RIETI Discussion Paper Series 12-E-051

The Compressed Development of China's Photovoltaic Industry and the Rise of Suntech Power

MARUKAWA Tomoo
Institute of Social Science, University of Tokyo

RIETI
Research Institute of Economy, Trade & Industry, IAA
The Research Institute of Economy, Trade and Industry
http://www.rieti.go.jp/en/

RIETI Discussion Paper Series 12-E-051
August 2012

The Compressed Development of China's Photovoltaic Industry and the Rise of Suntech Power

MARUKAWA Tomoo
Institute of Social Science, University of Tokyo

Abstract

The global demand for photovoltaics (PVs), or solar cells, increased by 53 percent per annum during 2000 to 2010. Japanese PV manufacturers, which had been the leading force of the technological development of the industry since the 1970s, were in a good position to profit from this explosion of demand for PVs, but in 2010, about half of the global PV production was attributed to Chinese PV manufacturers which entered the industry only after 2002. This paper explains the reason for the dramatic rise of Chinese PV manufacturers and the decline of Japanese PV manufacturers. Through a detailed case study on Suntech Power, the largest PV producer since 2010, the paper identifies two points that have been critical for the rise of the Chinese PV industry: choice of technology and fundraising strategy. The paper also tries to shed new light on the understanding of the global value chain through a case study of the global PV value chain.

Key words: Compressed development, Photovoltaics, China; Suntech Power; Global value chain
JEL classification: Q42, O14, L69

This paper was written for the research project "Research on the Asian Business and Human Resource Strategy of Japanese Companies" at RIETI. The author would like to express special thanks to Professor Fang Yong at Nanjing University for making the interviews with Chinese PV manufacturers possible.

1. Introduction

Japanese manufacturers had been the leading force in the global photovoltaic (PV) industry until mid 2000s. They entered the industry during the 1960s and 1970s, when the device was only suitable for providing electricity where no other power was available—such as in satellites and remote lighthouses, for example—because of its high cost. They had been the main force in expanding its application to electronic products such as watches and calculators by reducing its production cost. In 1994, a Japanese manufacturer launched the residential solar power generation system which could produce the electricity a household needed on top of their house's roof. Since then, many countries around the globe started to regard solar power as one of the most prospective sources of energy in the future, by which, hopefully, mankind may be able to reduce its reliance on fossil fuels for energy and prevent the global warming process. With the introduction of feed-in-tariff policies in some developed countries, the global demand for photovoltaics, or solar cells, has skyrocketed since 2000, increasing at 53 percent per annum during 2000-2010. But when Japanese manufacturers were about to harvest the fruits of their long development efforts, many Chinese entrepreneurs jumped into the manufacturing of PV cells and modules and have taken away Japan's leading position in the industry, accounting for 62 percent of the global production in 2011. The Chinese PV industry is the most recent, and perhaps the most dramatic, case of "compressed development" (Whittaker, Zhu, Sturgeon, Tsai, and Okita 2010). The purpose of this paper is to explain why such a rapid rise of the Chinese PV industry and, at the other side of the coin, the rapid decline of the Japanese PV manufacturers have taken place.

PVs are a kind of semiconductor. Accordingly, China's rise in the global PV industry has certain factors commensurate with its rise in the global electronics industry: the modularity of product architecture, which made it easy for latecomers to enter the global value chain by specializing in the production of a certain module; and the shift of production technology from device manufacturers to equipment manufacturers, making it possible for latecomers to improve their technological capabilities rapidly simply by buying state-of-the-art production equipment. Besides these, two additional factors are notable in the case of China's PV industry: the fund-raising strategy and the choice of technology. The former two factors, namely, modularity and technology shift to equipment makers, can only explain why Chinese PV manufacturers could catch up with the forerunning Japanese manufacturers. The latter two, the fund-raising strategy and the choice of technology, are the critical factors that explain the reason that Chinese entrepreneurs were able to surpass their Japanese forerunners. This paper will discuss these points in detail.

In addition, this paper will discuss two points that will be relevant in comparing the case of the PV industry with other cases of latecomer's industrial development. The first is the role of the state. It was the Japanese rather than the Chinese Government, that has acted as a "developmental state" (Johnson 1982) in the development of the PV industry. We must consider the negative as well as positive impact of governmental involvement in industrial development. The second is the role of "lead firms." In the literature on global value chains, the dominant role of "lead firms," which are typically headquartered in developed countries, in shaping the structure of value chains and in assigning the role that suppliers must play seems to be taken for granted (Gereffi, Humphrey, and Sturgeon 2005). In the case of the PV industry, however, lead firms in major markets had only limited roles in shaping the structure of the value chain, and they were smaller in size than their suppliers in China. This observation leads us to an interesting question: what determines the power balance between lead firms and suppliers?

The remainder of this paper is structured as follows. In the second section, we introduce a framework to evaluate the choice of technology by PV manufacturers. The third section briefly reviews the development of the global and the Japanese photovoltaic industry. The fourth section discusses how Chinese entrepreneurs have made their way into the global PV industry and become leading manufacturers, focusing on Suntech Power, the largest PV manufacturer in the world since 2010. This section also discusses the central and local governments' role in Chinese PV industry development. The fifth section describes the relationship between the lead firms in major PV markets such as Germany and PV suppliers in China, and discusses the factors that shape the power balance between lead firms and suppliers. The sixth section concludes the paper.

2. Choice of Technology

The PV industry's value chain consists of five stages (Vietor 2012). The first stage is the production of solar-grade polysilicon. The method of making solar-grade polysilicon is quite similar with the method of making high-quality polysilicon for use in integrated circuits (ICs), though the requirement for purity in the case of the former is not as strict as in the case of the latter: solar-grade polysilicon is "seven-nine" (99.99999%) pure, while semiconductor-grade silicon is "eleven-nine" (99.999999999%) pure. The second stage consists of silicon ingot and wafer production in the case of crystalline silicon PVs. This stage is skipped in the case of thin film PVs. The third stage is the production of solar cells. By forming a junction of positive (P)-type and negative (N)-type semiconductors, the material will create electric current upon exposure to light. The fourth stage is the creation of modules, which are interconnected arrays of cells. The fifth stage is the integration of solar systems. A solar system consists of racks that mount solar modules on the ground or on the roof and an inverter which converts direct current (DC) electricity produced by solar cells to alternating current (AC) electricity.

