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Broader Perspectives

The Chinese Silicon Photovoltaic Industry and Market: A Critical Review of Trends and Outlook

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With manufacturing capacity ranking number 5 in the world in 2005, China is rapidly emerging as an important player in the global silicon solar cell and module market. Production capacity has been growing by more than 70% per year over the last 7 years and future ambitious plans for the further expansion of the domestic production are likely to transform China in one of the largest (if not the largest) PV hubs in the world. However China's ability to fulfil its goals is challenged in the short term by a global shortage of silicon and in the medium to long term by the ability of the government to stimulate innovation and to introduce the necessary incentives to grow the domestic market significantly given that 80% of the production is currently exported to Germany and the USA.

The article addresses these issues by reviewing the recent technological and market trends in the Chinese PV industry. It also explains the major domestic manufacturing strategies and indicates the possible future direction of photovoltaic power generation in China. The study is based on personal interviews conducted in China from May to July 2005 with the major players along the solar supply chain, as well as with representatives of the Chinese photovoltaic R&D sector and policy makers. Copyright © 2006 John Wiley & Sons, Ltd.

KEY WORDS: silicon photovoltaic; photovoltaic industry; solar manufacturing strategies; future PV outlook; China

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INTRODUCTION

China is rapidly emerging as a photovoltaic (PV) producing country: in the first half of 2005 China's silicon (Si) PV manufacturing capacity ranked number 5 in the world[1] and one Chinese company, Suntech Power Co., is now among the top 10 cell and module world producers. This spurs a number

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of questions that need to be addressed to better understand the future development of the world PV industry and market:

1. Can China pose a competitive threat to other PV manufacturers in Europe, Japan or the USA?
2. Is China competing only on razor-thin margins because of its large pool of cheap labour, or is it moving rapidly up the technology and quality ladder?
3. Can China's PV industry sustain the current impressive rate of growth and if yes, under which conditions?
4. Is China willing to tap its own solar resources by promoting favourable conditions for the development of the internal market?
5. After Japan and Germany, will the next PV market be in China?

The article addresses these questions by using data and information collected by the author in China from May to July 2005 while interviewing senior figures of the major Chinese wafer, cell and module manufacturers, along with policy makers involved in renewable energy promotion and solar energy R&D representatives. The paper offers a comprehensive and up-to-date overview of the Chinese solar industry technology and innovation plans and potential, which have not been widely reported and analysed, and offers some reflections on key aspects of the future outlook. The article is organised as follows. The first part briefly describes the evolution of PV developments in China over a period of about 20 years. The second part provides an overview of the main technological trends, focusing in particular on R&D activities. The third part discusses manufacturing industry development and strategies, while the fourth focuses on the market. Future outlook and conclusions are discussed at the end.

Global solar energy demand has grown at about 25% per annum over the past 15 years.[2] In 2004 cumulative installed PV power in the IEA countries reached just under 2·6 GW[3] representing a 2076 MW increase on 1999 installed power figures (Figure 1).

The most important market drivers behind this rapid growth have been public programmes to stimulate on-grid installed capacity in domestic markets, especially in Japan and Germany (Figure 2).

The dramatic growth in the demand has been matched through time by an expansion of the solar cell and module production capacity (Figure 3). Maycock refers to a world PV cell and module production of 1195 MW in 2004 representing a 57% increase on the previous year (761 MW).[4] Half of the world's cell and module production originates in Japan where the national and local governments, the utilities and the PV manufacturers have all been actively working on the development of PV systems.[5]

Although the bulk of the remaining supply comes from Europe (mainly from Germany) and the USA, it is interesting to note that the manufacturing production of the rest of the world has been growing at an annual rate of 38%, the second fastest growth rate after Japan (50% annually since 1995).[6] Among the emerging producing

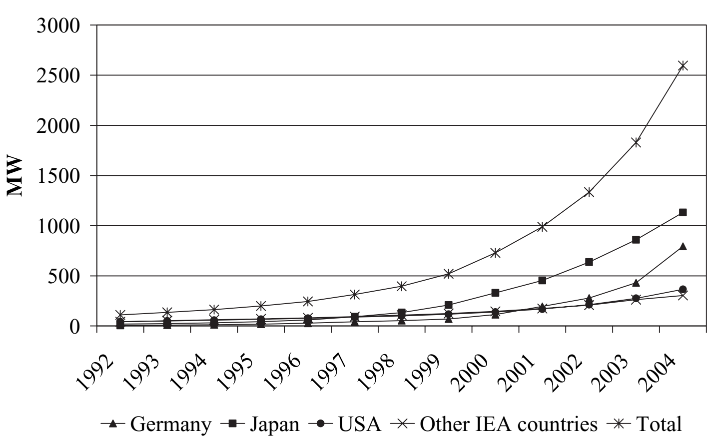

Figure 1. Cumulative installed PV power in IEA countries

Source: Based on data from IEA.[3]

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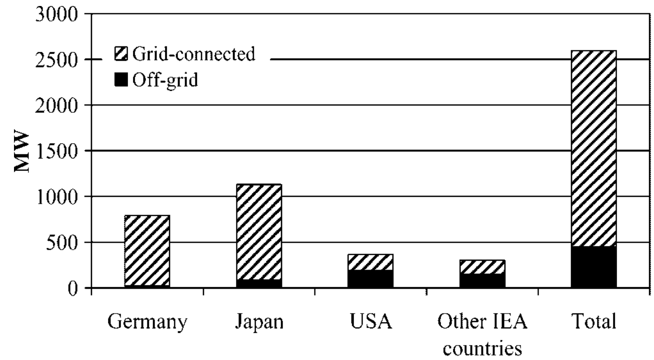

Figure 2. Cumulative installed PV power in reporting IEA countries as of the end of 2004

Source: Based on data from IEA.[3]

nations, China's silicon cell producers increased their capacity from 14 MW in 2003 to over 64 MW in 2004.[7] The outlook for 2005 may well be impressive if Si cell producers can achieve more than 257 MWp production capacity (as the expansion plans suggest) and module capacity could be close to 300 MW.

DEVELOPMENT OF THE PV INDUSTRY AND MARKET IN CHINA

Although research on PV in China dates back to 1958, it was only in the early 1970s that the first pilot space and terrestrial applications were launched.[8,9] The true manufacturing base was established in the late 1970s when three semiconductor plants in Ningbo, Kunming and Kaifeng were transformed into PV monocystalline silicon cells manufacturers with modified production lines for solar cell production.[10] Three other companies were established during the 1980s (in Beijing, in Qinhuangdao and in Harbin—the latter producing amorphous silicon).

