Chapter 5.
Suntech Power Case Study
5.1. Introduction

In this chapter, a case study on solar cell manufacturers Suntech Power in China is presented. The framework described in chapter 2 provides a structure that will be used to facilitate the enquiry of capability building within Suntech Power, a photovoltaic cell and module manufacturer in China. First producing photovoltaic cells in 2002, Suntech Power (Suntech) has grown rapidly to become the fourth largest producers of cells worldwide in 2006. This case study illustrates a successful company technology strategy in China, a country where the technological system for photovoltaics manufacture was in its infancy. The case study looks at the origin of the company, its technological progress and milestones, and the learning mechanisms utilised by the company over time. Suntech’s interactions with the technological system; the evolution of institutional environment and the structure of the industry and markets are also documented.

By comparing the way that capability building occurred in this case with the theoretical propositions embodied in the framework, explanations will be proposed for the success of Suntech and the Chinese innovation system that may be applicable more broadly.

Suntech was chosen as a revelatory example, since high levels of capabilities, including innovative capabilities for cell manufacture, have been rapidly and successfully built.

In section 5.2, the case study method is described. Background on the status of the PV industry in developing and industrialising countries is given in section 5.3. The historical development of the PV industry in China is described in section 5.4.

The development of Suntech, its expansion and the development of capabilities is outlined in sections 5.5 and 5.6. In section 0, the role of the Chinese innovation system in facilitating the success of Suntech is analysed.
5.2. Design of the Case Study Research

The research aims to identify the determinants of successful technological capability building in the manufacture of PV system components in developing countries. The focus of the research is at the enterprise level. How have enterprises built capabilities? Why have some been more successful than others?

Case study research and histories are deemed to be appropriate to explanatory studies where the questions of how or why something occurred are central to the research. Survey-based and archival studies, conversely, are most appropriate to questions of what, how many, how much (Yin, 1989). Case studies have been selected as the primary method in this research, since they enable an explanatory study of the capability building phenomenon at an enterprise-level. These case studies are designed to be what Stake (2000) calls instrumental, in that they facilitate understanding of a general case, and hence a step towards theory building.

The modern sector case study has been organised around a framework developed through a review of literature on technological capability building in industrialising countries, organisational learning, and innovation systems. This framework and the propositions arising from the framework are introduced in the following section of this document.

Preliminary Survey Design

A preliminary survey of modern-sector cell and module manufacturers in developing countries was employed to guide the case study research by providing some insight into what capabilities and external enabling factors are important (see Appendix ??).

Surveys and interviews are being carried out with module and cell manufacturers in industrialising countries in order to determine the technological capabilities of the firms, the barriers to competitiveness and the positive impacts that may be obtained through manufacturing domestically.

Measures used to estimate the overall technological capabilities of firms include: cell efficiency, production line yield, product and process certifications, number of tertiary educated staff, training of staff, the extent of technology generation and linkages with other organisations. Innovative effort and capacity is being assessed on the basis of R&D expenditures, the number of staff engaged in R&D and research linkages.

The importance of linkage capabilities and the nature of linkages and access to institutions available in developing countries are being assessed. Potential institutional barriers to competitiveness that are being considered include unfavourable conditions in business environments such as corruption, challenging administrative procedures and lack of access to infrastructure. The research explores potential advantages to manufacture in industrialising...
countries, including low costs of inputs to production, low wages and proximity to emerging markets.

There is insufficient data to make statistically significant conclusions as yet, but preliminary findings are noted in section ??.

## Case Study Design

The case study research comprised a number of structured and semi-structured interviews with the chief technical officer, the use of secondary sources of information that have documented technological milestones and progress, comments by Shi and Green and follow up questions to other key staff members.

Comparison of Suntech with other companies in China. Technology strategy, sources of knowledge, learning modes, inter-organisational relations.
5.3. The PV Manufacturing Industry in Developing and Industrialising Countries

Many multinational cell manufacturers are setting up operations, particularly module assembly, but also cell manufacture in developing countries, in order to potentially access markets in close proximity with reduced transportation costs; and to take advantage of cheaper labour and capital. BP Solar has a joint venture with TATA in India, and makes modules in China. RWE Schott Solar has a plant in the Czech Republic and Sanyo assembles modules in Mexico and Hungary. There are a number of other international manufacturers that assemble modules in India and China (Photon, 2006b). Kyocera has consciously pursued a strategy of globalisation, establishing local module production companies in Mexico, to supply the US market; the Czech Republic to supply the European market; and in China to access the growing Chinese market; while the Japanese plant will continue to supply cells to all the module assembly plants, and make modules for the Japanese market, which is one of the largest in the world (Kyocera, 2004).

16% of the manufacture of modules in 2004 listed in the Photon Magazine market survey (Schmela, 2005d) took place in developing countries, with the market share increasing to 26% in 2005. China has tripled its module production between 2004 and 2005 and Chinese firms are still ramping up capacity, the largest of more than 25 producers being Suntech Power, Shenzhen Jiawei, Ningbo Solar Cell Factory and Shanghai Solar. There is also significant expansion in production in Eastern European countries, mainly through Kyocera and Schott Solar in the Czech Republic and Sanyo in Hungary, but there are also smaller operations such as Solar Cells in Croatia and Energy Solutions in Bulgaria. In Mexico, Sanyo is operating a new plant. In Africa, most of the production comes from Total Energie / Tenesol in South Africa, but there is also Racell Uganda, and Liselo in South Africa. In India, there are at least 13 module producers, but most of the production comes from TATA BP Solar. There are a number of small producers each in Thailand, South Korea and Taiwan.

??I need to update these graphs with the 2006 figures??
Almost 12% of the worldwide cell production in 2004 was in developing countries, increasing to 16% in 2005. China and other Asian nations make up the bulk of this production. Many of the countries with cell manufacturing facilities already have capacity in related high-tech industries, such as electronics manufacture. Of the largest vertically integrated cell and module manufacturers, Suntech in China is the only one based primarily in a newly industrialising country.
Products from developing countries have a reputation for poor quality. 5 years ago a solar panel made in China had a bad reputation. Need to gain market acceptance – warranties – international testing & certification etc.

China is starting to produce some quality products. Suntech is one of these. Suntech is starting to get a good reputation.

Industrialising countries such as India, Thailand, China, Russia and Eastern Europe have are increasing their share of module assembly and cell production.

Countries with electronics industries have long been producing BOS components, both through subcontracting arrangements, and under their own brands.

Until recently, most manufacturers in developing countries have been foreign owned, accessing cheap labour and materials. FDI companies may not be well connected locally, in terms of government contacts, contacts to access the raw materials etc. Local companies without access to the technology from overseas have also been a disaster.

Joint ventures have enabled companies to access expertise from overseas, but also to maintain government connections and access to local resources.

Suntech is local but has accessed technology by either buying it or establishing links with research institutes.
There is also significant expansion in production planned in eastern European countries, as well as in central and south America.

Of the firms in industrialising countries, only Sunpower (Philippines FDI, high efficiency), Orion (Israel, Dye cells) and Ulicia (China, recycled solar cells) are producing cells using a radical design.

### Preliminary Survey Results - Cell Manufacture

This actually includes data about Suntech, which I surveyed as well, and since there were only about 5-6 responses, everything is in here – I need to take the Suntech stuff out & maybe I should just delete the whole thing?!

Cell manufacturers in developing countries tend to export a lot of their production, so proximity to markets has not been important in many cases. There is a tendency towards semi-automated, rather than fully automated processing. Cost reduction and yield, followed by reduced capital costs and greater flexibility, are the greatest stated advantages to manual processing. Some companies have been able to generate new process technology, and this can be quickly incorporated into production with flexible manual loading and unloading of wafers. The up time for equipment can be very high in developing countries. Because labour costs are low, it is cost effective to have a team of trained maintenance technicians standing by in case of equipment failure. In countries where the labour costs are very high it is often necessary to bring in technicians to repair equipment instead.

Links with research institutions and internal R&D are considered to be important sources of technology, as are equipment purchases and technical support from suppliers. High temperatures and cleanliness are considered to be challenging technical issues. Quality control is also difficult, requiring large effort, especially in the early stages of production. Fragile wafers and avoiding variability in processing are also identified as difficult technical challenges.

The cost of wafers and other materials make up much of the cost of production in developing countries (up to 90%), particularly in China, where capital depreciation is only around 5% due to cheap locally produced equipment. Wages are between 1-2% of production costs. Short and medium term access to supplies of silicon are important for all manufacturers, and small manufacturers with less established links or ability to lock into long term contacts are potentially disadvantaged.

Equipment for critical processes is still imported in China, but there is a gradual build up of capability in the production of increasingly sophisticated equipment and materials by Chinese companies in response to the demand from cell manufacturers. Cz wafers, for example
are now produced very cheaply in China, making China a very attractive destination for cell manufacture. Manufacturers in many other LDCs tend to import most of their equipment and materials.

The firms surveyed thus far do not indicate that obstacles in the business environment are problematic; perhaps the only problem in China is the risk of losing skilled staff as more companies enter production and compete for staff. Governments in some countries offer support, such as tax holidays or reductions, secure supply of electricity and cheap land, to cell manufacturers. Government support for the industry, and industry linkages with the Chinese government, along with China’s capacity to expand infrastructure rapidly, have enabled manufacturers to expand rapidly, and producers upstream to set up quickly in response to, and with the support of cell manufacturers.

In general, access to technological expertise, enabling efficient technology and production expertise and high yields is considered highly important. FDI operations may not be as well connected as local companies, but often have better access to the international knowledge stock.

Due to low response to the survey, it is not possible to make statistically significant conclusions about the technological capabilities of developing country manufacturers compared with those in industrialised countries, or to make conclusions about the impact of innovative effort on capabilities.

**Preliminary Survey Results – Module Manufacture**

Internal R&D and research institutions as well as technology licensing, equipment purchases and technical support from suppliers, and feedback from customers were cited as important sources of technology for module manufacturers. Adaptation of standard technology is the most common form of technology acquisition.

In-line quality testing is common, but production lines are often not fully automated. Lower costs, followed by higher yield were cited as the most important advantages for manual processing.

Fragile wafers are considered to be the most difficult technical problem to overcome. The costs of cells & other materials strongly dominate production costs (>90%). Wages are as low as 1%. In countries such as China, much of the equipment and materials required are available locally. Export incentives, tax holidays and cheap land are common incentives offered by the Chinese government. In China and Thailand, links with the government were considered to be particularly important, followed by market links and then supplier links.