The choice of technology which will be discussed in this section concerns the third stage the PV industry's value chain. While ICs use only monocrystalline silicon to make P-type and N-type semiconductors, PV cells can use various materials to make them. Currently, five types of materials are used in commercial-scale production of PV cells. *Monocrystalline silicon* will make PV cells with high conversion efficiency, that is, the proportion of sunlight energy converted into electrical energy, but its production cost is the highest among the five types of materials. *Multicrystalline silicon* will make PV cells that cost less and consume less electricity during the production process than monocrystalline silicon PV cells, though their conversion efficiency is lower than the latter. Thin-film silicon PV cells using *amorphous silicon* can be even cheaper, because their production does not need the process of casting ingots of crystalline silicon and slicing them into wafers, as in the cases of the former two materials. Instead, thin films of amorphous silicon are made by vapor disposition. This technology enables the manufacturer to economize the production cost, and to reduce the consumption of silicon materials to only 1% of the amount necessary to make crystalline silicon cells. There are two other types of materials currently used in the commercial-scale production of PV cells: *cadmium telluride* (CdTe) and *copper indium gallium selenide* (CIGS).[1]

Because PV cells are usually expected to have only one function—to generate electricity—there is almost no room for product differentiation by adding other functions to PV cells.[2] But, as mentioned above, there are several technological approaches using different materials to realize the function of generating electricity. These technologies can be evaluated by their conversion efficiencies and production costs.[3] Figure 1 shows

---

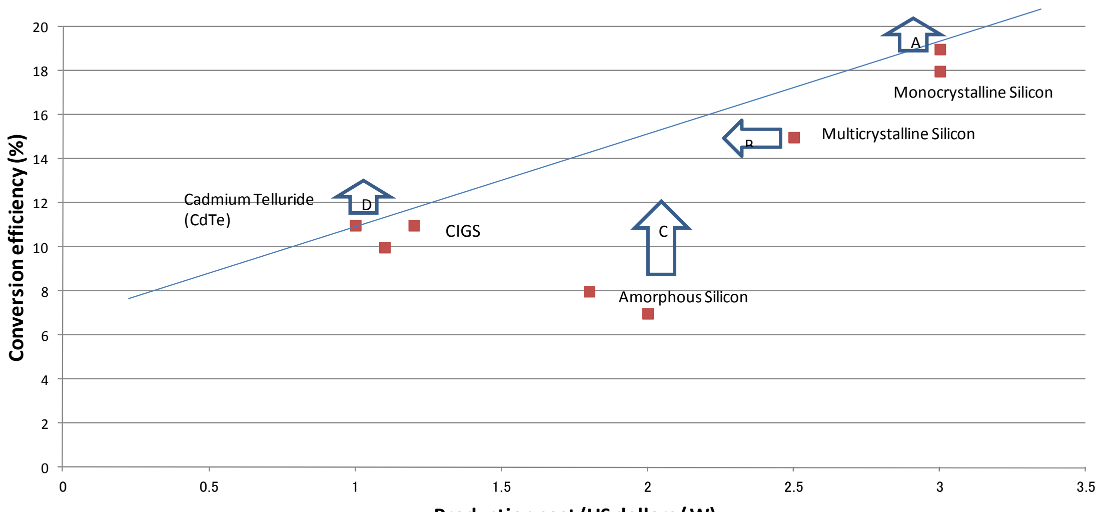
[1] Some other materials have the potentiality to be widely used in making thin film PV cells, such as *gallium arsenide* (GaAs) and *conductive organic polymers* (Saito 2009).

[2] There have been some attempts by PV manufacturers to add properties to PV cells to increase their applicability. For example, some Japanese manufacturers developed flexible PV cells that can be attached to curved surfaces.

[3] Another important point in evaluating the technologies is the durability of PV cells. Cells using conductive organic polymers are less durable than cells using inorganic materials (Saito 2009), but there seems to be no evidence about the durability of cells using various inorganic materials such as silicon, GaAs, CdTe, and CIGS. We assume that there is no difference in the durability of various types of cells compared in the following.

the conversion efficiency and production cost as of 2010 of the five most widely produced types of PV cells. Generally speaking, there is a trade-off between conversion efficiency and production cost; the higher the conversion efficiency is, the higher the production cost is. The envelope of the most cost-effective technologies, which is indicated by the straight line in Figure 1, represents the frontier of current technologies. PV cells using technologies that are far below the technological frontier, such as amorphous silicon in Figure 1, will find it difficult to compete with cells using technologies near the frontier, unless they have other useful properties. How, then, will the PV cells using technologies near the frontier be selected by their users?

Figure 1 Conversion Efficiency and Production Cost of Various Types of PV Cells



(Source) *Nikkei Electronics*, Feb. 8, 2010

Consider a photovoltaic power station that is going to erect a new PV plant in a limited space. The station is considering which type of PV cell to use in the new plant. The condition for the new plant to recover the initial investment and to earn profits can be written as

$$mypT \geq xm + Y(m), \qquad (1)$$

where m denotes the size of the plant in terms of the amount of PV cells used in the plant, y denotes the wattage that a single PV cell can generate in one hour, p denotes the price of electricity (per watt-hour) that the PV plant can expect to earn, and T denotes the duration (in hours) for which the PV plant is expected to operate. The left-hand side of the equation denotes the total revenue that the PV plant can earn during its lifetime. The right-hand side indicates the total cost of building the plant, in which xm denotes the cost of PV cells and x denotes the unit price (production cost) of the PV cell, and $Y(m)$ denotes other costs necessary for installing and operating the plant, including the cost of ancillary equipment such as inverters, construction cost, and maintenance cost. These costs will increase as the size of the plant increases, but because there is scale economy, they will not increase proportionately with the plant size. Hence, $Y'(m)>0$, $Y''(m)<0$.

As was discussed earlier in this section, there is a trade-off between the conversion efficiency and production cost of various types of PV cells around the frontier of current technologies. Assuming that there is a linear relationship between conversion efficiency and production cost at the frontier for simplification, we can write the relationship as fx, and since the wattage that the PV cell can generate per hour is proportional to its conversion efficiency, $y = Afx$, where A is a constant. Therefore, we can rewrite equation (1) as

$$mAfxpT \geq xm + Y(m). \qquad (2)$$

The first-order condition to maximize the profit (that is, the left-hand side minus the right-hand side of equation (2)) is

$$\frac{\partial(mx(AfpT-1)-Y(m))}{\partial m} = x(AfpT-1) - Y'(m) = 0,$$

or $$x = \frac{Y'(m)}{AfpT-1}.$$

This condition means that as $Y'(m)$ decreases as m increases, the optimum unit price of PV cells is lower in large-scale PV plants than in small-scale PV plants. In other words, an expensive type of PV cell, even if it were on the technological frontier and had a high conversion efficiency, will only be adopted by small-scale plants.

Evidence that PV plant owners are actually selecting the type of PV cells according to the above calculation is found in the prices of PV modules (that is, packaged and connected sets of PV cells) in major PV markets. In Japan, where most of the PV plants are small-scale residential PV systems installed on the rooftops of houses, the price of a typical module was 4.3 US dollars in 2010. In Spain, where most of the PV plants are large-scale power stations, module prices ranged from 1.8 to 2.6 US dollars. In Germany, where there are both the small-scale rooftop plants and large-scale stations, module prices ranged from 2.6 to 4.7 US dollars (IEA-PVPS 2011).

The above discussion indicates that there are several choices for PV cell manufacturers to be competitive in the PV industry. Not only those which succeeded in developing the cells having the highest conversion efficiency can be competitive; those which succeeded in cutting production costs of conventional cells can also be competitive. Therefore, there are several strategies that have actually been adopted by one or some of the global PV manufacturers to be competitive in the industry. In the following I will classify them into four.

