Commercialization of Solar PV Systems in China

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June 1, 2000

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1. Background

1.1 Objective of Project

In 1995, the State Science and Technology Commission (SSTC) of the People's Republic of China and the United States Department of Energy (U.S. DOE) jointly signed a cooperation framework on energy efficiency and renewable energy. Since that time, a series of cooperative documents have been signed, and many cooperative projects have been carried out. In 1996, the State Economic and Trade Commission (SETC) of China and the U.S. DOE signed an annex promoting the commercial development of renewable energy enterprises in China and the United States. In light of this agreement, the Renewable Energy Development Center of the Energy Research Institute, under the SSTC, and the U.S. National Renewable Energy Laboratory (NREL), conducted a joint project aimed at increasing mutual understanding between renewable energy companies in China and the United States. Other goals of the project include increasing opportunities for business collaboration and widening financing channels through the activities of information exchange, personnel training, and the creation of market opportunities.

In this project, experts on both sides conducted a joint systematic investigation of the status of photovoltaic (PV) technology in China, including PV generation technologies, PV systems, and PV manufacturers and sellers.

In spite of the rather large market potential, the PV industry in China is a latecomer, and the technical level is rather backward. The PV products are poor in quality and high in price compared with those in developed countries. This greatly restrains the development of PV manufacturers and their market penetration. Most Chinese PV manufacturing enterprises are faced with the problem of updating and reforming their technologies to adapt them to market development and competition. The purpose of this report is to (1) examine the current status of China's PV industry; (2) understand the interests and market trends for U.S. PV enterprises; and (3) communicate this, along with the Chinese government's plans and policies for PV development, to promote cooperation between Chinese and U.S. enterprises, thereby advancing the PV industry and its market development in China.

1.2 Solar Energy Resource in China

China is a vast territory located in the southern part of north latitude 45°, where the solar energy resource is very rich. The annual solar radiation energy on the land surface is about 50×10^{18} kilojoules (kJ) (12×10^{18} kilocalories [kcal]), equivalent to 170,000 millions of tons of coal equivalent (Mtce) . The annual solar radiation in China can be as high as 3,340–8,400 MJ/m^2/yr (80-200 kcal/cm^2/yr), with a median value of 5,852 MJ/m^2/yr (140 kcal/cm^2/yr). The areas where solar energy is abundant include Tibet, Qinghai, Xinjiang, southern Inner Mongolia, Shanxi, north Shaanxi, Hebei, Shandong, Liaoning, west Jilin, middle and southwest Yunnan, southeast Guangdong, southeast Fujian, east and west Hainan, and southwest Taiwan. Solar radiation is the highest in the Qing-Zang Highland. The average elevation of this area is more than 4,000 meters (m) above sea level; the atmosphere is thin, clean, and very transparent; and the latitude is low and sunshine time is long. For example, in Lhasa City, which is called the "Sunshine City," the annual average sunshine during 1961–1970 was 3,005 hours, the comparative sunshine rate was 68%, the annual average of clear days was 108.5, and the total solar radiation was 8,160 MJ/m/yr (195 kcal/cm$^{2/}$yr). The poorest solar radiation areas are located in Sichuan and Guizhou Provinces, especially in the Sichuan Basin, where there are few clear days. For example, in Chengdu City, nicknamed the "Fog City," during 1961–1970, the annual average sunshine was only 1,152 hours, the average relative sunshine rate was 26%, and the annual average good insolation period was 24.7 days.

The distribution of solar radiation is characterized by the following:

Both the high-value center and the low-value center are in regions between north latitudes 22° and 35°, with Qing-Zang Highland being the high-value center and Sichuan Basin the low-value center.

The total solar radiation in western areas is higher than that in the eastern areas, and the radiation in the southern areas is lower than that in northern areas, except in the Tibet and Xinjiang Autonomous Regions.

Because of the precipitation in most southern areas, the distribution of the solar energy resource in areas between north latitudes 30° and 40° is contrary to the normal rule of solar radiation (i.e., instead of decreasing as the latitude increases, it increases along with the latitude).

Based on the rate of annual solar radiation, the country's regions are divided into the following five categories:

First category. Annual average sunshine ranges between 3,200 and 3,300 hours. The total solar radiation received annually is around 6,680–8,400 MJ/m^2 (1,600–2,000 Mcal/m^2), equivalent to 225–285 kgce/m^2. This category covers the regions including north Ningxia, north Gansu, southeast Xinjiang, west Qinghai, and west Tibet. The solar energy resource in this category is the richest, equal to that in northern India and Pakistan. Solar energy in the Tibet Autonomous Region is especially plentiful at 8,400 MJ/m^2/yr, thus ranking it second highest in the world, behind only the Sahara Desert.

Second category. The annual average sunshine is between 3,000 and 3,200 hours. Annual solar radiation per square meter is 5,852–6,680 MJ (1,400–1,600 Mcal or 200–225 kgce). The regions include northwest Hebei, north Shanxi, south Inner Mongolia, south Ningxia, the middle portion of Gansu, east Qinghai, southeast Tibet, and south Xinjiang.

Third category. The annual average sunshine is between 2,200 and 3,000 hours. Annual solar radiation per square meter is 5,016–5,852 MJ (1,200–1,400 Mcal or 170–229 kgce). These regions include Shandong, Henan, southeastern Hebei, Beijing, Tianjin, south Shanxi, north Xinjiang, west Sichuan, south Guangdong, south Fujian, north Jiangsu, north Anhui, and southwestern Taiwan. These areas receive moderate levels of the solar energy resource.

Fourth category. The annual average sunshine is between 1,400 and 2,200 hours. Annual solar radiation per square meter is 4,190–5,016 MJ (1,000–1,200 Mcal or 140–170 kgce). These regions include Hunan, Hubei, Guangxi, Jiangxi, Zhejiang, north Fujian, north Guangdong, south Shaanxi, south Jiangsu, south Anhui, Heilongjiang, and northeastern Taiwan. These areas are poor in solar energy resource.

Fifth category. The annual average sunshine is between 1,000 and 1,400 hours. Annual solar radiation per square meter is 3,344–4,190 MJ (800–1,000 Mcal or 110–140 kgce). These regions, which include Sichuan and Guizhou, have the poorest solar energy resource.

Among the five categories, the first, second, and third categories, with annual sunshine of more than 2,000 hours and annual solar radiation above 586 MJ/cm^2/yr (140 kcal/cm^2/yr), cover more than two-thirds of the country's total territory and are good for solar energy exploitation. In the regions belonging to the fourth and fifth categories, solar energy is available, although the resource there is rather poor. The distribution of solar energy resources can be found in Table 1.1, and more detailed information can be found in Appendix Table 7.1.1.

Table 1.1 Distribution of China's Solar Energy Resource

Category	Annual Sunshine Hours	Total Annual Solar Radiation (kWh/m^2/yr)	Total Annual Solar Radiation (kgce/(cm^2/yr)	Covered Areas	Foreign Equivalent Areas
1	3,200-3,300	1,861–2,325	230-280	North Ningxia, north Gansu, southeastern Xinjiang, west Qinghai, and west Tibet	Northern India and Pakistan
2	3,000-3,200	1,628–1,861	200-230	Northwest Hebei, north Shanxi, south Inner Mongolia, south Ningxia, the middle portions of Gansu, east Qinghai, southeast Tibet, and south Xinjiang	Djakarta, Indonesia
3	2,200-3,000	1,394–1,628	170-200	Shangdong, Henan, southeast Hebei, Beijing, Tianjin, south Shanxi, north Xinjiang, Liaoning, Jilin, west Sichuan, south Guangdong, south Fujian, north Jiangsu, north Anhui, and southwest Taiwan	Washington, D.C.
4	1,400-2,200	1,164–1,394	140-170	Hunan, Hubei, Guangxi, Jiangxi, Zhejiang, north Fujian, north Guangdong, south Shaanxi, south Jiangsu, south Anhui, Heilongjiang and northeast Taiwan	Milan, Italy
5	1,000-1,400	931–1,164	110-140	Sichuan and Guizhou	Paris, France Moscow, Russia

Comparing China's solar energy resource with that of Japan and the United States (refer to Appendix Tables 7.1.2 and 7.1.5 for the annual average solar radiation of Japan and the United States), we find that, except for the Sichuan Basin and adjacent areas, the solar energy resource in the majority of China is rich—similar to that of the United States, and better than that of Japan. In other words, China has excellent solar energy resources, thus placing it in an advantageous position for solar energy exploitation and utilization.

1.3 Background and Developing Trends for PV in China

Solar cells (i.e., PV cells) convert solar radiation into electric energy. By combining several solar cells into modules, assembling the modules into a solar cell array, and then connecting them to other supporting devices such as an energy storage device, a control device, or a DC-AC conversion device, a solar cell (or PV) generation system is formed. Such systems have no moving parts and a long service life, produce no noise or pollution, are simple to maintain, convenient to use, and are quiet and flexible in capacity. Therefore, ever since its emergence in 1954, PV has been developing at a high speed. After only 45 years of development, it has become the basic electricity source for satellites and an important power source in areas where there is no—or not enough—electricity.

To assure a stable energy supply, alleviate environmental pollution and ecological deterioration, achieve a sustainable economy, and advance social development, many countries around the world—especially developed countries—give PV generation technology priority among the many renewable energy technologies. Since the 1980s, PV generation technology has grown at an annual rate of 10%–15%, independent of the development of the world economy. Entering the 1990s, it began developing more rapidly, and has become one of the fastest growing industries in the world. In 1998, the annual world production of solar cell modules reached 157.4 megawatts (MW), increasing by more than 29% compared with 1997. Of this global yield, 58.0 MW was produced in the United States (about 36.8% of the total); 47.5 MW in Japan, (about 30.2%); 35.8 MW in Europe (about 22.7%); and 16.1 MW in other countries (about 10.3%). Annual yields of PV modules can be found in Table 1.2. By the end of 1998, the total installed capacity of PV cells in the world had exceeded about 1000 MW.

Table 1.2 Annual Yield of PV Modules in the World (MW)

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998
U.S.	15.70	16.20	17.90	21.00	25.60	32.40	41.00	50.50	58.0
Japan	15.00	18.70	18.30	17.00	17.50	19.50	20.50	31.00	47.5
EU*	10.50	13.00	16.00	17.00	21.60	21.60	20.60	27.50	35.8
Others	5.70	6.00	6.00	6.00	6.00	7.50	8.50	13.00	10.1
Total	47.00	54.00	58.20	61.00	70.70	81.00	90.60	122.0	157.4

* EU = European Union

1.3.1 Industry Development and Market Exploitation

To greatly reduce the cost of PV cells, efforts have been made to improve technology, enlarge production scale, and exploit the market. In 1990, the U.S. Department of Energy initiated an industrialization plan for PV called Photovoltaics for Manufacturing Technology (PVMaT), with NREL being the implementing body. In 1990, DOE established the National Center for Photovoltaics, which conducts joint research with industrial organizations, universities, and research institutions. Significant achievements were obtained by the implementation of this plan. The photoelectric conversion efficiency of commercial crystalline silicon PV cell modules has reached 12%–15%, annual production has increased from 1–5 MW to 5-25 MW, production technology has been simplified, and automation has been improved. Similar plans are also being carried out in Japan and the EU countries. In the last four years, the production cost of crystalline silicon PV modules has decreased by more than 32%, to $3.00 U.S./peak watt ($W_p$).[1] The price of crystalline silicon PV modules in the world market is currently about $4.00 U.S./$W_p$. This trend is continuing, and a production cost of $1.7~1.8 U.S./$W_p$—about 60% lower than that in 1994—is expected soon. Competition stimulates developed countries to keep their PV technology at a similar level. Table 1.3 gives the cost/price forecast for terrestrial solar cell modules, and Table 1.4 lists the efficiency forecast for commercial solar cell modules.

[1] $1.00 U.S. = 8.3 RMB yuan

Table 1.3 Cost/Price Forecast of Terrestrial Solar Cell Modules (in 1990s $U.S.) Unit: $U.S./$W_p$

Cell Type	1990 (Cost/Price)	1995 (Cost/Price)	2000 (Cost/Price)	2010 (Cost/Price)
Monocrystalline silicon	3.25/5.40	2.40/4.00	2.60/3.33	1.50/2.50
Polycrystalline silicon	3.00/5.00	2.60/3.33	1.50/2.50	1.30/2.20
Non-crystalline silicon	3.00/5.00	2.00/3.33	1.20/2.00	0.90/1.50
Concentrator cell (silicon)	3.00/5.00	2.00/3.30	1.20/2.00	1.00/1.67
Thin-film silicon	----	2.00/3.33	1.20/2.00	0.75/1.25
Copper indium diselenide (CIS)	----	2.00/3.33	1.20/2.00	0.75/1.25
Cadmium telluride (CdTe)	----	1.50/2.50	1.20/2.00	0.75/1.25

Table 1.4 Efficiency Forecast of Commercial Solar Cell Modules (%)

Cell Type	1995	2000	2010
Monocrystalline silicon	15	18	22
Polycrystalline silicon	13	16	20
Non-crystalline silicon (GaAs, InP)	22	25	30
Concentrator cell (silicon)	7-9	10	14
Thin-film silicon	8-10	12	15
CIS	7-9	12	14
CdTe	7-9	12	15

The current applications of PV systems in the world are 45% for residences, village power supplies, and water pumping; 36% for communication and remote facilities; 14% for grid-connected power generation; and 5% for calculators, watches, and other small-scale products. In recent years, great changes have taken place in the world PV market. The application of PV is gradually moving from mainly supplying power for special applications, such as remote rural areas, communication facilities, weather observatories and stations, and navigation lights, towards conventional power supply, such as grid-connected power generation and building energy supply. By 1995, the installed capacity of PV systems for grid-connected power generation had reached 12 MW. In Germany, the total installed capacity of PV modules for grid-connected power generation has reached 33 MW, of which 10 MW was installed in 1997. Worldwide, there are now six PV generation stations, each with a capacity of more than 1 MW. The capacity of the largest one is 6.45 MW.

Many countries have formulated PV development programs. The United States began the Million Solar Roofs Initiative in 1997. The goals of this plan are to install 3,000 MW of PV systems on 1 million rooftops in 325 cities by 2010, thus reducing the cost of PV power generation to $0.06 U.S./kWh. The Japanese government plans to install 400 MW of PV by 2000 and 4,600 MW by 2010. During April 1997 through March 1998, 9,400 rooftop PV systems (4 kW each), with a total capacity of 37 MW, have been installed, with subsidies of $92 million U.S. In addition, $168 million U.S. was invested into PV systems directly or indirectly by the Japanese government during that fiscal year. This greatly stimulated not only the Japanese PV industry and market, but also the world PV industry and market.

In addition to these government plans, many large companies have formulated plans to enlarge the scale of PV production and markets. In 1999, the total production capacity of PV cells reached 263.5 MW. For example, BP Solar Company plans to enlarge its annual production capacity of PV cells from 20 to 50 MW. Also, a new polycrystalline factory will be built by Shell in Germany with a production capacity of about 25 MW/year.

PV generation technologies, as well as related industries, are currently developing at a very rapid rate. In the next 10 years, the production of PV modules may increase at an annual rate of 30% or more, perhaps reaching 400 MW/yr by 2000 and 4.6 gigawatts (GW)/yr by 2010. By then, the total operating capacity may reach 20 GW. In applications, PV systems will move from supplementary energy in remote and rural areas to substitution energy for the whole society. It is further expected that electricity generated by solar energy may eventually account for 15%–20% of the world's total electricity generation, thus making PV one of the world's most important energy sources.

1.3.2 Research

Much research and development (R&D) aimed at reducing PV generation cost has been carried out in developed countries. High-efficiency cells based on crystalline silicon material and thin-film cells are the focal points of basic research. At the University of New South Wales, Australia, high-efficiency monocrystalline silicon cells have reached efficiencies of 24%; in the United States, Japan, and Germany, efficiency has reached 23%. Research on thin-film cells is mainly focused on amorphous silicon, CdTe, CIS, and polycrystalline silicon cells. For amorphous silicon cells, double-junction and triple-junction layer-by-layer cells are used to overcome attenuation and increase efficiency—current laboratory efficiency has exceeded 12% (stabilized, total area). The efficiency of CdTe cells has reached 16% and CIS cell efficiency has reached 19%. Pilot-scale CIS production lines with module efficiencies above 12% have already been built by Siemens Solar. Research on polycrystalline silicon cells has developed very rapidly since 1987; laboratory efficiency has now reached 17%. In 1995, the University of New South Wales, Australia, and the Pacific Energy Company together invested $5 million U.S. to develop industrialized technology for a new, crystalline silicon thin-film cell. The funds will also be used to establish a production line with an annual capacity of 20 MW within the next seven years. Feasibility analysis shows that when the cost of a cell is below 1 Australian dollar per peak watt, the power generation cost of this technology will be comparable with that of conventional technologies. This kind of research is also being carried out actively in the United States, Japan, and Europe. The "Gratzel" cell, which is named after its inventor, Dr. Micher Gratzel of the Federal Technology Research Institute of Switzerland, is based on the sensitization of TiO_2 by a kind of light dye; its efficiency exceeds 11%. A new type of cell in the PV field, it has attracted broad attention and strong interest worldwide.

PV modules with micro DC-to-AC converters have been developed. This kind of module will bring change to PV system installation and integration with buildings.

PV generation for buildings is currently a hot area of research for utilizing solar energy on a large scale. The United States, Japan, and EU countries are now making great efforts to promote this technology. In addition to the PV cell panels that can be installed on rooftops, products that can be installed with solar cells inside the roof tiles have already been developed.

1.3.3 Developing Trends

Expected developing trends of PV technology in the next 20 to 30 years can be summarized as follows:

(1) Crystalline silicon PV cells will continue to be an area of research; high efficiency and low cost will be the major research directions. Crystalline silicon is expected to continue to serve as the basic cell material. Currently, the large capacity of crystal growers and the expensive multiple-wire saws required for manufacturing silicon material and wafers suitable for cells is resulting in a single wafer cost of $1.50 U.S./W. Processes to cut wafers thinner and make flat crystals larger, are now under development to reduce the single wafer cost by half. It is expected that costs can be reduced to $1.00 U.S./W within the next 5 to 10 years, and to $0.50 U.S./W within 15 to 20 years. If this occurs, the production cost of this type of PV modules will decrease from the current cost of \$3.00 U.S./W_p to \$1.50 U.S./W_p within 15 years. If the price of PV systems decreases to \$4.00 U.S./W_p in 10 years and further decreases to \$2.00 U.S./W_p in 30 years, the electricity generation cost of household PV systems will be about equal to that of conventional generation technologies.

The main technical obstacles hindering the increase of conversion efficiency of monocrystalline silicon PV cells are: (a) the shading effect of grids on cell surface; (b) light reflection loss; (c) electric conduction loss; (d) internal recombination loss; and (e) surface recombination loss. To reduce these losses, new technologies have been developed. These include: (a) single- and double-layer anti-reflecting film; (b) laser scribing and grid embedding; (c) high-efficiency reflector; and (d) light absorption. Based on these technologies, new types of monocrystalline silicon PV cells, such as point-contact silicon PV cells, laser-scribed PV cells and passivating emitting area and rear local diffusion (PEARL) cells, have already been developed.

Because the reduction of silicon material cost is the key to decreasing the cost of silicon PV cells, and because the cost of polycrystalline material is lower than that of monocrystalline silicon material, research efforts can also focus on polycrystalline silicon solar cells in the following areas: (a) polycrystalline silicon production technology, (b) surface treatment technology, (c) improvement of silicon wafer quality, and (d) continuous and rapid cell wiring technologies.

(2) A new generation of thin-film solar cells will provide the brightest prospects. A thin-film PV cell is composed of thin semiconductor films (with thicknesses from one micron to 10 microns) deposited on glass or other low-cost substrates. With a very thin semiconductor layer, less material is needed and production costs can be greatly reduced. These cells are currently the focus of worldwide research in advanced PV technology.

Research highlights include:

(a) A-Si PV cells. A-Si cells are composed of a semiconductor deposited on a substrate. When silicon gases (such as SiH_4) are injected into a vacuum-reaction chamber, they are decomposed through electric discharge. The decomposed silicon is then deposited on glass, stainless steel, or a plastic substrate. This kind of cell has a transparent electrode and can be heated to about 300°C. The advantages of this technology are low temperature during the production process and a low heat energy requirement; production based on gas reaction suitable for continuous and large-area production; a semiconductor layer with a high light-absorption ratio; and only 1 micron thickness. United Solar and BP Solarex operate production plants in the United States.

(b) CdTe PV cells. Through a relatively simple technology, CdTe, CdS, and other II-VI compound semiconductors are deposited on a glass substrate. Current research is focused on reducing cost, increasing yield, and improving efficiency. First Solar, BP Solarex, ANTEC, and Matsushita are building production facilities.

(c) CIS PV cells. CIS cells are relatively higher in light absorption and conversion efficiency than a-Si PV cells. The cell conversion efficiency is currently 19%; 11%-12% CIS modules are commercially available from Siemens Solar Industries.

(3) Key balance of system equipment, such as controllers and inverters, will be more reliable, higher efficiency, and lower cost.

(4) Long life, low cost and maintenance free batteries that are more suitable for PV systems will be developed.

(5) Integrated system technologies will be developed to encourage standardization, component integration and use of intelligent control systems.

1.4 Current Status and Problems of PV Technology in China

Research on solar cells began in 1958 in China and the first solar cell with practical value was developed in 1959. In March 1971, China used solar cells for the first time as the electric source for a scientific research satellite. In 1973, with an experiment to supply power for the buoy light of Tianjin Harbor, the terrestrial application of solar cells was initiated.

1.4.1 Current Status

1.4.1.1 Industry and Products

By 1998, there were seven factories manufacturing PV modules, with an annual production capacity of 4.4 MW, of which 2.4 MW were monocrystalline silicon cells and 2 MW were amorphous silicon cells.

The main PV cell products are monocrystalline silicon cells and amorphous silicon cells. Monocrystalline silicon cells are mainly round slices with a diameter of 100 mm. The conversion efficiency of commercial modules is 12%–13%, and the capacity of modules of 36 cells is approximately 37 W. Some factories can produce 100 x 100 mm^2 cast polycrystalline silicon cells, but these products have never been put into formal production due to equipment and cost limitations. At present, one pilot test production line of the Beijing General Research Institute of Nonferrous Metals produces cast polycrystalline silicon cells. The largest commercial amorphous silicon PV cell module is 305 x 915 mm^2 with a capacity of 11–12 W and a conversion efficiency of 5%–6%. This is for a single-junction p-i–n cell. The conversion efficiency of test products of polycrystalline silicon PV cell modules is 10%–12%.

The annual production of PV cell modules in 1998 was 2.3 MW. Of that total, 1.6 MW were monocrystalline silicon PV cell modules and 0.5 MW were amorphous silicon PV cell modules. In 1998, about 400 kW of monocrystalline silicon PV cells and modules were imported, and about 1 MW of amorphous silicon cells were exported.

In 1998, the price of monocrystalline silicon PV cell modules in China was 40-45 yuan/W_p, and that of amorphous silicon PV cell modules was 24-26 yuan/W_p.

1.4.1.2 Research

Research on high-efficiency monocrystalline and polycrystalline silicon cells, amorphous silicon thin-film cells, CdTe thin-film cells, CIS thin-film cells, polycrystalline silicon thin-film cells, as well as relevant technologies and application systems, has been conducted by research institutions, colleges, universities, factories, and businesses. Laboratory efficiency and size of the main PV cells are listed in Table 1.5. In recent years, with the support of the Ministry of Science and Technology and the Beijing Municipal Government, some achievements have been made in the National New Energy Engineering Center and the Beijing Municipal Solar Energy and Photoelectricity Center. The efficiency of high-efficiency monocrystalline silicon cells has reached 19.8%; the efficiency of large-area (5 x 15 cm^2) notching and grid embedded monocrystalline silicon cells reached 18.6%; the efficiency of polycrystalline silicon cells reached 13.5%; and the efficiency of 10 x 10 cm^2 polycrystalline silicon cells reached 11.8%. The efficiency of polycrystalline silicon thin-film cells, manufactured on inactive substrates by rapid-heating chemical vapor deposition (CVD) technology, has reached 12.11%; the efficiency of multi-microcrystalline silicon/amorphous silicon layer thin-film cells, manufactured by plasma-enhanced chemical vapor deposition (PECVD) technology, has reached 9.5%.