The efficiency of cells used, production expertise and market links are emerging as the most important factors influencing competitiveness. Plant size, yield, the cost advantage of technology used, low wages and manual processing are also important factors.
Some module manufacturers do not yet have quality certification. Low price is more important in developing countries markets, whereas quality is more important in export markets.

Engineers with specific PV experience are valued by module manufacturers, as they are better at quality control and searching for new technologies.
5.4. The PV Industry in China

The period up to 2000

Research on photovoltaics in China began in 1958, and small pilots were launched in the 1970s (Yang et al., 2003). In the late 1970s, three state-owned semiconductor plants in Ningbo (Ningbo Solar Cell Factory), Yunnan (Yunnan Semiconductor) and Kaifeng (Kaifeng Solar) were converted into monocrystalline cell manufacturing plants (Dai et al., 1999). In the late 1980s, the existing manufacturers upgraded their production lines and four more companies were established (Dai et al., 1999; Marigo, 2006):

- Non-Ferrous Academy, a state owned firm in Beijing, which was affiliated with Beijing General Institute for Non-Ferrous Metals and folded prior to 1999;
- Qinhuangdao Huamei in Qinhuangdao, which folded in 2003;
- Yu Kang Solar in Yunnan, which was a joint venture between Yunnan government, Korean and International Finance Company, which folded in 1997 because of marketing failures; and

All of the companies were state-owned, apart from the joint ventures Harbin-Chronar and Yu Kang Solar, which were state-foreign joint ventures. All production lines were financed through government R&D programmes or international aid programmes (Li, 2004b). Either the whole production line or all of the major equipment was sourced from mainly US suppliers, including equipment for monocrystalline silicon ingot pulling, ingot squaring and wafer slicing, cell fabrication, and module lamination (Shi, 2005; Yang et al., 2003). China did not produce capital equipment for photovoltaics manufacturing until 2000 (Yang et al., 2003).

Table 1: Chinese Cell Manufacturers, Equipment Source, Technology and Production, 1995

<table>
<thead>
<tr>
<th>Company</th>
<th>Starting Date</th>
<th>Equipment</th>
<th>Technology</th>
<th>Production Capacity 1995</th>
<th>Production 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harbin-Chronar</td>
<td>1991</td>
<td>All imported</td>
<td>a-Si</td>
<td>1 MW</td>
<td>200 kW</td>
</tr>
<tr>
<td>Non-Ferrous Academy</td>
<td>1987</td>
<td>All imported</td>
<td>mc-Si</td>
<td>100 kW</td>
<td>20 kW</td>
</tr>
<tr>
<td>Qinhuangdao Huamei PV</td>
<td>1990</td>
<td>Key imported</td>
<td>sc-Si</td>
<td>1 MW</td>
<td>200 kW</td>
</tr>
<tr>
<td>Kaifeng Solar</td>
<td>1975 New line</td>
<td>Key imported</td>
<td>sc-Si</td>
<td>300 kW</td>
<td>180 kW</td>
</tr>
<tr>
<td>Ningbo Solar Cell Factory</td>
<td>1976 New line</td>
<td>Key imported</td>
<td>sc-Si</td>
<td>300 kW</td>
<td>300 kW</td>
</tr>
<tr>
<td>Yunnan Semiconductor</td>
<td>1983 New line</td>
<td>All imported</td>
<td>sc-Si</td>
<td>500 kW</td>
<td>300 kW</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total:</td>
<td>1.2 MW</td>
</tr>
</tbody>
</table>

Source: (Dai et al., 1999)
According to Table 1, the production capacity of the six cell manufacturers in 1995 was about 3.2 MWp per year, but the actual production was 1.2 MWp (37.5% of capacity), due to ‘serious equipment bottlenecks in different parts of these production lines’ resulting from lack of finance to invest in the necessary imported equipment (Dai et al., 1999, p 4). The technology used in the older plants in the 1990s was basically the same as that used in the late 1980s (Dai et al., 1999; Yang et al., 2003), and the entrance of foreign companies in the mid 1990s increased the pressure on domestic producers. Dai et al. (1999) observed that ‘some domestic manufacturers still work well, some run under difficulty and some are even going to close or are already closed.’

The efficiency of Chinese manufactured solar cells averaged 10-12% in 1999, while the maximum achieved was 13.5%. In contrast, foreign manufacturers were producing cells that were on average 14-15% efficient (Dai et al., 1999). Given fixed manufacturing costs per cell, the approximately 20% lower efficiency achieved by Chinese manufacturers translates into 20% lower production output for the same input. Chinese manufacturers were therefore struggling to make a profit and were consequently unable to invest in capital. Zhao (2001) reported that production capacity in 1998 was 4 MWp and production was 2.3 MWp (an improvement to a still unsatisfactory 57.5% of capacity). Dai et al. (1999) reported that production capacity was 5 MW in 1999. Zhao et al. (2006a, p 27) describe the 1990s in the Chinese PV industry as a period of “importation, digestion, absorption and innovation”, resulting in capacity increases and capability improvements.

5.4.2. The post-2000 period

There was only one more new entrant (Trony) prior to the early 2000s, when a number of new cell and module producers started up, including Shagahi Topsol (2000), Suntech (2001), Baoding Yingli (2001), Shenzen Topray (2002), Soltech (2003), Tainjin Jinneng (2003) and Nanjing PV Tech (2004).

In 2000, Topsol (Shangahai Topsol Green Energy Co. Ltd.) collaborated with the Insitute of Solar Energy of Shanghai Jiaotong University (SJTU) to install a production line for c-Si solar cells, with some of the equipment, including a furnace and laminator being designed in-house (Yang et al., 2003). Topsol has accessed experts from SJTU, national research institutes and well-known enterprises. The diffusion furnace and laminator were designed in-house.

Baoding Yingli (Baoding Tianwei Yingli), formed in 2001, and first producing cells in 2003, was the first solar cell and module manufacturer in China to produce its own multicrystalline ingots (Schmela, 2005a). Baoding Yingli purchased wire saws from Switzerland and module production equipment from Italian manufacturer Helios. Almost all the materials, including interconnect ribbon, EVA and even silicon carbide used to cut wafers was
imported from Europe or the US. The company was slow to get the production line working. It took until 2006 before production reached 77 MWp.

In 2004, Nanjing PV Tech (CEEG), a joint venture between the Chinese Electrical Equipment Group in Jiangsu and a group of Australian experts was established. CEEG have a strategic partnership with the University of New South Wales (UNSW) to jointly research and develop technology. Doctor Zhao Jianhua, who was Associate Professor at UNSW is the General Manager. By the end of 2005, capacity was around 300 MWp and production around 150MWp.

New start-ups Jing Ao, Jiang Ying Jetion, Shanghai Chaori, SMIC, Solarfun and Big Sun have entered production in 2006, and a number of other firms are preparing production facilities. In Jing Ao, JingLong Industry has 55% shares, Australia Solar Development Company has 30% shares, and Australia PV Science & Engineering Company has 15% shares. JingLong Industry manufactures Cz-Si ingots, wafers, and manufacturing equipment. Established by Dr Dai Ximing, Dr Bruce Beilby, Mr Ted Szpitalak and Mr Yang Huaijin. Whole production lines were imported from Europe and the United States.
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<table>
<thead>
<tr>
<th>Company</th>
<th>Date Formed</th>
<th>Planned Production 2007</th>
<th>Capacity 2006</th>
<th>Production 2006</th>
<th>Production 2005</th>
<th>Production 2004</th>
<th>Production 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaifeng Solar</td>
<td>1975</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td>Ningbo Solar Cell Factory</td>
<td>1976</td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>25</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Yunnan Semiconductor</td>
<td>1983</td>
<td>25</td>
<td>35</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>Harbin-Chronar</td>
<td>1988</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.8</td>
</tr>
<tr>
<td>Hua Mei PV Device</td>
<td>1990</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>Trony</td>
<td>1993</td>
<td>5.8</td>
<td>0</td>
<td>5.8</td>
<td>4.5</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>Suntech Power</td>
<td>2001</td>
<td>265</td>
<td>300</td>
<td>160</td>
<td>82</td>
<td>35</td>
<td>8</td>
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<tr>
<td>Shenzhen Topray Solar</td>
<td>2002</td>
<td>70</td>
<td>35</td>
<td>18</td>
<td>20</td>
<td>4</td>
<td>0.9</td>
</tr>
<tr>
<td>Baoding Yingli</td>
<td>2003</td>
<td>150</td>
<td>60</td>
<td>37.02</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Shanghai Topol Green Energy</td>
<td>2003</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Soltech</td>
<td>2003</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Tianjin Jinneng</td>
<td>2003</td>
<td>5</td>
<td>2.5</td>
<td>2</td>
<td>2.2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Nanjing PV Tech Co. Ltd</td>
<td>2004</td>
<td>130</td>
<td>192</td>
<td>48</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jing Ao Solar</td>
<td>2005</td>
<td>29.5</td>
<td>75</td>
<td>29.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jiangsu Linyang</td>
<td>2005</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jiang Ying Jetion</td>
<td>2005</td>
<td>50</td>
<td>25</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shanghai Chaori Solar</td>
<td>2005</td>
<td>25</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>SMIC Corp.</td>
<td>2005</td>
<td>3.5</td>
<td>5</td>
<td>3.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Solarfun</td>
<td>2005</td>
<td>26</td>
<td>60</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trina</td>
<td>2005</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Big Sun</td>
<td>2006</td>
<td>21</td>
<td>0.6</td>
<td>0.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CSI</td>
<td>2006</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wuxi Shangpin Solar Energy</td>
<td>2006</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>960.8</td>
<td>850.1</td>
<td>388.42</td>
<td>150.7</td>
<td>51.8</td>
<td>14</td>
</tr>
</tbody>
</table>

Sources: (Dai et al., 1999; Hirshman et al., 2007; Jäger-Waldau, 2006; Schmela, 2005d, 2006) and company websites

??Make figure like jager waldau 2006 figure 23, showing expected growth in China production vs Japan, Europe etc…??

The companies with the highest cell efficiencies are Suntech (17.6%), E-Ton (17.5%), Jiang Ying Jetion (17.5%) and Jing Ao Solar (17.2%), whereas some of the lowest efficiency (sc-Si) include Soltech (13.8%), Baoding Yingli, and Trony.
Figure 3: Chinese Solar Cell Manufacturers, Production, Capacity and Production Plans
Since 2000, manufacturing of silicon feedstock, ingot and wafer production has developed in China, as well as most of the production equipment and materials for cell and module manufacture (Zhao et al., 2006b).

