies of scale—will be better positioned to bid lower power prices at the solar-project auctions. This auctioning effort contains two parts: a nationwide plan and a provincial-level plan.

The nationwide plan applies to very large solar developments: those with total capacities of 500 megawatts or above. For these installations, the National Energy Administration conducts the auctions. In the first ten months of 2016, the government conducted national auctioning for eight solar mega-developments, called "bases." Each base contains at least five individual "projects." Each project will have a capacity of approximately 100 megawatts. All told, the government expects the mega-development auctioning to cover several thousand megawatts of solar deployment across the country per year. The auctioning appears to be reducing solar prices even more than the government anticipated. Before the auctioning, the government expected that this national auctioning would reduce the rate paid to those projects by between ¥0.05 ($0.01) and ¥0.10 ($0.01) per kilowatt-hour below the 2016 feed-in-tariff rate. In fact, the auctions in 2016 have reduced the rate as much as ¥0.35 below the feed-in-tariff rate. Mr. Liang, of China's National Energy Administration, predicted the

[287] The range was set to account for the difference in the solar resource across China; solar projects in areas with a better solar resource will be assured the right to sell to the grid a minimum number of hours of full-load output that is toward the higher end of that range.
[288] Op. cit., Zhipeng Liang

winning tariffs in auctions for projects in parts of China with good solar resources will be approximately ¥0.60 ($0.10) per kilowatt hour.[289]

The Chinese government is attempting to reduce deployment costs through a range of innovative solar-financing measures.

The separate provincial-level auctioning plan applies to projects with individual capacities of between 10 and 100 megawatts. The central government anticipates that, all told, the provincial-level auctions it will cover up to 10,000 megawatts of solar projects in China per year. The precise rules of provincial-level auctioning will be up to officials in each province. But, according to Chinese officials, provincial officials will consider a variety of factors in a company's bid. Price will be one factor, with lower-price bids getting more-favorable reception. Other factors will include the number of jobs a project will bring to a province.

6.4.1.5: New Procedure for Solar-Project Approval

Beyond restructuring the feed-in tariff itself, China also has reorganized the process by which the government decides which solar projects can qualify for the subsidy.

In 2014, as part of Chinese President Xi Jinping's anti-corruption push, China's central government changed the way solar-project approval is done in the country. Under the new system, like under the old system, at the start of each year the central government issues nationwide solar-deployment targets, and in the middle of the year it allocates deployment targets to the provinces based on those national targets. Under the new system, however, the provinces, rather than the central government, have authority for granting project-specific approvals.

Once a solar developer identifies a site for a solar project, the developer applies to the local government for approval. Once the local government has approved potential projects, it is up to the provincial government to select which of those will receive the central-government feed-in-tariff subsidy—effectively a prerequisite for the projects to be built. The provincial government selects the winning projects through the auctioning system described above.[290]

6.4.2: New Solar-Deployment Financing Mechanisms

In addition to far-reaching reforms of its feed-in tariff, the Chinese government is attempting to reduce solar-deployment costs through a range of innovative financing measures. Some of these measures involve China's existing slate of solar financiers, primarily large banks. Other measures seek to attract to China's solar industry new sorts of financiers, notably pension funds and insurance companies, including those from abroad. These attempts by the Chinese government come on top of efforts by several of China's large solar manufacturers to employ new solar-deployment financing techniques, some of which have faced market resistance.

The Chinese government has begun convening a consortium of players with an eye toward formulating ways to reduce financing costs for solar projects in the country. This initiative, called the Alliance for Solar Power Advancement and Financing, is in its early stages. It seeks to enable member entities to secure third-party certification to access more financing.[291] In addition, Chinese and U.S. government officials have been discussing innovative ways of solar-finance cooperation under the auspices of the U.S.-China Renewable Energy Partnership, a bilateral organization established by the two countries in 2009.[292]

[289] Ibid.
[290] Ibid.
[291] Ibid.
[292] U.S.-China Renewable Energy Partnership web page, http://www.U.S. National Renewable Energy Laboratory.gov/international/uscrep.html

Another area of interest in China is using government loan guarantees to help solar developers get bank financing for their projects. Small city-level pilots of this structure recently have been launched. In 2016 in Shanghai, for instance, the municipal government, in the case of a handful of solar projects, provided a guarantee for the loan that the project's developer takes out from the bank. The interest rate for the loans is approximately 5%. Without the government loan guarantee, Mr. Liang said, the developers probably would not be able to persuade a bank to give them a loan, because the developers lack sufficient assets to use as collateral. Two banks are involved: The Bank of Shanghai and the Shanghai branch of the Bank of Beijing. So far, just three commercial rooftop solar projects have been financed as part of the pilot. One of them is the Shanghai Energy Efficiency Center, an arm of the Shanghai government that conducts energy-efficiency research and promotes energy-efficiency projects. More projects have applied for the loan guarantees to finance solar installations under the program. The government expects this approach will expand.[293]

6.4.3: New Financial Structures for Deployment

Chinese banks are aggressively supporting domestic solar deployment, much like they aggressively supported domestic solar manufacturing over the past decade. The China Development Bank financed approximately half of the 43,500 megawatts of solar capacity that China had deployed as of the end of 2015. Senior Chinese government officials estimate that the cost of deploying 1 kilowatt of utility-scale solar capacity in China is approximately ¥7,000 ($1,015.30).[294] This implies that the CDB financed approximately ¥304.5 billion ($44.2 billion), in domestic solar deployment. Prevailing interest rates on these deployment loans were approximately 7% in the early years of large-scale solar deployment in China; the rates have fallen to approximately 5% today.[295]

Jinko in 2015 received at least $781 million in loans for project deployment in China.[296] [297] [298] [299] In the same year, Trina received new loan facilities to finance between 500 megawatts and 1,000 megawatts of Chinese project capacity within three years.[300] Said JA Solar's chief financial officer: "Downstream in China is much easier than abroad. The Chinese market is a relatively stable growth environment."[301]

China-based solar manufacturers are embracing a range of new structures to finance their solar deployment:

6.4.3.1: Yieldcos

Several China-based solar manufacturers at one point embraced the idea of yieldcos, though recently most have abandoned those plans. A yieldco is an investment vehicle spun off from a parent company to own assets, such as solar projects, and provide cheap capital to acquire more assets. Solar companies initially created yieldcos to help reduce transaction costs in expanding their market share. The yieldco structure is designed to provide several benefits. In theory, it is a way to erase tax liability at the corporate level, though in practice yieldcos

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293 Op. cit., Zhipeng Liang

294 Ibid.

295 Ibid.

296 "JinkoSolar Signs US$90 Million Working Capital Loan Agreement with China Development Bank," Jinko press release, Jan. 7, 2015: http://jinkosolar.com/press_detail_1022.html

297 "JinkoSolar Power Co. Ltd. Signs RMB 320 Million Loan Agreement with China Development Bank for Projects in Hengfeng County, Jiangxi Province," Jinko press release, March 10, 2015: http://jinkosolar.com/press_detail_1034.html

298 "Jinko Power Signs RMB 3 Billion Line of Credit Agreement with Ping An Bank," Jinko press release; July 28, 2015: http://jinkosolar.com/press_detail_1071.html

299 "Jinko Power Signs $150 Million Financing to Expand Project Portfolio," Jinko press release, July 16, 2015: http://www.nasdaq.com/press-release/jinko-power-signs-150-million-financing-to-expand-project-portfolio-20150716-00203

300 "Trina Solar Announces Partnership with PingAn Trust and Jiuzhou Investment to Develop Photovoltaic Power Plants," Trina press release, Feb. 12, 2015. http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-newsArticle&ID=2016039

301 Conversation with JA Solar financial officer, June 1, 2015

sometimes still face some corporate tax liability.[302] In addition, the yieldco structure allows a company to provide investors with a steady stream of dividends from the cash flow of the project—and it can minimize the individual tax that investors face on those dividends. As a result, the yieldco structure allows a company to raise capital less expensively.[303]

Several leading China-based solar manufacturers announced plans over the past few years to establish yieldcos. But they have backed off those plans following the high-profile crashes of several U.S. solar yieldcos in 2016. The most notable is U.S. solar player SunEdison. In summer 2015, it launched TerraForm Global, a yieldco intended to acquire renewable-energy assets in developing countries including China and India. In early 2016, however, SunEdison, whose debt was ballooning, filed for bankruptcy protection. It remains embroiled in a legal battle with TerraForm Global and other SunEdison entities, and the future of SunEdison's yieldco activities remains in question.

Trina established a project company, Jiangsu Trina Solar Power Investment & Development Co., in late 2014; that constituted the necessary first step for forming a yieldco. However, Trina has altered those plans. In September 2015, the company said it planned not a yieldco but a "growthco," a structure that it said it thought was a better way to fund downstream growth, particularly in China. Delays in China in government subsidy payments to solar firms and serious curtailment problems make it difficult for a solar firm to pay the reliable dividends that are an intrinsic part of the yieldco structure, company officials suggested. By contrast, under a growthco, cash from existing solar projects could be invested in new projects.[304] After those plans, though, the company proceeded with privatization plans, culminating in December 2016 in vote by shareholders approving the privatization plan, as explained in Section 3.2. How that privatization will affect the prospects for a Trina growthco is unclear.

Jinko too in November 2014 announced plans to form a yieldco, which likely would have involved spinning off its downstream subsidiary, Jinko Power, in the United States or Hong Kong.[305] However, the company later decided against pursuing those yieldco plans, and in late 2016 the company agreed to sell for $250 million a controlling stake of its unit that develops and operates solar projects in China to a group of investors led by Jinko Chairman Xiande Li.[306]

And Canadian Solar announced plans in early 2015 to form a yieldco, which would be fueled by project assets acquired through Canadian Solar's takeover of U.S. solar-project developer Recurrent Energy.[307] However, Canadian Solar announced in mid-2016 that it had made a "strategic decision to no longer pursue" a yieldco, a reflection of "the market environment," it said.[308]

The fact that several leading China-based solar manufacturers pursued plans for yieldcos—and later abandoned them—is just one indication of the extent to which the Chinese solar industry is, for better or worse, looking to the United States for financial innovation. A deeper discussion of China's interest in U.S. solar-finance innovation, and recommendations about how to pursue that opportunity, is in Section 7.5.2.

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[302] In this sense, a yieldco seeks to mimic another tax-advantaged corporate structure, the master limited partnership, or MLP. A yieldco, however, lacks the full corporate-tax shield of an MLP.

[303] U.S. National Renewable Energy Laboratory, "A Deeper Look Into Yieldco Structuring," https://financere.U.S. National Renewable Energy Laboratory.gov/finance/content/deeper-look-yieldco-structuring

[304] "Trina Plans IPO of 'Growthco' to Manage Solar Farm Developments," Bloomberg, Sept. 11, 2015, https://www.bloomberg.com/news/articles/2015-09-11/trina-plans-ipo-of-growthco-to-manage-solar-farm-developments

[305] John Parnell, "Jinko Yieldco Could Float in U.S. or Hong Kong," PV Tech, Nov. 20, 2015: http://www.pv-tech.org/news/jinko_yield_co_could_float_in_us_or_hong_kong

[306] "JinkoSolar Enters Into Definitive Agreement for the Sale of Jinko Power Downstream Business in China," Jinko press release, Oct. 11, 2016. http://ir.jinkosolar.com/zhen/en/press.php

[307] Aisha Abdelhamid, "Canadian Solar Yieldco IPO on the Way," CleanTechnica, March 22, 2015. http://cleantechnica.com/2015/03/22/canadian-solar-yieldco-ipo-on-the-way/

[308] "Canadian Solar Second-Quarter-2016 Earnings Results Filing With U.S. Securities and Exchange Commission," Canadian Solar, Aug. 18, 2016. http://investors.canadiansolar.com/phoenix.zhtml?c=196781&p=irol-sec

6.4.3.2: Financial Leasing

Financial leasing remains in its early stages in China, but it offers strong potential to improve companies' operating cash flow, increase the liquidity of project assets, and obviate large up-front expenditures during project development.

Under financial leasing, an investor (or a group of investors) develops a solar project for a company and then leases the project to that company, which is called the lessee. The lessee typically gets the revenue generated by the solar project's electricity sales, assumes certain risks of owning the project, and gets the option to buy the project at some future date. This arrangement can improve balance sheets, allowing the lessee to develop more solar projects or make additional investments of other types.

This type of financial leasing, in China and elsewhere, typically occurs with utility-scale solar projects. In the United States, a variant of financial leasing has gained popularity to finance a different sort of solar project: rooftop arrays either on homes or on business buildings. Under this variant, commonly called "solar leasing," a solar developer pays to install a solar array on the roof of a home or business, and it agrees to sell power to the owner of the home or building at a specified rate for a specified number of years. The developer assumes the potential financial upside and downside of selling power from the array into the electrical grid. SolarCity, for example, has built its business on this model.

In China, Jinko plans to develop solar power in part through the traditional financial-leasing model. In March 2015, Jinko reached an agreement with China Development Bank Leasing Limited (CDBL) under which CDBL would provide financing for at least 200 megawatts of new Chinese solar-project capacity annually for five years; CDBL and Jinko will sign financial-leasing contracts for specific projects.[309] This model has the potential to tap into a broader and more retail-oriented customer base in China. A Jinko executive confirmed in December 2016 that the financial-leasing arrangement remains underway and would not be affected by the company's plans to sell its China-project-development-and-operation business to the investor consortium led by Mr. Li, the Jinko's chairman.

6.4.3.3: Convertible Loans

Convertible loans are a type of debt under which the company that borrows the debt has the option to avoid paying back part or all of the principal by, instead, giving the lender an equity share in the company—an equity share whose value equals that of the debt.

Trina adopted this strategy in February 2015 in investment agreements it signed with Ping An Trust and Jiuzhou Investment. The agreements call for co-development within the next three years of between 500 megawatts and 1,000 megawatts of solar projects in China. Ping An will take stakes of up to 49% in each project.[310] Trina is, through these deals, effectively trading long-term project returns for short-term gains in the form of inexpensive financing and a foothold in deployment. This approach has been popular in the past among cash-strapped China-based manufacturers, particularly in 2012, when the industry faced deep financial troubles.

6.5: Future Force: Deployment by China-Based Solar Manufacturers

China's solar manufacturers are a small but growing—and globally influential—driver of the country's massive deployment of solar power.

The majority of China's solar capacity has been installed by state-owned power companies and independent power producers—companies whose primary business is electricity generation. China's largest state-owned power companies, in line with government policy, have grown increasingly

[309] "Jinko Power Signs Strategic Project Development Agreement with China Development Bank Leasing Limited," Jinko press release, March 18, 2015: http://jinkosolar.com/press_detail_1036.html

[310] "Trina Solar Announces Partnership with PingAn Trust and Jiuzhou Investment to Develop Photovoltaic Power Plants," Trina press release, Feb. 12, 2015: http://ir.trinasolar.com/phoenix.zhtml?c=206405&p=irol-newsArticle&ID=2016039

aggressive in deploying solar projects in the country. For example, China Longyuan Power Group, a subsidiary of China Guodian Group, one of the country's top five state-owned power producers, has become the country's top wind-power producer and also one of its largest solar-power producers. It has been particularly active in solar deployment in western China, particularly in Qinghai Province, home to some of China's best solar resources and some of its largest solar farms.

Private investment groups also are becoming major solar deployers in China. One such firm, China Minsheng New Energy Investment Co., is developing in the Ningxia region of northwest China what will, if finished according to plan, be one of the biggest solar projects in the world. The solar farm is slated to have a capacity of 2,000 megawatts; as of mid-2016, half of the project had been constructed and roughly 380 megawatts of its capacity had been connected to the grid, according to Minsheng, which has said it intends to spend ¥100 billion ($14.5 billion) over the next five years to deploy some 12,000 megawatts of solar capacity.[311]

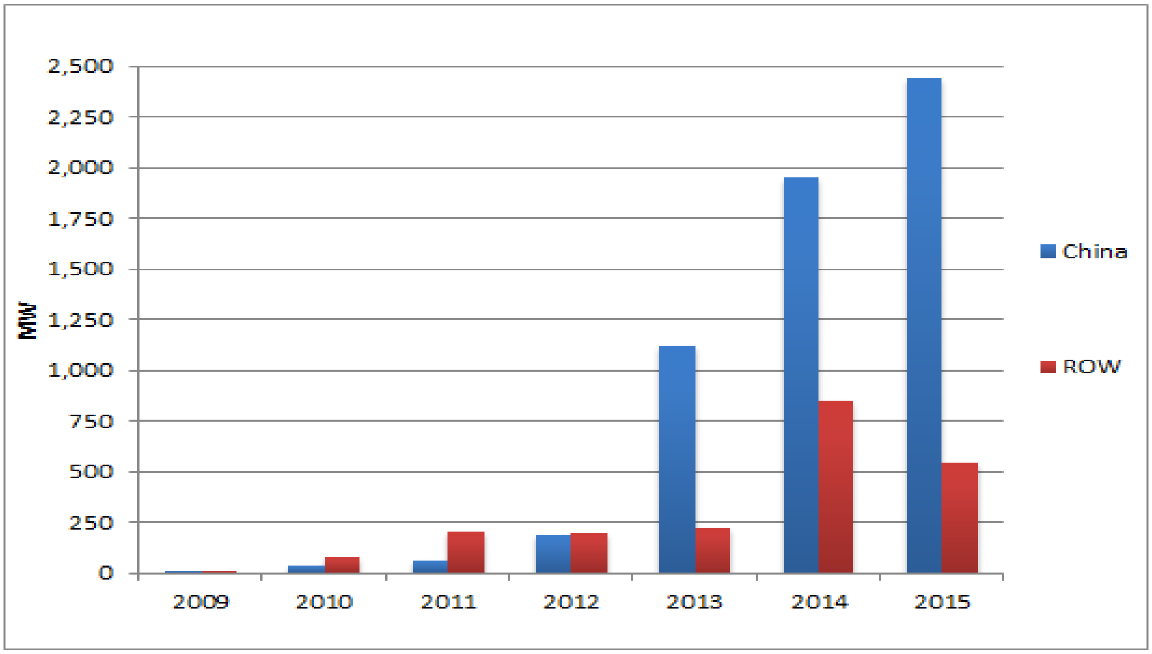
China's domestic solar-equipment manufacturers were responsible for only approximately 13% of China's total installed solar capacity at the end of 2015: As indicated below in Figure 37, they were responsible for 5,800 megawatts of the 43,500 megawatts of solar capacity installed in China at that point.

Even though deployment by China's solar manufacturers represents a small slice of China's total solar deployment, it is of particular relevance both because the slice is getting bigger and because it constitutes a major new force shaping the solar industry both in China and around the world. Deployment is a way for these manufacturers to expand demand for their modules in an increasingly competitive market. It also typically offers them higher profit margins than their manufacturing does. Deployment is increasingly important to the bottom lines of China's top solar manufacturers—companies that are defining the global solar industry's future. As a result, this section examines solar deployment by China's solar manufacturers.

Today, as Figure 37 below indicates, China's solar manufacturers are focusing most of their deployment within China.

[311] "Out of China's Dusty Northwest Corner, a Solar Behemoth Arises," Bloomberg News, Sept. 19, 2016. http://www.bloomberg.com/news/articles/2016-09-20/out-of-china-s-dusty-northwest-corner-a-solar-behemoth-arises

Figure 37: China-Based Manufacturers' Annual Project Deployment, in China vs. in Rest of World (ROW)



Source: Corporate filings; discussions with company executives; Bloomberg New Energy Finance

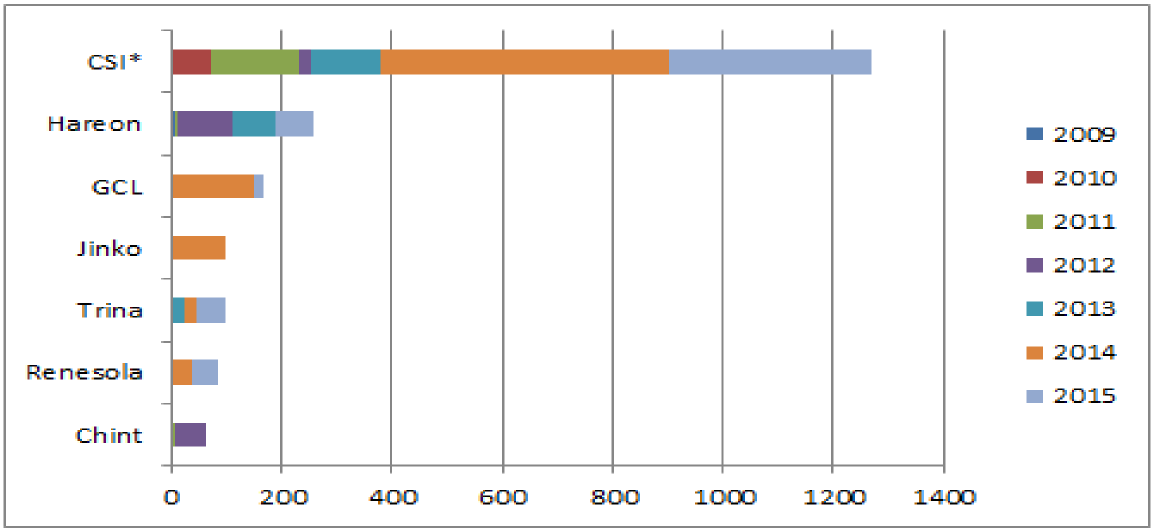
Note: This chart represents publicly available data on all types of deployment activity by China-based solar manufacturers. It attributes to a manufacturer the full capacity of any solar project in which it has been involved. It counts only those projects that have been fully commissioned.