Table 1.5 Laboratory Efficiency and Size of China's Main PV Cells

Cell Type	Highest Efficiency (%)	Maximum Size
Monocrystalline silicon cell	20.4 14.0	2 cm x 2 cm 10cm (utility-type)
Gallium arsenide cell	20.1	1 cm x 1cm
Polycrystalline silicon cell	13.1 12.0	2 cm x 2 cm 10 cm x 10 cm
Concentrator cell	17.0	2 cm x 2 cm
Amorphous silicon cell	11.2 (single-junction) 11.4 (double-junction) 8.55 7.88 6.17	several mm^2 several mm^2 10 cm x 10 cm 20 cm x 20 cm 30 cm x 30 cm

Great progress has also been made in PV generation systems. During the Eighth Five-Year Plan (1991-1995), 15-kW and 30-kW DC-AC converters for stand-alone PV generation systems were developed. Their conversion efficiency is higher than 90%. A series of controllers and monitoring devices specifically designed for PV systems has also been developed.

A great deal of progress has also been made in applications, such as PV water-pumping systems, PV power supplies for communications, stand-alone PV power stations, gas and oil pipeline cathodic protection, household PV generation systems, and solar/wind hybrid power systems.

1.4.1.3 Applications and Markets

Since 1973, the terrestrial application of PV cells in China has been increasing steadily. Before 1980, PV technology was used on a limited basis, the power was low, and annual sales of PV cells were no more than 10 kW. Before 1985, PV cells were mainly used as electric sources for navigation lights, railway signals, instruments in weather stations/observatories, electric fences, small communication equipment, black-light lamps, DC headlamps, and lamps for rubber tapping; and the power of each system was low. Under the support of the former State Science and Technology Commission, some demonstration projects to guide market exploitation have been implemented, such as unmanned solar microwave relaying stations, small-scale solar-charging stations, a PV power supply for rural telephone systems, a solar power supply for petroleum pipeline cathodic protection, and reservoir anchor gate cathodic protection. In the late 1980s, with the introduction of several PV cell production lines, the price of PV cells decreased, production increased very rapidly, and new applications were exploited continuously. In the 1990s, PV cells were no longer used just as small electric sources, but were also used in different applications such as communications, traffic, petroleum, weather service, national defense, and rural electrification. The use of PV cells increased at an annual rate of more than 20%. By the end of 1998, 13.2 MW of PV cells had been in use in China. Table 1.6 shows the yield, price, and cumulative capacity of PV cells in China during the last two decades.

Table 1.6 Yield, Price, and Cumulative Capacity of PV Cells in China

Year	Annual Yield (kW_p)	Module Price (yuan/W_p)	Cumulative Capacity (kW_p)
1976	0.5	400.0	0.5
1977	1.0	200.0	1.5
1978	2.0	120.0	3.5
1979	5.0	100.0	8.5
1980	8.0	80.0	16.5
1981	15.0	75-80	31.5
1982	20.0	70.0	51.5
1983	30.0	60.0	81.5
1984	50.0	50.0	131.5
1985	70.0	45-50	200.0
1986	80.0	40-45	280.0
1987	100.0	4.0	380.0
1988	a-Si 200.0 c-Si 150.0	a-Si 21-23 c-Si 35-45	730.0
1989	a-Si 300.0 c-Si 250.0	Si 23 c-Si 35-37	1,280.0
1990	a-Si 100.0 c-Si 400.0	a-Si 22-25 c-Si 38-40	1,780.0
1991	a-Si 100.0 c-Si 450.0	a-Si 23-25 c-Si 38-40	2,330.0
1992	a-Si 150.0 c-Si 500.0	a-Si 25 c-Si 40-42	2,980.0
1993	a-Si 250.0 c-Si 650.0	a-Si 25-27 c-Si 40-47	3,880.0
1994	a-Si 200.0 c-Si 900.0 imported 100.0	a-Si 25-27 c-Si 40-47 imported 50-60	5,080.0
1995	a-Si 200.0 c-Si 1000.0 imported 350.0	a-Si 25-27 c-Si 40-47 imported 50-60	6,630.0
1996	a-Si 450.0 c-Si 1420.0 imported 300.0	a-Si 25-27 c-Si 40-47 imported 50-60	8,800.0
1997	a-Si 600.0 c-Si 1500.0 imported 500.0 exported 400.0	a-Si 25-27 c-Si 40-47 imported 45-60	11,000.0
1998	a-Si 500.0 c-Si 1800.0 imported 400.0 exported 500.0	a-Si 24-26 c-Si 40-45 imported 45-60	13,200.0

1.4.2 Problems

There is a big gap between PV technology and industry in China and that in more developed countries. The main problems are:

(1) Small production scale. Currently, the production scales and technological levels in four monocrystalline silicon PV cell production factories still remain the same as that during 1987–1990, when the production lines were imported. At that time, every factory expected its annual production capacity would be 1 MW; however, the actual production was only about 0.5 MW per year, due to different bottlenecks in the technical processes in different factories. Therefore, the total annual production capacity of crystalline silicon PV cells is only 2.4 MW. In 1998, the annual production of monocrystalline silicon PV cell modules was 1.8 MW, accounting for only 1.14% of global output. Production scale of PV cell modules in China is an order of magnitude lower than that of foreign countries, which generally produce between 5 and 20 MW.

(2) Low technology level. Currently in China, the photoelectric efficiency of commercialized monocrystalline silicon PV cell modules is 10%–12%; however, the packaging quality of the modules is low. After 3–5 years of usage, yellowing, bubbling, delamination of contacts, and an efficiency decrease appeared in some modules. Thus, their actual service life is shorter than that of foreign products. Currently, no production factory for polycrystalline silicon PV cells exists in China. Amorphous silicon PV cell factories cannot produce double-junction and triple-junction cells, but can only produce single-junction cells. These cells have poor stability and their efficiency is low.

(3) Out-of-date auxiliary equipment. Currently, no factory in China has the facilities to produce and test auxiliary equipment for PV generation systems. Controllers and DC/AC converters are only produced on a small scale. The quality of these products is not very good, reliability is low, varieties and specifications are limited, prices are high, and there aren't enough resources to research and develop more advanced products.

(4) Low level of localization of specific materials. Key packaging materials such as silver paste, low iron hardened glass, and ethylene vinyl acetate (EVA) have not yet been manufactured domestically. Localization of specific materials is a key component of the Eighth Five-Year Plan. Although there have been some achievements, the performance of domestic products is still poorer than that of foreign products. To assure the quality of the products, most of the materials currently being used still must be imported.

(5) High cost and price. At present, the production cost of crystalline silicon PV cells is about 26–30 yuan/W_p, and the average market price is about 40–45 yuan/W_p. Both of these prices are higher than those of foreign products; therefore, domestic products are less competitive than foreign products in the market.

1.5 State Programs for PV Technology Development in China

In November 1995, the State Planning Commission, the State Science and Technology Commission, and the State Economic and Trade Commission jointly formulated the *Development Program for China New and Renewable Energy During the Year 1996–2010.* This program emphasizes the development and application of PV generation technology. According to the program, vigorous efforts should be directed towards R&D of PV modules and balance-of-system equipment, as well as system cost reduction. Before the year 2000, the construction of stand-alone PV generation stations in Tibet's nine counties should be completed, the dissemination and application of small power PV systems should be strengthened, and demonstrative decentralized and centralized grid-connected PV generation stations at the MW scale should be constructed. Some measures are also put forward aimed at awakening consciousness, strengthening guidance, formulating preferential policies, improving R&D, speeding up industrialization, widening international cooperation, and introducing advanced technologies and foreign funds.

To implement the program, *Preferential Projects for the Development of China New and Renewable Energy* was formulated, and solar PV technologies were listed in the second part. This part includes two major activities.

1.5.1 Research on High-Efficiency, Low-Cost Solar Cells

(1) Targets. Improve efficiency, reduce cost, enlarge scale, and promote PV industrialization. First, develop high-efficiency, low-cost polycrystalline silicon solar cell technology through a combination of independent research and importing to build a production line with an annual capacity at the MW scale. Second, improve the efficiency of monocrystalline silicon solar cell modules, reduce production cost, fully utilize the current capacity, and fulfill market demand.

(2) Contents. First, construct polycrystalline silicon solar cell module production lines at the MW scale, with module efficiencies of 13% and a service life of 20–25 years. Second, update monocrystalline silicon solar cell module production lines, with module efficiencies of 14%–15% and a service life of 20–25 years. Third, research and develop new types of high-efficiency and low-cost solar cells.

1.5.2 Demonstration of PV Cell Applications

(1) Targets. First, through the implementation of the program, realize the industrialization of small PV electric sources. Second, develop balance of system component, standardize, and commercialize stand-alone PV generation systems with capacities below 100 kW. Third, develop and prepare a large-scale application of grid-connected PV.

(2) Contents. First, industrialization of small PV electric sources with capacities at the 100-W and 1000-W scales. Total production capacity reaches more than 1 MW and production cost should be reduced by more than 30% compared with the average cost in the Eighth Five-Year Plan. Second, standardization, and commercialization of stand-alone PV stations with a capacity of 10–100 kW. Production cost of the system should be reduced by more than 30% compared to the average cost in the Eighth Five-Year Plan. Third, demonstration of grid-connected PV generation technologies, including a pre-feasibility study on MW-scale PV stations, a DC/AC converter for 10-kW, grid-connected PV stations, operation of PV stations in electric power system and related technologies. Fourth, high-water-head PV pumps with delivery heights of 50–100 meters and solar cell power of 5–10 kW.

In 1996, the Ministry of Power Industry formulated the *Program for the Development of Solar Power Generation During the Years 1996–2020*. The objective of the program is that, by the end of this century, 70 million rural people with no current access to electricity should be supplied with electric power, no counties should be without a power supply, and more than 95% of all households should be supplied with electricity. In accordance with the national power development plan, the rural electrification plan, and the current status of solar technology, the program raises the following development targets for PV generation in China during 1996–2000 and 2001–2020.

(a) Supply electricity for lighting and TVs for more than 15 million households with no current access to power. Household PV systems will be used to supply electricity for 1/10 of these households—about 1.5 million. Before the year 2000, supply electricity to 300,000 households. The average capacity of each system is 50 W_p, so the total capacity will be 15,000 kW. During 2001–2020, annual installation will be 60,000 systems, with a total capacity of 3 MW. The 20-year accumulation will be 1.2 million systems and 60 MW.

(b) During 1996–2000, 50 small-scale PV stations (10 kW average) for county, town, and village use, will be constructed each year; by the end of the year 2000, the total installed capacity will be 2.5 MW. In addition to continuing the construction of PV stations in remote areas with comparatively high population density but no access to power, during 2001–2020, 50 small grid-connected or stand-alone PV stations with an average scale of 30 kW will be built in urban areas each year. The total installed capacity will be 30 MW by 2020.

(c) By the end of 2000, two large-scale, grid-connected PV stations with a capacity of 500 kW will be constructed. During 2001–2020, five large grid-connected PV stations with a capacity of 1 MW each will be constructed. At the same time, the program issues some recommendations on research, industrialization, and policies and measures for putting forward this program.

(d) In order to assist in meeting the poverty alleviation objectives of the central Government and foster the rapid development of rural renewable energy systems, the State Development Planning Commission initiated the Brightness Program in 1996. The program will use PV and wind power to provide electricity to 23 million people by 2010. The near term goal of the program is to supply electricity to 8 million people by 2005.

2. PV Market

2.1 Evaluation of Current PV Market Status

By the end of 1997, the cumulative capacity of PV cells for terrestrial application in China reached 11 MW. The major applications are:

(1) Communication
- Microwave relay stations
- Optical-cable communication stations
- Wireless calling stations
- Terrestrial stations for satellite communication
- Terrestrial stations for satellite TV transit
- TV transit stations
- Communication facilities in rural areas
- Military communication facilities

(2) Other industrial areas
- Systems for railway and road signals

- Navigation lamps and light towers
- Weather observatories/stations
- Earthquake-forecasting stations
- Cathodic protection for petroleum pipelines and reservoir anchor gates
- Forest fire warning systems
- Railroad switches
- Frontier defense sentries
- Road signals

(3) Agricultural and rural electrification
- Stand-alone PV generation stations
- Household PV electric sources
- PV water pumping systems
- Solar lighting lamps
- Solar/wind hybrid power systems
- Electric source for electric fences
- Solar black-light lamps
- Solar lamps for tapping

(4) Civil commodities and others
- Solar cool cap
- Solar charger
- Solar calculator
- Solar watch
- Solar bell
- Solar street lamp
- Solar courtyard lamp
- Solar yacht and barges
- Solar automobile ventilator
- Solar semiconductor refrigerator
- Solar toy
- Solar advertising lamp box

Table 2.1 shows the market share of each application.

Table 2.1 Market Share of Different Applications

Application Field	**Cumulative Used Amount (kW_p)**	**Market Share (%)**
Agriculture and rural electrification	3,960	30
Communication	5,280	40
Other industrial fields	2,640	20
Civil commodities and others	1,320	10
Total	13,200	100

2.1.1 Rural Electrification

By the end of 1996, 98.6% of towns, 96.7% of villages, and 94% of rural households—totaling 880 million people—had access to electricity. However, there were still 16 counties, 649 towns, and 24,800 villages with more than 14 million rural households and more than 70 million peasants and herders who still had not been supplied with power. China is now putting forward a rural electrification program to solve this problem and supply electricity to 95% of peasants and herders by the year 2000. PV generation is an important measure for implementing this program.

2.1.1.1 Distribution of Consumers

The beneficiaries of rural electrification by PV generation in China are mainly situated in the seven northwest provinces and autonomous regions, including Inner Mongolia and Tibet. By the end of 1997 there were still about 2 million rural households - about 10 million people - with no electricity in these seven provinces and autonomous regions, as listed below in Table 2.2.

Table 2.2 Rural Households with No Power Supply in Seven Regions

Province/Autonomous Region	Rural Households with No Power (millions)	Agricultural and Pasturing Population (millions)
Inner Mongolia	4	20
Xinjiang	5	25
Qinghai	1	4.5
Gansu	4	20
Ningxia	2	8
Shaanxi	3	15
Tibet	1.2	5
Total	20.2	97.5

In these seven provinces and autonomous regions, villages that are suitable candidates for PV generation for household and production power have some common features:

(1) They are rich in solar energy resources. In 19 counties not connected to power grids in Qinghai Province, the average annual sunshine is 2,300–3,650 hours, the sunshine ratio is 60%-80%, the annual total radiation amount is 5,860–7,540 MJ/m^2, and the annual average direct radiation is 4,190 MJ/m^2. In the Alashan Meng League, in the westernmost part of Inner Mongolia, there is a concentration of farmer and herdsman households with no electricity. The annual sunshine is 3,400 hours with an annual total radiation of 5,000-6,000 MJ/m^2. Shuanghu County, which is located in Qiangtang Highland of Naqu district of North Tibet, and where the elevation is 5,100 m above sea level, the annual sunshine is 3,000 hours, and the annual total radiation is 7,830 MJ/m^2. Xinjiang, located in the center of Eurasia, with a latitude between 33.5^o and 48.5^o, belongs to the typical continental climate. The annual sunshine is 2,500–3,500 hours, sunshine ratio is 60%–80%, and the annual total radiation is 5000–6000 MJ/m^2. The solar energy resource ranks second in China, behind Tibet.

(2) There is a low population density and low power load. There are 1.25 million households (5.80 million people) scattered throughout rural areas in Inner Mongolia, where the population density is very low. The average population density of the whole autonomous region is 17.4 people/km^2, whereas there are only 8.1 people/km^2 in this area. In rural areas that have 369,000 households and 1.81 million people, the population density is even lower—about 2.5 people/km^2. One site only consists of 2–5

households. During the summer, herdsman families often leave their site, and the population density in remote rural areas is less than 1 person/km^2. Situations in rural areas of Tibet, Qinghai, and Xinjiang, are similar to that in Inner Mongolia. In most rural areas of Tibet and Qinghai, the inhabitants are more dispersed, and population density is lower. For example, in Qinghai, the population density of the whole province is six people/km^2, whereas that of Yushu and Guoluo prefectures is as low as 1.16 people/km^2. In these areas, power loads will not change greatly. People there will be very satisfied to get a power supply for lamps, radios, and televisions. PV generation systems with a capacity of 50–100 W are suitable there.

(3) Power grids are often located at great distances. The total area of Yushu prefecture in Qinghai for example, is 197,800 km^2, and the average population density is 1.18 people/km^2. Counties in this prefecture are far from each other, and the distance from a county town to a village is often tens, even hundreds, of kilometers. In some rural counties, the terms “town” and “village” are only concepts for administrative management. Besides sites where town governments are located, sites with more than 10 households are very scarce. It is the same in Inner Mongolia in the rural areas. In cities with an area of 708,600 km^2, which account for 59.9% of the whole autonomous region, there are only 1.8 million herdsmen; the population density there is 2.5 people/km^2. Obviously, it is uneconomical to supply power for such areas by extending power grids.

(4) There are insufficient hydropower resources. In most of the above-mentioned areas, insufficient hydropower resources are available. Even in those areas with small hydropower resources, conditions for exploitation are rather poor due to geographical and weather conditions. In rural areas in Tibet and Qinghai, the annual average temperature is usually below 0^oC, and the winter is cold and very long, so it is hard to exploit small hydropower resources. The electricity generation from several currently existing small hydropower stations is very unsatisfactory.

(5) Their economy is less developed and they have below-average income. Out of 592 poor counties supported by China’s “Eight Seven Aid Poor Plan,” 174 counties are situated in these provinces and autonomous regions. In these counties, the economy is less developed, science and culture are poorly developed, and traffic is inconvenient. Most of these counties are located in mountainous areas and most peasants and herdsmen are minorities. Obtaining warm clothes and enough food to eat are still big problems for many of these people.

2.1.1.2 System Scale and Developing Process

At present, three types of PV generation systems are used in rural areas: small-scale stand-alone PV generation stations, household PV generation systems, and PV water-pumping systems.

(1) Small-scale, stand-alone PV generation stations

Supported by state commissions and ministries, local governments, international organizations, and foreign companies, some small-scale, stand-alone PV generation stations and solar/wind hybrid power stations have been constructed in the above-mentioned seven regions, as well as in some counties, towns, and villages that are without electricity but have a high population density. These power stations not only supply electricity for lighting, TV sets, offices, hospitals, and schools, but also demonstrate the potential for further expansion.

By October 1998, 39 small-sized, stand-alone PV generation stations had already been built and put into operation in rural areas, and about 417.4 kW of solar cells had been installed. Of these power stations, 8 are in Tibet, with an installed solar cell capacity of 256 kW; 2 are in Xinjiang, with a capacity of 9 kW; 2 are in Gansu, with a capacity of 14 kW; 7 are in Qinghai, with a capacity of 21.4 kW; 17 are in Inner Mongolia, with a capacity of 104 kW; 1 is in Shandong, with a capacity of 5 kW; and 2 are in Hebei, with a capacity of 8 kW. With a PV cell installation of 256 kW, Tibet ranks first among all regions in the country. With an installed capacity of 100 kW, the Anduo County PV generation station in the Naqu Region of Tibet, completed in October 1998, ranks first among all PV generation stations in China.

The small-sized, stand-alone PV generation stations have evolved from small to relatively large, from simple to rather complex, from being constructed in the plains to the Tibet highlands, from domestically built to Sino-foreign co-construction.

In 1982, China's first PV generation station was built in Guligutai village (Gazha), Bayantala town (sumu), Balinyou banner, Chifeng city of Inner Mongolia. The capacity of this station is only 560 W. The station is used for charging storage batteries, which are distributed to each of 80 herder households in pairs—one in use and one being charged. Only one fluorescent lamp was used in each household. There were two black-and-white televisions for public use: at night, the herdsmen would gather in the entertainment room to watch TV.

In October 1985, the first kW-scale PV generation station was completed at the Fukang County Breeding Sheep Husbandry facility. This facility is 70 kilometers east of Urumqi City, Xinjiang Autonomous Region. Installed PV cell capacity at this station is 5 kW. This power station supplies power not only for households, but also for production. The main power consumption facilities include: energy-saving DC pumps, five-blade shearing machines, a 10-kilometer electric fence, TV secondary stations, color television receivers, radios and recorders, and a wired broadcast station, as well as lighting for households, offices, and production.

In October 1985, a 10-kW PV generation station was constructed in Yuangzi Village, Yuzhong County, Lanzhou City, Gansu Province, with support from Kyocera Company of Japan. This is the first 10-kW PV generation station constructed with the support of a foreign country.

In June 1990, the first 10-kW PV generation station designed and constructed completely by China was built in Geji County, Ali Region of Tibet, where the elevation is 4300 m. This is the first PV generation station built in a place where the elevation is so high, traffic is so inconvenient, and the climate conditions are harsh. The successful construction of this power station has advanced the application of PV generation into a new stage.

In January 1995, a 30-kW wind/solar hybrid power station, which was a key scientific and technological research project of the Eighth Five-Year Plan, was completed and put into operation in Xiaoguan Island, Jimo City, Shandong Province. This is a wind/solar hybrid power station comprising five sets of 5-kW wind generators and one 5-kW solar cell array.

In June 1996, a Demonstrative Solar Energy School in China Rural Areas for the 21st Century, co-sponsored by the China Sciences Association and the United Nations Educational, Scientific, and Cultural Organization, was built in Lingxi Middle School, Mancheng County, Baoding City, Hebei Province. This project includes two parts: solar heat utilization and PV utilization. PV utilization is obtained through a 4-kW PV generation station. This power station supplies electricity for both teaching and living. It supplies power for the lighting of teachers' offices, students' classrooms, the microcomputer teaching room, an audio-visual teaching room as well as satellite TV receiving equipment. It also supplies power for lighting teachers' dormitories, students' dormitories, the kitchen and bathroom, as well as electric fans, televisions, radios, and recorders.

In August 1998, a 100-kW PV generation station, in which diesel generating sets are used as a reserve power supply, was completed in Anduo County, Naqu Region, Tibet Autonomous Region.

(2) Residential PV systems

To fulfill the electricity needs for such household uses as lighting, radio, and TV for rural inhabitants, China started research on small, portable household PV electric sources in the middle and late 1970s. Some small-scale, multiple-point application experiments and demonstrations were done. In the mid-1980s, a joint symposium was held by the Technology Bureau of State Economic Commission, the Second Bureau of State Science and Technology Commission, and the Science and Technology Bureau of Ministry of Electronic Industry. The purpose of this symposium was to standardize and further promote the production, demonstration, and application of household PV electric sources. After the symposium, the three bureaus jointly printed and distributed a summary of the symposium and demanded that related provinces, municipalities, and autonomous regions, as well as research institutions, factories, and enterprises support this work. In the late 1980s, with the support of the State Science and Technology Commission and the State Economic Commission, as well as related provinces, municipalities, and autonomous regions, 10- and 20-W products were developed in succession by research institutions, colleges and universities, factories, and enterprises in succession. These products were produced on a small scale and were sold in the market. After that, China entered a primary phase of household PV electric source dissemination and application. The amount of electricity used increased at an annual rate of 20%–30%. Since the 1990s, with the decrease of the production cost of PV cells, the gradual improvement of products' technical characteristics and quality, as well as the gradual implementation of preferential subsidy policies, household PV electric sources have entered into a period of relatively large-scale dissemination and application in Qinghai, Inner Mongolia, Xinjiang, Gansu, Ningxia, Tibet, Liaoning, Jilin, Hebei, Hainan, and Sichuan Naba prefectures. According to incomplete statistics, by the end of 1997, about 150,000 households, with a total PV capacity of about 2.9 MW, had some type of PV system.

The Golden Plan project, a scientific and technological cooperative effort between China and Germany, will build household PV power supply systems in poor mountainous areas of Jianchang County, Liaoning Province. The project was completed and put into operation in March 1997, and 25 kW of polycrystalline silicon PV modules were installed. In this project, 100 AC power systems with 100 W of PV modules in each and 300 DC power systems with 50 W of PV modules in each were used. The project can supply power for 400 households distributed among 15 towns, 19 villages, and 20 village groups in the county. With the electricity supplied by the project, the use of electric lamps, radios, recorders, and TV sets is no longer a problem for these households, and the history of lighting with diesel or seed oil for generation after generation ended.

Another project involved putting PV electric sources in remote mountainous areas of Huadian City, Jilin Province. In this project, PV equipment was purchased and installed uniformly by the Municipal Rural Power Bureau. Users pay most of the equipment cost and municipal finance gives a few incentives. This project supplies electricity for more than 80 households for lighting, radio and recorder playing, and watching black-and-white TV. The system consists of a 38-W monocrystalline silicon PV module, a set of 12V, 65Ah, sealed and maintenance-free lead-acid storage battery, and a small-sized controller.

