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Sunrise in the East

China's Advance in Solar PV—and the Competitive Implications for the Industry

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For most of its history, the solar photovoltaic (PV) industry has been the domain of companies from developed economies. The past several years, however, has seen a wave of Chinese competitors crash upon the scene and quickly capture a significant share of the market. These players continue to expand their reach and pose an increasingly formidable challenge to non-Chinese firms seeking to compete in the space.

Are Chinese companies destined to dominate the industry? They have critical strengths—foremost among them are sizable cost advantages—that provide the companies with a strong tail wind. But there remain opportunities for U.S., European, and Japanese firms, provided they pick their market segments carefully and employ the right business models. Key to that pursuit is understanding the industry's evolution and the factors that have fueled the Chinese companies' recent surge.

Solar PV: Strong Developed-Country Roots

Though silicon-based solar cells were invented almost 70 years ago, their exorbitant cost during the early years of development limited their usage to big-budget applications such as satellites and space exploration. But costs were driven down, and the development of solar PV accelerated in the 1970s as the Arab oil embargoes prompted increased government and private-sector investment in solar energy and as major oil companies, including Atlantic Richfield, Exxon, Mobil, and Shell, acquired solar businesses. These oil companies, along with electronics manufacturers such as Motorola and Westinghouse Electric of the United States and Sharp Electronics, Sanyo Electric Co., and Kyocera Corporation of Japan, began commercializing solar PV systems during the 1980s, and some continued into the 1990s. Corporate restructurings, recessions, and inconsistent levels of government support led a number of these companies to exit the market in subsequent years. However, BP, which had acquired Solarex Corporation through its purchase of Amoco, and the Japanese manufacturers remained steadfast.

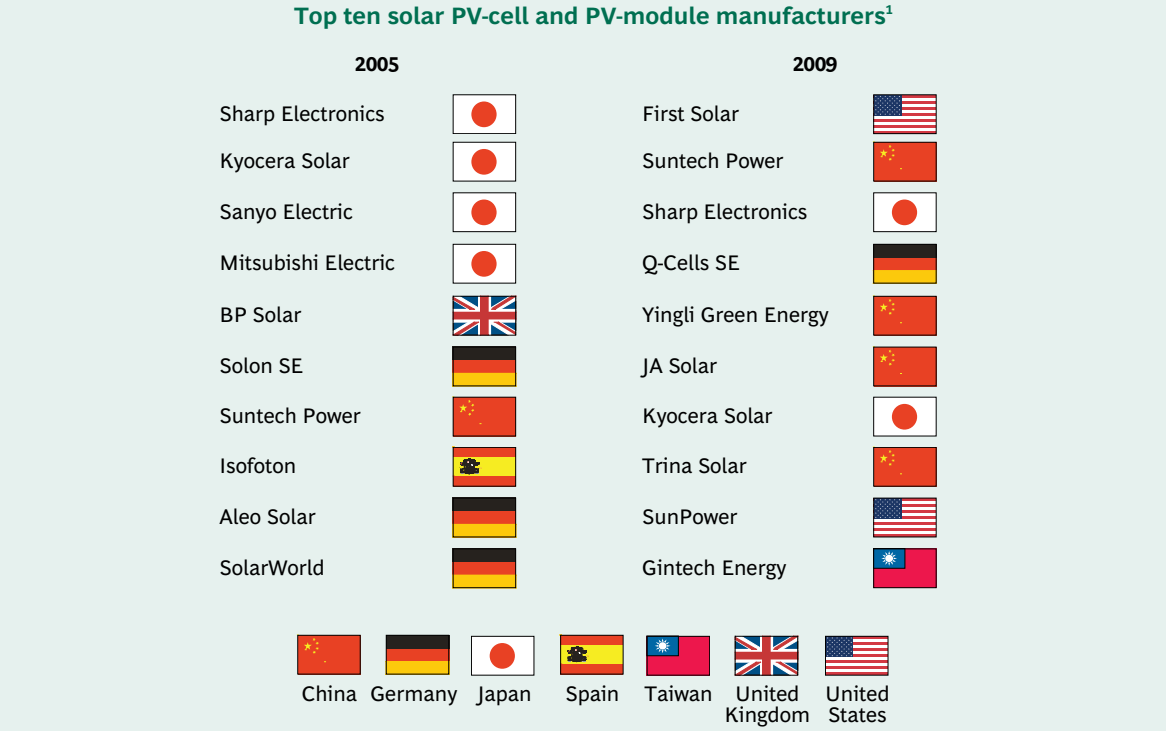
With the adoption of the Kyoto Protocol in 1997, the market for solar PV began to take off, particularly in Europe. Countries such as Spain and Germany introduced high feed-in tariffs to stimulate demand. Germany also instituted a powerful set of government subsidies and incentives. In response, a cluster of German manufacturers, such as Wacker Chemie A.G. (polycrystalline silicon, or polysilicon) and Siemens (equipment), emerged across the value chain. By 2005, eight of the top ten PV-cell producers and nine of the top ten PV-module manufacturers were either Japanese or European. (See Exhibit 1.) In addition, nearly 80 percent of PV production capacity was located in developed countries, close to sources of polysilicon and market demand.