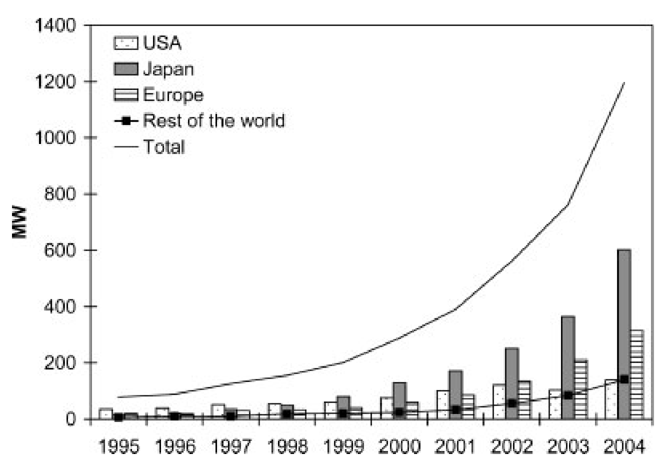

Figure 3. World PV cell and module production in 1995–2004 (MW)

Source: Maycock.[4]

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While a detailed account of the early developments of the Chinese industry can be found in several articles,[9,10] here we focus only on some key features of what can be called the first generation of Chinese solar cell and module producers:

- All companies established in the late 1970s and early 1980s were state owned (SOEs)
- All companies imported the whole production line or key equipment mainly from the USA (before 2000, China did not have the capacity for PV process equipment[8]).
- Only three of these first generation companies (the ones in Ningbo, Kunming and Harbin) are still producing solar cells and modules, though under different ownership.

This first generation of manufacturers was very dependent upon the central government's decisions and factories had neither the mandate nor the incentive to experiment with the technology and innovate.[11] According to Dai and Shi, although by 1995 China had six solar cell manufacturers with total designed production capacity of about 5MW per year, the actual production was much lower due to '[. . .] serious equipment bottlenecks in different parts of these production lines'.[10] During this first phase of China's silicon PV industry, increases in production capacity were modest and new entrants did not appear in the market until the beginning of the 2000s.

With the economic reforms implemented since 1979, involving the gradual dismantling of the centrally planned economy and greater integration with the world economy, a number of new actors have recently started to operate in the Chinese solar PV energy scene. Since the early 2000s several new silicon solar cell and module producers have emerged. This second generation of PV companies has several features that are distinct from the first generation companies:

- The companies are shareholdings with a private/public partnership.
- Most companies are domestic. Only one module producer (Kyocera-Tianjin) is a joint venture between Kyocera Corporation and Chinese Tianjin Yiqing Group (Holding Share) Co., Ltd.[12] Another, Canadian Solar Inc. (CSI), is a Canada based solar OEM (original equipment) manufacturer and application developer.[13]
- Some key production line equipment is still imported (but mainly from Europe and not only from the USA) but the rest is produced in China—in some cases according to the PV manufacturer's own design and requirements.
- All the producers are driven by global market demand and are not dependent upon the central government's priorities or decisions. The domestic market actually plays a marginal role in the sales of the domestic producers.

A distinctive feature of China's recent PV development, as will be explained in more detail later, is that the industry seems to be on a rapid growth track. This can be explained by the new inflow of key players in the market, but it is also rooted in a well consolidated tradition of experimenting with and producing, even on a small scale, silicon solar cells and modules. New entrepreneurs, who in some cases gained their education and experience abroad, are then operating in an environment where R&D on PV technology has a long standing tradition and where they can count on existing expertise.

RECENT R&D AND TECHNOLOGICAL TRENDS

The central government supports R&D in renewable energy through the National Development and Reform Commission (NDRC) and the Ministry of Science and Technology (MOST).[14] MOST is responsible in particular for the 863 Programme, aimed at supporting R&D in high technology, and for the 973 Programme meant to support basic research to meet the nation's major strategic needs.[15]

According to a senior government official recently interviewed in China, during the 10th five year plan (2001–2005) MOST, mainly through the two mentioned programmes, provided 50–60 million RMB (5·2–6·2 million €) for PV research, development and demonstration projects (PV RD&D). The public budget

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for PV RD&D and demonstration for the next 11th five year plan (2006–2010) may well be, according to the same source, in the region of 120 million RMB (12·4 million €). As a comparison, in 2004 alone, Germany devoted a budget of 24·4 million € to RD&D in PV while Japan spent 147 million.[16]

The strategic approach for PV R&D in China focuses mainly on the materials used in PV cells and in the accompanying manufacturing process. Zhao[17] and Yang[8] offer a comprehensive overview of the main PV R&D activities currently underway in China.

Of all the materials under development to produce solar cells (mono- and poly-crystal silicon, amorphous silicon, CdTe, CIGS, GaAs and polymers) only two have reached the stage of considerable industrial production, namely mono crystalline silicon (mono-Si) and polycrystalline silicon (poly-Si). Amorphous silicon (a-Si) is also commercialised in China but has a much smaller market penetration: by the end of 2005, if all the production capacity expected can be achieved, it should account for less than 10% of China's total module capacity. In this respect China is in line with the global trend where technologies based on crystalline silicon account for 93% of the world market share.[18]

The cost of a PV system is determined by the module costs and by the costs of the balance of system, in which the other system components (such as inverters, batteries and control electronics) are included. Although the costs of the balance of system's components affect the overall costs for PV systems—they represent 25% of the installation cost of a small 3 kW grid connected system[19]—China's R&D emphasis in this field is less pronounced. Similarly, despite the need to expand the domestic market for solar electricity, China is apparently not trying to integrate the R&D effort in a broader strategy regarding energy policy and market deployment. As an example, although the world R&D community started recently to work on the adaptations of PV modules to facade elements (not only roof-top solutions),[20] this application does not seem to attract the attention of the Chinese R&D programmes and none of the interviews conducted with R&D representatives have highlighted a strong interest in it.

Talbes I and II show the cell and module efficiencies achieved in Chinese laboratories and industries and compare them with the results achieved in the world.

China's cell and module efficiencies have improved through time especially on the commercial side: Dai and Shi refer to a commercial module efficiency of 9–10% during the 1990s[10] significantly lower than the efficiencies shown in Table II. However the table suggests that a gap with the results achieved in laboratories across the world still remain.

China's limited investment in R&D, when compared to other countries, and strong focus on cell materials raise the question of whether China is well equipped to face the global challenge and will be able to foster the development of its own industry and market, as the following two sections discuss.

Table I. Best conversion efficiency of various solar cells developed in laboratories in China and in the world

Category	China		World	
	Efficiency (%)	Area (cm^2)	Efficiency (%)	Area (cm^2)
Silicon				
Mono-Si cell	20·4	4·00	24·7 ± 0·5	4·00
Poly-Si cell	16·0	4·00	20·3 ± 0·5	1·002
Si (thin film)	13·6	1·00 (on inactive silicon substrate)	16·6 ± 0·4 (thin film transfer)	4·017
III-V Cells				
GaAs (crystalline)	21·9	1·00	25·1 ± 0·8	3·91
Thin film chalcogenides				
CIGS (cell)	12·1 *CIS (Cells)*	1·00	18·4 ± 0·5	1·04
CdTe (cell)	13·36	0·5	16·5 ± 0·5	1·032
Amorphous Si				
Si (amorphous)	8·6	100	9·5 ± 0·3	1·070

Source: China's cells efficiency in laboratory: REDP;[21] world's solar cell efficiency: Green *et al.*[22]

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Table II. Commercial solar PV module efficiency in China and in the world