Another project was a demonstration village of household PV electric sources in the southern mountains of Tibet. Sangzhudeqing village, in Changzhu Town, was selected as the demonstration site. PV electric sources were installed for 25 households to supply power for lighting, radios and recorders, and black-and-white TV. Each electric source includes a 40-W monocrystalline silicon PV module, a set of 12V, 35Ah sealed maintenance-free lead-acid storage battery, and a controller.

(3) PV water-pumping system

A PV water-pumping system was highlighted in key science and technology plans of both the Seventh Five-Year Plan and the Eighth Five-Year Plan. In 1992, a PV water-pumping system developed by Hefei Industry University passed provincial certification in Anhui. The product won a silver award at the National New Rural Energy Products and Technology Exposition, a gold award at the Urumqi Exhibition of National Spark Plan Achievements, as well as several patents. It also won the first-class award of scientific and technological advancement granted by the Ministry of Machinery Industry, and the class award of national scientific and technological advancement. In 1994, the products were recommended as Excellent Energy-Saving Products in the Year 1994 by the State Planning Commission, the State Economic and Trade Commission, and the State Science and Technology Commission. It was also listed in the state-level Spark Plan, "853" Key Engineering Projects of Anhui Provincial Government, as well as national "production, learning, and research" projects.

To transfer research results into production as soon as possible, a technical renovation with a total investment of 22 million yuan and an annual yield of 10,000 NSP PV water pumps was completed at the Wannan Minitype Water Pump Factory in June 1993, and approved by the Economic and Trade Commission of Anhui. In August 1996, this technical renovation project was completed, certified, and put into formal operation. The factory, located in Ningguo County in Anhui Province, is currently the only one in China designed specifically for PV water pump production.

The small-scale production of PV water pumps is continuing in this factory; more than 150 PV water-pumping systems have been sold to Fiji, Egypt, Burma, Canada, Australia, Jordan, and Saudi Arabia. Good responses have been received.

There are 20 PV water-pumping systems, either produced by China itself or supplied by cooperative foreign countries, that have been installed in Inner Mongolia, Xinjiang, Qinghai, Gansu, Tibet, and other provinces and autonomous regions for experiments and demonstrations.

(a) Two NSP series PV water-pumping systems with a water head of 30 meters were installed in Gangcha County and Gonghe County in Qinghai Province for experiments and demonstrations.
(b) A floating PV water-pumping system was installed in Xining City for experimental purposes.
(c) The New Energy Village in Yihe Village, Daxing County, Beijing, a cooperative project between China and Germany, provided for the installation of a deep-well diving pump system with PV cell power of 10 kW and one irrigation pump system with PV cell power of 1.1 kW for experimentation and demonstration.
(d) Under the Golden Plan, a cooperative science and technology project between China and Germany, two PV water-pumping systems, with 800 W of PV cells in each, have been installed in Jianchang County, Liaoning Province, for demonstration purposes.

(e) In Ritu, Shiquan He, and Gaize, Ali Region of Tibet, three PV water-pumping systems with 900-W PV cells in each were installed for experiments and demonstrations.

PV water-pumping systems are mainly used in the mountains, grassland, desert areas, and sea islands, where there is lots of sunshine, for lifting water for irrigation or supplying drinking water for people and animals. For example, the Inner Mongolia Grassland is located in an arid area. Middle and western grasslands with deficient water account for 23.3% of the total available grassland, and grassland with an insufficient water supply accounts for 38.2%. In the Inner Mongolia Pasturing Area, the area of artificial feed base and artificial grassland is only a little more than 2 million mu, 0.15% of all grassland; the harvest there mainly depends on the weather. The animals and inhabitants have to follow the water and grass. When wells are dug, a big market for PV water-pumping systems will emerge.

2.1.1.3 Technical Characteristics and Cost

(1) Small-scale, stand-alone PV generation stations

Hanwula PV Generation Station

Located in Hanwula Village (Sumu), Azuo Banner, Alashan Meng League, Inner Mongolia Autonomous Region, this power station was completed in 1995. The capacity of PV cells is 8 kW for which a central power supply mode is used. Diesel generators are used as a reserve power supply for cloudy days and during December, January, and February, when the sunshine is insufficient. The sumu is a livestock production village with no industry. Therefore, the power load is not large. The distance between that sumu and the nearest power grid is more than 100 kilometers, so it is uneconomical to supply power to it by extending the power grid. Before the construction of this PV generation station, a diesel generator was used to generate electricity at night; it provided only enough power for lighting. The average electricity generation time was 3–4 hours a day, and the power generation cost was as high as 3.8 yuan/kWh.

The construction cost of the power station was 600,000 yuan, about 74.6 yuan/W_p, as shown in Table 2.3.

Table 2.3 Construction Cost of Hanwula PV Generation Station

Item	**Construction Cost (Yuan/W_p)**
Monocrystalline silicon PV cell module	42.0
Controller and DC-to-AC converter	5.6
Module support, wire, and cable	3.7
Storage battery unit	5.2
Transportation	1.1
Civil engineering, installation, and modification of electric transmission line	7.5
Management and maintenance	4.0
Design and travelling	3.0
Other	2.5
Total	74.6

According to 15 years of data, daily shared construction cost is: 596,800 yuan ÷ (15 yrs x 365 days) = 109 yuan, 30 kWh electricity generated daily, power generation cost per kWh is 109 yuan ÷ 30 kWh = 3.63 yuan.

In the above calculation, the operating cost of the power station is not considered. Also, the service life of the whole system is assumed to be 15 years, based on the fact that the service life of a PV cell module is 20 years and that of a storage battery is 10 years.

The static electricity generation cost of PV generation is 3.63 yuan/kWh, which is 0.17 yuan/kWh lower than that of diesel generation, which is 3.8 yuan/kWh.

Geji County PV Generation Station

This PV generation station, located in Geji County, Ali Region, Tibet Autonomous Region, was put into operation in June 1990. The station consists of five main parts: a solar cell array system, an energy storage system, a measuring and control system, a DC-to-AC conversion system, and a distribution system. The total capacity of solar cells in this power station is 10,088 W. On December 25, 1990, the Chinese Academy of Sciences held a certification conference. They concluded that the successful construction of this station, at an elevation of 4,300 m and under such difficult conditions, was the first of its kind in the world.

(a) It symbolizes the status of PV generation technology in China, which has advanced into remote areas, thus generating significant, far-reaching effects.
(b) The power station ranks first in capacity among all PV generation stations designed and constructed independently by China.
(c) The general design of the power station is reasonable, technologies are advanced, functions are complete, and protective measures are also included.
(d) The construction of this power station has bridged a technological gap in China, placing the latter in a position close to the advanced level of other countries having the same type of PV generation stations. This station will make great contributions to the exploitation and utilization of new energy resources in China.

The power station, which has operated for more than eight years, has proven to be safe and reliable. It has stood the test of long-term operation without any operational failures. Construction costs of the power station are listed in Table 2.4.

Table 2.4 Construction Cost of Geji PV Generation Station

Item	Investment (million yuan)	Percentage (%)	Note
Solar cell module and support	0.4	40.82	Monocrystalline silicon solar cell modules are used.
Storage battery unit	0.2	20.21	Fixed dry-charge, lead-acid storage battery units are used.
Distribution, detecting, and control system	0.06	6.13	
DC-to-AC converter	0.07	7.14	One DC-to-AC converter imported from Germany is used.
Material	0.02	2.04	
Package and transportation	0.03	3.06	
Civil construction	0.1	10.20	Passive solar house is used.
Design	0.03	3.06	
Installation and construction	0.04	4.08	
Management and others	0.03	3.06	
Total initial investment	0.98	100.00	
Replacement cost of storage batteries	0.2		Storage batteries will be replaced at the end of the 10th year of operation.
Total investment	1.18		

A detailed technical and economic analysis of the power station is shown below.

- Rated power (kW_p).. 10 kW_p
- Annual energy output.. 21,160 kWh
- Present value of total cost .... 119.81 x 10^4 yuan
- Annual cost .... 9.58 x 10^4 yuan
- Present value of unit electricity generation cost .... 2.83 yuan/kWh
- Production cost of unit electricity generation....................................... 2.769 yuan/kWh
- Investment of unit electricity generation .... 2.788 yuan/kWh
- Investment of unit kW power (10000 yuan/kW) .... 11.8 x 10^4 yuan/kW

As seen in the above table, the per-unit generation cost of using PV technology is comparable to that of a diesel generator in local conditions; however, the performance of PV generation is much better than that of diesel power generation. Therefore, PV generation technology has received a warm welcome, and the prospects for dissemination and application in Tibet are quite bright.

<u>Cuoqin County PV Generation Station</u>

This PV generation station was completed and put into operation in December 1994. In October 1995, it passed the state-level certification organized by the Ministry of Power Industry and was recognized as an excellent project. This power station is located 4,700 m above sea level in Cuoqin County, Ali Region, Tibet Autonomous Region, approximately 969 km from Lhasa and 783 km from Shiquanhe Town, where the regional government is located. The power station's generation system is shown in Figure 2.1.

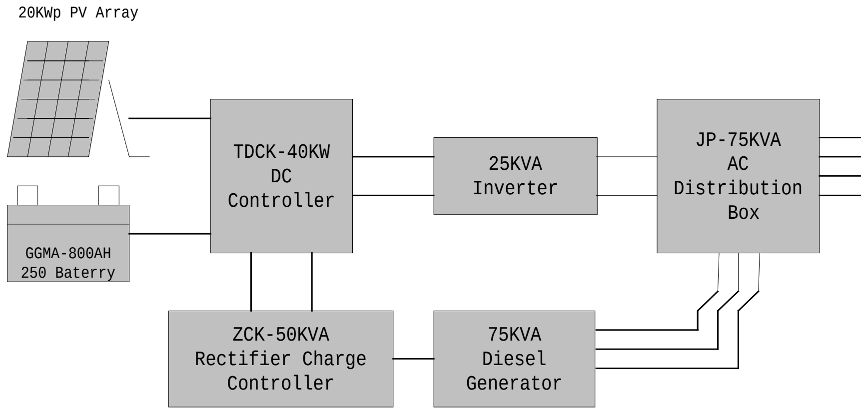

Figure 2.1 Flow chart of PV power station in Cuoqing County

Results of a comparison with diesel generation are shown in Table 2.5.

Table 2.5 Economic Analysis of Cuoqin County PV Generation Station

Name of Power Station: Cuoqin County PV Generation Station Daily Electricity Supply (hours): 5 Height above sea level: 4,700 m Latitude: 31° N Longitude: 85° E		
System composition	Solar cell module: 20 kW_p Battery unit: 250 V/2,400 Ah (400,000 yuan) Controller: 40 kW x 1 DC-to-AC converter: 25 x 1 Commutation and charging cabinet: 75 kVA x 1	Diesel generator: 75 kW x 1 Power distribution facilities: 75 kVA x 1 (only 50% of diesel engine's efficiency can be obtained here)
Investment for electric source	1,800,000 yuan	200,000 yuan
Capital expenditure	700,000 yuan	150,000 yuan
Total initial investment	2,500,000 yuan	350,000 yuan
Annual fuel cost	No fuel	90,000 yuan
Annual maintenance cost	5,000 yuan	10,000 yuan
Service life	30 years (15 years for storage battery)	5 years
Total cost during 30 years	3,550,000 yuan	4,150,000 yuan
Quality of power supply	Excellent	Very poor
Reliability	Very high	Very low
Environmental influence	No pollution, no noise	Pollution, noise

The power generation cost of the station is 3.64 yuan/kWh, lower than that of diesel power generation. The power station is an Assist-Tibet project. If equipment depreciation is ignored, the power generation cost will be 0.45 yuan/kWh.

(2) Household PV power supply system

Household PV systems used in China can be divided into three main types: DC systems, AC systems, and AC PV/wind hybrid systems. DC systems can be divided into four main classes: 10 W, 20 W, 35 W, and 50 W. AC systems can be divided into four main classes: 70 W, 100 W, 150 W, and 200 W. AC PV/wind hybrid systems can be divided into three main classes: 35 W PV/100 W wind, 70 W PV/200 W wind, and 140 W PV/300 W wind. Presently in China, income is still low, and warm clothing and sufficient food is still a problem for many rural households. Therefore, among 3 main types and 11 main classes of PV generation systems, the DC 10-W class and the DC 20-W class products are the majority, accounting for 80% of the total.

DC systems consist of a PV cell array, controller, and a storage battery, as shown in Figure 2.2.

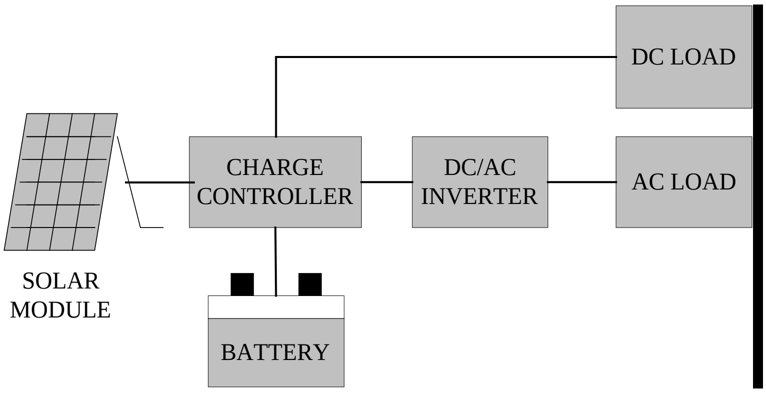

Figure 2.2 Flow chart of DC PV home system

AC systems consist of a PV cell array, a controller, a DC-to-AC converter, and a storage battery, as shown in Figure 2.3.

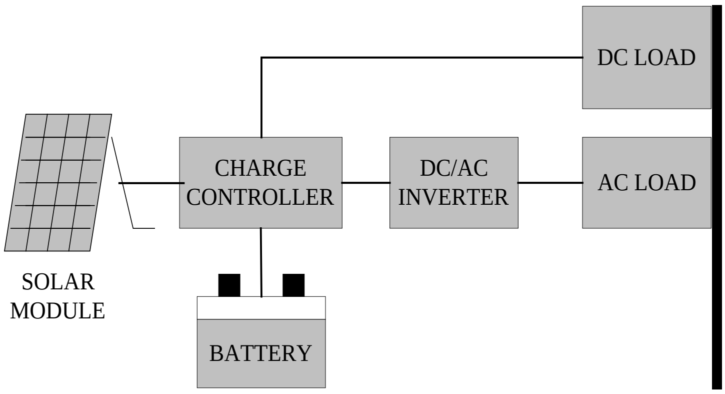

Figure 2.3 Flow chart of AC PV home system

AC PV/wind hybrid systems consist of a PV cell array, a wind generator, a controller, and a storage battery, as shown in Figure 2.4.

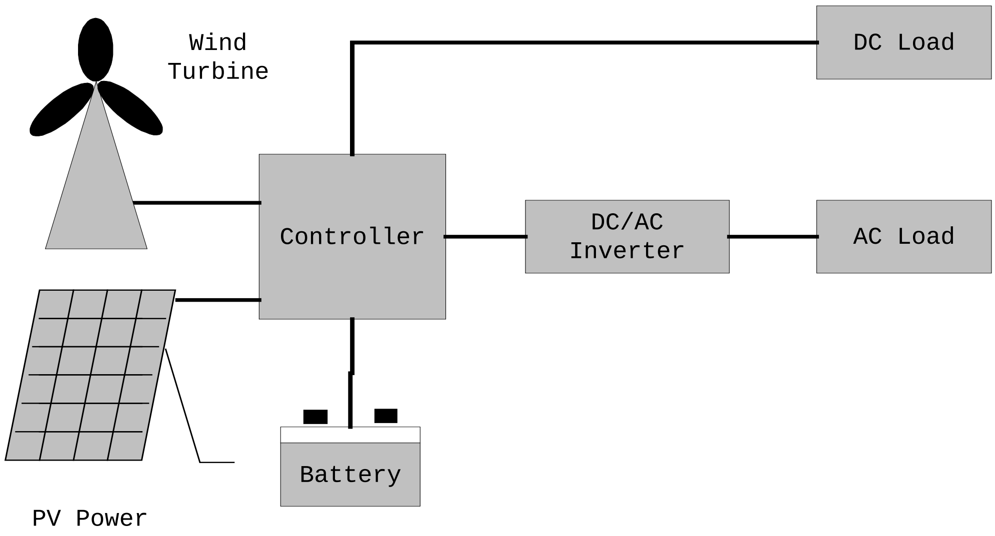

Figure 2.4 Flow chart of PV/wind hybrid home system

User requirements for household PV systems can be summarized as follows:

(a) The system and all its parts should be in accord with prescriptions, standards, criteria, or technical conditions formulated by national, industrial, or local authorities.
(b) The system should fall within the parameters given by producers, especially power output and power supply time.
(c) The service life of PV modules should be longer than 20 years, with a warranty period of more than 5 years; that of storage batteries should be longer than 5 years, with a warranty period of more than 1 year; and that of a wind generating system, controller, and DC-to-AC converter should be longer than 10 years, with a warranty period of more than 2 years.

In the current market, the technical characteristics and quality of products vary considerably. Some are good, whereas others are not and cannot completely fulfill the above-mentioned basic demands. The main problems are: no uniform technical criteria and standards and no strict test methods; the controller and DC-to-AC converter are of poor quality and unstable; energy-saving lamps, especially DC energy-saving lamps, are of poor quality and have a short service life; to reduce initial costs, system manufacturers usually use low-quality storage batteries, such as automobile batteries, which results in low quality, short service life, difficult maintenance, and the emission of acid fumes; service is not adequate and results in many difficulties for consumers; and the price of some products is too high; and the system price is as high as 110–120 yuan/ W_p.

The current average selling price of DC and AC PV systems is 80–90 yuan/W_p, and the net profit for manufacturers is about 10%–20%.

(3) PV water-pumping system

A PV water pumping system uses electricity generated by PV cells to drive a motor and pump sets. This system consists of a PV cell array, a DC-to-AC converter with maximum power point tracker (MPPT), and a diving or floating pump. The system is shown in Figure 2.5.

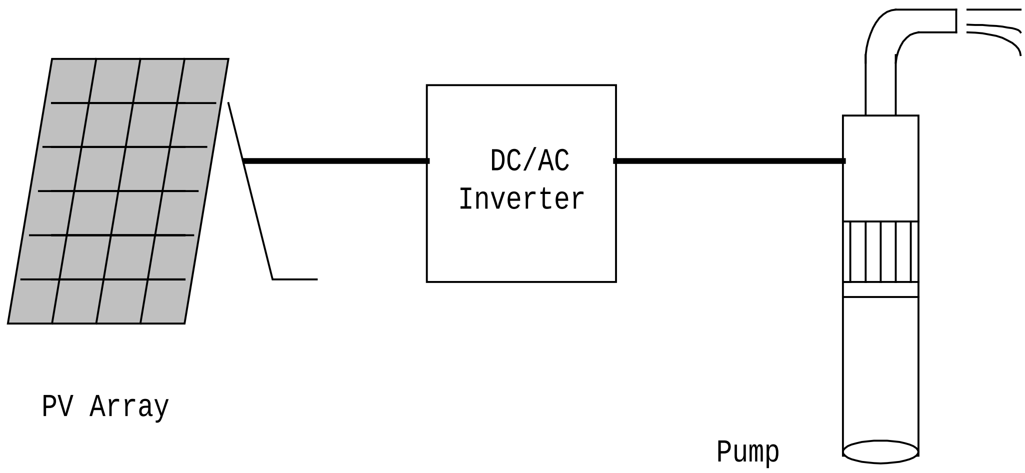

Figure 2.5 PV water pump system

Models and main technical parameters of the NSP series of PV water-pumping systems, which have been commercialized in China, are listed in Table 2.6.

Table 2.6 Technical Parameters of NSP Model PV Water Pumps

Model	**NSP-100**	**NSP-200**	**NSP-300**	**NSP-400**	**NSP-500**
Power of PV cell module (W_p)	100	200	300	400	500
Rated flow (m^3/hr)	1.5	1.5	1.5	1.5	1.5
Rated delivery lift (m)	8	16	24	32	40
Rated rotational speed (r/min.)	3,800	3,800	3,800	3,800	3,800

The selling price of a PV water-pumping system is approximately 70 yuan/W_p and that of a PV module and support is approximately 45 yuan/W_p. A water pump, DC-to-AC converter, and underwater cable are approximately 25 yuan/W_p.

2.1.2 Communication

Communication systems are a major market for PV cells, accounting for 45% of the worldwide PV applications. They also constitute a major market in China. At the end of 1998, communication systems accounted for approximately 40% of the cumulative application of PV—about 5.28 MW.

Presently in the communication field, PV is mainly used as an electric source for microwave relaying, optical-cable communication, wireless calling, terrestrial satellite communication, terrestrial satellite TV, secondary TV and communication facilities in rural areas, and military communication facilities.

Communication is a basic industry of China’s national economy and will occupy an important position in the coming decades. Therefore, the demand for PV cells in the communication field is expected to increase rapidly and to occupy a larger proportion of the market. We can see this trend from the construction of optical-cable communications in 1997, when approximately 33,000 km of new optical cable was installed, of which 15,000 km is main cable between provinces. Eight main optical-communication lines—such as Beijing-

Jiujiang-Guangzhou and Jinan-Shijiazhuang-Yinchuan—were under construction or put into operation; 12 optical communication lines, including Huhehaote-Beihai and Xian-Hefei, were started; and the capacity enlargement of some main optical-cable lines, such as Jing-Han-Guang, Jing-Jin-Hu, and Jing-Tai-Xi was completed. In these projects, PV cells were used as electric sources for many optical-communication stations.

When PV cells are used as electric sources for communication, no fossil fuel is consumed and there is no need to span power transmission lines. Other advantages include high reliability, easy and convenient maintenance and management, and no watchman. Because of these advantages, PV cells are one of the basic electric sources for communication.

In August 1998, the Lan-Xi-Lha main optical-communication line, the most difficult communication project in China, was completed and put into operation. The total length of the optical line is 2,754 km, of which 558 km are in Tibet. The project passes through many mountains over 4,500 m, where the topography is very steep, the climate is atrocious, and travel is inconvenient. In this project, PV cells are used as electric sources for 26 optical-communication stations; and approximately 100 kW of monocrystalline silicon solar cell modules, which are produced by Qinhuangdao Huamei Electric Equipment Company, are installed.

PV power supply systems used for communications in China can be divided into different scales: below 100 W, 100–1,000 W, and 1,001–10,000 W. They can also be divided into totally PV and hybrids such as PV/grid power, PV/wind, PV/diesel, and PV/wind/diesel. The average price of the systems, including PV cells, storage batteries, and controller, is about 75-85 yuan/W_p, which is lower than that of a diesel power-generating unit.

2.1.2.1 PV Electric Source for Chenshan Microwave Relaying Station

Microwave communications are an important part of the communication field. Most microwave communication lines have to pass through desolate and uninhabited mountainous and desert areas where there are no AC electric sources or the sources are far away. With the development of communications, unmanned microwave communication stations will be the developing trend. In the past, the power consumption of microwave communication facilities has been large. If PV cells are used to supply the power, the investment will be large and the economic benefits will be poor, which hinders the application of PV cells. Since the 1980s, low-power-consumption microwave relaying equipment has been successfully developed and used. The cost of PV cells has decreased to the extent that the cost is close to that of diesel generators. All of these have created an environment for using PV cells in microwave communication relaying stations.

In March 1984, a decision was made to use PV cells to supply power for the W0061 relaying equipment at the Chenshan microwave communication station, a station of the Hangzhou (Beigaofeng)—Shangyu (Chenshan)—Ningbo (Fenghua) microwave line, co-implemented by the Zhejiang Provincial Radio and TV Office, the 6th Research Institute under the Ministry of Electronic Industry, and the Ningbo Solar Electric Source Factory. After operating for more than 20 months, the PV modules and cadmium-nickel storage battery units were stable, reliable, and the power supply system proved to be rationally designed. The conversion efficiency of the DC/AC electric converter was high (>70%), ripples were small (<1mV), the allowable varying extent of input voltage was wide (22–32 V), output voltage was stable, and the system fulfilled the use demand. The project passed technical certification in April 1986. The project showed that using PV cells as the electric source for microwave communication relaying stations has advantages, such as easy installation, reliable performance, safe and stable power supply, and low maintenance, which makes it an effective way to solve the problem of supplying power for unmanned microwave relaying stations.