About the same time that European demand was increasing, a new set of companies from mainland China and Taiwan—including Suntech Power Holdings Co., Yingli Green Energy Holding Co., and Trina Solar—were emerging. They were only 10 to 20 percent of the size of the market leaders, but within five years they rose to near the top of the PV leadership list.

The Rise of Chinese Companies

Once a center of China's textiles industry and a key rice market, Wuxi, some 125 kilometers northwest of Shanghai, is today one of China's industrial powerhouses. It is also home to Suntech, the largest Chinese manufacturer of crystalline silicon cells and modules and the second-largest module producer in the world behind First Solar of the United States. Suntech's rise has demonstrated the power of combining China-based manufacturing with world-class technological expertise, which was developed internally and in

Exhibit 1. Chinese Companies Have Emerged as Very Strong Competitors



Sources: EuPD Research; *Photon International;* BCG analysis.
[1]The companies were rated by production volume and include manufacturers of silicon-based modules and thin-film solar cells.

collaboration with the University of New South Wales's School of Photovoltaic and Renewable Energy Engineering. Suntech's founder and CEO, Zhengrong Shi, is an alumnus of the school and has maintained strong ties to the faculty; one of its senior members serves as Suntech's chief technology officer.

After earning his PhD in record time under Martin Green, one of PV's leading scientists, Shi was invited by Green to join him in a new venture. Shi agreed, and the company went on to achieve a breakthrough: it drastically cut the cost to manufacture PV cells by significantly reducing the required amount of silicon.[1] A few years later, Shi was lured to Wuxi with an offer of $6 million in start-up funds from the city government, and in 2001, Suntech was created. Production commenced the following year. Suntech quickly evolved into a global cell and module manufacturer by focusing its strong R&D team on producing modules that yielded higher cell-conversion efficiencies than the competition and had a cost structure well below those of developed-market manufacturers.

The company also made a number of key strategic moves. Upstream, it secured its silicon supply through a number of long-term contracts and made strategic equity investments in some suppliers. This was particularly important prior to 2009, when the global silicon supply was limited: Suntech's arrangements spared the company the tremendous cost escalation that its competitors faced.

Downstream, Suntech continuously expanded its global sales and distribution channels. It also diversified its revenue base by acquiring U.S. integrator and installer EI Solutions, for example, and establishing a joint venture with MMA Renewable Ventures in multimegawatt projects, a partnership that has continued following MMA's acquisition by Spain's Fotowatio in early 2009.

Suntech also proved itself highly flexible. In 2007, 86 percent of its revenue came from Spain and Germany. After pullbacks in feed-in tariffs, demand from those markets fell, and Suntech focused on building its

1. "China's New King of Solar," *Fortune,* February 11, 2009.

business in Australia, China, and Korea, as well as in the United States, where it is now building a manufacturing plant. By the second quarter of 2009, Suntech was capturing demand for 25 percent of new project capacity in California, significantly closing its gap with market leader SunPower Corporation.[2]

More recently, Suntech has diversified into thin-film technology via the construction of an amorphous silicon (a-Si) production facility in Shanghai. This will likely enable Suntech to develop a position in the higher-margin building-integrated-photovoltaics (BIPV) segment. Suntech entered this segment through its 2006 acquisition of MSK Corporation, one of the world leaders in BIPV systems design, and then expanded through partnerships with other BIPV companies, including Open Energy Corporation in the United States.

For all its strengths, however, Suntech faces a host of challenges. Not the least of these is a market awash in excess capacity, in part due to the aggressive expansions of Suntech and its Chinese peers across the value chain. The surge in capacity led to a free fall in prices of polysilicon, and therefore cells and modules, that has largely persisted since 2009.

Yingli Green Energy Holding Co. is another example of the new breed of PV companies from China, though it has taken a different approach to its development. Currently ranked third in the world in terms of production, Yingli has pursued a strategy of cost minimization through vertical integration in manufacturing and rapid expansion of production capacity. Yingli has grown from 50 megawatts of module production in 2004 to 600 megawatts of capacity in ingots, wafers, cells, and modules by July 2009, when it also commenced operations at a new polysilicon plant with a capacity of 3,000 metric tons per year. Although Yingli has recently increased its investment in R&D and was granted government approval to set up a state key laboratory (which receives significant government support), its focus to date has been more on cost minimization than on achieving improvements in cell-conversion efficiencies.