The first strategy is to adopt the most efficient technology, monocrystalline silicon, and devote R&D resources to improve its conversion efficiency. This strategy is shown by the arrow “A” in Figure 1, and it has been pursued by Sanyo (later to merge with Panasonic), a Japanese manufacturer, and SunPower, an American manufacturer. Sanyo has a proprietary cell technology, which is called a HIT (heterojunction with intrinsic thin layer) cell, that combines monocrystalline silicon semiconductors with amorphous silicon layers. SunPower produces the “all-back contact” cells, which have removed wires from the front side of the cells to capture more sunlight. With these technologies, Sanyo and SunPower produce PV cells that have the highest conversion efficiency among the mass-produced cells in the world. But because of its high production cost, these cells will be an optimal choice only for small-scale residential PV plants. Therefore, the size of the market for high-efficiency PV cells remains small.

The second strategy is to adopt a technology that is easily accessible, such as multicrystalline silicon, and decrease its production cost by low input costs and large-scale production. This strategy is shown by the arrow “B,” and has been pursued by Chinese PV manufacturers including Suntech.

The third strategy is to select a technology that is not on the current technological frontier but has potential for improvement and devote R&D resources to improve its efficiency. This strategy is shown by the arrow “C,” and was pursued by Sharp, a Japanese manufacturer.[4] This strategy will be effective if the manufacturer succeeds in improving the technology’s efficiency dramatically and/or if the technological frontier moves downwards. During 2006-2008, the price of polysilicon, which is the material to make crystalline PV cells, soared from 66 US dollars per kilogram in 2005 to 300 US dollars in October 2006, and to 450 US dollars in April 2008.[5] With the steep rise in the polysilicon price, the production costs of PV cells using silicon were expected to rise, which would push the frontier downwards and give advantage to technologies that could economize the consumption of silicon.

The fourth strategy is to create a proprietary technology for making PV cells and let nobody else follow the technology by protecting it with intellectual property rights and vertical integration of equipment fabrication. This strategy is pursued by First Solar, an American manufacturer, which specializes in CdTe PV cells and modules.

A manufacturer may pursue two or more strategies at the same time, but in most cases, their focus is on one strategy. Therefore, the rise and fall of a PV

---

[4] *Nikkei Microdevices*, August 2008.

[5] *21-shiji jingji baodao*, February 20, 2009.

manufacturer is closely related with the rise and fall of a particular technology.

3. The Development of the Photovoltaic Industry

Photovoltaic cells were invented by Bell Laboratories of the United States in 1954. As mentioned in the "Introduction", PV cells were only suitable in providing electricity at places where no other power was available until the 1970s. In those days, the *energy payback time* of monocrystalline PV cells, which is the period of operation that is necessary to generate the equivalent amount of energy consumed for the production of the PV cell, was nineteen years (Hamakawa 1981: 27). This meant that unless the PV cells worked for more than nineteen years, producing PV cells was a sheer waste of energy. The leading force of the PV industry in those days was US manufacturers, accounting for 75% of the global production of PV cells in 1981 (Denki gakkai taiyo denchi chosa senmon iinkai 1985: 282). Since the 1980s, Japanese PV production grew by expanding the fields of applying PVs to calculators, watches, trickle chargers, and other portable electronic products. Since these products require only small power, amorphous silicon is extensively used for the PV cells installed in them. Japanese PV manufacturers accounted for 45% of the global PV production in 1987 (Maycock 1994). The share of Japanese manufacturers in global PV production has declined since then because of the saturation of PV cell markets for consumer electronic goods.

A new turning point came in 1994, however, when Sharp developed a residential PV system. This product was one of the results of the "Sunshine Plan", a plan administered by the Agency of Industrial Science and Technology, under the Ministry of International Trade and Industry, which, starting in 1974, aimed to develop new energy technology, including solar thermal, wind, geothermal, and solar power generation. One of goals of this Plan and the subsequent "New Sunshine Plan", starting in 1993, was to reduce the production cost of PV cells (RIST, 2012). Also in 1994, the Japanese Government introduced a subsidy program that would subsidize households constructing residential PV systems. This program lasted until 2005, as many as 254 thousand households received subsidies, and the total capacity of the PV systems installed using the program amounted to 932 MW (Sangyo taimuzusha 2007: 185). The electricity generated by the PV systems would be primarily consumed by the household that installed the system, but net billing was offered by the electricity utilities under a voluntarily scheme called the "excess electricity buying menu." The initial investment is large for a household (a 5.2-kW PV system cost 3.5 million yen, including the construction fee, in 2002), but the investment can be recovered partly by government subsidy, partly by the reduction in expenses for buying electricity, and partly by the sales of excess electricity. These policies stimulated the spread of PV systems among Japanese households. Japan had the largest cumulative installed capacity of PV systems in the world until 2004 (IEA-PVPS 2007). The expansion of the PV market in Japan triggered the growth of Japanese PV manufacturers. Japan's share in world PV production was only 24% in 1994, but since then, it started to expand, reaching 55% at its peak in 2004. As can be seen from the above, Japan's initial success in the PV industry is closely related to the Japanese Government's supportive policies in R&D and in creating demand for PV systems.

The severe deficit of the Japanese Government's budget, however, did not allow the subsidy program for PV system installment to continue. The end of the program in 2005 led to a decline in domestic demand for PV systems after 2006 (Table 1), though subsidy programs run by local governments continued. With the wane of the Japanese market, the main market for PV systems shifted to Europe. Germany's annual installed capacity of PV systems surpassed that of Japan's in 2004 (Table 1), and its cumulative PV system capacity has been the largest in the world since 2005. Germany accelerated the introduction of renewable energy resources since 2000, when the country decided to abolish nuclear power plants in the future and promulgated the Renewable Energy Sources Act. This act obliges power utilities to buy all the electricity produced by renewable energy sources, such as wind power and solar energy. Utilities must buy such electricity at a price fixed by the law. The price is adjusted every year, but for an individual plant, the selling price of electricity is fixed for twenty years from its establishment. The price was very favorable for an investor in a PV power plant: in 2006, for example, the selling price was 0.518 euros/kWh, when the retail price of electricity for households was 0.18 euros/kWh. This was a very favorable condition for PV system investors compared to that in Japan. In Japan, the selling price of electricity produced by PV plants was 24 yen/kWh (approximately 0.16 euros) in 2006, which was the same as the retail price of electricity for households. Utilities buy only the excess electricity that the household does not use by itself. There was no guarantee for the duration of this buying scheme, so investors were uncertain of whether they could recover their initial investment or not. The Renewable Portfolio Standard Act promulgated in 2003 obliged utilities to use renewable energy sources up to a certain percentage of their total procurement of electricity, but since this obligation was very low (it was 1.35% in 2010, for example), utilities were reluctant to buy electricity from large-scale PV plants and wind power generators. Therefore, most of the PV power plants in Japan are small-scale residential PV systems. There were 719 thousand residential PV plants at the end of

March 2011, the average capacity of which was 3.8 kW.[6] Faced with the stagnation of the growth of PV system installations and the decline of the Japanese PV industry, the Japanese Government tried to boost PV demand by doubling the buying price of electricity made by PVs in November 2009 and by obliging power utilities to buy electricity at this price for ten years from 2009. This policy led to the recovery of PV installations in Japan (Table 1), but because this policy was applied only to small-scale residential PV plants, the size of the Japanese PV market fell far short of Germany's. The new Feed-in Tariff Law, which was approved by the parliament in August 2011 and will be effective in 2012, will boost the installations of PV systems in Japan, because this law will enable not only small-scale residential PV plants but also utility-scale PV plants to sell all the electricity they produce to power utilities at a fixed price for a duration of fifteen to twenty years.