Category	China		World	
	Efficiency (%)	Module (model and dimensions)	Efficiency (%)	Module (model and dimensions)
Mono-Si module	14	Suntech STP175S-24/Ab, 1580 × 808 × 50 mm	14·2	Sharp NT-185-U1, 1575 × 826 × 46 mm
Poly-Si module	13	Suntech STP060-12/Nb, 995 × 453 × 30 mm	12·6	Sharp ND-167U1, 1328 × 1004 × 46 mm
a-Si	5	Soltech PVS 60-24, 1549 × 787	5	RWE SCHOTT Solar ASITHRU-30-SG, 1000 × 600 mm

Source: PV module manufacturer's product specification on their corporate websites[23,24,25,26]
Note: Efficiency was calculated as module power divided by total module area

CURRENT STATUS OF THE SILICON PV INDUSTRY IN CHINA AND MANUFACTURERS' DEVELOPMENT STRATEGIES

Since the early 2000s, when two new Si cell and module manufacturers, Suntech Power and Tianwei Yingli New Energy Resources, began production, China's PV cell and module production has been growing rapidly. Figure 4 shows the evolution of both the total Chinese PV production capacity and the production only for the domestic market, together with the growth of global production capacity. The previously mentioned take off of the Chinese PV industry is clearly visible in the figure and seems to follow the global trend quite closely but with a noteworthy difference: while global PV production has been growing at an average annual rate of 36% since 1997, the annual growth of production capacity in China has been nearly double this, 70%, during the same period.

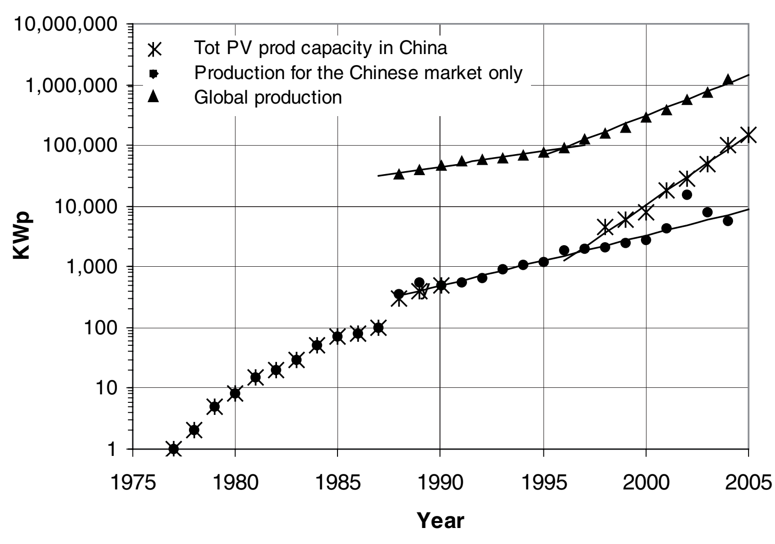

Figure 4. China: total PV production capacity (asterisks) and production only for the domestic market (small dots) compared to global production (triangles)

Source: Compilation of data from: Ma and Xu[27] for China's early total production capacity; Maycock,[28] for global production; REDP,[21] for domestic (no export) market production; Zhao,[7] for 2005 China's total production capacity.

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Another striking fact emerging from the data plotted in Figure 4 is the existence of a growing gap between the real production sold in the domestic market and the industry's production capacity. As the following section explains, on average 80% of the modules produced in China are exported.

We now look more closely at China's silicon PV production chain and at the main manufacturers' strategies, which are likely to guide the industry's development in the near future.

In China solar presence on the value chain is from wafering to cell production, module assembly and PV system installation.[21] Table III, compiled by the author from information collected during interviews and several other sources, provides an overview of the main players in 2005, and indicates where they are active in the value chain and what products they offer. A map of the location of the main players can also be found in Figure 5.

The domestic industry is currently unbalanced and a fairly high capacity in module assembly outweighs a very limited production of solar wafers, as shown in Figure 6.

Silicon feedstock

China's PV industry depends almost entirely on imports of silicon feedstock from abroad. Despite having a domestic semiconductor industry that supplies electronic grade silicon, its production capacity is very limited (less than 200 tons/year) and almost entirely devoted to the integrated circuit industry.[21,29] Currently between 30 and 40 tonnes/year of the domestically produced silicon feedstock is for the internal PV market; this translates to a mere 3 to 5 MW of crystalline Si solar cell production.[21,29,30] Some relief from the heavy dependence on imported feedstock could come between 2007 and 2010 as a consequence of a planned expansion of the domestic silicon production capacity in Leshan, Sichuan province and Luoyang, Henan province (Talbe III). By that time it is expected that capacity for silicon feedstock will reach 1500 tons/year.[30,31] However domestic capacity may well be higher if two other producers, China Silicon High-Tech Company and Wangxiang Guifeng Electronics Co., Ltd start producing silicon feedstock, as suggested by an anonymous referee. It remains to be seen how much of the expected expansion in production will go to the PV industry and how much will be provided to the national and international integrated circuit industry.

Wafer production

There are fewer than 10 mono (mono-Si) and polycrystalline (poly-Si) wafer manufacturers in China with a total capacity of 71·5 MWp by mid 2005. They are unable to satisfy the domestic cell demand not only because their capacity is fairly limited, but also because, as noted, less than 20% (between 15 and 20 MW) of their wafers are for the internal market.[29,30] The bulk of the production, as in the case of Ningjin Songgong Semiconductor Company (Talbe III), is exported mainly to Japan. Two wafer producers, Ningbo Solar Electric Power and Tianwei Yingli New Energy Resources, are vertically integrated companies and are present along the production chain from wafers to module assembly. In this way they can secure wafer supply to their cell plants. While Ningbo's mono crystalline wafer capacity is only 1 MW,[29,30] Tianwei Yingli is expecting to have, at the beginning of 2006, a wafer capacity of 70 MWp that will feed into its expanded cell production (from 6 MWp in 2005 to 60 MWp in 2006). A new independent wafer producer, LDK Solar Hi-Tech Co., Ltd., is also due to come fully on line with 75 MWp of polycrystalline solar wafers in March 2006.[32] Furthermore, according to a recent report by Wang Sicheng two other companies, Jinggong Solar in Zhejiang and Changzhou Trina Solar Energy Co., Ltd in Jiangsu are expected to have a wafer capacity of 10 MW and 25 MW respectively by 2006.[30]

If all the production capacity expected for 2006 is to be realised, by the end of next year China might have a total solar wafer production capacity of 250 MWp. The new capacity additions in wafer production may well help in re-balancing the domestic supply chain that is currently skewed towards module assembly (Figure 6), and so ease the dependence on imports.