But China-based solar manufacturers are beginning to show interest in developing solar installations abroad. Statistics through year-end 2015 show the very early stages of this trend. By that point, top China-based solar manufacturers had deployed a cumulative capacity of just 2,100 megawatts outside China—a fraction of 1% of the cumulative capacity in those countries. As Figures 38 and 39 below indicate, those activities were, as of the end of 2015, dominated by one China-based company, Canadian Solar, whose deployment abroad centered on one country, Canada.[312] Nevertheless, discussions with executives of China-based solar manufacturers suggest this trend is intensifying and will be a significant factor in shaping the global solar market.

China-based solar manufacturers are beginning to show interest in developing solar installations abroad.

[312] Canadian Solar's manufacturing is centered in China. The company's name derives from the fact that its founder and chief executive spent many years in Canada studying the science of solar energy. True to its name and heritage, Canadian Solar has focused its non-Chinese deployment on Canada.

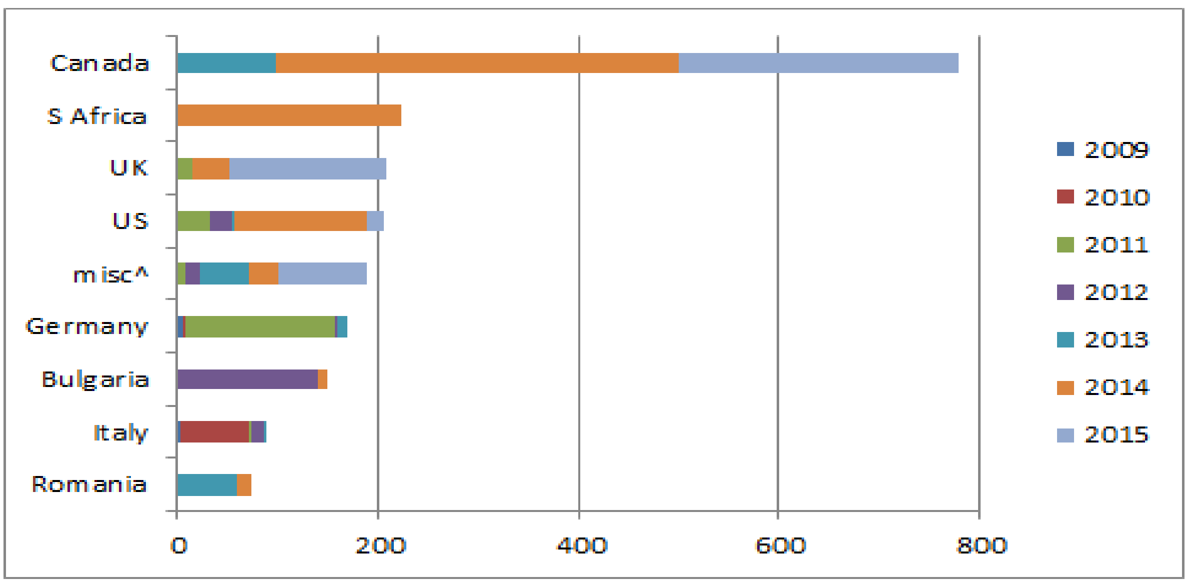
Figure 38: China-Based Manufacturers' Annual Project Deployment Outside China, by Company



Source: Corporate filings; discussions with company executives; Bloomberg New Energy Finance

Note: This chart represents publicly available data on all types of deployment activity by Chinese solar manufacturers. It attributes to a manufacturer the full capacity of any solar project in which it has been involved. It counts only those projects that have been fully commissioned.

Figure 39: China-Based Manufacturers' Annual Project Deployment Outside China, by Country



Source: Corporate filings; discussions with company executives; Bloomberg New Energy Finance

Note: This chart represents publicly available data on all types of deployment activity by China-based solar manufacturers. It attributes to a manufacturer the full capacity of any solar project in which it has been involved. It counts only those projects that have been fully commissioned. ^Miscellaneous category encompasses countries with fewer than 30 megawatts of capacity in operation at the end of 2015. Those countries include France, Thailand, Greece, India, Japan, Australia, and Switzerland. Miscellaneous category also includes 66.4 megawatts of capacity added by Hareon in an undisclosed foreign country in 2015.

By year-end 2015, China's top solar manufacturers deployed 780 megawatts of solar capacity in Canada—all but 100 megawatts of it in 2014 and 2015 alone. All of that Canadian deployment came from Canadian Solar.

Canadian Solar has its corporate headquarters in Ontario; it manufactures the vast majority of its solar cells in China's Jiangsu Province; and it assembles in Ontario those modules it will sell in Canada. That is because Canada, which traditionally had a generous feed-in tariff, also has had a requirement than modules sold in the country be assembled there too.

Nearly 30% of the project capacity that Canadian Solar deployed in China came through Recurrent Energy, a U.S.-based solar developer that Canadian Solar bought in early 2015 in large part because of Recurrent's extensive project pipeline.[313]

So far, as a group, China's top solar manufacturers have deployed only a small amount of solar projects in the United States. China-based solar manufacturers had deployed approximately 210 megawatts of solar capacity in the United States by year-end 2015, and more than 60% of that amount were linked to Canadian Solar. As the only top-tier China-based solar producer that so far manufactures in North America, Canadian Solar has been able to sell modules in the United States that are not saddled with the extra cost of tariffs; the company produces those U.S.-bound modules on its Canadian assembly lines.[314]

But U.S. deployment by China's top solar manufacturers shows signs of increasing. In the United States, Canadian Solar reports having 770.9 megawatts of utility-scale, late-stage solar projects currently under construction, 2,600 megawatts of projects expected to come online within the next five years, and several more thousand megawatts of potential U.S. projects with undefined pipelines. Most of these projects came through the company's March 2015 acquisition of Recurrent Energy.[315] In addition, several other leading China-based solar manufacturers have established sales offices in the United States—most of them in the San Francisco Bay area—and are, according to executives at those companies, looking actively for U.S. projects.

One China-based solar manufacturer with particularly aggressive deployment plans in the United States is GCL. As of mid-2016, the company owned only about 30 megawatts of solar-project capacity in the United States, according to the chief executive of GCL's U.S. operation. But GCL intends by the end of 2016 to have signed power-purchase agreements to sell power from approximately 500 megawatts of U.S. solar-project capacity, the executive said. Then, in 2017, the company intends to build approximately 600 megawatts of solar-project capacity in the United States.[316] If those plans materialize, they are likely to make GCL the largest U.S. deployer among China-based solar manufacturers. More broadly, they would mark a major increase in solar deployment in the United States by the Chinese solar industry.

[313] Eric Wesoff, "Canadian Solar Finally Acquires Recurrent Energy For $265 Million In Cash," Greentech Media, Feb. 2, 2015, http://www.greentechmedia.com/articles/read/Canadian-Solar-Finally-Acquires-Recurrent-Energy-for-265-Million-Cash

[314] Nevertheless, Canadian Solar executives said the profitability of the Canadian plant is insufficient and that the company is trying to restructure operations there to boost margins.

[315] "Canadian Solar Reports Fourth Quarter and Full Year 2015 Results;" PRNewswire; March 10, 2016: http://www.prnewswire.com/news-releases/canadian-solar-reports-fourth-quarter-and-full-year-2015-results-300233988.html

[316] Discussion with Peng Fang, chief executive of GCL's San Francisco-based U.S. unit

Chapter 7: Recommendations

7.1: Overview

Solar power is at a key turning point. It has grown massively in recent years and yet it still represents just 1% of global electricity generation.[317] Mainstream observers now predict that solar photovoltaic could provide 16% of global electricity by mid-century, and credible sources predict even higher levels.[318] That would require continued progress in reducing solar power's cost and in developing a variety of enabling technologies related to the transmission grid and to energy storage. Cost cuts are needed in manufacturing solar equipment and in deploying solar projects. Energy storage, which in many ways is several years behind solar in its technological development but is following a similar path, needs both R&D gains and deployment-cost reductions in order to enable solar at mainstream scale. And transmission, essential to moving utility-scale solar from often distant resource-rich areas to cities, often must overcome deep public resistance to siting and serious controversies over who will pay for it.

The best way for any country—including the United States—to derive lasting economic gain from the growing solar industry is to help maximize the industry's efficient global growth. As for the energy-storage industry, an in-depth analysis is beyond the scope of *The New Solar System*. But, as this chapter explains, the strategy likely to maximize U.S. economic benefit—and global environmental benefit—from the solar industry is applicable to the energy-storage industry as well. And to the extent that solar reaches significant levels of penetration, the imperative for transmission increases.

China has important structural features that facilitate promoting a new energy source that the United States does not: an autocratic central government, a deep manufacturing base, a rapidly growing population and thus a growing energy appetite, and noxious air pollution that makes cleaner energy a top priority for much of the public. All those drivers in China are intensifying. At the same time, much of China's support for solar has been, by the admission of Chinese officials themselves, scattershot and inefficient, resulting in large sums of wasted money. However, China, as *The New Solar System* has explained, is restructuring its support for solar to make it more efficient.

Any country's best way to derive lasting gain from the solar industry is to maximize the industry's efficient global growth.

All of this suggests that China will be the driving force in the global solar industry for the foreseeable future. That clearly will be the case in the manufacturing of today's commodified solar goods: those based on crystalline-silicon technology. It appears almost certain to be the case in solar-project deployment, where China already leads, and is expected to continue to lead, other nations. And it increasingly is the case in certain areas of R&D—particularly improvements to today's crystalline-silicon solar cells. It is by recognizing China's key role, rather than resisting it, that the United States will contribute most profoundly to the expansion of cost-effective solar energy globally and, in the process, grow a solar sector in the United States that is significant in scope and profitable over the long term.

[317] Op. cit., International Energy Agency's Photovoltaic Power Systems Program, "Trends 2015 in Photovoltaic Applications."
[318] Op. cit., International Energy Agency Technology Roadmap, 2014.

In considering how to build a solar sector in the United States that is economically successful, it is instructive to consider how the U.S. solar challenge differs from the Chinese one. China entered the solar industry as a manufacturer; only later, when its solar-manufacturing industry was reeling amid global overcapacity, did China move in a significant, nationally coordinated way to ramp up solar R&D and domestic solar deployment, both moves intended largely to help the Chinese solar-manufacturing industry. For China, in other words, manufacturing was paramount, and R&D and deployment were secondary. Now, however, having decided it needs to improve the return that it gets for every yuan that it spends on R&D and deployment, China is undertaking significant reforms of both with an eye toward improving their efficiency.

China needs to improve its R&D and deployment; the United States needs to improve its ability to manufacture and deploy at large scale.

The United States, by contrast, entered the solar industry by focusing overwhelmingly on R&D. There are several reasons for that: R&D historically has been the United States' technological strong suit; solar power long was regarded in the United States as a scientific research project rather than as an energy source that was economically viable in the near term; and a longstanding reality of the Washington political tussle over new technologies is that getting bipartisan support for government spending is far easier for R&D—particularly early-stage R&D—than for manufacturing or deployment.

Yet now, just as China needs to improve its R&D and further expand its deployment to maximize the global effectiveness of its solar-manufacturing prowess, the United States needs to improve its ability to manufacture and deploy at large scale the solar technologies that its vaunted R&D system cranks out. One important way for the United States to do that is to better understand China's approach to solar: its long-term energy policy-making (the Chinese version of which is the five-year plan), public-private technology partnerships (the Chinese version of which is the company-based state key lab), and technology commercialization. Another crucial way for the United States to improve the relevance of its solar R&D is to admit to itself, as China has done, that it has been economically inefficient in the way it has pursued solar power—and that it needs to get more efficient.

7.2: Overarching Priorities

This framework suggests three overarching priorities for U.S. policymakers in building a domestic solar sector that delivers long-term economic benefit:

- seek above all else to reduce solar power's costs, a goal clarified, as explained in Section 7.2.1 below, in November 2016 in newly aggressive cost-cutting targets—cuts on the order of 50%—issued by the U.S. Department of Energy's Solar Energy Technologies Office, also known as the SunShot Initiative;[319]
- embrace the reality of a globalizing solar industry;
- and focus federal support for solar in the United States primarily on R&D and deployment and only secondarily on manufacturing.

Each priority is explained briefly below and is embodied in subsequent sections of this chapter. Those sections recommend a path forward in the

[319] As noted in Chapter 1 and in Section 4.6.3, the U.S. Department of Energy's Solar Energy Technologies Office provided Stanford University with the research grant that funded *The New Solar System*; the grant provided Stanford's Steyer-Taylor Center for Energy Policy and Finance with full independence and authority to frame the inquiry, conduct the research, draw conclusions, and write *The New Solar System*.

U.S. approach to, respectively, solar R&D, manufacturing, and deployment.

7.2.1: Priority 1: Above All Else, Cut Solar's Costs

Solar power, despite significant cost cuts over the past decade, remains too expensive to scale to the level that would make a meaningful environmental difference, particularly when its intermittency is taken into account. One sign of that is that the DOE's SunShot Initiative, a federal effort launched in 2011 to render solar power without subsidies cost-competitive with conventional electricity sources by 2020, felt it necessary to announce in November 2016 a new round of cost-cutting targets. At its inception, the initiative targeted costs at $0.06 per kilowatt-hour for utility-scale solar, $0.07 per kilowatt-hour for commercial rooftop solar, and $0.09 per kilowatt-hour for residential rooftop solar by 2020. In May 2016, the DOE announced that the solar industry had realized 70% of those cuts. Then, in November 2016, the DOE announced new unsubsidized-cost targets for 2030: $0.03 per kilowatt-hour for utility-scale solar, $0.04 per kilowatt-hour for commercial rooftop solar, and $0.05 per kilowatt-hour for residential solar.

The chief objective of solar policy—in the United States and elsewhere—should be to reduce the capital investment required to generate a given amount of solar electricity. A ruthless focus on this goal would require policies that prioritized maximizing low-cost power over maximizing domestic solar-manufacturing jobs. To be sure, U.S. solar policy already focuses more on deployment than on manufacturing. But it will be increasingly important to maintain that focus in the coming years. An expansion of solar power will indeed boost solar employment. But boosting solar employment should be a means to expanding solar power—not the other way around. This is a crucial distinction for policymakers to keep in mind.

As noted in Section 1.2, recent research from MIT and NREL estimates that meeting global greenhouse-gas-reduction targets would require deploying between 2,000 gigawatts and 10,000 gigawatts of solar capacity by 2030.[320] The actual number in that range would depend on how big a share solar took in carbon reductions. Nevertheless, deploying any amount in that range would represent a massive increase from the status quo; today's global solar-manufacturing base, growing at a rate similar to that of the past few years, would result in a cumulative 1,000 gigawatts of solar capacity by 2030, according to MIT-NREL projections.[321] Today, China and the United States each have roughly 1,000 gigawatts of installed electricity-generating capacity from all sources combined. Building a global solar capacity that is two to 10 times the capacity of the entire generating system in each of the world's two biggest electricity-generating nations would be a colossal undertaking that would involve massive investment. As explained in Section 1.2, according to one informed estimate, building a cumulative 3,000 gigawatts of solar capacity by 2030 would require some $265 billion in investment in new manufacturing capacity, and building a cumulative 10,000 gigawatts by 2030 would require approximately $817 billion in new manufacturing capacity. What is more, actually deploying the solar goods produced by this hugely expanded solar-manufacturing base, so that the goods produced and delivered electricity to consumers, would require many trillions of dollars more.

A key priority, therefore, is R&D: to bring to market solar technologies that are either significantly cheaper to manufacture, or significantly higher in efficiency, or both. Such technologies have the potential to increase solar's bang for the buck—to generate a greater amount of solar-powered electricity for every dollar spent on solar-equipment manufacturing. The surest way to cut manufacturing costs would be "through technological innovation to increase manufacturing throughput, streamline process steps, reduce the time of new tool development, and lower polysilicon use," according to a second paper now under development by researchers

[320] Op. cit., David Needleman, Jeremy Poindexter, Rachel Kurchin, I. Marius Peters, Gregory Wilson, Tonio Buonassisi.
[321] Ibid.

who include several of the authors of the earlier MIT-NREL research.[322]

Reducing the cost of solar energy enough to significantly scale it up would require more than increased R&D spending, however. It would require heightened economic efficiency—that is, a reduction in wasteful spending—everywhere across the solar value chain. It would require maximizing international R&D cooperation, manufacturing in the most-cost-effective locations, and improving solar-project permitting and deployment. And it would require significant advances in two enablers—energy storage and transmission—that will be crucial to overcoming solar's intermittency and its varying availability across regions including North America. Cost cuts in storage and massive increases in transmission deployment will be particularly important for solar to achieve ever-higher percentages of the installed electricity base around the world.

All of these gains will be challenging. But solar energy has achieved a momentum over the past few years that is unprecedented in its history. The price of solar modules has dropped some 60% to 80% over the past half-decade; the next round of cost reductions necessary to make solar a truly large-scale energy source may prove far harder. Yet according to many experts, realizing these cost reductions will be crucial, because scaling up solar will be important to meeting global climate goals.

7.2.2: Priority 2: Leverage—Don't Fight—Solar's Globalization

U.S. policy bearing on solar should reorient fundamentally so that it seeks to leverage, not defeat, China. The solar industry is rapidly globalizing, meaning that the sector's success in any one country depends increasingly on its success in others. More than ever before, the solar industries in China and the United States are intertwined: Shareholders across the globe invest in both of them, capital moves between them, many of the same companies are active in both of them, and market dynamics in one influence fortunes in the other. Discussions with scientists, solar executives, and government officials in both countries suggest, in fact, that each country is coming to conclude that it stands to benefit from specific sorts of cooperation with the other. The United States has much to learn from China about efficient solar manufacturing and about improving the real-world performance of silicon solar cells, the technology that dominates today's market and that is dominated by China. China has much to learn from the United States about next-generation solar technologies and, crucially, about innovative methods of solar finance. Key players in both countries increasingly believe that they will profit more if each country focuses on exploiting its comparative advantages in the globalizing solar industry than if it orients policy around trying to beat the other. That conclusion marks a major shift from the thinking that prevailed just five years ago, when the solar sector was more a patchwork of small and distinct national industries than the interconnected, international force it is becoming today.

U.S. policy bearing on solar should reorient fundamentally so that it seeks to leverage, not defeat, China.

It is important to be clear: This notion of international comparative advantage is no rose-colored vision of borderless global harmony. It is, rather, the increasing reality of the cutthroat international solar market today. It does not ignore very real tensions between China and the United States, including the ongoing solar-tariff dispute, doubts about the protection of intellectual property in China, and concerns by both the U.S. and Chinese governments about national security. Rather, it puts those concerns into perspective, which is something that investors, corporations, and governments try to do every day.

[322] Op. cit., Nancy Haegel et. al.

Whether they are based in China, the United States or Europe, the leading global solar firms have reached similar conclusions about where in the world to carry out particular parts of their operations. As economically rational entities, they tend to make similar strategic decisions when presented with similar facts on the ground. The footprints of today's leading solar companies are massively more global and complex than they were just a few years ago. This globalization has proved crucial in cutting solar energy's costs, and it is certain to intensify. Policymakers in the United States and elsewhere are likely to succeed more by understanding and exploiting this globalization than they are by resisting it.

7.2.3: Priority 3: Be Realistic and Surgical About U.S. Solar Manufacturing

The United States is a small player in global solar manufacturing. In 2015, according to IHS Markit, the United States manufactured 0.5% of solar wafers, 0.9% of silicon-based solar cells, and 1.2% of silicon-solar modules. It produced 10.6% of global polysilicon, a bigger but still-small slice of the global manufacturing pie. And all those percentages were down from the 2010 levels.[323] (For an explanation of the different products and steps in the creation of a solar module, see Section 5.1.1.)

As is explored in Section 7.4.1.1, several new or expanded U.S. solar-cell and -module factories are under construction or expected to be built over the next two years, and yet predictions are that, at least in the near term, U.S. solar manufacturing will remain small in the global context.

Certain types of solar manufacturing in the United States seem increasingly feasible. But U.S. policymakers should regard manufacturing as a subordinate, not a primary, policy goal. Three caveats, explored in Section 7.4, are crucial.

- Solar manufacturing is unlikely to produce large numbers of U.S. jobs, because it is an increasingly automated process. The majority of solar jobs are in areas other than manufacturing: in sales, installation, operation and maintenance, and R&D.
- U.S. solar manufacturing is likely to prove economically viable for three categories of solar products:
    - products for U.S. consumption that are expensive to import;
    - export-oriented goods that the United States can competitively produce at large scale because of cheap U.S. natural gas;
    - and export-oriented goods developed with U.S. R&D talent that the United States is well-positioned to manufacture in relatively small quantities in initial factories but that may shift to cheaper manufacturing locations overseas as they scale up.
- Solar manufacturing in the United States will deliver more long-term economic benefit if pushed by domestic R&D and pulled by domestic deployment than if forced by direct manufacturing subsidies or mandates.

Most countries that have scaled up solar manufacturing into significant sectors—notably China and Malaysia—have done so with generous incentives, such as discounted or free land, heavily subsidized plant construction, and major corporate-tax breaks. These countries also have broader manufacturing bases and cheaper labor than the United States does in the second decade of the 21st century. It will be difficult for the United States to compete with these countries for solar manufacturing without offering similarly rich or even richer incentives. And it is far from clear that U.S. taxpayers will—or should—support these sorts of incentives at the scale that likely would be necessary to catapult the United States into the ranks of the world's largest solar-equipment manufacturers.

