A Duel in the Sun

The Solar Photovoltaics Technology Conflict between China and the United States

A REPORT FOR THE MIT
FUTURE OF SOLAR ENERGY STUDY

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Executive Summary

A debate is raging among government officials, industry members, technologists, and trade specialists about the nature of the competition between the United States and The People's Republic of China (PRC) in developing, deploying domestically, and selling internationally solar photovoltaic (PV) electricity-generating technology. Over the past three years, China has dramatically expanded its manufacturing capacity for crystalline silicon PV modules, 90% of which are exported at steadily declining prices to Europe and the United States.

One view characterizes Chinese behavior as a state-directed effort to dominate the global PV market by "dumping" product at below cost.[2] In November 2012, the United States imposed an import tariff of up to 30% on certain Chinese PV manufacturers to compensate for unfair trade practice; the European Union (EU) has similar trade action under consideration. The alternative view is that Chinese new entrepreneurship, driven primarily by private equity investment, explains the rapid expansion of Chinese PV module production.

However, overexpansion of production capacity combined with dampening of subsidized demand, mainly from Europe, has led in 2010–11 to an oversupply of product, a collapse in PV prices (in contrast to cost), and massive financial losses for Chinese companies. These different views need to be resolved to avoid a lengthy trade conflict, which is important if the United States and China wish to encourage cooperation in Research and Development (R&D), technology transfer, investment, and trade in renewable technologies, goals that both governments frequently state are in their common interest.

In this paper, we consider the competition from three vantage points: (1) the structure of the PV industry in each country, (2) the recent trends in trade, and (3) the pattern of government assistance to the PV industry in each country. We expect that it will take several years for the global PV market to regain profitability and its forward momentum. The recovery time will depend on some shrinking in worldwide PV device capacity, expansion in demand with subsidies for deployment (whether by feed in tariffs or renewable portfolio standards), and a firming of device prices to a level that is sustainable financially.

We conclude that the US–China PV competition is best understood not in terms of a bilateral clash between government-led policies, but instead in terms of a global PV industry structure within which US and Chinese firms play roles consistent with their strengths. Each country extends different assistance mechanisms and each country has conflicting purposes for such assistance. Both countries lack a transparent, quantitative evaluation methodology to assess the cost effectiveness of the assistance. We suggest some policy changes to make government assistance more consistent with the global character and long-term opportunity of this important technology.

Differing Views of the Issues

Informed observers in the United States hold two widely divergent views of the development of the Chinese PV industry. One view argues that Chinese PV development is best understood in terms of a deliberate central government decision to establish global dominance for this industry through a wide range of subsidies and unfair trade practices. The consequence of this policy is that Chinese PV module sales compete unfairly in the international market (importantly in Germany, Italy, and Spain), and have destroyed the prospects of domestic US PV manufacturers. The current collapse of PV module prices, attributable to overcapacity primarily in China, is seen as a tactic to accept short-term economic loss in order to drive out competition and establish long-term dominance.

A second view argues that Chinese PV development is the product of technology entrepreneurship under competitive market conditions. From this perspective, the industry's advance has been driven not by top-down support from the central government, but instead by bottom-up actions by private entrepreneurs. These entrepreneurs — mostly returnees from overseas with considerable experience in the global semiconductor industry — were able to establish and rapidly expand manufacturing facilities by accessing private capital and state-of-the-art production equipment in global markets. The public support they have received comes from municipalities and provinces rather than the central government, provided via the sort of tax concessions, loan guarantees, and land grants routinely used by local governments worldwide, including in the United States, to attract business. The industry boomed largely because of engineering and manufacturing competence — the ability to scale rapidly in the face of surging demand from European markets, while maintaining production quality, continuous product improvements, and steady cost reductions.[3]

However, in the face of plummeting European demand, the Chinese PV industry now faces overcapacity, negative margins, and a pending shakeout. It is only at this point that the Chinese central government, previously indifferent to the sector, has begun moving tentatively to bail out producers and stimulate domestic PV demand.

Importance of Resolving the Issues

Cooperation between the United States and China on energy technology has been a prominent part of the dialogue between the two countries in the context of common efforts on climate change and in the broader discussion of liberalized conditions for technology transfer, investment, and trade.[4]

In both countries, public officials and private firms see energy technology, especially "green" technologies such as PV, as an important opportunity for investment and sale of products into some part of the value chain. During the late 2000s, global PV installations grew at an annual rate of 50% to 100%, although a sharp decline in annual growth is projected, in the range of 10% to 20% to 2016.[5] Global PV installation grew to 69.7 Gigawatts (GW) by the end of 2011.[6]

It is not surprising that the two countries contemplating such forecasts will be keen to encourage the growth and competitive success of their respective national industries. Acrimonious differences over the "fairness" of each other's government subsidization and trade practices, if left unattended, will infect the entire technology and commercial relationship as both countries pursue growth and global competitiveness. The effects are likely to be felt far beyond just PV.

Shedding light on this issue must start with a clear and thorough side-by-side comparison of the circumstances of the PV industry in each country with regard to (1) technology focus, (2) the products and markets that are being addressed, and (3) the nature of public assistance for technology development and international trade. Such a comparison is not easy for several reasons.

THE PV INDUSTRY HAS DEVELOPED DIFFERENTLY IN EACH COUNTRY

Both the United States and China have firms arrayed across the solar PV value chain, yet industry capabilities and competitive strengths differ substantially.[7] The US PV industry has been focused on upstream, R&D-intensive efforts to develop next generation technologies that over the long term hold the promise of being more cost effective than traditional crystalline silicon. In the near term, though, such technologies face substantial economic and technical hurdles to commercialization.

The United States has also been a global leader in several parts of the contemporary PV value chain. US firms lead the world in the provision of PV manufacturing and test equipment and integrated manufacturing solutions. Several US firms today are also major providers of high-value components for PV manufacturing, such as silicon (Si) inks, metalization, resins, and front and back sheet films.[8] US-based firms such as Applied Materials and Hemlock Semiconductor (a joint venture between majority partner Dow Corning and minority partners Shin-Etsu Handotai and Mitsubishi Materials Corp.) are among the handful of global companies that have the ability to produce high-purity polysilicon. In short, US firms provide the equipment and key inputs that allow Chinese PV manufacturing to happen; as such, they are critical suppliers to Chinese PV manufacturers.

The Chinese PV industry, by contrast, is focused primarily on the manufacturing of PV wafers, cells, and modules, largely for crystalline silicon production devices. China today has limited capacity for new technology creation and relies substantially on imports for production equipment, high-quality polysilicon feedstock, and high-end components. In sum, the US content of Chinese PV manufacturing is significant.

COMPARISON BETWEEN THE TWO COUNTRIES IS DIFFICULT BECAUSE THE MECHANISMS THAT EACH COUNTRY USES TO SUPPORT THE INDUSTRY ARE QUITE DIFFERENT

In neither country are they transparent or are their public costs easily tallied. PV, with its promise of essentially infinite and affordable energy from the sun, is a popular technology with the public and government officials. But, it is by no means clear what assistance mechanisms are most cost effective for achieving desired, and at times, quite divergent, goals.

Both the United States and China have firms arrayed across the solar PV value chain, yet industry capabilities and competitive strengths differ substantially.

The United States has a collection of federal and state subsidies for PV through direct support for research, development, demonstrations, tax incentives, and regulatory mandates to encourage deployment. A comprehensive assessment of the purposes (discussed further in this document) and public costs of all these assistance mechanisms is not available. (The stimulus program that followed in the wake of the 2008 financial collapse contained significant assistance to PV projects motivated as much by job creation as by technology advancement.) Some US PV firms have also benefited from subsidies that state, country, and city governments routinely extend on an ad hoc basis to attract business — particularly in manufacturing through tax relief, loan guarantees, and direct grants. However, it is not clear how much support has been extended across the sector as a whole.[9]

China also has a variety of central government and local subsidies for PV. At least through 2011, central-level subsidies, including grants for upstream R&D and support for downstream deployment, have been relatively small. However, extensive support, particularly for cell and module manufacturing, has come through the kinds of incentives that provincial and municipal governments have for years generally showered on industrial producers. To promote local economic growth and attract investment, localities have long competed against one another to provide firms with tax breaks, access to low-cost or free land, and sometimes direct grants.

Among the most important sources of support has been the financing available from quasi-public investment corporations established by virtually every province, county, and municipal government in China. These "local government financing vehicles" (地方政府融资平台) are bond-issuing entities that extend preferential credits to local manufacturers, including PV producers.[10] PV firms have also been provided extensive credit lines from the China Development Bank and the four major state-owned commercial banks.[11] Whether such loans should be characterized as market-based financing or state subsidization is an endlessly debated and essentially unresolvable issue given the intermingling of state and private ownership in the Chinese market. It is worth noting, however, that as PV firms have begun defaulting on these loans, the banks are seeking redress through China's courts.[12]

It is also worth noting that the type of support provided to the PV industry is typical of what non-state firms, including foreign-invested and foreign-owned ones, routinely receive in China. The pattern — found not just in PV, but also in electronics, auto parts, and numerous other manufacturing sectors — has consistently led to massive firm entry, intense competition, overcapacity, price wars, and firm failure.[13] It is one of the reasons for high levels of local debt in the current Chinese banking system.

