Technological Innovation of the Chinese Photovoltaic Industry

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Introduction

Solar energy is a clean, abundant and inexhaustible energy. It is expected that by the middle of next century solar energy in China and in the world would account for a large proportion of total energy consumption. It is very important to exploit its huge potential in order to save the Planet Earth from possible disastrous global warming and environment pollution caused partly by burning fossil fuels. In the international efforts on this issue, China is a significant player.

The major ways of directly utilizing solar energy today include solar heating, including using solar heat to generate electricity, and solar power generation that transforms solar energy directly into electricity by photovoltaic (PV) effect. PV industry in this study refers to the industry that develops, manufactures, markets, sells and services solar PV cells, modules, systems and components. Today, the Chinese PV industry is still weak compared with its foreign competitors, though it has grown quickly in recent years. In order for China to establish a competitive PV industry, technological innovation is imperative.

Schumpeter gave the primary conception of technological innovation as follows: "He…who made the discovery of the machine, or who first usefully applied it, would enjoy additional advantage, by making great profits for a time." With this idea, technological innovation in this study is defined as a process that includes the research and development, commercialization, industrial production, marketing, application and diffusion of the technology. Gaining profit from the innovation is emphasized because it marks the success or failure of technological innovation.

Chapter One Background, Objectives and Research Methods

1. Solar Energy Resources in China

China has abundant exploitable solar energy resources. The average annual insolation (incoming solar radiation) on the land surface of the mainland China is $50*10^{18}$ kJ, which approximates to 170 Btce. The total insolation per m^2 around the whole country is 335-837 kJ with a median of 586 kJ. Solar energy in two thirds of China is abundant or fairly abundant with more than 2000 hours of average annual sunlight and more than 586 kJ/m^2 of total insolation.

2. Development of the World Photovoltaic Industry

During the past 20 years, worldwide development of photovoltaic technologies and their applications have made remarkable progress and, at the same time, photovoltaic industry has expanded with high speed (15%-20% annually). In addition to military use, PV systems are also used as power supply in household and industries. Because of the price drop and efficiency increase, the applications of PV system have been growing steadily. In 1992, global sales volume of PV modules was 58.2 MW, and it

increased to 88.5 MW in 1996 and 157.4 MW in 1998, an average annual growth rate of 18%. U.S. has the world's largest market with an increased capacity of 58.2 MW alone. The sales volumes were 47.5 MW in Japan, 35.8 MW in Europe, and 16.3 MW in all other countries. By 1998, the total installed capacity of solar PV systems reached about 750 MW.

3. Market of PV products in China

In China, PV systems are mainly used in the northwest China, where desert and plateau take a very large portion of land with hush natural conditions and there are about 70 million poor people living in rural areas where grid-based electric power supply is lacking. Although commercial energy resources are short, solar energy resources in these areas are abundant. With rich insolation, long sunlight hours and dry weather, PV system is a good alternative energy for household power supply there. Besides, PV systems are also widely used in communication systems, navigation marks and pipelines in desolate land.

According to the Chinese government plan, total installed PV systems will reach 31 MW by the end of 2000, including 15 MW household PV systems, 3.5 MW county PV power stations, 11.5 MW public PV power systems and 1 MW grid-connected PV power stations. However, total installed capacity was only about 7 MW in 1997, far below the planed 31 MW in 2000.

In the past 5 years, the Chines PV industry developed vary fast with continued market expansion and the sales of domestic PV products rose from 900 kW in 1993 to 2000 kW in 1997. However, it is still far behind its foreign competitors. There are still many obstacles it must overcome in order to competitive in both domestic and the world markets.

4. Objectives of the study

The objectives of this study are twofold:

- to investigate current status and problems of the development and technological innovation of the Chinese PV industry; and

- to make recommendations on the strategy and policy for fostering the development and technological innovation of the Chinese PV industry.

5. Methods of the study

In order to achieve our objectives, the following methods are used:

- Literature review: The development of domestic PV industry has been an important issue facing the Chinese government. There have been several major studies of PV industry in China in 1990s, sponsored by UNDP, WORLD BAND, US DOE, the State

Development Planing Commission (SDPC), the State Economic and Trade Commission (SETC) and the Ministry of Science and Technology (MOST). These studies focused on the current development status of the domestic industry and they also introduced the latest technology progress in the world. Usually they pointed out some of the problems that impeded the development of the domestic industry in order to let government leaders be aware of various problems and adopt their policy recommendations. However, none of the past studies deal with this issue from the point of view of technological innovation under market economy. This study, for the first time, then, tries to systematically investigate the practice and problems in technological innovation of the Chinese PV industry.

- Questionnaire survey: 20 questionnaire are returned from five PV cell manufacturers, four service firms, five experts and two relevant government officials who are in charge of solar energy development. There are two kinds of questionnaires in our research: expert questionnaire that focuses on the general status of the industry and manufacturer questionnaire that focuses on the management and technological innovation in the peculiar manufacturer.

- Expert interview: Most expert interviews were conducted when we asked experts to fill in the questionnaire. In this way, we could obtain more detailed, more extensive and clearer opinions from experts.

- Analysis: Based on the general methodologies and principles of technological innovation, the results of literature review, expert interviews and questionnaire survey, an analysis is made on the problems of the development and technological innovation of domestic PV industry. Then, the recommendations on the strategies, policies and measures of technological innovation of the Chinese PV industry are proposed.

In Chapter Two, the results obtained from using the above three basic approaches will be used for the discussions of each topic whenever appropriate.

Chapter two Results of the Study: Part one - Domestic PV industry and market

1. Past, today and the future of the Chinese PV industry and its market

To a large extent, the development of the Chinese PV industry goes along with the development of photovoltaic cell technology in China. China began its PV cell R&D in 1950s and did not devote great efforts on its industrialization until 1970s. Because of the similarity of PV technology and industry to semiconductor technology and industry, the Chinese PV industry naturally extended from existing Chinese semiconductor industry. In 1970's, three semiconductor device manufacturing plants, Ningbo, Yunnan and Kaifeng, were transformed into manufacturing PV cells with modified production lines for manufacturing solar cells. In late 1970s, worldwide oil crisis caused the upsurge of R&D on PV technology and China also followed. From 1983 to 1988, China introduced seven PV cell production lines from the U.S, Canada and other countries, establishing the manufacturing capability of solar cells. By 1995,

China had six solar cell manufacturers, i.e., the three mentioned above and three more plants in Beijing, Harbin and Qinhuangdao, with total designed production capacity of 5MW per year. The actual production capability is far below it, because of serious equipment bottlenecks in different parts of these production lines. After 1990, domestic PV module market grew quickly as seen in Table 1, but the technologies used in these plants are still basically the same as that in late 1980s.