Table 1 Annual Installations of Photovoltaic Power by Selected Countries

Unit: MW

Country	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Germany	7	5	9	44	110	110	143	635	906	951	1,274	1,955	3,799	7,411
Japan	32	42	75	122	123	184	223	272	290	287	210	225	483	991
United States	12	12	17	22	29	44	63	101	103	145	207	338	448	918
Spain	0	0	0	0	2	3	5	11	25	99	557	2,758	60	392
Korea	0	1	1	1	1	1	1	3	5	22	45	276	167	131
Italy	1	1	1	1	1	2	4	5	7	13	70	338	723	2,321
China	-	-	-	-	6	-	10	10	5	10	20	40	160	500
All IEA PVPS Countries	62	74	116	207	288	371	481	1,058	1,367	1,639	2,465	6,146	6,265	14,195

(Source) International Energy Agency, *Trends in Photovolatic Applications:Survey Report of Selected IEA Countries* between 1992 and 2010. Report IEA-PVPS T1-20:2011.

The PV systems market in some other countries has been very unstable since 2008. The sudden expansion of PV installations in Spain in 2008 was an outcome of a fluctuation of policy. Spain introduced a generous feed-in tariff scheme for PV plants in 2007, with a national cap of PV installations of 400 MW per year. The government considered in 2008 raising the cap and then lowering it. While the government was considering the new rule, investors tried to install as many projects as they could before the new rules were set. Faced with the unexpected expansion of PV installations, the Spanish Government dramatically shrunk the incentives for PV plants in 2009 (Wong 2009). The sudden rise of Italy in 2010 also has a similar reason. Italy started an incentive program for PV installations in 2005. The third phase of the program

6 These data are calculated on the basis of the information provided on the Renewable Portfolio Standard Act website, Agency for Natural Resources and Energy.

announced in August 2010 led investors to expect that feed-in tariffs would be reduced from 2011, triggering a sharp increase in the number of installations (IEA-PVPS 2011).

The big fluctuations in demand for PV systems since 2004, together with the shift of the main market from Japan to Europe, may have been one of the reasons for the decline of Japanese PV manufacturers. The size of PV installations in 2010 by the Photovoltaic Power Systems Program (PVPS) members of the International Energy Agency, which consists of twenty-five countries that cover all the important PV markets in the world, was more than thirteen times larger than that in 2004. Japanese PV manufacturers did respond to the shift in the market by expanding exports: in 2002, 68% (186 MW) of the PV cells they produced were sold in Japan, but in 2008, 79% (884 MW) were exported. However, this was not enough to fulfill the steep rise in demand in Europe. This gave room for new entrants to expand their sales.

Table 2 PV Cell Production by Major Manufacturers (Unit: MW)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Suntech (CH)				28	82	158	327	498	704	1,584	2,070
First Solar (US)			3	6	20	60	207	504	1,011	1,400	1,981
JA Solar (CH)						25	113	277	509	1,464	1,775
Yingli Solar (CH)					10	35	143	282	525	1,117	1,684
Trina Solar (CH)						7	37	210	399	1,116	1,604
Motech (TW)	4	8	17	35	60	102	176	275	360	715	1,120
Canadian Solar (CH)							8	72	326	523	1,058
SunPower (US)					23	63	100	237	398	520	922
Gintech (TW)							55	180	368	800	882
Sharp (JP)	75	123	198	324	428	434	363	473	595	745	857
Neo Solar (TW)							36	102	200	530	806
Hanwha-SolarOne (CH)							88	173	220	532	788
Q-Cells (GER)		8	28	75	166	253	389	570	537	939	783
Kyocera (JP)	54	60	72	105	142	180	207	290	400	650	660
Sun-Earth (CH)							8	80	260	421	
E-TON (TW)							60	95	225	420	
Sanyo (JP)	19	35	35	65	125	155	165	215	260	405	
China Sunergie (CH)							80	111	160	336	
Schott (GER, CZ)	21	30	42	63	95	93	79	145	102	320	
Mitsubishi (JP)	14	24	42	75	100	111	121	148	120	210	
Kaneka (JP)	8	8	14	20	21	28	43	52	40	25	
Total	371	542	749	1,199	1,782	2,459	3,710	6,823	10,660	23,889	

(Source) PV News Vol.31 No.5, Vol.30 No.5, Vol.29, No.5, Vol.28, No.4

In 2007, Sharp lost its leading position in global PV cell production, which the company had kept for seven years in a row since 2000, to Q-Cells of Germany, which was a new entrant to the industry. Q-Cells was established in 1999 and started producing PV cells in 2001. Q-Cells was a specialized PV cell manufacturer until recently, but the company can now supply PV systems as a whole. Its technology strategy is the “B” type according to our classification in Figure 1. The company has adopted easily accessible technologies, such as monocrystalline and multicrystalline silicon, and reduced production costs by erecting a manufacturing plant in Malaysia. In

2009, First Solar of the United States became the top PV cell manufacturer in the world. First Solar's strategy is the "D" type according to our classification: the company has a proprietary technology of CdTe cell production, and has achieved high conversion efficiency with low production costs by continuous research and development. This is not to say that CdTe technology is monopolized by First Solar; in fact, Panasonic (Matsushita) produced CdTe cells in the early 1990s (Maycock 1994: 698). But Japanese manufacturers were reluctant to pursue CdTe technology because it used cadmium, a substance which has a bad reputation in Japan for being harmful to human health. They were surprised when the European market, which was believed to be strict on harmful substances, accepted the import of First Solar's PV cells on a large scale (Nikkei Microdevices and Nikkei Electronics 2008: 95). In 2010, Suntech of China became the largest manufacturer of PV cells in the world. In this year and the subsequent year, four of the top five PV cell manufacturers were Chinese companies (Table 2). The reason that the Chinese manufacturers could reach this position so rapidly and the reason for the rapid decline of Japanese manufacturers are the topics to be discussed in the next section.