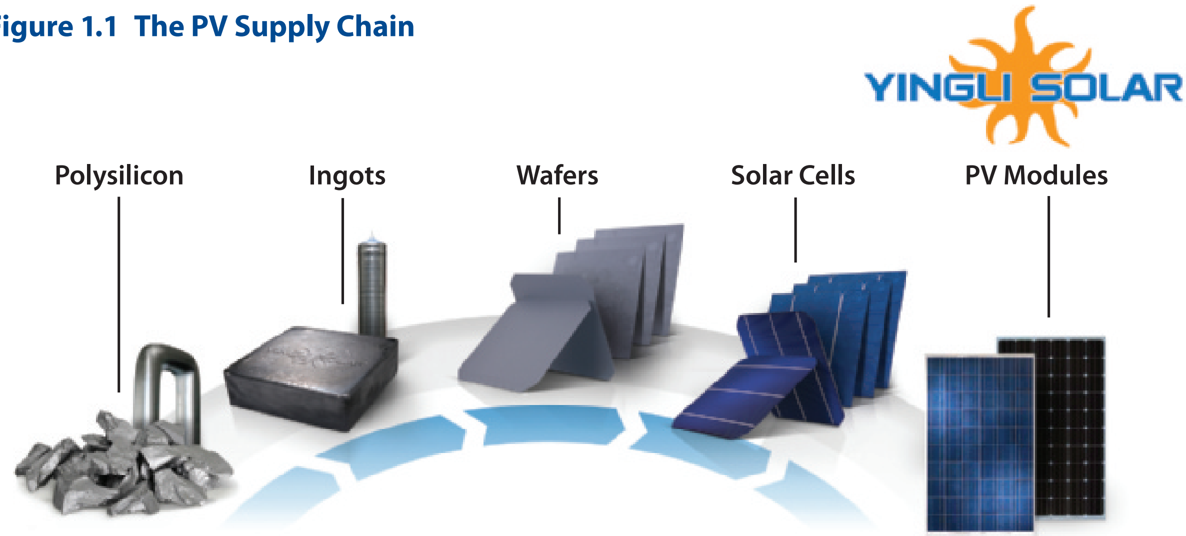
This pattern is different from what happens in "strategic" industries targeted by the central government (i.e., telecommunications, oil and gas, electric power, banking, et al.). In those sectors, the central government limits entry to only a few (two, three, four) large-scale, state-owned enterprises. Those firms, reliant primarily on the domestic market, reap massive profits under conditions of oligopoly. It is also different from what takes place in areas like microelectronics and information technology equipment that have been deemed by the central state to be particularly important. Those sectors may not be characterized by state-owned oligopolies, but they are under the aegis of designated government ministries and receive substantial direct R&D support.

PERHAPS THE MOST IMPORTANT BARRIER TO A SUCCESSFUL COMPARISON IS THE VERY RAPID PACE OF CHANGE IN THE PV INDUSTRY WITH REGARD TO TECHNOLOGY, (SUPPORTED) DEMAND, AND SUPPLY

Data from as recently as 2008 with regard to production, unit cost of cells or modules, and installation are not relevant today.

Despite (or perhaps because of) these difficulties in comparing the development of PV in China and the United States, our judgments of measures that should be considered to resolve this issue should be informed by facts on the ground.

Figure 1.1 The PV Supply Chain



Source: From http://www.yinglisolar.com/us/products/manufacturing/ with permission from Yingli Solar

PV Industry Framework

Production of PV devices begins with the assembling of photo-active wafers into **cells**, which are in turn assembled into **modules** that are encapsulated and include electrical integration to produce Direct Current (DC) electricity. Modules are, in turn, formed into **arrays** that are either grid-generating plants or distributed units with power conditioning "inverters" to produce Alternate Current (AC) power, which may or may not be connected to the grid. Installation, depending on location and central versus distributed generation, can be (and is in the United States) a significant fraction of the project cost. Material cost and capital for manufacturing and test equipment are the major fractions of the cost of PV modules; labor is less than 10%.

It is important to appreciate that the PV supply chain is global in nature. Manufacturers of PV products are quick to absorb and utilize globally available components, sub-systems, and processes that might permit them to compete more effectively in global markets. Transportation is typically a small fraction of the cost of manufacturing, and individual companies might very well rely on a globally dispersed network of suppliers. Thus, there are companies spread across the world that specialize in pure Si production, crystalline silicon production of ingots, ribbons, or amorphous powder; manufacturing equipment; test equipment; solar glass; and electrical interconnects. "Balance-of-plant" items such as meters and supervisory control and data acquisition (SCADA) systems are also necessary components.

It is important to appreciate that the PV supply chain is global in nature.

First Solar, a leading US PV thin-film firm, offers an interesting example of international involvement.[14] Initial production facilities were located in Arizona and Ohio. For operational and cost reasons, the company adopted a policy to build every production line with 6.6 Megawatt (MW) capacity to the same design. This put First Solar in a good position to choose to build plants in countries that offered the greatest concessions; subsequently, the company built plants in France, Germany, and Malaysia. In 2009 and 2010, the company announced plans to build new production facilities in France, the United States, and Vietnam. The downturn however, caused First Solar to announce in February 2012 that it would postpone commissioning the new plants, close the German facility, and indefinitely shut down the Malaysia facility in response to vanishing profit margins and a stock price decline from the range of $150 per share in 2011 to $25 per share in Q3 2012.

Leading Chinese PV manufacturers also source supplies and equipment globally. Shanghai-based and NASDAQ-listed JA Solar, in a fashion completely typical for China's Tier 1 PV producers, sources production equipment from California-based Applied Materials, PV components from Delaware-headquartered Dupont, and polysilicon from Tennessee- and Michigan-based Hemlock Semiconductor. JA Solar's US-trained CEO had previously held senior managerial positions in California with Applied Materials and AMD, and the firm's CTO had previously worked for Wacker Siltronic, Germany's leading producer of Si wafers.[15] Similar patterns can be observed in China's other leading PV producers – Yingli, Suntech Power Holdings, Canadian Solar, SolarOne, Trina, JA Solar, and LDK Solar.

The model of a linked global supply chain for cell and module manufacturers in different countries suggests that **cost** differentials will depend mostly on comparative scale and efficiency at manufacturing, given that labor costs are small and capital is available globally at roughly similar terms. However, **subsidies** to manufacturers or firms in the supply chain can make a difference to the **price** at which cells or modules can be offered with reasonable return to international users. In their analysis comparing the manufacturing costs of crystalline silicon PV, MIT Professor Tonio Buonassisi and colleagues from the Department of Energy (DOE) National Renewable Energy Laboratory find that the lower manufacturing cost of a Chinese factory relative to a US factory today is explained by scale and supply-chain advantages, such as supplier location and transportation costs. In the future, these authors argue that innovative technologies may result in effectively equivalent minimum sustainable manufacturing prices for the two locations.[16]

Origin of the Conflict — the Trade Issue

In the mid-to-late 2000s, the Chinese business ecosystem proved extremely adept at supporting firm-level entry and rapid scale-up of manufacturing. With Europe's surging demand for PV, Chinese entrepreneurs were able to access the financing for capital equipment, land, and the regulatory permitting needed to get production facilities up and running rapidly. As a result, during those years, China experienced a boom in the construction of crystalline silicon cell and module plants based mostly on state-of-the-art manufacturing equipment imported from abroad, including the United States. Today, China's production capacity for PV cells and modules stands at roughly 36 GW.[17] Tier 1 producers, the country's 10 largest and technically most sophisticated firms, account for at least 15 GW. The remaining capacity pertains to Tier 2 producers that may have numbered as high as 200 in 2010, but are likely down to roughly 40 today.[18]

The speed the Chinese showed in launching PV ventures in the early & mid 2000s has established their reputation in engineering and manufacturing.