This PV system consists of 175 monocrystalline silicon PV cell modules, each having a capacity of 433.3 W_p, and 20 GN-500 cadmium-nickel storage batteries, with a total storage capacity of 1,000 A/hr. The DC/AC converter is shown in Figure 2.6.

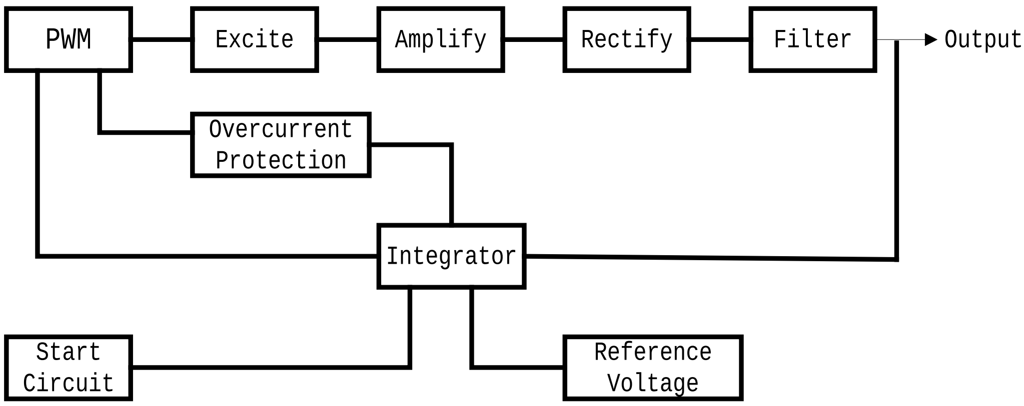

Figure 2.6 DC/DC charger

2.1.2.2 PV Cell Electric Sources for Communication in Rural Areas

In rural areas far from power grids, supplying power for communication equipment is difficult. Through demonstrations and applications in provinces and autonomous regions such as Inner Mongolia, Henan, Tibet, Yunnan, Qinghai, Fujian, Jiangsu, Shangdong, and Heilongjiang, as well as Sichuan Ganzi and Aba prefectures, using PV systems to supply power for communication equipment has been shown to be ideal. Approximately 1.5 MW of PV modules have been installed throughout the country.

In September 1986, the Rural Telephone Bureau of Inner Mongolia implemented some demonstration projects to use PV systems for rural communication in (1) the Geni and Sanchahe post and telephone branch bureaus (stations) of the Arong Banner, Xinglong post; (2) the telephone branch bureau (station) of Molidawa Banner, East Autonomous Region Hulunbeier Meng League, Hailisu and Narenbaolige post; and (3) the telephone branch bureaus (stations) of Wulatehou Banner, West Autonomous Region Bayannaoer Meng League. At each site, 190 W of PV cells were installed to supply power for wave-carrier and super-high-frequency wireless equipment. The power consumption of the communication equipment is 15 W and its working voltage is 12 V. Storage batteries work in a floating state, and 24-hour uninterrupted communication under all weather conditions is required. This demonstration showed that PV cells have the following outstanding characteristics: (1) reliability of the communication system is improved; (2) there is no AC interference on communication equipment; (3) lightning can be prevented from entering the stations; (4) the PV system is simple and convenient to operate and maintain; (5) neither fuel nor conventional electricity consumption is required, resulting in cost savings; (6) the cost of transmission lines and roads can be saved; and (7) there is no pollution and no noise. Therefore, after the success of the demonstrations, PV systems were distributed at an annual rate of 10–12 branch bureaus (stations) in the autonomous region for rural telephone systems. By the end of 1990, PV systems were installed in 42 post and telephone branch bureaus (stations) in eight Meng leagues in the autonomous region within four years, and the total installed capacity was 6,700 W_p. In the Inner Mongolia Autonomous Region, among more than 1,600 post and telephone branch bureaus (stations), there are more than 400 that have not been connected to the power grid. Up until now, PV systems have been installed in approximately 250 of these branch bureaus (stations) and the total installed capacity is more than 600 kW.

2.1.2.3 PV Power Supply System for Communication in Tu-Wu-Da Road

To accelerate Xinjiang's economic development, a road was built between Tulufan, Urumqi, and Dahuangsha in Xiangjiang—named Tu-Wu-Da road—with a loan from the World Bank. The road passes through places where the terrain is complex and the climate is atrocious. To maintain communications between project headquarters and each construction unit, a wireless communication station was built in a desert 35 km to the east of Tulufan, with a PV system providing power. The system is composed of a 640-W PV cell array, containing 16 16.7-V, 2.4-A, 40-W monocrystalline silicon PV modules in parallel; a storage battery unit consisting of four 12-V, 210-Ah lead-acid storage batteries, with a total capacity of 840 Ah, (10.08 kWh); and two controllers in two groups. This system was completed and put into operation in March 1995. Since then it has been working very well, ensuring safe and reliable communications and simple operation and maintenance.

2.1.2.4 PV System for Menshi Coal Mine TV Receiving Station

This system is located at the foot of Gangrenboqi Peak (the main peak of the Gangdisi Mountains in the Ali Region of Tibet and designated as a "sacred mountain"). It was completed and put into operation in August 1991. The mine's opening is 5,105 m above sea level and, thus, is the world's highest coal mine. The whole system consists of: (1) a set of 3-m parabolic satellite receiving aerials; (2) three C_3 satellite receivers; (3) one high-frequency head; (4) one three-line power distributor; (5) three 3-W color TV secondary machines; (6) three median frequency modulators; (7) four television monitors; (8) five J-25 video recorders; (9) 1,000 W_p monocrystalline silicon PV modules; (10) a fixed, sealed anti-acid-fog and dry-charge, lead-acid, 600-Ah storage battery unit; (11) a power source control and distribution cabinet with two 500-VA DC-to-AC converters; and (12) an operating platform. Up to now, the system has operated for more than seven years, and the PV system is still working well. The satellite signal receiving system and the TV secondary system also work well. Pictures and sounds in three channels are fine, and the relaying effects are good. Miners and inhabitants like the system very much.

2.1.2.5 PV Cell Electric Source for Jincheng Microwave Relaying Station

The Jincheng microwave relaying station was completed in Shanxi Jincheng several years ago. The PV system is equipped with 3,300 W_p of monocrystalline silicon PV modules and a 48-V/100-Ah sealed lead-acid storage battery unit. Comparing it with the investment of diesel generation, a PV electric source has virtues such as short construction time, easy installation, convenient use, low maintenance, a stable and reliable power supply, no pollution, no noise, no staff, and no fuel consumption. Although the initial investment of this system is larger, the integrated average cost in five years is much lower than that of diesel generation, and the integrated economic efficiency is better (as shown in Table 2.7).

Table 2.7 Comparison of PV Power Generation and Diesel Power Generation in Jincheng Microwave Relaying Station

Item	**PV Cell Power Generation**
PV cell module and support	150,000 yuan
Storage battery unit	50,000 yuan
Controller	30,000 yuan
Others	20,000 yuan
Total investment of electric source	250,000 yuan
Fuel cost	No need
Maintenance cost	1,000 yuan/yr
Service life	20 years for PV cell, etc. five years for storage battery
Total cost in five years	95,000 yuan
Item	**Diesel Power Generation**
Diesel electric generating set, Rectifying and distribution equipment	50,000 yuan
Others	5,000 yuan
Total investment of electric source	55,000 yuan
Fuel cost	15,000 yuan/yr
Maintenance cost	15,000 yuan/yr
Service life	Five years for diesel electric generating set, (total cost is 40,000 yuan), 20 years for other parts
Total cost in five years	130,000 yuan

2.1.3 Other Industrial Applications

PV systems are also used in other industrial fields. The major uses include electric sources for railway and road signal lamps, navigation lamps and lighthouses, weather observatories and stations, earthquake forecasting stations, railroad switches, frontier defense sentries, road signals, cathode protection of oil and gas pipelines and reservoir anchor gates, and forest fire warning systems. Statistics (although incomplete) show that PV cells used in industrial fields account for approximately 20% of the total application of PV cells in China.

2.1.3.1 PV Electric Source for Railway Signal Lamps

Railway signals are indispensable in guaranteeing the safety and punctuality of trains. At present, among 6,000 railway stations in China, more than 1,000 are located in places where there are either no AC electric sources or where those sources are unreliable. In the past, either oil lamps or dry batteries were used to supply power for signal facilities in these railway stations. Therefore, the performance of signal facilities was poor and unreliable. Furthermore, fuel consumption and labor intensity were high. In February 1975, PV electric sources were introduced for the first time to supply power on an experimental basis to a signal facility in Puantang Station, Loudi Section of the Guangzhou Railway Bureau. In June 1979, a PV system with a total capacity of 720 W_p (the largest PV system at that time) was installed at the Ketu railway station of the Qing-Zang railway. The system was built by the Ministry of Railway and the Ministry of Metallurgy to supply power for signal facilities. At the same time, the Ministry of Railway selected some signal facilities in a group of railway stations to expand the experiment. Those stations belong to different railway bureaus, such as Guangzhou, Liuzhou, Lanzhou, Xi'an, Huhehaote, Qiqihaer, and Harbin Railway Stations, and are located in different areas of China—middle south, southwest, north, and northeast. By the end of 1984—except for the Beijing, Shanghai, and Shenyang Railway Bureaus, which have reliable AC electric sources, and the Chengdu Railway Bureau, where the weather is too foggy and cloudy—more than 160 systems with a total installed capacity of more than 10 kW were installed.

During 1980 and 1981, PV systems were installed to supply power for all the signal lamps in the Jing-Bao and Ji-Er Lines' 35 stations. Later, PV systems were installed to supply power for all the signal lamps in the Jing-Bao, Jing-Lan, and Ji-Er Lines' 27 stations without electricity. A few years ago, five solar-grade cross-signal facilities were built on the Jing-Bao, Ji-Er, and Bao-Huan lines. It is estimated that the total installed capacity of PV cells used as electric sources for railway signals in China is approximately 150 kW. Huhehaote Railway Bureau ranks first in total capacity of PV cells.

A PV railway signal system is composed of the following parts: PV cell array, PV storage battery unit, electric source controller, signal lamps, electric transmission line, and array tray, support, and tracker.

The Gaolingzi Railway Station of the Harbin Railway Bureau is located on top of a mountain, and both the upward and downward lines are on 13% slopes. The climate there is atrocious and the temperature difference between day and night is very large. On windy and snowy nights, trains are often unable to arrive at the station, either because the oil lamp has blown out or because the visibility distance of the oil lamp is too short for the driver to see the signal. Annually, there are at least 3 instances of trains stopping outside the station and 50 instances of guiding arrival. This results in train delays and seriously affects running safety. In the past, 300 kg of diesel fuel and 130 kg of bean oil, worth more than 400 yuan according to prices at the time, was used annually by the eight signal lamps of the station. After using PV, the cost savings in 10 years will be equivalent to the cost of purchasing PV cells and cadmium-nickel storage batteries. In the Ketu railway station, located between Xining and Germu, on the Qing-Zang railway, the efficiency of diesel electric generating sets will decrease by more than 30% because the elevation there is high and the air is thin. This means more diesel consumption and heavy maintenance. When PV is used, operation becomes simple—diesel fuel is saved, and little maintenance is needed. These practical applications show that using PV cells as railway signal electric sources has advantages, such as stable voltage, more reliable and steadier signals, and longer viewing distance, which are important to ensure the safety and punctuality of the trains.

2.1.3.2 PV Electric Source for Navigation Signals

A navigation signal is a guidance facility for ships in channels such as short seas, rivers, lakes, canals, and reservoirs. In the past, signals were diesel lamps and were set in only a small quantity of rivers. A navigation lamp is an important part of a navigation signal. The technical requirements for navigation lamps are: (1) high lighting reliability in the long range, and the ability to show lighting characters according to prescription; (2) low energy consumption and long service life; (3) simple maintenance and low cost; and (4) easy testing, replacement, water resistance, and firmness.

Navigation lamps can be divided: into several types: gas fuel lamps (commonly acetylene-flash lamps and propane-flash lamps); diesel lamps; and electric lamps. Currently, the sources of electric lamps include storage battery, dry battery, alternate current, wave energy, wind energy, hydropower, and solar cell.

Electric navigation lamps are mainly composed of a light source, light filter, lamp body (including lens and other beam equipment), electric source, lamp support, wire, and automatic devices (such as an electric flash facility, and a lamp-replacing machine).

In 1973, the Tianjin Channel Bureau and the Tianjin Electric Source Research Institute started an experiment to supply PV power for buoy lights in Tianjin Harbor. By October 1976, PV cells were used as electric sources for all buoy lights in the harbor. The capacity of the PV cell modules was 14.7 W. Three-second-light and 2.7-second-dark, 9-W flash lamps and 100-Ah cadmium-nickel storage batteries were used. The application proved that PV electric sources performed well and were stable and reliable. PV electric sources were praised by the Ministry of Traffic and passed its certification. PV cells with a capacity of 290 W and 150-Ah cadmium-nickel storage batteries were used to supply power for a 150-W bromine-tungsten lamp with a flashing period of 1-second light and 5-second dark. In September 1980, the Kaifeng Solar Cell factory produced a 350-W PV electric source for the Shanghai Channel Bureau, later installed in the Dongtingshan beacon. The total capacity of PV for navigation lights produced by the Shanghai Navigation Signal Factory in these years exceeded 200 kW. It is estimated that by the end of 1997, the total power of PV electric sources for navigation lights used in China was more than 200 kW. The PV electric sources are mainly distributed in Tianjin, Shanghai, Guangzhou, and Changsha channel bureaus, from the Xisha archipelago at 9° north latitude to Daqindao at 34° north latitude.

2.1.3.3 PV Electric Source for Earthquake Telemetry Stations

Earthquakes occur frequently in some regions of China. Therefore, to reduce losses, earthquake monitoring and forecasting is very important. Many earthquake telemetry stations were built to form a nationwide earthquake surveillance network. Some of the stations are located in remote mountain areas, far from a power grid, where travel is inconvenient. Therefore, to assure the normal operation of surveillance facilities and the timely exchange of surveillance information, reliable electric sources are very important. Through many years of experimentation and application, PV systems have proven to be ideal electric sources.

In the Xinjiang Autonomous Region, many PV electric sources are used in earthquake telemetry stations. Urumqi City is located in the middle of the Northern Tianshan Earthquake Zone. A plan to use PV electric sources in earthquake telemetry stations in the Urumqi region was formulated in 1987. The Liuhuanggou earthquake telemetry station—the first one using a PV electric source in Xinjiang—was designed and completed in 1988. At that time, four earthquake telemetry stations using PV were built in this region. The PV system in the Liuhuanggou earthquake telemetry station consists of a PV cell array, a storage battery set, a controller, and a regulator. There are a total of 240 W_p of monocrystalline silicon PV modules and eight 12-V, 105-Ah lead-acid storage batteries installed in this system.

2.1.3.4 PV Electric Source for Meteorological Observatory and Station

Many meteorological observatories and stations are located in the highlands, high mountains, deserts, remote forests, rural areas, and islands. Most of these observatories and stations are far from power grids, so self-contained diesel or gasoline electric generating sets are used to supply power. In the highlands, the efficiencies of diesel or gasoline generators decrease greatly due to high elevation and thin air. It is also very hard to install this equipment in these areas. Therefore, to assure normal operation, these observatories and stations are equipped with seven diesel generating sets. Searching for an ideal electric source is important but difficult for these meteorological observatories and stations.

To solve this problem, in 1976 Xi'an Jiaotong University developed a small PV electric source with power of 20 W_p for the Huashan meteorological station to supply power for a sender-receiver. In 1982, the Science and Education Department of the State Weather Bureau arranged the experimental application of PV electric sources in the Nuomuhong and

Chaka meteorologic stations in Qinghai Province. The two stations are located in the Qing-Zang Highland where the elevation is more than 3,000 m above sea level. The solar energy source there is very rich, whereas other conditions are very poor. The main parts of the power system are a monocrystalline silicon PV cell array (rated voltage of 15 V and rated current of 6.7 A, with a maximum output power of 100 W; 300-Ah cadmium-nickel storage batteries in Chaka Station; and 400-Ah cadmium-nickel storage batteries in Nuomuhong Station) and a voltage-stabilizer to prevent storage batteries from overcharging. The structure of the systems is shown in Figure 2.7.

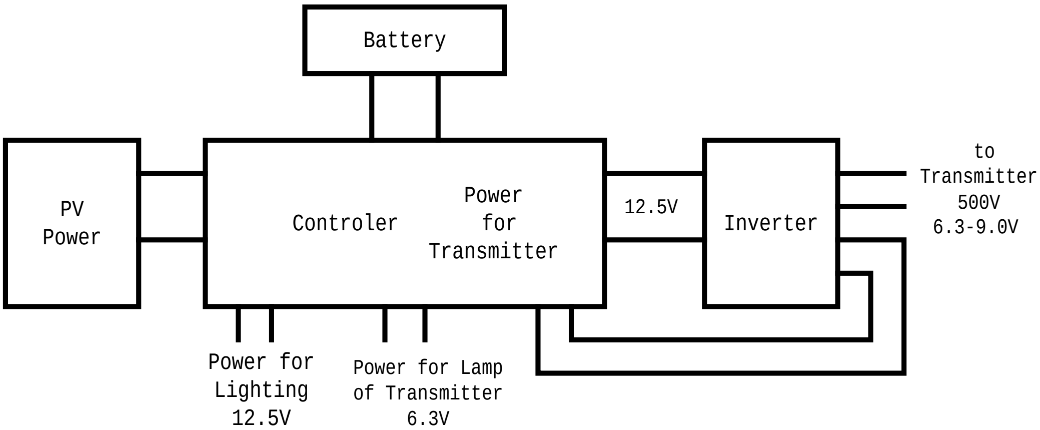

Figure 2.7 Flow chart of PV power system for observatory

According to incomplete statistics, PV cells have been used in dozens of meteorological observatories and stations as electric sources in China, and the total capacity is approximately 4,050 kW.

2.1.3.5 PV Power Systems for Cathodic Protection of Gas and Oil Pipelines

By the end of 1996, more than 19,000 km of raw oil and natural gas pipelines had been built in China, of which more than 900 km was offshore natural gas pipelines. Because most of the oil and gas pipelines are made of metal, corrosion is a problem. In the 1960s, according to foreign statistics, the annual metal loss caused by corrosion was more than $100 million U.S. worldwide, or approximately 10% to 20% of the annual metal production. According to statistics of the U.S. pipeline industry in 1975, the economic loss caused by corrosion is as high as $500 million U.S. It is very common for holes to begin to appear on some underground oil and gas pipelines that have only been in operation for 1–2 years. The average corrosion rate of underground oil pipelines is more than 1.5 mm per year. Pipeline corrosion results in leakage of oil and gas, as well as the loss of material and manpower for maintenance and repair. Moreover, it results in explosions and fire, especially for natural gas pipelines. That is why corrosion protection is so important.

An anti-corrosion facility is an important part of the pipeline project. In order to assure the long-range, safe operation of pipelines and to prevent damage to people and enterprises nearby, governments of all countries and pipeline enterprises have formulated systems, laws, and regulations for pipeline corrosion protection.

Corrosion of metal pipelines can be divided into two types. One type is chemical corrosion, which is caused by a chemical reaction between a metal surface and ambient media. The other type is electrochemical corrosion, which refers to the electrochemical reaction between a metal surface and ambient media. The electrochemical reaction can cause both primary battery corrosion and electrolytic corrosion. Cathodic protection is used to prevent electrochemical corrosion. At present, cathodic protection is widely used for underground oil, gas, and water pipeline protection. The two types of cathodic protection in use are sacrificial-anode cathodic protection and impressed-current cathodic protection. Currently, impressed-current cathodic protection is more widely used. In this type of protection, the metal to be protected is connected to the negative pole of a DC electricity source, and the auxiliary anode is connected to the positive pole.

Most of the areas through which the pipelines pass in the field are far from power grids, so electric sources for impressed current cathodic protection is a big problem. Experiments and demonstrations have proved that PV systems are worth promoting and spreading. In China, these systems have been used in cathodic protection for oil and gas pipeline projects for nearly 20 years. The application effects are good, and the total amount used is a little less than 200 kW.

The earliest application of cathodic protection equipment for underground oil pipelines is the PV system installed in 1980 in the Shaoyang County Oil Pump Station in Shandong Province. The power of the system's PV cell array is 300 W_p, and the array is composed of three sub-arrays with a unit power of 100 W_p, a working voltage of 18 V, and a working current of 4 A. These sub-arrays can automatically track the sun. The storage battery set is composed of 40 500-Ah alkali-iron-nickel storage batteries, with 10 connected in series, and 4 sets connected in parallel. During use, the system is stable and can supply power normally.

The PV system that is the largest in scale, and built in the worst and most complex project environment, is the one used in the cathodic protection project for Ta-Zhong 4—Lunnan oil and gas pipelines. The system was completed in 1996. It horizontally traverses Takelamagan Desert. Among the nine stations of the oil and gas pipeline project—which is over 300 km long—AC electric sources are used in two stations at the beginning and end of the project, and PV systems are used to supply power for the other seven stations. In the whole system, 39,900 W_p TDB-100-38-P monocrystalline silicon PV cell modules, seven sets of 24-V/6,000-Ah valve-control liquid-aspiration, sealed and maintenance-free lead-acid storage batteries, and seven 24-V/180-A/ 6,000-W controllers were used. After being put into operation, the system has performed well; it supplies stable and reliable power. It is highly praised by the headquarters of Talimu Oil Exploration and Exploitation.

2.1.4 Consumer Products and Others

Solar products that have already been developed and are available in China are chargers, cool caps, calculators, watches, street lamps, courtyard lamps, yachts and barges, automobile ventilators, semiconductor refrigerators, toys, and advertising lamp boxes. These products are estimated to account for about 10% of the total applied capacity of PV cells in China.

It is estimated that China has already exported approximately 1.5–2.0 million cool caps, several thousand courtyard lamps, more than 100,000 automobile ventilators, 50,000 chargers, 500,000 semiconductor refrigerators, 100,000 toys of all kinds, and 50,000 watches and solar calculators. Domestically, more than 50,000 chargers, 100,000 cool caps, 200,000 toys of all kinds, 50,000 watches, and 200,000 calculators have been sold. In addition, approximately 50 advertising lamp boxes, street lamps, and several thousand solar bells have been installed in some medium and large cities. More than ten solar yachts and vehicles have been produced for experiment. Most of the PV cells used in these projects are amorphous silicon.

The market potential of these products is fairly large. If the market is well developed, the sales volume of PV cells will be large both domestically and in foreign markets.

2.2 Estimation of Future Markets

In the 21st century, the world energy structure will change from one in which fossil energy (which is a limited resource and causes serious pollution) plays a major role, to a diversified and mixed one in which clean renewable energy—which is infinite—will play a major role. However, in the first 30–40 years of the next century, fossil energy will also supply most of the world's energy. Although the ratio will rise, renewable energy, not including hydropower, will not account for a large proportion of worldwide energy consumption because a change of that magnitude takes more than 100 years. Following in this report, an elementary estimation of China's PV market in the next 12 years (1999–2010) will be given, according to the Chinese government's long-range objectives for economic and social development, as well as the general trend of the worldwide PV market, starting with the current status.

The following market and price estimations are based on technological forecasting.

(1) Crystalline silicon PV cells will still play a major role in PV technologies before the year 2010, whereas rapid progress will be made towards high efficiency and low cost.

(2) Thin-film PV cells will be the major focus after the middle of the 21st century. The prospects for this kind of cell are bright. Great breakthroughs are expected to be made in about 2010; the cells will then be put gradually into commercial production and applied in fields such as PV rooftop power generation.

(3) Key balance of systems (BOS) equipment, such as controllers and DC-to-AC converters, will become more reliable, efficient, and inexpensive; in addition, great advances will be made.

(4) Long-life, low-cost, large capacity, multifunction, and maintenance-free storage batteries, more suitable for PV generation, will be studied and developed.

(5) System integration (including grid-connected system) technology will be developed, including standardization, automatic control, and autonomous operation.

2.2.1 Development Estimation of Non-Grid-Connected Systems

All of China's current PV generation systems are non-grid-connected ones (i.e., stand-alone) PV generation systems. It is estimated that in the next 12 years—from 1999 to 2010—the installed capacity of PV cells in China's non-grid-connected PV generation systems will increase at an annual rate of more than 20%, as shown in Table 2.8. The relationship between this estimation and the following sub-item estimation is not an additive one, and the sub-item estimation is larger than the total estimation.