Unlike Suntech, Yingli has not invested significantly in downstream operations. To keep its marketing, sales, and distribution costs low, Yingli sells predominantly to distributors and systems integrators rather than directly to end users. Most of its sales staff is located in China despite most of its sales coming from overseas markets.

The Strength of the Chinese Companies' Business Models

To evaluate the strength of the Chinese players and the sustainability of their businesses, it is helpful to put them in context vis-à-vis their global peers. The current position of all PV companies is generally the result of strategic choices they have made in the areas of technology, manufacturing, and value-chain strategy, and how well they have executed.

Although there are a host of technologies under development, companies essentially have a choice between using standardized (and typically lower-cost) designs and developing proprietary, higher-efficiency designs. In manufacturing, companies can choose between crystalline silicon (c-Si) and thin film. Additionally, companies from developed countries can choose to retain manufacturing at home or migrate it to low-cost countries.

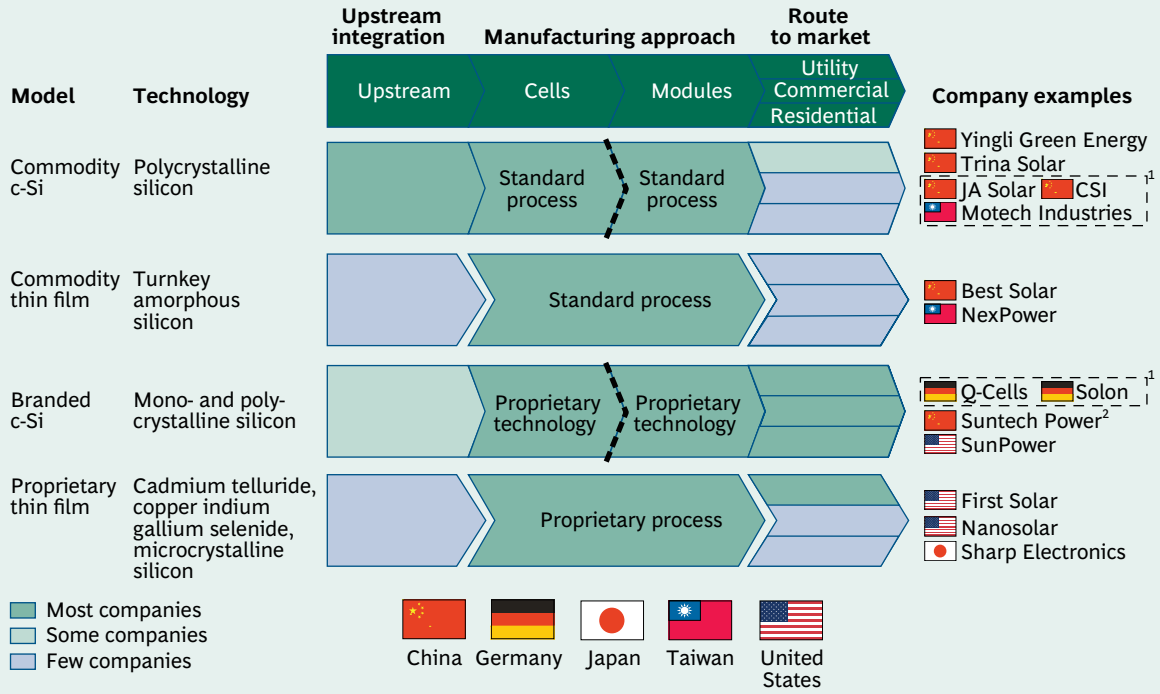
Regarding value-chain strategies, as we have seen in the strategies employed by Suntech and Yingli, c-Si players can choose whether or not to integrate backward into polysilicon production, and all players can choose whether or not to expand into project development or sales and installation.

These choices have led companies to follow one of four broad business models, with variations in technology, upstream integration, manufacturing approach, and route to market. (See Exhibit 2.) The models can be characterized as follows:

- *Commodity c-Si.* Using standardized technology and manufacturing processes, companies such as Yingli, Trina, and JA Solar Holdings Co. have achieved lowest-cost market positions by leveraging low-cost-

2. "Suntech Grabs 25% Market Share in California: U.S. Plant Plans Imminent," PV-Tech.org, August 21, 2009.

Exhibit 2. Manufacturers Employ Four Broad Business Models



Source: Company reports.
[1]CSI Solar Products sources from JA Solar and Motech Industries; Solon sources from Q-Cells.
[2]Licensed technology from the University of New South Wales, the Australian-based leader in laboratory efficiency.

country factor costs and aggressively ramping up production capacity. In four years, from 2006 through 2009, these upstarts caught up in production capacity to Sharp, which has been in the business for more than 50 years. They have achieved additional cost efficiencies by partnering to establish vertically integrated wafer plants. They have typically invested less in process automation than their peers, making up for this with proportionately more—but lower-cost—labor. And in the current economic cycle, these companies have benefited from the dramatic fall in the price of silicon, improving their cost advantage over commodity and proprietary thin-film companies as well as branded c-Si competitors.