Cell production

Cell production in China has surged in the last year: from a 64 MW capacity in 2004 (56 MW of poly-Si and 8 of mono-Si)[29] to a probable 257 MW at the end of 2005. This is due to both the expansion plans undertaken in 2005

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Table III. China: main PV producers and their activities along the value chain

ID	PRODUCERS	LOCATION	PRODUCT TYPES AND YEARLY PRODUCTION CAPACITY (2005)									
		(city and province)	Silicon feedstock (Tonnes)	Wafers (MWp)		Cells (MWp)			Modules (MWp)			
				mono-Si	*poly-Si*	*mono-Si*		*poly-Si*	*mono-Si*		*poly-Si*	*a-Si*
1	CSI Solar Technologies Inc.	Suzhou—Jiangsu								15		
2	Emei Semiconductor Materials Factory	Emeishan—Sichuan	20									
3	Harbin-Chronar Solar Energy Electricity	Harbin—Heilongjiang										
4	Hope Industry and Trade Co.	Beijing							4		4	
5	Kyocera (Tianjin) Solar Energy Co.	Tianjin								12		
6	LDK Solar Hi-Tech Co., Ltd	Xinyu—Jiangxi			75 (in March 2006)							
7	Luoyang Zhonggui Material Co., Ltd	Luoyang—Henan	20 (300 under construction)									
8	Nanjing PV-Tech Co.	Nanjing—Jiangsu					30					
9	Ningbo Solar Electric Power Co.	Ningbo—Zhejiang		1		50			50			
10	Ningjin Songgong Semiconductor Co.	Ningjin—Hebei		50								
11	Shanghai Solar Energy S&T Co.	Shanghai				10				10		
12	Shanghai Topsola Group	Shanghai				10			30			
13	Shenzhen Jiawei Industries Co.	Shenzhen—Guangzhou								2		
14	Shenzhen Nenglian Electronic Co.	Shenzhen—Guangzhou								2		
15	Sichuan Xinguang Silicon Technology Co. Ltd..	Leshan, Sichuan	1260 (under construction)									
16	Soltech Corp.	Beijing								5		10
17	Suntech Power Co.	Wuxi—Jiansu					120			80		
18	Tianjin Jinneng Solar Cell Co.	Tianjin										8
19	Tianwei Yingli New Energy Resources Co.	Baoding—Hebei			6			6		15		
20	Xi'An Rew Co.	Xi'An—Shaanxi								30		
21	Xinri Silicon Materials Co.	Jinzhou—Liaoning		10								
22	Yunnan Tianda Photovoltaic Co.	Kunming—Yunnan		0·5			30			30		
23	Zhejiang Sino-Italian Photovoltaic Co.	Ningbo—Zhejiang			2							
24	Zhong Lian Solar Technology LTD Co	Beijing						1		1		
25	Other			2						17		6·5
	TOTAL CAPACITY		**40** (*used by the PV industry*)	**71·5** (*Domestic* available 15–20 MW)			**257**			**292**		**24·5**

Source: Compiled from information collected during 2005 interviews and from companies' web sites. For information on feedstock: Wang[30]

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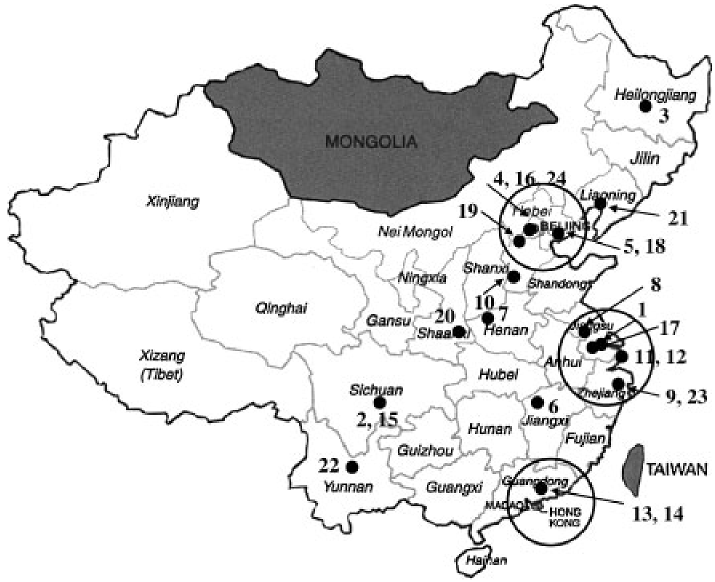

Figure 5. Map of China's main PV producers

Source: Information collected during interviews in China, May-July 2005.
Note: numbers in the map refer to ID numbers in Table III.

by nearly all the existing cell producers and the emergence of a new actor on the Chinese solar cells scene: Nanjing PV-Tech. Co., which will come on line with 30 MW by the end of 2005. At present the largest cell manufacturer (producing both mono-Si and poly-Si) is Suntech Power with a capacity of 120 MW. As will be discussed later, manufacturers are planning to further expand their cell production capacity from 2006 to 2008.

Module production

Module production in China offers a more scattered picture, with a lot of producers with less than 5 MW production capacity. Total module production capacity should reach nearly 300 MW by the end of 2005. Currently

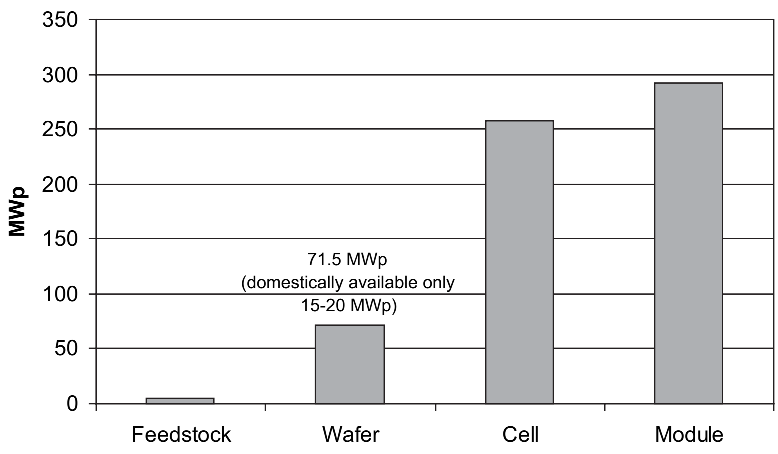

Figure 6. China: capacity along the crystalline silicon production chain (2005)

Source: Wang[29] for data on feedstock and wafer production. Cell and module data were collected by the author during interviews in China, May-July 2005.

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the largest module producer is Suntech with a capacity of 80 MW, but it might well be overtaken at the beginning of 2006 by Tianwei Yingli which is completing a new line with 100 MW production capacity. The multitude of module producers with limited production capacity is not surprising. Assembling cells into modules does not require the same level of technical expertise needed in cell production and putting in operation a module assembly line is technically easier and faster than setting up a cell production line. This is particularly true if the module assembly line is partially or even fully manual, which is often the case with Chinese module producers.

As Table III shows, the vast majority of modules produced in China are based on crystalline silicon and only a very limited number of producers specialise in amorphous silicon modules.

Manufacturer's strategies

Chinese PV manufacturers are developing a number of strategies to remain competitive in the global PV market.

Expansion of production capacity

As highlighted in the previous section, several Chinese PV manufacturers have just expanded their production capacities or are planning to do so in the next three years. Figure 7 provides an overview of what silicon cell production capacity might look like in 2008, according to the plans for future expansion capacity recently announced by a number of cell producers.

It is worth noting that at the end of 2005 China's cell production capacity may well be greater than that of the United States (171 MW in 2004) and in 2006 may overtake the European cell producers' capacity (425 MW in 2004).[33] However China's ability to fulfil its capacity expansion goals will depend on a number of factors, including the availability of silicon feedstock, which is currently in short supply.

Silicon wafer capacity is also planned to increase by 2008 and it might well exceed 800 MW if the expansion plans of Tianwei Yingli and LDK Solar Hi-Tech alone are completed on time.