[323] Op. cit., IHS Markit

Domestic manufacturing jobs have long held particular allure to politicians, not just in the United States but in most countries. But changes in the global economy make it more important than ever that policymakers consider domestic manufacturing jobs in context—as just one factor among many other important ones—when they assess how a sector or product will affect the national economy. This notion of the need to keep in proper perspective the importance of U.S. manufacturing in global industries was underscored in a March 2015 study by the National Academy of Engineering, called "Making Value for America":

> Concerned about growing competition from companies and workers overseas, American business and government leaders have focused considerable attention on the need to strengthen U.S. manufacturing in order to support innovation and job creation. But framing the debate on manufacturing only in terms of whether it is done in the United States or overseas misses the big picture.
>
> The way that products and services are conceived, designed, produced, and distributed is changing. Increasingly, it is important not just to "make things" but to "make value."[324]

To that end, "Making Value for America" proffered a variety of recommendations, including making permanent the U.S. federal R&D tax, boosting public-private cooperation on investing "in pre-competitive research in long-term, capital-intensive fields"—fields such as energy—and changing the way the federal government accounts for the impact of various economic sectors. "The current method—classifying manufacturing, services, and information activities in distinct industries based on the primary activity at an establishment—is an increasingly unrealistic depiction," the report said.[325] Congress made the federal R&D tax credit permanent in December 2015.[326]

It is far from clear that U.S. taxpayers will—or should—support incentives at the scale likely necessary to make the United States one of the world's largest solar manufacturers.

This realization of the myopia of the United States' traditional focus on domestic manufacturing as the primary metric of a sector's economic value is important in framing a solar strategy that can deliver maximum economic value to the nation—to say nothing of the world.

7.3: R&D Recommendations

The United States remains a global leader in solar R&D—at national labs, universities, and companies large and small. As *The New Solar System* has documented, China is improving its solar R&D, both in conventional crystalline-silicon technology and in emerging technologies. That reflects the reality that solar R&D, like all aspects of the solar industry, is quickly globalizing—a promising development for the prospects of cost-competitive solar power.

[324] National Academy of Engineering, "Making Value for America," March 2015. http://www.nap.edu/catalog/19483/making-value-for-america-embracing-the-future-of-manufacturing-technologyhttp://h/
[325] Ibid.
[326] "Permanent Research Credit Enacted," PricewaterhouseCoopers, Dec. 22, 2015. http://www.pwc.com/us/en/tax-services/publications/insights/assets/pwc-permanent-research-credit-enacted.pdf

It also underscores that longstanding U.S. leadership in solar R&D is no longer a foregone conclusion. The United States remains a leader in many aspects of solar R&D. This leadership has been backed by significant U.S.-government funding, and it will be important to solar's global growth. To maximize its benefit to the U.S. economy and to the planet, U.S. solar R&D needs to be recalibrated to take realistic stock of China's increasing solar-R&D role. The United States and China will continue to compete in many aspects of the solar industry. But both countries have something to gain from collaboration. Collaboration with China carries strategic and economic risks. Mr. Trump has signaled his concerns about China's trade posture and pledged to "bring trade cases against China."[327] Nevertheless, collaboration with China that is intelligently conceived and surgically executed will do more to help U.S.-based solar firms than will unfettered competition with China. The U.S. strategy on solar R&D should seek not to thwart but to leverage China's role.

The United States and China still will compete in the solar industry. But both have something to gain from collaboration.

Three main changes in U.S. solar-R&D strategy are important. Each is introduced here and detailed later in this section. The United States should:

- Significantly increase U.S. spending on R&D for solar and for solar-enabling technologies such as storage and transmission, in both the public and private sectors, to help propel solar's global growth and to ensure that the United States remains a leader in it.

- Broaden international solar-R&D efforts to include China so that China's increasing solar innovation informs efforts elsewhere For the United States, cooperating with China on solar R&D poses real and important challenges, including concerns about the protection of intellectual property and about national security. But not cooperating with China on solar R&D also presents significant risks, including reduced relevance in the silicon-based solar technologies that command the majority of today's market.

- Reform a federal policy that requires that those who accept federal R&D funding, including for solar R&D, promise to manufacture "substantially" in the United States any technologies that they develop through that R&D. According to a wide range of U.S. solar executives, scientists, and even government officials involved in implementing it, this provision is outdated and counterproductive. In its effort to maximize U.S. solar-manufacturing jobs, it risks weakening U.S. solar R&D, an activity with potentially greater long-term economic value to the United States than solar manufacturing.

A fuller discussion of each of these three suggested changes follows.

7.3.1: R&D Recommendation 1: Increase Solar-R&D Spending

In December 2015, the United States, along with China and 18 other countries, pledged to double its government spending on clean-energy R&D over five years. That collective international pledge, made at the United Nations climate-change talks in Paris, is known as Mission Innovation. It was accompanied by the creation of the Breakthrough Energy Coalition, in which a group of 28 prominent and wealthy people from 10 countries—people including Microsoft founder Bill Gates, investor George Soros, Facebook CEO Mark Zuckerberg, and Alibaba Executive Chairman Jack Ma—pledged to significantly increase private investment in cleaner energy technologies. They pledged to

[327] "Trade: Donald J. Trump's Vision," Donald J. Trump website, https://www.donaldjtrump.com/policies/trade/

focus particularly on those technologies that are at an earlier stage in their development.[328] Then, in December 2016, Mr. Gates and other wealthy individuals behind the Breakthrough Energy Coalition formed Breakthrough Energy Ventures, a venture-capital fund intended to spend more than $1 billion over the next 20 years in what the fund calls "risk-tolerant investments in next generation technologies to provide reliable, affordable, zero-carbon energy, food, and products to the world."[329] [330]

The U.S. government says it budgeted $6.4 billion on clean-energy R&D in fiscal year 2016 and that under its Mission Innovation pledge it "will seek to" double that figure to $12.8 billion in fiscal year 2021.[331] Whether the United States follows through on that pledge will depend on the Trump administration's budget requests and on Congressional decisions. Assessing whether the United States is on track to fulfill its pledge will not be difficult. Doubling U.S. clean-energy R&D spending over five years, the government has noted, means raising that spending by approximately 15% in each of those five years.[332]

As explained in Section 4.6, the U.S. government has spent more on solar R&D than any other country, according to the International Energy Agency's Photovoltaic Power Systems Program's latest report on the global solar industry. Importantly, however, that report offered no estimate of Chinese solar-R&D spending, the Chinese government offered no such estimate in its Mission Innovation pledge, and no such information is available in the documents from the Chinese government that are available on the Mission Innovation website. All of this points to the difficulty of obtaining Chinese solar-R&D-spending data. It also points to the serious need for China to reveal the details of its solar-R&D investment, and its energy-R&D spending more broadly, as the United States and other nations have long done. Increased R&D collaboration with China is likely to be more difficult without this information.

As explained in Sections 1.2 and 7.2.1, new analysis suggests that, to make meaningful progress toward meeting global climate targets, cumulative installed global solar capacity would have to increase to between 2,000 gigawatts and 10,000 gigawatts by 2030—significantly more than the 1,000 gigawatts of global capacity able to be deployed by then by today's solar-manufacturing base. Boosting installed capacity to those levels would require a range of improvements unrelated to R&D. It would require a variety of further manufacturing efficiencies, such as additional and improved assembly-line automation, both to reduce labor costs and to improve product yield. It also would require efficiencies in solar deployment, such as trimming the costs of permitting solar projects and more-innovative solar-deployment financing. But more R&D in solar power and in enabling technologies such as energy storage, while not sufficient, is absolutely necessary. The gains from R&D will magnify the gains from deployment. In doing so, they also will minimize the costs. R&D is an aspect of the solar enterprise that the United States traditionally has done better than anyone else. Done well, it is likely to prove among the most cost-effective ways to use public dollars to increase solar power and grow a successful global solar industry, with potentially significant economic upside for the United States.

R&D gains are needed in developing solar cells with significantly higher efficiencies and in developing manufacturing methods that are significantly less expensive than today's. In the words of a paper now under development by some of the most prominent solar researchers around

[328] Breakthrough Energy Coalition website, http://www.breakthroughenergycoalition.com/en/who.htmlhttp://h/
[329] Bill Gates, "A New Model for Investing in Energy Innovation," Gates Notes, Dec. 12, 2016. https://www.gatesnotes.com/Energy/Breakthrough-Energy-Ventures
[330] Breakthrough Energy website. http://www.b-t.energy/faq/
[331] Mission Innovation website, http://mission-innovation.net/about/http://h/
[332] "Advancing Clean Energy Domestically and Abroad and Taking Action on Climate Change," White House press release, https://www.whitehouse.gov/sites/default/files/omb/budget/fy2017/assets/fact_sheets/Advancing%20Clean%20Energy%20Domestically%20and%20Abroad%20and%20Taking%20Action%20on%20Climate%20Change.pdfhttps://www.whitehouse.gov/sites/default/files/omb/budget/fy2017/assets/fact_sheets/Advancing Clean Energy Domestically and Abroad and Taking Action on Climate Change.pdf

the world, "research leading to lower capital cost for manufacturing equipment could reduce the investment that is needed" to radically increase global solar deployment.[333]

A consensus is emerging among global solar researchers, government officials and solar-company executives about the kinds of technological improvements that might maximize solar-power production for each dollar spent. Among them:

- So-called "epitaxial" technology, in which a very thin layer of photovoltaic material is created on a substrate and then removed to be used in a solar cell. The process dramatically reduces the amount of photovoltaic material that is required.
- The combination of thin-film photovoltaic layers atop silicon solar cells.
- Solar-wafer production technologies that entirely eliminate "kerf," the waste material generated when a block, or ingot, of silicon is sliced into individual wafers. Several so-called "kerfless" wafer technologies are under development; they produce wafers in high volume but individually, meaning that they do not involve the ingot slicing that produces the waste.

A common strategy to minimize the cost of solar cells is to radically reduce the thickness of silicon wafers. The April 2016 paper by MIT and NREL researchers that was explained in Sections 1.2 and 7.2.1 estimates that slashing solar-wafer thickness from the current level of approximately 180 microns to as thin as between 10 microns and 20 microns would cut required capital spending on solar-cell manufacturing by 90%. "Multiple technologies exist," it explains, "some of which have already demonstrated high efficiency on wafers as thin as 35 millimeters, including silicon grown epitaxially directly from vapor sources, silicon wafers produced directly from molten silicon without casting and wire-sawing, and thinner wire saws." One of the authors of the April 2016 paper estimates that reducing capital spending on cell manufacturing on the order of 90% would translate into reducing by approximately 20% the cost of producing a solar module of the sort that now dominates the global market—bringing today's module production cost, which hovers in a range of roughly 45 cents per watt to 50 cents per watt, to a range of approximately 35 cents per watt to 40 cents per watt.[334] Other solar experts believe that technologies that cut solar-wafer thickness as much as described above would produce a smaller, though still significant, reduction in cell-manufacturing capital spending—on the order of 50% rather than 90%.

Even assuming that, as analyzed in Section 4.6, the United States already spends more on solar R&D than China does, the reality is that achieving the technological potential outlined above may require a significant increase in U.S. federal solar-R&D spending—both for the global expansion of solar as an energy source and for U.S. leadership in the expanding solar industry.

The United States pledged under Mission Innovation to double total U.S. federal clean-energy R&D spending. It did not specify how that increase would be divided among different energy technologies. Some solar experts argue that achieving the further cost reductions necessary to scale up solar to the point where it contributes meaningfully to global climate targets would require major technological improvements in solar—improvements these experts contend are likely to require much more than a doubling in U.S. solar-R&D spending. In addition, non-government solar-R&D spending also will need to be significantly increased. An important next stage of analytical work will be to develop a realistic roadmap for U.S. solar R&D—to specify by how much and in what specific areas U.S. federal, as well as private, solar R&D funding would need to be increased to maximize the chances of reaching specific decreases in solar costs and specific ambitious solar-deployment milestones. Support for energy R&D—particularly earlier stage energy

[333] Op. cit., Nancy Haegel et. al.

[334] Discussion with Gregory Wilson, U.S. National Renewable Energy Laboratory

R&D—has won bipartisan support in the past, and it is conceivable that it will win support in the future. Solar power is on the cusp of becoming a strategic global industry and could emerge as a significant contributor to global carbon reductions and economic output. In recognition of these shifts, several countries—China and many others—are increasing their solar-R&D spending. Now would be the wrong time for the United States to abandon government support for research into this burgeoning technology. At the very least, the United States should maintain the pledge to double clean-energy R&D spending that it made under the multilateral Mission Innovation pledge at the Paris climate conference in 2015. Improving R&D specifically in solar and more broadly in cleaner energy sources could bring domestic economic benefits as well as global environmental ones.

Now would be the wrong time for the United States to abandon government support for research into this burgeoning technology.

7.3.2: R&D Recommendation 2: Approach R&D More Strategically

As noted above, further study is needed to quantify how the United States—both its public and private sectors—should increase total spending on solar R&D and should parse that total spending among specific solar technologies and related areas of need. What already is clear beyond the imperative for more R&D money, however, is the need for a rethink of the United States' underlying strategy toward solar R&D.

Calls are mounting in the United States for the federal government to restructure its approach to energy-related R&D, largely because of an increasing consensus that the current R&D enterprise is not scaling up low-carbon energy technologies as quickly or as broadly as a changing climate demands.

The U.S. government recalibrated its solar-R&D approach in 2011, when the DOE launched the SunShot Initiative, an effort to render solar power without subsidies cost-competitive with conventional electricity sources by 2020. As explained in Section 7.2.1, the initiative targeted costs at $0.06 per kilowatt-hour for utility-scale solar, $0.07 per kilowatt-hour for commercial rooftop solar, and $0.09 per kilowatt-hour for residential rooftop solar. The DOE announced in May 2016 that the solar industry had realized 70% of those targeted cost cuts, and it announced in November 2016 new, more-aggressive cost targets for 2030: $0.03 per kilowatt-hour for utility-scale solar, $0.04 per kilowatt-hour for commercial rooftop solar, and $0.05 per kilowatt-hour for residential solar.[335]

Among the forces that has most contributed to the drop in the cost of solar power since the launch of the SunShot Initiative in 2011 is the rise of China as a global solar manufacturer. Given that shift, and given the U.S. government's prioritization, at least up to now, of continued solar-cost reductions, a range of potential new approaches to new energy-R&D structures in the United States are worth debating:

- The federal government investing in an R&D facility located at a solar manufacturer's U.S. factory following an open competition among companies for federal support.
- A solar manufacturer building a U.S. factory beside a federal or university laboratory.
- Any number of novel arrangements in which the federal government and solar companies work together either to expand an existing solar laboratory or to launch a new one.

[335] U.S. Department of Energy's SunShot Initiative website, at http://energy.gov/eere/sunshot/about-sunshot-initiativehttp://energy.gov/eere/sunshot/about-sunshot-initiative
http://energy.gov/eere/sunshot/about-sunshot-initiative

- Targeting geographic clusters of solar R&D, manufacturing, and deployment.

The point here is not to suggest that any of these specific approaches will necessarily work in the United States—and some may not. It is to underscore that, as policymakers, solar researchers, and solar executives consider new structures for U.S. solar R&D, they should take careful note of the lessons—the successes as well as the failures—that China's public-private solar-R&D alliance offers even to countries with political systems very different from China's. Policymakers, solar researchers, and solar-company executives will have to decide whether to pursue any of these approaches.

The United States could do much more to tie R&D more closely to real-world questions of manufacturability.

In solar as in other technological pursuits, the United States has long excelled in basic, long-term research. That explains why many of the solar technologies deployed at scale today are based on breakthroughs that occurred in U.S. laboratories over the past several decades. Now that solar has advanced around the world from a futuristic subject for research into a sizeable industry, it is time for the United States to focus more of its research on developing solar advancements that can be deployed at scale in less than a decade and perhaps a good deal more quickly than that.

It is important to be clear: This is not to suggest that the United States should withdraw from its commitment to fundamental breakthrough research. As explained in Section 1.2, ramping up solar to levels that would measurably curb carbon emissions will require an array of technological developments so significant that they could plausibly be labeled revolutionary. At the same time, however, maintaining the momentum that solar has developed over the past five years will require a greater focus on near- and mid-term R&D.

As the United States considers its next steps for solar R&D, the experience of China is worth studying. Particularly instructive, as described in Sections 4.6.1.4 and 5.4.2, is China's solar-R&D ecosystem—particularly its state key labs, which are supported by government funding, sit beside the factories of two of China's major solar manufacturers, and are staffed by scientists and researchers employed by those companies. For instance, as explained in Section 5.4.2, one of the state key labs sits at Trina's headquarters in Changzhou, China, adjacent to a main Trina factory. On the ground floor of the lab, Trina operates a pilot assembly line that it calls the Golden Line and that it uses is to tweak production to minimize cell-efficiency losses—a process that involves continuous communication, reevaluation, and reengineering between managers and technicians on the Golden Line and researchers upstairs in the lab. The company says that cells produced on the Golden Line are as much as 0.6 of a percentage point more efficient than comparable cells produced on Trina's conventional line—a significant gain given that improvements in solar-cell efficiency are measured in tenths of a percentage point.

Massive differences exist between the nature of the Chinese government's relationship with Chinese private companies and the relationship of the U.S. government with U.S. companies. Indeed, it is far from clear that the U.S. government would or should establish what amounts to a nationally significant laboratory on the grounds of a U.S. corporation. Far short of that, however, the United States could do much more—for instance, through government-assisted solar-industry clustering—to tie R&D to more closely to real-world questions of manufacturability. Such a reorientation of the U.S. solar-R&D approach could, importantly, increase the contribution of R&D to U.S. economic growth. Cooperation among the U.S. federal government, the State of New York, and universities and solar companies has assembled a notable cluster of solar R&D and manufacturing in upstate New York. The New York solar cluster, discussed in Sections 7.4.1.4.1 and 7.4.2.3 below, is growing, but it remains tiny in comparison to solar clusters elsewhere in the world, particularly in China. As explained in Section 7.4.2.3, there is more that could be done to expand that cluster in ways likely play to the United States' comparative strengths.

The whole gamut of solar-relevant R&D should be reconsidered in terms of the value of clustering: Not just R&D related to solar cells and solar modules, but also R&D in:

- new solar applications, such as the use of photovoltaic roof shingles, building tiles, and other forms of so-called building-integrated photovoltaic (BIPV) systems;
- non-photovoltaic types of solar power, such as concentrated solar power (CSP);
- and a range of enabling technologies that will be necessary for the cost-effective deployment of solar at many times its current scale—technologies including energy storage, ranging from seconds for voltage support to potentially months for seasonal variations in insolation, and including transmission and demand response.

7.3.3: R&D Recommendation 3: Cooperate Intelligently on R&D With China

The need for the United States to focus more on the manufacturability of new solar technologies leads, in turn, to another recommendation for U.S. R&D policy: The United States should, more than it does now, cooperate intelligently on solar R&D with China.

Several forums exist to promote the exchange of solar-R&D information between researchers in the United States and those in China. As explained in Chapter 4, several leading China-based solar companies have official relationships with leading solar-R&D laboratories in the United States as well as in Europe. Scientists from both China and the United States have the opportunity to meet at global conferences. Efforts such as the International Energy Agency's Photovoltaic Power Systems Program provide networks in which researchers from around the world can interact. And government-sponsored laboratories in the two countries collaborate on R&D areas that they deem non-competitive. For instance, researchers from the U.S. National Renewable Energy Laboratory and China's Electric Power Research Institute have met to discuss ways to better integrate solar energy into their respective countries' electrical grids.

But R&D collaborations between U.S. and Chinese researchers are lacking in the underlying technological areas that will be important if solar power is to be scaled up to a level and at a pace that will significantly address the climate challenge. Key among these areas is the development and manufacture of lower-cost and higher-efficiency solar cells.

Tellingly, what is perhaps the highest-profile venue for clean-energy R&D collaboration between the two countries, the U.S.-China Clean Energy Research Center (CERC) does not include a focus on solar power. The CERC, whose funding the leaders of the two countries agreed in November 2014 to expand through 2020, focuses on four areas: cleaner vehicles; energy efficiency in buildings; ways to minimize carbon-dioxide emissions from coal-burning power plants; and the relationship between energy and water. People familiar with the CERC say a significant reason that the institution does not work on solar is that the political dispute over solar tariffs, now in its fifth year, has made the political relationship between the U.S. and China over solar too tense.

Beyond tariff tensions, solar executives in the United States express deep concerns about cooperating too fully with China in solar R&D. They worry that their companies' intellectual property will be taken without adequate compensation. They worry that they will lose financial control over the future of their technologies. And they worry that, in cooperating with China, they will give an edge to a country they have been conditioned to regard as an enemy.

These concerns about the perils of cooperating with China are all but certain to endure for many years in the United States. Today, however, a realization is dawning on U.S. business executives, scientists, and even government officials that there is an even bigger threat than engaging with China on solar R&D: failing to engage.

The twin realities that China has scored world records on multicrystalline-silicon solar cells, the prevailing solar technology, and that China is narrowing the gap with the West on next-generation silicon-based solar technologies are beginning to persuade many in the U.S. solar R&D community that, in the words of one U.S. government official, the United States "could be left behind" if it does not partner with China on solar R&D. That is a significant shift from the U.S. attitude just a few years ago, and it represents an opportunity for collaboration between the two countries that is real precisely because it rests on enlightened economic self-interest.

In the area of crystalline silicon, the technology that commands the vast majority of the global solar market, China has much to teach the United States about manufacturing efficiency and, increasingly, about underlying scientific gains. Particularly instructive are China's solar state key labs. As further explained in Sections 4.4.2.4 and 4.6.1.4, the state key labs, funded jointly by the government and solar companies, are institutes housed at two of China's largest solar manufacturers; the institutes sit adjacent to the manufacturers' volume-production lines, an arrangement designed to ensure that improvements generated in the lab are rapidly integrated into actual products. China's state key labs offer two important lessons for the United States.

First, given the silicon-cell-efficiency gains they have achieved—particularly the one at Trina—China's state key labs offer valuable insight into solar technology itself. "We should be figuring out how to collaborate and work with (China) on the R&D side," said one official who works for a U.S. laboratory deeply involved in solar R&D. "In the future, maybe it's going to be world records that are set between (U.S. R&D institutions) and state key labs in China. I think we need to get past denial."