- *Commodity Thin Film.* The entry of a host of commodity thin-film players into the industry has been enabled by the deployment of turnkey manufacturing systems from Applied Materials, Oerlikon, and Ulvac Technologies. Representative of these commodity thin-film companies are China's Best Solar Co. and Taiwan's NexPower Technology Corp. They have had ambitious plans to ramp up their manufacturing scale above 1 gigawatt and achieve commensurate unit-cost benefits. However, until they execute, these companies will continue to be at a cost disadvantage relative to their commodity and branded c-Si competitors—a situation that has been made worse by the decline in silicon prices. These companies remain relatively small today.

- *Branded c-Si.* Technology leaders such as Germany's Q-Cells SE, Japan's Sanyo, and U.S. firm SunPower have focused on achieving higher module-conversion efficiencies through proprietary technologies. For most companies, this has come at the expense of higher manufacturing costs resulting from the companies' proprietary processes and their decision to manufacture in high-cost countries. The notable exception is China's Suntech, which as discussed earlier has lower costs than its peers. Many of these companies that manufacture branded c-Si high-efficiency modules have also invested downstream to leverage their brand and technology advantages. For example, SunPower acquired systems integrator PowerLight Corporation in 2007, and Suntech owns installers in both the United States and Japan and has developed its own large project pipeline. Some of the branded c-Si players have begun to outsource upstream production to fabricators based in low-cost countries (for example, Q-Cells has outsourced to

Flextronics International), following a similar transition that happened a decade ago in semiconductors.

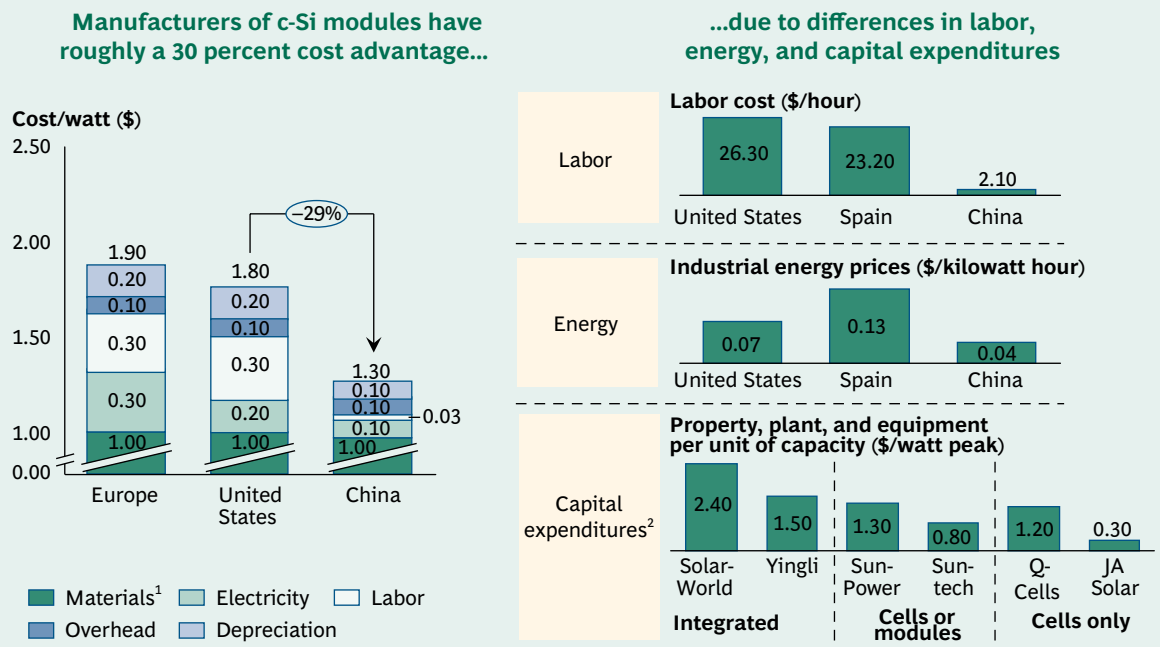
- *Proprietary Thin Film.* A number of companies, ranging from venture-capital-funded PV startups to global technology leaders in related industries, are seeking to develop innovative thin-film manufacturing processes that achieve cost and efficiency breakthroughs. Among this group, First Solar, with its proprietary cadmium-telluride (CdTe) process, has emerged as the global cost leader, with module costs now below 85 cents per watt peak and manufacturing capacity approaching 1.3 gigawatts (and projected by the company to exceed 1.8 gigawatts by 2012). Given the comparatively low conversion efficiencies of their modules, these players are more actively involved in large-scale solar-farm development, where their products can be more economically deployed than in space-constrained rooftop locations. The potential game-changers in this group will be those companies that are able to commercialize newer copper-indium-gallium-selenide (CIGS) technology, which has achieved conversion efficiencies approaching those of c-Si modules and would thus also be suitable for rooftop applications.