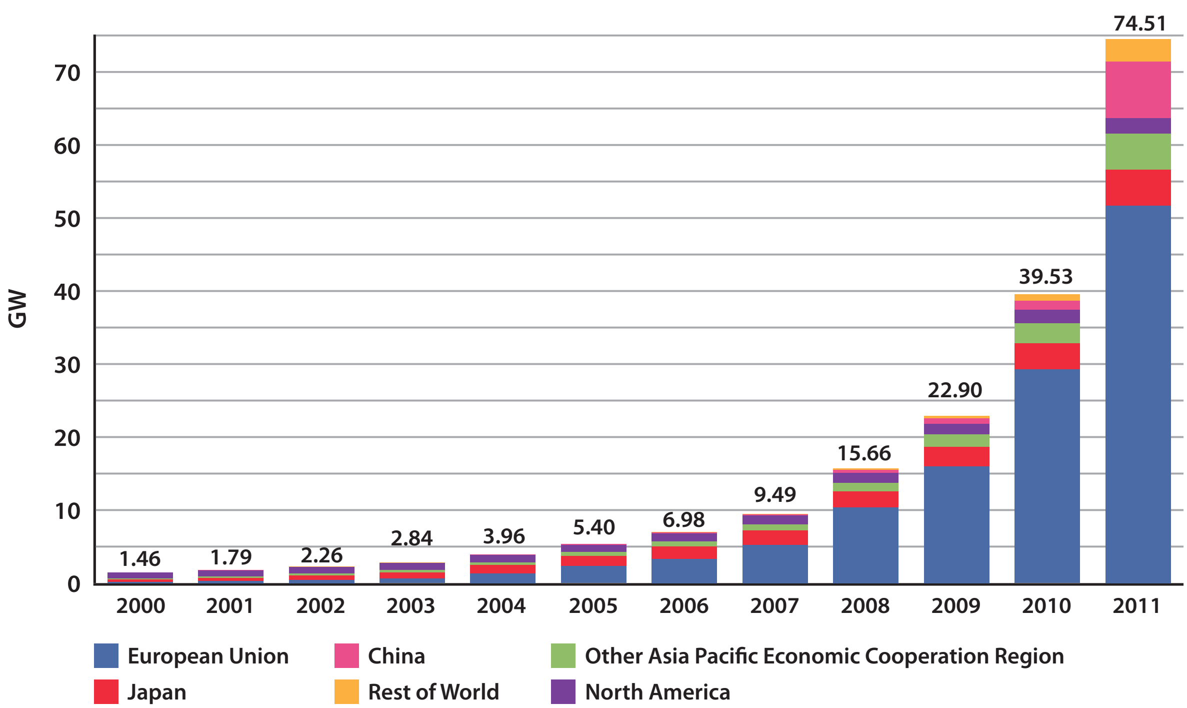
The initial timing of Chinese entrepreneurs was fortuitous: production expanded precisely when global Si prices were dropping, financial markets were willing to provide capital for initial public offerings (China's five largest PV producers are all publicly listed in the United States), and subsidized European electric utilities were subsidized to adopt PV generation.

The Earth Policy Institute[19] gives a vivid illustration in the rapid expansion of global PV production capacity:

Table 1.1 Annual PV Production by Country, 1995–2010 (MW)

Year	China	Taiwan	Japan	Germany	United States	Others	World
2005	128	88	833	339	153	241	1,782
2006	342	170	926	469	178	374	2,459
2007	889	387	938	777	269	542	3,801
2008	2,038	813	1,268	1,399	401	1,207	7,126
2009	4,218	1,411	1,503	1,496	580	2,107	11,315
2010	10,852	3,639	2,169	2,022	1,115	4,248	24,047

Figure 1.2 Global Installed Cumulative PV Capacity (2000–2011) (GW)



Source 2000 to 2010: European Photovoltaic Industry Association, *Global Market Outlook for PV until 2015*, page 8. Available at: http://www.heliosenergy.es/archivos/eng/articulos/art-2.pdf

Source 2011: European Photovoltaic Industry Association, *Global Market Outlook for PV until 2016, May 2012*, pages 12 and 14. Available at: http://www.epia.org/news/publications/global-market-outlook-for-photovoltaics-until-2016/

Note: In 2011 the top four EU countries incremental PV installations were Italy 9.3 GW, Germany 7.5 GW, France 1.7 GW, and UK 0.78 GW. Page 13 from Source 2011

Global PV capacity grew rapidly between 2000 and 2011 (see Figure 1.2). In 2011, however, the global market for PV collapsed due to supply overcapacity and reduction in the pace of demand expansion. Chinese companies began competing brutally against one another, often with little proprietary knowledge distinguishing them. Top-tier producers tried to leverage scale, supply chain integration, and some technology advantages by the rapid introduction of high-end equipment and components from overseas suppliers. Bottom-tier producers sought cost advantages by other means, including neglect of environmental strictures.[20] Whether at the top or bottom, though, all Chinese producers today are locked in price wars that push profit margins into negative territory and undermine corporate share prices. Major producers like LDK Solar have already defaulted on domestic bank loans.[8] Teetering on the brink of financial disaster, the industry is awaiting central government bailouts that may or may not be forthcoming. And, there is some question whether the industry is now stuck with capital investments in traditional production technologies that will prove to be obsolete. Table 1.2 illustrates the financial collapse of the leading Chinese companies.[21]

From the United States' perspective, the origin of the PV conflict is easily seen from a schedule of industry activity between the years 2009 and 2011. The data in Table 1.2 are taken from the annual *Solar Photovoltaic Cell/Module Shipment* US Energy Information Administration (EIA) website.[22] The clear time-series presentation of the data is comforting, but some caution is warranted since all the data are based on an annual, voluntary survey of industry participants.[23]

Table 1.2 Changes in Net Income of Selected Chinese PV Companies 2010–2011 (As reported)*

		2010		2011		2012	
Chinese Company	Ticker Symbol	Net Income $000	Share Price $	Net Income $000	Share Price $	Share Price $	Profit Margin TTM
Sun Tech	STP	$236,900	$8.01	($1,018,600)	$2.21	$0.89	– 44.2%
Yingli	YGE	$210,446	$10.10	($509,837)	$4.26	$1.76	– 50.5%
Trina	TSL	$311,453	$23.39	($37,820)	$7.85	$3.02	– 17.2%
Canadian Solar	CSIQ	$50,569	$13.52	($90,804)	$2.99	$2.61	– 10.2%
JA Solar	JASO	$266,378	$7.21	($89,664)	$1.34	$0.71	– 21.6%
LDK Solar	LDK	$29,797	$10.12	($655,459)	$4.19	$1.06	– 101.6%
Total		**$1,105,543**		**($2,400,173)**			

*The per-share price data in 2010 and 2011 are as of 12/1/2010 and 12/1/2011 and the per-share price data for 2012 is for 12/10/2012. The Trailing Twelve Month (TTM) change in profit margin is the change from Q3 2012 reported financial figures.

Table 1.3 US Shipment and Sources and Dispositions of PV Modules and Cells 2000–2011 (Thousand kW)

Year	Shipments by Type			Shipments (Cells + Modules)			Source (Cells + Modules)			Average Price	
	Cells	Modules	Total	Exports	Domestic	Total	Imports	Domestic	Total	$/Wp Cells	$/Wp Module
2000	33	55	88	68	20	88	9	79	88		
2001	31	67	98	61	36	98	10	87	98		
2002	48	64	112	67	45	112	7	105	112	$2.12	$3.74
2003	29	80	109	61	49	109	10	100	109	$1.86	$3.17
2004	38	143	181	103	78	181	48	133	181	$1.92	$2.99
2005	22	205	227	92	134	227	91	136	227	$2.17	$3.19
2006	17	320	337	131	207	337	174	163	337	$2.03	$3.50
2007	24	494	518	237	280	518	238	280	518	$2.22	$3.37
2008	66	921	987	462	524	987	587	400	987	$1.94	$3.49
2009	94	1,189	1,283	681	601	1,283	743	539	1,283	$1.27	$2.79
2010	1,039	2,644	3,683	1,142	2,541	3,683	2,203	1,621	3,823	$1.13	$1.96
2011	1,667	3,772	5,439	1,708	3,889	5,597	4,802	1,612	6,415	$0.92	$1.59

Between 2009 and 2011, the volume of shipments of cells and modules increased dramatically, by almost a factor of 3.6 from 1.23 Gigawatt-peak (GW_p) in 2009 to 5.6 GW_p in 2011. Imports increased from 58% of shipments in 2009 to 86% of shipments in 2011. In 2011, there was an almost 500,000 difference between source and shipments of cells and modules, indicating a sizable inventory buildup.

Table 1.4 gives the country of origin for US-imported modules in 2009 and 2011. China-based companies have established a leading position in the global PV cell and module market. Clearly this presence will cause concern as prices fall, especially as margins are squeezed. China supplied over 50% of the US PV imports in 2011, and Chinese PV exports to the United States rose tenfold, from about 240 Megawatt-peak (MW_p) in 2009 to 2,450 MW_p in 2011.

Between 2009 and 2011, the price of modules decreased from $2.79 to $1.59 per watt, while China supplied from 30% to 50% of US imports.

Table 1.4 Percent Contribution of Countries to US Cell and Module Imports

Country of Origin	2009	2011
China	32	51
Japan	11	2
Malaysia	–	16
Philippines	29	21
Taiwan	8	0.3

Data on Chinese production and exports of PV cells and modules are not available in the same detail as for US activity.[24] However, the 2010 International Energy Agency (IEA) PV Annual Report contains an informative submission from China, which clearly indicates China's emphasis on exports over production for domestic installation.[25, 26]

Table 1.5 Chinese Production and Export of PV Modules 2006–2010

	2006	2007	2008	2009	2010	2011 Est.*
Production MW	400	1,088	2,600	4,011	8,000	13,500
Export MW	390	1,068		3,851	7,500	
Installed MW	10	20	40	160	500	2,500
% Export	97.5	98.2	98.5	96.0	93.8	

*2011 export estimate uncertain because of inventory changes.