The recent Mission Innovation pledge by governments to double their clean-energy R&D funding over five years typifies this opportunity. It represents a chance to increase not just the amount of spending but also, through strategic international collaboration, the efficiency of that spending. In one example of this new thinking, an April 2016 paper by Columbia University's Center on Global Energy Policy, titled "Solar Together," proposed a new organization to shepherd greater international collaboration on solar R&D.[336] The test of any such new organization would be whether it reflected a new attitude by the federal government: an embrace of the idea that greater solar-R&D collaboration between the United States and China could benefit not just the planet but the U.S. economy too.

This, in turn, raises the second important lesson that China's state key labs offer for the United States: a lesson about how to structure a national solar-R&D campaign. China's state key labs represent a perspective very different from the traditional U.S. one on how an economy can integrate R&D and manufacturing—and about how a strategic partnership between a national government and a leading global company can accelerate that integration.

Context here is crucial. Given that the United States has a fundamentally different type of political system and economy than China does, Washington has significantly less direct sway over U.S. companies than Beijing does over Chinese ones. Moreover, when the U.S. federal government does partner with U.S. companies in an effort to spur technological development, it tends to do so with a group of companies rather than with individual companies, in an effort to improve the results by both leveraging competition and encouraging cooperation among companies.

[336] Colin McCormick and David Sandalow, "Solar Together: A Proposal," Columbia School of International and Public Affairs' Center on Global Energy Policy, April 2016.
http://energypolicy.columbia.edu/sites/default/files/energy/Center%20On%20Global%20Energy%20Policy_Solar%20Together_April%202016.pdfhttp://energypolicy.columbia.edu/sites/default/files/energy/Center On Global Energy Policy_Solar Together_April 2016.pdfhttp://energypolicy.columbia.edu/sites/default/files/energy/Center On Global Energy Policy_Solar Together_April 2016.pdf

7.3.4: R&D Recommendation 4: Decouple Federal Solar-R&D Funding From Domestic Manufacturing

Historically, the U.S. government held patent rights for technologies developed by people who were using federal R&D money at the time they developed them. Over time, Congress made changes to this approach, allowing researchers to retain patent rights for technologies they developed with federal R&D funding—a shift intended to spur commercialization of these new technologies by harnessing the profit motive. But federal law lets federal R&D-funding agencies require entities they fund to meet certain conditions in order to retain these patent rights. Among the conditions the Department of Energy has established is that funding recipients, to preserve their patent rights, must agree to manufacture "substantially in the United States" any products they develop with DOE funding or must negotiate with the DOE a legal waiver from that requirement.

The DOE has authority to impose this requirement on what the federal government classifies as "large" companies and on foreign companies as a result of a provision in a law called the Non-Nuclear Energy Research and Development Act. This so-called U.S. Competitiveness Provision reads as follows:

> "The Contractor agrees that any products embodying any waived invention or produced through the use of any waived invention will be manufactured substantially in the United States, unless the Contractor can show to the satisfaction of DOE that it is not commercially feasible to do so. In the event DOE agrees to foreign manufacture, there will be a requirement that the Government's support of the technology be recognized in some appropriate manner, e.g., recoupment of the Government's investment, etc. The Contractor further agrees to make the above condition binding on any assignee or licensee or any entity otherwise acquiring rights to any waived invention, including subsequent assignees or licensees. Should the Contractor or other such entity receiving rights in any waived invention undergo a change in ownership amounting to a controlling interest, then the waiver, assignment, license or other transfer of rights in any waived invention is suspended until approved in writing by DOE."

The DOE also has authority to impose patent-ownership conditions on what the federal government classifies as "small" companies, as well as on universities and non-profit organizations, under a different law, the U.S. Patent and Trademark Law Amendments Act. That law, enacted in 1980, is commonly known as the Bayh-Dole Act.[337] In 2013, more than three decades after the Bayh-Dole Act's passage, the DOE implemented the U.S.-manufacturing provision for the federal-R&D-grant recipients covered by the act: companies defined as "small," universities, and non-profit organizations. That policy shift came in the form of a "Declaration of Exceptional Circumstances" issued by the DOE's Office of Energy Efficiency and Renewable Energy (EERE).[338] In it, the DOE issued a requirement much like the one that had been established previously for large and foreign companies: that if a small company, university or non-profit organization wants to obtain title to an invention that it creates through R&D funded by the DOE, the entity agrees that any product developed through that R&D be "manufactured substantially in the United States."

In justifying the need for this new policy, the DOE noted that solar manufacturing was shifting to other countries. "Notwithstanding its leadership in research, development, and deployment of energy

[337] The law is named for Birch Bayh of Indiana and Robert Dole of Kansas, the senators who sponsored it.

[338] The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy includes the Solar Energy Technologies Office. As noted in Chapter 1 and in Sections 4.6.3 and 7.2.1, the Solar Energy Technologies Office provided Stanford University with the research grant that funded *The New Solar System*; the grant provided Stanford's Steyer-Taylor Center for Energy Policy and Finance with full independence and authority to frame the inquiry, conduct the research, draw conclusions, and write *The New Solar System*.

efficiency, renewable energy, and advanced energy technologies, the United States lags behind other nations in the manufacturing of those technologies," the new DOE policy directive stated, adding: "More particularly, in the field of solar technologies, China currently has 523 fully commissioned solar manufacturing plants (44% of world total) and Germany has 96 (8% of world total), while the United States has 87 (7% of world total)."

In additional language similar to that applied by the DOE to large and foreign companies, the new policy for smaller entities allowed them to "request a waiver or modification of the U.S. Manufacturing Plan from the DOE upon a satisfactory showing that the original U.S. Manufacturing Plan is no longer economically feasible and where the funding recipient can demonstrate an alternate net benefit to the U.S. economy notwithstanding the requested waiver or modification."

Although different laws are at play for different sorts of entities, the effect on all entities that want to retain patents for R&D funded by the DOE is similar: They must agree to manufacture "substantially in the United States" any products that emerge from that funding or they must obtain a waiver from the U.S.-manufacturing requirement from the DOE.

Discussions with scientists, solar-industry executives, and a range of DOE officials make clear that many scientists and executives disagree with the U.S.-manufacturing requirement and that there is disagreement even within the DOE about the requirement's advisability.

Frequently, according to these individuals, companies involved in applications for federal solar-R&D funding have bristled at the U.S.-manufacturing requirement; they have concluded that, if they end up manufacturing a product resulting from the R&D, they will want to do so in a country in which they have determined manufacturing costs are significantly lower than they are in the United States.

The result, according to discussions with a range of people involved in these cases, is that the U.S.-manufacturing provision is producing uneven results, because U.S. companies are reacting to it in differing ways. In some cases, concern over the requirement has led U.S. solar companies—including the two most prominent ones, SunPower and First Solar—to walk away from available federal solar-R&D funding, according to several people involved with these cases. In other cases in which companies in line for federally funded solar R&D have chafed at the U.S.-manufacturing requirement, the DOE has granted them legal waivers from the requirement or has signaled to them informally that it does not intend to enforce the requirement in their case, according to government, scientific, and corporate officials knowledgeable about these situations. According to a former U.S. government official who specializes in emerging technologies and who has extensive experience with the U.S.-manufacturing provision, the provision "amounts to a poison pill for U.S. subsidies. And that is what has happened—it has poisoned subsidies." This person added: "DOE constantly has said it won't enforce it—a wink and a nod. But that's not good policy; lawyers (for potential funding recipients) can't take that to the bank."

An October 2015 report by a U.S. federal commission tasked with reviewing the DOE's national laboratories also raised the U.S.-manufacturing provision as a concern. The report noted that, though federal law "requires a preference U.S. manufacturing for any intellectual property stemming from" a federal R&D award, the "DOE has specific guidance that makes this requirement more stringent than other agencies." The commission's report cited these "heightened DOE U.S. manufacturing requirements as impediments to industry engagement" in U.S. R&D.[339]

[339] "Securing America's Future: Realizing the Potential of the Department of Energy's National Laboratories: Final Report of the Commission to Review the Effectiveness of the National Energy Laboratories," Volume 2: Technical Chapters and Appendices, page 206. https://energy.gov/sites/prod/files/2015/10/f27/Final%20Report%20Volume%202.pdf

A U.S. solar executive called the U.S.-manufacturing provision “ineffective,” adding: "The bottom line is it's a feel-good for a politician. It's a great sound bite to say, `My predecessor supported federal dollars to move jobs offshore and I'm not going to do that.'" This executive continued, referring to the United States: "You can't hold technology hostage to a non-competitive manufacturing environment.”

The U.S.-manufacturing requirement might hurt the U.S. by impeding solar R&D more than it helps by promoting solar manufacturing.

It is noteworthy that, while the United States has resisted the idea that products developed with U.S. federal R&D funding will be manufactured in other countries, it has accepted the notion that the federally funded R&D itself will involve foreign entities. The DOE allows non-U.S. entities to receive U.S. R&D funding, though it typically requires that they be acting as subcontractors to a U.S. entity that is the main funding recipient. In one such case, Germany's Fraunhofer Institute for Solar Energy Systems, one of the world's leading solar-research laboratories, and a lab with a long tradition of collaboration with U.S. researchers, received funding for work on PERC solar cells under a DOE contract in which the main funding recipient was Suniva, an Atlanta-based solar maker. Fraunhofer's work, which occurred at its laboratories in Germany, "ultimately accelerated" the research that Suniva was conducting, said one U.S. official with knowledge of the situation. Suniva, which has a factory in Atlanta, is building an additional one in Michigan. Importantly, as explained in Section 3.4, Suniva now is controlled by a China-based solar firm, Shunfeng; after announcing plans for its Michigan factory, Suniva, which need an infusion of capital, sold a controlling stake to Shunfeng, which has said it is moving forward with the Michigan factory.

Today, with the solar industry globalizing more than ever before, it is time to ask whether U.S. policymakers should be more accepting of the notion that certain solar manufacturing is better conducted abroad than in the United States—just as they are of the notion that certain solar R&D is sometimes worth conducting elsewhere. More specifically, U.S. policymakers should consider the possibility that the U.S.-manufacturing requirement hurts the U.S. economy by impeding U.S. solar R&D more than it helps the U.S. economy by promoting U.S. solar manufacturing. When an applicant for federal solar-R&D funding that scored high on a DOE technical-merit assessment walks away because of concerns about being hamstrung by the U.S.-manufacturing requirement, that R&D funding may go to an applicant that was deemed technologically less deserving. In that sense, the DOE's U.S.-manufacturing requirement threatens over time to erode U.S. R&D leadership.

When the DOE implemented the "declaration of exceptional circumstances" in 2013, it made clear that it would review the policy in the future to assess whether it continued to be effective and justified. Congress urged, but did not require, the DOE to do more to ensure that solar technology developed with federal R&D funding was manufactured in the United States rather than abroad. The DOE chose to institute the U.S.-manufacturing provision, and it has legal authority to withdraw the provision.

Based on the above, the DOE should undertake a review of the U.S.-manufacturing provision in light of current conditions in the solar industry and consider revising or withdrawing it. As Section 4.4 explains, the sort of U.S. solar manufacturing that delivers long-term economic benefit will be better encouraged not by made-in-America requirements but by subtler policies that create the conditions in which U.S. solar manufacturing is more economically sustainable.

7.4: Manufacturing Recommendations

U.S. solar manufacturing is rising significantly but from an extremely small base. Several new or expanded U.S. solar-cell and -module factories are under construction or expected to be built over the next two years, and yet predictions are that, at least in the near term, U.S. solar manufacturing will remain small in the global context. Whether the United States will become a globally significant solar manufacturer over the long term is an open question. Importantly, the recently announced U.S. solar-factory additions depend on significant government incentives—not unlike those in China. But the United States is unlikely to provide subsidies over the long term that are large enough to overcome the manufacturing advantages of certain other countries. The key opportunity for the United States is to identify those sorts of solar manufacturing that are likely to be economic absent significant government subsidy. It is this challenge and opportunity that this section explores.

This section on U.S. solar manufacturing consists of two parts. The first part reviews the current status of solar manufacturing in the United States, including analyzing recent and projected U.S. factory additions, the prospects for U.S. solar-manufacturing jobs, the status of U.S. tariffs on solar goods imported from China, and lessons that two other sectors—semiconductors and automobiles—provide about the potential trajectory of U.S. solar manufacturing. The second part recommends several ways to increase U.S. solar manufacturing—ways that are likely to prove economic over the long term.

7.4.1: U.S. Solar Manufacturing: The Lay of the Land

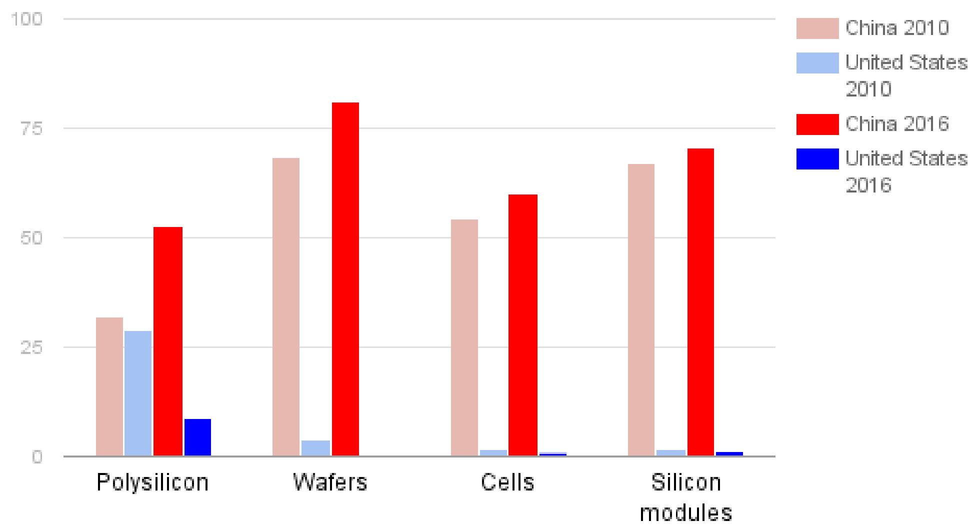
7.4.1.1: U.S. Solar Manufacturing is Expanding But Still Small in the Global Context

Announcements of solar-cell and solar-module factories expected to be built in the next few years in the United States suggest that U.S. manufacturing of those products will rise. But even with that increase, the United States is widely expected to remain a small player in global cell and module manufacturing at least in the near term. Cell and module manufacturing is increasing in other parts of the world—particularly in Asia—much faster than it is increasing in the United States.

As shown in Figure 40 below, for four main solar-related products, the Chinese share of global production has risen since 2010 and the U.S. share has fallen. The sharpest drop in U.S. share has come in polysilicon, the one product for which the United States had a sizeable share of global production. The U.S. share of global polysilicon production fell from 29.1% in 2010 to 10.6% in 2016.[340]

[340] Op. cit., IHS Markit

Figure 40: China and U.S. percent of global production for four solar segments, 2010 and 2016



Source: IHS Markit

Note: 2016 figures are IHS Markit estimates based on actual data for the first three quarters of 2016 and projections for the fourth quarter of 2016. IHS Markit projects U.S. wafer production for 2016 at 0.08% of the world total—an amount too small to be visible on this chart.
Source: IHS Markit

Looking ahead a couple of years, IHS Markit projects that U.S. solar-manufacturing capacity will rise in both absolute and percentage terms but will remain a very small share of the global total.

In 2017, IHS Markit projects, U.S. crystalline-solar-module capacity will reach 1,894 megawatts, or 1.7% of the global total, up from the 1,123 megawatts of crystalline-module capacity, or 1.3% of the global total, that IHS Markit says the United States had in 2015.

China, according to IHS Markit's projections, will have module-manufacturing capacity of 74,316 megawatts in 2017, representing 67% of the global total for that year, down from 65,220 megawatts, or 72% of the global total, in 2015.

IHS Markit's projections for cell manufacturing are broadly similar: The United States will have 1,602 megawatts of cell-manufacturing capacity, or 1.7% of the global total, in 2017, up from 661 megawatts, or 0.9% of the global total, in 2015. China will have 53,014 megawatts of cell-manufacturing capacity, or 58% of the global total, in 2017, compared with 44,378 megawatts, or 62%, in 2015.[341]

Several U.S. solar factories are under construction or on the drawing board, as discussed further in Sections 3.4 and 7.4.2.3. California-based SolarCity is building in upstate New York a solar-module factory that it has said ultimately will have an annual capacity of 1,000 megawatts—a size that, if it materializes, will make it one of the largest solar factories in the world. SolarCity calls this its "gigafactory," a nod to the factory's large production capacity, given that 1,000 megawatts equals 1 gigawatt. Massachusetts-based 1366 Technologies is building, also in upstate New York, a solar-wafer factory with an initial annual capacity of 250 megawatts and, the company says, an expected ultimate annual capacity of 3,000

[341] Ibid.

megawatts. Atlanta-based Suniva now has a 200-megawatt plant in Georgia and is doubling its U.S.-manufacturing capacity to 400 megawatts with the addition of a 200-megawatt factory in Michigan.[342] And German-based SolarWorld has said it is increasing the annual capacity of its Oregon module-manufacturing plant from 380 megawatts to 530 megawatts.

All the U.S. factory projects now underway or planned are being aided by government action.

Several structural changes are improving the United States' prospects for solar manufacturing:

- Solar manufacturing is growing increasingly automated, making less relevant the low-wage advantage that developing countries traditionally have had. Moreover, wages in many of those countries, notably China, are rising.
- The massive surge in U.S. production of natural gas, and its consequently lower cost, has reduced U.S. wholesale electricity prices. That is important to the solar industry because processing silicon and manufacturing solar modules—particularly wafers and cells—uses large amounts of electricity, which in much of the United States comes primarily from natural gas.
- Deployment of solar projects in the United States has been rapidly expanding, which increases the logic of locating at least module-assembly plants in the country as a way to minimize shipping costs, which can be significant for high volumes of modules coming from Asia. (Assembling solar modules in the United States also allows a solar manufacturer to market the modules as made-in-America, a distinction that for which some buyers, including the federal government, are willing to pay extra.)

Yet several caveats about the current upswing in U.S. solar manufacturing are crucial to keep in mind.

First, many of these ostensibly American solar stories are in fact the beneficiaries of the globalization sweeping the industry. SolarCity obtained the solar-cell technology that it has been seeking to commercialize at its New York factory by buying the company that owned the technology, Silevo. (Silevo, launched in California, received significant cash investment from Chinese venture-capital investors and ramped up manufacturing in China before SolarCity bought Silevo in 2014 for some $175 million.) And Suniva, hungry for capital to fund its manufacturing-expansion plans, obtained it in 2015 by selling a 63% stake in the firm for $57.8 million to China's Shunfeng.

Second, none of these U.S. manufacturing facilities currently approaches the size of China's solar factories. IHS Markit projects that, by the end of 2016, China's top solar manufacturers will have achieved the following full-year crystalline-solar-module production levels: Trina, 5,172 megawatts; Jinko, 4,951 megawatts; JA, 4,509 megawatts; Canadian Solar, 4,263 megawatts; and GCL, 3,503 megawatts.[343]

Third, all the U.S. factory projects now underway or planned are being aided by two types of government action: state and local manufacturing subsidies, not unlike some of those offered in China; and U.S. tariffs against Chinese-made solar modules, which make U.S.-made modules more cost-competitive.

Fourth, the United States' share of global cell and module manufacturing is likely to increase much less than the country's share of global polysilicon manufacturing continues to fall. Polysilicon

[342] Ehren Goossens, "Solar Billionaire-Backed Shunfeng Buys Majority Share of Suniva," Bloomberg, Aug. 12, 2015. http://www.bloomberg.com/news/articles/2015-08-13/solar-billionaire-backed-shunfeng-buys-majority-share-of-sunivahttp://h/ http://h/

[343] Op. cit., IHS Markit

traditionally was the one solar product of which the United States was a world-leading producer. That is due largely to inexpensive electricity, particularly hydropower in the U.S. Northwest, because processing polysilicon is a particularly energy-intensive part of the multi-step process that starts with silicon and ends with finished solar modules. But the tariffs that China imposed on U.S.-made polysilicon—following the tariffs that the United States imposed on Chinese-made solar cells—have rendered U.S.-made polysilicon less economically competitive in China. Polysilicon is made into solar wafers; one consequence of China's rise as the global polysilicon producer is that China has come to dominate solar-wafer production as well. Before the rise of the Chinese solar industry, most solar-wafer production occurred in Europe.

Finally, none of the companies that has announced plans to build a new solar-cell or solar-module factory in the United States is among the world's largest solar manufacturers. The leading global manufacturers—including those whose headquarters sit in the United States—continue to do most of their manufacturing in Asia.

SunPower and First Solar, the largest U.S.-headquartered solar manufacturers, have U.S. factories that are relatively small-scale and that function chiefly as manufacturing test beds for technological improvements developed by their R&D operations, which are located in the United States near the test factories. SunPower's R&D operations and test factory are in California; First Solar's R&D operations and test factory are in Ohio. But SunPower—which, though commonly described as a U.S. company, is 66% owned by French oil company Total—manufacturers most of its cells and modules in Mexico and the Philippines. Of the 8,309 full-time employees that First Solar reported as of January 2016, 1,283, or 15%, were in the United States; 4,881, or 58%, were in the Philippines, and 2,145, or 26%, were in other countries.[344] And First Solar manufactures some 80% of its modules in Malaysia. Executives at both SunPower and First Solar say manufacturing in Asia is far less expensive than in the United States, due both to supply chains in those countries and to government incentives there, particularly exemptions from corporate income taxes. Executives at both SunPower and First Solar say they have no plans to materially boost U.S. manufacturing.

China's large solar manufacturers, as explained in Section 5.6.3, conduct most of their manufacturing in China but increasingly are ramping up manufacturing beyond the mainland, mostly in Southeast Asia. Several of them report having looked into setting up factories in North America, including in the United States, largely in anticipation of a growing U.S. solar market. But executives at several China-based solar companies said Mexico is a more desirable location than the United States for a module-assembly plant because wages and environmental requirements are lower there. Both Trina and JA Solar have looked into opening Mexico module-assembly plants, according to executives at the two companies.