The rapid rise of Chinese companies, most of which have pursued commodity strategies, has been possible for three reasons. First, they have used standardized, low-cost manufacturing processes and equipment. Second, these companies have aggressively expanded capacity and consequently achieved scale advantages. Third, they have received local and central government support, which has stepped up significantly since the global financial crisis. The overwhelming cost advantage these companies have managed to achieve has enabled them to stay competitive with branded and proprietary players.

Sources of Cost Advantage

Where exactly are these cost advantages derived? We estimate that in the c-Si space, the Chinese manufacturers enjoy a 30 percent cost advantage over their U.S. counterparts due to savings in labor and energy costs as well as in capital expenditures. (See Exhibit 3.) Labor rates in China's PV-manufacturing industry are less than 10 percent of those in the United States, while energy costs (as well as the costs of other

Exhibit 3. Chinese Manufacturers Enjoy a Sizable Cost Advantage over Their U.S. and European Counterparts



Sources: Ardour Capital Investments; Barclays Capital; Deutsche Bank; HSBC Holdings; JPMorgan Chase & Co.; Photon Consulting; Yuanta Financial Holding Co.; company reports; The Economist Intelligence Unit; the International Energy Agency; Compass International; China's industrial policy; BCG analysis.
Note: The cost of conversion using standard processes at a U.S. reference plant excludes margins of production intermediaries.
[1]The cost of materials includes polysilicon costs at $40 per kilogram with a conversion factor of 8 grams per watt, cell-conversion consumables including metallization pastes and gases, and glass and aluminum for module assembly.
[2]Property, plant, and equipment figures are 2009 estimates sourced from 2009 fourth-quarter analysts reports.

utilities, such as water, which is often subsidized at the local level) can be almost 50 percent less. In addition, by using semiautomated rather than fully automated production processes, these companies' expenditures on capital equipment are lower by 40 percent or more when compared with those of their U.S. counterparts. Their labor costs are proportionately higher as a result, but the dramatically lower wage rates more than make up the difference.

Chinese manufacturers also maintain a significant cost advantage—approximately 10 percent—over other low-cost countries, such as Malaysia and the Philippines. This is largely due to China's lower labor and energy costs and takes into account the investment incentives these other countries' governments have offered to large international companies.

Government-Driven Domestic Demand

Prior to 2008, Chinese manufacturers' growth was largely driven by exports, particularly to Europe, where demand was strong due to government stimulus programs. Even though China's government had been promoting the adoption of renewable energy for some time, until early 2009 there was no material domestic market to speak of for solar PV. The government's laws, plans, and programs heavily favored the development of hydroelectric and wind power because of their comparatively low generation costs. Nevertheless, China's manufacturing sector had embarked on a massive buildup of PV capacity, and by 2009, it had established more than 3 gigawatts of manufacturing capacity and made the country the world's largest manufacturer and exporter of PV modules. For example, 86 percent of Suntech's 2007 revenue came from Spain and Germany alone.[3]

This emphasis on exports nearly proved catastrophic, however. The global financial crisis, the collapse of the Spanish PV market, and declines in PV prices and demand in other countries weighed heavily on the Chinese exporters, with more than 80 percent of them reportedly facing imminent collapse by the end of 2008.[4] In March 2009, however, in an apparent policy reversal, China's central government announced the first of two major initiatives aimed at stimulating domestic demand for solar PV. The first offered subsidies of roughly $3 per watt peak for new rooftop or BIPV installations meeting minimum scale and efficiency requirements. The second, which was launched in July 2009, provided subsidies for utility-scale PV projects, covering 50 to 70 percent of the projects' capital costs. In addition, though still handled on a case-by-case basis, the government has established favorable tariffs for ground-based PV projects. For example, the first phase of a planned 500-megawatt installation in Dunhuang, a city in China's Gansu province, will receive a tariff of RMB 1.09 per kilowatt hour, roughly three times the rate for thermal coal power.