During this same period, the price of PV modules fell from $2.79 per Watts-peak ($W_p$) to $1.59 per W_p.[27] The explanation for this simultaneous sharp increase in production and sharp price reduction is **not** entirely the happy economic event of unit cost reduction from economies of scale and improved technical performance with preservation of commercially attractive profit margins. Rather the explanation for this price decline is **overexpansion** in global, primarily Chinese and Asian, production capacity of cells and modules, combined with a reduction in the demand growth of heavily subsidized PV markets in Europe caused by the financial crisis.[28]

A complicating factor is that during this period of rapid production expansion, intensifying competition, and declining margins, Chinese PV firms have also made important incremental engineering advances in production. While acknowledging that much of the PV module price reduction between 2010 and mid-2012 stems from overcapacity, a report issued by the global industry association Semiconductor Equipment and Materials International (SEMI) points out a number of other technical factors that have driven costs down, including reduced use of Si in wafers and silver in PV cell interconnections and improved cell performance through the use of advanced glass, coatings, and films.[29] China's larger PV manufacturers have played critical roles in pioneering many of these manufacturing advances.[30]

Despite these engineering achievements, the squeeze on profit margins caused by overcapacity has created significant financial hardship for PV manufacturers globally. Numerous firms in both the United States (e.g., Evergreen Solar, Solyndra, BP Solar, Energy Conversion Devices, Beacon) and China have failed, closed plants, or reduced operations. One US market research firm reports that Chinese module suppliers' net margins fell to double-digit negative values beginning in 2Q 2011, and remain at this level over a year later.[31]

NYSE-listed and Wuxi-based Suntech Power Holdings, the largest PV panel maker in the world, currently has $2.3 billion in outstanding debt and is expected by the close of 2012 to post a loss of $495 million. Suntech had $541 million in convertible notes due in March 2013, roughly three times the firm's current market capitalization.[32] Suntech declared bankruptcy at the end of March 2013 and the Chinese government has yet to show interest in bailing out the company.

The collapse of the PV market has repercussions for overseas suppliers as well. The 2012 PV revenues of Applied Materials, the global leader in PV production equipment, are one-eighth of those in 2011.[33]

US Trade Action

The US perception of the Chinese response to this worldwide economic crisis in PV markets was that China "dumped" PV products into the US market, selling at prices below "cost," although likely above variable costs. Unsurprisingly, a group of US PV manufacturers filed a complaint with the US Department of Commerce (DOC) and International Trade Commission (ITC) alleging that Chinese PV manufacturers of crystalline silicon cells and modules were selling product into the United States below cost and harming US manufacturers.[34] The process of assessing trade complaints is complex, but has resulted in imposition of substantial anti-dumping duties (as much as 30% or more) on a number of Chinese crystalline silicon cell and module manufacturers in a preliminary decision in May 2012; a final decision was issued in November 2012.[2] On September 6, 2012, the European Community announced the initiation of an anti-dumping inquiry against Chinese PV manufacturers.[35]

CHINESE RESPONSE

The Chinese have responded to the US action in three ways. First, the Chinese PV industry, which is active and sophisticated, strenuously objects to the US Government (USG) action,[36] urging the Chinese government to dispute strongly the US tariffs. The Chinese argue that their industry is more efficient than the US industry at the PV cell and module manufacturing levels, and that this explains the difference in cost and selling price between firms in the two countries. Chinese companies have also moved actively to change the location of their manufacturing activities, mostly elsewhere in Asia, to circumvent tariffs on imports to the United States.

Second, the Chinese government through its Ministry of Commerce (MOFCOM) has indicated its support for the domestic PV sector,[37] with MOFCOM bringing to the World Trade Organization counter allegations of unfair US trade practices in PV. [38]

Finally, the debate over trade practices and the difficult financial circumstances of the Chinese PV industry appear to have prompted the central government to review its strategy for supporting solar energy in general, and providing assistance to the distressed PV industry in particular.

DEEPER CURRENTS ABOUT COMPETITIVENESS

This is not a simple trade dispute. Both the United States and China see PV as a key future technology that will be widely adopted in their countries and elsewhere in the world. Establishing a dominant national position in the technology has advantages for both domestic deployment and international competitiveness. Moreover, PV carries the aura of being a renewable technology that provides jobs without endangering the environment or emitting CO_2, thus attracting broad public support. Not surprisingly, both governments, but especially the Clinton and Obama administrations in the United States, have been eager to encourage all aspects of PV industrial development, including R&D on new technologies, demonstration of new technologies, and a wide array of policy measures to encourage deployment of PV domestically over less desirable conventional electricity generating technologies. Many of the policy measures have the indirect effect of advantaging domestic PV firms in international markets.

Industrial firms and their trade associations see policies in each country in terms of the perceived impact on commercial competitiveness. They publicly depict the competition entirely in bilateral terms with little appreciation of the differences in policy mechanisms between the countries, and no concrete ability to assess the net level of government assistance in each country. Most importantly, the international character of the industry in terms of capital and operations is largely omitted in the public debate, although there is mention of "domestic content."

In the following two sections, we discuss the different patterns of government support for PV in the United States and China, and point out that it is a large effort in both countries. A conclusive and satisfying comparison is not possible because of the absence of reliable data on the magnitude of the public assistance for either China or the United States.

Public Assistance for PV in the United States

The Congressional Research Service (CRS) has recently presented a useful report on PV industry trends, global PV trade, and federal support.[39] The report lists the following US mechanisms:

- An advanced energy 30% manufacturing tax credit (MTC) was aimed at supporting renewable energy manufacturers. It reached its funding cap of $2.3 billion in 2010.

- The Section 1705 Loan Guarantee Program directs funds to manufacturing facilities that employ "new or significantly improved" technologies. Over $13 billion has gone to 13 solar production facilities.

The pattern of public assistance for PV is different in the United States and China.

- The investment tax credit provides financial incentives for solar power at a rate of 30% effective through December 31, 2016, after which it will revert to a permanent rate of 10% for commercial investments and expire for residential investments.[40]

- The Section 1603 Treasury Cash Grant Program requires solar projects to begin construction by December 31, 2011, and be in service by December 31, 2012. Grants have exceeded $2.1 billion.

- The *Sunshot* Initiative is one of several US DOE programs to support the solar industry and increase domestic PV manufacturing.

There are three points to make about this list. First, the *Sunshot* Initiative is only one of several Research, Development, and Deployment (RD&D) PV programs at DOE designed to improve PV manufacturing. R&D support for PV has had its ups and downs over the years, but certainly has exceeded $100 million per year for several decades, if support from all DOE program offices is included (Office of Science, Energy Efficiency and Renewable Energy Office, and Advanced Research Projects Agency – Energy (ARPA-E)).

Second, as noted above, stimulus funding in the American Recovery and Reinvestment Act (ARRA) of 2009 included significant support for PV, but it is unlikely these benefits will continue in the future.

The EIA issued a report on federal energy subsidies in 2010.[41] Five different categories of federal subsidies were included: (1) direct expenditures to producers and consumers; (2) tax expenditures; (3) R&D, (solar R&D expenditures were $348 million in 2010);

(4) loans and loan guarantees; and (5) regional electricity programs, e.g., the Tennessee Valley Authority and the regional power marketing administrations such as Bonneville Power Authority. The EIA identified a total for electricity production of $37.1 billion ($14.8 billion from the ARRA stimulus package), of which $14.7 billion was for renewables, with solar accounting for $1.1 billion. [Arriving at these totals requires a good deal of judgment about the appropriate cost of interest subsidies—EIA used a range of 4.5% to 6.5%, which is discussed in detail in their report.]

It is important that neither this EIA report nor any other USG report attempts a quantification of the **benefits** of these subsidies. In the case of solar subsidies, a variety of desirable public purposes are advanced: encouraging renewable technology, encouraging carbon-free electricity, creating jobs, strengthening national security, and improving international economic competitiveness. As of 2012, PV and other solar electricity-generating technologies provide a tiny fraction of US electricity generation despite decades of federal support.

Third, most support for PV **deployment** comes from state assistance programs that are not included in the CRS report quoted earlier. The assistance comes either in the form of tax benefits, direct payment allowances (although the United States makes much less use of feed-in tariffs (FITs)), or as regulatory mandates that impose a requirement on utilities to provide a certain percentage of their generation from renewable sources.[42] As of December 2012, 29 US states and the District of Columbia had enacted quantity-based renewable portfolio standard (RPS) programs requiring that a minimum fraction of electricity demand be met by renewable energy.[43] These policies typically require load-serving entities to obtain renewable energy credits (RECs) produced by state-certified renewable generators in proportion to their output. Moreover, PV and other renewable generators may be given preferential rates and dispatch rules. We know of no comprehensive estimate of the public cost of US state subsidies for PV or other electricity-generating technologies. Advantages in a domestic market, of course, have indirect benefit for firms

In the case of solar subsidies, a variety of desirable public purposes are advanced: encouraging renewable technology, encouraging carbon-free electricity, creating jobs, strengthening national security, and improving international economic competitiveness.

competing in international markets because of the addition to scale and the subsidization of fixed costs, especially technology development and non-recurring engineering expenses. However, it is important to note that unless RPSs have local content provisions, they do not benefit domestic PV producers over imports of cheaper Chinese-produced arrays.