Still, it is entirely conceivable that the United States could prove a competitive place to manufacture at least certain types of solar products. A top JA Solar executive predicted that manufacturing future generations of solar modules in the United States might make sense.

He said he could not foresee manufacturing in the United States modules that are generally similar in their design to the ones the Chinese supply chain has ramped up to manufacture at low cost. There is "no way" the United States will be competitive in manufacturing solar modules that, as today's commoditized modules do, use metal frames, back sheet, glass and conventional silicon cells, this executive said.

[344] SunPower annual filing (10k) to U.S. Securities and Exchange Commission for year ending Dec. 31, 2015, http://investors.sunpower.com/secfiling.cfm?filingID=867773-16-101&CIK=867773http://investors.sunpower.com/secfiling.cfm?filingID=867773-16-101&CIK=867773
http://investors.sunpower.com/secfiling.cfm?filingID=867773-16-101&CIK=867773

However, "if we do not need frames and back sheet, and all we need is glass and cells, anything can happen. So the United States should develop new technology," he said. "We should be realistic. It won't happen in two or three years. But it may happen in five to ten years." If, as he expects, automation of solar manufacturing continues and technological developments continue, "the United States will have an advantage" in solar manufacturing.

If automation and technology continue, says a solar executive in China, "the United States will have an advantage" in solar manufacturing.

7.4.1.2: U.S. Solar-Manufacturing Jobs Are Likely to Be Few

As noted above, increasing automation in solar manufacturing raises the possibility that, over time, the United States could become a globally competitive location for production of a greater range of solar products. But policymakers must recognize that that automation is a double-edged sword. Already today, automation means that solar manufacturing in the United States is likely to provide relatively few jobs. Over time, as automation increases, those manufacturing jobs will be even fewer.

Outside of manufacturing, U.S. solar-related jobs today are growing rapidly. They totaled 208,859 in November 2015, a number greater than the country's 187,200 oil-and-gas-production jobs and significantly greater than the country's 67,929 coal-mining jobs, according to a January 2016 report by The Solar Foundation, a non-profit group that says its "mission is to increase understanding of solar energy through strategic research that educates the public and transforms markets."[345]

Still, solar represents a tiny slice of U.S. employment—only 0.1% of the total.[346]

Within the solar sector, jobs related to deployment vastly exceed those related to manufacturing. (This is one reason that many solar-installation companies argue that the tariffs the United States has imposed on Chinese-made solar modules, regardless of the tariffs' legal merit, damage the U.S. economy.) Of the 208,859 U.S. solar-related jobs in 2015, according to the Solar Foundation, 57.4% were in installation. Just 14.4% were in manufacturing—and that percentage was down four percentage points from in 2014, according to the foundation's statistics. Even the combined 2015 percentage of solar jobs in sales and distribution (11.6%) and in project development (10.7%) exceeded the percentage in manufacturing. The upshot seems clear: U.S. solar jobs are increasing, but policy makers and taxpayers should be under no illusion that the solar sector is likely to become a major source of U.S. manufacturing jobs.

7.4.1.3: Tariffs Against China Are Not Making the United States a Solar-Manufacturing Power

Disagreement is intense over whether the tariffs the United States has imposed on Chinese-made solar cells are legally justified—that is, whether the tariffs, described further in Sections 1.5 and 5.3.1, are appropriate under international law as a response to subsidies by the Chinese government and to alleged "dumping" of solar modules by China-based companies. Regardless of the legal question, however, facts on the ground make two things clear. First, the tariffs are not dramatically boosting solar manufacturing in the United

[345] "National Solar Jobs Census 2015," The Solar Foundation. http://www.thesolarfoundation.org/wp-content/uploads/2016/01/TSF-2015-National-Solar-Jobs-Census.pdfhttp://www.thesolarfoundation.org/wp-content/uploads/2016/01/TSF-2015-National-Solar-Jobs-Census.pdf

[346] Total U.S. nonfarm employment in November 2015 was 142,875,000. "Employment, Hours, and Earnings from the Current Employment Statistics Survey (National), U.S. Bureau of Labor Statistics, Current Employment Statistics Survey.
http://data.bls.gov/pdq/SurveyOutputServlet?request_action=wh&graph_name=CE_cesbref1http://data.bls.gov/pdq/SurveyOutputServlet?request_action=wh&graph_name=CE_cesbref1
http://data.bls.gov/pdq/SurveyOutputServlet?request_action=wh&graph_name=CE_cesbref1

States—a hope expressed by many supporters of the trade complaint that led to the tariffs and by many supporters of the tariffs themselves. Second, the tariffs appear unlikely to go away anytime soon.

To be sure, the tariffs were not intended as overarching U.S. federal solar policy. They are the result of legal action in 2011 brought not by the U.S. government but by Germany-based SolarWorld and several U.S.-headquartered solar manufacturers. Once the action was filed, the U.S. government's International Trade Commission was, under federal law, obligated to consider the legal merits of the petition and rule on it. During the four years since the commission imposed the tariffs, it has, in several decisions, adjusted their levels, all the while maintaining its view that the tariffs remain legally justified because of action by China's government and certain China-based solar companies.

Mr. Trump has long indicated support for U.S. tariffs as an antidote to what he has described as illegal help from the Chinese government to a range of Chinese industries. According to the White House website's description of the Trump administration's position on trade, "the United States will crack down on those nations that violate trade agreements and harm American workers in the process. The President will direct the Commerce Secretary to identify all trade violations and to use every tool at the federal government's disposal to end these abuses."[347] It remains to be seen how Mr. Trump, as president, will apply that trade approach to China.

Government officials in other countries have said that, if the Trump administration does not follow through on the climate pledges the Obama administration made as part of the Paris climate conference, they will consider levying a specific sort of tariff on goods they import from the United States: a tariff designed to compensate for what these countries argue will be the U.S. government's failure to impose sufficient carbon constraints on U.S. industry.[348] For several years, officials of some countries have raised the specter of imposing carbon tariffs on imports from countries they see as failing to act adequately to tax their greenhouse-gas emissions. In 2009, then-U.S. Energy Secretary Steven Chu indicated potential support for idea of the United States imposing carbon tariffs against China and India.[349] Scholars continue to debate the merits and disadvantages of carbon tariffs. Some of them argue that the tariffs can hurt more than help industry in the country that imposes the tariffs. The reason: The tariffs can raise the price of imports used by companies in the imposing country to manufacture finished products that those companies then sell abroad. As a result, the tariffs can end up rendering the imposing country's own exports less competitive on the global market.[350]

Amid this uncertainty, the way U.S. tariffs on Chinese-made solar products have played out underscores the need for a thoughtful and efficient recalibration of U.S. policy. The tariffs are raising the price of solar energy for U.S. consumers at the same time that the U.S. government is spending taxpayer money to subsidize U.S. consumers' solar purchases—subsidies that come in the form of the federal investment tax credit (ITC) and accelerated depreciation for solar projects. In effect, the United States with one hand is trying to make solar cheaper, through the ITC and other Congressionally established subsidies, and with the other hand is making solar more expensive,

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[347] White House website, "Trade Deals That Work For All Americans." https://www.whitehouse.gov/trade-deals-working-all-americans

[348] Coral Davenport, "Diplomats Confront New Threat to Paris Climate Pact: Donald Trump," The New York Times, Nov. 18, 2016. http://www.nytimes.com/2016/11/19/us/politics/trump-climate-change.html?_r=0

"A carbon tariff against the United States is an option for us," Rodolfo Lacy Tamayo, Mexico's under secretary for environmental policy and planning, says in this article.http://www.nytimes.com/2016/11/19/us/politics/trump-climate-change.html?_r=0

[349] Trevor Hauser, "Why Carbon Tariffs Are a Bad Idea—For Now," Foreign Policy, March 26, 2009. http://foreignpolicy.com/2009/03/26/why-carbon-tariffs-are-a-bad-idea-for-now/http://foreignpolicy.com/2009/03/26/why-carbon-tariffs-are-a-bad-idea-for-now/

[350] Christoph Böhringer, André Müller, and Jan Schneider. "Carbon Tariffs Revisited." Discussion Paper 2014-64. Cambridge, Mass.: Harvard Project on Climate Agreements, March 2014. http://belfercenter.ksg.harvard.edu/files/dp64_bohringer-et-al.pdfhttp://belfercenter.ksg.harvard.edu/files/dp64_bohringer-et-al.pdfhttp://belfercenter.ksg.harvard.edu/files/dp64_bohringer-et-al.pdf

through the tariffs.[351] This series of events almost certainly is not what U.S. policymakers envisioned when they implemented the ITC and the accelerated-depreciation policy. But it is the way that the intensely globally competitive solar industry has played out.

The tariffs are not, on balance, markedly increasing U.S. solar manufacturing. At least thus far, they have failed to significantly increase U.S. manufacturing in the one part of the solar value chain—crystalline solar cells—that the tariffs were crafted to address. As explained in Sections 5.6.3 and 5.6.4, , the tariffs are pushing China-based solar companies to ramp up solar-cell manufacturing beyond the Chinese mainland in a strategy to circumvent the tariffs, but those companies are not yet choosing to locate their non-Chinese manufacturing in the United States. Rather, they are locating them predominantly in Southeast Asian countries, and, to a lesser extent, in certain Eastern European and African nations, and in India.

The attraction of Southeast Asia is twofold: labor there is less expensive than in the West; and components manufactured by mainland China's extensive solar supply chain can be exported to Southeast Asian assembly factories at relatively little added cost.

The shift to Eastern Europe and Africa is driven mainly by domestic-content requirements that those countries have imposed. Companies that want to sell into those markets have no choice but to set up a factory there. In the narrowest sense, domestic-content rules succeed: They boost solar manufacturing in the country that imposes them. In a broader and far more important sense, however, they are counterproductive: They typically raise the cost of solar power. They raise it particularly for consumers in the country that imposes the local-content rules. They raise it too for consumers around the world. Moreover, as explained in Section 5.3.2, domestic-content rules in the solar industry increasingly are being rolled back after having been found by the World Trade Organization to violate WTO rules.

At the same time, the tariffs are having an overwhelmingly negative effect on the one area of solar manufacturing in which the United States traditionally has been a leading global player: the production of polysilicon.

The United States with one hand is trying to make solar cheaper, through subsidies, and with the other is making solar more expensive, through tariffs.

Polysilicon is the fundamental building block of today's solar modules. The material is derived from the element silicon. It is purified through a chemical process, melted into a long ingot, and then sliced into thin wafers that, through further processing, become solar cells.

Polysilicon, as noted in Sections 5.2.2.2 and 5.5.4.1, also is an important component of the global solar-tariff fight. After the United States and then the European Union imposed tariffs on Chinese-made solar cells, China in 2014 imposed tariffs on U.S.- and European-made polysilicon.

The Chinese tariffs have made U.S. polysilicon less competitive in China, in whose solar-wafer factories the vast majority of the world's solar-grade polysilicon is consumed.

In one sign of the effect on the United States, REC Silicon, a Norway-based polysilicon manufacturer with a large polysilicon plant in Moses Lake, Washington, announced in November 2016 that it was running the Moses Lake factory at only half its output and was laying off some 70 workers. (Previously REC temporarily closed the Moses Lake plant, citing the Chinese tariffs as a major reason.) REC reported that its third-quarter 2016 earnings before income taxes, depreciation, and amortization were 42% lower than in the year-earlier quarter, a drop that REC blamed on "the ongoing solar trade war between the U.S. and

[351] Jeffrey Ball, "Facing the Truth About Climate Change," New Republic, Feb. 3, 2015. https://newrepublic.com/article/120914/how-congress-can-compromise-climate-change-legislation

China," which it said "continues to restrict REC Silicon's access to polysilicon markets in China." [352] [353] "This is really stupid," an REC executive told Reuters. "The necessity and value in putting on tariffs to protect solar panels in the U.S. was just not thought through. We've suffered enormous financial damage as a result of this."[354]

Similarly, Hemlock, the U.S.-based polysilicon manufacturer, decided in 2014, after China had implemented the tariffs on U.S.-made polysilicon, to close a $1.2 billion polysilicon plant that it had built in Clarksville, Tenn.—a plant that it had finished building just the year before.[355]

Wacker, the largest exporter of polysilicon to China, negotiated an agreement with the Chinese government under which Wacker would be able to avoid the tariffs in exchange for agreeing not to sell its polysilicon in China below a specific price.[356] As a result, Wacker has fared better than some of its competitors in its sales to China-based solar makers—particularly regarding the polysilicon that it processes in the United States. In April 2016, Wacker opened a new $2.5 billion polysilicon plant in Tennessee.[357] In December 2016, Wacker announced plans to expand the plant with an additional $150 million facility that will turn a byproduct of the polysilicon-manufacturing process into a sellable commodity.[358]

The reality of this geopolitical tit-for-tat does not impugn tariffs' legitimacy as legal instruments. But it does impugn their effectiveness as tools to meaningfully boost U.S. solar manufacturing. As noted in Section 7.4.1.1, U.S. production of polysilicon has plummeted from 29.1% of the world total in 2010, just before the tariff war began, to 10.6% at the end of 2015, according to IHS Markit. The global polysilicon market, dominated by solar-grade polysilicon, was worth $4.71 billion in 2015 and is projected to grow to $8.9 billion by 2021, according to a recent report.[359] China's share of the global polysilicon market rose from 31.8% in 2010 to 50.5% in 2015, according to IHS Markit.

Amid calls in several countries over the past two years for an end to the solar-tariff dispute, the value of the global polysilicon market has prolonged the trade fight. In summer 2015, SolarWorld and China-based companies quietly negotiated a proposal to settle the dispute, according to people involved in the discussions. The proposal would have ended the tariffs by establishing minimum selling prices in the United States for a variety of classifications of Chinese-made solar modules—a structure used in the settlement of a similar tariff dispute between the European Union and China. But the proposal was not accepted. One reason, according to these informed people, is that the Chinese government wanted the full range of U.S. polysilicon producers to agree to a minimum selling price for their polysilicon in China. U.S. officials rejected that idea, arguing that would give too great an advantage to Chinese-based polysilicon producers. As of late 2016, both the U.S. tariffs against Chinese solar products and the Chinese tariffs against U.S. polysilicon remain in place.

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[352] REC Silicon Third-Quarter 2016 Results. http://www.recsilicon.com/media/newsroom/newshandler/?feed=/R/136555/PR/201611/2053462.xml
[353] REC Silicon Third-Quarter 2016 Report. http://hugin.info/136555/R/2053462/768542.PDF
[354] Earlier, in 2012, Wacker slowed construction on the plant because of a downturn in global polysilicon prices.
[355] Eric Snyder, "Hemlock Permanently Closing Clarksville Plant, Walks Away From $1.2B Investment," Nashville Business Journal, Dec. 7, 2014. http://www.bizjournals.com/nashville/blog/2014/12/hemlock-permanently-closing-clarksville-plant.html
[356] John Parnell, "China To Extend Anti-Dumping Duties on EU Polysilicon," PV Tech, April 29, 2016. http://www.pv-tech.org/news/43775
[357] Mike Pare, "Wacker Eyes Another Factory Even as it Marks Opening of New Bradley County Plant," Chattanooga Times Free Press, April 19, 2016. http://www.timesfreepress.com/news/business/aroundregion/story/2016/apr/19/wacker-here-stay-second-factory-could-come-br/360844/
[358] Mike Pare, "Wacker Adding Second Plant in Bradley County; $150 Million Investment To Add 50 Jobs," Chattanooga Times Free Press, Dec. 15, 2016. http://www.timesfreepress.com/news/business/aroundregion/story/2016/dec/15/wacker-adding-second-plant-bradley150-milliin/403097/
[359] Markets and Markets, "Polysilicon Market Worth 8.90 Billion USD by 2021," Oct. 14, 2016. http://www.marketsandmarkets.com/PressReleases/polysilicon.asphttp://www.marketsandmarkets.com/PressReleases/polysilicon.asphttp://www.marketsandmarkets.com/PressReleases/polysilicon.asp

7.4.1.4: Lessons From Other Industries: Semiconductors and Automobiles

The histories of two industries, semiconductors and automobiles, offer important insight into the way that solar manufacturing is likely to develop and into the long-term role that the United States is likely to play.

In the semiconductor industry, global manufacturing. Over time, that manufacturing has moved almost entirely to Asia—first to Japan, and then to Taiwan, and now, increasingly, to China. U.S. companies remain dominant in the semiconductor industry, but they employ a global strategy: They do the majority of their R&D in the United States and the majority of their manufacturing in lower-cost countries, overwhelmingly in Asia.[360]

The histories of two industries, semiconductors and automobiles, offer insight into how solar manufacturing is likely to develop.

manufacturing is concentrated in Asia. U.S.-based firms remain dominant in the industry, in significant part because they, like their competitors elsewhere in the world, manufacture in Asia and export the semiconductor chips that they make there to markets around the globe. The United States has little semiconductor manufacturing but derives significant economic value from the semiconductor sector.

In the auto industry, manufacturing is decentralized among end markets. The world's leading auto manufacturers, regardless of the country in which their headquarters sit, have assembly plants in the world regions in which they sell large numbers of cars and trucks. Several of these companies—Asian and European firms as well as American ones—have major factories in the United States. The United States remains one of the major auto-manufacturing centers of the world.

In the solar industry, certain products seem likely to follow the semiconductor manufacturing model—notably solar cells. Other goods, particularly solar modules, seem more likely to follow the automotive path. A fuller discussion follows.

7.4.1.4.1: Semiconductors

The United States was, through the 1980s, the undisputed global leader in semiconductor manufacturing. Concern that the United States was losing its dominance in global semiconductors led the U.S. government in the late 1980s to launch a partnership with U.S. semiconductor manufacturers. That partnership is called the Semiconductor Manufacturing Technology, or SEMATECH, consortium.

Over several years, the U.S. government invested hundreds of millions of dollars in the consortium. By the mid-1990s, U.S. companies had regained market share in the global semiconductor industry—although the United State had not regained its position as a globally dominant semiconductor manufacturer. U.S. firms, like their Asian competitors, were manufacturing their products overwhelmingly in Asia. At that point, SEMATECH shifted its focus from helping U.S. semiconductor manufacturers to advancing global semiconductor R&D. As part of that shift, the U.S. government ceased funding SEMATECH, and the consortium broadened its membership to include the world's largest semiconductor makers, regardless of where in the world they are based.

In the early 2000s, SEMATECH formed a large research partnership with the State University of New York Polytechnic Institute's (SUNY Poly's) Colleges of Nanoscale Science and Engineering, located in Albany, in upstate New York. SEMATECH and SUNY-Poly together created the Albany Nanotech Complex, a globally significant semiconductor-R&D complex. Today, U.S.

[360] What is more, they do much of their manufacturing abroad not in factories that they own themselves but rather in factories owned by contractors. Many of those contractors, indeed, manufacture semiconductors for multiple firms.

semiconductor companies are some of the strongest in the industry, and the high-volume manufacturing of semiconductor chips remains concentrated in Asia.[361]

Though it began as an attempt to claw back U.S. manufacturing, SEMATECH evolved over time into a broad international R&D consortium involving manufacturers from around the world. Under SEMATECH, the world's leading semiconductor makers, fierce competitors all, work together on certain aspects of R&D under the auspices of a university: SUNY-Poly. This evolution reflects a conclusion by consortium officials that the United States could derive significant economic value from the semiconductor industry even if most semiconductors themselves were manufactured abroad.

The SEMATECH initiative at SUNY-Poly has broadened from information technology into solar work. The SUNY-Poly Albany Nanotech Complex is the site of a $300 million effort called the U.S. Photovoltaic Manufacturing Consortium, a public-private venture created with money from the U.S. Department of Energy and involving several dozen U.S.-based solar companies and organizations.[362] [363] The consortium, which focuses on developing next-generation CIGS thin-film solar cells, is a partnership among SEMATECH, SUNY-Poly's Colleges of Nanoscale Science and Engineering, and the University of Central Florida. One facility that is part of the U.S. Photovoltaic Manufacturing Consortium is SUNY-Poly's Solar Energy Development Center, built in Halfmoon, New York, a half-hour drive north of Albany.

With that as a base, the time now is ripe for the SEMATECH solar endeavor to evolve in much the same way that the SEMATECH information-technology effort did: into an R&D consortium that is truly global. The potential for expanding the upstate New York solar cluster in ways that play to the United States' comparative strengths is discussed in Section 7.4.2.3 below.

Solar cells—the wafer-like slices of silicon that, once processed with various chemicals, are assembled into solar modules—are akin to semiconductor chips in the sense that they are small and light and thus easy to ship. It is worth noting that semiconductors and solar cells do differ in an important respect. One semiconductor firm's chips differ from another's mostly because of the way the chips are designed; the fact that the intellectual property lies mostly in the design makes it easy for semiconductor firms to contract out their chip manufacturing to third-party firms whose large factories are concentrated in Asia. Solar cells, however, are differentiated mostly by the way they are manufactured; that is one reason that a large percentage of solar cells still are manufactured by the companies that designed them. But this difference does not negate the fundamental similarity between semiconductor and solar production: Manufacturers, whether they are based in the United States or China, typically find it most economic to manufacture cells, like chips, in Asia.

7.4.1.4.2: Automobiles

The auto industry provides a different perspective for the solar sector. Through the 1960s, auto makers, wherever they were based in the world, manufactured mostly for their home—or for nearby—national markets. As a percentage of total sales, exports to distant parts of the world were a small part of the auto business. That meant that, in the United States, U.S. firms traditionally dominated. But that began to change in the 1970s, when U.S. automakers began to lose significant

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[361] "SEMATECH History," SEMATECH website, https://web.archive.org/web/20130702191328/http://www.sematech.org/corporate/history.htmhttp://h/

[362] "SUNY Poly CNSE's Solar Energy Development Center," SUNY Poly Colleges of Nanoscale Science and Engineering's website. http://www.sunycnse.com/LeadingEdgeResearchandDevelopment/ResearchCentersPrograms/SolarEnergyDevelopmentCenter.aspx

[363] U.S. Photovoltaic Manufacturing Consortium website. http://www.uspvmc.org/membership_members_PVMC.html

market share to Japanese firms, who had developed smaller and more-fuel-efficient cars for their home market—cars that quickly caught on with big-car-loving American consumers who were reeling from surging gasoline prices in the wake of the 1973 Arab oil embargo.