The expansion of Silicon module capacity was much more difficult to assess not only because producers are numerous and scattered across the territory, and so it was impossible to interview all of them, but also because the majority of the companies interviewed declared that expanding module capacity is easier and less capital intensive than expanding wafer or cell capacity and so a careful planning of expansion in this segment of the production chain is not necessary.

From a strategic point of view, Chinese PV manufacturers have been responding to the challenge of rapidly rising global solar electric demand (especially in Germany), by ramping up production capacity. In particular,

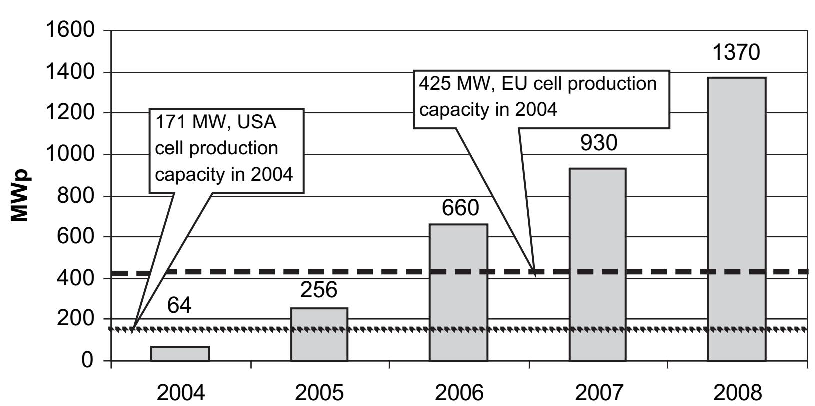

Figure 7. China: current and expected PV cells production capacity

Source: compiled from data obtained from interviews in China, May-July 2005. Data for EU and USA capacity obtained from IEA-PVPS.[33]

Note: if companies did not declare expansion plans for the following year it is assumed that the production capacity remains the same as in the previous year.

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Chinese producers are trying to position themselves among the top world producers in terms of capacity expansion and market shares. This is also testified by the fact that an increasing number of Chinese firms have been attending PV conferences and fairs around the world in the past two years.

Another reason behind the expansion capacity underway in China is the attempt to reduce the costs of production. There are several studies[34,35] that testify how cost reductions in manufacturing are closely associated with high production volumes, sustainable markets and technological advances. During the interviews it appeared clear that companies with a production capacity under 10 MW are struggling not only to cut down costs and then to compete with domestic silicon producers with larger production capacity, but also to secure feedstock and other production materials (glass, ethylene-vinyl acetate–EVA–sheets for encapsulation of solar cells, etc.) at discounted prices.

Cost reduction and higher value added

Labour cost is a particularly important variable in those labour intensive activities along the production line, such as module assembly. To save on the overall cost of production Chinese silicon manufacturers are making the most of the domestically available cheap labour by operating nearly entirely manual module assembly lines. This strategy, that proved successful while China's production capacity was skewed towards module production, is now being rethought. Companies are planning to expand their businesses to cell and wafer production in order to reap higher returns in premium markets where there is still limited capacity in China. Cheap labour in these activities is less important and cost reduction in more high-tech manufacturing activities becomes hence more relevant. This will partially come along with expanded production capacity volumes but can also be achieved by improving production and reducing the initial capital costs of the production line. Interviews with silicon manufacturers indicated that they can save up to 70% of what their foreign competitors spend if they buy part of the production line equipment in China or if they are able to design and produce some of the machines by themselves (the etch station, used for cell surface etching, is a good example of this). Chinese PV producers are engaging in the transition to higher value added by activities passing from the simple, labour-intensive parts of the industry to more profitable areas where more advanced technological capabilities, product design and marketing skills are crucial.

R&D and quality standards

In-house R&D plays a strategic role in enhancing the technological capabilities and the competitiveness of the silicon cell and module producers in China. On average the companies interviewed devote 10% of their annual turnover to R&D activities (with the exception of one company that, despite its very limited production capacity of 1 MW, is investing more than 50% in R&D) and tend to have links with universities and research institutes. The main purpose of engaging in R&D activities is not only to modify existing products/process (improvement of high cut-speed processes on wire saw squarer/bricketers is a good example) but also to focus on independent design and equipment or product development capacity. One company has for instance patented its own technology to produce a fine textured surface on the crystalline silicon, thus increasing the cell efficiency.

The importance attached to in-house R&D is only one way to address quality issues and to add value beyond cheap labour. In order to get access to target export markets, Chinese silicon cell and module producers have also the strategic need to meet critical standards and specific quality requirements. For this reason the vast majority of the companies interviewed have obtained the international certifications needed to gain product acceptance in European and American markets, i.e. IEC, for the performance of the components in PV modules, TUV, to ascertain the safety of the modules, CE, to declare conformity to the relevant EU directives, etc.

THE MARKETS

Despite the potentialities offered by the internal market in terms of possible applications, both off- and on-grid, and by solar resource endowments, the solar domestic market is still only partially exploited and cell and module producers prefer to export their products to reap greater profits abroad.

As noted, interviews with the main producers highlighted that on average 80% of the domestically produced modules are exported. The main destination markets are in Europe (mainly in Germany), in the USA and to a

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lesser extent in other countries in Asia, with Japan's market playing only a marginal role despite the explosive growth of installed capacity in recent years. Although it is difficult to assess the exact share of the Chinese solar products going to different world markets, it is interesting to note that exports by Chinese Si module manufacturers may well have contributed to the rapid expansion in PV installations in Germany (794 MWp of total installed capacity at the end of 2004[36]). The PV Status Report for Germany, prepared by the IEA, emphasises that although the percentage of German modules used in the 100,000 roofs programme (which ended in 2003) has increased, still about 60% of the modules installed are imported.[37] Although it is not known how much of this 60% can be ascribed to Chinese producers, it is interesting to note how the high German subsidies are indirectly supporting foreign producers.

Although PV silicon producers are for the time being more interested in exporting their products, the Chinese government has implemented a number of schemes (and will continue to do so) to increase domestic solar installed capacity. At the end of 2004 the total PV installed capacity was about 60 MWp and the price of domestically produced modules was about 25–30 RMB/Wp[21] (2·60–3·1 €/Wp) (Figure 8).

In contrast with what is happening in the global PV market (see Figure 2), in China installed capacity has been driven by off-grid applications. In 2003, according to the report published by China Renewable Energy Development Project (supported by the Chinese Government, the Global Environment Facility and the World Bank), the rural PV market accounted for 28 MW, i.e. more than half of the total installed capacity[21] (Figure 9).