US PV exports were about $1 billion in 2011. Several USG programs encourage the export of renewable energy products. The Export-Import Bank (Ex-Im) provides direct loans to solar manufacturers through its Environmental Products Program, under which it allocates a certain portion of funding to renewable energy and energy-efficient technologies. For example, First Solar received an Ex-Im $455.7 million guarantee to support exports of 90 MW of modules to Canada.[44]

In summary, the United States, presently and in the past, has extended diverse and significant public assistance to the development and deployment of PV (as well as other renewable electricity-generating technologies, notably wind). The mechanisms favored by the United States are direct support for R&D, regulatory mandates to encourage deployment (in contrast to FITs), and from time to time huge bursts of production subsidies. Over the years, both the federal and state governments have extended significant assistance, but a disciplined process of evaluating the costs and benefits of this assistance has not been done.

Public Assistance for PV in China

Though China is a single-party authoritarian state, official public policy and actual practice frequently diverge. Several aspects of the Chinese governance system contribute to this situation.

First, despite moving far beyond socialist command planning, the central government still guides the economy through five-year plans with specific policy targets. These targets, frequently aspirational in nature, are rarely accompanied by precise guidelines or policy measures for their achievement. Central ministries and local governments, however, take the targets seriously and use them to guide their actions.

Second, the system is extremely decentralized. Provincial and municipal governments frequently initiate policy experiments to achieve the goals laid out by the five-year plan. Those experiments often exceed or directly contravene existing legal and regulatory regimes. If and when the experiments prove successful, they tend to propagate nationally. Only at that point does the central government revise the existing regulations in a scramble to legitimize previously non-compliant behavior.

Third, despite the system's hierarchical nature, political power is dispersed in unpredictable ways. In recent years, for example, several large state-owned corporations, in part due to their position in the interpersonal networks of party leaders and their families, appear somewhat immune to supervision and regulatory stricture by even the highest level government agencies.[45]

Fourth, the central government has increasingly tried to regulate the economy through market-based mechanisms such as taxes, subsidies for compliance, and fees for non-compliance. However, when such measures fail to produce the desired results, the central government falls back on command-and-control approaches.

Fifth, in an increasingly open market system with many economic actors, the state still pervades economic activity. This is particularly apparent with regard to financial intermediation. The boundaries between commercial credit provision and state-directed financing are opaque at best; providers of capital are generally state-owned; and the term "state-directed" applies both to local and central directed financing.

All five of these characteristics are apparent in the manner by which the PV has been regulated in China. Prior to 2011, the central government appeared relatively indifferent to the PV sector. In its 2007 Renewables Energy Law, the Chinese government enacted a FIT for wind power, but not for solar. China's market for wind turbines rapidly became the largest in the world, while the nation's demand for solar remained flat.[46] In presentations of the 11th Five-Year Plan for energy development, National Development and Reform Commission (NDRC) officials when discussing renewables consistently prioritized wind, biofuels, and biomass over solar.[47]

Despite the absence of PV in national plans, PV firms grew through entrepreneurial initiative supported by municipal governments eager to promote high-tech manufacturing. China's PV sector exported over 90% of its output since there was very limited encouragement for domestic installation. Moreover, the China state grid company (SGCC), a politically powerful entity, is an additional barrier to domestic deployment because it is notoriously reluctant to provide grid access to renewables, regardless of the regulatory mandate.[48]

In part, because China lacks the highly developed science and technology base of the United States, the central government has only modestly supported PV R&D. China's Ministry of Science & Technology (MOST) supports R&D through three programs: (1) the National High-tech R&D Program (Program 863) supports innovation in strategic high-tech fields, (2) the National Basic Research Program (Program 973) supports basic scientific research for long-term development, and (3) the Key Technologies R&D Program supports R&D for the current development of the national economy. Each of these MOST programs has supported PV but to a limited extent. The Climate Policy Initiative's informative report survey of PV in China and Germany estimates expenditures of about € 25 million for the period 2006–2010.[49]

Central government efforts to support domestic deployment of PV have been quite modest until recently. Funding for domestic deployment and demonstration projects began in 2009 with the central government's Golden Sun program.[50] The program, which supports deployment for rural areas, building-integrated PV (BIPV) systems, and large-scale grid connected projects, is viewed by industry insiders as an important contributor to the 4 GW of PV deployed in 2011.

More ambitious efforts to support domestic PV markets have come with the NDRC's July 24, 2011 announcement of a national FIT for PV.[51] The FIT is consistent with the government's increasing preference for market-based regulation. Because PV is more expensive than other conventional electricity generation, some mechanism is needed to finance its expansion especially since electricity prices are controlled. After 2011, China like Europe has opted for a FIT, rather than RPS, to finance the cost of the more expensive PV.

The FIT system for solar is in principle supposed to be applied at the provincial level with allowance for balancing FIT payments between provinces that had produced more and less renewable generation. The new FITs for both open and non-competitive PV project tenders are slated to be above those accepted previously. Electricity grid operators are to pay solar developers 1.15 Yuan (US $0.18) per Kilowatt hour (kWh) on projects approved before July 1, 2011, or to be completed by the end of 2011 and 1 Yuan/kWh on projects approved after July 1st.

However, whether the FIT will be widely implemented is open to question. Part of the uncertainty stems from the policy's origins. A number of industry participants assert that the policy came about as a post hoc effort by the NDRC to catch up with events on the ground in Qinghai province. Qinghai, among China's poorest interior provinces, recently began promoting an aggressive FIT of its own. In part eager to develop PV projects that could export energy to the more developed coast, and in part determined to build out its own provincial supply, Qinghai initiated a FIT of 1.4 yuan/kWh. Qinghai also had the reputation of having a particularly good relationship with the local branch of the state grid company, thus increasing the likelihood of grid access. A "gold rush" ensued with project developers moving in en masse. At that point, the NDRC scrambled to announce a national FIT to avoid a situation in which provinces would compete against one another with escalating tariff programs. It is by no means clear that the NDRC or any other central agency has the capacity or desire to force the state grid company to participate in the FIT program.

In these circumstances, it is not surprising that the central government has included traditional command-and-control directives to promote PV deployment. In September 2012, China's National Energy Administration (NEA) released its 12th Five-Year Plan on solar power development.[52] The plan calls for installed capacity of 21 GW by 2015 and 50 GW by 2020; the majority of this capacity will be PV, while solar thermal will be about 10%. Industry insiders are now claiming that in early 2013, the deployment target for 2015 will be raised to 35 GW. Even at the lower target, the plan is ambitious, using the term "going out" to characterize the intention to enter international markets. It is worthwhile to quote the "guiding ideologies" of the Five-Year Plan:

"Thoroughly implement scientific concepts of development, and seize opportunities as countries around the world emphasize the development of new energy; focus on the goal of reducing the costs of PV power generation; improve the quality of PV products; strengthen China's PV industry; endeavor to promote the innovation of key technologies; improve production techniques; break bottlenecks of equipment R&D; and promote mass applications, so as to significantly enhance the overall competitiveness of China's PV industry."

But, the plan also offers little indication of the level of public spending that will be extended to reach the stated goals.[53] For example, the FIT is mentioned only once:

"Promote and improve technology systems and management mechanisms fit for PV power generation."

Key Focus Areas in the Five-Year Plan Are:

- High-purity polysilicon production
- Si ingots/Si wafers
- crystalline silicon cells
- Thin-film cells
- High-concentration solar cells
- BIPV modules
- Specialized production equipment
- Ancillary materials
- Grid and energy storage systems
- Public service platforms

The plan states specific objectives for cost objective and market shares. The plan targets that by 2015 the cost of PV modules installed will drop to 7 Yuan per watt and the cost of PV power generation will be 0.8 Yuan/kWh. By 2020, the cost of PV modules will drop to 5 Yuan per kilowatt (kW) and that of power generation to 0.6 Yuan/kWh. The plan also includes a number of specific policy measures, but without any indication of the resources that will be applied to each. One measure is noteworthy:

"Strengthen industry organization and actively participate in international competition."