**Silicon Ingots**

Much of the silicon production in China is monocrystalline silicon, since the plant is cheaper, the techniques are mature, so the quality is equivalent to imported ingots and the equipment can be manufactured locally (Zhao et al., 2006a). Domestically produced furnaces achieve high quality and are 1/3-1/2 the price of imported ones (approximately US$150 000 each) (Pichel, 2006). The plants are smaller and investment and construction times are also less. This production relies on imported feedstock. China had capacity for the production of 2386 tons of monocrystalline ingots in 2005, equivalent to 200 MWp of solar cells. The polycrystalline silicon manufacturers are using an adapted Siemens process, which is more energy intensive than the most advanced techniques and the scale of operations in China is also too small to achieve low costs (Zhao et al., 2006a). All the polycrystalline ingot furnaces are imported. In 2005, Chinese manufacturers supplied 80 tons of polycrystalline silicon, while the demand from the PV industry was 1596 tons.

**Cell Production Equipment**

Wafer etching, diffusion furnaces, drying furnaces, plasma etching machines and testing and sorting machines are produced in China and widely used by local manufacturers. The cost of the Chinese equipment is on average 30% of the cost of imported equipment. Some of this equipment performs well and is of good quality. About half of the equipment now sold to Chinese manufacturers is domestically produced (Zhao et al., 2006a). Key equipment is still imported, mainly from Europe (Marigo, 2006). For example, parallel plate PECVD machines and automatic screen printers, however cannot be made domestically, and the cell handling for automated production lines cannot be produced locally. The materials such as aluminium paste, wet chemicals and slurry can also be produced domestically.

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Figure 4: Number of Equipment Suppliers in China, Germany, Japan, USA and Australia

<table>
<thead>
<tr>
<th>Country</th>
<th>Total</th>
<th>Testers &amp; Sorters</th>
<th>Other Furnace (Drying, Firing)</th>
<th>Screen Printing</th>
<th>Cell Coating</th>
<th>Diffusion Furnace</th>
<th>Turn-key</th>
<th>Cell Cleaning</th>
<th>Wet Etching</th>
<th>Plasma Etching</th>
<th>Laser Etching</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>17</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
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<tr>
<td>Germany</td>
<td>30</td>
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<td>4</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>USA</td>
<td>21</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
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<tr>
<td>Australia</td>
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Source: (ENF, 2007)

Module Encapsulation

The Chinese PV Industry was once focused on producing modules, which require the least know-how and can be assembled by hand with quality results. Chinese modules developed a bad reputation, and most did not have quality certificates, or had counterfeit ones (Hug & Schachinger, 2006). Faked module junction boxes were detected in Europe, purporting to be produced by a Swiss manufacturer (Schmela, 2005b). Since Chinese manufacturers have been accessing the growing German market, they have required certification, which most manufacturers have achieved, as described in section 0. Most module encapsulation in China is still done by hand, which is competitive due to low cost labour.

The Chinese PV Market

In 1992, there were less than 10 companies retailing, installing and maintaining PV systems in China, all affiliated with government sponsored R&D institutes. In 1998, the number
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had risen to over 50, including many privately owned enterprises (Dai et al., 1999). At this time, state-owned enterprises occupied the majority of the market.

China’s PV market in 2003 was comprised of 51% remote rural applications, 36% remote industrial and communications, 9% consumer products and 4% grid connected (REDP, 2004). The Chinese government has implemented large scale rural electrification programmes over the past few years (see Box 1), with a doubling of installed capacity from 20MWp to 40MWp in 2002 alone. The target of the Brightness programme is to install 300 MW by 2010 (Schmela, 2005b). The fast market growth and high competition resulted in a price drop from US$4.50/Wp to $3.50/Wp over two years, which prevented most local manufacturers from competing for market share (Li, 2004b, p 72). BP Solar, Shell, Siemens Solar, Sharp, Sanyo, SEC and Photomatt all had a presence in the Chinese PV market from the late 1990s (Dai et al., 1999).

The small grid-connected PV market, is expected to take at least five years to develop due to many barriers (Shi, 2005). Local governments have begun to promote this application for PV. In October 2005, the Shanghai municipal government endorsed the 100,000 Roof Project for which a feasibility study was commissioned in August 2004 (Suntech Power, 2006f), while Jiangsu province is planning a scheme for 1,000 PV rooftops.

<table>
<thead>
<tr>
<th>Box 1: PV Market Programmes in China</th>
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<tbody>
<tr>
<td><strong>Main current PV activities</strong></td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• 2002–2004: Township electrification programme (part of the Brightness Programme). Rural electrification based on PV, wind and small hydro. Subsidy (208 millions 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.</td>
</tr>
<tr>
<td><strong>Other PV activities</strong></td>
</tr>
<tr>
<td>• 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 Billions)</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• On-grid PV in the Gobi desert (Gansu province): feasibility study under way for 8MWp to be installed</td>
</tr>
<tr>
<td>• PV for the 2008 Beijing Olympic Games. Road lamps, lawn lighting facilities, lamps for public lavatories and irrigation</td>
</tr>
</tbody>
</table>

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

Source: (Marigo, 2006)

The total installed capacity in China in 2004 was 60MWp, and is projected to be 400MWp by 2010 (Marigo, 2006). The market is small compared to the annual cell production capacity of 390MWp in 2006 and will remain so for a while. Chinese manufacturers will
therefore continue to rely mainly on exporting their products and international markets to drive growth. This leaves them vulnerable to the risk of changes in the level of support for PV in other countries.

The NPC passed a renewable energy law for China on February 28th 2005, which was implemented on January 1st, 2006. China has a goal to generate 10 percent of its energy from renewable energy sources by 2020, and 17% by 2020 (Jäger-Waldau, 2006). There have been some reports (Lewis & Wiser, 2005; Marigo, 2006) that China intends to introduce an aggressive feed in tariff under the renewable energy law, whereas other suggest PV will be considered on a project basis (Photon, 2006a).

**Figure 5: Three Scenarios for Future Cumulative PV Installations in China**

![Graph showing three scenarios for future cumulative PV installations in China.](source: Marigo, 2006)

### PV R&D in China

In China, the Ministry of Science and Technology (MOST) is responsible for implementing R&D projects. MOST has been responsible for the National R&D Project, the 863 Project and the 973 Project (Marigo, 2006). The National R&D Project has supported PV since 1981, and the support has included projects such as the upgrading of manufacturing lines at Ningbo and Kaifeng, R&D projects on crystalline, amorphous and polycrystalline silicon solar cells and materials and the development of equipment for measuring solar cells (Zhao et al., 2006a). The 863 Project (2000-2005) has supported CdTe and CIGS solar cell research, while the 973 Project (2000-2005) has supported research into low cost and long life thin film, dye-sensitized and polymer solar cells.

The State Development Planning Commission (SDPC) and the State Economic and Trade Commission are responsible for the industrial development of the industry. The innovation fund for Middle/Small-Scale Enterprises provides investment matching grants to support the development of innovative products and mass commercialisation (Zhao et al., 2006a).
2006a). The government also supports universities and research institutes in R&D, including the state-run research institute the Chinese Academy of Sciences.

Suntech was the recipient of the largest single government grant for commercialisation in 2004-2005. The grant was 4 million Yuan for R&D on key technologies for the industrialisation of crystalline silicon solar cells.

Dai et al. (1999) reported that the PV industry consensus was that too many government agencies were involved in the implementation of PV support programs, resulting in inefficient use of resources, poorly organised and under-achieving R&D projects, and lack of commercialisation of research. There were more than 40 institutes, universities and manufacturers carrying out R&D at that time, primarily focused on improving cell efficiency and developing new device structures.

PV R&D in China is now supported at a fairly high level through the R&D departments of some manufacturers (including Suntech, Jiangsu Linyang Solarfun and CEEG), and through national and local governments. The MOST budget for PV R&D in the 11th year plan (2006-2010) is expected to be around 120 million Yuan (12.4 million euros) (Marigo, 2006). For comparison, in 2005, Germany spent US$30.3 million, Japan spent US$60.5 million and the US US$86 million on PV R&D (IEA PVPS, 2006). Zhao et al. (2006a) believe that although the problem of lack of commercialisation has been overcome and there are now good industry-research linkages, R&D now suffers from lack of human capital (technical expertise and training), within enterprises and within research organisations.

Table 3 shows that China has greatly improved their research outcomes with laboratory solar cells since 2002.

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<tr>
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<tbody>
<tr>
<td></td>
<td>Highest Efficiency</td>
<td>Area (cm²)</td>
<td>Highest Efficiency</td>
<td>Area (cm²)</td>
</tr>
<tr>
<td>Silicon</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mono-Si</td>
<td>20.4</td>
<td>4.00</td>
<td>20.4</td>
<td>4.00</td>
</tr>
<tr>
<td>Poly-Si</td>
<td>14.5</td>
<td>4.00</td>
<td>16.0</td>
<td>4.00</td>
</tr>
<tr>
<td>Si (thin film)</td>
<td>13.6</td>
<td>1.00</td>
<td>16.6</td>
<td>4.017</td>
</tr>
<tr>
<td>III-V Cells</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>GaAs (crystalline)</td>
<td>20.1</td>
<td>1.00</td>
<td>21.9</td>
<td>1.00</td>
</tr>
<tr>
<td>Thin Film Chalcogenides</td>
<td></td>
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<tr>
<td>CIGS</td>
<td>9</td>
<td>1.00</td>
<td>12.1</td>
<td>1.00</td>
</tr>
<tr>
<td>CdTe</td>
<td>7</td>
<td>0.03</td>
<td>13.36</td>
<td>0.5</td>
</tr>
<tr>
<td>Amorphous Si</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Si (amorphous)</td>
<td>8.6</td>
<td>100</td>
<td>8.6</td>
<td>100</td>
</tr>
</tbody>
</table>

Sources: (Green et al., 2003, 2005; REDP, 2004; Yang et al., 2003)
5.5. Suntech

First producing photovoltaic cells in 2002, Suntech Power was profitable in their first full year of production and grew rapidly to become the 10th largest producer of cells worldwide by 2004, the 8th largest in 2005 and the 4th largest in 2006. The company is implementing innovative high-efficiency, low-cost technologies and has continually improved production yields and reduced the use of silicon material in the cells.

Suntech has accomplished rapid capability building and implemented a successful technology strategy in the PV industry in China, a country where the innovation system for photovoltaics manufacture was in its infancy. The case study first looks at the origin of the company and its technological progress and milestones in section 5.5. The learning mechanisms utilised by the company over time are examined in 5.6. Suntech’s interactions with the PV innovation system in China, the evolution of the institutions, networks and markets are also examined in 0.