By the 1990s, several Japanese automakers had built assembly plants in the United States. These so-called "transplant" factories made economic sense for four reasons. First, the United States was a rapidly expanding market for these Japanese firms. Second, cars are large and heavy, making them expensive to ship. Third, assembling the cars in the United States allowed the Japanese firms that owned the transplants to market the cars to U.S. consumers as having been American-made. And fourth, Japanese automakers were accustomed to paying relatively high wages back home, meaning that U.S. labor rates were not excessive by comparison.

Noteworthy too is where within the United States the Japanese auto makers chose to locate their transplants. They did so largely in rural areas in southern states. Labor unions were weaker there than in the industrial Midwest, allowing the Japanese companies to pay lower wages. And hunger for economic development was intense in the U.S. South, leading state officials to offer the Japanese firms generous subsidies for building their factories there.

To be sure, automakers today export large numbers of cars across the world. But they tend to do so mostly with models whose foreign sales numbers are relatively low. Once foreign sales of a model reach a certain level in a distant market, it becomes economic to build an assembly plant there.

Solar modules have a similarity with cars. Their weight—largely a function of their glass sheeting and their metal edges—makes them more expensive than solar cells to ship. That is particularly true given the number of solar modules required to generate a significant amount of electricity. A typical solar module has a capacity of between 250 watts and 350 watts. So a solar project with a capacity of 10 megawatts—a relatively small utility-scale project—would require between 28,500 and 40,000 modules. A solar project with a capacity of 100 megawatts—the size of some large projects—would require between 285,000 and 400,000 modules. The large numbers of solar modules necessary to produce meaningful quantities of electricity makes local module-assembly plants sensible once a domestic market reaches high volume.

Local solar-module-assembly plants become sensible once a domestic market reaches high volume.

Like automobiles, glass offers an example of a sector that has chosen to localize production in end markets once sales in those end markets reach certain levels. Glass, of course, is a key component in solar modules. As explained in Section 5.2.2.2, one of the world's major glass makers, China's Flat Glass, has manufacturing located near some of China's largest solar factories. Localization of manufacturing in the glass industry, as in the auto industry, offers a plausible path for segments of the solar sector—particularly for those components, such as solar modules, whose weight makes them relatively costly to ship long distances.

What annual volume in a given country justifies a local module-assembly plant is a matter of disagreement. Solar executives interviewed during the research for *The New Solar System* offered differing views on the threshold at which they believed it would make economic sense for their company to build a solar-module-assembly plant in the United States. Some said it would make sense when their company sold as little as 50 megawatts' worth of modules annually in the

United States. Others put the sales threshold at 500 megawatts annually. Whatever the actual number, more U.S. deployment will increase the likelihood of more U.S. manufacturing. That observation leads to the first of several recommendations for steps the United States could take to develop a solar-manufacturing presence that is economically sustainable over the long term.

The United States appears increasingly likely to have a viable future in solar manufacturing—but in quite specific areas.

7.4.2: U.S. Solar-Manufacturing Recommendations

7.4.2.1: Manufacturing Recommendation 1: Rely on a Push and a Pull

The most important step the United States could take regarding domestic solar manufacturing has nothing directly to do with manufacturing. It has to do with the way the nation approaches manufacturing as an element of the broader solar enterprise.

Politicians often portray manufacturing as the part of any industry that is most important to their domestic economy. They typically make this claim regardless of what industry they are discussing, including solar. And they typically do so regardless of what country they represent, including in the United States.

But it seems unlikely that U.S. taxpayers will support the level of direct manufacturing subsidies likely to be necessary to catapult the United States into the ranks of the world's top solar-manufacturing nations from its tiny base today.

Rather than direct manufacturing subsidies, many U.S. solar executives cite a reduction in the U.S. corporate-income tax as the government action that would be most instrumental in persuading them to build a solar factory in the United States. At 35%, the United States' marginal national-corporate-income tax rate is among the highest in the world. Corporate-tax breaks are common, and they bring the corporate-income-tax rate paid often by U.S. firms down to below 15%. Still, solar executives frequently cite the high marginal rate as a significant driver of their decision to locate their solar factories in other countries—countries that have lower rates to begin with and that often give these manufacturers effective holidays from all corporate income taxes for periods of 15 years or more.

The idea of significantly cutting the U.S. corporate-tax rate is highly controversial. To some, it would be prudent industrial policy. To others, it would be excessive corporate welfare. *The New Solar System* takes no position either way. It is far from clear whether the tax is likely to be reduced anytime soon. However, talk in Washington is mounting about sweeping tax reform; a reduction in the corporate-tax rate, for good or ill, could well be part of such reform.

A smarter strategy to induce solar manufacturing in the United States—a strategy aimed at inducing the sort of solar factories that would deliver maximum long-term economic benefit to the country—would employ a subtler approach. Rather than layer on direct manufacturing subsidies, it would rely on an indirect push and pull. The push would be to boost domestic solar R&D, successive waves of which could maintain in the United States cost-effective initial factories for new solar technologies that were developed on U.S. soil. The pull would be to expand domestic solar deployment, which would create domestic demand for sufficient volumes of solar products to justify decisions by global solar makers, both U.S.-based and non-U.S.-based, to locate at least module-assembly plants in the United States.

7.4.2.2: Manufacturing Recommendation 2: Target Three Types of Solar Manufacturing

The United States appears increasingly likely to have a viable future in solar manufacturing. But that future is likely to be in quite specific areas. Effective U.S. policy should recognize this nuance, targeting the specific areas of solar manufacturing for which the United States is suited rather than aspiring to grab the significant share of global solar manufacturing that is likely to remain more economic in other countries. Three very different categories of solar products seem likely to be able to be competitively manufactured in the United States.

7.4.2.2.1: Final Assembly of Large or Heavy Solar Goods for U.S. Consumption

One group includes products that cost more to manufacture in the United States than in other countries but that are so expensive to import, typically because of their size and weight, that manufacturing them in the United States for U.S. use makes sense once the U.S. market for them has reached a critical mass. The U.S.-manufactured products in this category likely would not be cost-competitive for export. And the U.S. factories making products in these categories probably would perform only final assembly; manufacturing of the components themselves probably still would take place in countries with lower manufacturing costs.

Solar modules are the clearest example of a solar product in this category. As described in Section 7.4.1.2.2, in the quantities necessary to produce meaningful amounts of electricity, they are large and heavy. This means that, once the U.S. market reaches a certain size, the higher cost of assembling them in the United States is likely to be outweighed by the savings in not having to ship them in from abroad. (One analog here is the wind-turbine industry, which years ago set up assembly plants in a variety of local markets, primarily because wind turbine components such as blades and towers are so large. Another is the glass industry, which, similarly, positions factories close to its end markets to avoid the cost of shipping its heavy product long distances.)

7.4.2.2.2: Manufacturing of Energy-Intensive Solar Goods for Global Export

Another group are solar products that the United States has a structural advantage to manufacture—a structural advantage so compelling that it renders the United States an economically attractive manufacturer not just for domestic consumption but for export too. One such product is polysilicon, the processing of which is so energy-intensive that inexpensive U.S. energy—mainly from hydropower or natural gas—makes the United States one of the most economic manufacturing sites in the world. A 2016 report by consulting firm Biggins Lacy Shapiro & Co. concluded that median electricity prices for industrial customers are between 34% and 49% lower in the United States than in China.[364] Nevertheless, as explained in Section 5.1.2, polysilicon manufacturing is shifting from the United States to China despite these low electricity prices in parts of the United States, in large part because of the tariffs on U.S.-produced polysilicon that the Chinese government imposed after the United States imposed tariffs on Chinese-produced solar goods. In other words, in addition to raising the cost of solar power for U.S. consumers, there is a second unintended consequence to U.S. tariffs on Chinese solar products: reduced demand for U.S. polysilicon in China, the world's biggest market.[365]

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[364] "A Comparison of U.S. & China Electricity Costs," Biggins Lacy Shapiro & Co., 2016. http://blsstrategies.com/docs/news/News_181.pdfhttp://blsstrategies.com/docs/news/News_181.pdfhttp://blsstrategies.com/docs/news/News_181.pdf

[365] As noted above in footnotes to Sections 2.4 and 5.3.1, a Greentech Media study in 2014 projected that the price of China-made solar modules imported into the United States would rise an average of 14% as a result of the tariffs, but several U.S. solar-industry experts said they have seen no credible analysis of how much the tariffs have, in fact, pushed prices up recently. That is a potential area for future research.

7.4.2.2.3: Manufacturing of Technologically Sophisticated Solar Goods for Global Export

A third category of solar products likely to be cost-effectively manufactured in the United States are those based on cutting-edge technologies developed in the country—technologies for which the innovative U.S. R&D is so intrinsic to the manufacturing process that putting at least the first factory in the United States makes economic sense despite the fact that U.S. labor is more expensive, and that the U.S. manufacturing supply chain is thinner, than in China or in several Southeast Asian countries.

New generations of various types of solar goods fit into this category. One example is kerfless solar wafers, which were described in Section 7.3.1.

But there are two important caveats to the notion of the United States as a globally competitive manufacturer of solar products developed through cutting-edge U.S. R&D.

First, as export-focused manufacturing of these products shifts to high volume, subsequent factories are likely to be built outside of the United States—in countries where, both because of established manufacturing supply chains and because of government willingness to provide direct manufacturing subsidies, companies are likely to be able to manufacture these products less expensively than they could in the United States. As a result, the U.S. factories that produce these leading-edge solar products should be thought of as initial manufacturing sites, or "first factories."

This reality is important in framing U.S. solar strategy. Rather than try to fight the progressive offshoring of the manufacture of new solar technologies as they scale up—rather, that is, than trying to keep a new solar technology's subsequent factories in the United States—the United States should focus on continuously advancing from one solar technology's first factory to the next solar technology's first factory, and on and on. It is a strategy resembling a surfer's: always aiming for the leading edge of the next solar-technology wave. As noted above, this is, in essence, the strategy already employed by the two largest U.S.-headquartered solar manufacturers, SunPower and First Solar, which have relatively small U.S. factories near their R&D operations but which do the majority of their manufacturing abroad. As the SunPower and First Solar examples underscore, these first factories provide an important economic benefit to the United States even if the large-scale factories that follow them are built offshore. Pursuing the goal of keeping and multiplying first factories on U.S. soil helps shape U.S. solar R&D, because it puts a premium on the R&D that is most likely to be commercialized at scale. In addition, the first factories themselves work as important R&D tools, providing researchers with a nearby assembly line where they can test and tweak the technologies they are developing in an effort to improve their commercial viability.

China's increasing sophistication in solar R&D suggests it too will emerge as a home for first factories for novel solar technologies.

Second, China's increasing sophistication in solar R&D, as documented in *The New Solar System*, suggests that it too will emerge as a viable home for first factories for novel solar technologies. The firms that dominate today's solar industry, regardless of where their headquarters sit, are increasingly global. The strongest among them are able to buy or develop a novel solar technology in, say, the United States, and then commercialize it on the other side of an ocean—in, say, Asia. As explained above, this is the strategy employed by the two biggest U.S.-based solar manufacturers, First Solar and SunPower. There is much reason to believe that this model will grow more common over time. Given this reality, first factories will remain competitive in the United States to the extent that the United States continues to innovate—staying, through robust R&D, on the leading edge of the ever-advancing solar-technology wave.

7.4.2.3: Manufacturing Recommendation 3: Encourage Solar-Manufacturing Clusters

Around the world, solar manufacturing, like manufacturing in many other sectors, has centered on geographic clusters that leverage well-developed supply chains, established transportation infrastructure, abundant low-cost energy, and often partnerships with local R&D institutions such as universities or government-affiliated labs.

Globally prominent solar-manufacturing clusters have developed in the following locations:

- China's Yangtze River Delta: As detailed in Section 5.2, the Yangtze River Delta is home to the majority of China's—and the world's—large solar-cell and -module factories;
- Malaysia's Kulim and Penang: Two neighboring coastal cities in northwest Malaysia that together account for a large percentage of Malaysia's growing solar-manufacturing capacity. Kulim is the site of solar plants run by the United States' First Solar and Japan's Panasonic. Penang is home to solar factories run by China's JA and Jinko.
- Germany's Solar Valley: An area of eastern Germany south of Berlin that, in the early 2000s, the heyday of German solar manufacturing, was home to the vast majority of German solar plants. Several of these factories have since shut down.

In the United States, two geographic areas have emerged as solar-manufacturing clusters, though neither approaches the size of the clusters in China, in Malaysia, or in Germany during the height of German solar manufacturing. One is California's Bay Area; the other, as noted in Section 7.4.1.4.1 above, is the region of upstate New York near Buffalo.

The Bay Area in California is the undisputed center of solar R&D in the United States and, in many respects, in the world. A number of laboratories and universities in the Bay Area are engaged in solar research, including the Lawrence Berkeley National Laboratory; the University of California, Berkeley; the Lawrence Livermore National Laboratory; and Stanford University. An array of solar-technology firms started and remain based in Silicon Valley, south of San Francisco. Several of those companies have small manufacturing lines that are linked with their R&D labs. In an attempt to encourage more solar manufacturing in the area, the U.S. Department of Energy in 2011 launched the Bay Area Photovoltaic Consortium, an initiative involving the DOE, area universities, and area solar firms. The goal of the consortium, according to its website, is "to find and fund the best research in universities around the United States to advance photovoltaic manufacturing technologies, developing innovations that can be transferred to industry within three to five years."[366] [367] Nevertheless, solar manufacturing in the Bay Area remains infinitesimal—essentially a handful of pilot lines—against the backdrop of large-scale solar manufacturing in Asia.

The Buffalo area of upstate New York will, if construction plans materialize, be within the next few years the largest solar-manufacturing cluster in the United States and, indeed, in the Western Hemisphere. That the Buffalo region is on track to earn that distinction is a measure of two things: the aggressiveness of the state of New York in proffering subsidies to two U.S. solar manufacturers, and the lack of sizable solar manufacturing anywhere else in the world beyond Asia.

As discussed in Section 7.4.1.1, SolarCity is building in Buffalo a solar-module plant with a 1,000-megawatt annual capacity.[368] And 1366 Technologies has announced plans to build in New

[366] Bay Area Photovoltaic Consortium website. https://bapvc.stanford.edu

[367] The Bay Area Photovoltaic Consortium is based at Stanford University. The Steyer-Taylor Center for Energy Policy and Finance also is based at Stanford.

[368] "Governor Cuomo Announces New SolarCity GigaFactory Complex at RiverBend," New York State Economic Research and Development Authority (NYSERDA) press release, Sept. 23, 2014. http://www.nyserda.ny.gov/About/Newsroom/2014-Announcements/2014-09-23-Governor-Cuomo-Announces-New-SolarCity-GigaFactory-Complex-at-RiverBendhttp://www.nyserda.ny.gov/About/Newsroom/2014-Announcements/2014-09-23-Governor-Cuomo-Announces-New-SolarCity-GigaFactory-Complex-at-RiverBend

York's Genesee County, between Buffalo and Rochester, a 250-megawatt solar-cell factory that the company says it ultimately plans to expand to an annual capacity of more than 3,000 megawatts.[369]

Both the SolarCity and 1366 Technologies factories were lured with significant subsidies from New York State—incentive packages similar in several respects to those that Chinese provincial and local governments have provided to China-based solar manufacturers. Even before New York state offered those incentives, it had worked with the federal government to create a solar cluster in the area, as explained in Section 7.4.1.4.1 above. The cluster includes the SEMATECH semiconductor-research initiative based at SUNY-Poly in Albany.

New York State's support for the SolarCity factory totals $750 million, part of an economic-development strategy laid out by New York Gov. Andrew Cuomo for upstate New York—a strategy that, in reference to the level of state subsidies involved, the Cuomo administration has dubbed the "Buffalo Billion." According to a press release from the New York State Energy Research and Development Authority (NYSERDA), SolarCity is expected to spend $5 billion through 2024 launching and operating the factory. The $750 million in state support will pay for the majority of the 1.2-million-square-foot factory and to buy equipment for it. Gov. Cuomo noted in the NYSERDA press release about the SolarCity deal that "the fundamental strength was the available hydropower," given that solar manufacturing uses large amounts of electricity.[370] In addition to the state's $750 million, SolarCity is spending $150 million on the factory, the total cost of which will be $900 million.[371]

New York State support for the 1366 factory totals $56.3 million, according to the NYSERDA, one of the state agencies providing the 1366 incentives. 1366 will invest $100 million initially on the factory and, according to New York state, approximately $600 million more over the expected build-out of the project. An added attraction of the site is the availability of as much as 8.5 megawatts of inexpensive hydropower, according to the NYSERDA.[372]

Whether subsidies of this magnitude are a prudent use of taxpayer funds is a matter for policymakers to debate. However, to the extent that a U.S. state or local government or the federal government decides to subsidize the development of solar factories in the United States, concentrating that support on the solar clusters that already are underway seems a prudent strategy to leverage economies of scale and thus to maximize the efficiency of the public money spent.

There is room to evolve the effectiveness of the upstate New York solar cluster, if government and corporate officials decide that New York is an economically advantageous location on which to focus U.S. solar research and manufacturing. For one thing, despite the addition of the SolarCity and 1366 factories, the upstate New York solar cluster remains significantly smaller than the world's primary solar cluster, China's Yangtze River Delta, which is discussed in detail in Sections 5.2.1 and 5.2.2. For another, the solar technology on which the SEMATECH consortium in New York has focused its research is not the technology that SolarCity or 1366 are pursuing in their factories. The SEMATECH research focuses on CIGS, which, as explained in Section 4.2.2.1, is a thin-film solar technology. SolarCity and 1366, by contrast, are focusing on silicon-based technologies.

[369] "Governor Cuomo Announces 1366 Technologies to Construct Advanced Manufacturing Facility in Genesee County," NYSERDA press release, Oct. 7, 2015. http://www.nyserda.ny.gov/About/Newsroom/2015-Announcements/2015-10-07-Governor-Cuomo-Announces-1366-Technologies-to-Construct-Advanced-Manufacturing-Facilityhttp://www.nyserda.ny.gov/About/Newsroom/2015-Announcements/2015-10-07-Governor-Cuomo-Announces-1366-Technologies-to-Construct-Advanced-Manufacturing-Facility

[370] Op. cit., NYSERDA press release about SolarCity.

[371] David Robinson, "SolarCity Construction Nears Completion" Buffalo News, Aug. 26, 2016. http://buffalonews.com/2016/08/26/solarcity-construction-nears-completion/http://buffalonews.com/2016/08/26/solarcity-construction-nears-completion/http://buffalonews.com/2016/08/26/solarcity-construction-nears-completion/

[372] Op. cit., NYSERDA press release about 1366 Technologies.

One way to grow the upstate New York solar cluster would be, as noted in Section 7.4.1.4.1 above, to expand the SEMATECH-related solar-R&D effort to include companies beyond those based in the United States. This expansion would harness the globalization that has come to shape the solar industry already and that all but certainly will define it even more in the years ahead.

Whether the United States extends the Ex-Im Bank's authorization could significantly impact foreign sales by U.S. solar firms.

7.4.2.4: Manufacturing Recommendation 4: Reengage the U.S. Export-Import Bank

An important element of China's buildup of its solar-manufacturing enterprise has been the financing that Chinese lenders have provided to China-based solar firms for their international expansion: manufacturing in foreign markets, exporting abroad solar modules made in China, and developing solar installations in other countries using Chinese-made modules. Chinese banks have been crucial players in this regard. And the Chinese government now is articulating an even stronger policy of support for China-based companies establishing operations abroad. The Export-Import Bank of China, a particularly important player in the government's strategy, says on its website that it has "intensified support to projects involving new energies such as wind, solar and biomass power, which have produced good economic and social returns."[373] The Asian Infrastructure Investment Bank, a new multilateral development bank led by China, has said it will prioritize clean-energy-infrastructure investments, and news reports suggest the bank is mulling an investment on the order of $500 million in solar deployment in India, a country with ambitious solar-deployment targets[374] that also is a major and growing customer for China-based solar manufacturers.[375]

Other countries similarly subsidize the foreign expansion of their companies through government-backed financing.

In June 2015, the U.S. Congress declined to renew the charter of the U.S. Export-Import Bank, the result of complaints by some members of Congress that the low-interest loans that the bank provides to U.S. companies to finance exports of their products amount to unneeded taxpayer subsidies for large corporations. In December 2015, however, the Congress voted to reauthorize the Ex-Im Bank's charter. Yet the bank remains unable to approve deals of over $10 million—deals that constitute a significant part of the bank's business. Such deals require the approval of three of the bank's five board members, and only two of the bank's board seats now are filled, the result of an ongoing dispute in the Senate about whether to fill a third board seat.[376]

The Ex-Im Bank provides government-guaranteed—and thus low-cost—financing to foreign buyers of U.S. exports. In 2014, the bank financed $336 million of purchases of environmentally oriented products, including solar modules, from U.S. firms. In 2011, it said it would provide more than $455 million in project financing for sales by First Solar in Canada.[377] The Ex-Im Bank's reauthorization extends through 2019. Supporters call it necessary given that other countries, including China, provide low-cost financing for exports of their domestic goods.