The 2012 NEA five-year plan is ambitious, comprehensive, and determined. Several DOE PV plans have the same character, but plans are intensions, not reality. The one difference in tone between the NEA plan and a comparable DOE plan is that the DOE plan is more nuanced about the government and industry role for technology and market risk.[54] The NEA five-year plan, for example, gives specific economic objectives for the size of enterprises:

"Support will be provided to major enterprises to grow stronger so that by 2015, leading polysilicon enterprises will reach 50,000 metric tons per year, and major enterprises will reach 10,000 metric tons per year; leading solar cell enterprises will reach the 5 GW level, and major enterprises will reach the 1 GW level. By 2015, in China there will be one PV enterprise with annual sales revenue exceeding RMB 100 billion, 3–5 PV enterprises with annual sales revenue exceeding RMB 50 billion, and 3–4 enterprises specializing in PV equipment manufacturing with annual sales revenue exceeding RMB 1 billion." (1RMB = 1 Yuan)

Chinese industry advocates find even this ambitious plan underwhelming given that present production capacity today is above 35 GW and that external markets are effectively limited, regardless of what government stipulates about "going out." The EU is in no financial condition to support FITs, and shale gas has changed the economics of electricity generation in the United States, making the rate of solar deployment more uncertain. Hence, China's PV producers are hoping for support from a growing domestic market. Even given the possibility of an extended target by 2015 of 35 GW installed (translates into 9 GW installed annually between 2013 and 2015), is well below China's current production capacity of 36 GW. Moreover, foreign firms such as First Solar and SunPower will seek to supply some of China's domestic PV projects.[55] The government's announced expansion goals, ambitious though they may be, are sufficient only to sustain China's Tier 1 producers, its seven to ten largest firms; many smaller firms have already failed.

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It is likely that for the next several years, Chinese firms will have few resources to pump into equipment upgrading and modernization. This leads to a global problem. Chinese cell and module manufacturers have been the main customers of the leading global providers of PV production equipment, advanced materials, and components, including US firms such as Applied Materials, Dow Corning, Honeywell, and Dupont.[56] These US firms have located production and/or R&D facilities in China as a business decision based on supplier relations (including, possibly, a requirement for contracts) or Chinese incentives (another potential source of US allegation of unfair competition).

Chinese PV manufacturers and high-end equipment and materials providers from the United States and elsewhere are interdependent and form an important global ecosystem for innovation. A slowdown in the growth of Chinese PV manufacturing implies a sharp decline in business for high-tech firms in the United States and elsewhere that currently develop the technology on which future progress of PV depends. The debate about US–China competition in PV should not ignore the global linkage between production in China and the prosperity of high-tech supplier firms, an area in which the United States is currently an undisputed leader.

Conclusions

We present our conclusions in three sections:
(1) observations about the PV industry,
(2) observations about recovery in the global PV market, and
(3) advice to government.

OBSERVATIONS ABOUT THE PV INDUSTRY

1. The structure of the PV industry should be seen in global terms with demand coming from many countries and with many international suppliers involved in the various stages of the supply chain. PV is not a bipolar competition between China and the United States for manufacturing of crystalline silicon cells and modules. There is strong supply chain linkage and mutual dependence between technology generation and deployment in the United States and manufacturing of cells and modules in China.

2. The respective PV sectors of China and the United States are developing in different ways that reflect the strength of each nation's industrial base and each nation's government policies. The United States has relative strength in the creation of new technologies that are potentially of lower cost and meet end-use needs in different ways (whether distributed or central generation). China has demonstrated its relative strength in rapidly introducing high-quality, low-cost manufacturing. The situation is not static: China certainly is interested in moving up the food chain and the United States is interested in improving domestic manufacturing performance generally.

3. Technology generation is one important factor determining economic competitiveness and this motivates countries, especially the United States, to support research, development, and demonstration of new technologies. The PV story is that the technology is pretty well globally available and innovation depends more on rapid and low-cost application than on technology creation.

4. Accordingly, the **risk for US-based industry** is that firms cannot execute large-scale manufacturing (either in the United States or abroad) as well as China (either in China or abroad, including, potentially the United States). **The risk for China-based industry** is that firms will miss new technologies that have more desirable performance/cost characteristics than traditional crystalline silicon, and in missing these technologies, will continue to make premature investments, resulting in large financial loss.

5. There is no credible data that permits one to establish whether the sum of all public subsidies for PV in the United States, both state and federal, are larger than the sum of all Chinese subsides for the domestic and exporting PV industry, but it is possible. Up to the present, the balance of deployment assistance to production assistance is likely greater in the United States than in China. With regard to subsidies to capital, China appears to favor subsidizing debt through easy bank loans while the United States appears to favor subsidizing equity through tax credits or direct assistance, although loan guarantees are also used.[57] We are unable to conclude whether government assistance to capital is greater in China or the United States.

6. We have not uncovered evidence that government subsidies, low labor costs, or stolen technology are sufficient factors to explain the apparent Chinese advantage in manufacturing. If American firms cannot meet and exceed Chinese cell and module manufacturing competence, US firms should focus on the many other attractive parts of the PV supply chain, especially those with higher profit margins. The outcome of the PV manufacturing competition may well foretell how successfully the United States will compete with China and other Asian economies in manufacturing other products.

OBSERVATIONS ABOUT RECOVERY IN THE GLOBAL PV MARKET

Unquestionably, the combination of decline in demand for PV modules and the cutback of generous FITs from European countries, primarily Germany, Italy, and Spain, and the enormous increase in supply capacity, primarily from China, has fundamentally disrupted the global PV market.

The most serious reflection of market disruption is the disparity between PV module **prices** and **cost**. PV module **prices** in 2011–2012 were in the range of $1 per W_p, and even lower in some cases, at the end of a long period of price reductions.[58] The evidence from 2011–2013 is that some of the recent reduction of the price of PV modules does not properly reflect full cost-reduction experience but simply a squeeze on profit margins from selling products at low prices to reduce excess capacity. Market recovery to certain PV producers certainly means an **increase** in module price in order to achieve higher margins and the "minimum sustainable price,"[16] required to sustain growth. The Center for American Progress has clearly explained the dilemma posed by the need for higher prices required to sustain supply but that will dampen demand.[59]

General economic conditions, such as fiscal constraints, the availability of low-cost natural gas, and the cost of capital will influence the economic competitiveness of PV as an electricity-generating technology option.

Restoring order to the PV market also requires some adjustment in demand and supply. On the demand side, it is likely that at least out to 2016, the European countries that have been an engine for demand will not maintain policies that have previously encouraged rapid growth. The European Photovoltaic Industry Association projects two scenarios for future PV installations reflecting a "moderate" scenario in which the expected phase-out of generous FITs in Spain, Italy, and Germany occurs and a "policy-driven" scenario in which these incentives are retained. The spread in European cumulative deployment in these two scenarios is between 155 GW (policy driven) and 96 GW (moderate) in 2016 relative to 51 GW at the end of 2011.[60] If global PV demand is to maintain its past pace of growth, European demand will need to be replaced by demand from Asia (primarily China) and the United States.

There are also important uncertainties on the supply side. Will the Chinese continue to allow their excess capacity to diminish or will policies be adopted to encourage production? How rapidly will new PV technologies be introduced and will these new technologies be of lower cost? Finally, general economic conditions, such as fiscal constraints, the availability of low-cost natural gas, and the cost of capital will influence the economic competitiveness of PV as an electricity-generating technology option.

The net result is that large uncertainties confront the PV industry for at least the next several years.

We stress that our work is restricted to PV and we do not suggest and we do not believe that our findings should be extended to other industries in which the United States and China compete. Nor do we suggest that generalizations can be drawn about the outlook for US manufacturing competitiveness from this US–China case study.

ADVICE TO GOVERNMENT

The natural temptation for governments when faced with a popular and promising new industry opportunity that faces international competition is to quarrel with competitors and adopt policies that are perceived to give domestic industry advantage — consider the examples of commercial air transport, computers and electronics, pharmaceuticals, nuclear power, and space. We should not expect all folly to be avoided, but the effort should be made to avoid the greatest excesses.

1. The most immediate risks are (a) that the Chinese will continue to push sharp commercial practices that sell unprofitable products on global markets at below prices that recover full costs and (b) the United States will adopt protectionist trade practices in response to this Chinese action, e.g. adopt domestic content requirements for PV systems. The net result will be that the Chinese industry will continue to lose money and the US PV industry will be shielded from the reality of competitive manufacturing.

2. Both China and the United States need to reassess their portfolios of assistance measures for PV from two points of view: what are the goals of the subsidies (development, deployment, employment, reducing greenhouse gas emissions, competitiveness) and are the subsidies achieving these goals in a cost-effective manner?

3. To the extent government-assisted PV technology programs in the United States and China have the objective of achieving innovations that improve competitiveness, the assistance programs need to address both technology creation and adoption.

   Public support of technology is justified when individual firms do not undertake R&D because they cannot appropriate the benefits to lowering their production costs, and the R&D knowledge is spread to many firms. The intent is to benefit US firms and workers, but the PV example shows the difficulty of applying this principle in an industry that has a complex supply chain and a global character.