5 Origin and Start Up

Suntech was the initiative of the Chinese government. Based on experience accumulated in the manufacture of photovoltaic space cells, the Chinese government had attempted unsuccessfully to establish PV manufacturing for decades. It was recognised that the low efficiency of cells produced and the inability to operate cost effectively in Chinese PV plants was primarily due to the use of old technology and equipment.

The Chinese government looked worldwide for nationals who had become highly trained and expert in photovoltaics at overseas institutions. In 2000, Wu Xi region government officials offered Dr Shi Zhengrong, an Australian citizen who was born in Jiangsu Province, the opportunity to set up a new PV manufacturing company in China, using conventional technology, with capital of $US6 million. Dr Shi received his PhD degree from the University of New South Wales (UNSW) on multicrystalline silicon thin film solar cells in 1992. He has since worked as a senior researcher at UNSW and was the deputy research director at Pacific Solar, a company set up to commercialise the thin film crystalline silicon on glass technology initially developed at UNSW. Dr Shi is one of the inventors on the key patents for the Pacific Solar technology, which now being commercialised by CSG solar in Germany. His duties at CSG also included business management functions.

In 2001, there were several PV companies in China that were all performing poorly and losing money. Dr Shi had reservations about the potential for establishing a successful PV firm in China, and was also reluctant to leave Pacific Power, which was in an interesting stage of its technology development. During a two week visit to China, however, Dr Shi saw that China’s
infrastructure had improved and that, with the right technological expertise and capital, the potential for successful PV manufacture in China existed. Dr Shi asked Professor Stuart Wenham, the Director of the ARC Centre for Excellence for Advanced Silicon Photovoltaics and Photonics at UNSW, for assistance with production technology in the proposed new firm, including setting up production line and optimising the processing parameters. Professor Wenham had previously been involved in setting up and fine-tuning production lines at BP Solar in Australia and Eurosolare in Italy. Dr Shi obtained agreement from Professor Wenham in 2001, before committing to involvement in the new firm. On the 9th September 2001, Suntech Power Co. Ltd was officially established in Wu Xi near Shanghai.

Box 2: Suntech Vision:

"Suntech is committed to becoming the "lowest cost per watt" provider of PV solutions to customers worldwide. By focusing on technical leadership through leading R&D and a culture based on innovation, cooperation and integrity, Suntech is working daily to realize its vision to be a global energy leader, providing efficient solar solutions for a green future.

At Suntech we have a vision of becoming one of the world's largest solar energy providers. By producing low cost per watt solar solutions through ongoing investment in R&D combined with our low-cost China-based manufacturing"

(Suntech Power, 2006f)

The government offer included a 25% share of ownership of the company to attract Dr Shi. Once Suntech was established, the government sold their share to companies such as Jiangsu-based Little Swan Group, which subsequently sold its major shareholding prior to the public float in 2005. Suntech produced its first modules from purchased cells in March 2002 and began producing cells in September 2002. Originally Suntech made modules for the local markets and later modules for export. But that was a temporary transition until they got the local cell production up to scratch.

3 Milestones and Achievements

The following indicators illustrate Suntech’s ability to learn about, develop and utilise technology quickly:

Box 3: Suntech Milestones and Achievements

- Maintaining Profitability
- Rapid Production Expansion
- Continually Improving Cell Efficiency
- Thinner wafers & Higher Yields
- Quality Certifications
- Successful New York IPO

5.5.2.1. Profitability
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Despite rapid expansion necessitating continuous new investments in capital, Suntech began making a profit in its first full year of production and has maintained profitability since (Figure 6).

**Figure 6: Suntech Annual Revenues Q4 2004 - Q2 2006**

As Suntech has secured contracts for the supply of silicon, they have needed to rely less on deals which involve the reciprocal sale of cells, and have been able to convert more of their cell production into modules. Hence the profits from the sales of cells have decreased.

### 5.5.2.2. Rapid Production Expansion

Cell production began in September 2002 with an initial production capacity of 2 MW of cells, Suntech produced 8 MW in 2003, increased production to 35 MW (20 MW monocrystalline and 15 MW multicrystalline) in 2004, 82 MW in 2005 and 160 MW in 2006, always fulfilling production targets set the previous year. Suntech has expanded rapidly to achieve production scales on par with the leading international companies. Each increase in capacity has involved improved technology and implementation of increasingly local equipment. The first factory was located in Wuxi new district, a national high-technology development area in Jiangsu (further discussed in section 5.7.4). This production grew to 60MW capacity by May 2005 when new facilities were built a few minutes from the first factory, and began operating in September 2005. The latest planned increase includes
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manufacturing and R&D facilities in Caohejing high-technology development area in Shanghai. The facilities are expected to begin operations in early 2008. (Suntech Power, 2006e)

Figure 7: Suntech Cell Capacity and Production 2002-2006

Throughout this rapid expansion, Suntech has maintained almost full capacity utilisation. Utilisation varies a little bit from line to line, but overall it is about 92% operational, and is best for the newest lines, which are more reliable.

5.5.2.3. Efficiency

Suntech was able to produce 14% efficient cells from the start, and was producing cells of up to 14.5% efficiency within the first few of months of production in late 2002. International PV firms, many of which had been operating for many years and had developed their product over a long period of time, were producing on average about 15.5% efficient cells. 14.5% was a very good start for Suntech, and enabled them to be profitable within the first 12 months. Each year, the efficiency of cells has been increased by a between 0.5 and 1% (Figure 8). The first cells produced on the newest production line are 18% efficient.
5.5.2.4. Thin Wafers & Yield
When Suntech first began production, they suffered 20% breakage of wafers, but quickly sorted out the teething problems and achieved 95% yield, which can be largely attributed to good quality control, as discussed in section 5.6.1.2. Yield in late 2006 was 98.2%, well above the industry average, estimated to be between 90-95% (Hegedus & Luque, 2003; Lüdemann, 2005).

With extremely low labour and equipment costs in China, and very high prices for silicon feedstock and wafers worldwide, the cost of silicon makes up approximately 80% of Suntech’s cell manufacturing costs. To minimise this cost research is being conducted to reduce the thickness of wafers. Starting with 270 μm wafers, Suntech reported shifting production to 210 μm wafers by the end of 2005 (Suntech Power, 2006c), helping to reduce production costs even while silicon prices continued to rise. Successful manufacture of cells on 180 μm thick wafers with 98% yield was reported in mid 2006 (Suntech Power, 2006d). Although Suntech is able to use 180 μm wafers, most suppliers are currently only producing 210 μm.

5.5.2.5. Certifications
Suntech’s modules achieved UL certification on May 1st 2006. Suntech has also attained quality certificates including ISO 9001:2000, TuV and CE certificates and met international test standards including IEC61215: 1993 (Suntech Power, 2006b).

5.5.2.6. IPO
Stock exchange scouts spotted Suntech’s potential and invited the firm to list on the New York in 2005. Dr Shi bought out the other investors in the company and listed Suntech on the New York Stock Exchange in December, retaining 45% of the shares. The IPO raised between US$300-350 million, and facilitated further expansions. The share price soared from $US15 to $US21.20. Since peaking at $US43.40 in January it has dropped to $US26.48.

**Figure 9: Suntech Share Price December 2005 - 2006**

*Source: (Seeking Alpha, 2006)*
5.6. Capability Building at Suntech

This section explores the capability building strategies of Suntech through the hypotheses that were proposed in chapter 3:

1. **Explicit Innovative Effort and Strategy**

   Learning in PV manufacture requires explicit effort, organisational routines, structures and strategies for remaining competitive in changing technological circumstances. Producers make a choice between improving mature technologies and investing in new product technology, but require innovative capabilities to remain competitive in the long term in either case. Explicit effort directed at employing improvement routines and internal R&D will aid the understanding of and fine-tuning of existing processes and also the adoption of innovations, whether developed internally or externally.

2. **Human embodied capabilities**

   The tacit components of technology are embodied in humans and training and hiring experienced personnel are likely to be the primary routes to obtaining these. Successful technology acquisition efforts will the transfer of tacit knowledge via effort in training and learning.

3. **Interactions with Suppliers**

   Scaling up and the development of new materials and equipment for innovative processes or products are likely to involve learning by interactions with suppliers. Vertical integration is a route to internalise these capabilities and capability building processes.

4. **Interactions with Research Organisations at the International Technological Frontier**

   Since research institutes are the largest source of innovations in the PV industry, the access that firms have to the technology possessed by these institutes via purchases, collaborations or other arrangements is important in relation to the development of innovative production capabilities.

5. **Complementary Assets**

   Complementary assets such as procurement, marketing and distribution channels will be required alongside technological capabilities.

6. **Explicit Innovative Effort and Strategy**

   5.6.1. Internal R&D
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Suntech’s initial emphasis was on learning manufacturing competences, but began building R&D capabilities as well as research linkages from its inception. Initially, Suntech’s expertise was embodied in Shi and the other scientists recruited and sourced through collaborations with UNSW, but the firm began to develop its own proprietary expertise through R&D. Although Suntech has a mature technology in production, it is constantly improving the existing technology and looking for improved processes and device designs.

Suntech has set up an R&D laboratory from scratch, particularly difficult, given the specialised equipment and high standards of cleanliness required. 56 full-time researchers are employed, which is a huge number relative to the industry average. The cost of employing these researchers in China, however, is equivalent to employing about 8 full time researchers in Germany.

Much of Suntech’s research is done through collaborations with the University of New South Wales (UNSW) in Australia (described in section 5.6.4), and with firms in other parts of the supply chain (described in section 5.6.3). The R&D activities at Suntech include work related to these collaborations, as well as some independent R&D. The research has resulted in patenting and the rapid commercialisation of a number of product and process improvements over the standard technology and proprietary equipment generation. Through both internal and external R&D, Suntech have accumulated significant expertise in silicon materials, solar cell device physics, theoretical simulation and characterization, processing technologies and the design of advanced PV manufacturing equipment. Suntech have also made significant progress in developing innovative silicon purification technologies to substantially reduce silicon costs.