Table 2.8 Estimation of Installed Capacity of PV Cells Used in China's Non-Grid-Connected PV Generation Systems in Years 1999–2010

Year	Application of PV Cells (MW)
Baseline year (1998)	2.00
1999	2.40
2000	2.88
2001	3.46
2002	4.15
2003	4.98
2004	5.98
2005	7.18
2006	8.62
2007	10.34
2008	12.41
2009	14.89
2010	17.87
Total for 12 years	**95.16**

2.2.1.1 Rural Electrification

Market Estimation

By the end of 1998, there will still be an estimated 14 million households and 60 million rural people with no access to power. A fairly large proportion of these people live in areas with a rich solar energy resource, including northwest China's five provinces and autonomous regions, Inner Mongolia, Tibet, Yunnan, Hainan, and Sichuan Aba. In these areas, PV generation technology can be used to supply these people with power for basic household needs and for production use. In the following table, PV market potential in rural areas is initially estimated, according to the state overall demand on rural electrification as well as plans and assumptions made by related departments and provinces (autonomous regions).

Table 2.9 Estimation of PV Market Potential in China Rural Areas in Years 1999–2010

Province, Autonomous Region	Estimated Number of Households With No Access to Power by the End of 1998 (10,000)	Potential Demand (10,000 sets)	Market Demand in 1999–2000 (MW)	Market Demand in 2001–2010 (MW)
Total	About 1,400	210.8	12.0	80
Tibet	12	10.8 (12 x 90%)	1.0	10
Inner Mongolia	40	32.0 (40 x 80%)	2.0	15
Qinghai	10	8.0 (10 x 80%)	1.0	10
Xinjiang	50	40.0 (50 x 80%)	4.0	10
Gansu	40	28.0 (40 x 70%)	2.0	10
Ningxia	20	14.0 (20 x 70%)	0.5	5
Shaanxi	30	18.0 (30 x 60%)	0.5	10
Others	About 1,200	60.0 (1,200 x 5%)	1.0	10

Clearly, market demand in rural areas will account for more than half of China's PV market, involving stand-alone PV generation stations, household PV systems, and solar water pumps. Market demand in 1999–2000 has involved PV cell capacity of PV electric source systems in the World Bank and Netherland Shell projects. In the above table, the capacity of household PV electric sources is assumed to be 20–50 W before the year 2000 and 50–100 W from 2001 to 2010.

Plans and forecasts for related provinces and autonomous regions have also been considered in the estimation. Inner Mongolia has forecast a near-future PV market in the autonomous region as follows. Approximately 500–1,000 village PV generation systems with a unit capacity of 2–10 kW, approximately 300,000 household PV electric sources, and more than 20 MW of PV cells will be needed. Gansu's planned target is that household PV electric sources will be installed in 100,000 households during the Ninth Five-Year Plan and 140,000 during 2001–2010. Xinjiang's planned target during the Ninth Five-Year Plan is to install 20,000–30,000 household PV systems, 500 PV generation stations, and 3 village PV systems for lighting and TV in rural areas. The Qinghai Provincial Power Bureau's "Aid-the-Poor Power Projects During Year 1995–2010" plans to install 75,000 household PV electric sources with a total capacity of 1.4 MW, and construct PV central power supply projects with a total capacity of 340 kW in counties and towns.

Price Estimation

The most widely used household PV system (a 20-W DC) is used as an example for a rough estimate. The current average price of a household PV system is 1,800 yuan (i.e., 90 yuan for one peak-watt system), containing the following components:

- PV cell module: 20 W_p x 42 yuan/W_p = 840 yuan
- Maintenance-free sealed lead-acid storage battery: 12 V/30 Ah x 1 yuan/Wh = 360 yuan
- Controller: 200 yuan
- Case: 100 yuan
- 9 W DC power saving lamps: 2 x 35 yuan = 70 yuan
- Wire and connectors: 50 yuan
- Tax: 180 yuan.

Thus, the price of PV modules accounts for approximately 50% of the whole system cost. The cost-reduction potential of the PV module is very large, and it is possible to reduce its selling price from the current one of approximately 42 yuan/W_p to 35 yuan/W_p by the year 2000, with further reductions to 30 yuan/W_p in 2005 and 20 yuan/W_p in 2010. In this case, the selling price of a household PV system will decrease from the current price of 90 yuan/W_p to 75–80 yuan/W_p by 2000, to 60-70 yuan/W_p by 2005 and to 50-55 yuan/W_p by 2010. With the increase of peasants' and herdsmen's income, the unceasing rise in price of conventional electric power, and the decrease of the selling price of domestic PV systems at such a high rate, peasants and herdsmen will be able to afford PV systems gradually. Therefore, the PV market will become larger each year.

Currently, the system manufacturing cost of PV generation stations is 90–100 yuan/W_p in common areas, whereas the cost is 120–130 yuan/W_p in areas with high elevation, such as Tibet. The price of PV modules accounts for about 45%–50% of the total system manufacturing cost. If the selling price of PV cells can decrease at the above-mentioned rate, it is possible to reduce the system manufacturing cost of PV generation stations to below 60 yuan/W_p by 2010. In that case, the power generation cost of PV generation stations will be lower than that of diesel power generation and will be only two times higher than that of conventional power plants, making this technology competitive in some areas.

Currently, the price of a PV water-pumping system is 70 yuan/W_p, of which approximately 45 yuan/W_p is for PV modules and support (about 64%), and 25 yuan/W_p is for the pump, DC-to-AC converter, and submarine cable (about 36%). According to the above-mentioned estimate on the price reduction of PV cells, it is possible to reduce the selling price of a PV water-pumping system to 40–45 yuan/W_p by 2010. Therefore, the market demand for PV water-pumping systems will increase several times.

2.2.1.2 Communications

Market Estimation

It is estimated that in 1998, approximately 0.8 MW of PV modules were used for communications in China. It has also been estimated that during the next 12 years, PV modules used for communications will increase at an annual rate of 10% during the first 7 years and 5% in the next 5 years, as listed in Table 2.10. These PV cells will be mainly used for such things as optical, microwave, and rural communications. The increase rate is assumed to be 5% in the latter 5 years because (1) the base is large and (2) the construction speed of the communication industry will slow down after the completion of main communication networks.

Table 2.10 Estimation of China's Communication Industry Demand for PV Cells During 1999–2010

Year	Demand (MW)
1998*	0.80
1999	0.88
2000	0.97
2001	1.07
2002	1.18
2003	1.30
2004	1.43
2005	1.57
2006	1.65
2007	1.73
2008	1.82
2009	1.91
2010	2.01
Total for 12 years	**17.52**

* Baseline year

Price Estimation

The current average system price of communication PV electric sources, including PV cells, storage batteries, controllers, etc., is about 7–85 yuan/W_p. According to the above analysis, it is possible that the price will decrease to 60–65 yuan/W_p by the year 2005 and to 50-55 yuan/W_p by the year 2010.

2.2.1.3 Other Industrial Fields

Market Estimation

Based on the assumption that the demand for PV cells by other industries accounts for 20% of the whole PV market, this demand will be 0.40 MW in 1998—the baseline year—0.58 MW in 2000, 1.44 MW in 2005, and 3.57 MW in 2010.

The application prospect of PV cells will be broad in areas such as seawater desalinization, electric cars, industrial reserve power supplies, and hydrogen production. The demand for PV cells for cathodic protection of pipelines, road signals, railroad switches, and railway signals, will also increase to a large extent.

Price Estimation

Currently, the average system price is 85–90 yuan/W_p, and it is estimated that the price will decrease to 65–70 yuan/W_p in 2005 and to 50–55 yuan/W_p in 2010.

2.2.1.4 Consumer Products and Others

Market Estimation

Based on the assumption that PV cells used in these areas account for 10% of the whole market, the demand will be 0.20 MW in 1998—the baseline year—and 0.29 MW in 2000, 0.72 MW in 2005, and 1.8 MW in 2010. The demand for PV cells for products such as solar street lamps, toys, courtyard lamps, and advertising boards will increase substantially.

Price Estimation

According to estimates, the average system price will decrease to 60–70 yuan/W_p in 2005 and to 45–50 yuan/W_p in 2010.

2.2.2 Development Estimation of Grid-Connected Systems

Grid-connected power-generating systems are one approach for allowing PV technologies to enter a period of large-scale power generation and to become part of the power industry. This seems to be the developing trend in PV technology throughout the world. Grid-connected systems can be divided into two types: systems directly connected to the grid and systems combined with buildings (i.e., rooftop grid-connected systems). In China, grid-connected PV power systems are still in a gestation period, and as yet, there is no actual application of this technology. Measures should be taken now so the construction of two or three 10-kW-scale rooftop PV grid-connected systems can begin in 2000. These systems are for publicity, demonstration, and improvement of the technology.

2.2.2.1 Concentrated grid-Connected Power Generation

Market Potential

With the decrease in manufacturing costs of PV systems, the shortage of conventional energy, the unceasing rise of the integrated cost of conventional energy power generation, and the increasing demands of environmental protection, the market demand for grid-connected power systems will gradually increase. The estimate is that 3–5 PV large scale concentrated grid-connected systems, with the total installed capacity of 0.1 - 1 MW, will be constructed by the year 2005; the total installed capacity of concentrated grid-connected PV systems will be more than 10 MW by 2010.

Price Estimation

Because electricity from grid-connected systems is transmitted to the power grids directly and storage batteries for energy storage are no longer needed, the manufacturing cost of these systems is about 15%–20% lower than that of stand-alone PV systems. The estimate is that the system manufacturing cost will be 65–70 yuan/Wp in 2000, 50–60 yuan/Wp in 2005, and 40-45 yuan/Wp in 2010.

2.2.2.2 Grid-connected Roof Power Generation

The climax of the development of grid-connected roof power generation in developing countries was coming since 1990's. The grid-connected roof power generation can use the best of the decentralized sun light. The PV modules of roof power generation can be installed on the roof of house. Many countries have put emphasis on roof power generation because the roof power generation are more flexible and economic than large-scale grid-connected PV station.

Market Estimation

The combination of PV generation and building-integrated PV systems has become very popular in foreign countries in recent years, and the market is broad. The grid-connected roof power generations are divided into two types: one can be dispatched and one can not be dispatched. The dispatched grid-connected roof power generations have little battery, the major role is to supply the electricity during the rush hours. There is not any battery in undispatched grid-connected roof power generations. The characteristics of these systems are as follows.

- For the undispatched grid-connected roof power generation, they are connected to power grids, so the use of storage batteries can be avoided.
- The PV modules are not only the power sources but also the construction materials. The PV modules of roof power generation can be manufactured to the tiles, or be a part of building though the skillful design, the construction cost of buildings can be reduced, thus reducing the cost of PV systems.
- These systems are suitable for scattered loads.
- They can adjust the power grid's load to a certain extent.

By 2000, it is estimated that 5-10 rooftop PV systems with a total installed capacity of 80–120 kW will have been built; 10,000 systems with an installed capacity of 20–40 MW by 2005; and by 2010, 100000 systems with an installed capacity of 100–500 MW will have been built.

Price Estimation

By 2000, the expected price of the system will be 60–70 yuan per peak watt, 50–55 yuan in 2005, and 40–45 yuan in 2010.

3. Evaluation of PV Sales Companies

3.1 General Overview and Barriers to PV System Sales

Previously, domestic PV systems depended mainly on government subsidization or bilateral and multilateral assistance projects. However, once PV systems began to appear on the market, sales independent of subsidization increased rapidly during the 1990s. Before 1992, there were fewer than 10 PV system sales companies connected with the research institutes that were supported by the state and whose main task was to implement government subsidization or bilateral and multilateral assistance projects. However, by the end of the first half of 1998, the number of these companies had exceeded 50, and some private companies were selling PV systems commercially. For example, there is a whole street of PV system companies in Qinghai Province. There are more than 10 PV system sales companies just in Xining, among which there are 5 or 6 private companies, owned by former employees of the Research Institute of Solar Energy of Qinghai.

There are 17 companies that meet the initial selection requirements of the Global Environment Facility (GEF)/World Bank Project of Renewable Energy Commercial Development. They are located in Inner Mongolia (two companies), Gansu Province (four companies), Qinghai (six companies), Xinjiang (four companies), and Beijing (one company). Eight of these companies are state run, seven of them are privately run, and two are a combination of state/privately run. These 17 companies, which assemble and sell solar home systems, predominantly serve markets of central and northwest China. There are other companies that just sell solar home systems on a commission basis or that sell just a few. Developed by former employees of the local research institute of renewable energy, most of these companies were founded in the last five years on a comparatively small scale, with fewer than 50 staff members and few fixed assets.

The solar energy market is fairly easy to enter. The technology is comparatively simple and can be learned easily, and the need for fixed assets is low. This, coupled with the quality-of-life improvement, has resulted in the rapid increase in sales in central and northwest China in the past few years. It can be seen from the statistics data of the 17 initially selected companies that the sales amount increased from about 17,000 systems (more than 400 kW) in 1995, to more than 40,000 systems (nearly 1 MW) in 1997. The main market for these companies is peasants and herdsmen in remote areas of Qinghai, Gansu, Inner Mongolia, Xinjiang, Sichuan and Tibet who are without electricity.

The production process of these companies is similar—purchasing solar cell panels and batteries; producing controllers, inverters, lamps, and lanterns by themselves (with the exception of two or three companies); then assembling and selling the systems. The production capability is not the restricting factor in the development of these companies. Of the 17 selected companies:

- The companies run by research institutes have an advantage over private companies in the technology development of new products, quality testing, and controlling; and they generally have good financial management.

- The private companies have a much wider sales distribution network and a closer relationship with the users than state-run companies.

To the domestic solar PV power system industry, the establishment of sales networks and post-sales services are more important than other aspects.

The main problems restricting the commercial development of these companies are the following:

- There are no unified technology standards for PV solar home system, so it is difficult to guarantee the product quality with different standards in different regions.

- Markets are confused. For example, there are bogus products of low quality on the market, some unrealistic advertisements mislead the consumers, and dumping products at a low price often occurs.

- Most of the companies have no experience in getting loans from banks. Therefore, the shortage of capital—especially current capital—is the major barrier for companies seeking to expand their sales and improve post-sales services.

- The fierce competition, irregular markets, and decreased purchasing power produced by economic conditions, have left many companies with deficits, making it difficult for them to develop.

3.2 PV System Sellers

3.2.1 Huade New Technology Company of Inner Mongolia

Founded in 1993, the Huade New Technology Company of Inner Mongolia is a state-owned company. It is a high-technology development company with a staff of 30, engaged in technical research, product development, production, and marketing in the wind and solar energy fields.

In 1990, the institute began several Sino-German technology cooperation projects. Since then, many wind, PV, and wind/PV hybrid systems and products have been developed. There are 23 kinds in 8 series, including 10–20 W_p, and 50–300 W_p PV systems and 100–300 W_p wind/PV hybrid systems. At present, the annual production capability of the company is 3,000 wind, PV, and wind/PV hybrid systems. More than 700 systems were sold in 1997. The main markets are in the central and western regions of Inner Mongolia, Qinghai, and Tibet.

There are infrastructure facilities within the company that can be used for wind energy research and product development, including facilities for producing and assembling small wind turbines, blades, controllers, inverters, and metal-machining facilities. The company has strong capabilities in scientific research and technological development, and also has experience in cooperating with foreigners.

3.2.2 Huanyu Wind and Solar Energy Ltd. of Inner Mongolia

Huanyu Wind and Solar Energy Ltd., of Inner Mongolia, is an independent commercial company concentrating on science, production, and trade as a whole. The foundation of the company was proposed by the Shangdu Husbandry Machinery Factory of Inner Mongolia, which engaged in new energy research and popularization, particularly in the field of wind turbines, for many years. Founded in February 1998, the company was jointly invested by the Shangdu Husbandry Machinery Factory of Inner Mongolia, the Natural Resource Institute of Inner Mongolia, the Agriculture and Husbandry College of Inner Mongolia, and the Hydro-Science Institute of Rural Areas of Ministry of Hydropower. The company is located in the “new energy experiment and demonstration base of Inner Mongolia,” which is at the 559-km point of No.110 national road in the east suburbs of Huhhot. The company has a staff of 46 and is mainly engaged in the sales of PV and wind/PV hybrid systems.

The main member of the company, Shangdu Husbandry Machinery Factory of Inner Mongolia, has more than 20 years history in distributing and applying new energy It has excellent production and distribution experience and advanced testing methods. It produces more than 50 products, such as 10 8-kW_p PV systems, 50 7-kW_p wind turbines, and 50 1-10-kW_p wind/PV hybrid systems. More than 1,600 PV and wind/PV hybrid systems were assembled and sold in 1997. The main markets are in Inner Mongolia, Xinjiang, Gansu, Tibet, and Qinghai. The products are also exported to more than 20 countries and regions of the world.

The company has engaged in new energy distribution and application for a long time and has a great deal of experience in cooperating with foreigners.

3.2.3 Solar Energy Company of State-Run Zhongxing Electronic Instruments Factory

As one of the enterprises producing pulse-signal sources for the Ministry of State Electronics Industry, the state-run Zhongxing Electronic Instruments Factory is subordinated directly to the Electronic Group of Gansu. The factory is over 30 years old, with a staff of more than 1,000. It is capable of assembling electronics, machining, and producing molds. The factory produces instruments, meters, and basic electronics.

In order to produce and sell solar products on a large scale, the Zhongxing Factory founded the Solar Energy Company in 1992 as an independent entity, assuming sole responsibility for its profits and losses. The company, with 15 staff members, is engaged in R&D and sales of PV generation sources and products. The main products of the company are 10–300-W_p PV power sources. With a plant building of more than 800 square meters and excellent production facilities, the company can produce 6,000 systems per year. The company sold more than 2,800 sets in 1997.

The company is a subsidiary of the Zhongxing Electronic Instruments Factory and can guarantee the production and product quality of the company. The Zhongxing Factory has the capability of machining energy-saving lamps and assembling electronics. Meanwhile, the company is also working on new product development and its sales channel is wider. The company’s products are relatively well known.

3.2.4 GNERI Solar Power Ltd. of Gansu

Founded in 1990, the GNERI Solar Power Ltd. of Gansu (previously known as GNERI PV Company of Gansu) is the first PV company in Gansu to concentrate on R&D, production, and sales as a whole. Through the implementation of the United Nations’ “Development Project of PV Application Technology in Western China,” the Planning Commission of Gansu Province proposed to found the company by combining the technology and equipment of the Energy Research Institute of Gansu and the space of the Zhongxing Factory of Lanzhou. At the beginning of 1993, the company was divided in two, with one part belonging to Zhongxing and one to the Energy Research Institute. According to the requirements of corporation law, the Energy Research Institute and the staff members of the PV office jointly founded the “GNERI Solar Power Ltd. of Gansu” in August 1996. The shareholders are the Energy Research Institute (collective) and the 10 staff members of the

PV office (personal). With more than 700,000 yuan invested so far, 80% is the collective share and 20% is the personal share.

As a special company in the field of solar PV technology, GNERI Solar Power Ltd. of Gansu has been engaged in the development and distribution of PV technologies for many years. Relying on Energy Research Institute technology, and guided by the market, the company has developed a series of PV products, the first generation in Gansu Province, with the specifications of 4 W_p, 10 W_p, 20 W_p, 50 W_p and 200 W_p. These products can meet the demands of various users, while occupying a particular market segment.

The company has 36 staff members (25 of which are engineers and technicians). There are more than 200 square meters of production space, special testing equipment for more than 40 PV systems, more than 400 square meters of PV laboratory space, and more than 2,000 square meters of outdoor labs. The annual production of home solar systems is more than 3,000, and the total output value is more than 5 million yuan. Sales during 1997 were 833 systems in Gansu, Qinghai, and Tibet. The company has the experience and the ability to execute international cooperation and assistance projects, especially in the field of PV marketing. The company is familiar with the markets and can develop the proper PV products. It also has experience in opening up PV markets.

3.2.5 Lanxin Industry and Commerce Company of Gansu

Founded in July 1988, the Lanxin Industry and Commerce Company of Gansu is a subsidiary of the Lanxin State-Run Radio Factory. The company is an independent corporation, collectively owned, with registered capital of 995,000 yuan, and a staff of 20. It is mainly engaged in development, production, and maintenance of PV systems.

Relying on the Lanxin Factory, the Lanxin Company has engaged in development, production, marketing, and post-sales service of PV systems for many years. In June 1990, the company began developing PV systems. A series of amorphous silicon PV products, LST-25, –60, –100, –300, and –500 were developed in 1991–1994, and the designs were finalized on the provincial level. From 1995 to the present, a series of PV monosilicon products (LTD-20, –40, –75, –100, –150, and –300) were developed, and the designs were finalized and passed the energy-saving production test. A solar cream separator and water-heater were also developed.

The company excels in the development, production, and marketing of solar products, and its annual production has reached 1,000 systems. The market is in rural areas of Gansu, Qinghai, Xinjiang, Inner Mongolia, Tibet, Sichuan, Ningxia, and Shanxi that are without electricity.

3.2.6 Sino-U.S. Solar PV Joint Venture Ltd. of Gansu (Anhua PV)

The GNERI PV Company of Gansu (later renamed the Lanzhou Kelan Industry and Commerce Company to avoid being confused with the Gansu Natural Energy Research Institute) was founded in 1991. On that basis, the Sino-U.S. Solar PV Joint Venture Ltd. of Gansu was founded in 1994 through the investment of the Solar Electric Light Fund (SELF). The total investment is 4.286 million yuan, and the shareholders are the Lanzhou Kelan Industry and Commerce Company with 51%, and the Solar Electric Light Company (SELCO) with 49%. The company has experience in acquiring loans from banks with excellent reputations.

The company has a Board of Directors organized by both China and the United States to make policy, and a general manager appointed by both sides to lead daily operations. The company has a staff of 42, and consists of eight departments: office, marketing, financial accounting, materials, R&D center, post-sales service, quality inspection, and a factory.

The annual production capability is 10,000 systems, and, in 1997, sales were more than 4,000 systems. The main products are solar home systems (brand name of Anhua) from 8 W_p to 200 W_p. The company has a sound sales network. The markets and users are the peasants in Gansu, Ningxia, and Shanxi, and the herdsmen and small homes without electricity in remote areas south of Gansu, Qinghai, Sichuan, Inner Mongolia, Tibet, and Xinjiang.

3.2.7 Solar Energy Power Ltd. of Qinghai Province

In October 1983, the Qinghai New Energy Research Institute set up a PV research office to research and distribute PV systems. The PV research office changed into an independent corporation concentrating on science, production, and trade in February 1993, called the Science and Technology Development Company of Solar Energy of Qinghai Province. The company specializes in solar home systems. At the beginning of 1995, the New Energy Research Institute of Qinghai decided to close down the former company. The Institute as one entity, and 33 other people, jointly sponsored the Solar Energy Power Ltd. of Qinghai Province with capital shares. The company is a private science and technology company, engaging in the research, production, and marketing of PV systems. It has a staff of 34, of whom 24 are engineers and technicians.

The company is engaged mainly in the development, service, transfer, and consulting of solar PV technologies; PV products; the design, production, marketing, installation, and service of new energy products and energy-saving products; and the sales of high-efficiency, energy-saving lamps.

The annual production capability is 10,000 PV systems, and the annual sales are approximately 7,000 systems. The main products are more than 30 kinds of remote power systems. The current markets are in Qinghai, Tibet, Sichuan, Gansu, Xinjiang, Ningxia, and Yunnan. A small number of products are exported to Mongolia, Nepal, and India.

The company is very strong in technology development and has good production and research equipment. With a good sales and maintenance network, the company’s products cover wide regions.

3.2.8 Tianpu Solar Energy Science and Technology Ltd. of Qinghai

West of Ocean PV Ltd. of Xining was founded in 1995 and reorganized in both 1996 and 1997. Tianpu Solar Energy Science and Technology Ltd. of Qinghai was founded in 1998. The chief director and general manager hold 56% of the shares, and other parties hold the remaining 44%. The company is a privately run corporation without a direct subordination relationship with the government. It has a staff of 28. The sponsor of the company was the original director of the PV office of New Energy Institute, who began to study, develop, and distribute solar home systems in 1987.

The company has developed a DC system series of solar home PV systems, an AC system series of solar home domestic PV systems, and the DC–AC high-efficiency, energy-saving lamps. The main products of the company are 10–100 W_p PV DC and AC systems, controllers (3 kinds), and inverters (5 kinds). The current production capability is 7,000 systems per year; more than 3,800 were sold in 1997. The company’s markets are mainly in

Qinghai, Tibet, and Xinjiang. The company has excellent technology capabilities and the ability to perfect its sales network in a short time.