Accompanying these programs has been a tenfold increase in the government's targets for China's PV-generation capacity, which now stand at 2 gigawatts for 2011 and 20 gigawatts for 2020. These initiatives have triggered a series of announcements by China's state-owned independent power producers for major new PV projects, which when fully developed would add more than 9.4 gigawatts of capacity. Some of these announced initiatives include the following:

- Datang Power is to build 100 megawatts of capacity between 2010 and 2013, 200 megawatts of capacity by 2015, and 1 gigawatt of capacity by 2020.
- Huadian Power International Corporation is to build 50 megawatts of capacity per year over the next five years.
- Guo Hua Energy Investment Co. is to build 10 megawatts of capacity by 2011, 50 megawatts of capacity by 2015, and 200 megawatts of capacity by 2020.
- China Guodian Corp. is to complete a 200-megawatt power station in Golmud by 2011.

3. Suntech's 2007 annual report.

4. Xingxue Tong, director, president, and COO of LDK Solar stated, "80 percent of domestic PV enterprises are facing shortages of cash. Some of them have already started to limit their production and some have already shut down the factory." First Financial Daily (来源：第一财经日报, 王佑), November 19, 2008. Data from China Investment Consulting shows that by the end of 2008, 350 PV enterprises had collapsed or stopped operation; only 50 enterprises remained. Changchun News, March 2, 2009; www.ccnews.gov.cn.

The major beneficiaries of the government's push have included the largest Chinese manufacturers, such as Suntech, which has recently announced projects that would add close to 2 gigawatts of capacity for large developments in western China. However, other companies, such as Yingli and LDK Solar, have also been awarded similar massive-scale projects. Even international players have been let into the game, with First Solar having recently announced a 2-gigawatt project in Ordos, Inner Mongolia.

Still, challenges remain for the growth of the domestic industry, as the areas with abundant sunshine (largely in the remote western provinces) are not the places requiring the bulk of power (the eastern coastal regions). Grid connectivity is a major issue for new utility-scale installations (as it has also been for the country's blossoming wind farms). Despite investment in new ultrahigh-voltage transmission lines by the State Grid Corporation of China, the country's largest electric-power transmission and distribution company, efficient transmission of electricity from west to east will take years to be realized.

Nevertheless, if China's economy continues to remain strong through the global downturn, it is likely that the country's favorable policies to stimulate domestic demand will remain in effect. In turn, this should further support the growth and development of China's manufacturers, and help them maintain globally competitive levels of scale.

The Future Business Model and Industry Structure

Does this imply that yet another manufacturing industry will succumb to Chinese dominance? Not necessarily, for what ultimately matters most to power customers is the levelized cost of electricity (LCOE), and this depends on more than just the cost of PV modules. The LCOE is also driven by the cost of balance-of-system (BOS) components and installation. (BOS components are the components used to connect PV modules safely to the grid. They include inverters and other power-conditioning equipment, circuit breakers, lightning protection, cables, connecters, enclosures, and storage batteries.). Without question, the Chinese manufacturers have a clear cost advantage on module cost. However, BOS and installation costs are linked to the size and voltage of each installation. The smaller the installation space, the higher the proportion of LCOE that is represented by BOS and installation. And since installations with higher-efficiency modules require fewer panels for the same electricity output, producers of high-efficiency modules have the ultimate advantage here. Hence, the grip of the Chinese players is not unshakeable.

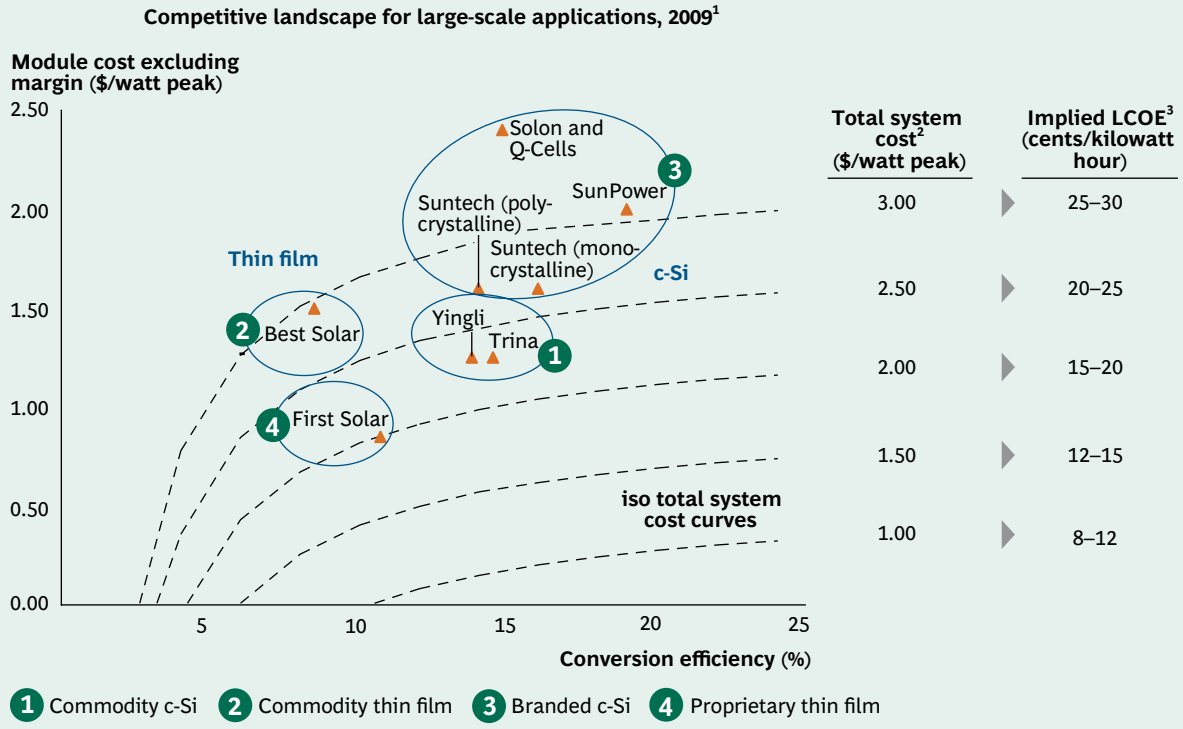
The relative importance of these cost and efficiency factors differs according to the end-use application, but in general, proprietary thin-film technology tends to be more cost competitive in utility-scale applications, while branded c-Si high-efficiency modules can be more cost competitive in residential and small commercial applications.