Through internal R&D, a new method involving selective diffusion and texturing of multicrystalline wafers via chemical processes was developed at Suntech in 2003 (Li et al., 2003). The selective emitter design was made up of a heavily doped area under the metal contacts in order to improve electrical contact and lateral conductivity, and a lightly doped area between the gridlines, to avoid high rates of recombination throughout the emitter and a consequent ‘dead layer’ in the region of the cell where long (blue) wavelengths are absorbed. The acid-based chemical etching reduced reflectance to 5% for wavelengths 300-1000 nm. The innovations resulted in average cell efficiencies of 15.8% on the production line, and the theoretical potential for the device was calculated to be 16.5% using production line equipment.

Published research from Suntech include work on module lamination (Yuan et al., 2005), balance of systems (Zhaoyuan & Lin, 2005), process and cell optimisation (Chen et al., 2005; Zhu et al., 2005a, b), material quality and impacts on processing (Li et al., 2005).

Although Suntech have built the capabilities to do all their own basic research, they are still looking to the collaborative research with UNSW to get their new cutting edge technology. Suntech prefer this collaborative approach, because they can access expertise at low cost, and are more concerned with continual improvement as a competitive strategy than protecting IP.
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As a percentage of total operating expenses, Suntech’s R&D budget has steadily increased from around 10% to around 30% between 2001 and 2004 (Figure 10). Much of the work in collaborative research is not measured as part of the internal R&D budget, so the figures are somewhat misleading, but still indicate an increasing focus on building R&D capabilities.

**Figure 10: Suntech Operating Expenses, General & Admin, Sales and R&D Expenses 2004-2006**

Suntech has been able to pursue a successful R&D strategy, largely because of Dr Shi’s technical expertise and involvement in the research. Dr Shi knows more about the technology than most CEOs, so he is able to make very good strategic decisions very quickly and because he is the CEO, can align research with production and company resources effectively. He doesn’t need to consult various levels of management for recommendations.

### 5.6.1.2. Quality Control
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Suntech has a rigorous quality control scheme, with regular inspections all the way along the production line. They have advantages in quality control because they have developed a high level of expertise in quality control, and because they can afford to invest more person-hours into quality control due to the low cost of labour. Because the labour costs are low, they can have a team of trained maintenance technicians standing by in case the equipment breaks down. When equipment is purchased from Europe, Suntech usually negotiates a deal with the supplier to train Suntech’s technicians to do ongoing maintenance on the equipment. Suntech’s rapid expansion has given them good leverage in negotiations with equipment suppliers who would prefer a maintenance contract.

In places where the labour costs are very high it is often necessary to fly people over and pay them to repair equipment because it doesn’t make sense to have trained people for every piece of equipment standing around waiting for something to do.

Other companies may not be as thorough in quality control because they don’t have the expertise to know which tests are useful. Suntech production line engineers have been educated to understand and use many simple tests to maintain the quality along the line through the Virtual Production Line software, developed at UNSW as a training tool for production line engineers (further discussed in section 5.6.2). Operators are also trained in these techniques and are motivated by yield and throughput targets associated with pay bonuses. Graphs of performance in these measures are often displayed on the wall.

A novel quality control technique (Sustained Luminescence Testing) recently developed at UNSW is being implemented at Suntech and has already identified various previously unknown processing problems. The technique gives information about carrier lifetimes and uniformity of wafers at any stage in the production sequence, which can be used for crack detection, spatially resolved series resistance monitoring, quality control of raw material and process control of individual key processing steps such as the emitter diffusion; and is hence an extremely valuable tool in improving production techniques. Suntech has also published a number of papers on various types of innovative measurements used for process optimisation (Chen et al., 2005) and to establish the critical parameters that determine completed cell characteristics (Zhu et al., 2005a). Yield at Suntech is now 98.2%, above the average and continually improving.

5.6.1.3. Flexibility and Continuous Upgrading

Suntech has pursued a strategy of continuous improvement and upgrading of product and process technology. They have been able to adopt this strategy as they expand and build new production lines, but also on the old production lines. Upgrading on the old production lines has been possible because Suntech use what they call semi-automated operations, which means whenever it makes sense for them to use labour intensive processes; they do, because it is
cost effective in the context of low labour costs in China. The manual handling of cells allows Suntech to implement production changes very rapidly and a little cost. Using expensive highly automated equipment with a 10 year depreciation schedule commits a manufacturer to a process, without variation, for the next 10 years, delaying the adoption of innovations. Manual operations have allowed Suntech to adopt innovations rapidly, one of the reasons they have been able to bring new technologies to commercialisation rapidly.

Not only is manual processing cheaper and more flexible, but Suntech has also found that they can get higher yields using manual operations. Yields are higher in a mature industry for automated processes, and it has been assumed that the same would apply to the PV industry (Eberhardt, 2005; Lüdemann, 2005; Swanson, 2004), but photovoltaics isn’t a mature industry. The highly automated equipment hasn’t been around that long and the technologies keep evolving so that the equipment needs to be redesigned to handle the wafers in a different way for a different type of processing. Highly automated equipment results in very high yields when a stable process has been used for many years and there has been an opportunity to refine the equipment and the way it handles the wafers.

5.6.2. Human embodied capabilities

While there is a shortage of people skilled in PV manufacturing and research in China, Suntech has pursued a strategy of capability building through internal training, learning through searching and the implementation of improvement routines such as quality control.

5.6.2.1. Hiring

Suntech has recruited good quality staff and developed them through training. The key staff, including the CEO, Zhengrong Shi; the chief technical officer, Stuart Wenham, and the key R&D staff came to the firms and research organisations with significant international research and production experience (Box 4). General process engineering and automation expertise are important, but specific PV experience allows Suntech to make optimal strategic technology decisions.

Dr Shi (CEO) and Dr Wenham (CTO) are key to the technological capabilities in the company. Dr Wenham makes many of their technology decisions and sorts out problems with their production. Unusually, he is employed on a contractual basis, and spends only some of his time at Suntech, while he carries out other roles at UNSW in Australia. Suntech has chosen to retain Dr Wenham, despite his other commitments, since his experience and expertise is invaluable.

??This section needs work??
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Box 4: Key Staff at Suntech

CEO
Dr. Zhengrong Shi is Suntech's founder, chairman of the board of directors and chief executive officer. Prior to founding Suntech in 2001, he was a research director and executive director of Pacific Solar Pty., Ltd., an Australian PV company engaged in the commercialization of next-generation thin film technology, from 1995 to 2001. From 1992 to 1995, he was a senior research scientist and the leader of the Thin Film Solar Cells Research Group in the Centre of Excellence for Photovoltaic Engineering at the University of New South Wales in Australia, the only government-sponsored PV industry research center in Australia. Dr. Shi is the inventor for 11 patents in PV technologies and has published or presented a number of articles and papers in PV-related scientific magazines and at conferences. Dr. Shi received a bachelor's degree in optical science from Jilin University in China in 1983, a master's degree in laser physics from the Shanghai Institute of Optics and Fine Mechanics, the Chinese Academy of Sciences in 1986, and a Ph.D degree in electrical engineering from the University of New South Wales in Australia in 1992.

Chief Technical Officer
Dr. Stuart Wenham has been the chief technical officer since July 2005. He is also currently a Scientia Professor and the Director of the Centre of Excellence for Advanced Silicon Photovoltaics and Photonics, at the University of New South Wales in Australia. From 1995 to 2004, he was the co-director of Research at Pacific Solar Pty. Ltd. From 1999 to 2003, he was the head of School for Photovoltaic Engineering and the director of the Key Centre for Photovoltaic Engineering at the University of New South Wales. From 1996 to 1998, he was the head of the Electronics Department and from 1991 to 1998, the associate director of the Photovoltaics Special Research Centre, also at the University of New South Wales. In 1999, Dr. Wenham received The Australia Prize for Energy Science and Technology and in 1998, the Chairman's Award at the Australian Technology Awards, in both cases jointly with Martin A. Green. Dr. Wenham received his Ph.D. degree in electrical engineering and computer science from the University of New South Wales in Australia in 1986.

Senior Research Scientist
Dr. Jingjia Ji is a director and senior research scientist at Suntech and has been with the Company since 2003. From 1995 to 2002, Dr. Ji worked as a senior research scientist at Pacific Solar Pty., Ltd. From 1991 to 1994, he worked at the University of New South Wales as a senior research assistant. From 1985 to 1990, he worked in the Shanghai Institute of Organo-Fluorine Materials in China as the head of the department of chemical engineering. Dr. Ji received his bachelor's degree in chemical engineering from the East China Institute of Chemical Technology in China in 1983, and a Ph.D degree in industrial chemistry from the University of New South Wales in Australia in 1994.

Manager R&D
Mr. Yichuan Wang is a manager of Suntech's PV cell research and development department and has been with our company since 2001. From 1979 to 2001, he worked at Yunnan Semiconductor Co., Ltd. on the research, development and manufacturing of PV products. From 1996 to 2000, he worked on sci-tech planning projects organized by the PRC Ministry of Science and Technology. In 1984, he participated in the introduction of the PV cells manufacturing line. Mr. Wang received his bachelor's degree in physics from Yunnan University in China in 1968.

Dr. Tihu Wang joined Suntech as vice general manager of R&D. Dr. Wang has 23 years of experience in leading and conducting advanced scientific research on high-efficiency solar cells, semiconductor crystal growth, material characterizations, and physical metallurgy. Prior to joining Suntech, Dr. Wang worked at the U.S. National Renewable Energy Laboratory where he acquired extensive expertise in the entire line of silicon photovoltaic technology, from silicon feedstock production, crystal growth and solar cell manufacturing, to thin-film silicon fabrication.

Director R&D
Mr. Guangchun Zhang is Suntech’s deputy research director of research and development and has been with the Company since November 2005. He specializes in research on high-efficiency solar cell design. From January 2003 to October 2005, Mr. Zhang was a professional officer at the Centre for Photovoltaic Engineering and the School for Photovoltaic Engineering at the University of New South Wales. From 1997 to 2002, Mr. Zhang was a research engineer at Technology Development Group and was seconded to Pacific Solar Pty. Limited from the University of New South Wales. From 1994 to 1996, he worked at the Photovoltaics Special Research Centre and the Centre for Photovoltaic Devices and Systems, also at the University of New South Wales. From 1982 to 1994, Mr. Zhang taught and researched at the School of Electronic Engineering at Shandong Polytechnic University in China, first as an assistant lecturer, then as a lecturer and finally as an associate professor. Mr. Zhang received his bachelor's degree and his master's degree in 1982 and 1988, respectively, from the School of Electronic Engineering at Shandong Polytechnic University.

Source: (Suntech Power, 2006c)
Suntech has been able to attract and retain good quality staff despite the strong
competition for trained staff in the photovoltaics industry in China. The firm has a strong focus
on people (Box 5).