3.2.9 New Energy Development Ltd. of Xining Qinghai

Founded in April 1996, the New Energy Development Ltd. of Xining Qinghai is a limited-liability company with eight shareholders. As a private independent corporation, the company has no direct subordination relationship with the government. There are 45 staff members in the company now.

The company is mainly engaged in the marketing of PV systems. After three years of hard work, the company developed PV systems with the brand name of “Nida.” The main products are three series of systems of 8–300W_p DC small systems, DC/AC PV systems, and DC/AC office PV systems. The annual production capability is 10,000; more than 5,600 were sold in 1997. The company has a strict quality control and management system, and has comparatively well-developed marketing and post-sales service networks.

3.2.10 Dawa Solar Energy Ltd. of Xining Qinghai

Founded in November 1997, Dawa Solar Energy Ltd. of Xining Qinghai is a limited liability company with nine shareholders. As a private, independent corporation, the company has no direct subordination relationship with the government. There are currently 19 staff members in the company.

The predecessor of the company is Dawa Solar Energy Marketing Department of Changqing Computer Company of Qinghai, founded in July 1996. Solar home products with the brand name of Dawa were first produced in August 1996. The objective of the company is 10-20 W_p of solar home systems, which are the main products of the company. More than 3,000 were sold in 1997. The main markets are in Tibet, Sichuan, Qinghai, Gansu, and Xinjiang.

3.2.11 Solar Power Development Center of Xining Qinghai

Founded in November 1997, the Solar Power Development Center (Company) of Xining Qinghai is a limited liability company with four shareholders. As a private, independent corporation, the company has no direct subordination relationship with the government. There are 42 staff members in the company now, 13 of whom are technicians and engineers.

The company concentrates on the development, research, production, and marketing of solar systems. The sponsors began trial production and sale of solar products in rural areas in 1992, and developed solar automatic protection power sources with the brand names of “New Star”, and “Gangwasi” in the TDZ and TDJ series. The main products are three kinds of 4 W_p–300 W_p domestic small power systems, domestic color TV (lighting) systems, and office systems. The annual production capability is 10,000; more than 4,600 were sold in 1997. The main markets are in Qinghai, Gansu, Sichuan, and Inner Mongolia. The company’s marketing and post-sales service networks are comparatively well developed.

3.2.12 Gesang Solar Energy Ltd. of Xining

Founded in March 1998, Gesang Solar Energy Ltd. of Xining in Qinghai province is a limited liability company with two shareholders. As a private, independent corporation selling solar products, the company has no direct subordination relationship with the government. There are 21 staff members in the company, 16 of whom are from Tibet.

The predecessor of the company is Gesang Ltd. of Xining, which was founded in May 1996 under the department of Solar Power Development Ltd. of Xining. The main products are 4-50 W_p systems of eight specifications with the brand name of “Ousai.” The annual production capability is 10,000. More than 5,000 were sold in 1997. The main markets are in Tibet, Qinghai, Gansu, Sichuan, Inner Mongolia, and Xinjiang. The company is expanding its sales networks into Tibet.

3.2.13 Solar Science and Technology Development Company of Xinjiang

Founded in July 1993, the Solar Science and Technology Development Company of Xinjiang was invested solely by Xinjiang Energy Research Institute and was a state-owned company registered in the high-tech development zones of Urumqi, Xinjiang. It was approved as a high-tech company whose income tax was exempt for the first three years and reduced to half in the following three years. The company has a staff of 52.

The research, production, and marketing of the company depend on the Xinjiang Energy Research Institute. There are 4,600 square meters of research experiment buildings, consisting of electronics production and component laboratories and machining facilities. The laboratories are equipped with solar radiation meters and Hewlett Packard electronics comprehensive testing apparatus. There are 300-ton hydraulic press machines, bending machines, spot-welding machines, and other machining equipment to produce various solar systems; and there are two plastic injection machines of 300 grams to produce the shells of the lamps.

The company is engaged in research, development, production, and marketing of solar photo-thermal and PV products. Since 1994, the accumulated sales are more than 2,000 systems of 20-W and 50-W DC/AC home systems, 100-W wind/PV hybrid color TV systems, and 20-W monosilicon home systems. The company produced more than ten 150-W–2,520-W small PV stations, including satellite TV receiving, microwave communication, small solar water-pumping systems (including a 2.5-kW water-pumping system that was the first one in China), the color TV video recorder system of a village culture center, and central electric lighting systems for frontier posts. The company’s products were registered as “Tianshan.” The company has accumulated 30 years of complete data on solar energy meteorological radiation in the Xinjiang area. It has experience in the design and maintenance of large, medium, and small solar PV systems. The circuit is designed using computer-aided design (CAD). Research, production, and service form a coordinated process. The company has both the experience and the ability to cooperate with foreigners.

The company can produce 10,000 solar home systems per year. More than 500 were sold in 1997. The market and users are residents without electricity in rural areas of Xinjiang.

3.2.14 Xinjiang Wind Energy Company

Subordinated to the Hydropower Office of Xinjiang Autonomous Region, Xinjiang Wind Energy Company is a state-run company. The Power Bureau of the Hydropower Office is responsible for the company. Its predecessor—Hydropower Research Institute of Xinjiang—was engaged in the R&D of small hydropower projects. In 1985, the company began to introduce and distribute the technologies and products of solar and wind energy. Then the Department of Rural Energy was founded to distribute the solar equipment and small wind turbines. The Department of Rural Energy was reorganized as a stock-cooperative enterprise subordinated to the Wind Energy Company. (The company and its staff hold 60% of the shares, and the state holds 40%.)

The main products are solar panels used in rural houses, solar supply systems (including various electric appliances), 100-W_p small wind turbines, and wind/PV hybrid systems (100-W_p wind turbines, 20- to 40-W_p solar cells). More than 300 of the 20- to 40-W_p systems were produced and sold in 1997.

The products are used by peasants and herdsmen all over Xinjiang. They are also used as relay station power sources for radio communication networks, and irrigation networks in rural areas.

3.2.15 Lida New Energy Electronic Ltd. of Xinjiang

Lida New Energy Electronic Ltd. of Xinjiang was jointly invested by Lida Satellite TV Equipment Company of Xinjiang, Hi-Tech Development Company of Xi'an, and Key Electronic Ltd. of Xi'an, with registered capital of 1 million yuan. Lida New Energy Electronic Ltd. of Xinjiang, invested by the above three companies, produces solar and wind energy power systems. It is an independent company with the advantage of marketing, technology, and capital. Its main products are 20-W_p or greater solar home and wind/PV hybrid systems. Other products include electric appliances such as TV sets, satellite TV receiving systems, camcorders, recorders, and telegraph receiving and transmitting machines.

After nine years of work, Lida Satellite TV Equipment Company of Xinjiang installed 30,000 satellite aerial receiving systems. The cooperators provide solar cell panels, batteries, and wind turbines; the company itself produced controllers and lamps. Approximately 500 solar and wind/PV hybrid systems were produced and sold in 1997. The company is going to expand its operations on the basis of shareholders' technology, the availability of raw materials, and technicians at the radio factory nearby.

3.2.16 Solar Electronic Engineering Company of Urumqi

The Solar Electronic Engineering Company of Urumqi was founded in 1987. The company has 18 staff members, of whom 3 are senior engineers, and 5 are engineers. Its predecessor was the Research Institute of Xinjiang Semiconductor Factory, which began to research silicon solar cells and components, solar electric fences, and solar energy lamps, as well as to distribute PV products in Xinjiang in the 1980s. The company developed an "integrated solar special energy storage TV set," combining the functions of a TV set, energy storage equipment, its protection equipment, and an aerial amplifier. Other practical solar systems were also developed.

The company, with 1,800 square meters of working space, has the ability to produce 10,000 solar home systems. The main products are: lamps and lanterns; black-and-white TV sets; recorders and acoustic products; territory station TV satellites; relay equipment; integrated special energy storage TV sets; and home power sources with 20-W_p solar cells. The main markets are in Xinjiang. More than 1,600 20-W_p solar home systems were sold in 1997.

The company has R&D experience in new products and distributing these products in a wide area. Furthermore, the company has set up networks for sales and maintenance all over Xinjiang's 84 districts, cities, and counties through TV set factories.

3.2.17 Jike Energy New Technology Development Company of Beijing

The Jike Energy New Technology Development Company of Beijing is a state-run enterprise subordinated to Energy Research Institute under the State Planning Commission. Founded in the light of reform and a more open policy at the end of 1992, the company concentrates on science, technology, production, and trade, engaging specifically in the development, production, sale, installation, and post-sales service of solar PV products.

There are 16 staff members, of whom 5 are senior engineers and 9 are engineers. The company produces controllers, inverters, solar home systems, and wind/PV hybrid systems. It also designs PV generating systems and various PV products. At the same time, it sells foreign and domestic solar cell panels and storage batteries.

In 1997, 70.2 kW of PV systems were finished, 54% of which (38 kW) are solar home systems; 100 kW will be finished in 1998. The main markets are in Xinjiang, Qinghai, Inner Mongolia, Gansu, Tibet, and Northwest China. With excellent capabilities in research and technology, the company is in a good position to cooperate with foreigners.

4. PV Industry

4.1 PV Cells

There are seven factories producing solar cells in China, with an annual designed production capacity of 4.5 MW. Among these seven factories, five produce crystalline silicon solar cells, and the other two produce amorphous silicon cells. The five factories producing crystalline silicon solar cells are state-run enterprises located in Beijing, Yunnan, Zhejiang, Henan, and Hebei; the two producing amorphous silicon cells are Sino-foreign joint ventures located in Heilongjiang and Shenzhen. Yukang Solar Energy Company of Shenzhen stopped production. The Beijing Research Institute of Non-Ferrous Metal is mainly engaged in technology research; therefore, its products are mainly used for demonstration purposes.

4.1.1 Monocrystalline Silicon Solar Cells

4.1.1.1 Huamei PV Equipment Company of Qinhuangdao

Located in Qinhuangdao City of Hebei Province, this company is a state-run, medium-sized company jointly operated by the state-run Hongguang Electronic Tube Factory and the Qinhuangdao Electronic Tube Factory. It has 230 staff members, one-third of whom are engineers and technicians. The company has a strong capability in technology development.

The company, which began production in 1989, is the largest factory to produce monocrystalline silicon solar cells in China. The annual production capability of silicon wafers is 600 kW_p, and that of PV cells and their components is 1 MW. The sales volume was 320 kW_p in 1997. The main products are 75-mm to 100-mm diameter silicon wafers, TDB 100-mm silicon single-crystal cells, TDM 25-mm x 25-mm monocrystalline solar cells, various standard solar cells, and their electronic products. The solar cell production equipment was imported from the Spire Corporation (U.S.), including three production lines of silicon wafers, single-crystal cells, and modules.

The product quality of the company is reliable. It is currently used by the communication network of the national defense forces. Post-sales service is good, and the users' response is excellent. In the application field, communication engineering (including transportation signals), independent PV stations, and home systems. The company's products were adopted for some PV stations and communication projects that have a high quality requirement. These projects include the independent power stations of Tibet Cuoqin (20 kW) and Anduo (100 kW), the wind/PV hybrid power station of Shandong Jimo (30 kW), and communication artery and light-cable artery projects at the state and provincial levels.

The company provides users with complete solar power products and electric apparatus, and also designs, installs, and debugs solar systems for users, and provides technological consultation and training.

4.1.1.2 Semiconductor Component Factory of Yunnan

Located in Kunming City of Yunnan Province, this company is a state-run enterprise with a staff of 200. The main products are crystalline silicon solar cells, components, and products. Since its founding in 1977, the factory has been engaged in the research of monocrystalline silicon solar cells with a textured surface. Monocrystalline silicon cells with diameters of 40 mm and 75 mm were developed in 1979. The production line was imported from the United States in 1984. After several years of development, the factory has become a medium-sized enterprise whose main products are solar cells and automobile electronic products. The annual production capability of silicon wafers is 600 kW_p, and that of monocrystalline silicon components is 500 kW_p. The annual sales total 350 kW_p.

The company's products are mainly used in the fields of electronic microwave, post and telecommunications, forest fire alarm stations, national defense communications, and home systems. The main products are the high-power panels, but low-power panels were produced in recent years because of the increasing demand for PV home systems. The products are mainly used in the engineering field. Recently, the products have been used in some key projects on a national level, such as independent power stations in Tibet, a light cable communication artery on the Eurasian continent, several digital microwave arteries on the national and provincial level, and satellite communications in Tibet. The products are used in every province but Taiwan, and exported to many countries and regions. The users have rated the products' quality and the post-sales service as being quite good.

The factory's organizations are completely set up. The technicians and engineers constitute 40% of the total staff, so the factory is strong in technology R&D. The factory took part in drafting and examining the standard for solar power source systems in cooperation with the state, the Ministry of Post and Telecommunication, and the Ministry of Electronics. It undertook the science and technology programs of the Eighth Five-Year Plan and the Ninth Five-Year Plan.

4.1.1.3 Kaifeng Solar Cell Factory

Located in Kaifeng, Henan Province, and founded in 1964, the Kaifeng Solar Cell Factory is the first special silicon solar cell factory in China to begin research and production of monocrystalline solar cells in 1975. Supported by the SSTC, and together with the Solar Power Source Factory of Ningbo, the factory introduced advanced solar cell production technology, key production and testing equipment from ARCO, Spire, of the United States, and the British Petroleum Company (BPC). The main products are monocrystalline silicon cells and components. The annual production capacity of silicon wafers is 150 kW_p, and that of cell components is 300 kW_p. The annual sales for 1997 were 180 kW_p.

The factory has two facilities of 12,000 square meters. The staff consists of 120 people, one third of whom are engineers and technicians. It undertook some solar cell projects of SSTC from the Sixth Five-Year Plan to the Eighth Five-Year Plan. It has strong capabilities in R&D. Indeed, the factory can undertake R&D of new products, and the distribution and application of solar cells. It can also provide various kinds of single-crystal cells, components, and arrays. The solar cells produced by the factory have been used as navigation marks, signals, posts, in telecommunications, microwave relay stations, meteorological inspections, cathodic protection, water-pumping irrigation, frontier posts, and home systems. The products are sold in 30 provinces throughout China and in foreign countries.

4.1.1.4 Ningbo Solar Power Source Factory

Located in Ningbo, Zhejiang Province, the Ningbo Solar Power Source Factory is a state-run enterprise subordinated to the Electronic Instrument Bureau of Ningbo. The factory, which was founded in 1976, is a member of both the China Microwave Communication Group and the China PV Technology Development Center. There are 150 people on staff, 30% of whom are engineers and technicians.

Supported by the SSTC, and together with Kaifeng Solar Cell Factory, the factory introduced advanced solar cell production technology, key production and testing equipment from ARCO, Spire, RTC, and BPC of the United States. The full production factory was completed in 1987. The main products are monocrystalline solar cells and components. The annual production capability of silicon wafers is 200 kW_p, and that of cell components is 500 kW_p. The total sales for 1997 were 550 kW_p. The factory passed the ISO9001 certification testing in December 1998.

The factory’s products are widely used for microwave relay stations, post and telecommunication, cathode protection, navigation marks, and home systems. Most of the products are low power. The factory has the lead in large areas of the market; for example, almost all of the solar cells used for navigation marks are made by the factory. The quality of the products is stable, post-sales service is good, and the response of users is excellent.

The factory can design and provide special components and arrays that meet the requirements of users, can install and debug solar energy generating systems, and can provide technical training for users. It has strong abilities in R&D.

Table 4.1 (on the following page) provides detailed information about these companies.

4.1.2 Amorphous Silicon Solar Cells

4.1.2.1 Harbin-Chronar Solar Power Company

Located in Harbin, Heilongjiang Province, this company is a joint venture; investors include the Harbin Steam Turbine Factory, the Heilongjiang Movie Machine Factory, and the Chronar Corporation of the United States. The total investment is 40.55 million yuan. It was formally put into operation in April 1988. The main products are amorphous silicon solar cells and components. The annual production capability is 1 MW; the total sales for 1997 were 300 kW_p.

There are 107 staff members, of whom 54 are engineers and technicians. The company has capaabilities in science and technology development, and has also developed a solar wind cap. The two production lines—production technology and production technology equipment—were introduced from the parent company, the Chronar Corporation. After the Chronar Corporation went into bankruptcy, The APS Company took over the joint venture. APS, however, closed down and became a state-run company. Because of the bankruptcy of the parent company, it is difficult to purchase spare parts, so equipment maintenance and the continued functioning of the production lines depends fully on the company's own engineers and technicians.

The company's products are widely used in the forests, meteorology, oil field development, geological exploration, national defense, post and telecommunication, solar home systems, and solar energy stations.

The company's market has not been stable for the last 10 years. The company stopped production for two years, but it has since resumed. The products were mainly sold in China several years ago, but in recent years they were mostly exported to foreign countries. The exported amount was 60% of the total production in 1996 and 70% in 1997. The main markets are in Africa.

4.1.2.2 Shenzhen Yukang Solar Energy Ltd.

Located in Shenzhen of Guangdong Province, Shenzhen Yukang Solar Energy Ltd. was registered as a Sino-foreign joint venture in 1988. The company was formally put into operation in 1992. The main products are amorphous silicon solar cells and components. The designed production capability is 1 MW. There are more than 50 staff members.

Table 4.1 State of Main PV Cell Factories in China

Name of Factory	Legal Status	Kinds of Products	Annual Production Capability of Silicon Wafers (MW)	Capacity (MW)	Annual Production (MW)				
					1993	1994	1995	1996	1997
Huamei PV Equipment Company of Qinhuangdao	State-run	Monocrystalline silicon	0.6	1	0.13	0.20	0.26	0.30	0.32
Semiconductor Component Factory of Yunnan	State-run	Monocrystalline silicon	0.6	0.5	0.15	0.22	0.28	0.32	0.35
Kaifeng Solar Cell Factory of Kaifeng	Collective-run	Monocrystalline silicon	0.15	0.3	0.10	0.20	0.20	0.25	0.18
Solar Energy Power Source Factory of Ningbo	State-run	Monocrystalline silicon	0.2	0.5	0.18	0.25	0.35	0.50	0.55
Research Institute of Non-Ferrous Metal of Beijing	State-run	Crystalline silicon	0.1	0.1	0.05	0.10	0.10	0.15	0.02
Chronar Solar Energy Power Company of Harbin	Joint venture	Amorphous silicon	—	1	0.20	0.18	0.15	0.30	0.30
Yukang Solar Energy Company of Shenzhen	Joint venture	Amorphous silicon	—	1	0.05	0.02	0.05	0.15	0.20
Total			**—**	**4.5**	**0.86**	**1.17**	**1.39**	**1.97**	**2.10**

When the company was registered, there were five shareholders: the Interaction Finance Corporation of World Bank, the Chronar Corporation, the Oil Industry Group of Korea, the Development Company of Shenzhen Special Regions, and the Shenhan Science and Technology Company of Shenzhen. Each shareholder has 20% of the total shares. After its bankruptcy, Chronar's shares were split between the other four companies, so each now owns 25% of the shares. The Oil Industry Group of Korea is withdrawing from the group, and the Shenhan Science and Technology Company of Shenzhen has settled accounts and is also preparing to withdraw. The World Bank has been a passive partner. Therefore, the real shareholder is the Development Company of Shenzhen Special Region. For several reasons, the company has stopped production several times in recent years.

The Development Company of Shenzhen Special Region adjusted the management of the Yukang Ltd. in June 1998. The managers of the company were engaged in the reinstatement of production. Both production lines of the company were imported from the Chronar Corporation. The production line can produce but is not stable. Some orders are beginning to come in. The main markets are in Africa.

4.2 Key Components of PV Systems

PV systems consist of solar cells as well as controllers, inverters, storage batteries, lamps, and lanterns.

4.2.1 Inverters and Controllers

Most inverters and controllers are developed by PV system companies in workshops. There is no economy of scale and the quality is low. The controllers and inverters of medium and large PV systems are designed according to actual circumstances—that is, a set consisting of a controller and an inverter for a project.

There are several joint ventures involved in the development and production of controllers and inverters. Domestic manufacturers have difficulty competing with joint ventures that are fully funded and able to reach economic scale.

4.2.1.1 Jike Energy New Technology Company of Beijing

Located in Beijing and founded in 1992, this company is subordinated to the Energy Research Institute of the State Development and Planning Commission. The company is engaged in the development, design, production, marketing, installation, and post-sales service of PV and wind/PV hybrid systems. The company is one of 17 PV companies meeting the initial selection requirement of the GEF/World Bank project.

The company is strong technologically and rich in practical experience. With excellent post-sales service, the company is well known in regions where PV systems are widely used. In recent years, the company has developed many large independent PV stations, solar energy demonstration schools in the countryside, and cathode-protection projects. The company's developed projects and products have received several awards at the local and ministerial levels.

The company is involved in almost every field of PV application: solar PV stations, wind/PV hybrid systems, solar energy systems with cathode protection, communication signals, solar energy schools, and other areas. It can design and produce various sine- and square-wave DC/AC inverters with different power levels, charging and discharging controllers, integrated controller and inverter machines, constant potential apparatus used for cathode protection, electric quantity meters, and testing machines for solar cell arrays.

4.2.1.2 Electric Engineering Research Institute of Academy of Science of China

Located in Beijing, the institute is subordinated to the Academy of Science of China. There is a New Energy Research Office under the institute, engaging in wind and solar energy research. The institute began researching solar systems in 1978, concentrating mainly on the optimized design of solar PV systems, the operation of solar systems, controllers and inverters, and testing methods and machines.

The company is strong technologically and rich in practical experience. With excellent post-sale service, the company is well known in regions where PV systems are widely used. In recent years, the company developed many large independent PV and wind/PV hybrid stations. The institute designed China's largest independent PV station: Tibet's Anduo 100-kW_p PV station. Some of its engineering projects and products have been awarded the prize of the Science and Technology Progress of Academy of Science of China several times.

The Jikedian Renewable Energy Technology Development Center of Beijing was founded under the guidance of the New Energy Office of Electric Engineering Institute. The center provides consultation and services in PV and wind/PV hybrid technologies for residential and village systems. It performs engineering design and construction, international cooperation, and installation development. It can also provide small solar PV systems, controllers, and inverters used for home and village wind/PV hybrid systems and PV stations.

4.2.1.3 Solar Power Source Ltd. of Hefei

Located in Hefei, Anhui Province, and founded in 1992, Solar Power Source Ltd. of Hefei is a high-tech, privately run company engaged in R&D and production of inverters. The company has a group of high-level engineers engaged in R&D of electric power and electronic products.

The power capacity of the inverters produced is from 60 kVA to 100 kVA, and the DC input voltage is 12 V, 24 V, and 48 V. Computers control the circuits, which have various protection functions and do not need maintenance.

4.2.1.4 Qingdao Agent Office of Germany Steca Company

Located in Qingdao of Shandong Province, the company is responsible for the processing of Germany Steca Company's raw materials. The products are controllers, inverters, and DC lamps, which together form a complete set of solar systems.

Germany Steca Company is the largest manufacturer of solar charging controllers in the world, and Germany Fronius Company is a manufacturer of on-grid converters in PV field. The two companies cooperated to develop controlled converters that integrate charging control with converters. Steca Company is responsible for the sale of the products.

At the end of 1995, the Qingdao Agent Office of Germany Steca Company began to produce controllers by processing raw materials to German specifications. In 1998, the production was 30,000, and production is expected to reach 50,000 in 1999. The agent office began producing DC lamps by processing raw materials to German specifications. Both controllers and DC lamps are produced. The products are in series with reliable quality, but the price is high, and most of the products are sold in foreign countries. Some household users have begun to use the company's products, but the amount is small because of the high price. The company is currently beginning to develop the domestic market.

4.2.1.5 Zhongda Industry and Commerce Ltd. of Shenzhen

Located in Shenzhen of Guangdong Province, the company is a special company of PV application. It produces DC lights, solar PV generating systems, water-pumping systems, controllers, and DC/AC inverter series. In the beginning, the main products were the solar PV water-pumping systems. Currently, the main products are the DC and AC lights.

The company is one of the first enterprises to develop and produce electronic energy-saving lamps. The brand name of the company's lamps is Xinruoda. On the basis of AC energy-saving lamps, the company developed a series of DC energy-saving lamps powered by a 12-V storage battery. The products can be divided by appearance into two kinds: integrated and replaced tube, and by power into three kinds: 7 W, 9 W, and 11 W.