[373] Import-Export Bank of China website, http://english.eximbank.gov.cn/tm/m-aboutinfo-en/index_731.html

[374] Varun Sivaram, Gireesh Shrimali, and Dan Reicher, "Reach for the Sun: How India's Audacious Solar Ambitions Could Make or Break its Climate Commitments," Stanford Steyer-Taylor Center for Energy Policy and Finance, Dec. 8, 2015. https://law.stanford.edu/reach-for-the-sun-how-indias-audacious-solar-ambitions-could-make-or-break-its-climate-commitments/

[375] "China-led AIIB eyes first loans to India," Reuters, March 31, 2016, http://in.reuters.com/article/asia-aiib-india-idINKCN0WX0T3http://h/

[376] Jackie Calmes, "A Single Senator Stymies the Export-Import Bank," The New York Times, June 27, 2016. http://www.nytimes.com/2016/06/28/business/international/a-single-senator-stymies-the-export-import-bank.html?_r=0http://h/

[377] "Senators Push U.S. Export-Import Bank Toward Brink," Greentech Media, July 13, 2015, https://www.greentechmedia.com/articles/read/Senators-Push-US-Export-Import-Bank-Towards-Liquidationhttp://h/

Opponents call it corporate welfare. Whether the United States extends the bank's authorization in three years could significantly impact foreign sales by U.S. solar firms, assuming the dispute over the bank's board members is resolved.

7.5: Deployment Recommendations

Deployment is the ultimate objective of the global solar enterprise. R&D seeks new technologies that are cheaper and more efficient than the old ones—with the goal of increasing the share of solar power in the energy mix. Manufacturing, as *The New Solar System* has argued, should be seen not as an end in itself but as one step in the attempt to harness the sun's energy as cost-effectively, and thus as broadly, as possible. Deployment—installing solar modules so they can produce electricity—is the true test of solar power's viability as a mainstream low-carbon energy source.

Significantly ramping up solar deployment would require a range of policy changes at the federal and state levels. The policy changes should be calibrated for maximum economic efficiency: to produce the biggest solar-deployment bang for the taxpayer buck.

Certain areas of the United States—particularly the Southwest, Mountain West, and California—have some of the best solar resources on the planet. Largely in those regions, U.S. solar deployment is surging. In 2015, the United States was the third-largest deployer of solar modules in the world, behind China and Japan. It installed 7,200 megawatts of solar capacity in 2015, up 16% from 2014. Cumulatively, the United States has installed 25,600 megawatts of solar capacity as of 2015, placing it fourth globally, behind China, Germany, and Japan.[378] And in 2016, new U.S. solar deployment increased hugely to 14,600 megawatts, essentially twice the figure for 2015. Although 2016 figures from many other countries had yet to be reported as of early 2017, preventing a global ranking for 2016, it is clear that the United States is becoming an increasingly important deployment market.[379]

Yet despite this growth, the United States ranks 25th globally in the percentage of its electricity—just under 1%—that it generates from solar. By contrast, Italy, Greece, and Germany each generate between 7% and 8% of their power from the sun. In six additional countries—Belgium, Japan, Bulgaria, the Czech Republic, Australia, and Spain—more than 3% of electricity comes from solar power. Each of these nine economies is just a fraction of the size of the United States.[380] Several of them enjoy extraordinarily rich solar resources across a majority of their land mass. That stands in contrast to the United States, in which excellent solar resources exist in some, but not all, parts of the country—and in which transmission capacity is often lacking to move utility-scale solar from resource-rich areas that often have low populations to urban areas that often have poor solar resources and inadequate land for large-scale solar development. Moreover, many of these countries have higher conventional electricity prices than the United States, an economic reality that helps solar compete. It is also important to note that solar deployment has slowed dramatically over the past two years in Germany, Italy, Greece, and Spain, as those countries have rolled back previously generous deployment incentives. That slowdown is a sobering illustration of the extent to which, despite recent drops in price, solar in most places remains dependent on government subsidy.

Still, in scaling up solar power, both for itself and for the world, there is much more that the United States could do. These actions fall into two general categories that this chapter explores:

- domestic energy policies, including those that help cleaner energy technologies in general and those that help solar and

[378] International Energy Agency Photovoltaic Power Systems Program, "Trends 2016 in Photovoltaic http://iea-pvps.org/index.php?id=256http://iea-pvps.org/index.php?id=256
[379] "U.S. Solar Market Grows 95% in 2016, Smashes Records," Greentech Media, Feb. 15, 2017, https://www.greentechmedia.com/articles/read/us-solar-market-grows-95-in-2016-smashes-records
[380] Ibid.

related enabling technologies like storage and transmission particularly;

- and federal action that facilitates engagement by U.S. investors and financial institutions in the Chinese solar market.

7.5.1: Domestic Energy Policies

7.5.1.1: Price on Carbon

More than any other single policy, a significant price on carbon in the United States would induce a market shift from higher-carbon to lower-carbon technologies. Several carbon-pricing mechanisms already are in place in the United States: direct ones such as the Regional Greenhouse Gas Initiative on the East Coast and California's carbon-trading system, and indirect ones such as the federal government's Clean Power Plan and Corporate Average Fuel Economy standards. None of these policy instruments, however, imposes a price on carbon that is high enough to curb U.S. emissions significantly. A discussion of the intricacies of a carbon-pricing mechanism—whether through a carbon tax, a cap-and-trade system, or some other mechanism—is beyond the purview of *The New Solar System*. But an intelligently crafted and meaningful price on carbon would send a powerful positive signal to the entire solar value chain, from technology developers to manufacturers to project developers to financiers. It would send a particularly profound signal to technologists—a signal of a demand for more-efficient solar technologies over the long term.

More than any other single policy, a significant price on carbon would induce a shift from higher- to lower-carbon technologies.

7.5.1.2: Clean Power Plan

The Clean Power Plan, a federal rule finalized in 2015, would cut greenhouse-gas emissions from U.S. power plants and help propel the shift from higher-carbon to lower-carbon electricity sources. In February 2016, the Supreme Court, responding to petitions from more than two-dozen states and from an array of industry groups, stayed implementation of the plan pending a lower-court review.[381] If the plan is implemented as intended, it will amount to a boost for solar power. In addition to the continuing legal challenge, the Trump administration has expressed opposition to the plan. As noted in Section 1.4.2, the Trump administration's "America First Energy Plan," published on the White House website, pledges that "President Trump is committed to eliminating harmful and unnecessary policies such as the Climate Action Plan"—a broad suite of policies that includes the Clean Power Plan.[382]

Even if the Clean Power Plan were to be implemented in the way that the Obama administration intended, the extent of the boost that it would provide to solar power is far from clear. Research suggests that the extent to which the Clean Power Plan induces a shift to solar rather than to other low-carbon energy sources would depend significantly on economics: how the prevailing price of solar power at the time compared with the prevailing price of other energy sources, particularly natural gas and, to a lesser extent, wind.

Modeling reported in a 2015 paper found that the amount of solar capacity the Clean Power Plan induced by 2030 would vary widely—anywhere from 7,000 megawatts to 99,000 megawatts above the levels to be expected without the Clean Power Plan. The 7,000-megawatt scenario assumes solar costs do not fall much from their current levels; the

[381] Greg Stohr and Jennifer A. Dlouhy, "Obama's Clean-Power Plan Put on Hold by U.S. Supreme Court, Bloomberg, Feb. 9, 2016. http://www.bloomberg.com/politics/articles/2016-02-09/obama-s-clean-power-plan-put-on-hold-by-u-s-supreme-courthttp://h/

[382] Op. cit., "An America First Energy Plan," White House website.

99,000-megawatt scenario assumes installed solar prices fall to about 75 cents per watt. "The magnitude of the increase in solar generation [from the Clean Power Plan] is highly dependent on the assumed solar capital cost," the paper explains. "When solar capital cost is assumed to decline very little from its current level, the increase in solar generation due to the draft CPP is small."[383] In its role as a potential magnifier of cost-effective solar power, the Clean Power Plan increases the motive for the federal government to take more-fundamental steps—particularly in R&D—to reduce the price of solar. The more-aggressive cost-cutting targets for solar power that the DOE recently announced under its SunShot Initiative are an example of such steps.

Among the strongest drivers of distributed solar in the United States have been net-metering policies.

7.5.1.3: Renewable-Portfolio Standards

State renewable portfolio standards (RPSs) have been key drivers of solar deployment in the United States. An RPS is a regulatory mandate to increase production of energy from renewable sources such as wind, solar, biomass and geothermal. The RPS mechanism places an obligation on electricity generators to produce a specified fraction of their power from renewable energy sources. Certified renewable energy generators earn certificates for every unit of electricity they produce and can sell them, along with their electricity, to supply companies.

RPSs are on the books in 29 states.[384] Some states, such as California and New York, recently have toughened their RPS mandates. In others, such as Texas, the states met their RPS requirements but have not gone back and made them stricter. Still other states, such as Ohio, have put their RPSs on hold following controversies about the mandates. Overall, RPSs have spurred development of renewables, including solar, and according to recent analysis they have done so with generally modest increases in electricity rates.[385]

Falling solar prices make renewable-portfolio standards more affordable. Yet these standards remain important as a means of driving solar deployment—particularly large, utility-scale solar projects—because solar power remains, in most places, more expensive than conventional power. Without the legal requirement to buy more solar power, many utilities would choose other forms of generation.

7.5.1.4: Speeding Permitting for Utility-Scale Solar Projects

In December 2015, a new law took effect that requires federal agencies to collaborate much more than before in the way they conduct environmental reviews and permitting of a host of large-scale developments, including renewable-energy projects. The requirements appear in the nation's transportation bill, known as the Fixing America's Surface Transportation ("FAST") Act. The relevant renewable-energy-project language that appears in the act was developed in a previous bill, the Federal Permitting Improvement Act of 2015, co-sponsored by Republican Sen. Rob Portman and Democratic Sen. Claire McCaskill. The requirements in the new law apply to renewable-energy projects that are expected to involve an investment of more than $200 million and that are

[383] Wesley Cole, Trieu Mai, Kelly Eurek, Daniel Steinberg, and Robert Margolis. "Considering the Role of Solar Generation under Rate-Based Targets in the EPA's Proposed Clean Power Plan," Electricity Journal, 2015. http://www.sciencedirect.com/science/article/pii/S1040619015001852http://h/

[384] Jocelyn Durkay. "State Renewable Portfolio Standards and Goals," National Conference of State Legislatures website, July 27, 2016. http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspxhttp://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

[385] A Survey of State-Level Cost and Benefit Estimates of Renewable Portfolio Standards, U.S. National Renewable Energy Laboratory and Lawrence Berkeley National Laboratory, http://www.U.S. National Renewable Energy Laboratory.gov/docs/fy14osti/61042.pdf (2014)

subject to review under the National Environmental Policy Act (NEPA).

Broadly, the requirements in the law seek to speed up federal review of proposed projects, including renewable-energy ones, by pressing various federal agencies to coordinate with each other as each of them conducts its particular review of the project. Among the law's requirements, for instance, is an overarching, multi-agency plan for the entire permitting review. The law requires that this "Coordinated Project Plan" include a "comprehensive schedule of dates by which all environmental reviews and authorizations, and to the maximum extent practicable, State permits, reviews and approvals must be made." The new requirements could significantly speed up approval of utility-scale renewable energy projects while still ensuring a comprehensive federal review of the projects' potential environmental downsides. A significant question, however, is how smoothly the law will be implemented. Ensuring federal agencies adhere to the law's requirements—and addressing as quickly as possible any problems with the law's implementation—could significantly increase solar deployment across the country.[386]

Uncertainty over net-metering policies is slowing distributed-solar deployment in some of the sunniest parts of the United States.

7.5.1.5: Resolving the Future of Net Energy Metering for Distributed Solar Projects

One of the strongest drivers of distributed solar installations in the United States have been policies that require utilities to pay consumers for electricity—generally solar power—that the consumers generate and feed into the power grid. These "net energy metering" (NEM) policies exist in 43 states, according to the U.S. National Renewable Energy Laboratory.[387] In several states, net-metering policies have generated intense opposition from utilities. The utilities argue that even consumers who generate power on their rooftops—and thus buy less power from the utilities—are using the electricity grid and should be required to pay for that use. Solar advocates contend that homeowners or companies with solar modules on their buildings' roofs ease pressure on the grid precisely during the time of day when power demand typically peaks—also the time that, in many places, sunlight is most intense. As a result, say solar advocates, these solar-power producers obviate the need for expensive "peaker" generating plants and thus should not have to pay grid fees.

In a particularly far-reaching decision, Nevada's public-utilities commission voted in December 2015 to cut by 75% over several years the amount of money that utilities are required to pay consumer solar generators for every kilowatt hour of energy that such consumers produce. That decision dramatically reduced solar installations in the state. In September 2016, state regulators decided to restore net metering for state residents who applied for residential solar systems before the end of 2015, but they left in place for new solar customers the cut in net-metering income they had imposed several months earlier.[388]

In several other states, public-utility commissions are weighing whether to impose direct levies, called grid-maintenance fees, on consumers who generate distributed solar power—and, if the commissions do impose those fees, how they should structure them.

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386 David Hayes. "Congress Just Enacted New Permitting Requirements for Energy Projects: Did You Miss It?" Stanford Law School blog, Dec. 10l, 2015. https://law.stanford.edu/2015/12/10/congress-just-enacted-new-permitting-requirements-for-energy-projects-did-you-miss-it/#comments)

387 U.S. National Renewable Energy Laboratory webpage. http://www.U.S. National Renewable Energy Laboratory.gov/tech_deployment/state_local_governments/basics_value-of-solar_tariffs.htmlhttp://h/

388 "Nevada Regulators Restore Net Metering for Existing Solar Customers," Greentech Media, Sept. 16, 2016, https://www.greentechmedia.com/articles/read/nevada-regulators-restore-net-metering-for-existing-solar-customershttp://h/

A potential model for a solution to this dispute emerged in August 2016 in Colorado. There, the dominant utility, Xcel Energy, and the solar industry had been engaged in a long-running fight over a proposal by Xcel to impose grid fees. In August 2016, Xcel and nearly two-dozen parties, including a variety of solar companies and advocates, proposed a settlement of the dispute to the Colorado Public Utilities Commission, the state's utility regulator. Under the settlement, Xcel would withdraw its request for the imposition of grid fees for solar-power producers. Instead, Xcel would phase in a new electricity-pricing model, known as time-of-use rates.[389] Under this system, customers would pay more for electricity that they used during times of day when electricity demand is high, and they would pay less for electricity that they use during times of day when electricity demand is low. Solar advocates say this system more fairly accounts for the value of solar power, since the sun shines brightest, and thus solar-power production peaks, at the same time of day when electricity demand typically surges: the afternoon.

Another potential solution to the net-metering battle is what is called a value-of-solar tariff. Under this rate structure, which is in effect in Minnesota and in Austin, Texas, electricity consumers with solar panels pay the local utility the retail rate for all the electricity they use, but the utility pays them for all the solar power they generate—and does so at a separate rate, the so-called value-of-solar rate, that is calculated to reflect solar power's benefits to the system as well as its costs. The value-of-solar rate takes into account such things as the transmission-and-distribution grid services that even consumers with solar panels on their homes or businesses continue to use.[390] But, notes NREL, coming up with a fair way to calculate the value-of-solar rate is difficult, and if a jurisdiction decides to recalculate the value-of-solar rate each year, consumers who produce solar power have no way of predicting how much revenue they will earn from their solar modules in the future.[391] That uncertainty can thwart adoption of solar.

The uncertainty over the future of net-metering policies is slowing distributed-solar deployment in some of the sunniest parts of the United States. Achieving an equitable outcome—one that recognizes both the benefit of distributed solar generation and the need for a robust and well-maintained electricity grid—would smooth the growth of solar in a country that is shaping up to be one of the largest markets for solar in the world.

7.5.1.6: Tax Incentives

The federal investment tax credit (ITC) for solar provides investors in U.S. residential and commercial solar projects with a tax credit worth 30% of the cost of the project. In December 2015, Congress approved an extension of the ITC that reduces the credit over a period of five years. The credit remains through 2019 at 30%; it drops in 2020 to 26%; and it drops in 2021 to 22%. After that, it phases out entirely for residential projects, and it drops for commercial projects to 10%, where under the current legislation it will remain indefinitely.

The ITC has helped produce a massive expansion of solar in the United States. But, as a means of solar support, it has a key inefficiency. Only investors with sufficient tax equity are able to take advantage of its tax break. Those institutions have been chiefly investment banks, which have used the ITC to build profitable businesses investing in solar projects. The paucity of tax-equity providers under the ITC, explained in Section 3.3.1, has allowed those providers to charge high rates for

[389] Joseph Bebon, "Utility And Solar Stakeholders Unite Under Massive Settlement Agreement in Colorado," Solar Industry Magazine, Aug. 16, 2016. http://solarindustrymag.com/utility-and-solar-stakeholders-unite-under-massive-settlement-agreement-in-coloradohttp://solarindustrymag.com/utility-and-solar-stakeholders-unite-under-massive-settlement-agreement-in-colorado

[390] Jeff Bingaman, George P. Schultz, Dan Reicher, Jeremy Carl, Alicia Seiger, David Fedor, and Nicole Schuetz, "The State Clean Energy Cookbook: A Dozen Recipes for State Action on Energy Efficiency and Renewable Energy, Steyer-Taylor Center for Energy Policy and Finance," Sept. 11, 2014. http://www.hoover.org/sites/default/files/research/docs/shultz-bingaman_statecleanenergycookbook_2014.pdfhttp://www.hoover.org/sites/default/files/research/docs/shultz-bingaman_statecleanenergycookbook_2014.pdf

[391] Op. cit., U.S. National Renewable Energy Laboratory webpage.

their investments, diverting into their coffers money that, under a more efficient incentive, would pay for more solar projects. By some estimates, as much as 30% of the federal money spent on the ITC ends up as profit for this handful of large investment institutions.[392] As the federal government already is recognizing, there are less-expensive tax tools to use to support the continued growth of solar power.

The phasedown of the ITC recognizes that the costs of solar have fallen dramatically. But extending to solar certain other tax benefits enjoyed by fossil-fueled energy projects make sense to aid this cleaner form of energy. One such tax benefit is the master limited partnership (MLP). MLPs were authorized by Congress in 1981 and are used to provide tax-advantaged financing primarily to U.S. oil and gas pipelines and related infrastructure. MLPs ownership interests trade like corporate stock, which opens them up to investment by millions of U.S. retail investors. But MLPs are taxed only as partnerships, which means that the partnership's income is taxed only once—not at the corporate level, but at the investor level. Currently, though oil-and-gas investments are eligible for MLP status, renewable-energy investments are not. That prohibition makes little sense.[393]

Another important tax benefit for solar and other clean-energy technologies is the their eligibility for accelerated depreciation through the Modified Accelerated Cost-Recovery System (MACRS). MACRS, first authorized in 1986 for certain technologies and since expanded, provides five- and seven-year accelerated depreciation schedules, depending on the particular clean energy technology. In addition, certain technologies qualify for a 50 percent bonus depreciation, allowing investors to deduct half of their qualifying investments in the first year and the remainder spread over the following four years. It was initially authorized under the Economic Stimulus Act of 2008 and extended most recently in 2015.

7.5.1.7: Federal Loan Guarantees

Federal loan guarantees are designed to facilitate the commercialization and early deployment of advanced energy and vehicle technologies by providing a government backstop that allows investors in these projects to secure less-expensive financing. The program, administered by the DOE's Loan Programs Office (LPO), supports energy and transportation technologies that are ready for commercial deployment but face challenges raising capital in the debt markets. A review of the DOE loan-guarantee program issued in April 2015 by the Government Accountability Office found that 34 loans and loan guarantees totaling about $28 billion had been issued, of which five loans totaling $807 million had resulted in defaults. In other words, the default rate for the program portfolio was 2.8%.[394]

Two of the five loan defaults were in the solar sector. Both of those were for solar factories: one for Solyndra and the other for Abound Solar.[395]

In addition, as of 2015, 14 solar-generation projects had received funding under the program; as of the release of the GAO report, none had defaulted.[396] Before 2010, there were no solar projects in the United States with capacities of more than 100 megawatts. The loan-guarantee program helped finance the first five utility-scale PV projects; since then, private debt markets have financed many more.

While the LPO has used upward of half of the loan authority originally provided by Congress, the program currently has over $40 billion in remaining authority to fund clean-energy and

[392] Jeffrey Ball, "Tough Love For Renewable Energy: Making Wind and Solar Power Affordable," Foreign Affairs, May/June 2012, https://www.foreignaffairs.com/articles/2012-04-20/tough-love-renewable-energy

[393] Felix Mormann and Dan Reicher, "How to Make Renewable Energy Competitive," The New York Times, June 2, 2012. http://www.nytimes.com/2012/06/02/opinion/how-to-make-renewable-energy-competitive.html

[394] "DOE Loan Programs: Current Estimated Net Costs Include $2.2 Billion in Credit Subsidy, Plus Administrative Expenses," U.S. Government Accountability Office, April 2015. http://www.gao.gov/assets/670/669847.pdfhttp://www.gao.gov/assets/670/669847.pdf

[395] Ibid.

[396] Ibid.

advanced-vehicle-technology projects.

U.S. policymakers should learn from the loan-guarantee program's successes and failures. In particular, as the federal government considers future loan guarantees, it should take into account the challenge of seeding U.S. solar factories, as evidenced by the Solyndra and Abound defaults. Solar factories face far greater technology-commercialization risk than do solar projects, which typically have long-term contracts to sell their power at agreed-upon prices. The fact that solar factories are, by their nature, riskier investments than solar-generation projects illustrates why, as *The New Solar System* has argued, it is crucial for the U.S. government to be surgical in the types of domestic solar manufacturing that it supports.

Solar factories are riskier investments than solar-generation projects, so it is crucial for the U.S. government to be surgical in the types of solar manufacturing that it supports.