The main reason for this is a combination of the distribution of solar resources across the territory and domestic demand. Although China, as a country, is relatively rich in solar resources, some parts of the Western provinces (namely the west of Tibet, north of Ningxia, north of Gansu, east of Xingjiang and west of Qinghai) have the most abundant solar resources.[21] These provinces are also those where the majority of households with no access to the electricity grid are located. Chinese sources estimate that there are about 28000 villages and 7 million rural households (roughly 3·6% of the total population)[38] that could benefit from de-centralised energy systems based on renewable sources of energy such as solar and wind. This combination of factors is

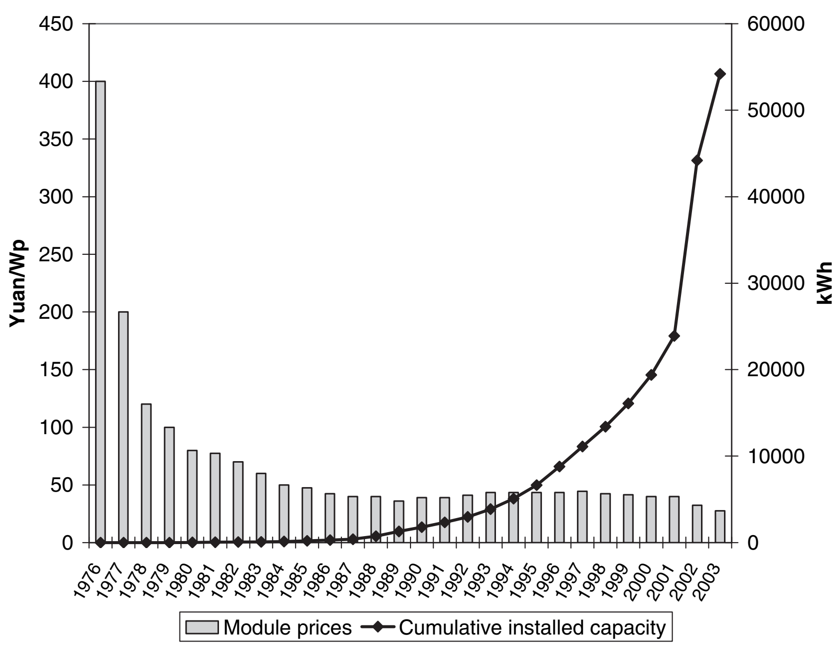

Figure 8. China: total PV installed capacity and module prices
Source: REDP.[21]

Note: module prices refer to Si-c modules only.

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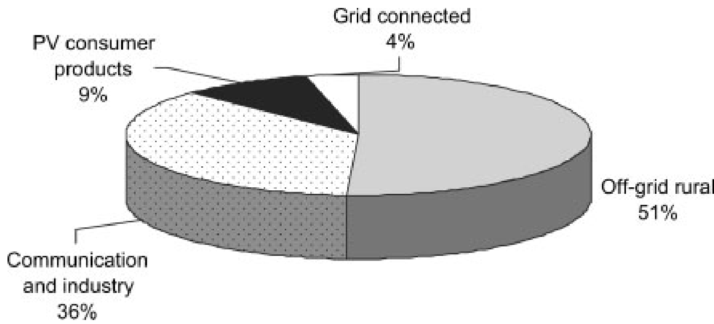

Figure 9. China's PV market shares by application in 2003

Source: REDP.[21]

the main reason behind the Government's rural electrification programme launched in 1998 and better known under the name of the 'Brightness programme'. The overall target of the programme is to provide electricity for 23 million people in remote areas by 2010 using PV modules and wind power systems.[39]

The Township Electrification Programme and its follow up, the Village Electrification Programme, are two other schemes that the Government has adopted and will adopt from 2006 onwards to provide electricity access via solar energy to remote rural areas.[40] If the government's rural installation schedule is going to proceed according to plan, by 2010–2015 all Chinese households should be electrified. This may well spur the government to promote comprehensive strategies to sustain the domestic PV market after 2015 and the solution is quite likely going to be in the on-grid market. With this in mind, together with the need to meet the increasing energy demand while reducing the energy-related emissions, in February 2005 the Standing Committee of the National People's Congress passed the Chinese Renewable Energy Promotion Law which is expected to enter into force sometime in 2006.[41] Although the new law will probably provide an impetus to installed capacity from renewable energy sources, the exact role that PV is expected to play in terms of installed capacity and applications is still unclear (this is discussed in more details in the future outlook paragraph below). Moreover, although a number of the interviewed policymakers and solar energy experts believe that a feed-in tariff scheme similar to the German one will be adopted to stimulate domestic on-grid solar electricity demand, a recent article by Photon International seems to point in a different direction. According to the journal, which quotes the director of renewable energy at the National Development and Reform Commission (NDRC), Shi Lishan: '[. . .] China has decided that grid-connected PV is too expensive for incentive support, with projects only being considered on a case-by-case basis'.[42] For the time being the main confirmed plan regarding PV is the completion of the already mentioned rural electrification programmes.

Some smaller scale initiatives to stimulate on grid PV capacity exist and are summarised in Talbe IV. These include: a 100,000 solar roofs initiative in Shanghai, an 8 MW solar energy power plant in the Gansu desert and several solar initiatives to be promoted during the Beijing Olympics in 2008. Table IV also provides benchmarking information on programmes implemented in Japan and Germany that currently represent the upper end of active PV policymaking.

SOME THOUGHTS ON THE FUTURE OUTLOOK

According to the Chinese Electrical Power Research Institute (CEPRI) China's electricity demand is expected to rise 5·6% annually, from 357 GW capacity in 2002 to 950 GW in 2020.[21,29] Since conventional energy sources (i.e. coal, nuclear and hydro) will not be sufficient to satisfy the increasing demand, renewable energy sources (i.e. biomass, PV, small hydro and wind) are expected to fill the gap and to provide nearly 11% of the total electricity needs by 2020 (Talbe V). Although a more recent figure by CEPRI seems to suggest that the gap

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Table IV. Main policies to promote PV installed capacity: China vs. Japan and Germany

CHINA

Main current PV activities

- 1996–2010. *Brightness Programme*: goal is to provide 100 watts of capacity per person to ≈23 million people with de-centralised energy systems based on solar and wind.
- 2002–2004: Township electrification programme (part of the Brightness Programme). Rural electrification based on PV, wind and small hydro. Subsidy (208 million € in total) on the capital cost of equipment. Total installed PV capacity at the end of the programme in 7 western provinces is about 20MWp.

Other PV activities

- 2006 (?). Village electrification programme (a follow up of the Township programme). Electrification of 20,000 villages in China's off-grid western provinces. 300MWp are expected to be installed. Total budget about 20 Billion RMB (2 Billion €)
- 2006. *China Renewable Energy Promotion Law* comes into effect: will there be a feed-in tariff for PV?
- 2006. *On-grid roof-top* plans in some cities/municipalities (i.e.100,000 roofs in Shanghai and 1,000-rooftop PV programme in Wuxi). Subsidy on the installation equipment.
- *On-grid PV in the Gobi desert* (Gansu province): feasibility study under way for 8 MWp to be installed
- *PV for the 2008 Beijing Olympic Games*. Road lamps, lawn lighting facilities, lamps for public lavatories and irrigation

Installed PV capacity 2004: 60 MW
Expected installed capacity in 2010: 400 MW
Cell production capacity 2004: 64 MW

GERMANY

Main current PV activities

- 2000. Renewable Energy Sources Act (EEG). Feed in tariff—annually decreased by 5%—for PV fed into the grid: 0,457 €/kWh. An extra bonus for small PV systems and PV building integrated is also granted. Around 300 MW installed in 2004

Other PV activities

- Some programmes defined by the Federal States (Länder) to support the application of renewable energy and energy conservation.
- Initiatives to build PV-demonstration and pilot systems launched by a number of utilities