Table 1 The volume of solar cells sold（kW）

Application	1993	1994	1995	1996	1997	1998
Tele-communication	450	720	852.5	1085	920	
Rural use	270	300	465	651	920	
Grid-connected	0	0	0	0	100	
Others	180	180	232.5	434	360	
Total	900	1200	1550	2170	2300	3000
Growth rate (%)		3.3	29.2	40.3	5.7	30.4

Official statistics shows that majority of PV products sold in China are made in China as seen in Table 2. In mid 1990s, foreign-made solar cell accounted for 10-15% of the domestic market, but the figure rose to 30-40% in 1998 without counting dissembled products, which add additional 20-30%. Because of the expected increase in demand and the constraints of domestic industry's production capability, experts anticipate that the share of foreign products will continue to rise in the next 10 years.

Table 2 Market share （kW）

	1993	1994	1995	1996	1997
Domestic	900	1100	1200	1870	2000
Import		100	350	300	300
Total	900	1200	1550	2170	2300

In 1990s, there has seen fast development of domestic PV market, both in stand-alone household PV systems, which accounts for 30% of the market, and in other uses. Small PV household system (8W, 10W, 20W) are welcomed now and maintain 80% of household system market. Sales of the household PV system used to depend on government subsidy. Since early 1990s, the linkage between the sales and subsidy has evaporated. The most important thing affecting sales today is the price. Because most potential buyers are poor and could not afford such a "luxury" thing at present, finding solutions to this contradiction is key to expand the market. The forecast by expert as shown in Table 3 indicates that there are great potentials for the household PV products in China.

Table 3 Plan of the installed capacity of household PV system

	2000	2010
Installed Capacity (MW)	79～120	400～900
Electricity（TWh）	170～250	880～2000

The market of the PV system used for other uses, such as telecommunication and navigation, expanded in 1980s and now has a relatively stable size, about 1MW per year. PV systems used for these purposes require long lifetime, high stability and reliability. Foreign companies have considerable competitive advantages in these areas and are occupying most of the domestic market today.

In early 1980's, the means that China government used to support the development of domestic PV industry was mainly government funding and subsidy. As the reform in China went on, other stimulating policies in tax, price and loan were used. In mid 1990's, foreign PV companies began to enter the Chinese market and market competition has become increasingly intense. Some domestic manufacturers still work well, some run under difficulty and some are even going to close or already closed. However, there are still some companies that want to enter this industry, such as the Beijing New Building Material Company, a large company that are listed in Shenzhen Stock market. The Chinese PV industry is still in its early development stage and it will have a bright future.

2. Industrial organization and structure

The institutions involved in the Chinese PV industry include both government sector and industry sector.

(1). Government sector: In literature review, we already mentioned some relevant government ministries, including the State Development Planing Commission (SDPC), the State Economic and Trade Commission (SETC) and the Ministry of Science and Technology (MST). There are some other relevant government ministries, such as the Ministry of Agriculture (MOA) and National Electric Power Company.

All these government ministries are responsible for making decision on the development of the Chinese PV industry. They support the industry in various ways. In addition to formulate development policies by these ministries, MST is responsible for planing and organizing R&D of PV technologies and now it manages the National Key R&D Program that includes R&D fund for PV technology during the period 1996-2000, and SDPC and SETC focuse on the industrial development of Chinese PV industry. The central government also supports the institutes of the Chinese Academy of Sciences, universities and other R&D institutions to advance domestic PV technologies. Because so many government agencies participate in the policy making and implementation, there exist many problems under such an inefficient multi-institution management system for developing Chinese PV industry. As is complained by people: “Everybody is in charge, so nobody is in charge”. As a result, limited resources are improperly used, R&D projects are poorly organized, R&D achievements are not fully commercialized and industrialized. PV industry has a lot of complaints about the shortcomings of such management system.

(2). Industry sector: The Chinese PV industry consists of four components: manufacturer, R&D institution, service provider and foreign company.

- Manufacturers of solar cells: Firms that manufacture solar cells are the core of the Chinese PV industry. Surrounding these firms, there are a number of firms supplying various components and materials for their production. Today, there are 6 such manufacturing firms in China as shown in Table 4 and each of them operates with one production line. Among them, four state-owned firms (Qinhuangdao, Kaifeng, Ningbo and Yunnan) manufacture single-crystalline silicon solar cells, one state-owned firm (affiliated with Beijing General Institute for Non-ferrous Metal) manufactures polycrystalline silicon solar cells and another firm (a joint venture with a US firm, Harbin Krola Solar Electric Power Company) manufactures amorphous silicon solar cells. Yu Kang Solar Energy Company, also a joint venture set up by Shenzhen government, Korean and International Finance Company (IFC), closed in 1997 because of marketing failure. Now, total designed annual output is 5MW.

Table 4 Manufacturing Firms of Solar Cells in China

Firm	Starting Date	Equipment	Solar cell type	Output Designed/1995
Harbin Krola Solar Energy Co.	1991	All imported	amorph. Si	1MWp/200kWp Beijing
Non-ferrous Academy	1987	Key imported	poly-C Si	100kWp/20kWp
Qinhuangdao Huamei PV Co. Ltd.	1990	All imported	single-C Si	1MWp/200kWp
Kaifeng solar cell Plant				
Old line:	1975			
New line:	1988	Key imported	single-C Si	300kWp/180kWp
Ningbo Solar Energy Plant				
Old line:	1976			
New line:	1988	Key imported	single-C Si	300kWp/300kWp
Yunnan Semiconductor Plant				
Old line:	1983			
New line:	1987	All imported	single-C Si	500kWp/300kWp

- R&D Institutions: There are more than 40 institutes, universities and manufacturing firms that dedicate to the R&D of PV technologies. Most R&D activities concentrate on improving efficiency of existing solar cell and exploring new types of solar cell, among others.