4. The Rise of Suntech Power and the Chinese PV Industry

In 1984, the first PV cell in China was produced by a state-owned electronics manufacturer based in Nanjing.[7] The growth of the PV industry in China, however, started with the establishment of Suntech Power in 2001. The company was created by a Chinese engineer named Shi Zhengrong, who had earned a Ph.D on photovoltaic engineering at the University of New South Wales. Dr. Shi returned to China in 2000 with a plan to manufacture PV cells. He asked Shanghai City and his hometown Yangzhong City, Jiangsu Province, whether they were interested in investing in his venture. Finally Dr. Shi managed to persuade Wuxi City Government to help his venture. Wuxi City agreed to let local state-owned enterprises and government funds invest 6 million US dollars in the venture, while Shi would contribute the technology he owned and 400,000 dollars of his own money in exchange for 25 percent stake in the venture (Dai and Kishimoto 2011, Davila, Foster, and Jia 2010). In 2002, Suntech created a PV cell-manufacturing line with an annual capacity of 10 MW. This was the first mass production line of PV cells in China. The total PV cell manufacturing capacity

[7] Xu Ruilin, Jiangsu Photovoltaic Industry Association, interview with the author, August 24, 2011.

in China before the launch of Suntech's production line was 2.7 MW per year.[8] In 2005 Shi bought out the shares of the state-owned shareholders for 100 million US dollars to have full control of the company and to pave the way for the listing of its stocks on the New York Stock Exchange (NYSE) in December 2005 (Powell 2009). Suntech's success in exporting its PV cells and modules to the European market, and the listing of its stocks on the NYSE, by which the company raised almost 400 million US dollars in its initial public offering (IPO), has stimulated the emergence of many followers in China. As can be seen in Table 2, many Chinese companies have started the production of PV cells since 2005 and have aggressively expanded their production volume.

The rapid rise of Chinese PV manufacturers was made possible, firstly, because production technology shifted from PV manufacturers to equipment manufacturers. Japanese PV manufacturers had tried to keep their production technology to themselves by fabricating the production equipment on their own, except for the initial stage of mass production (Watagi 2008: 14). But gradually, equipment manufacturers absorbed the production technology and marketed PV manufacturing equipment to new entrants. Some equipment makers, such as Applied Materials, Ulvac, and OC Oerlikon Balzers, even provide "turn-key solutions" of PV cell manufacturing, which makes it very easy for new entrants to start production if they have the money to buy such solutions (Kawai 2008).

The rapid growth of Suntech Power in solar module manufacturing since 2006 may also be related to the acquisition of MSK Corporation, a small Japanese PV manufacturer, in 2006. Suntech explained to its shareholders that the purpose of the acquisition was to acquire the building integrated photovoltaics (BIPV) technology on which MSK had several patents and to expand distribution channels in Europe and Japan which MSK had exploited (Suntech 2007). But another hidden motive of acquiring MSK was to absorb Sharp's solar module production technology. MSK had been engaged in OEM production of solar modules for Sharp since 2000.[9] Through the relationship as a contract manufacturer for Sharp, it is likely that the module production technology of Sharp, which was the top brand of PV systems at that moment, was transferred to MSK. In fact, Suntech transferred MSK's module production facility to China after the acquisition[10] and in 2007, the next year of the acquisition, the proportion of revenue from selling modules increased to 99 percent, markedly higher than in 2006 (79 percent) and in 2005 (75 percent).

---

[8] Chen Xiaodong, Suntech Power Holdings, interview with the author, August 23, 2011.
[9] Shinji Horiuchi, MSK Corporation, interview with the author, January 22, 2007.
[10] Suntech Q1 2007 Earnings Call Transcript, May 29, 2007.

The second reason for the rapid rise of Chinese PV manufacturers resides in the fact that they can enjoy low input costs. Lacking experience in PV production, new entrants may produce PV cells that are inferior in their conversion efficiency than the products of incumbent manufacturers. But Figure 1 suggests that, even if the efficiency of the PV cells produced by the new entrant is one percentage point lower than those made by incumbent manufacturers, the new entrant can still be on the technological frontier if it succeeds in cutting production costs by 8 percent. Therefore, Chinese PV manufacturers can easily make marketable cells by taking advantage of low input costs. Shi Zhengrong of Suntech Power said in 2003 that the company could sell solar panels at 2.8 dollars per watt when the standard industry price was 4.5 dollars per watt and still had 20 percent profit margins (Powell 2009). Suntech also reduced automation in its cell manufacturing process to use more manpower and to take advantage of low labor cost in China (Davila, Foster, and Jia 2010).[11] The reason that most of the Chinese PV manufacturers have selected conventional technologies such as multicrystalline silicon technology and not new technologies such as CIGS, which had been selected by many of the new entrants in the Japanese PV industry, is also related to their considerations on labor cost. The production process of CIGS requires highly skilled workforce, while multicrystalline silicon does not,[12] so the Chinese manufacturers can take full advantage of low wages of unskilled labor in China.

The decline of Japanese PV manufacturers can also be explained by their input costs. Japanese manufacturers were reluctant to erect PV plants outside of Japan because they were afraid of leakage of technology. This decision has created room for new entrants to have an advantage in production costs over Japanese manufacturers. It is reasonable for Chinese manufacturers to select an accessible technology and try to reduce production costs by mobilizing cheap inputs and by enlarging the production scale, namely, the "B" strategy discussed in Section 2.

The third reason for the rise of Chinese PV manufacturers is their aggressiveness in raising funds compared to their Japanese rivals. Chinese PV manufacturers need to raise the funds to expand production capacity because most of them are private ventures that receive little, if any, support from the government. Suntech's success in raising 400 million US dollars by listing its stock on the NYSE has become a model case that virtually all major PV manufacturers in China have imitated. Among the eight Chinese manufacturers listed in Table 2, all of them except for

[11] Contradicting with this view, however, Bullis (2011) reports that Suntech had "increased automation over the last few years" and used less workers than before.
[12] Chen Xiaodong, interview.

Sun-Earth have their stocks listed either on the NYSE or on the NASDAQ. Such globalization of fund-raising is also found in other new industries of China, such as economy hotel chains, semiconductors, and internet services. Because the domestic stock exchanges in China give priority to state-owned enterprises, more and more private ventures go directly to foreign stock exchanges, in particular to the United States, to raise funds by IPO. Chinese PV manufacturers invested most of the funds raised in the United States in the expansion of production facilities in China. With this new route of raising funds, Chinese PV manufacturers have never given way to their Japanese rivals, which are vertically integrated and horizontally diversified conglomerates, in the race for production expansion.

The critical year was 2007, when new incentives created a surge of demand for PV systems in Germany and Spain, and the global production of PV cells recorded a 51% growth. The sudden growth in PV cell production led to a shortage of solar-grade polysilicon and a steep rise in its price. Before then, PV cells used the waste of semiconductor-grade polysilicon. But as demand for PV cells increased, waste polysilicon would not be enough to fulfill demand. Polysilicon manufacturers invested in new plants for making solar-grade polysilicon, but before these new capacities started operation, its supply remained tight. Chinese PV manufacturers did their best to procure polysilicon because with insatiable demand for PV cells at that time, the only bottleneck PV manufacturers faced was the shortage of polysilicon. Suntech entered a ten-year agreement in 2006 with MEMC, an American silicon wafer maker, to buy 5-6 billion US dollars of silicon wafers in total. Besides this, Suntech acquired minority stakes in six polysilicon and wafer makers in May 2008 and January 2009 (Suntech Form 20-F, 2008). All of these investments in upstream suppliers were based on the need to acquire the material. Japanese manufacturers were less aggressive in procuring polysilicon than their Chinese and European rivals at that time. This was because they faced tighter cash constraints than their rivals. Chinese PV manufacturers and Q-Cells could raise the cash to procure polysilicon directly from the stock markets through IPO. But since Japanese PV manufacturers are divisions of diversified conglomerates, they need to go through internal procedures for the allocation of funds within the corporation. The headquarters of Japanese conglomerates would not increase the allocation of funds to the PV division so quickly, because such decision would sacrifice their other lines of business. Because of the shortage of polysilicon, Japanese PV manufacturers suffered from low growth rates compared to the world average in 2007 (see Table 2).