Installed PV capacity 2004: 794 MW
Expected installed capacity in 2010: 1 GW
Cell production capacity 2004: 198 MW

JAPAN

Main current PV activities

1994. Residential PV System Dissemination Programme. Decreasing subsidy through time on the PV installation cost (645€/kW in 2003). Over 200·000 grid-connected residential home systems installed from 1994 to 2004 (corresponding to over 800 in total MW)

Installed PV capacity 2004: 1132 MW
Expected installed capacity in 2010: 5 GW
Cell production capacity 2004: 604 MW

Source: for programmes, installed and production capacity in China: Ma,[43,39] Wang,[29] Zhu,[41] Liu;[44] for programmes, installed and production capacity in Germany: IEA-PVPS,[37] Maycock,[45] European Commission;[46] for programmes, installed and production capacity in Japan: Ikki,[5] Maycock.[47]

Table V. China: electricity generation capacity by type of fuel in GW and as a percentage of total generation (2002 and projection for 2010 and 2020)

Mode of electricity generation	2002		2010		2020	
	GW	%	GW	%	GW	%
Coal	266	74·5	400	68·40	592	62·3
Hydro	86	24·1	135	23·10	220	23·2
Nuclear	4·5	1·3	12·5	2·10	36	3·8
Renewables	0·5	0·1	37	6·40	102	10·7
Total	357	100	584·5	100	950	100

Source: REDP,[21] for 2010 and 2020 projections; Wang,[29] for 2002 data.

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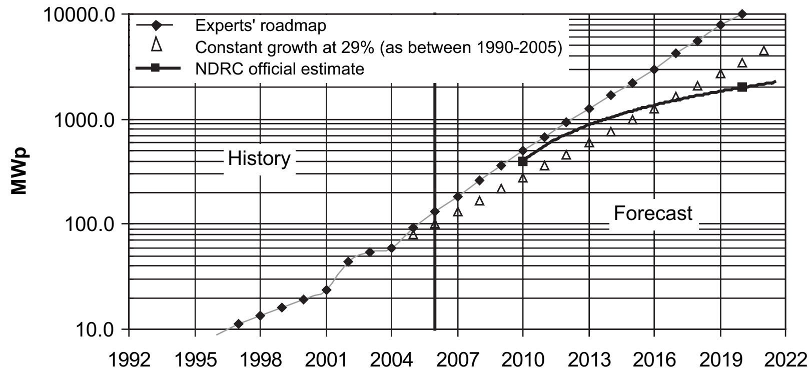

Figure 10. Three possible scenarios for China's PV cumulated installed capacity

Source: for experts' roadmap, Wang,[29] Zhao;[7] for NDRC official estimate, Wang.[30]

to be filled by renewables in 2020 may be smaller (8·2%) due to a larger role to be played by gas generation of electricity,[30] the government's commitment towards a greater reliance on renewable energy by 2020 seems firm.[48]

What the role of PV in closing this gap in power requirement will be remains an open question. Solar energy R&D representatives and experts interviewed in China seem to believe that a 41% per year expansion of PV installed capacity until 2010 followed by a 36% rate of growth until 2020, can be achieved.[7,29] This would bring PV from its current level of 60 MW to 500 MWp in 2010 and 10 GWp in 2020[29] (see Figure 10). A similar optimistic view appears in the World Bank REDP report where cumulated PV installations are expected to reach 30 GWp in 2020 and 100 GWp by 2050.[21] However, a recently published report suggests that the National Development and Reform Commission (NDRC) might have far less ambitious expectations, not as much as for the short term, where 400 MWp by 2010 are foreseen, but for the medium term where only 2 GWp by 2020 are expected.[30]

This new possible scenario seems to be in line with the previously mentioned NDRC's decision not to include PV in a feed-in tariff scheme and casts doubts on the government's will to tap its solar resources and to create a substantial domestic market.

If the experts' roadmap, which is quite likely based on the expectation of a long term feed-in tariff for PV, appears to be ambitious, the new government's forecast for 2020 appears even lower than what would be achieved by following the current business as usual scenario. It is worth noting that the total internal installed capacity has grown at a constant rate of less than 29% between 1990 and 2005. If this trend is confirmed during the next 10 years, the total installed capacity would reach 1 GWp in 2015 and would fall just short of 3·5 GWp by 2020. Figure 10 summarises the three possible scenarios.

The above figures seem to suggest that the very ambitious growth targets set by the PV industry for the following years might not be matched, at least for the time being, by a significant market pull on the part of the government. If the plans are going to proceed as scheduled, China could well have a Si cell production capacity of 1370 MW by 2008 but have installed only between 400 and 500 MW of solar electricity by 2010. This might well transform China into one of the largest (if not the largest) PV producing countries in the world. Indeed, if the trends for the Chinese and the global production capacity already presented in Figure 4 are extrapolated assuming the same rate of growth as in the last ten years, China's production is set to saturate the global market by 2015 (Figure 11). This trend seems hardly sustainable in the absence of new global solar electricity markets and in particular of the taking off of the domestic market.

The ability of China to scale up its production capacity and to create its own internal PV market is challenged by a number of issues that would need to be properly addressed in order for China to fulfil its ambitions.

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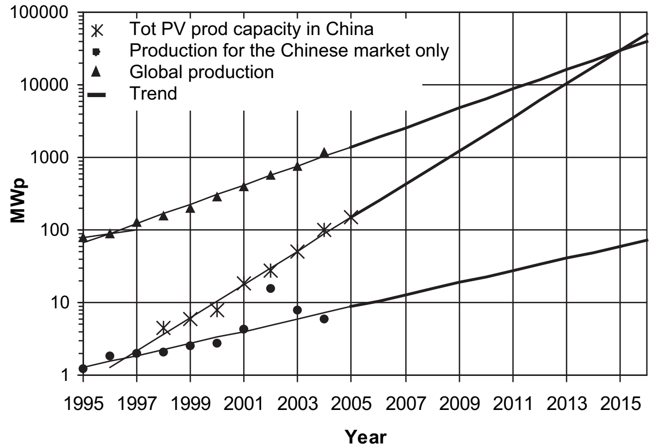

Figure 11. Extrapolation of the consolidated PV production capacity trend in China over the last 10 years

Source: Author's elaboration on the following data: Ma and Xu;[27] Maycock;[28] REDP;[21] Zhao.[7]

Supply challenges

1. Feedstock requirements

The rapid increase in global solar electricity demand in the past few years (world cell production increased by 57% in 2004 to reach 1194 MWp[36]) has put a strain on the availability of pure silicon, which is used by the PV industry as feedstock. Traditionally and until the solar electricity demand was limited, the solar industry has used the scrap from the electronic industry. However with the recent rapid increase in PV demand feedstock supplies are becoming tighter and with demand greater than supply in 2004, this shortage could prevent the sector from achieving its plans for expansion.

Sarti and Einhau[49] estimate that, depending on the technology used to produce wafers and cells, the silicon based PV industry requires between 15 and 20 tons of silicon feedstock to produce 1 MWp. According to these estimates the silicon feedstock requirements of the solar cell industry in China may have already increased considerably in the last year: from between 960 and 1280 tons, to reach a production capacity of 64 MW in 2004 to 3840–5120 tons at the end of 2005 if China is going to hit 256 MW by the end of 2005 (Figure 12).