- Service firms: The major functions of service firms are to market, sell, install and service PV system and its components. Often times, they also develop and manufacture some components, such as converter and controller.

Since five years ago as PV industry development began to accelerate, the number of service firms has increased fast. In 1992, there were only less than 10 service firms and all of them were affiliated with government sponsored R&D institutes. The only operation of these firms is to make use of Chinese government subsidy as well as

foreign government aid to sell PV systems. In early 1998, the number of service firms exceeded 50, many of which are private firms operating with market practice. For example, there is a PV product street in Xining city, the capital of Qinghai province in northwest China, that has more than 10 service firms there and 6 of them are private firms. The situation shows that a domestic PV market is growing. It is also obvious that stated-owned service firms still have large technological and financial advantages, so they have a large share of domestic market. For example, two state-owned PV service firms have 80% share of the market in Qinghai province, three firms occupy 70% of the market in Xinjiang Weiwuer Autonomous Region, and in Inner Mongolia, one company even has 70% of the local market.

Alpha Solar Power Co. Ltd. in Qinhuangdao, is a joint venture of the US firm Alpha Solar and China. It imports an assembly line to produce concentrator photovoltaic systems and all the solar cells of the system are imported from the US. Since it doesn't have its own production capability of the solar cell, we prefer to classify it as a special service firm rather than a manufacturing firm.

- Foreign Companies in China: China began its reform and opening to the world in 1979. As a result, the Chinese PV industry has been competing and cooperating with foreign firms. People have realized that closing the market is never an appropriate way to develop domestic industry.

Almost all major companies of the world PV industry have entered the Chinese PV market. British Petroleum (BP), Dutch Royal Petroleum (Shell), Siemens Solar, Sharp, Sanyo, SEC(USA) and Photomatt(France)are some big names among them. As mentioned before, over one half of the domestic PV market is taken by foreign companies and they are continue to enlarge their shares in the Chinese market. For example, Shell establishes the UNISONO Co, Ltd, to market PV products in China and is going to invest USD$30 million to exploit house-hold PV system market in Xinjiang Weiwuer Autonomous Region.

3. Development of Domestic PV Industry

(1). Current Status of Domestic PV Industry: In our questionnaire survey, experts are asked to evaluate the development status of domestic PV industry. Table 5 shows the results.

Table 5 Evaluation of the development status of domestic PV industry

	Gov. Officer	Manufctrg firm	Service firm	Total
No industry, no competitiveness	0	0	0	0
Infant industry, weak competitiveness	2	2	0	4
Industry there, some competitiveness	1	3	2	6
Mature industry, strong competitiveness	0	0	0	0
Total	3	5	2	10

The table shows that experts agree that domestic PV industry is neither nothing there nor well-established. People agree that there is already a domestic PV industry, but it is still in its early stage of development with certain competitiveness, though not strong. There is no doubt that many problems must be solved to enhance the competitiveness of domestic PV industry.

In the following discussion, we will discuss problems facing the Chinese PV industry today.

- Solar cell manufacturing firms: several issues are facing the solar cell manufacturing firms.

* Production capacity: Currently, existing solar cell plants are only running at about 50% of production capacity. This is partly because of the shortage of money needed to import full-line production line that results in bottlenecks of production. Shortage of wafer in general and small diameter wafer in particular also constrain production capacity. For instance, the designed production capacity of Qinhuangdao Huamei Solar Equipment Company is 1MW per year, but actual production capacity is only 500kW per year. In the March of 1999, there were only 70 workers working in workshop, less than half of the total staff.

* Efficiency - The efficiency of the domestically made solar cell can reach 13.5% and the average level is 10-12%, while foreign firms can produce solar cells with average efficiency of 14-15%. Some Chinese firms claim that there is no big difference between the efficiency of native solar cells and imported cells. It seems right, but if we calculate the efficiency of PV module, not to mention the efficiency of PV system, we will find obvious difference between them.

The following is the calculation:

Native module (made by Hua mei Solar Equipment Company in Qinhuangdao):

Efficiency of solar cell: 14%
Size of the module: 1.312m×0.31m=0.40672 m2
Power of the module: 0.038 kW
Efficiency of the module: 0.038÷0.40672=0.0934 kW/m2，
Standard isolation rate: 1kW/m2
Efficiency of the module: 9.34%

Foreign module (made by Solares Company in the USA):

Efficiency of the solar cell: 15%
Size of the module: 1.908×1.13=2.15604 m2
Power of the module: 0.240 kW
Efficiency of the module: 0.240÷2.15604=0.1113kW/ m2，
Standard isolation rate: 1kW/m2
Efficiency of the module: 11.31%

The module efficiency can even reach 13% by some foreign firms, such as ASE of USA, and the number is much higher than that of the domestic products. Two reasons cause the difference. First, the efficiency of native solar cells in the market are low, though the best ones have relative high efficiency. Second, the cells used to make module are usually round wafers or pseudo-square wafers with smaller areas for the module to receive insolation than the standard square wafers used by foreign producers. PV modules used for telecommunication and cathode protection must have high efficiency, otherwise, more modules and components will be needed in a system to provide required power, which is technically and financially undesirable. As a result, whenever possible, high efficiency module, usually made abroad, is preferred to build PV system used for telecommunication system. On the other hand, users of household PV systems do not care much about insignificant difference in efficiency. Therefore, these low efficiency products occupy a large part of the PV market in China.

* Quality: In the questionnaire, all domestic manufacturers are confident about the quality of their products as shown in Table 6, but expert have quite different opinions about this as shown in Table 7. Although there won't be significant differences between electrical parameters of native products and imported products, users of household PV system still prefer foreign modules psychologically in the belief that importated goods always perform better than local ones.