**Box 5: Suntech Culture - A Focus on People**

“At Suntech, we believe that good people build great companies. We strive to foster a spirit of innovation,
cooperation, teamwork, and speed through incorporating our employees into our family and treating them
with concern and compassion. The relationship between the company and its people is reciprocal. As they
grow, personally and professionally, we grow.”

(Suntech Power, 2006f)

Suntech tries to enthuse all the employees about the dual business and social
responsibility aims of Suntech. All of the staff have watched Al Gore’s film ‘An Inconvenient
Truth’. The firm also has a strong social responsibility to its employees. When a Suntech
employee was recently taken ill, the staff, beginning with Dr Shi, donated money to pay for his
hospital expenses, saving his life. Suntech is now in the process of establishing a health fund for
staff.

Salaries are good (above average) by Chinese standards.

Suntech have 56 researchers out of 1500 staff. Suntech will target specific foreign staff
where they really need the expertise.

High educational qualifications? Bonuses, pay, reviews? Most of the new ideas in the
company still come from Zhengrong. He is still heavily involved in the technical side R&D and
production, as well as the overall business direction.

First quarter 2006, New manufacturing & R&D facilities in Shanghai: “We believe that
the proximity to central Shanghai will also help us to continue to attract highly qualified staff.”
Dr Shi (Suntech Power, 2006e)

The benefits of hiring locals include their:

- lower salary requirements;
- familiarity with the language, culture, and organization of the society; and
- their connections to local institutions or government bodies.

Formerly, the government assigned students to a work unit, or danwei, and a job for life
after graduating. China’s economic reforms have rendered the old system obsolete, and students
are now able to search for jobs on their own.
5.6.2.2. Training and the Virtual Production Line

Initial 1-2 week visits by Professor (Dr??) Wenham to Suntech during 2002 were dedicated to tuning the production line. Training of staff running the production line started immediately after the production line was operating acceptably, because Wenham wasn’t going to be able to be in China very often and the people making decisions on the line needed to have the skills to keep the line working well, including the analysis and fault diagnosis. The training focused on how to optimise the possessing parameter interdependencies of all the different parts of the process and the use and interpretation of quality control tests.

Groups of 20 engineers who were not from a PV background were trained during 2-3 hour classes. There were usually about three classes during each occasion Wenham visited Suntech, usually for 1-2 weeks at a time. Wenham visited Suntech twice in 2002, four times in 2003, and six times in 2004, 2005 and 2006. Suntech has now had Wenham write an exam to strengthen the training, but it hasn’t been implemented yet.

Much of the teaching was done using the Virtual Production Line (see attached cd/Appendix ??). The virtual production line is modelled on the real production environments of several manufacturers with production lines located in various countries. Strong support in its development has been provided by companies such as Eurosolare in Rome, BP Solar in Sydney and Suntech. Of particular importance has been the generation of reliable and accurate data relating to parameter interactions. ??I can include more detail about the VPL??

Most of the students don’t speak English very well, but they can speak enough English to use the Virtual Production Line, apart from the help files, which explain how the processes and quality control tests work. The software is being translated into Chinese.

Wenham no longer trains the production line operators. They are now trained by more senior operators. Suntech has built a critical mass of people with the knowledge to do the training without Wenham. Wenham now spends more time directly training the research team and the management of the research team, which he indirectly leads in his capacity as CTO. The training is related to technology development and running of the pilot lines.

As well as less formal exchanges of personnel between Suntech and UNSW, Suntech has also sent engineers to UNSW for training and intend to send students to do the photovoltaics degree at UNSW.

8 Interactions with Suppliers

Suntech started by importing equipment and materials, but the intention of the business was to develop low-cost, high quality Chinese manufacture of these items and the firm has always tried to source local equipment where possible. Suntech has invested in setting up firms to supply them with materials and equipment. The firm has also expanded vertically, engaged in OEM manufacture and expanded horizontally to access new markets and expertise.
5.6.3.1. Equipment

Suntech has progressively moved from imported to local equipment as it has become feasible to source equipment locally. Their first production line was almost entirely imported, because the PV manufacturing equipment industry in China was in its infancy, the quality of equipment was unknown and Suntech couldn’t afford the time and expense to test it. Second-hand equipment for the first production line was purchased cheaply from the US. The only things initially purchased in China were some of the chemical benches.

In the first expansion, more equipment was purchased in China, but the major plant came half price from a Japanese manufacturer who was eager to shift it, along with some second hand pieces of equipment from Italy. The yields were initially 20%, but engineers from the Japanese supplier rectified the problems.

Critical equipment is still imported, usually from Europe, in cases where Chinese suppliers have not been able to achieve the quality required for sensitive processes. For example, SiNx antireflection coating deposition is a critical process and the PECVD equipment for the process must be high quality. Suntech purchases PECVD equipment from Centrotherm. The quality of the screen printer has also been found to be critical, which Suntech import from Baccini in Italy. Non-critical equipment of good quality is now made very cheaply in China. Suntech now purchases all of the non-critical equipment in China, including furnaces for diffusion and high temperature processes, and all of the chemical benches.

When Suntech has developed proprietary processes, they have tried to work with local manufacturers to produce the equipment they need. For example, they developed a new method of texturing multicrystalline wafers via chemical processes in 2003 (Li et al., 2003). The baths for the texturing are relatively sophisticated and have particular capabilities. These baths have been custom designed and made in China.

In the case of the semiconductor finger technology co-developed with UNSW, which has just being put into large scale production in late 2006, the lasers are all being made in China, especially to suit that process. A laser has been designed that can achieve a fairly high throughput, with the capabilities required for this technology, but without a lot of extra capabilities that would have increased the price. Suntech have worked closely with and assisted suppliers to design equipment to satisfy the requirements of their proprietary processes.

5.6.3.2. Pastes, EVA, Glass and Chemicals

Suntech initially tried to use local materials (in 2002), but they were looking to export and found the local pastes, EVA and chemicals to be inadequate. They didn’t use them in their product until quite a bit of development work was done to improve their quality so that they matched the quality of materials available internationally. They switched to the Chinese materials once the quality was suitable.
Suntech worked with the materials suppliers, giving them iterative feedback until the materials gave good results. They informed the paste manufacturers what they needed out of a paste and in what ways the available pastes were deficient. In some of the pastes, the conductivity wasn’t good enough. Others didn’t have good enough adhesion. Some of them had problems with reacting with the encapsulation. Some caused the wafers to bow. As the problems were resolved, new low cost, good quality products became available to Suntech.

In general the Chinese chemicals for the wet chemistry process were more suitable from the start, but in a minority of cases the purity needed to be improved before Suntech could use them. Suntech also worked with Chinese manufacturers to improve their EVA formulation. Suntech has been importing glass, but has been evaluating Chinese glass and trying to improve the suitability of PV glass in China.

5.6.3.3. Silicon

Suntech has worked closely with Luoyang Silicon to improve their in-house technology for purifying silicon and producing feedstock suitable for making Cz ingots. Suntech carried out extensive research on the performance of wafers with different impurities after different processes, such as lasering and high temperature processes and under different processing conditions, as published in (Li et al., 2005), for example. Suntech provided feedback on the suitability of the material and also gave Luoyang some financial support to do some of the R&D work, and to move to commercial scale production of the technology.

Suntech and Luoyang have now set up a joint venture to manufacture solar cells using all of the silicon that is produced from the new Luoyang silicon plant, which has been set adjacent to the original Luoyang plant. Suntech owns 89% of the joint venture and the cells will be branded Suntech. In late 2006, 0.2 Ω.cm p-type 200 μm silicon wafers of 4 nines purity (99.99%) with a minority carrier lifetime in the vicinity of 0.5 μs had been manufactured at a quarter of the price of the usual high purity (at least 6 nines) wafers. It is predicted that by reducing this wafer thickness from 200 μm to 50 μm the cost could be further halved.

Suntech has also invested US$5 million in Emei Semiconductor Material Factory, which produces solar-grade silicon. The investment has allowed Emei to triple production to 300 metric tons annually (Hirshman, 2005). The investments in Chinese silicon production have allowed Suntech to avoid the long-term supply contracts with controlled prices that silicon manufacturers are currently demanding as a prerequisite for expanding their production capacity.

5.6.3.4. OEM Manufacture, Horizontal Expansion and Downstream Expansion

In 2005-2006, Suntech produced modules under an OEM agreement with SolarWorld. The German firm supplied specifications and technological know-how (Schmela, 2005c).
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In 2006, Suntech purchased the Japanese BIPV manufacturer MSK, giving Suntech access to the Japanese market via MSK’s well developed sales and distribution network; and to the product development capabilities, systems integration, commissioning and maintenance expertise. Suntech has moved MSK’s manufacturing to China and plans to integrate the two firms and combine many overlapping areas of the operations, including manufacturing, sales, purchasing, R&D and back office functions (Suntech Power, 2006a). The acquisition has the potential to provide great synergies by combining the complementary capabilities of the two firms.

Suntech has helped a number of equipment and materials manufacturers in addition to Luoyang Silicon to learn the technology and get established, even sometimes lending them money. In this way, Suntech has been able to acquire all the materials and equipment they have required at low cost, and both Suntech and the other companies have developed knowledge, skills and complementary capabilities through the interactions.

Suntech does some module assembly, but also provides cells to other OEM companies that they have helped to establish. The OEM companies benefit from a guaranteed supply of cells and marketing opportunities, while Suntech continues to expand and increase market share. In the first quarter of 2006, Suntech won system integration contracts in China of 2.2MW (Suntech Power, 2006c).

In August 2006, Suntech announced the founding of Suntech America Inc., a subsidiary that will help Suntech access US markets (Hirshman, 2006). The firm also established Suntech Power (Hong Kong) Co., Ltd. In the first half of 2006, in order to improve international purchase and sales linkages (Suntech Power, 2006d). Shenzhen Suntech was set up in 2006 to carry out solar power grid integration projects in Southern China. New manufacturing, R&D facilities and a sales office were also established in Shanghai to develop sales in the domestic PV market (Suntech Power, 2006e).

6 Interactions with Research Organisations at the International Technological Frontier

Having spent fifteen years studying and working at UNSW and Pacific Power, Dr Shi has strong links with the Australian organisations. In December of 2002, Suntech signed a technical cooperation agreement with the Centre for Photovoltaic Devices and Systems (now the Centre of Excellence for Advanced Silicon Photovoltaics and Photonics at UNSW) at the University of New South Wales. During the 2nd quarter of 2006, the agreement was extended until the end of 2010 (Suntech Power, 2006d).