Sharp was the most extreme example. The company was one of few cell manufacturers that experienced negative growth in 2007. This was not only the result of the company's failure to procure polysilicon, but also the result of the company's technology strategy. With the steep rise in the polysilicon price, Sharp expected that amorphous silicon cells would be an economical choice for PV plants.[13] The company started the construction of a 1-GW amorphous silicon cell plant (Nikkei Microdevices and Nikkei Electronics 2008: 36). Sharp expected that the shortage of polysilicon would continue for a while, and that this fact would push the technological frontier downward. On the other hand, the company expected that it would succeed in enhancing the conversion efficiency of amorphous silicon cells to more than 10% by 2010.[14] Sharp adopted the "C" strategy according to our classification in Figure 1.

As things turned out, however, all of the expectations that pushed Sharp to erect a huge amorphous silicon cell plant were wrong. The sharp reduction of incentives for PV plants in Spain in early 2009 led to the stagnation of demand for PV cells in Europe. Besides this, several solar-grade polysilicon plants started operation during 2008-2009 (Fuji Keizai 2009: 151-156). These facts caused the spot price of polysilicon to drop from 450 US dollars per kilogram in April 2008 to only 65 US dollars per kilogram in May 2009. Besides this, the conversion efficiency of amorphous silicon cells did not improve as Sharp had expected. Another unexpected incident was the growth of First Solar that specialized in CdTe cells. The efficiency of First Solar's cells improved from 10.4% in 2007 to 11.3% in 2010 while the production cost of modules dropped by 45% during the same period, which pushed the technological frontier upward, leaving amorphous silicon technology far below the frontier. Suntech stopped operating its amorphous silicon cell plant in 2010,[15] while Sharp remained indecisive. Sharp's persistence in pursuing the development of amorphous silicon technology might have been influenced by the government-led R&D program in Japan, the "New Sunshine Plan", which had listed amorphous silicon and compound semiconductor[16] as the main focus of R&D.

Besides the choice of technology and aggressive fund-raising, vertical integration strategy may partly explain the rise of Suntech and other Chinese PV manufacturers. With a big fluctuation of demand for PV systems, caused by policy changes in major markets, the desirable vertical integration strategy changes from time

---

[13] Mr. Mikio Katayama, president of Sharp, said in an interview in April 2008 that "thin-film silicon cells will be very cost effective. It is also a technology in which Sharp can show its advantage" *Nikkei Electronics*, May 5, 2008.

[14] Interview with Mr. Tetsuro Muramatsu, cited in *Nikkei Microdevices* August 2008.

[15] Suntech Power Holdings Co., Ltd, *2010 Corporate Report*; interview with Mr. Chen Xiaodong.

[16] Compound semiconductors are those that use two or more elements, such as CIGS, which has been adopted by many new entrants in the Japanese PV industry.

to time. During 2007-2008, when the demand for PVs was rapidly increasing, while their supply could not catch up with the increase of demand due to the bottleneck in polysilicon supply, those manufacturers which could have an ample supply of polysilicon were at a good position in expanding their market share. It was natural that Q-Cells, which had REC, a polysilicon and wafer maker, as a subsidiary, and Suntech, which invested aggressively in upstream suppliers during these years as mentioned above, could exceed Sharp in production volume. Sharp did not join the scramble for polysilicon because it believed that amorphous silicon technology would be competitive in the near future.

In 2009, however, when the Spanish market collapsed, having a captive supplier of polysilicon became meaningless because polysilicon was now easily available at a low price. When there is oversupply of PVs, PV manufacturers try to secure sales by integrating the downstream of the value chain. Sharp has been actively pursuing the downstream integration strategy since 2010. In 2010, Sharp established a joint venture with Enel of Italy to run solar power plants in Italy and other countries, and acquired Recurrent Energy, an American developer of solar power plants. In 2012, Sharp invested in solar plants in Canada. Suntech started integrating the downstream in 2008, when it formed a joint venture named Gemini Solar to develop, finance, own, and operate solar power plants in the United States, and acquired El Solutions, a system integrator which gave advices to solar power investors on system engineering and design (Vietor 2012). In Europe, Suntech invested in Global Solar Fund (GSF) in 2008, which provided financing to solar plant developers. The weakness in downstream sales channels may explain the reason of the predicament of Q-Cells, which filed for insolvency in April 2012. Starting as a specialized PV cell manufacturer, Q-Cells relied 69 percent of its sales on PV cells, while 15 percent came from modules and 16 percent from systems in 2010. Q-Cells tried to expand its sales from modules and systems, but during the severe recession of PV demand in Europe in the latter half of 2011, the company had difficulties in the finding the market for its cells.

Chinese PV manufacturers, including Suntech, were accused of receiving unfair state supports, and were imposed a punitive import tariff by the United States government in May 2012. However, the Chinese PV industry had relatively little support from the central government during the course of its development, compared to many other industries. The national five-year plans never referred to the PV industry until the current Twelfth Five-Year Plan (2011-2015), in which photovoltaic power generation is referred to as one of the “strategic new industries,” along with wind power generation, new-energy vehicles, and many other industries. When the plan was drafted, China was already the top PV producer in the world. The government's involvement in the PV industry is in sharp contrast with that in wind power generation. The government obligated wind power stations to procure windmills that had a local content of more than 70% during 2005-2009. This policy induced the growth of domestic windmill manufacturers such as Sinovel, Goldwind, and Dongfang Electric, all of which are more or less state-owned. By contrast, all of the major PV cell and module manufacturers in China, with the exception of Sun-Earth, are private companies. They raised funds abroad because they were underprivileged in the domestic capital market. The government did not make requirements regarding the local content of PV plant equipment. In fact, there was virtually no market for PVs in China until recently (see Table 1). The PV industry is one of the few industries in China in which few state-owned enterprises are involved, and the domestic market has not been important.

Some local governments have played a slightly more positive role than the central government in the development of the PV industry. As mentioned before, Wuxi City invested 6 million US dollars in Suntech. This was a great help for Suntech to get started, but the initial investment by the state sector in the venture is dwarfed when compared with the 400 million US dollars raised by the company on the NYSE. Shangrao City, Jiangxi Province, has given preferential treatment to Jinko, a PV manufacturer, in the provision of land and electricity.[17] However, these are only generic preferential policies that will be extended to all kinds of high-tech ventures. It is not that these local governments have targeted the PV industry as a "developmental state" would do.