This is because in large-scale applications (for example, those generating tens or hundreds of megawatts), the modules comprise 50 to 70 percent of the total cost, so module efficiency is less important than module cost. U.S. firm First Solar has the most competitive LCOE in these large-scale applications at 15 to 20 cents per kilowatt hour; however, China's Yingli and Trina are close at about 20 to 25 cents per kilowatt hour. (See Exhibit 4.)

In residential and small commercial applications, where modules comprise a smaller proportion of the total cost, high module efficiency is more important to compensate for proportionately higher module cost. In these smaller-scale applications, although Yingli and Trina are most competitive with a LCOE of 60 to 65 cents per kilowatt hour, Suntech and SunPower are not far behind at 65 to 75 cents per kilowatt hour. (See Exhibit 5.)

What does the future portend for PV players? It seems likely that both c-Si and thin-film technologies will continue to develop in parallel, with residential and small commercial applications using the former and large-scale applications employing the latter. However, it is likely that, over time, c-Si technologies will converge around both low cost and high efficiency. The gap between higher- and lower-efficiency c-Si players is narrowing, and it is likely that low-cost commodity Chinese c-Si players will eventually lead this segment, as they appear to be narrowing the efficiency gap faster than the high-efficiency companies are addressing the cost gap.

Exhibit 4. Thin-Film Technology Is Most Competitive in Large-Scale Applications



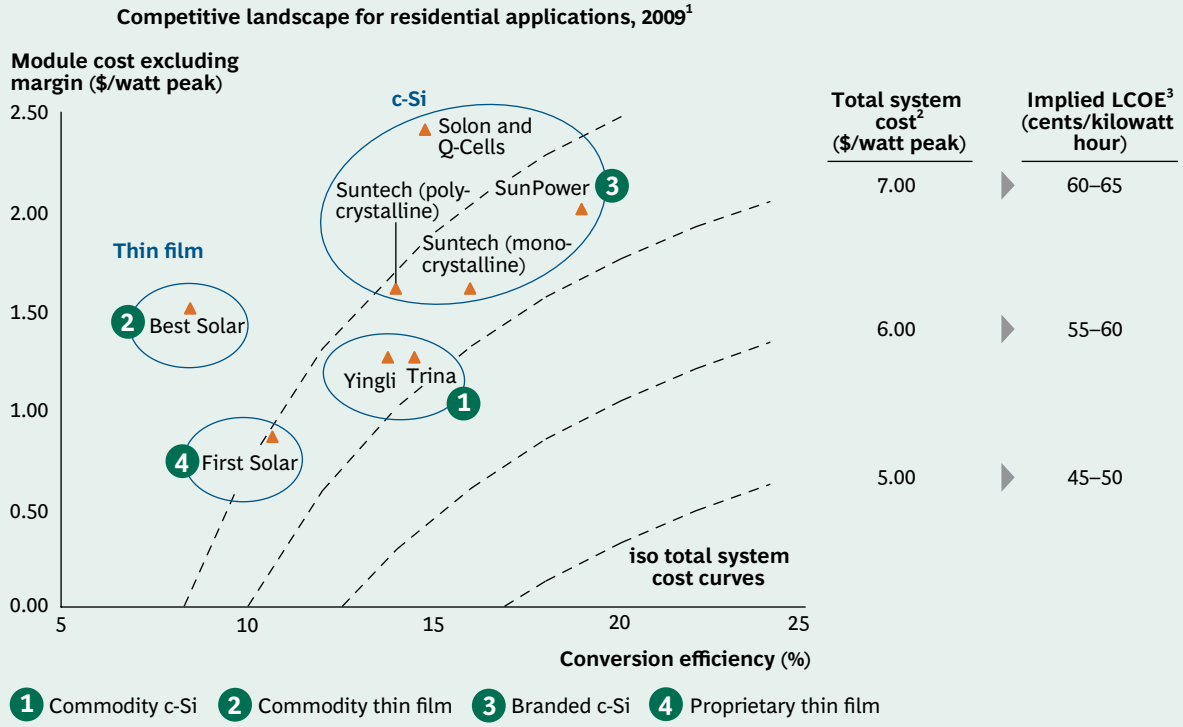
Sources: EuPD Research; IMS Research; SunPower; Yuanta Financial Holding Co.; company reports; Morgan Stanley; Needham & Company; BCG analysis.
[1]A large-scale application is typically 10 megawatts or more.
[2]Total system cost includes a 20 percent margin on modules plus balance-of-system and integration costs. Calculation assumes balance-of-system and installation costs of $1.10/watt peak for a 10 percent efficiency module (70 percent of cost is variable).
[3]This calculation assumes 1,200 kilowatt hours generated from 1 kilowatt peak, a 9 percent weighted average cost of capital, and a 1 percent operating cost of initial capital expenditures per year.