4.2.2 Lamps and Lanterns

As is generally acknowledged, lamps and lanterns are the weakest link in PV systems. In these systems, DC fluorescent lamps are generally used, and the most common shortcomings are that the light tube becomes black easily, the life is short, and the power tube is easily damaged, which directly influences the consumer's activity. Some even replace it with DC incandescent lamps.

At present, many domestic companies, including research institutes and system companies, produce DC lamps, but not on a large scale. There are no enterprises whose product quality is satisfactory.

Some foreign special companies are beginning to enter the Chinese market for DC lamps, and they are importing better-quality DC lamps, especially for PV systems; however, the price is still too high to be accepted in the domestic market.

4.2.2.1 Qingdao Agent Office of Germany Shidekai Company

See 4.2.1.4 for information about this company.

4.2.2.2 Zhongda Industry and Commerce Ltd. of Shenzhen

See 4.2.15 for information about this company.

4.2.3 Storage Batteries

The storage batteries used in PV systems are usually purchased from large storage battery factories. At present, the storage batteries are produced on a large scale, and the quality of products can be guaranteed. However, there is no special battery used in PV systems, which should be a lead-acid battery with deep discharging and long life.

4.2.3.1 Shuangdeng Power Source Ltd. of Jiangsu

Located in Jiangyan City of Jiangsu Province and founded in 1986, the company is one of the first companies to engage in the research and production of sealed, valve-controlled lead-acid batteries. The annual production capability is up to 200 MWh, and the total sales are 120 million yuan. The company's assets are 85 million yuan, the land occupied is more than 0.7 million mu (1 mu = 1/15 hectare), 10,520 m^2 of which are occupied by the production buildings. There is a science institute under it with strong R&D capabilities.

The company imported a complete line of production equipment and testing machines from the United States, and it has special production lines of storage batteries that are sold internationally. The company produces three series and 35 kinds of sealed, valve-controlled lead-acid batteries. The products are widely used in post and telecommunications, electric power, transportation, and energy resource fields. They have passed the ISO9002 qualification certification, and the certification of post and telecommunications and national defense communication networks.

The company has a complete marketing, production, development, and information system, ranging from design, quality control, and planning to sales and post-sales service. There are ten branch companies and several affairs offices that provide reliable installation, maintenance, and post-sales service.

4.2.3.2 Zibo Storage Battery Factory

Located in Zibo of Shandong Province, the factory is subordinated to the Shipping Industry General Company of China. Passing ISO9001 certification, the factory researches and produces ordinary and valve-controlled lead-acid storage batteries. There are 18 series and more than 200 kinds of battery products, which are widely used in the national defense, science research, post and telecommunications, railway, electric power, mining, shipping, and automobile fields. The factory is powerful in production and technology and has great ability to develop new products. The products are stable, and have been awarded several provincial, national, and ministerial prizes.

Valve-controlled, lead-acid storage batteries produced by the factory are suitable to be used in wind and solar generating systems. The specified capacity of these batteries is 15 to 100 Ah, and they have the characteristics of stable working voltage and being able to discharge in large current.

4.2.3.3 Huada Power Source System Ltd. of Shenzhen

Located in Shenzhen, Guangdong Province, and founded in 1988, the company is a Sino-foreign joint venture. The company imported from the United States advanced liquid-gel electrolyte production technology and a complete line of production equipment. The product—a sealed lead-acid storage battery requiring no maintenance—is internationally distributed in the 1990s. The XM liquid-absorbing, sealed, lead-acid storage battery (specified voltage is 12 V, 6 V, and 4 V, with a specified capacity from 32 to 260 Ah, used for surface or circulation) is suitable for wind and solar energy systems.

4.2 Barriers to Domestic PV Industries

4.3.1 Capital Barriers

R&D in the PV field still depends on bilateral and multilateral assistance loans and grants and on limited state science and technology funds, so the input is small. The existing factories produce solar cells on a small scale, are weak both technologically and economically, have out-of-date production equipment, charge high prices, and have difficulty in adapting to the fierce competition in the international PV market. The PV companies depend on their own strength, which is difficult in the current market. It is hard to raise capital to maintain production, make technological reform, and expand production. Therefore, it is difficult to produce on a larger scale, and the process of industrialization is slow.

At the beginning, the development of the PV industry depended on the support of the government in the areas of policy and finance. At present, some large transnational corporations, such as German Siemens, Netherlands Shell, and the British Petroleum Corporation, are beginning to get involved in the PV industry, which accelerates the process of industrialization. The large companies in China are not involved in the PV industry. With the rapid development outside of China, the gap between the Chinese level and the advanced international level (in either technology research or industrialization progress in the PV field) is growing.

4.3.2 Out-of-Date Equipment

Most of the domestic solar cell production lines are at the international level of the mid-1980s. Production scale is small, and the cost is high. They differ greatly from current international advanced technology and equipment.

The equipment of most enterprises can't form a complete system, so there is a bottleneck in the production line. Among the four monocrystalline silicon manufacturers, only the Yunnan Semiconductor Factory has an equivalent production capability between silicon and components; however, the other three factories' capability to produce silicon is weak. The production capability of components is 1 MW_p, 500 kW_p, and 500 kW_p in the Qinhuangdao Huamei PV Equipment Company, the Ningbo Solar Cell Company, and the Kaifeng Solar Power Source, respectively; however, their production of silicon is only 600 kW_p, 300 kW_p, and 150 kW_p. The production capability of silicon wafers heavily restricts the ability to increase the output of PV production.

The technology and equipment of the two amorphous silicon factories were imported from the Chronar Company (which went bankrupt). In addition to problems within the factories themselves, the production lines have stopped, and two lines of Yukang have been combined into one that will soon begin production.

Most of these solar cell factories remain in their present state because they can't make technological reforms or acquire new equipment. The economic positions of these factories are generally bad, with large initial investments and heavy liability burdens.

4.3.3 Imperfect Standards

There are no unified standards for design, production, installation, or maintenance of PV systems. The standards decided upon by the enterprises themselves can't guarantee the reliability and safety of the system. With the increasing demand for PV systems, more and more companies are getting involved in the field. No unified standards make for a lot of confusion in the design, production, and installation of PV systems.

Current status in the various PV-related areas is as follows:

- Basic standards, specifications, and technological requirements are imperfect and the existing ones aren't implemented rigorously and seriously.

- Though there are fairly good product-testing systems and methods in solar cell component and storage battery companies, they are not implemented rigorously and seriously in all cases. The situation is even worse in some small battery factories that have no testing system or method at all.

- Most controllers, inverters, and DC lamps are produced on a small scale at a high cost. Incomplete testing machines and equipment, a shortage of inspections during the process, and no strict quality control result in low-quality products.

- Some PV products on the market have no trademark, nameplate, complete illustration, or installation and use manual. In addition, some of the products on the market are fake and of very poor quality, which damages users' benefits and the reputation of PV products.

Stipulating production, design, and installation standards for PV systems; setting up PV factories, and standardizing the activity of PV factories in the PV market are top priorities.

4.3.4 Weak Production Ability of System Components

PV solar systems consist of solar cells, controllers, inverters, batteries, and DC lamps. There are no specific companies that produce PV application systems on a large scale. Among system components, battery production is mature and standardized, and solar cells have been produced on a large scale, but production of controllers, inverters, and DC lamps is inadequate. Although there are many battery factories, there are no lead-acid batteries of deep discharge and long life specifically designed for PV systems. The life of small lead-acid batteries now used in solar home systems is just 2 to 3 years. Loss of battery effectiveness is one of the main problems encountered with solar home systems. Most controllers and inverters used in PV systems are produced on a small scale and are high in cost and low in quality; in addition, their reliability and safety can't be guaranteed. The weakest link of PV systems is the DC lamp, which is unstable and short-lived.

The only way to improve the life and expand the application fields of PV systems is to develop a series of products that will enable PV systems to be produced on a large scale.

4.3.5 Shortage of Raw Materials

The production volume of monocrystalline silicon solar cells is only 1.4 MW, well short of the designed capacity of 2.4 MW. The shortage of raw materials and silicon wafers is the main problem that constrains the production of solar cells. The ideal raw materials for monocrystalline silicon solar cells are the waste wafer material available from the semiconductor electronics industry, whose price has been increased largely with the development of the monocrystalline silicon solar cells industry. This kind of raw material is limited even in the world market. The shortage of raw materials is a major barrier to expanding the scale of monocrystalline silicon production and decreasing the cost.

5. Main PV Activities

5.1 Domestically Funded Projects

To push sustainable development forward, the Chinese government has formulated a series of policies to mobilize renewable energy development and input many resources to renewable-energy-related programs and projects. Particular attention has been paid to providing electricity for the more than 900 million people living in the vast rural and village areas.

5.1.1 National "Eight-Seven Poverty Alleviation Program"

In March 1994, the Chinese government formulated the National "Eight-Seven Poverty Alleviation Program." The goal of this program is to help 80 million people dress warmly and get enough to eat by concentrating man-hours, material, and financial resources during the last seven years of the century. The program marks the last stage of this assistance project. The objectives are as follows:

- Enable poor families to get warm clothes and enough food, develop and use natural resources effectively and reasonably, and find jobs.
- Popularize elementary education as a whole, wipe out illiteracy in children, develop adult occupational education programs, and train young laborers with one or two practical agricultural skills.
- Control the population growth rate to the average level of the country, establish a health protection system to decrease diseases and eliminate disease caused by a shortage of iodine.
- Construct roads to poor towns and villages, expand the coverage of broadcast and television in counties and villages with electricity.
- Resolve the problems of peoples' and livestock's drinking water, the problems of fuel for living, and reverse the tendency of biological and environmental deterioration in poor areas.

In order to achieve these objectives, the Chinese government will allocate 4.5 billion yuan each year.

As part of the National "Eight-Seven Poverty Alleviation Program," 592 counties were selected. These counties have a poor population of 58.6 million and make up 73% of the total poor population in China. Among these 592 counties, 377 are in mountain areas, and 259 are in minority nationality areas. Five hundred fifteen of them are in central and west China. There are 31 counties with 0.86 million poor people in Inner Mongolia, 5 counties (34,000 people) in Tibet, 50 counties (3.5 million people) in Shanxi, 41 counties (3.8 million people) in Gansu, 14 counties (0.417 million people) in Qinghai, 8 counties (0.899 million people) in Ningxia, 25 counties (0.839 million people) in Xinjiang Autonomous Region, and 5 counties (0.1 million people) in Hainan. A large part of the population without electricity in these counties may use PV and wind power to resolve the problem.

“Giving Jobs Instead of Giving Money" is one of the programs being used to combat poverty. In the past, assistance programs focused on providing money and goods to the poor. Now the government has begun to organize peasants to construct irrigation systems, drinking-water projects, roads, village communication alliances, etc., and teach them better use of farmland, prevention of water and soil erosion, and reforesting. The government then pays them a wage to do those things.

By the end of 1994, the “Poverty Alleviation Program” had been implemented in six rounds. The total input from the central government is 14 billion yuan, and the input from local governments is 12 billion yuan. The program has made remarkable achievements. One of them is the increase of small hydropower to 400 MW and more than 20,000 km of electricity lines in rural areas.
According to the national “Eight-Seven Poverty Alleviation Program" of 1994, “Giving Jobs Instead of Giving Money” will concentrate on assisting key counties in the northwest and southwest. The current financing is 4 billion yuan a year.

Household PV systems were distributed to meet the basic electricity demands of peasants and herdsmen in five provinces of southwest China, Inner Mongolia, and Tibet. In 1996, 50-W and 100-W household PV systems were installed in 400 houses with no electricity. Two PV water-pumping systems with 800 W of solar cells were installed to irrigate orchards in poor mountain areas in Jianchang County of Liaoning Province. Assistance funds and the "Gold Program" jointly contributed 1 million yuan to this project.

5.1.2 China Brightness Program

By the end of 1995, there were 16 counties, 828 townships, and 29,783 villages, totaling 17.3 million homes, and 76.56 million people with no electricity. As most of them are far from any power grid, and have small and scattered power loads, it is impossible to supply electricity to them by extending existing power grids.

According to estimates of the wind energy resource in China, there are about 23 million people living in areas where there is currently no electricity, but plenty of wind energy. The goal of the China Lighting Project is to use wind power to give those 23 million people electricity of 50 to 100 W per capita by 2010. A related goal is to supply electricity to border posts, communication stations, meteorological stations, oil and gas pipe maintenance stations, and railway signals in areas with an abundant wind energy resource.

In addition to wind power systems, the China Brightness Program will also build a certain number of PV systems to form some wind/PV, wind/diesel, and wind/diesel/PV hybrid systems.

5.1.3 Project to Raise Income Levels of the Poor by Introducing Electricity

The Ministry of Electric Power began this project as part of a rural electrification program. The short-term objective is to supply electricity to more than 95% of the counties that are currently without electricity. At the same time, they want to complete the electrification of 1,000 counties and increase electricity consumption in these counties to 520 billion kWh.

From 1992 to 1996, 17 counties and more than 50 million people were supplied with electricity. By the end of 1996, 98.6% of townships, 96.7% of total villages, and 94% of rural people were supplied with electricity. In Beijing, Tianjin, Shanghai, Liaoning, Jilin, Shandong, Ningxia, Jiangsu, Anhui, Hebei, Fujian, and Zhejiang, and 12 other provinces, municipalities, and autonomous regions, there were no villages without electricity.

Supported by the project, small independent PV stations and solar PV generation systems were distributed in the regions rich in solar energy such as Tibet, Xinjiang, Qinghai, Gansu, Ningxia, Shanxi, and Inner Mongolia. An independent PV station with an installed capacity of 100 kW was built in Naquanduo County in Tibet in October 1998. That makes six county-level PV stations, and installed capacity totaled 250 kW at the end of 1998.

5.1.4 National Science and Technology Key Project

From the early 1970s, the Chinese government began to pay attention to renewable energy and issued a series of supporting and encouraging policies. From the Sixth Five-Year Planning period, new and renewable energy projects financed by the government have been put into National Key Science and Technology Projects every year.

The SSTC and SPC were previously responsible for allocating funds. After governmental reform in 1998, the Ministry of Science and Technology was put in charge of the funding allocation.

In the Eighth Five-Year Plan, the funds for renewable energy were 60 million yuan, of which 5 million yuan were used for PV technologies. In the Ninth Five-Year Plan, the funds for renewable energy were 82 million yuan, of which 12 million were used for PV technologies. Of the 12 million yuan going to PV technologies, 9 million were used for PV cell research, 2 million for PV system research, and 1 million for other research.

In the Ninth Five-Year Plan, there are four areas of special concerns: production of crystalline silicon, new types of solar cells, solar generation systems, and amorphous silicon solar cells.

5.2 International Cooperation Projects

5.2.1 U.S. DOE Project

The U.S./China Protocol for Cooperation in the Fields of Energy Efficiency and Renewable Energy Technology Development and Utilization focuses on three sustainable energy goals: (1) to advance world energy security interests by helping China develop more diversified energy resources, thereby reducing its future demand for oil; (2) to mitigate the environmental damage associated with a rapid growth in energy demand through deployment of renewable energy and energy efficiency measures; and (3) to enhance U.S. industry competitiveness in China's energy market. The Protocol was signed in February 1995 by the U.S. Department of Energy (DOE) and the Chinese Ministry of Science and Technology. The U.S. National Renewable Energy Laboratory (NREL) implements renewable energy activities focusing on rural energy development, wind energy development, and business development.

The rural energy development activities focus on the use of village-scale renewable energy technologies to provide energy or electricity to rural areas in China.

- Gansu Solar Home System Project — PV solar systems were installed in 320 homes and 10 schools by 1998 as phase 1 of this project. In a follow-on activity stimulated by the project, systems were installed in 280 additional households by the Gansu Solar Electric

Light Fund. Phase 2 of this project will include installations of additional solar home systems and two PV school systems that will be equipped with computers.

- Rural Biomass Collaboration — An assessment of biomass resources, a description of China's technological biomass capability, and an initial techno-economic assessment of potentially useful biomass and bioenergy systems, including several economic case studies.
- Inner Mongolia Hybrid Household Project — Case studies on household and village power systems, including technical performance and economic analyses of 41 households and 3 villages in 1997. In a pilot project, 341 household PV/wind systems are being installed in 2000.
- Rural Energy Survey and Analysis — Collected rural energy survey and socio-economic household data for provinces in northwestern China, including Inner Mongolia, Qinghai, Gansu, and Xinjiang and performed renewable energy options analyses on systems for various regions given local renewable energy resources and incomes.

- Asia Pacific Economic Cooperation (APEC) Tibet Solar Electrification Project — Two companies are installing 200 solar home systems (30–36-W systems) in rural areas within the Lhasa prefecture. The goal is to identify business development strategies for PV installations in Tibet.
- Training — Intensive biomass training sessions were conducted at NREL on life-cycle assessment (LCA) and Geographical Information Systems (GIS) analysis. A two-week training was held for local technicians and government staff at the Asia-Pacific Solar Energy Training Center in Lanzhou during November 1999.

The wind energy development activities focus on accelerating sustainable large-scale development of wind power in both grid-connected and off-grid village power applications in China.

- Wind Resource Assessment and Mapping — Completed a local wind-mapping assessment of Nan'ao Island in southeast China and a regional southeast China wind resource assessment and mapping project in 1998 in the provinces of Jiangxi, Fujian, and the eastern half of Guangdong.
- Xiao Qing Dao Village Power Project — Current development of a pilot project using a wind/diesel/battery system to electrify 120 households on Xiao Qing Dao Island located in the Yellow Sea off Shandong Province.
- Training — Each year, two Chinese engineers are trained at NREL for 2-3 months on various topics including wind resource assessment, hybrid systems modeling, and wind utility interconnection modeling.

Renewable Energy Business Development — DOE/NREL workshops and outreach activities have been successful in helping U.S. companies facilitate business partnerships and develop markets for renewable energy technologies in China.

- Provincial Renewable Business Profiles — Business development studies were prepared, discussing factors that influence the deployment of renewable energy in six provinces and changes that have been made under China's government restructuring.
- Chinese PV Industry and Technology Assessments — An evaluation of local PV businesses and applications was conducted and published: *China PV Business and Application Evaluation*.
- Business Development Workshops and study tours — A U.S./China Rural Electrification Workshop was held in 1998 to provide information to U.S. companies on rural electrification opportunities and plans and to facilitate networking between U.S. and Chinese companies. A follow-up U.S./China Renewable Energy Business Workshop and

study tour was conducted with 13 U.S. companies in China during November 1999. A three-day workshop on Wind Energy Business Development and Policy Analysis was held in April 1999 to train Chinese officials and companies in business development for grid-connected wind power.

- Energy Policy — In August and September 1998, Chinese energy analysts from the Center for Renewable Energy Development participated in a policy study and extensive tour of the U.S. and prepared a report on a comparison of U.S. and Chinese renewable energy policies. This policy study tour had a significant impact on the development of policy initiatives within the State Development Planning Commission, resulting in the consideration of several policy initiatives for inclusion in the Tenth Five-Year Plan. A primary emphasis is being placed on development of an RPS (Renewable Energy Portfolio Standards) type system for China.
- Renewable Energy Forum — In April 2000, DOE/NREL and the Chinese Ministry of Science and Technology held the US/China Renewable Energy Forum in Washington D.C. . The event was attended by 125 participants including 50 Chinese delegates and 24 U.S. Companies. The Forum focused on an exchange of information and experience on US and China technology research and development program and lessons learned in policy development and technology development.
- Research staff for the Brightness Program attended an extended training session at NREL in May 2000. Delegates came from the central government, Jikedian Center for the Brightness Program and from Inner Mongolia, Xinjiang, Tibet and Gansu. The main purpose was to train these policy makers as they prepare and design the Brightness Program, which is the largest rural electrification program in China.

Outreach — A Web site at www.nrel.gov/china provides information on the U.S./China Bilateral Protocol as well as business and policy information for companies that are interested in the Chinese markets. This will be linked to a Chinese Web site that will provide information in the Chinese language.

5.2.2 The Netherlands/Shell Project

In 1998, the governments of Holland and China agreed in principle to support the Shell Solar Company in installing 60,000 home PV systems in Xinjing using hybrid loans—that is, Dutch government grants and government credit loans. To date, this project is the largest non-commercial foreign-aid activity in the PV field.

5.2.3 Eldorado Program

The Eldorado Program, which began in 1991 and ended in 1996, is a collaborative Sino-German science and technology project in rural areas of China. The project, which utilizes both PV and wind resources, supplies 400 families scattered throughout 15 townships and 19 villages in Jianchang County with electricity for lighting, radios, TVs, and water pumping.

The Sino-German demonstration project of PV home systems is located in Jianchang County, Liaoning Province. The demonstration consists of two parts: home PV systems and PV water pumping, which were put into operation in March 1997. Twenty-five kilowatts of multicrystalline silicon cell components were built for household use—100 sets of AC power systems with an installed capacity of 100 W each and 300 sets of DC power systems with a capacity of 50 W each. Two PV water-pumping systems were built, each with a capacity of 800 W.

5.2.4 World Bank/GEF Project

With financing of $35 million U.S. from GEF and $100 million U.S. from the World Bank, the project will:

- Construct 190 MW of on-grid wind power generation capacity, using the $100 million U.S. loans from the World Bank and the $10 million U.S. grants from GEF.

- Distribute 200,000 sets (10 MW) of PV home systems in remote areas of Qinghai, Gansu, Inner Mongolia, and Xinjiang using the remaining $20 million U.S. in grants from the GEF.

In the long term, this project is expected to develop a market for PV home systems, reduce the cost, and improve the quality of PV products. Products are distributed commercially—PV systems are sold to users by PV companies through their sales networks. The grants from GEF are only paid to the PV companies as a subsidy after the companies are certified as having provided users with good post-sales services on the products they sold. This differs from domestic and foreign assistance projects implemented before, in that PV companies gained direct subsidization if they reached stipulated sales targets. However, the shortcoming of that method is that post-sales service can't be guaranteed once the project is finished and no subsidization is available.

The project will start in early 1999 and will last for five years. At present, 17 companies have been selected for the World Bank projects. For a listing and description of these 17 companies, see Chapter 3 of this report.

5.2.5 United Nations Development Programme (UNDP) Project

In 1995, the UNDP and the Chinese government applied for GEF funds for a project to accelerate renewable energy commercialization. The objective of the project is to promote the commercial development of renewable energy in China, to overcome the barriers in this area, and to encourage enterprises and financial organizations to invest in renewable energy. The tasks include establishing a renewable energy industries association in China, promoting renewable energy, mobilizing competition, and creating an environment that encourages international and domestic enterprises, individuals, and other financing bodies to invest in renewable energy. A second objective is to develop some demonstration projects with aid from GEF/UNDP and foreign governments.

The project's total budget is $24 million U.S., of which $8.8 million is grants from the GEF, and $2.5 million and $3 million are bilateral government grants from The Netherlands and Australia, respectively. The project will install 3 wind/PV hybrid village systems in coastal islands and in western China where resources are suitable. The project was approved by the GEF, and formally started in March 1999. The project will continue for five years.

5.2.6 The United Nations Educational, Scientific, and Cultural Organization Project

In 1996, the China Science and Technology Society cooperated with the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in a project to "demonstrate solar schools in villages in China in the 21st century," initially selecting Lingxi Middle School in Mancheng County in Baoding of Hebei. The project was put into operation in June

1996. Jike Energy New Technology Company of the Energy Research Institute of SPC implemented the project.

Located at the foot of Taihang Mountain, 25 km northwest of Mancheng County of Baoding City, Hebei Province, the Lingxi Middle School is a junior school. The school is 1,790 square meters, with a staff of 582. The school's electricity supply is very limited.

The project has two parts: PV generation and solar thermal utilization. The PV generation is a stand-alone PV power station with a solar cell capacity of 4 kW_p and AC electricity from the power grid as a supplement. The solar thermal utilization is composed of three parts:

- Passive solar house. The total area is 160 square meters, the temperature inside the house stays at 8°–10°C during the day and above 0°C at night even on the coldest winter day.

- Solar bathroom. The bathroom is equipped with 10 square meters of solar thermal collector made of copper aluminum compound tubing and can service more than 20 people.

- Solar cooker. Two 2.4-square-meter solar cookers, each with a rated power of about 1,200 W, were installed to supply boiled water for the school.