4. The prospect of carbon-free electricity generation from PV means there is a global public good in subsidizing PV technology development. The tight linkage between US and Chinese PV firms raises the question of whether there are practical mechanisms of public support that could advance the global PV enterprise better than the separate efforts of each country. Such integration could have three aspects: cross investment, technology transfer, and joint development or production projects in either country. Integration would blur outcomes of jobs, revenue, and technology advances from national firms to the results of the global enterprises. Of course, much detailed analysis and negotiation would be required before the United States and China could decide if they wished to encourage or discourage greater integration between their PV industry sectors.

This is a report for the MIT Future of Solar Energy study and several of the key issues that are raised in this paper — PV manufacturing private and public costs, PV technologies, supply chain relationships, and the rationale and choices of different public assistance mechanisms — will be analyzed further in the study effort.

Notes

[1] We thank our MIT colleagues for constructive comments during the course of this work: Vladimir Bulovic, Tonio Buonassisi, Michael Greenstone, Joseph Hezir, Henry Jacoby, Ernie Moniz, Richard Schmalensee, and Robert Stoner.

[2] We largely avoid the use of the term "dumping" in this paper for several reasons: First, the definition of dumping in trade disputes is complicated, e.g., WTO:

"Dumping is, in general, a situation of international price discrimination, where the price of a product when sold in the importing country is less than the price of that product in the market of the exporting country. Thus, in the simplest of cases, one identifies dumping simply by comparing prices in two markets. However, the situation is rarely, if ever, that simple, and in most cases it is necessary to undertake a series of complex analytical steps in order to determine the appropriate price in the market of the exporting country (known as the "normal value") and the appropriate price in the market of the importing country (known as the "export price") so as to be able to undertake an appropriate comparison." http://www.wto.org/english/tratop_e/adp_e/adp_info_e.htm

Second, selling product at a price above variable cost and below total cost is common business practice at times of oversupply, which is how the Chinese characterize this behavior.

Third, our purpose in this paper is to understand the different practice and attitudes in China and the United States rather than to espouse a position on the trade issue or examine the length proceeding before the Department of Commerce, see, for example, http://ia.ita.doc.gov/frn/2012/1205frn/2012-12798.txt

[3] Jonas Nahm and Edward S. Steinfeld, "Reinventing Mass Production: China's Specialization in Innovative Manufacturing," MIT Political Science Department Working Paper 2012-25, July, 2012

[4] There is a decidedly underwhelming $150 million five-year energy technology cooperative agreement between US and China that addresses clean vehicles, advanced coal technology, and building energy efficiency. China and the US fund the program in equal parts. In the United States, industry partners provide $47.3 million and DOE $37.5 or a bit more than $2 million per year for each of the three areas (minus the cost of administering the program by NREL). Department of State, Office of Science and Technology Cooperation, Bureau of Oceans and International Environmental and Scientific Affairs, *Biennial Report to Congress on United States China S&T Cooperation*, p4 (July, 2012). Available at: www.state.gov/documents/organization/197119.pdf

[5] IMS Research is a subsidiary of IHS and maintains a PV industry web site. The forecast mentioned is found at: http://www.pvmarketresearch.com/free-resources/research-data.php#Chinese%20Module%20Supplier%20Gross%20Margins%20&%20Net%20Margins

[6] IEA, *Renewable Energy – Medium Term Market Report 2012*, page 159. Available at: http://www.iea.org/w/bookshop/add.aspx?id=432

[7] Germany also has an active PV industry which has suffered a fate similar to the United States.

[8] Dupont, for example, is a leading provider of such components. See: http://www2.dupont.com/Photovoltaics/en_US/products_services/index.html

[9] Louise Story, "As Companies Seek Tax Deals, Governments Pay High Price," *The New York Times*, Dec. 1, 2012. The article estimates that $25.5 billion in incentives are extended to manufacturing firms annually. Evergreen Solar provides a good example in the PV sector. The firm received $58 million in incentives from the state of Massachusetts to build a manufacturing facility at Fort Devens. See: Todd Wallack, "Evergreen Solar Loses Tax Breaks Worth Millions," *The Boston Globe*, May 20, 2011.

[10] For example, in 2008, Suntech received a three-year interest-free RMB 20 million loan from the Jiangsu International Trust & Investment Corporation. Thilo Grau et al., "Survey of Photovoltaic Industry in Germany and China," CPI Report, March 2011, p. 35. For additional information on local trust and investment corporations, see: Henry Sanderson and Michael Forsythe, *China's Superbank* (Singapore: John Wiley & Sons, 2013); Sun Tao, "The Path Toward Reconciling Financing Vehicle Risk," China Reform (Zhongguo Gaige), October 2012.

[11] The extent to which firms have drawn on these credit lines is debated. A 2011 Bloomberg report claims that through 2010 the China Development Bank had extended a $29 billion credit line to 15 solar and wind companies, but only $866 million had been drawn. See: Sally Bakewell, "Chinese Renewable Companies Slow to Tap $47 Billion Credit," Bloomberg, Nov. 16, 2011. The situation appears to be changing now with the downturn. Jingko Solar in December 2012 accepted a five-year, $1 billion financing package from the China Development Bank. See: "Jingko Solar gets $1 billion infusion from Chinese development bank," SustainableBusiness.com News, Dec. 12, 2012.

[12] On Nov. 21, 2012, the Shanghai Agricultural and Commercial Bank brought suit in the Shanghai courts against LDK Solar for non-payment of a one-year RMB 100 million loan. "Small to Medium-Sized Banks Assume the Burden of the Credit Crisis in PV," *Jingji Guangcha Wang* (*Economic Observer Net*), Dec. 4, 2012.

[13] Shao Ning, "The Economy's New Stage," *Zhongguo Gaige* (*China Reform*), Oct. 2012.

[14] http://en.wikipedia.org/wiki/First_Solar

[15] http://www.jasolar.com/webroot/company/team.php

[16] A. C. Goodrich, D. M. Powell, T. James and T. Buonassisi, *Preliminary Analysis for Review: Quantifying regional costs to manufacture of c-SI solar PV*, presentation made at MIT, Cambridge MA, March 12, 2012.

Alan C. Goodrich, Douglas M. Powell, Ted L. James, Michael Woodhouse, and Tonio Buonassisi, *Assessing the Drivers of Regional Trends in Solar Photovoltaic Manufacturing*; submitted for publication.

[17] China Photovoltaic Industry Alliance, "China PV Industry Annual Report, 2011–2012" (地方政府融资平台), May, 2012.

[18] The actual number of Tier 2 firms is difficult to determine. After rapidly entering during the market upturn, many have temporarily shuttered their production lines during the downturn. Similar estimates of roughly 40 remaining Tier 2 producers in 2012 were provided by a major overseas PV equipment supplier and by a leading Chinese PV trade association in discussions with the authors.

[19] Compiled by Earth Policy Institute (EPI) with 1995–1999 data from Worldwatch Institute, *Signposts 2004*, CD-ROM (Washington, DC: 2005); 2000 data from Prometheus Institute, "23rd Annual Data Collection - Final," *PVNews*, vol. 26, no. 4 (April 2007), pp. 8–9; 2001–2006 from Prometheus Institute and Greentech Media, "25th Annual Data Collection Results: PV Production Explodes in 2008," *PVNews*, vol. 28, no. 4 (April 2009), pp. 15–18; 2007–2010 from Shyam Mehta, GTM Research, e-mail to J. Matthew Roney, EPI, 28 July 2011.

[20] In September 2011, the Chinese press reported widely on the shuttering of a Zhejiang-based Jinko Solar facility for dumping toxic waste products into local waterways. See: "Solar plant partially closed after pollution concerns," Xinhua News Service, Sept. 20, 2011.

[21] This financial data comes from data on the Yahoo financial web site assembled from public reporting of companies.

[22] The EIA PV website is located at: http://www.eia.gov/renewable/annual/solar%5Fphoto/

[23] The annual EIA survey form, EIA 63-b, and instructions can be found at http://www.eia.gov/survey/#eia-63b

[24] A useful guide to official Chinese energy statistics is found on the web maintained by the Oslo Group on Energy Statistics, http://og.ssb.no, at www.ssb.no/ocg/china.doc. An older guide on Chinese energy data is J. E. Sinton and David G. Fridley, Lawrence Berkeley Laboratory, LBL-20924, (2001). Available at: http://china.lbl.gov/publications/guide-chinas-energy-statistics

[25] See Table 9, *PVPS Annual Report 2010*, April 14, 2011, p. 51, http://www.iea-pvps.org/index.php?id=6

[26] See Table 1, 3 & 5, *PVPS Annual Report 2010*, April 19, 2012, p. 47, http://www.iea-pvps.org/index.php?id=6

[27] Modules are sold on the basis of dollars per peak watt, $\$/W_p$, which does not depend on insolation at a particular location or refer to the conversion efficiency. The peak watt is understood to come from a reference sunlight intensity of 1 kW/m^2. So if a manufacturer offers a module with 1 kW_p it is understood to produce 'q' kW_e-h per day, if the solar insolation at the site is 'q' kW-h of sunlight for the 24-hour period. If the conversion efficiency were perfect, the area, A, of this module would be 1 m^2. For conversion efficiency, η, the area of the module needed to produce 1 kW_e is $A=1/\eta$ m^2. If a PV buyer determines the insolation at the site, for example, is 4 kW-h/m^2 per day, the buyer knows that a 1kW_p device will produce 4 kW_e-h per day and then determines the number of modules required to provide the desired electricity. The buyer determines area required to produce this electricity by dividing by the efficiency, e.g., for η =0.2 the required area would be 5 m^2.