Only after 2009 did the central government start to promote the expansion of photovoltaic applications in China. Since 2009, the government has launched several large-scale solar power plant projects, as if to adjust the excessive reliance of the domestic PV industry on exports. In August 2011, the government announced the selling price of electricity generated by PV plants to be 1.15 yuan/kWh (0.125 euros) for the first time. This announcement will trigger the growth of domestic PV installations, because PV plants can now be certain that the electricity they produce will be bought by power utilities, though the selling price is very low, compared to the prices in Germany and Japan. These positive policies may be the result of lobbying conducted by major PV manufacturers.[18] Insertion into the global value chain of PV systems has led to the dramatic expansion of the PV industry in China. And the growth of the PV industry in

[17] Based on the author's interview with Jinko Solar, August 16, 2010.

[18] Jiangsu PV Industry Association, which was organized by Suntech and other major PV manufacturers in Jiangsu Province and headed by Dr. Shi Zhengrong of Suntech, has been lobbying for provincial government support for the PV industry.

China, which was beyond the expectations of the government, is now in turn promoting the application of PVs in China. Without the growth of the domestic PV industry, the Chinese Government would not be interested in installing PV plants, because their cost of generating electricity is still much higher than conventional power plants and windmills, and because China has not yet committed itself to a reduction in CO2 emissions. Compressed development of the PV industry induced the compressed development of PV application in China.

5. Relationship between Lead Firms and Chinese PV Manufacturers

The growth of Chinese PV industry is triggered by the expansion of demand for PV systems in Europe, the United States, and Japan. The Chinese PV industry constitutes only a part of the global value chain of PV systems. To understand the structure of this chain, we will pay attention to the three key factors that, according to Gereffi, Humphrey, and Sturgeon (2005), determine the type of global value chain governance, namely, 1) complexity of transactions, 2) ability to codify transactions, and 3) capabilities in the supply base.

Chinese PV manufacturers supply PV modules or cells to European companies, and the latter combines them with other parts of the system and sells them through various channels to end-users in Europe. European companies act as lead firms in this value chain. There are two types of division of labor between Chinese suppliers and European lead firms.

First, Chinese suppliers provide PV cells and European firms manufacture PV modules. The modules carry the latter's brand, and are sold directly to EPC (engineering, procurement, and construction) companies, which procure the equipment (including PV modules) and construct PV plants, or to installers of PV systems through dealers.[19] This is the type of division of labor found between Suntech and Aleo Solar AG of Germany, for example. In this case, an arm's length market relationship is seen between the cell suppliers and module manufacturers. This is because the complexity of the transaction is low, the transaction is easily codified—only a few figures, such as the conversion efficiency and the size, will be sufficient to describe the PV cell—and capabilities in the supply base are high because of the diffusion of cell production technology by equipment manufacturers. In this type of division of labor, end-users may not be aware that they are using PV cells made by Chinese manufacturers.

Secondly, Chinese suppliers provide PV modules and European firms combine

[19] Aleo Solar AG, *2010 Annual Report*.

them with inverters and other ancillary equipment and provide them to installers. In this case, PV modules are sold under Chinese suppliers' brands. This is the type of division of labor found between Suntech and German companies such as Bihler GmbH and IBC Solar. Again, the transaction is easily codified—the specification of PV modules can be completely described by some figures—and the capabilities in the supply base are high. However, the transaction is somewhat more complex than the first type, because the PV module suppliers offer product warranty to the end-users. Both Bihler and IBC Solar procure PV modules from four suppliers including Suntech. This relationship can be classified as a "modular" type of supply chain governance (Gereffi, Humphrey, and Sturgeon 2005).

In Europe, Chinese manufacturers including Suntech are acting only as suppliers of PV cells and modules, but, in Japan's residential PV systems market, Suntech is supplying the whole PV system to end-users, by procuring inverters and other ancillary equipment on its own.[20] This fact indicates that Suntech's role in the global value chain is not shaped unilaterally by the lead firms in developed countries. Suntech can become the lead firm itself, as in the case of the Japanese residential market, if it is necessary to assume this role to enter the market. Besides this, Chinese PV manufacturers are not like the suppliers in developing countries that capture only a fraction of the total value of the products they manufacture. Compare the size of total assets and ROA of Suntech and one of its lead firms in Europe, Aleo Solar AG (Table 3). Suntech is much bigger in size, and has almost equally high ROA. How can the component suppliers in the PV industry enjoy high ROA? What determines the power balance between lead firms and suppliers?

Table 3 Comparison of Suntech and Aleo Solar

(Unit: Million US$, percent)

Year	2007	2008	2009	2010
Total Assets				
Suntech	1967	3207	3984	5217
Aleo Solar	148	276	215	239
ROA				
Suntech	14%	10%	9%	10%
Aleo Solar	9%	8%	7%	17%

(Source) Corporate Reports

It seems that the relative importance of PV cells in determining the technical features and cost of the PV system determines the strong position of PV cell

[20] Based on the author's interview with Mr. Yutaka Yamamoto, Suntech Power Japan Corporation, November 28, 2011.

manufacturers. PV cells account for at least 50% of the total cost of constructing a PV plant.[21] Since the competitiveness of a PV system largely depends on the PV cells used in the system, the cell supplier assumes the leading role in the value chain.

6. Conclusion

The rapid growth of the Chinese PV industry and the rise of Suntech Power show how the development path of developing countries can be compressed by insertion into the global value chain. When production technology is easily accessible simply by buying state-of-the-art equipment, developing countries do not need to accept foreign direct investment (FDI) to obtain the latest technology. The only thing they need is the money to buy such equipment. The money can also be raised abroad if domestic entrepreneurs can persuade investors that they have the potential to be competitive. A "developmental state" that mobilizes funds for investment is not necessary. The development of the Chinese PV industry indicates that industrial development in a developing country can take place without a developmental state and without inward FDI. What China had were entrepreneurs like Dr. Shi Zhengrong, who had the technology and the devotion to the PV business. In a rapidly-changing industry, the speed of making decisions can be crucial. Sharp lost its position as the top PV manufacturer because it was slow in procuring polysilicon. Q-Cells went bankrupt because it was slow in downstream integration. The choice of technology must also be made at the right time. Sharp persisted on amorphous silicon technology even after the price of polysilicon collapsed, leading to its decline in the global PV industry. PV cells with high conversion efficiency may have a robust demand when a lot of small-scale residential PV systems are installed, but their growth may slow down when a lot of large-scale solar power plants are built. Suntech survived all of these challenges because it has been quick in adapting to the changes in the global PV market.