However an even more impressive demand for silicon could be expected by 2008 if cell producers are to be able to fulfil their expansion plans. For a possible cell production capacity of 1370 MW, between 20550–27400 tons of silicon will be required (assuming that the hypothesis of 15 to 20 tons per 1 MW produced remains constant until 2008).

Rogol provides an estimate of the global Si feedstock to the solar sector until 2010.[50] According to his projections solar silicon supply will be in the region of 27000 tons by 2008, which is sufficient to accommodate only the expected expansion in Chinese cell production capacity.

Although it is quite likely that the 15 to 20 tons requirement per MW can be relaxed and that the Chinese industry will need less than 15 tons per MW produced (this can happen through a more rational use of silicon, by reducing the thickness of the wafers used to produce the cells or by recycling silicon from silicon containing waste[49]), it appears clear that the availability of silicon feedstock is bound to be a serious bottleneck in the future capacity of the Chinese PV industry to meet both export and domestic demand.

2. Investment requirements

Scaling-up production capacity requires heavy capital investment.

As a rule of thumb for the capital investment in building a crystalline silicon solar cell plant, Solarbuzz quotes 846·000 €/MW (US$1M/MW[51]), while the European Commission has a higher figure of

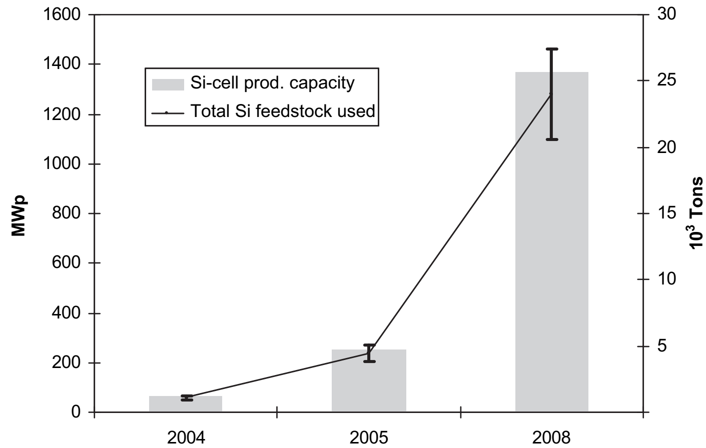

Figure 12. China: future Si feedstock requirements

Source: compiled from data obtained from interviews in China, May-July 2005.

1·5 million €/MW, which includes production equipment, building and infrastructure expenditures, electricity and gas supply, waste management supply, etc.[52]

Reaching an expected cell production capacity of more than 1300 MW by 2008 will then require substantial investment and willingness to take risks. For the time being the industry seems to be able to count on big inflows of private and public capital. It remains to be seen whether with the perceived uncertainty caused by a limited, and increasingly more expensive, feedstock and by a still underdeveloped market, investors will be willing to hold on to the solar electricity industry.

Demand challenges

As highlighted, the domestic industry is currently driven by the high level of global solar electricity demand and the vast majority of the modules produced in China are exported. This constitutes a potential weakness for the future development of the local industry, which is heavily dependent on the generous subsidies paid by some European countries and other government or international sponsored programmes. For this reason, and in view of a further expansion of the domestic production capacity, it would be crucial that the local market can take off to provide an alternative for local producers. In this respect the newly approved Renewable Energy Law could provide the necessary stimulus for PV to develop[53] but it seems that the government is not willing, at least for the time being, to provide a strong enough incentive by including PV in a possible feed-in tariff scheme.[42] Furthermore, as it is well documented by the experience accumulated in the EU, rapid expansion of renewable energy during the 1990s has occurred in those countries with long-established policies and long term legislative support[54] and these requirements seem to be lacking in the Chinese PV case.

The importance of consistent and long term policies is highlighted in Figure 4 and Figure 11 where a blip in domestic production occurred in 2002. In late 2001 the government launched the Township Rural Electrification Programme and in just 20 months, by subsidising the capital costs of the equipment, succeeded in installing 20 MW of PV.[39] The policy had a short term effect that lasted for the duration of the programme, but failed to have a long term impact on the industry that remained along the same growth path initiated in the late 1990s. On the positive side it is important to note how the industry was able to quickly react to the short term policy and to respond by reaching the installed capacity target set by the government.

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CONCLUSIONS

China has clear intentions to establish herself as a mass production hub for silicon PV: two clear indications in this respect are the domestic production capacity growth at double the pace of global capacity (Figure 4) and the ambitious capacity expansion plans for the coming years (Figure 7).

From a more qualitative point of view China is showing some interesting signs of improvement. Not only are manufacturers achieving cell and module efficiencies similar to those attained by international competitors (Table II), but they have also obtained international quality certifications in line with what is requested by importing countries in Europe and USA.

Moreover, the domestic producers seem willing to move quickly up the technological ladder by shifting their activities from labour intensive module assembly, where they can exploit their comparative advantage based on cheap labour, to more high tech and profit rewarding activities such as cell and wafer production.

In this respect this article suggests that China could represent a competitive threat to producers world-wide not only because by expanding production volumes it will probably be able to move down the learning curve and to cut down costs of production and hence to increase its competitive advantage, but also because it is moving towards higher value added segments of the production chain that have up to now been the nearly exclusive domain of foreign competitors.

However China's potential competitive threat and ultimately its ability to fulfil its production plans and ambitious targets are questioned by a number of challenges. In the very short term the main concern comes from the availability of silicon feedstock, expected to be in short supply at least until 2008, while on a medium to long term the major challenge will be the availability of a sufficiently big market to accommodate the expected expansion in Chinese and global production capacity.

The Chinese government has already proved with the Township Electrification Programme that it can attract domestic suppliers to increase PV installed capacity but it has also realised that it should provide a long term policy framework and interesting incentives if it wants to maintain domestic producers' confidence and persuade them to shift part of their production from high profit foreign markets to the internal market. For the time being neither the installed capacity that the government expects by 2020 (2 GWp) nor the limited measures in the pipeline for the following years, such as the roof top programme in Shanghai or the PV in the desert project, seem to suggest a government willingness to tap its own solar resources and to promote favourable conditions for the development of the internal market. Moreover, despite the great expectations that emerged during the author's interviews in China, it seems like the Renewable Energy Law will not provide a feed-in tariff for any kWh of PV fed into the grid. For the roadmap advocated by Chinese solar energy R&D representatives and experts to become a reality (10 GWp by 2020) a real step change would instead be needed. Considering the importance that public support is having in fostering PV in countries like Japan and Germany (Table IV), this apparent lack of interest on the part of the Chinese government will make the emergence of China as the next PV market quite difficult and ultimately cast doubt on the ability of domestic cell and module PV producers to fulfil their production plans.

Finally, when the drivers for innovation to stimulate a wider penetration of PV are considered, China's R&D spending might not be adequate. Although the public budget devoted to PV RD&D seems likely to increase in the next 5-year plan, China's spending lags well behind that of Germany and Japan. At the same time the RD&D effort seems mainly focused on advances in PV cell materials and related manufacturing technologies, while a stronger focus towards implementation and applications would be beneficial to foster market deployment and to bring China closer to its plan to become a world producer and market for PV technologies.

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