[28] The European Photovoltaic Industry Association (EPIA) observes that at the end of 2011 29.7 GW of PV systems were connected to the grid, up from 16.8 GW in 2010 and that PV is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity; 21.9 GW were connected in Europe in 2011, compared to 13.4 in 2010; Europe has the predominant share of the global PV market, with 75% of all new capacity in 2011, Italy installed 9.3 GW. China installed 2.2 GW and the United States installed 1.85 GW in 2011. Six countries have more than 1 GW installed. Six countries have more than 1 GW of PV installed: Italy, Germany, France, China, Japan, and the United States. http://www.epia.org/policies/sustainable-market-developmet/market-competitiveness/

[29] M. Fischer, A. Metz, and S. Raithel, "SEMI International Roadmap for Photovoltaics (ITRPV) – Challenges in C-Si Technology for Suppliers and Manufacturers, 2012.

[30] For example, Suntech, in R&D work done with the University of New South Wales, has through the incorporation of passivated emitters and lower temperature fabrication processes, achieved 20.3 percent efficiency on a production cell. See: James Montgomery, "More Solar Efficiency Marks," Renewable Energy World, Dec. 3, 2012 (http://www.renewableenergyworld.com/rea/news/article/2012/03/more-solar-efficiency-marks-solopower-suntech-isc-alta-devices-panasonic). In a different example, JA Solar was the lead customer and co-developer of Dupont's passive emitter silicon ink.

[31] The information mentioned is found on the IMS Research website previous cited at: http://www.pvmarketresearch.com/free-resources/research-data.php#Chinese%20Module%20Supplier%20Gross%20Margins%20&%20Net%20Margins

[32] "Analysts say solar power company Suntech's debt may be insurmountable," *Renewable Energy World*, October 10, 2012 (http://www.renewableenergyworld.com/rea/news/article/2012/10/analysts-say-solar-power-company-suntechs-debt-may-be-insurmountable)

[33] Applied Materials reports that 90 percent of its PV customer base is in China.

[34] US International Trade Commission, "Crystalline Silicon Photovoltaic Cells and Modules from China," Investigation Nos. 701-TA-481 and 731-TA-1190 (Final), Publication 4360, November 2012.

[35] "EU initiates anti-dumping investigation on solar panel imports from China" http://europa.eu/rapid/press-release_MEMO-12-647_en.htm?locale=en

[36] Chinese industry statement, November 1, 2011, available at: http://www.pv-tech.org/assets/documents/CSPV_Cell_Industry_Association_Statement_(English)_CREIA_(2).pdf. For the US position, see: US International Trade Commission, "Crystalline Silicon Photovoltaic Cells and Modules from China," Investigation Nos. 701-TA-481 and 731-TA-1190 (Final), Publication 4360, November 2012.

[37] Chinese Ministry of Commerce Statement, November 23, 2012, *New Policies Support Ailing Solar Industries*. Available at: http://english.mofcom.gov.cn/aarticle/newsrelease/counselorsoffice/westernasiaandafricareport/201210/20121008404784.html

[38] http://www.china.org.cn/business/2012-09/03/content_26410601.htm

[39] Michael D. Platzer, *US Solar Photovoltaic Manufacturing: Industry Trends, Global Competition, Federal Support*, Congressional Reference Service, June 13, 2012. Available at: http://www.fas.org/sgp/crs/misc/R42509.pdf

[40] The 2008 economic crisis made the ITC less attractive to solar developers as there were fewer tax equity investors that could benefit from the value of the incentives. In 2009, as part of ARRA, the ITC was modified and a new program was adopted which provided a new tax option for solar power developers: a direct cash grant, which may be taken in lieu of the federal business energy investment tax credit that they were otherwise entitled to receive.

[41] http://www.eia.gov/analysis/requests/subsidy/pdf/subsidy.pdf

[42] http://www.dsireusa.org

[43] See the website giving a Database for Energy Efficiency and Renewables. Also Richard Schmalensee, *Evaluating Policies to Increase Electricity Generation from Renewable Energy*, Review of Environmental Economics and Policy, 6, pp. 45–64, (2012). doi:10.1093/reep/rer020 Available at: http://reep.oxfordjournals.org

[44] Export-Import Bank of the United States, "Ex-Im Bank Announces over $455 Million in Project Financing for First Solar's Exports to Canada," press release, September 2, 2011, http://www.exim.gov/newsandevents/releases/2011/ex-im-bank-announces-over-455-million-in-project-financing-for-first-solars-exports-to-canada.cfm

[45] Several interview respondents in Chinese industry and government circles described the state grid company in these terms. For an example in the oil and gas industry, see: Edward S. Steinfeld, *Playing Our Game* (New York: Oxford, 2012), pp. 175–217.

[46] Sara Schuman and Alvin Lin, "China's Renewable Energy Law and Its Impact on Renewable Power in China," *Energy Policy* 51(0): 89–109.

[47] For example, see: Weiping Hu, "Introduction to the 11th Five Year Plan on Energy Development," Bureau of Energy, China National Development and Reform Commission, Sept. 10, 2007.

[48] Authors' discussions with global PV equipment suppliers and Chinese PV industry associations, Beijing, December, 2012.

[49] Climate Policy Initiative Report, *Survey of Photovoltaic Industry and Policy in Germany and China*, Thilo Grau, Molin Huo, Karsten Neuhoff, March 2011. Available at: http://climatepolicyinitiative.org/beijing/files/2011/03/PV-Industry-Germany-and-China.pdf

[50] Kan Sichao, *Chinese Photovoltaic Market and Industry Outlook (Part 1)*, IEEJ Energy Journal, Vol. 5, No. 2, 2010. Available at: http://www.eaber.org/sites/default/files/documents/IEE_Sichao_2010.pdf

[51] http://www.bakermckenzie.com/files/Uploads/Documents/China%20Update%202012/al_china_nationwidesolarpowerprices_aug11.pdf

[52] An English translation of the plan is available at http://www.americansolarmanufacturing.org/news-releases/chinas-five-year-plan-for-solar-translation.pdf

[53] http://www.china-briefing.com/news/2012/09/19/china-releases-12th-five-year-plan-on-solar-power-development.html

[54] The DOE SUN SHOT initiative is described at https://www1.eere.energy.gov/solar/sunshot/mission_vision_goals.html

[55] Chemical and Engineering News, 90, page 22, December 10, 2012.

[56] Ninety percent of Applied Materials' customer base for PV equipment is located in China.

[57] For example, DOE announced $5 billion in loan guarantees for five PV projects in the Western United States: http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=17782

[58] It is important to emphasize the range of interpretation in the meaning of cost per peak watt. Comparisons require an understanding of technology difference, cost of capital, including inverters and other features required for user and or grid connection.

[59] Melanie Hart and Kate Gordon, *The Complexities of the US Decision on Chinese Solar Panel Imports*, The Center for American Progress, March 15, 2012. Available at: http://www.americanprogress.org/issues/green/news/2012/03/15/11330/the-complexities-of-the-u-s-decision-on-chinese-solar-panel-imports/

[60] EPIA *Global Market Outlook for PV until 2016*, Figure 12, page 21. http://www.epia.org/fileadmin/user_upload/Publications/Global-Market-Outlook-2016.pdf

Acronyms

AC	Alternate Current
ARPA-E	Advanced Research Projects Agency – Energy
ARRA	American Recovery and Reinvestment Act
BIPV	Building Integrated PV
CRS	Congressional Research Service
DC	Direct Current
DOC	Department of Commerce
DOE	Department of Energy
EIA	Energy Information Administration
EU	European Union
Ex-Im	Export-Import Bank
FIT	Feed-in Tariff
GW	Gigawatt
GW_p	Gigawatt-peak
IEA	International Energy Agency
ITC	International Trade Commission
kW	Kilowatt
kWh	Kilowatt hour
MOFCOM	Ministry of Commerce
MOST	Ministry of Science and Technology
MTC	Manufacturing Tax Credit
MW	Megawatt
MW_p	Megawatt-peak
NDRC	National Development and Reform Commission
NEA	National Energy Administration
PRC	People's Republic of China
PV	Photovoltaic
R&D	Research and Development
RD&D	Research, Development, and Deployment
REC	Renewable Energy Credits
RPS	Renewable Portfolio Standard
SCADA	Supervisory Control and Data Acquisition
SEMI	Semiconductor Equipment and Materials International
SGCC	China's State Grid Company
Si	Silicon
TTM	Trailing Twelve Month
USG	US Government
W_p	Watts-peak

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