The collaborations have included the full spectrum of technology development, from basic research to commercialisation. Stuart Wenham, who is Suntech’s Chief Technology Officer and also Scientia Professor and Director of the UNSW PV centre, leads the research
collaborations. The collaborations have included the development of ‘semiconductor finger’ technology (Wenham et al., 2005a; Wenham et al., 2005b), which has achieved around 18% efficient cells in pilot production.

The technology, pictured in Figure 11, finds a solution to one of the major trade-offs in conventional cell design. In conventional screen printed cells, a heavily doped emitter is used to achieve good ohmic contact between the emitter and the metal contacts, and to reduce the resistivity of the emitter, through which current must flow laterally in order to reach the metal contacts. High rates of recombination of charge carriers, however, occur in the heavily doped region, reducing the current collected by the solar cell.

In the ‘semiconductor finger’ design, heavily doped laser scribed grooves (semiconductor fingers) allow good lateral conductivity for charge carriers to reach the metal lines screen printed perpendicular to the fingers (Figure 12). The front diffusion of the cell is a lightly doped area, with less emitter recombination than in conventional cells. Because the semiconductor fingers do not shade the cell, they can be located close together, reducing the problem of high resistivity in the lightly doped emitter.

Figure 11: Cross section of the Semiconductor Finger emitter design developed through collaboration between UNSW and Suntech

![Diagram of semiconductor finger design](image)

Source: (Wenham et al., 2005b)

The heavily doped semiconductor fingers make good ohmic contact with the metal contacts, which can be spaced much further apart than in conventional cells, since the fingers carry the current to the contacts. Reflection of sunlight from metal contacts on the front surface of the solar cell is therefore reduced.

Figure 12: Screen printed lines perpendicular to heavily diffused semiconductor fingers
Chapter 5. Suntech Case Study

A dielectric/AR coating passivates the top surface and isolates the metal from the lightly diffused top surface. Suntech have been able to get up to 18% efficiency with this new technology in production. The new process does not cost much more and should enable them to increase their margins.

This technology has been jointly developed at UNSW and Suntech, to be compatible with manufacturing using existing infrastructure and equipment. The research collaboration was wholly funded by Suntech, including all the collaborative research conducted both in China and at UNSW. The cash contribution alone for the research conducted at UNSW has been five hundred thousand Australian dollars for 2006. Suntech also funded all the living, travel and accommodation expenses for the UNSW staff and students who worked at Suntech on the collaborative research. After a pilot phase in 2006, the technology has entered mass production in 2007. The patent for the technology is jointly owned between UNSW and Suntech, so Suntech has the right to use it, while UNSW can license it to others. When the technology is licensed, Suntech receives half the income, since they are half owners of the patent.

Suntech and UNSW are currently developing another technology that can produce cells with 20% solar conversion efficiency. Pilot production is planned to begin in 2007. The new technology involves an innovative rear metal contacting scheme to overcome the high rear surface recombination velocities associated with conventional screen-printed solar cells. Initial experimentation again shows significant promise with this work being based on an earlier UNSW patent that predated this collaborative research agreement.

Collaborative research such as that behind the semiconductor finger technology is relatively cheap research for Suntech. When they fund projects at UNSW they only pay the incremental cost of doing the research. Suntech does not aim to own the technologies that are
developed outright, but want access to it for their own production. So have 50% funded a number of research projects which gives them the rights to use the developments, but also leaves UNSW IP rights. Suntech is not concerned about intellectual property, but more with using continual innovation to stay ahead of competitors. Suntech also collaborates with several universities in China on materials research as well, such as experimenting with lower purity silicon.

Suntech’s ability to work with research organisations has been of particular importance because innovations in PV technology emerge mainly from research institutions. The close links between research and manufacturing have enabled the technology to be commercialised within a short period of time. The experience of Suntech validates the hypothesis that links with research organisations are important sources of learning for latecomer PV firms.

The interactions have also provided opportunities for the exchange of personnel. Suntech scientists have spent time visiting UNSW laboratories and UNSW researchers often visit Suntech. There are also informal learning and training opportunities through these exchanges, as well as potential recruitment opportunities.

6 Complementary Assets

While high levels and continual upgrading of production, innovation and linkage capabilities in Suntech have been critical in ensuring their success, investment functions have also been essential.

Suntech has established long term supply contracts for silicon since their establishment, and as they have expanded; established a brand reputation and penetrated markets rapidly, perhaps partly due to the UNSW linkages; expanded quickly.

Much of this success can be attributed to the entrepreneurial abilities of Dr Shi, the CEO and his intimate knowledge of the industry. Dr Shi has been invited to join the New York Stock Exchange’s International Advisory Committee. The committee, made up of active chairs and CEOs of non-US companies, was formed by the NYSE to provide it with input on the interests and needs of non-US issuers in the global capital markets. This appointment is recognition of Dr Shi’s managerial and strategic decision making abilities.

Suntech has also appointed the right people to key roles within Suntech and has used international consultants where necessary. Australians Ted Spilitak and Samuel Yang took marketing roles in the initial stages of the firm’s operation, and provided expertise in equipment purchasing and commissioning.
5.7. The Role of the Innovation System

China innovation system has the ability to supply the resources – labour (university educated, often with experience in microelectronics or mass-production).

Suntech needed to help accelerate the learning in the innovation system by:

being a demanding customer

helping suppliers learn by interacting and learn by using equipment and materials in the factory

supplying finance

Figure 13: Cumulative Installed PV Capacity and sc-Si Module Prices in China 1976-2003

Resources

Human Capital

China has a fast growing PV industry and therefore a shortage of people skilled in production and innovation (Zhao et al., 2006a). China does, however, have many people with related competencies from the electronic industries. New Chinese firms have also recruited many international experts.
Since the late 1970s, China had a policy of sending students to study in overseas universities (Broaded, 1993; Li, 2004a). With booming economic growth, China has been able to attract back some of their nationals that have been trained abroad in foreign firms, universities, and R&D institutes. Chinese nationals have the advantage of local connections, understanding the way business is done, as well as being exposed to the international technology frontier, western ways of doing business, and speaking English.

**Equipment**

A large number of firms that can supply almost all of the materials and equipment required for PV manufacture at very low cost has developed; giving Chinese firms the opportunity to make savings by procuring equipment and materials locally.

**Silicon supply**

Silicon shortages are extremely problematic in China. The growing number of companies is all competing for the limited supply and the prices have soared. Lack of feedstock has constrained the production of solar cells in China for the past few years, and it is reported that some feedstock of low quality has been used due to lack of monitoring (Zhao et al., 2006a). Li (2006) says that the figures given by Chinese manufacturers are exaggerated, because they do not want to reveal low capacity factor and that the silicon shortages are causing most to produce at 30% capacity.

Despite large investments in new monocrystalline and polycrystalline silicon capacity, China will not be able to provide enough silicon to supply all the cell manufacturing capacity for a number of years. Small Chinese cell manufacturers are likely to continue to have problems sourcing material at reasonable cost, and even large ones will have difficulty unless the have supply contracts.

Some cell manufacturing firms have invested Chinese silicon production either directly or via joint ventures, to avoid the type of long-term supply contracts with controlled prices that silicon manufacturers are now demanding as a prerequisite for expanding their production capacity.

**Physical Infrastructure**

Although large parts of China are not well served by infrastructure, the large cities, and in particular the industrial districts are have reliable electricity supplies and transport networks. Industrial districts receive preferential access to electricity when there is a shortage. Hydro-electric schemes in some parts of China make large amounts of electricity available cheaply for very energy intensive activities such as silicon ingot production. China has a well developed transportation and ports infrastructure to serve its large and growing manufacturing industries.
5. **Technology Infrastructure**

The funding of Chinese research institutes in the PV area has been increased to become comparable with that of the leading PV countries, but the level of research still lags well behind in terms of laboratory cell efficiencies achieved, for instance. It will take some time for China to build up a critical mass of expertise in PV research and commercialisation and begin to compete with the leading countries. In the meantime, Chinese firms will continue to rely on international linkages for cutting edge research.

6. **Incentives**

The first generation of Chinese manufacturers were state owned and funded and were dependent on the government’s decisions. These state enterprises had neither the mandate nor the incentive to carry out R&D or innovate (Liu & White, 2001). Due to the limited market demand and a failure to address the need for technological improvements, the production cost was quite high and thus these companies could not operate profitably. Since the 1990s, producers have been operating independently of the government, and since 2000 have been driven mainly by export markets.

The Chinese Market for PV

The growth trajectory for the Chinese PV market is much smaller than for the PV cell production industry. For example, projections for PV installations in China in 2010 are 130 MWp and for 2020, 200 MWp (Wang, 2006). The 2006 capacity of Chinese cell manufacturers was already 850 MWp and planned production for 2007 is 960 MWp (see Table 2). The incentives for Chinese firms to invest and to improve are likely to come from export markets.

Export Markets and Standards

97% of Chinese modules were exported in 2005 (Wang, 2006). Most of the exports have gone to Germany, the US, and Japan. In many cases, German entrepreneurs with a booming home market sought out Chinese products, including via entrepreneur trips arranged for German PV companies to China (Hug & Schachinger, 2006; Schmela, 2005b).

In 2004 and 2005, the technical improvement component of the World Bank / GEF China REDP project supported about 10 manufacturers to achieve international standard IEC-61215 certification (ter Horst & Zhang, 2005). Almost all Chinese module manufacturers now have their products certified under international standards such as IEC (performance), TUV (safety) and sometimes CE (EU conformance) (Marigo, 2006). REDP (2004) attributes this change to the programmes, whereas other authors (Hug & Schachinger, 2006; Schmela, 2005b) suggest the impetus came from the requirements of the German market.
Export markets have been instrumental in the formation of the Chinese PV industry, both in stimulating growth, but also in providing incentives for improvement and opportunities for manufacturer-customer interactions.

**Government Support**

The Chinese government has provided a range of fiscal and financial incentives to supplement their competitive manufacturing advantages and stimulate the growth of a PV industry. The PV industry is seen as a strategic high tech industry. The usual company tax rate in China is 33%, but some municipal governments give 5-8 years tax holiday to encourage high-tech projects and foreign investment.

In particular, China has encouraged the export industry and the influx of foreign investment in domestic manufacturing. Materials for export products are exempted from import duties, which range between 8.5-14%, but the exemptions do not apply when the product is sold domestically (Li, 2004b). Joint ventures and FDI manufacturers are eligible for the import duty exemptions regardless, an inducement for foreign investment in manufacturing.