Table 6 Manufacturers' opinions about the quality of their products

Advanced in the world	Advanced in China	Average level in China	Hard to say	Total
0	6	0	0	6

Table 7 Experts' comparison of the quality of domestic and foreign solar cells

Answer 1	Answer 2	Answer 3	Answer 4
0	0	50%	50%

Answer 1: There won't be big difference in short time after installation
Answer 2: There will be big difference in short time after installation
Answer 3: There won't be big difference in long period after installation
Answer 4: There will be big difference in long period after installation

Data show that no experts think the difference in short time after installation is big, while experts are evenly split into two conflict camps: one thinks there is big difference between the two in long term, and the other believes the difference is not big.

* Price: Since the cost of solar cell is a commercial secret of manufacturers, we can only estimate the cost of the module. In western countries, the cost of single-crystalline silicon PV module is about USD$3/Wp and the cost of amorphous silicon PV module is about USD$2.2/Wp. In China, the cost structure is different

from that of foreign products. Compared with those in developed countries, management and labor cost in China is about 1/5, the cost of plant construction and buildings is about 1/3-1/5, and the cost of raw materials and electricity is about the same, whereas the proportion of low quality products is higher, the efficiency of solar cell is lower, tax rate is higher and most the manufacturers are in debt, so the cost of domestic PV module is about 10% higher than that of foreign products. Finally, the price of PV system is above 35RMB/Wp (USD$4.2/Wp) , much higher that that of foreign products.

- Government: PV technology is a high technology that needs lots of risky money for R&D. Also, it inherently has remarkably higher price with current technology than traditional energy, which makes its marketing difficult. On the other hand, the dissemination of PV products in |China today aims mainly at protecting environment and helping poor people. Consequently, government support is a key factor in developing PV industry.

In 1995, the Chinese government, namely, MST, SDPC and SETC together issued a joint document, "The Compendium of the Development of New Energy and Renewable Energy in China", to provide guidance for supporting the development of domestic PV industry. The goals of PV technology R&D are set as "improve efficiency, reduce cost, enlarge production scale for facilitating the development of the industry". Meanwhile, experts are now sponsored by government to draw up future plan for the R&D and demonstration of PV technologies as well as PV industry development.

In addition to domestic financial resources, government also finds various foreign financial resources to support domestic PV industry. One good example is the latest effort to introduce the World Bank loan and GEF money to install a large amount household PV systems in remote poor areas in western China and to support the localization of manufacturing PV systems.

- Service firms: Service firm is a very important bridge connecting the manufacturers and the market. In the past, service firms had a close relation with government under the planning economy. At that time, obtaining sales contracts from the government was more important than exploiting market to service firms. But things are quite different under market economy. Today, all service firms have to try their best to increase their sales on the market and to get orders from customers. Hence, as the government reduces its involvement in the PV market, service firms depend more on the market. Service firms have ambivalent views towards domestic PV industry. On the one hand, they live in the environment of market economy and must obey the rule of "the best wins and the worst loses", so they prefer to choose foreign products which are cheaper, more reliable and with better quality. On the other hand, they still have conceptions like "supporting domestic industry" ingrained in their minds. That makes them sell domestic products whenever possible. With such idea, service firms believe capital shortage is a key problems for the development of domestic PV industry, since technological innovation requires considerable money.

- Foreign governments and companies: Solar manufacturing and service firms have different views about the role foreign company plays in the development of domestic PV industry. Most manufacturers have to compete with both foreign companies and imported products. They think it is unfair for the foreigner to have low tariff or even zero tariff (some projects endowed by foreign governments) that lead lower product price and stronger competitiveness in the market. They insist that domestic industry needs some protection by limiting import and adopting government procurement policy. However, the opinion of service firms and PV system users have a quite different opinion. They like the environment of competition and believe that the best and only way to achieve the goal of "reducing cost and improving quality" is market competition. Therefore, foreign involvement plays a positive role in the development of domestic PV industry. For the government, it believes that it should balance those two views and that the best way is to open up the market step by step to protect the infant domestic PV industry and meet the market demand for PV products.

4. Issues in the Development of PV Industry

(1) Market: All experts and manufacturers think that current PV market in China is relative small. Table 8 shows the explanation of surveyees about the limited current PV market in China. It shows that high price and the lacking of subsidy and loan are the two main factors limiting the market size.

Table 8 Reasons for the limited PV market in China

Explanations	Manufacturers	Officers	Service firms
Users don't know the system quite well	0	1	0
Users aren't satisfied with the quality	0	0	1
Price is high	4	2	2
No adequate subsidy and loan	2	1	1
No favorable environment protection policy	1	1	0
Others	0	0	0

High price prevents people from buying PV systems. The lower the price, the higher the demand. So, price is the key to exploit the market. However, manufacturers complain about the shortage of subsidy and favorable loan. They think that with subsidy and favorable loan, they can sell more PV products and gain higher profit, and, in turn, expand production scale, reduce cost, increase sales, and thus gain even higher profit. It seems that manufacturers are running at vicious circle and they hope virtuous circle could come soon.

There is no consensus about this point of view, but we believe that market is in the beginning of the virtuous circle. In the questionnaire survey, almost all people are confident about the future market of the industry and they all agree that there will be a bright future for the domestic PV industry in the next 10 years. As mentioned above,

central government plans to install 31MW PV system all together by 2000. There is no doubt that the market will be large, but the question is how to exploit the market, where the potential market is and what the characteristics of the future market will be. This study finds the following results:

- Distribution of Future Domestic Market: Household PV system will be the main growing area of the market. In the government plan, 15MW household PV systems will be installed before 2000. However, there were only 2.6MW household systems installed by the end of 1997. In order to achieve this goal, the average annual growth rate of installed capacity must be over 79%, which is much higher than the growth rate of 30% in recent years, and strong measures have to be taken to attract consumers. It is estimated that the installed capacity of household PV systems will have 48% of total PV market in 2000.

The market of PV systems for telecommunication, navigation mark, cathode protection and others will likely be stable, about 1MW per year as show in Table 9. About 50% of this market is now occupied by foreign products because of high quality and competitive price. This trend may maintain in the near future.