7.5.1.8: Federal Procurement of Solar

The federal government is a major purchaser of renewable energy. For example, the U.S. Department of Defense has an aggressive goal to deploy 3,000 megawatts of renewable-energy capacity. But federal agencies face major impediments in their use of power-purchase agreements (PPAs), the long-term contracts that allow power developers to finance energy projects in exchange for buyers'—in this case federal government—long-term commitments to buy the power at a set price. For example, under federal law, civilian agencies typically may enter into PPAs for no more than 10 years, even though power developers typically need commitments of more than 20 years to finance projects. Several policy changes, described in a recent report by a federal task force reporting to the U.S. secretary of energy, would free up federal agencies in their use of PPAs.[397]

7.5.2: Solar Finance in China

China is today, and is likely to remain for years, the world's largest solar-deployment market. As noted in Section 6.1, China had some 76,500 megawatts of cumulative solar-power capacity installed as of the end of 2016. And the Chinese government has set aggressive targets for future solar growth; some informed officials believe the country's solar deployment will double by 2020. A robust expansion in China will be crucial to solar energy's achieving a scale of global penetration and associated cost reductions and that would meaningfully address climate goals. It also would be a lucrative opportunity for U.S. business. In a development that is widely under-appreciated in Washington, Chinese officials appear increasingly enthusiastic about welcoming U.S. investment and financial innovation into the Chinese solar-deployment market.

As noted in Section 6.4.2, U.S. and Chinese officials already have been discussing cooperating on new solar-financing structures as part of their ongoing talks under the U.S.-China Renewable Energy Partnership, a bilateral organization established by the two countries in 2009.[398]

Among the groups involved with the U.S.-China Renewable Energy Partnership is the American Council on Renewable Energy, a Washington-based trade group.[399] Its members include U.S.-based multinationals such as Amazon, Dow Chemical, Google, and IBM; investment banks such as Bank of America Merrill Lynch, Citigroup, Credit

[397] "Secretary of Energy Advisory Board Report of the Task Force on Federal Energy Management," U.S. Department of Energy, September 2016. http://energy.gov/sites/prod/files/2016/11/f34/9-22-16_Report_of_SEAB_Federal_Energy_Management_TF_w_transmittal.pdf
[398] Op. cit., U.S.-China Renewable Energy Partnership web page.
[399] Dan Reicher, one of the authors of this report, is chairman of the American Council on Renewable Energy.

Suisse, and JP Morgan; asset managers such as BlackRock; and major U.S. law firms.

It is unclear how the advent of the Trump administration will affect the potential for a closer relationship between the United States and China over clean-energy finance.

Helping China achieve its desired solar-power growth is one of the more important steps the United States could take in the field of solar power—both to maximize solar energy's global contribution to curbing climate change and to help U.S. companies in the solar sector grow and prosper. Amid continuing animosity between Beijing and Washington on many fronts, including on the issue of solar tariffs, the possibility of increased involvement by U.S. solar manufacturers and investors in China's solar-deployment market is a significant opportunity—one whose time has come.

Involvement between U.S. and Chinese solar businesses already is rapidly increasing. As explained in Section 3.4, several leading U.S. solar-technology firms have sold large stakes or their entire businesses to Chinese investors, and in many cases the U.S. workers have remained to try to commercialize their products under Chinese management. U.S. investment banks have been active in helping China-based solar firms tap the public markets for capital for manufacturing, both through initial public offerings and through follow-on offerings. And China-based solar manufacturers are beginning to invest significant sums in developing solar projects in the United States. So far, however, neither U.S. lenders nor U.S. solar developers have been active in China's burgeoning solar-deployment market.

The time is right for that to change. U.S. solar companies, investors, and policymakers have pioneered innovative methods of solar-deployment financing. Now, high-ranking government officials in China are concluding that, in order for the country to meet its aggressive solar-deployment targets, China needs to embrace certain U.S.-developed financial structures.

Also as explained in Section 6.4.2, one of Chinese officials' primary goals in pursuing more-innovative means of solar finance is to reduce the cost of that capital by expanding the pool of lenders beyond the state-affiliated Chinese banks that traditionally have dominated the market. Chinese regulators are interested in particular in opening up Chinese solar-deployment investment to institutional players such as pension funds and insurance companies. And they are keen to explore the possible adoption in the Chinese market of direct leasing by consumers of solar-rooftop systems, one of the fastest-growing structures for distributed solar in the United States.

Increased involvement in China by U.S. solar manufacturers and investors is an opportunity whose time has come.

The interest on the part of China in more-economically-efficient solar-financing methods represents a compelling area of potential cooperation in solar between the two countries, because it offers clear benefits for both. For China, it offers the possibility of lower-cost capital to finance a solar expansion. For U.S. financiers, it offers the possibility to help realize—and to profit from—the growth of the largest renewable-energy market in the world. Increasing U.S. financiers' involvement in China's solar market inevitably will raise complex issues, including questions about China's electricity-market regulations—regulations that currently make it difficult for foreign investors to participate. But the prize is substantial: China plans by 2030 to spend ¥41 trillion ($5.95 trillion) on low-carbon technologies, including solar.[400]

[400] Xinhua Finance Agency, "China to spend 6.7 trillion USD on low-carbon industries by 2030," Sept. 16, 2015. http://en.xinfinance.com/html/Economies/Investment/2015/142716.shtmlhttp://h/
http://h/

The U.S. government could act as a powerful facilitator of increased involvement by U.S. investors and solar developers in the Chinese solar-deployment market. Doing so could help unleash private capital to combat carbon emissions—as study after study has concluded that private capital will be far more important than direct government spending in cleaning up the global energy system. It is important that these financing discussions that have begun between U.S. and Chinese government officials—discussions such as those occurring through the U.S.-China Renewable Energy Partnership—continue and be made to produce real results. This is yet another area in which the United States could harness the globalization sweeping the solar industry to benefit its economy—not to mention the planet.

China and the United States have a compelling reason to work more closely together on solar: economic self-interest.

7.6: Conclusion

The solar-power sector, with China at its center, has grown feverishly over the past five years. It has achieved the status of a global industry: one with significant employment, geopolitical value, and economic interests, all of which the industry's partisans around the world will fight to protect and expand. Yet solar energy will have to grow many times larger if it is going to contribute meaningfully to combating climate change.

As *The New Solar System* has argued, smarter policies—from finance, to R&D, to manufacturing, to deployment—will be crucial if solar power is to meet its environmental potential. And China—its central government, key provincial governments, and its collection of China-based solar firms—is transforming its solar sector in an effort to position it for continued leadership and growth.

The United States has a distinct economic interest in growing its domestic solar activities in a way that is economically sustainable over time. That will involve sophisticated and surgical targeting of areas of the industry in which the United States is likely to be globally competitive. And it will involve recalibrating the U.S. approach to solar to cooperate with China in measured, careful, and mutually beneficial ways.

China and the United States find themselves at an unprecedented moment in the growth of solar power. How they proceed will do much determine whether solar energy emerges as a mainstream energy source and, in the process, as an engine of significant economic growth and carbon reductions. As *The New Solar System* has explained, there are many reasons to be skeptical that the world's two largest energy consumers and carbon emitters will find the will to work more closely together to scale up solar power to meaningfully address the climate challenge. Yet each of them has an even more-compelling reason to do so: economic self-interest.

Appendices

Appendix A: Laboratory-Scale Solar-Cell Efficiencies

A.1: HIT Laboratory-Scale Cell Efficiencies

Chinese Institution	Efficiency (%)	Date
Chinese Academy of Sciences Institute of Electrical Engineering	14.09	2007
Chinese Academy of Sciences Institute of Electrical Engineering	17.27	2008
Shanghai Jiaotong University, Institute of electrical engineering	20.25	2013
Institute of Microsystem and Information Technology	20.13	2013
Foreign Institute	**Efficiency (%)**	**Date**
Sanyo, Japan	12.3	1983
Sanyo, Japan	18.1	1992
Sanyo, Japan	20	1994
Sanyo, Japan	20.1	2001
Sanyo, Japan	21.3	2003
Sanyo, Japan	22.3	2008
Sanyo, Japan	23	2009
Sanyo, Japan	22.8	2009
Sanyo, Japan	23.7	2011
Sanyo, Japan	24.7	2013
Panasonic (Sanyo), Japan	25.6	2014

A.2: CIGS Laboratory-Scale Cell Efficiencies

Chinese Institution	Efficiency (%)	Date
Nankai University	7.28	1995
Nankai University	8.83	1999
Nankai University	9.13	1999
Nankai University	12.1	2004
Nankai University	15.35	2011
Nankai University	15.6	2011
Chinese Academy of Sciences Shenzhen Institutes of Advanced Technology	16.6	2011
Chinese Academy of Sciences Shenzhen Institutes of Advanced Technology	19.07	2013
Foreign Institute	**Efficiency (%)**	**Date**
NREL, United States	16.4	1995
NREL, United States	18.2	1998
NREL, United States	18.4	2001
NREL, United States	18.8	2006
NREL, United States	19.9	2008
ZSW, Germany[401]	20.1	2010
ZSW, Germany	20.3	2010
ZSW, Germany	20.8	2013
Solibro, Germany	20.5	2014
Solar Frontier, Japan	20.9	2014
ZSW, Germany	21.7	2014

[401] ZSW, located in Germany's Baden-Württemberg region, is, in German, the Zentrum für Sonnenenergie- und Wasserstoff-Forschung, and, in English, the Center for Solar Energy and Hydrogen Research.

A.3: Cadmium Telluride Laboratory-Scale Cell Efficiencies

Chinese Institution	Efficiency (%)	Date
Sichuan University	13.38	2001
Chinese Academy of Sciences Institute of Electrical Engineering	12.78	2012
University of Science and Technology of China	14.6	2014
Chinese Academy of Sciences Institute of Electrical Engineering	14.4	2014
Foreign Institute	**Efficiency (%)**	**Date**
NREL, United States	16.5	2001
First Solar, United States	17.3	2011
GE Global Research, United States	18.3	2012
GE Global Research, United States	19.6	2013
First Solar, United States	20.4	2014
First Solar, United States	21.5	2015

A.4: Perovskite Laboratory-Scale Cell Efficiencies

Chinese Institution	Efficiency (%)	Date
Hong Kong Polytechnic University	4.87	2013.1
Dalian Institute of Chemical Physics	5.55	2013.1
Tsinghua University	6.12	2013.6
Chinese Academy of Sciences Institute of Plasma Physics	6.54	2013.3
Huangzhong University	6.64	2013.9
Qingdao Institute of Bioenergy and Bioprocess Technology	7.5	2013.12
Tianjin University	9.1	2014.3
Chinese Academy of Sciences Institute of Physics	10.41	2013.12
Chinese Academy of Sciences Institute of Physics	11.63	2014.3
Peking University	15.4	2014.4
Foreign Institute	**Efficiency (%)**	**Date**
Not available	2.19	2006
Not available	0.36	2007
University of Tokyo, Japan	3.81	2008
Sungkyunkwan University, South Korea	6.5	2011
Sungkyunkwan University, South Korea	9.7	2012
Oxford University, UK	10.9	2012
Swiss Federal Institute of Technology in Lausanne, Korea Research Institute of Chemical Technology, Switzerland	12	2012
Korea Research Institute of Chemical Technology, South Korea	12.3	2013
Swiss Federal Institute of Technology in Lausanne, Switzerland	15	2013
Oxford University, UK	15.4	2013
Foreign Institute	**Efficiency (%)**	**Date**
Oxford University, UK	15.9	2013

Foreign Institute	Efficiency (%)	Date
Korea Research Institute of Chemical Technology, South Korea	16.2	2013
Korea Research Institute of Chemical Technology, South Korea	17.9	2014
University of California, Los Angeles, United States	19.3	2014
University of California, Los Angeles, United States	12.1	2014
University of Saskatchewan, Canada	10.2	2014

A.5: Organic Laboratory-Scale Cell Efficiencies

Chinese Institution	**Efficiency(%)**	**Date**
Chinese Academy of Sciences Institute of Chemistry	2%	2002
Chinese Academy of Sciences Institute of Chemistry, Chinese Academy of Sciences	3.18%	2006
South China University of Technology	5.40%	2007
Chinese Academy of Sciences Institute of Chemistry Institute of Chemistry, Chinese Academy of Sciences	6.50%	2010
Chinese Academy of Sciences Institute of Chemistry Institute of Chemistry, Chinese Academy of Sciences	7.59%	2011
South China University of Technology	8.37%	2011
South China University of Technology	9.20%	2012
South China University of Technology	9.28%	2014
Foreign Institute	**Efficiency(%)**	**Date**
Research Laboratories, Eastman Kodak Company, United States	1%	1985
University of California at Santa Barbara, United States	1%	1995
University of Linz, Austria	2.50%	2000
University of Linz, Austria	3.50%	2002
Princeton University, United States	5%	2005
University of California at Santa Barbara, United States	5%	2005
Wake Forest University, United States	5%	2005
University of California at Santa Barbara, United States	5.50%	2007
University of California at Santa Barbara, United States	6.10%	2008
Solarmer Energy, United States	8.13%	2010
Heliatek, Germany	8.30%	2010
Mitsubishi Chemical, Japan	9.20%	2011
Mitsubishi Chemical, Japan	10.70%	2011
HKUST and North Carolina State University	11.50%	2014

Appendix B:
A Description of the Solar-Trade Dispute Between the United States and China And Between the European Union and China

The trade dispute between the United States and China has consisted of two legal cases.

The first case began with the petitions filed before the U.S. Department of Commerce and International Trade Commission in October 2011 by a group of seven companies that manufacturer solar cells and modules in the United States. The group was led by SolarWorld, which is based in Germany but has a factory in Oregon.[402] The petitions alleged two types of legal violations by China-based solar manufacturers: dumping, under which a manufacturer sells products abroad at below its production cost; and subsidies by the Chinese government so excessive that they gave China-based manufacturers an unfair advantage in selling their products abroad.

On Nov. 8, 2011, the Department of Commerce initiated investigations of both allegations. The Department of Commerce selected two China-based solar manufacturers—Trina Solar and Suntech—as "mandatory respondents" in the case, given that they were the two largest exporters to the United States during the period under investigation.

In fall 2012, the Department of Commerce and the International Trade Commission ruled that certain China-based companies were guilty both of dumping and of having received excessive subsidies from the Chinese government. So the United States imposed a range of anti-dumping tariffs and "countervailing-duty" tariffs. (Countervailing duties are import taxes imposed under WTO rules to counteract foreign subsidies that have been determined to injure domestic manufacturers in the importing country.) Together, the two types of tariffs imposed by the United States totaled, in the case of some China-based companies, approximately 30% of the price at which they had been selling those cells in the United States.

These tariffs covered solar cells produced in China, whether the assembly of those cells into modules occurred in China or occurred in another country. But the tariffs did not apply to cells that were produced outside China and were then assembled into modules inside China.

To circumvent the U.S. tariffs, some China-based solar manufacturers began exploiting what some came to call this "loophole" in the U.S. ruling. These China-based manufacturers began either buying cells manufactured in third countries—particularly Taiwan—or themselves manufacturing cells in third countries, then importing those cells into China to assemble into modules in their Chinese factories, and then exporting those modules to the United States.

As a result, in December 2013, SolarWorld filed a second complaint with the International Trade Commission seeking to close this "loophole."[403] In December 2014, the International Trade Commission upheld this second round of allegations. It agreed that even those Chinese-made modules that used cells produced outside China and that were exported to the United States constituted dumping and had benefitted from too-

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[402] "Commerce Finds Dumping and Subsidization of Crystalline Silicon Photovoltaic Cells, Whether or Not Assembled into Modules from the People's Republic of China," U.S. Department of Commerce fact sheet, Oct. 10, 2012. http://ia.ita.doc.gov/download/factsheets/factsheet_prc-solar-cells-ad-cvd-finals-20121010.pdf

[403] "Commerce Finds Dumping of Imports of Certain Crystalline Silicon Photovoltaic Products from China and Taiwan and Countervailable Subsidization of Imports of Certain Crystalline Silicon Photovoltaic Products from China," U.S. Department of Commerce fact sheet, Dec. 16, 2014. http://enforcement.trade.gov/download/factsheets/factsheet-multiple-certain-crystalline-silicon-photovoltaic-products-ad-cvd-final-121614.pdf

high Chinese-government subsidies. Thus, punitive tariffs were again applied, this time to Chinese and Taiwanese-made modules, as well as cells made in Taiwan.

As a result of both of these solar trade cases, the United States has imposed punitive dumping and countervailing-duty tariffs on Chinese-made modules that use Chinese-produced cells and on Chinese-made modules that use Taiwan-produced cells. The United States continues to review and revise the level of these tariffs annually, based on the United States' determination of any changes in the degree of China-based solar manufacturers' compliance with international trade rules.

A similar trade dispute over solar products continues to divide Europe and China. The European Union in December 2013 imposed tariffs against Chinese solar products imported into Europe, doing so for much the same legal and economic reasons that led the United States to impose solar tariffs against China. The European Commission concluded the Chinese government was unfairly subsidizing China-based solar manufacturers and that those manufacturers were dumping their products onto the European market, both actions that the commission decided violated international trade rules. Several leading China-based solar manufacturers later reached a settlement with the European Commission under which the manufacturers agreed not to sell solar cells or sola modules in Europe below certain prices and, in exchange, the commission agreed to remove tariffs from the manufacturers' products.

However, in May 2015, the European Commission began investigating allegations that some China-based solar manufacturers were circumventing the tariffs by manufacturing solar products in Taiwan and Malaysia and selling those goods in Europe at prices below the mandated minimum level. In February 2016, the commission re-imposed tariffs on certain China-based solar manufacturers after concluding those manufacturers were indeed circumventing the tariffs by manufacturing in Taiwan and Malaysia.[404] The current European Union tariffs against China-based solar manufacturers are due to expire in March 2017. According to reports in December 2016, the European Commission has proposed extending the tariffs another two years—to 2019. In addition, in recognition of the extent to which the price of solar cells and modules continues to fall, the European Commission reportedly has proposed reducing the price floor it imposes on China-based solar manufacturers selling their products in Europe.[405]

[404] "The European Union's Measures Against Dumped and Subsidised Imports of Solar Panels from China," European Commission, Feb. 29, 2016. http://trade.ec.europa.eu/doclib/docs/2015/july/tradoc_153587.pdf

[405] Ian Clover, "EU Commission Recommends Two-Year Extension of Solar Tariffs Against China, MIP To Be Lowered," PV Magazine, Dec. 21, 2016. https://www.pv-magazine.com/2016/12/21/eu-commission-recommends-two-year-extension-of-solar-tariffs-against-china-mip-to-be-lowered/

Appendix C:
China Ministry of Industry and Information Technology's
Solar PV Manufacturing Industry Standards of 2013

- *R&D Spending*
  - A company must spend, annually, at least 3% of its revenue or ¥10 million ($1.5 million)—whichever is lower—on research and development.[406]
- *Manufacturing Scale*
  - Minimum capacities for manufacturing facilities throughout the solar value chain:
    - Silicon factory: 3,000 tons per year
    - Ingot factory: 1,000 tons per year
    - Wafer factory: 50 million wafers per year
    - Cell factory: 200 megawatts per year
    - Silicon-based-module factory: 200 megawatts per year
    - Thin-film module factory: 50 megawatts per year
- *Maximum Electricity Intensity of Factory*
  - Existing silicon-processing plant: 120 kilowatt-hours per kilogram
  - Renovated or newly built silicon-processing plant: 100 kilowatt-hours per kilogram
  - Existing ingot plant: 9 kilowatt-hours per kilogram
  - Renovated or newly built ingot plant: 7 kilowatt-hours per kilogram
  - Existing multicrystalline-silicon-wafer plant: 600,000 kilowatt-hours per million wafers
  - Renovated or newly built multicrystalline-silicon-wafer plant: 550,000 kilowatt-hours per million wafers
  - Existing monocrystalline-silicon-wafer plant: 400,000 kilowatt-hours per kilogram
  - Renovated or newly built monocrystalline-silicon-wafer plant: 350,000 kilowatt-hours per kilogram
  - Solar-cell plant: 150,000 kilowatt-hours per kilogram
  - Silicon-based module plant: 80,000 kilowatt-hours per kilogram
  - Thin-film module plant: 50,000 kilowatt-hours per kilogram
- *Environmental Protection*
  - Existing factories in zones designated by the government as environmentally sensitive and agriculturally important should be removed.[407]
  - No new plants should be built in environmental-protection zones.
  - Companies must comply with all environmental regulations, including those for water, air, solid waste, and noise.
  - Companies should receive certification under the following standards: ISO 4001 for environmental management; ISO 4064 for greenhouse-gas emissions; and PA 2050 or ISO 14067 for carbon footprints
- *Cell- and Module-Efficiency Levels*
  - Minimum efficiency levels for products manufactured at existing Chinese factories:
    - Multicrystalline-silicon cell: 16%
    - Monocrystalline-silicon cell: 17%
    - Multicrystalline-silicon module: 14.5%
    - Monocrystalline-silicon module: 15.5%

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[406] See Chapter 4 for an explanation of the way that this mandated minimum level of R&D investment, though low, affected the Chinese solar industry.

[407] According to the MOIIT standards, examples of these zones include areas that are drinking-water sources and are scenic and historical sites.

        - Amorphous-silicon cell: 8%
        - CIGS module: 10%
        - Cadmium-telluride module: 11%
    - Minimum efficiency levels for products manufactured at renovated and newly built Chinese factories:
        - Multicrystalline-silicon cell: 18%
        - Monocrystalline-silicon cell: 20%
        - Multicrystalline-silicon module: 16.5%
        - Monocrystalline-silicon module: 17.5%
        - Amorphous-silicon cell: 12%
        - CIGS module: 12%
        - Cadmium-telluride module: 13%
- *Degradation Rates*
    - Maximum rates of degradation in efficiency over two years:
        - Multicrystalline-silicon modules: 3.2%
        - Monocrystalline-silicon modules: 4.2%
        - Thin-film modules: 5% (and 20% within 25 years)
- *Quality*
    - Companies should be certified under the ISO 9001 standard.
    - Modules should have lifetimes of at least 25 years.
    - Warranties should last at least 10 years.

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