At the same time, there will be a role for producers of the highest-efficiency cells in the most space-constrained niche of the residential market. Additionally, these players should be able to reduce their cost disadvantage by relocating manufacturing to low-cost countries (SunPower has shifted its manufacturing to Malaysia and the Philippines, for example), though experience from other industries indicates that they will not be able to close the cost gap entirely. When compared with "localized" international players, native companies in low-cost countries still tend to be able to retain a cost advantage of at least 10 percent due to the absence of expatriate-staff costs and the ability to negotiate better terms on rent, utilities, and local incentives, among other factors.

For those c-Si players that are unable to aggressively reduce costs or gain a material advantage in module-conversion efficiency, life will be difficult indeed. However, with sufficient financing, most players should have time to make strides in these directions, even though the market will undoubtedly see new entrants in the years to come. The annual demand growth for solar power is likely to exceed 20 percent over the next decade. This will attract new companies, but it will also expand the industry to ten times its current size, providing plenty of opportunity for any company determined to close the gap in scale and experience with today's c-Si leaders. Furthermore, it is unlikely that thin-film technology will wipe out c-Si over the next decade. This is because c-Si has much lower cost efficiencies than thin film and the growth of CdTe technology could be constrained due to the scarcity of telluride. There are also questions about the ability to scale up other thin-film technologies, such as copper indium selenide (CIS) and CIGS.

The future for individual thin-film manufacturers is less clear. First Solar has established a clear and substantial lead, though safety concerns loom in the background regarding its use of cadmium. Meanwhile, companies that use turnkey systems are also aggressively moving down the cost curve. And though

Exhibit 5. Commodity c-Si Companies Are Most Competitive in Smaller-Scale Applications



Sources: EuPD Research; IMS Research; SunPower; Yuanta Financial Holding Co.; company reports; Morgan Stanley; Needham & Company; BCG analysis.
[1]A residential application is typically 3 to 10 kilowatts.
[2]Total system cost includes a 40 percent margin on modules plus balance-of-system and installation costs. Calculation assumes balance-of-system and installation costs of $7 per watt peak for a 10 percent efficiency module (70 percent of cost is variable).
[3]This calculation assumes 1,200 kilowatt hours generated from 1 kilowatt peak, a 9 percent weighted average cost of capital, and a 1 percent operating cost of initial capital expenditures per year.

they are not yet manufacturing at commercial scale, new players such as MiaSolé and Nanosolar are emerging with technologies that have the potential to be cost competitive. If one or several of these new technologies are able to quickly move down the experience curve, it could allow these companies to catch up to—and possibly overtake—First Solar.

U.S., European, and Japanese players seeking to compete in the solar PV industry face formidable competition in their Chinese counterparts. Yet there are opportunities to stake and defend a claim for those companies that choose their spots, execute flawlessly, and successfully navigate and help shape the evolving regulatory framework. There will also be opportunities that emerge as the technologies mature and potentially unleash new sources of competitive advantage. So this is not a space that companies from established economies should concede. It is clear, however, that under any scenario, China—its manufacturers and its market—will remain an important feature of the solar PV landscape, one that needs to be well understood by every industry participant and stakeholder.

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