Table 9 Installed capacity of PV Systems for telecommunication (kW)

1993	1994	1995	1996	1997
450	720	852·5	1085	920

PV systems used in rural areas have increased quickly in recent years. Many government programs aimed at providing electricity to remote counties, especially in Tibet, that have no electricity and getting peoples rid of poverty. China is going to install 500 PV stations and 3 village-used PV stations in Xinjiang Weiuer Autonomous Region before 2000. PV station, wind power system and small hydropower station are three major ways to make rural areas electrified. Small hydropower station has been developed well in areas with rich water resources. Its using, however, is limited by geographic condition and resource availability. Compared with it, wind power and solar power have their advantages in drought area and poor areas. Now, wind power system and PV system are mostly used separately, but in the future, combined system will be a good alternative.

People expect that two characteristics will be likely stand out for the market in the future. Firstly, people expect less government purchases. By the end of 1999, there won't be any county without electricity in China, so central government will not invest on large PV station project any more. What dominates future PV station market will be small PV station for villages and towns (usually have 10~20 families with station capacity between 1 kW and 2 kW). The money for building this kind of station is mainly raised from local government and villagers, so government purchase will drop quickly. Government will use policy measures to balance the market instead of directly purchasing PV systems. Secondly, people expect low profit for PV systems in the future. In the questionnaire survey, manufacturing firm managers said their profit

is low today with high production and operation costs. This trend will continue in the near future. If there is remarkable technological improvement, the cost will be reduced dramatically, or if we manage to run the manufacturing firms under virtual circle, profit will increase.

(2) High production cost: The cost of domestic solar cell is affected by many factors, among which the two most important factors are the outdated technology and small scale of production. Using advanced technology can raise production efficiency remarkably. For example, mature multi-line cutting technology can save silicon, so as to wafer, reduce cost and enlarge production scale. Domestic manufacturers usually use a knife with a thickness of 350 microns to cut silicon wafer, so the thickness of the thinnest wafer should be at least 400 microns. On the contrary, foreign manufacturers use steel wire that is less than 100 micron in diameter to cut silicon wafer, so the average thickness could be as high as 250micron. With the same amount of silicon, they can produce 150% more products than domestic manufacturers. For another example, foreign solar cell manufacturers can produce 6 inches wafer and use them to manufacture standard square wafer for assembling module. Domestic manufacturers, however, can only produce 4 inches wafer, which will reduce the effective areas to receive the insolation. Production scale also affects production cost greatly. The relationship between production scale and the price of PV system is shown in Table 10. Currently, the production capacities of all domestic manufacturers are around 1 MW or less, which is far from EOS size. However, there is not much room to improve today because of limited domestic market size.

Table 10 Relationship between production scale and price of PV system

Size of production（MW）	Cost of PV system（USD$/W）
0.5	5.31
15	1.8
500	0.85

(3) Capital shortage: Capital shortage from out of enterprises themselves happens in three major areas:

- Loan for starting business: To build plant and purchase equipment, loan is needed. The starting loan in 1990s is about RMB 25-40 million Yuan (about USD$3-5 million). Manufacturers have to earn profit in order to repay loan. Today, 4 of the 6 domestic manufacturers operate in a loss and the other two could just repay the interest of the loan instead of repay. Because of the unclear market for PV products and the repayment , banks are reluctant to give loans to new PV manafacturers.

- Revolving money: Revolving money is used by manufacturers to buy materials and various parts and components, pay for workers and other expenses to keep operation running. Some firms are in a shortage of revolving money so that they could not keep enough materials, parts and components to take large and urgent orders. For instance, Huamei Solar Equipment Company in Qinhuangdao had to give up an order of RMB

4 million Yuan because of lacking revolving money. Generally speaking, domestic manufacturers are hard to borrow revolving money from bank due to their poor credits of repaying previous loans and complicated procedures of obtaining loan.

- R&D fund: As a high technology industry, PV industry needs a large amount of money for R&D. Currently, there are two major sources for manufacturers and researchers to get PV technology research money. One is government and the other is from manufacturers. Currently, there are about 40 R&D institutions and manufacturers which are engaged in R&D on photovoltaic technology, but the R&D fund appropriated by central government is quite limited and could not support all R&D activities. Therefore, current practice is that government allocates certain amount of money and the manufacturers or institutions assigned by government to conduct the R&D have to contribute the rest of the required R&D money. Manufacturers without government support have to find R&D money themselves. Practically, it is very hard for those manufacturers with difficult operating situations to catch up with the world's advanced technology or to improve their production technology.

In the beginning of this year, a large domestic, enterprise, Beijing New Building Materials Company (listed in the Shenzhen Stock Exchange), showed eager intention to enter the PV industry. With sufficient financial resources, it can rely totally on itself to develop its PV product business. If things go smoothly, it can be a successful player in the domestic PV industry.

(4) Unsupportive tax: Tariff, value-added tax, income tax and local tax are four major
taxes that solar cell manufacturers should pay for.

There are three kinds of tariff: the general tax for importing raw materials (8-20%); the tariff for importing whole PV system (12%); and the tax rate of those PV systems donated by foreign governments (very low to zero). All the three kinds of tax rate are set by central government. Present tax policies discourage domestic production and encourage importing whole PV system. Such tax practice should be changed in order to stimulate the development of domestic PV industry. Specifically, the tax rate of importing raw materials should be lower than that of whole PV system in order to support domestic production of PV systems. For foreign endowed PV systems, the tax rate should be low or zero to encourage the endowment.

Value-added tax is a tax shared by central government and local government. Three tax rates (17%, 13%, 0%) represent the preferential degrees to which different industries are protected by the government. Experts of PV industry are appealing to reducing the rate of value-added tax for solar cell manufacturers, which is 17% now, the highest of the three rates.

Income tax for manufacturers is 33%. This is a special tax of state-owned firms and is also a heavy burden to them.

In the questionnaire survey, most people think one of the major problems for developing domestic PV industry is lacking supportive policies by the government, especially added value tax and import tax. They think the industry deserves support from government.