**Interactions**

Since the entrance of many new PV manufacturers after 2000, including a number of joint ventures and firms that have employed foreign experts, the intensity of Chinese firms’ interactions with both international and domestic research institutes and firms throughout the supply chain have increased. Chinese firms are now a visible presence on the international PV scene. For example, 38 of 334 exhibitors at the 2006 European PV conference were from China and Taiwan (Jäger-Waldau, 2006).

**OEMs**

Chinese OEM companies have been making solar cells and modules for sale under the brands of system integrators in Europe. Some of these European companies are now purchasing the Chinese OEM company, or engaging in joint ventures. Conversely, some of the OEM manufacturers may forward integrate by purchasing system integration companies in Europe and the US (Pichel, 2006).

**Research Institutes**

Most Chinese manufacturers have links with universities and or research organisations (see Appendix ??). Collaborations include product and process improvement for immediate commercial applications as well as new device design and equipment development (Marigo, 2006). Chinese PV research is now well funded, and research institutes and universities, through interactions with manufacturers are likely to achieve further progress.

**Vertical Integration**
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In order to achieve competitiveness, many Chinese manufacturers are moving towards vertical integration through purchases, joint ventures and vertical expansion.

**Value Chain Interactions**

The success of Chinese module and cell manufacture in global markets has spurred investment in equipment and materials manufacture in China. The presence of the new PV firms, with their technical expertise and good R&D linkages has enabled the supplier firms to improve their products and capabilities. Suntech may be seen as a prime mover in the Chinese PV value chain. Through aggressive financial and technical support of suppliers, Suntech has played a big part in the development of the Chinese PV value chain.

Although many linkages have been established between cell and module manufacturers and their suppliers, some of the more lucrative value-added downstream parts of the value chain have had less attention. There is no investment or interest in research into built environment PV products, such as BIPV on the part of Chinese R&D programmes (Marigo, 2006). There are a few large scale projects in planning, for example related to the Beijing Olympics in 2008 (Li, 2006). Consumer products manufacturers are, however, moving into street lights and park light products (Shi, 2005).

**Clusters**

Geographical clusters of PV firms have emerged in China (Figure 14). Zhejiang and Jiangsu provinces, near Shanghai hosts solar cell manufacturers Suntech, Nanjing PV Tech, Solarfun, Ningbo and a number of others, as well as wafer manufacturers Trina, NREI, Zhejiang Sunda and Jingong. A smaller cluster exists near Beijing and in Hebei province, where there are six module equipment manufactures and cell manufactures Tianwei Yingli and Jing Ao and Ingot manufacturers Jinglong.
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Figure 14: Geographical Clusters in the Chinese PV Industry

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSI Technologies</td>
<td>Modules</td>
</tr>
<tr>
<td>EMEI Semiconductor Materials</td>
<td>Silicon</td>
</tr>
<tr>
<td>Harbin-Chronar</td>
<td></td>
</tr>
<tr>
<td>Hope Industry and Trade Co.</td>
<td>Modules</td>
</tr>
<tr>
<td>Kyocera (Tianjin)</td>
<td>Modules</td>
</tr>
<tr>
<td>LDK Solar Hi-Tech</td>
<td>Wafers</td>
</tr>
<tr>
<td>Luoyang</td>
<td>Silicon</td>
</tr>
<tr>
<td>Nanjing PV Tech</td>
<td>Cells</td>
</tr>
<tr>
<td>Ningbo</td>
<td>Wafers, Cell, Modules</td>
</tr>
<tr>
<td>Ningjin Songgong</td>
<td>Wafers</td>
</tr>
<tr>
<td>Shanghai Solar</td>
<td>Cells, Modules</td>
</tr>
<tr>
<td>Shanghai Topsola</td>
<td>Cells, Modules</td>
</tr>
<tr>
<td>Shenzhen Jiawei</td>
<td>Modules</td>
</tr>
<tr>
<td>Shenzhen Nenglian</td>
<td>Modules</td>
</tr>
<tr>
<td>Sichuan Xinguang</td>
<td>Silicon</td>
</tr>
<tr>
<td>Soltech</td>
<td>Modules</td>
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<tr>
<td>Suntech</td>
<td>Cells, Modules</td>
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<tr>
<td>Tianjin Jinneng</td>
<td>Modules</td>
</tr>
<tr>
<td>Tianwei Yingli</td>
<td>Wafers, Cells, Modules</td>
</tr>
<tr>
<td>Xi'An</td>
<td>Modules</td>
</tr>
<tr>
<td>Xinri</td>
<td>Wafers</td>
</tr>
<tr>
<td>Yunnan Tianda</td>
<td>Wafers, Cells, Modules</td>
</tr>
<tr>
<td>Zhejiang Sino-Italian</td>
<td>Wafers</td>
</tr>
<tr>
<td>Zhong Lian</td>
<td>Cells, Modules</td>
</tr>
</tbody>
</table>

Source: (Marigo, 2006)

High Technology Development Zones

National and provincial governments in China have established high technology development parks to attract foreign investment and to promote export industries and interactions between foreign and domestic firms. Suntech’s main production facilities, for example are located in Wuxi New District (WND), a national high-technology development zone, approved by the state council in 1992. Within the 22 square kilometre district, over a thousand foreign-funded enterprises, including Sony, Panasonic, GE and Kodak; five national technological innovation and industrialisation bases, including high-tech incubation services;
3 Legitimisation

The Chinese government has made a commitment to renewable energy and to PV in particular. Institutional arrangements such as R&D and fiscal and financial support for manufacturers, recognition as a high tech industry have served to increase investment confidence. Certification of modules and BOS through the REDP programme and through the pressure of German markets has established a level of quality and performance in the PV industry and will improve consumer confidence. Market growth and increasing density of installations will also benefit consumers as the service from installers and maintainers improves.

The rapid growth of the German market and the promise of a strong future for export markets as more countries make commitments to reduce greenhouse gas emissions and support renewable energy has certainly provided the Chinese industry with buoyancy; while domestic market measures such as feed in tariffs also demonstrate the Chinese government’s commitment.

The primary force for the legitimisation of PV in China, however, has been the formation of networks of manufacturers, which provide opportunities for new entrants to procure the resources they need, opportunities for learning by interacting and an increase in the stock of technological knowledge. These networks will be able to lobby for the continuance of favourable or even improved institutional arrangements for the technology.

4 Competitive Advantages in China

As a result of the 130 million rural migrant workers that take low paid jobs in the cities, labour costs in China remain amongst the lowest in the world (Li, 2004b). Unskilled wages can be less than US$200/month, or about US$1/hour, 1/10th of the wages paid in industrialised countries (Li, 2006; Pichel, 2006). The low cost of labour has multiple effects, since reduced automation results in reduced capital costs and it is affordable to have many trained personnel carrying out quality control and equipment repair functions.

Locally manufactured equipment for all but the most complex production tasks can be purchased for 30% of the cost of imported equipment (Zhao et al., 2006a). The sales and administration and R&D costs are also lower, as are tax rates (Pichel, 2006). Construction costs are also 10-20% of the typical cost in Europe (Li, 2006). The average cost of industrial land is also very cheap: US$0.2-0.4 million / hectare, while electricity is US 6c/kWh.

Some smaller manufacturers can afford to offer modules for 5-10% less than established brands in order to access export markets (Li, 2006), while larger manufacturers can expand, invest in R&D or make profits.
5.8. Conclusion

China began the 21st century with a collection of underperforming PV manufacturers who used outdated equipment and produced cells with low efficiencies. The solar cell research in China, too, was well behind that of the world leaders, and there were virtually no suppliers of equipment or materials to the cell manufacturers.

A rapid turnaround has occurred within the last seven years. China has been able to build on low cost manufacturing advantages to become the fourth largest producer of solar cells in the world, with the most rapidly growing production capacity. The PV innovation system in China is now able to supply the materials and equipment that manufacturers require, although most of the silicon must be imported. The stock of technological knowledge has been built up both within firms and research organisations; although there is a shortage of skilled staff and most of the industry and research organisations still lag behind the technological frontier. The incentives to invest in production and innovation have come largely from export markets, but with the support of the government, and as a result of the institutional arrangements resulting from the government’s strategy of allowing non-government owned firms to enter the market, encouraging foreign investment and export production.

The most important factor in the Chinese PV industry’s success has been the interactions that have facilitated rapid and well-focused learning by interacting, learning by searching, and the efficient and effective supply of resources throughout the value chain. Networks and clusters of firms, particularly in the upstream part of the value chain have built capabilities for quality production and research. There have been many interactions between firms and research organisations, which have been important learning opportunities, in terms of building human capabilities, and in terms of accessing innovative technologies.

These networks and the government’s support for the industry have combined to legitimise the technology and ensure favourable institutional arrangements.

In chapter 4 hypotheses were proposed about the important factors in the innovation system:

- Facilitate links to the technological frontier
- Built human capital and technology infrastructure
- Build on competitive advantages
- Access export markets
- Build Clusters

These have been validated…
Chapter 5. Suntech Case Study

While the Chinese PV innovation system has allowed Suntech to succeed, Suntech has also been a critical actor in the formation of the networks and international linkages that have been so critical to the growth of the innovation system. Suntech has been able to do this by:

- Building up very good production capabilities and understanding of the processing parameter interdependencies through large investments in world class training, including building capabilities for maintenance;
- A focus on continual improvement and quality control, which has led to high yields and high efficiencies;
- Moving rapidly into R&D and building innovative capabilities, which have enabled better understanding of processes and the development of proprietary processes. There has been a continuous effort in commercialising new technologies, which has been made possible through the flexibility of manual processing. The R&D work has also;
- Aggressively interacting with local suppliers to improve their products, which has been highly advantageous in reducing costs and has allowed Suntech to learn a lot about the upstream parts of the industry.
- Rapid expansion to access scale advantages and more influence in negotiations.

Suntech was fortunate to begin production coincident with the beginning of the German market expansion after the introduction of the feed in tariffs in 2000. The good reputation of CEO, Dr Shi and UNSW internationally was helpful in breaking into the market. Dr Shi also had the advantage of having an intimate knowledge of the technology and a clear idea of the technological future of the industry through his research background.
References

Eberhardt, K. (2005), *PV Production Facilities adapted to Technology Requirements - a Prerequisite for cost effective Mass Production*, 1st International Advanced Photovoltaic Manufacturing Technology Conference, Munich, Germany, April 13th.
Chapter 5. Suntech Case Study