The main purpose of this paper is to explain the rapid rise of China's PV industry, but we can draw some implications for the Japanese governmental policies and corporate strategies. First, we need to point out that the Japanese policies had been very effective in nurturing an infant industry into a promising industry, by encouraging

[21] The cost of PV modules accounts for 61.5% of the total cost of building a PV system on the roof of an existing house, while the inverter, other ancillary equipment, and construction cost account for 12.3%, 10.8%, and 15.4%, respectively. The proportion of the latter three will be smaller in the case of large-scale PV plants built on the ground. PV cells account for 81.3% of the cost of modules, or 50% of the cost of building a rooftop PV system. Data are from Fuji Keizai (2009).

innovation and creating domestic demand. The decline of Japanese PV industry can be partly explained by the wane of domestic demand caused by the decrease in subsidies for PV installments. Incentives provided by the new Feed-in-Tariff Law, which will be effective in 2012, will boost the demand for PVs and may lead to the recovery of Japanese PV manufacturers. The development of PV industry still needs policy supports. Secondly, the Japanese Government must not resort to protectionism to help the waning domestic PV manufacturers. Some economists suggest that the Government must introduce compulsory equipment qualification system to curb the expansion of Chinese PV modules (Ohashi, 2012). But such system may pave the way for protectionism. Such policy may curtail domestic demand for PVs and weaken the competitiveness of domestic PV manufacturers. The peculiar structure of Japanese PV market itself, which is characterized by the abundance of small-scale PV power plants, provides an opportunity for Japanese PV manufacturers, which produce PV cells that have high conversion efficiencies. Thirdly, Japanese PV manufacturers must reconsider their product and development strategy. Having a long experience in selling household electronics to matured markets, they have a tendency to adopt product differentiation strategies. They have tried to add more value to their products by improving their function and quality and avoid commoditization. They have adopted the same strategy in the PV industry, and devoted R&D resources for the improvement of conversion efficiency, indicated as "A" and "C" strategies in Figure 1. This strategy, however, is not effective in the PV industry, because it is still growing very rapidly. By commoditizing PVs, which means to decrease their production cost, their demand can expand tremendously, because PVs will be preferred to other energy sources if they are cheap enough. Therefore, every player in the industry can win if they can collectively make PVs cheaper[22].

References

Bullis, Kevin. 2011. "Suntech Power's CTO argues that the secret to China's success is not cheap labor but advanced equipment for making solar cells" *Technology Review*, July 6.

[22] After finishing this paper, Suntech revealed that the company was defrauded by its subsidiary, Global Solar Fund (GSF), which falsely claimed that it had posted $691.68 million in German bonds as collateral for solar power plant projects built by GSF in Italy . With mounding debt caused by the downturn of European solar market since 2011, Suntech had planned to earn cash by selling its stake in GSF, but this plan may be frustrated by the outbreak of the fraud by GSF(Jiang, 2012). Amidst a difficult debt situation and allegations of financial impropriety, Suntech's founder, Dr. Shi Zhengrong announced to resign from CEO (Wesoff, 2012). Suntech will face insolvency crisis in the near future, but this fact does not necessarily mean that the strategy to commoditize PVs has been mistaken.

Dai, Erbiao and Chikashi Kishimoto. 2011. "Chugoku ryugakusei kigyo no yakushin to chiho seifu no yakuwari" [The rise of enterprises created by returning students in China and the role of local governments] *Akamon Management Review* Vol. 10, No. 1.

Davila, Antonio, George Foster, and Ning Jia. 2010. "Suntech Power Holdings (A): The Pre-IPO Years" Case E347-A, Stanford Graduate School of Business.

Denki gakkai taiyo denchi chosa senmon iinkai ed. 1985. *Taiyo denchi handobukku* [Handbook of photovoltaics] Tokyo: Denki gakkai.

Fuji Keizai. 2009. *2009 nen ban, Taiyo denchi kanren gijutsu, shijo no genjo to shorai tenbo* [The current situation and the prospects of PV-related technology and markets].

Gereffi, Gary, John Humphrey, and Timothy Sturgeon. 2005. "The Governance of Global Value Chains" *Review of International Political Economy* Vol.12, No.1

Hamakawa, Yoshihiro. 1981 *Taiyoko hatsuden nyumon* [An introduction to photovoltaics] Tokyo: Ohmusha.

IEA-PVPS 2007. *Trends in Photovoltaic Applications, Survey Report of Selected IEA Countries between 1992 and 2007*. Report IEA-PVPS T1-16:2007.

IEA-PVPS. 2011. *Trends in Photovoltaic Applications, Survey Report of Selected IEA Countries between 1992 and 2010*. Report IEA-PVPS T1-20:2011.

Jiang, Zhuoying. 2012. "GSF danbao pianju (GSF Collateral Fraud)" *21st Century Economic Herald (China)*, August 1.

Johnson, Chalmers. 1982. *MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925-75*. Stanford: Stanford University Press.

Kawai, Motonobu. 2008 "Taiyo denchi, nihon no shosan" [The solar cell: Japan's chance to win] *Nikkei Microdevices*, August.

Maycock, Paul D. 1994. "International Photovoltaic Markets, Developments and Trends Forecast to 2010." *1994 IEEE First World Conference on Photovoltaic Energy Conversion, 1994. Conference Record of the Twenty Fourth. IEEE Photovoltaic Specialists Conference - 1994*

Nikkei Microdevices and Nikkei Electronics. 2008. *Taiyo denchi 2008/2009* [Solar cells 2008/2009]. Nikkei BP.

Ohashi, Hiroshi, 2012. "Saisei ene kaitori seido no kadai" [The Problems of Renewable Energy Policy]. *Nihon Keizai Shimbun*, April 17.

Powell, Bill. 2009. "China's new king of solar" *Fortune*, February 11, 2009.

RIST (Research Organization for Information Science and Technology), 2012. "Sanshain keikaku/ Nyu sanshain keikaku (Sunshine Plan/ New Sunshine Plan)" in *Genshiryoku hyakka jiten ATOMICA* (Encyclopedia of Atomic Energy), from RIST website, http://www.rist.or.jp/index.html

Saito, Katsuhiro. 2009. *Yokuwakaru taiyo denchi* [Photovoltaics easily explained]. Tokyo: Nihon jitsugyo shuppansha.
Sangyo taimuzusha. 2007. *Taiyo denchi sangyo soran 2007* [Yearbook of photovoltaic industry]. Sangyo taimuzusha.
Suntech, 2007. *Suntech Power Holdings, Co., Ltd. 2006 Annual Report*.
Vietor, Richard H.K. 2012. "Suntech Power" Case 9-710-013, Harvard Business School.
Watagi, Tetsuya. 2008. "Taiyo denchi no fukyu wo kasokusuru mittsu no bureiku suru" [Three breakthroughs that accelerate the spread of PVs] in Nikkei Microdevices and Nikkei Electronics.
Wesoff, Eric. 2012. "Dr. Shi Steps Down as Suntech CEO" *Greentech Solar,* August 15, 2012 (http://www.greentechmedia.com/articles/read/dr.-shi-steps-down-as-suntech-ceo/).
Whittaker, D. Hugh, Tianbiao Zhu, Timothy Sturgeon, Mon Han Tsai, and Toshie Okita. 2010 "Compressed Development" *Studies in Comparative International Development* Vol. 45, No. 4.
Wong, Ucilia. 2009. "Spain: The Solar Frontier No More" *PV News* Vol. 28, No. 6.