5. Some recommendations for Developing Domestic PV Industry

To alleviate the problems mentioned above, we recommend the following measure for expanding domestic PV product market and developing domestic PV industries:

- Consumer investment: In foreign countries, it is very common that consumers invest on durable goods. In India and Indonesia, many farmers borrow money from local banks to purchase PV systems. They can repay the principle and only 10% or 15% more of the loan in two or three years. But this approach needs convenient loan processing and a strong finance system. So it is still under study in China now.

- Government subsidy: There is a successful example of using subsidy to promote sales of PV system. Five years ago, household PV product was rarely sold in Qinghai province. After the local government decided to subsidize the PV system users with RMB 300 Yuan per system (about 15% of total price), the sales rose remarkably. Nowadays, it even becomes a custom to greet a married couple with a PV system as a wedding present. So, government subsidy to PV product user is a very effective instrument in exploiting the market. Because market is the key to realize the virtuous profit circle, manufacturers could give the buyer's subsidy to government, and then government officers will be more willing to promote the sales of PV systems. The subsidy will not increase the cost in the long run, because larger market could be translated into lower production cost.

- Foreign aids: In recent years, many foreign governments or companies gave money or PV systems as gifts to China. Although they help foreign companies gain larger share of the big Chinese market, the aids show friendly relationship between China and the foreign governments, help poor people in remote areas to get electricity and give domestic manufacturers some pressure to improve their operation and quality of products.

- Favorable loan: Low or zero lending rate and long period of time for repayment will do great to help manufacturers. Developing capital market is also an important channel for PV industry to raise money.

- Favorable tax policy: Lowering tax makes manufacturers have more money to invest on R&D, to improve production technology and to have more revolving money for operation. The value-added tax is the main income of the central government, so it is very hard to lower at present, but government could lower import tariff of raw materials that are categorized as photo-sensitive materials and have a high tax rate. The government should list out all the raw materials that solar cell manufacturers need,

then set favorable tax rate on them.

- Strict environment protection regulation: Besides economical approaches, policy makers could help PV industry by enacting environment protection regulation. It could attract public attention on environment issues so that development of solar energy could gain stronger support. Also, penalties and compulsory regulations on environment pollution will make solar energy more competitive, which will eventually lead to the reduction of the use of fossil fuel energy, which helps enlarge PV market.

- Restructuring enterprises: Currently, most solar cell manufacturers are state-owned enterprises. In the questionnaire survey, people think that the quality of enterprise managers are lower than that of private and joint venture enterprises, which is one of the major reasons for inefficient operation of these enterprises. Also, the number of solar cell manufacturers are large compared with the market size today. In order to enhance the competitiveness of manufacturers, market competition, merger and acquisition should be encouraged.

Chapter Three Technological Innovation in the Chinese PV Industry

1. Current status of technological innovation

(1) Government involvement in the TI of PV industry: The central government has formulated plan for technological innovation of PV industry. In "The Compendium of the Development of New Energy and Renewable Energy in China", government set the technological targets for poly-crystalline silicon PV modules. In the "Ninth Five-year Plan of National Economic and Social Development", there are technological targets set for grid-connected PV power stations and single-crystalline silicon solar cells. Besides, central government also has the market exploitation plan for the industry as mentioned previously.

Central government supports R&D activities and technological innovation of PV industry mainly through funding R&D and supporting marketing. Currently, there is no competition mechanism for obtaining the funding. Also, there are no effective measures to control the quality and progress of the funded projects. Therefore, the waste of money is inevitable. More seriously, the supported R&D is mostly isolated from PV industry and the achievements hardly promote industrial development.

(2) R&D of solar cell manufacturers: The questionnaire shows that it is hard for the solar cell manufacturers to conduct R&D. The main reasons include:

- No in-plant R&D institution for R&D. Therefore, experiments have to be done in production line and the cost is very high. Once the experiment fails, all products become waste. With limited money, consecutive experiment is impossible.

- The experiment cost is high, but R&D funding is limited. As a result, manufacturers

have to give up R&D to maintain normal production..

- There are no enough quality engineers in manufacturers. Most engineers do not have college degree. Some experienced engineers prefer to work in joint venture companies for higher income and better research environment.

- The linkage between manufacturers and R&D institutions is weak. In recent years, only 30% of manufacturers adopted technologies developed by R&D institutions.

(3) Activities of R&D institutions: Most R&D institutions perform R&D in solar cell at laboratory level. Today, China is on the top range of R&D in the world on high-efficiency single-crystalline silicon solar cell and poly-crystalline thin-film silicon. However, it is still a "Technology Push" approach, for it is not based on market demand. The main purpose of the research is for tackling key technological problems, not for industrializing and marketing them.

Now, R&D institutions faces a serious problem that the commercialization of the technologies developed in laboratory is very poor. The questionnaire shows that 50% of experts think the commercialization of R&D in PV technologies is just OK, but the other 50% think it is bad.

The success of technology commercialization depends on many factors, not only solar cell technology, but also production equipment and instruments, materials and semi-conduct device manufacturing technologies. The availability of capitals, the quality of engineers and company managers are also very important. Taking single-crystalline silicon solar cell as an example. The efficiency of laboratory product reaches 20%, but the normal efficiency of factory product is 10-12%.

(4) TI in PV service firms: Service firm has two kinds of TI activities. One is the technology improvement on its own products, such as converter and controller, and the other is the exploitation of the PV market.

China has been moving from planned economy t market economy, and the marketing of PV system has also changed to adapt market economy. For large public projects, such as telecommunication and transport related projects, open bidding has become a common way for selecting project taker. PV household systems are sold by various service firms around the country, and state-owned service firms control the sales of PV products of government programs.

All service firms exploit the market actively. Because of the high profits of large PV projects, few domestic service firms put focus on selling PV household system in the past few years. Now, they find that a large share of this market is already taken by foreign companies, and they have to compete hardly to regain some market share with their higher price (sometimes), lower efficiency, poor packaging products.

(5) Users' influence on R&D in PV Industry: The user's influence on R&D is realized through the sales of PV products in the market. Most users of PV household systems are people who live in remote and poor areas. They care little about the technological difference of different products or the efficiency of the system, because they have no knowledge about it. Price is the key thing they care. So, it is the low-priced PV products employing effective cost-cutting technologies that is most meaningful for attracting consumer's attention. However, there is no sign that such technologies are emerging, so we do not see significant user's influence on the R&D activities in domestic PV industry.

The PV systems used of large projects do influence the development of technology in PV industry. Improvement of the efficiency and quality can enhance reliability and extend lifetime. Users prefer products with better performance and quality and this in turn determines the trend of technology development.

2. Problems in Technological innovation

(1) R&D labs in manufacturing firms: Nearly every solar cell manufacturer has its own R&D department. The main purpose of this department is to increase the efficiency of the solar cell and to improve the product technologies. R&D departments in service firms (especially the system integrators) focus on the design and production of converters and controllers. The proportion of people of R&D department in total staff in manufacturing and service firms are 10-15% and 30~40%, respectively, as shown in Table 11.

Table 11 Statistics of R&D department staff in manufacturing and service firms

		Staff in R&D lab	Staff in R&D lab / total staff (%)
Manufacturing firms	①	20	13.3%
	②	40	12.7%
	③	5	10%
Service firms	①	6	30%
	②	4	40%

(2) Sources of acquiring technology: Domestic PV industry acquires the technologies of converter and controller from domestic institutes and R&D labs of manufacturing and service firms. Because these technologies are not very sophisticated and R&D costs are not high, it is relatively easy for China to keep pace with foreign products.

Solar cell is the heart of a PV system. How to acquire relevant technologies is one of the central issue facing the Chinese PV industry. In the questionnaire survey, we ask people to identify the main approach to acquire solar cell technology. The result shown in Table 12 indicates that introducing foreign technologies dominates.

Table 12 Approaches to acquiring production technology of solar cell

Approach	Number of "Yes"	Percentage（%）

Develop by manufacturer	1	8
Develop with domestic R&D institutes	1	8
Commit domestic R&D institutes	1	8
Buy license	0	0
Import key Techs. & production equipment	5	42
Import whole productin line	2	17
Joint venture	2	17
BOT	0	0
Others	0	0
Total	12	100

With this background, it is interesting to know what people think about the best approach to acquiring advanced technology. In the questionnaire survey, we ask experts and manufacturers leaders to answer this question. The result shows that almost all people believe joint venture and introducing key technology are the most economic approaches in the near future. They also compare the advantages and shortcomings of the two basic approaches and the result is shown in Table 13.

Table 13 Comparison of domestic R&D with importing technology

	Domestic R&D	Introducing foreign Techs.
Advantages	Faster Tech. diffusion	Keep up with the best
	Save money	Sufficient Tech. information
	Effective Tech. Build-up	Saving time for Tech. upgrading
	Build up R&D talents	
Shortcomings	Hard to reach the best fast	Only one beneficiary
	Few Tech. Information	Require much more money
	Short of R&D funding	Weak Tech. Build-up
	Brain drain	Impossible to acquire the best

If we have all favorable supporting conditions, self-R&D may be the best way of acquiring advanced technology for China. However, domestic PV industry is now still in its early development stage and there are many factors constraining domestic R&D capability. In order for domestic PV industry to quickly catch up with the world best, the best way of gaining advanced technology is to introduce advanced foreign technologies through setting up joint venture and buying key technologies and production equipment.

(3) R&D Fund: Today, there are four major channels to get R&D money: self-financing, government money, foreign money and loan from bank.

The money of self-financing comes from the profit of firms. Central government prescribes that the manufacturers of solar cell, which are defined as high-tech enterprises, must use at least 1-3% of the total profit as R&D fund, booking to cost. We found that most manufacturers use 5-8% of the total income for R&D. As

mentioned earlier, service firms focus its R&D on converter and controller that does not need a large amount of money, so they pay for R&D with their own money.

Various central government agencies have allocated money since early 1980s to support R&D of solar energy technologies through development programs, including those of MST, SETC, SDPC, China Electric Power Company and Ministry of Agriculture. However, because renewable energy accounts for only a small percentage of China's energy consumption, the amount of government money is less than 1% of the that in the US and even less than that in India.

Though small amount, R&D money from government has large impacts on firms, because they are generally in bad financial condition and the money help reduce their financial burden and improve their R&D performance. Presently, the ratio of self-financing and appropriation is about 2 to 1 or more for manufacturers. Most domestic R&D institutions acquire R&D funding from central government and only a small part comes from manufacturers. Appropriation from central government has decreased year by year, and R&D institutions will face market directly in the future.

Foreign aid has been increasing in recent years. For example, the Dutch government donated Xinjiang with 100,000 sets of household PV systems that worth USD$15 million; GEF/World Bank's Renewable Energy Project in China is going to provide China with a loan of USD$390 million to support the demonstration and marketing of wind turbines and PV systems. Foreign companies aim primarily at making use of the aid to take larger share of the Chinese market and they rarely care about the technological innovation of domestic PV industry. Because government has certain control over these aids, some manufacturers can obtain some money for R&D.

Bank loan is a possible source. However, this instrument is rarely used today. First, people tend to stick to the habit of getting free money from government, so they are reluctant to borrow money from bank. Second, people often have a weak financial condition in the PV industry, and they tend to take a risk averse attitude towards borrowing money from banks.

(4) Targets of the future technology advancement: Essentially, technology advancement is the key issue to the development of PV industry in any country. The targets of the technology advancement in domestic PV industry depicted by experts has been included in the "The Compendium of the Development of New and Renewable Energy in China".

The technology of single-crystalline silicon solar cell is relatively mature with relatively high conversion efficiency, long lifetime and stable quality. Future efforts will focus on increasing wafer area, improving wafer-cutting technology and production process, cutting cost, and increasing module efficiency to 15%.

Poly-crystalline silicon solar cell uses low grade silicon wafer, so its cost is also low. But it has low conversion efficiency and short lifetime. In the future, efforts will focus

on increasing efficiency, lowering cost and expanding production scale.

Currently, Chinese made amorphous silicon solar cell has low cost, but efficiency is low and quality is not stable. In the future, China should develop dual-junction and multi-junction products, increase efficiency, improve quality stability, reduce cost and increase large area module.

In the questionnaire, we ask experts to forecast what kind of solar cell will dominate i the next 10 years and the result is shown in Table 14.

Table 14 Direction of PV Technology in the next 10 years

single-crystalline silicon	5
polycrystalline silicon	2
amorphous silicon	3

We can conclude from the statistics that because each of the three solar cell techniques has its own advantages and disadvantages, people believe that they might be developed in parallel with a bias towards single-crystalline silicon, for it has strong basis both in research and production.

Although "The Compendium of the development of New Energy and Renewable Energy in China" provides some guidance of future development, people complain that it is too general and put no particular emphases.

(5) Problems in introducing foreign technologies: Most solar cell manufacturers imported whole production lines as well as some production technologies and management skills. But how much technology did they introduce with the production line? Have they absorbed introduced technology? Can they innovate introduced technology?

- Introducing solar cell technology while importing production line: Generally speaking, major purpose of importing production line is to introducing advanced technology. But whether a manufacturer could import the needed technology successfully and roundly depends heavily negotiation skills. Technology providers tend not to transfer their best technologies, so technology receivers have to work hard to get good results. Let us take Huamei Solar Equipment Company in Qinhuangdao as a successful example. It managed to acquire most of the technological documents while they imported production line, which help the company greatly absorb the introduced technologies. On the contrary, Alpha Solar Energy Power Co. Ltd., which is only a few miles away from Huamei, failed to do the same. It set up a joint venture and spent USD$6.9 million to import an assembly line of concentrator photovoltaic system without introducing the production technology of the special solar cell, so they had to rely on importing the solar cells to go on production. It is only an assembly plant of the US partner without independent production capability.

- Follow-up innovation: After importing production lines, all manufacturers had to go through the process of adjusting and debugging all imported equipment in order to let them running normally. Through this process, they learned all functions of the production line. Then, the R&D efforts on improving solar cell efficiency and quality as well as on developing new products, that is, follow-up innovation, began. Currently, manufacturers are facing problems like the shortages of R&D fund and desirous technology. They could only make insignificant incremental improvements on the production line, such as changing encapsulation design. They are reluctant to perform R&D on increasing solar cell efficiency, because it requires a large amount of money and heavy skilled labor input and has high risk of failure.

(6) Problems in Marketing:

Every domestic manufacturer today is competing with foreign companies and other Chinese manufacturers in the limited Chinese market.

- Some state-owned manufacturers are still not accustomed with the practice of market economy. They still rely on the central government for money, policy, contract, and many others. Some manufacturing company managers are not trained to be a business man/woman and one of them even doesn't know any name of the foreign competitors.

- Users are inclined to foreign products because of their beautiful packaging and good reputation in quality. With limited efforts to improve their products, domestic manufacturers have to lower their prices in order to sell their inferior products.

- Profits of PV products, especially household PV system, are low. So the payback period of investment is long. Survey shows that the profits of PV systems for household and large project are 1-5% and 5-10%, respectively.

3. Measures for promoting Technological Innovation in domestic PV industry

(1) Establishing national quality standards of PV Products: Now, there is no national standards of the production and installation of PV products. The industry uses the standards of semiconductor industry, military industries and other industries. Many experts believe that establishing the national standard system of PV products will do a lot of good to a healthy development of domestic PV industry.

(2) Financing R&D of PV technology: Shortage of R&D money limits the technological progress, hence the development of domestic PV industry. Therefore, getting enough R&D money is a key issue of the technological innovation of domestic PV industry. This is especially true for an industry that is still in its early development stage and in a difficult financial condition. R&D institutes and manufacturers want government give them more R&D money, but government wants manufacturers support R&D by themselves. Today, government is more willing to spend money to subsidize the purchase of PV systems rather than to give money to finance R&D of manufacturers, because government doubts if the money could be used effectively.

To solve this problems, government purchasing might be a good approach. Specifically, whenever government money is used for purchasing PV systems, the products purchased must be domestically made. This is an indirect way for the government to subsidize domestic PV industry.

(3) Promoting market competition: Not all solar cell manufacturers work well now. As the reform of state-owned enterprise goes, these manufacturers must change their management style in order to survive in the market. It will be good for domestic PV industry to see some firms with bad conditions merged or acquired by others, or even bankrupt. We must believe in the selection of market competition and abandon the old practice of protecting poorly managed firms because they are state-owned.

(4) Enhancing international cooperation: Photovoltaic technology and its application developed quickly in recent years and there are lots of conferences, papers about this issue. China must enhance international cooperation for learning the new technology development and management practice and introducing advanced technologies. China should also make good use of various donations and favorable loans provided by foreign governments, international organizations and institutions to help millions of poor people in remote areas and to develop domestic PV industry.

Chapter Four Conclusions

In this report, we focus on the issues of the development and technology innovation of domestic PV industry. The purpose is to analysis the problems in the industry on the basis of questionnaire survey and to make policy recommendations for developing China's PV industry. We reach following conclusions:

1. Domestic PV industry is still in its early development stage. We reach this conclusion according to the market status, technology status and capital status of PV industry.

2. PV product market, especially the household PV system market, is quite small now, but we look forward to an optimistic market in the near future, say five to 10 years. Based on the questionnaire survey, future PV market will be shared buy household PV system and systems used for large projects, such as telecommunication, navigation mark and cathode protection. Rural electrification will play an important role in the future development of domestic PV industry.

3. Most industrial technologies of domestic PV industry are introduced from foreign countries. Domestic manufacturers are in difficult financial situations and they don't have enough money to carry out R&D. PV industry is a high-tech industry. Technological innovation and R&D play core role in it.

4. Many things, such as limited market, high products cost, capital shortage and unfavorable tax policy, stunt the development of domestic PV industry. The central

government will reduce the amount of government purchasing and let the market select the winner in the industry. We believe that market competition should be encouraged for improve the organizational structure of domestic PV industry.

5. Today, manufacturers, R&D institutions and even service firms face many problems in technological innovation. Although central government and local government have given subsidy to domestic PV industry for a long time, the results have been unsatisfactory. Therefore, people in this industry have to learn the way of operation in a market economy.