5.3 PV Activity in the North and Northwest Regions

Qinghai, Xinjiang, Gansu, Inner Mongolia, and Tibet are rich in solar energy. However, at the moment, many counties and villages in these areas have no electricity; thus, PV technologies have a huge potential market demand.

5.3.1 Qinghai Province

5.3.1.1 General Situation

The province governs 6 autonomous prefectures, 1 district, 1 city at the district level, 2 cities at the county level, 30 counties, 7 autonomous counties, and 3 townships at the county level. The total population was 4.74 million in 1994 comprising several nationalities. The majority of the population (70.91%) is engaged in agriculture and animal husbandry. The average population density in the province is six people per square kilometer, 5.7% of that in the whole country. The population density in the Yusu and Guoluo regions is only 1.16 people per square kilometer.

Located on the Xizang plateau, the province is rich in solar energy due to specific climate conditions, such as high altitude (90% of the area is more than 3,000 m above sea level) thin and clear air, few clouds, and lots of sunshine. The annual sunshine is between 2,314 and 3,550 hours, and the radiation intensity is about 584.9 to 741.4 kJ per square centimeter, with an averaged value of 730 kJ per square centimeter.

The solar energy resource is high in the west and low in the east—690.8 kJ per square centimeter in Chaidamu Basin in the west, and 741 kJ per square centimeter in Lenghu Lake. According to China's classification, 80% of the area in the province belongs to the first category, and 20% belongs to the second category.

At the end of 1994, one county (Maduo) was without electricity. Among the 48 townships in the Yushu prefecture, 36 were without electricity. Households with electricity make up only 28.9% of the prefecture, and only 9.2% of the whole country. Among the 51 townships in the Guoluo prefecture, 40 were without electricity. Households with electricity make up 15.5% of the prefecture, and about 1.3% of the whole country. The situation is described in Table 5.1.

Table 5.1 People Without Electricity

	Total	Without Electricity
Number of counties	43	1
Number of townships	437	106
Number of administrative villages	4,110	870
Number of peasants/herdsmen families	630,700	113,500
Families of peasants	485,400	17,100
Families of herdsmen	145,300	96,500

In 1995, PV technologies were considered an important part of the “1995–2020 Development Program of Rural Electrification in Qinghai,” worked out by the Qinghai Power Bureau. An electrification fund is created by levying an additional 0.002 yuan/kWh in electricity. Approximately 900,000 yuan are returned to peasants and herdsmen each year for purchasing solar systems. On average, each system is subsidized with 300 yuan. The Qinghai Energy Research Institute is responsible for distributing solar systems, improving technologies, and providing technological service in the province. The fund uses about 500,000 yuan each year.

Supplying PV-generated electricity to 70,000 peasants and herdsmen in Qinghai Province is part of a government program to increase the standard of living of rural households at the poverty level by supplying them with electricity. 1.4 MW of home solar systems and 340 kW of stand-alone systems will be installed. Plans are to install systems in 23,000 homes by 2000 and 47,000 homes by 2010.

5.3.1.2 Village PV Stations

Since 1990, seven village PV demonstration stations have been built with a total installed capacity of 21.4 kW. These stations supply electricity for lighting, recorders, and TV sets, as well as for washing machines, butter-making machines, territory satellite receiving machines, township government offices, schools, hygiene offices, veterinarian offices, and shops. One objective of building these power stations is technological demonstration. Table 5.2 provides basic information on the seven stations.

Table 5.2 Basic Information on Seven Demonstration Stations

Station	Operation Time	Scale (W_p)	Load
Zhihema Township Tianjun County	Sept. 1990	420	Supply electricity for lighting, a color TV, and a set of acoustics for 34 families.
Zhouqiu Township Tianjun County	Aug. 1991	504	Supply electricity for lighting and a color TV for 48 families.
Qiuzhi Township Qumacai County	May 1993	544	Supply electricity for lighting for 45 families.

Wangjia Township Zeku County	July 1993	1,088	Supply electricity for 42 lamps, a color TV set, a recorder belonging to the township government, a primary school, hygiene office, shop, veterinarian station, and bank.
Garila Village Shinaihai Township Gonghe County	Sept. 1993	4,850	Supply electricity for 200 lamps, 50 color TV sets, and 7 washing machines for 68 families.
Shengge Township Tianjun County	June 1996	7,000	Supply electricity for 140 lamps, 45 TV sets, 5 recorders, 7 washing machines, and 1 territory satellite receiving machine.
Suli Township Tianjun County	Oct. 1996	7,000	Supply electricity for lamps, a recorder, the territory satellite belonging to the township government, a primary school, hygiene office, shop, veterinarian station, and bank.

Among these stations, the 5-kW PV station in Garila Village Shinaihai Township Gonghe County is a UNDP assistance project, and the 7-kW PV station in Shengge Township Tianjun County is an assistance project in cooperation with Finland.

Plans to construct PV stations in villages have begun in Qinghai province. In 1996 to 2000, seven village PV stations will be built (a 7-kW PV station in Tianjun county was built in 1997—see Table 5.2), and the total power will be 38 kW (see Table 5.3). In 2001 to 2010, 25 township stations will be built, with a total power of 144 kW.

Table 5.3 Plan of Village PV Station Construction

Name of County	Number of Stations	Power of Solar Systems (kW)	Expected Investment (000's yuan)
Tianjun	1	7	120
Gaduo	1	5	80
Angqian	1	5	80
Qumacai	2	2 x 5	160
Maqin	1	5	80
Qibian	1	6	100
Total	**7**	**38**	**620**

5.3.1.3 Residential PV Systems

After more than 10 years of development, the demand for solar home systems increases yearly, and a commercial market has been established in Qinghai Province. Since 1995, the demand for solar cells for domestic systems has been more than 100 kW_p, with annual sales of 6,000–10,000 yuan, and the annual production output of the PV industry reached 8-10 million yuan. The accumulated application of domestic PV systems was about 40,000 by the end of 1998, most of which are DC systems of 8, 10, 15, 20, and 38 W. There are also a few AC systems of 50 and 100 W.

At present, there are more than 10 companies engaged in producing PV systems in Qinghai, with an annual production capacity of more than 20,000 sets. The products are not only sold in Qinghai, but also in Tibet and Aba of Sichuan Province.

5.3.1.4 Other PV Applications

There are three PV water-pumping systems in the province. Two systems with water heads of 30 meters were installed in Gancha and Gonghe Counties; one floating pump with a 7-meter water head and a solar cell capacity of 186 W was installed in Xining City. There are nearly 30 electric fences powered by PV in rural areas. PV systems with total power of more than 300 kW are used in microwave relay stations, optical-cable communication stations, rural telephone stations, meteorological stations, and television relay stations.

5.3.2 Xinjiang, Uygur Autonomous Region

5.3.2.1 General Situation

The population in Xinjiang, Uygur, is more than 17 million. The Uygurs make up more than half, and the rest is composed of Hanzu, Kazak, Huizu, Kirgiz, Mongol, Russ, Xibe, Tajik, Uzbek, Tatar, Daur, and Manzu. The capital is Urumqi, which covers 5 autonomous prefectures, 8 districts, 2 cities at the district level, 14 cities at the county level, 65 counties, and 6 autonomous counties.

Xinjiang is located in a medium-latitude area. Theoretically, the radiation should be less than that in the southeast regions at a lower latitude. But, in fact, the radiation is fairly high owing to less clouds and precipitation, a good, clear atmosphere, and lots of sunshine. Annual sunshine there is 2,550–3,500 hours, and the yearly average is 60% to 80%. The annual solar radiation on the horizontal plane is $5 \times 10^9 – 6.5 \times 10^9$ joule per square meter, and the annual average value is 5.8×10^9 joule per square meter, ranking second after the Tibet Xizang plateau in China. By the end of 1996, there were 2 counties, 60 townships, 1,683 villages, and 5.64 million households (26.6 million people) without electricity.

5.3.2.2 PV Stations

There are four existing PV stations with a total installed capacity of 15.42 kW. One is 6 kW for post, one is 4 kW for school, one is 5 kW for seed sheep fields, and one is 420 W for schools in rural areas.

The development objective during the Ninth Five-Year Plan is to build 500 small stand-alone PV stations in rural areas and 3 PV power systems for lighting and television in villages and townships.

5.3.2.3 Residential PV Systems

To give peasants and herdsmen access to electricity as soon as possible and give them the ability to buy home PV systems, the government implemented a program to subsidize people that buy the system. The subsidization is 300 yuan per PV power generation set or 10% of the purchase price of a PV system. So far, the number of PV systems throughout the region is almost 13,000. Most of them are 10-20-W DC systems. Most of the solar cells used are monocrystalline and polycrystalline silicon cells, and there are also some 20-W amorphous silicon cells.

In order to improve the development of the PV market in China, the French World Energy Funds Association donated 200,000 francs in 1995 and 1996 to build demonstration systems for village lighting and television in three places.

In addition, a project to mobilize the PV solar home system market was recently initiated cooperatively by the Xinjiang Autonomous Region and the Netherlands Shell Corporation. It has been approved by State Development Planning Commission (SDPC) and will be started soon. The project will install 70000 sets of 25W PV home systems and 8000 sets of 50 W PV systems. The total solar cells used will be 2.15 MW. The total budget is $25 million U.S. Assistance from the Netherlands will be $15 million (60% of the total), and Xinjiang will raise $10 million (40%). The project will be completed in 2000.

5.3.2.4 Other PV Applications

There are about 200 kW of PV systems used in cathodic protection of oil and natural gas pipelines. Along with the oil and natural gas development and international cooperation with the lateral countries, the demand for PV systems is expected to increase greatly.

Currently, there are more than 300 kW of PV systems used for communication; 100 kW is used for railway signals, railway communications, and various other applications. With the construction of the Nanjiang Railway, the need for PV systems will increase greatly.

Xinjiang will be a potential market for PV water-pumping systems; it currently has several demonstration systems. This market should be developed further.

5.3.3 Gansu Province

5.3.3.1 General Situation

The population of Gansu is 21.36 million; it comprises the following nationalities: Hanzu, Huizu, Zangzu, Dongxiang, Yugur, Bonan, Mongol, Kazak, Tuzu, Salar, and Manzu. The province has 2 autonomous prefectures, 7 districts, 5 cities at the district level, 8 cities at the county level, 60 counties, and 7 autonomous counties.

Gansu is surrounded by Xinjiang, Inner Mongolia, Xizang, and the Loess Plateau. Most of the area is over 1,000 meters above sea level. The weather ranges from monsoons in the southeast, arid conditions inland and high altitude and cold weather in Xizang. The atmospheric temperature and precipitation differ greatly in the different regions. The frost-free period is about four to seven months, and the annual precipitation is 40–800 millimeters. The precipitation in the Hexi Corridor is very low.

The solar energy in Gansu Province is fairly abundant. In the north, the annual sunshine is 3,200–3,300 hours, the annual radiation is 6,680–8,400 MJ per square meter; in the middle regions, it is 3,000–3,200 hours and 5,852–6,680 MJ per square meter; and in the southeast, it is 2,200-3,000 hours and 5,016–5,852 MJ per square meter.

5.3.3.2 Residential PV Systems

So far, there are about 400,000 peasant and herdsman households and 2 million people with no electricity. The province plans to distribute PV systems to 100,000 peasant and herdsman households by 2000, and to 140,000 households by 2010. Currently, there are more than 8,000 installed domestic PV systems. Most of them are 8–20-W DC systems, with a few 50-100-W AC systems. Through local financial support and PV funds, a 300-yuan subsidization per set is given to the families if they buy a PV system.

Gansu is the only province using bank credit to distribute domestic PV systems. The users may borrow money at a low interest rate (4%) to pay for a home PV system. The difference between this low interest and normal interest is paid by a fund raised by the provincial power company by adding 3 yuan/MWh to the electricity price.

A $500,000 U.S. grant from the DOE and 1.5 million RMB allocation from China, totaling 5.6 million RMB, ($675,000 U.S.) have been set aside for funding of domestic PV systems. In cooperation with SELF, Gansu Province demonstrated a home lighting project in Majiacha village using revolving credits.

5.3.3.3 PV Stations

There are two PV stations in Gansu. One is 10 kW, and the other is 4 kW. To supply electricity to townships and villages, small (4–10 kW) stand-alone power stations will be developed in the future.

5.3.3.4 Other PV Applications

By the end of 1998, there were more than 50 rural telephone stations powered by PV systems with a total power of more than 50 kW. PV sources for rural communications will develop rapidly in the future.

Based on solar heating demonstrations, the Gansu Natural Energy Resource Research Institute founded a PV technology training center to train qualified personnel for undeveloped countries. The training center is located in Lanzhou.

5.3.4 Inner Mongolia Autonomous Region

5.3.4.1 General Situation

The population of Inner Mongolia is 20.83 million people, with nationalities of Mongol, Hanzu, Daur, Ewenki, and Oroqen. One-ninth of the total population is Mongol. There are 8 leagues, 4 cities at the district level, 13 cities at the county level, 51 banners, 3 autonomous banners, and 17 counties in the region.

Inner Mongolia has a monsoon climate, which can be summarized as follows:

- The temperature goes up as you travel from northeast to southwest, while the precipitation does the opposite. There is less precipitation in the high-temperature areas and more precipitation in the low-temperature areas.

- The precipitation occurs mainly in the summer (about 60% to 75% of the year-round total).

- The total annual precipitation is 50–450 millimeters. Droughts happen almost every year.

- Winter is long, and the frost-free period is short. The lowest temperature in the region is below -40 °C. The winter can last as long as five months; in some regions, it lasts for up to seven months.

- Sunshine in most areas is more than 2,700 hours per year and can be as high as 3,400 hours in the west Alasan Plateau. The radiation in the region is 4,750–6,250 MJ per square meter per year.

- Wind energy is plentiful, especially in the winter and spring. According to preliminary estimates, the wind energy is about 310 million kW in the region, 250 million kW (81%) of which is in rural areas.

Mostly in rural areas, there are about 400,000 homes (2 million people) with no electricity. Inner Mongolia has 24 pure pastoral banners (cities) and 19 semi-agricultural and semi-rural banners (cities). Rural areas cover 910,000 square kilometers, accounting for 78.7% of the total area of the region, and are the important regions in which to develop new energy.

5.3.4.2 Activities

Inner Mongolia started the “Economic Assisting Method for Small Wind Turbines and Silicon Solar Cells” in 1986. From 1986 to 1996, the government allocated a total subsidization of 25 million yuan, (an average of 2.5 million each year) to small wind turbine and PV systems. Families buying a 100-W wind power system or a 16-W home PV system can get a 200-yuan subsidy. Each year, 300,000 yuan is allocated to the research of new energy technology. Organizations involved in distributing renewable energy technologies were founded in 56 banners, forming a service network from banner to township to village to provide installation, adjustment, repair, and consultation to users.

5.3.4.3 PV Stations

By 1997, there were 16 small stand-alone PV stations with a total power of 100 kW. In March 1998, a 4-kW PV station for schools was built through Sino-Japanese cooperation.

Since 1994, the Huade New Technology Company of Inner Mongolia has built more than 20 hybrid stations of 300-W wind/100-W PV in Xilinguole League, Wulanchabu League, and Bayanzuor League. In the future, PV stations for schools and wind/PV hybrid systems for townships and villages will be widely used.

5.3.4.4 Residential PV Systems

About 20,000 systems (mostly 16–20-W DC systems and a few 50–100-W AC systems) are now in use.

The Science and Technology Commission of the autonomous region, in cooperation with DOE, is demonstrating 240 sets of home PV/Wind hybrid power systems. The capacity of such systems is 150 - 500 W_p and can supply electricity to families for lighting, color TV, and even washing machines.

5.3.4.5 Other PV Applications

Inner Mongolia is first with respect to the application of PV power sources in rural communication. But there are still more than 250 township post offices and communication branches with no electricity. The Inner Mongolian prairie is also a very promising market for PV water pumps.

5.3.5 Tibet Autonomous Region

5.3.5.1 General Situation

The Tibet Autonomous Region has the smallest population density of any region in China—only 1.7 people per square meter. There are 26 nationalities in the region, including Zangzu, Hanzu, Monba, Lhoba, Huizu, Mongol, and Uygur. More than 90% of the total population is Zangzu. There are 6 districts, 1 city at the district level, 1 city at the county level, and 76 counties.

Xizang Plateau is the highest place in China—19.7% of the total area is more than 5,500 m above sea level; 6% is 5,000–5,500 m; 32.1% is 4,500–5,000 m; 8.4% is 4,000–4,500 m; 6% is 3,500–4,000 m; 2.4% is 3,000–3,500 m; 1.2% is 2,500–3,000 m; and 4.3% is below 2,500 m.

The climate in Tibet is characterized by:

- Thin air—Lhasa, the capital city of Tibet, at a height of 3,658 m above sea level, has an air density of 810 g per cubic meter and a barometric pressure of 652 millibars.

- Strong radiation and sunshine—In addition to thin air, Tibet also has less dust and vapor, so the atmosphere is very clear. Energy loss of sunlight through the atmospheric layer is very small. The radiation in Lhasa is 195 kcal per square centimeter per year, while it is just 88.6 kcal and 113 kcal in Chengdu and Shanghai, respectively. (Both are located at a similar latitude.) The total annual sunshine on the plateau is much higher than that in regions of similar latitude. In Lhasa, it is

3,021 hours, while in Chengdu and Shanghai, it is 1,186.8 and 1,932.5 hours, respectively.

- With its high elevation, Tibet's temperature is very low. The annual average temperature in Lhasa is only 7.5°C; the average temperature in July—the hottest month—is 15.1°C. In most areas of the plateau in northern Tibet, the temperature in July is less than 8°C. The temperature in Tibet is characterized by small annual differences and large daily differences. The annual temperature difference is 18°-20°C and the daily difference is 14°-16°C in Lhasa, Changdu, and Rikaze. The daily temperature difference on some days reaches 18.2°C. In Lhasa and Rikaze, the temperature in June can be as high as 27°-29°C at noon and drop to 0°–5°C at night.

- The weather can be divided clearly into a dry season and a rainy season, but the seasonal precipitation is very uneven. From October to April, the Tibetan plateau is controlled by a west wind that is dry, windy, and cold. From May to September, the plateau is controlled by a hot southwesterly monsoon. Ninety-seven percent of the annual precipitation occurs during this period. In southern Tibet, 80% of the total precipitation occurs at night. On the northern plateau, thunderstorms and hailstorms occur frequently. In Tibet, hailstorms occur, on average, 35 days a year. In 1954, there were 64 hailstorm days, a very rare occurrence.

For the past 10 years, under the guidance of the "Tibet Sunshine Program" (the first provincial and regional program in China), the Tibet Autonomous Region has actively developed PV programs and made great progress. These PV programs play important roles in supplying electricity, communications, broadcasts, and television for the Zangzu herdsmen.

5.3.5.2 PV Stations

By the end of 1998, seven small stand-alone PV stations were built with a total installed capacity of 420 kW. These PV stations supplies the electricity for seven no-electricity county without any hydropower resoures. The seven PV stations are:

- Anduo PV station in Naqu region with 100 kW installed capacity
- Gaize PV station in Ali region with 80 kW installed capacity
- Bange PV station in Naqu regions with 70 kW installed capacity
- Double Lake PV station in Naqu region with 25 kW installed capacity
- Cuoqin PV station in Ali region with 40 kW installed capacity
- Nima PV station in Naqu region with 55 kW installed capacity
- Geji PV station in Ali region with 50 kW installed capacity.

The plan is to build new PV power stations and extend county PV stations in Naqu and Ali region in 1999. By then, the total installed capacity will exceed 100 kW.

The county PV stations play important roles to supply the electricity for resident use and office use. General, the PV stations have substituted the diesel engine stations.

More small stand-alone PV stations should be built in Tibet in the future. The capacity is generally 3–5 kW for small stand-alone PV stations and 6–8 kW for big ones. On August 10, 1998, a 4-kW wind/PV hybrid station was put into operation in Nase village, Anduo County, Naqu Region, where the elevation is 4,800 m above sea level.

The market potentials of standalone PV stations are very large, especially for villages, schools and hospitals. There are about 100000 villages without electricity, mainly concentrated in the northwest of China, the potential demand is about 200 – 500 MW. The concentrated PV stations, which manages by special persons, have low trouble rate and high operation quality, charge on the electricity meter, and the return of investment could be guaranteed. It’s estimated that 10000 to 20000 standalone PV stations with 50 MW installed capacity will be built before 2010.

5.3.5.3 Power Sources for Communication

Presently, there are more than 200 kW of PV cells used in microwave relay stations in Tibet. Nearly 100 kW of PV cells are used in the 600-km Lanxila optical-cable communication project. Communication construction will develop rapidly in 1999–2000, so the need for PV cells will also increase.

5.3.5.4 Power Sources for Television

More than 20 satellite television receiving and transferring stations and television relay stations are powered by about 20 kW of PV cells in Shiquan River, Gaize, and the Mentu Coal Mine.

Harbin-Chronar Solar Power Company signed a contract with the Tibet Broadcast and Television Office to provide 100 PV systems for radio and television broadcasts in 1996. The contract has been finished. The technical indexes of the PV power system are:

- Amorphous silicon solar cell array: 140 W_p
- Cd-Ni battery groups: 12 V, 100 Ah
- Controller/inverter integrated machine: overcharging and over-discharging protection; 220 V, 50 Hz in inverter side; square-wave and output power 220 W; inverter efficiency 90%
- Load capacity: 200 W
- Daily working hours: 6 hours.

5.3.5.5 PV Water Pumps

To irrigate grasslands, the demand for PV water-pumping systems is large. For demonstration purposes, Shanxi province has set up three PV water-pumping systems, each with a capacity of 900 W_p in Ritu, Shiquan River, and Gaize in the Ali Region.

5.3.5.6 Residential PV Power Systems

There are approximately 20,000 PV systems used in Tibet, 13,000 of them in the Ali Region. Most of the systems are 8–10-W portable systems, with a few above 30 W. The Electric

Engineering Institute of the Science Academy of China implemented a village demonstration project in Sangdeqing Village, Changzhu Township, Shannan Region to install 40-W_p PV solar cells in 25 homes.

5.3.5.7 PV Stations for Schools in Rural Areas

There are more than 600 schools without electricity in Tibet. During the second phase of the Sino-Japanese cooperation project—" Research and Demonstration of School PV Stations in Remote Areas"—a 6-kW_p PV demonstration station will be built by May 1999.

6. Suggestions for Commercialization of PV Technology

As an important part of the new energy scenario in China, PV is an up-and-coming technology. The practice of other countries indicates that the development and commercialization of PV technologies is impossible without government support. In order to promote and accelerate the development and commercialization of new energy technologies, including PV, the United States, Japan, Germany, and other developed countries have taken some powerful measures. These include national programs and plans implemented with the aid of large amounts of R&D capital. Preferential policies to PV enterprises, such as exemption from taxes have been implemented. Users purchasing PV equipment within a certain period are eligible for subsidization and loans, which encourages the public to make use of PV equipment. The governments of some developing countries, such as India, are developing PV programs as well, and much money is being invested in R&D and demonstration. The government's support is an important reason for the rapid development of PV technologies in India. Although there are programs and supporting policies in China, and although there is local financial subsidization in some provinces and autonomous regions, there are still a lot of problems. The programs are so sketchy they are difficult to carry out. The capital sources are uncertain, little capital is used for R&D and demonstration, and the effects are weakened by being decentralized. Preferential policies for PV companies are not as numerous, and they are not standardized; subsidization and loan policies to users are incomplete, irregular, and the amount is small.

To accelerate the commercialized development process of PV technologies, the following suggestions are given according to foreign experience and domestic practice.

1. Under the lead of the State Council, form a united, authorized national group of new energy technology development and commercialization. This group will be responsible for formulating policies, organizing, coordinating, raising capital, and distributing new energy technology projects. This group will unite the power of the SETC, the Ministry of Science and Technology (MOST), the Ministry of Agriculture, and the State Power Corporation.

2. Formulate a detailed, practical "Seven-Year Plan for the Development and Commercialization of PV Technologies in 1999–2005." This plan should have objectives, projects, contents, requirements, capital sources, and measurements.

3. More support should be given to the development and commercialization of PV technologies through the "S-863 Program," "Torch Program," "Tackling Program of Key Science and Technology Projects," "Research Program of Fundamental Science," "The State Natural Science Funds," and others. More research tasks and demonstration projects should also be listed in these programs.

4. Increase the PV R&D capital and strengthen the management of R&D. As a developing country, China cannot contribute as much capital to the R&D of PV technologies as developed countries can. So it is very important to make full use of the limited capital. It should be made clear that the capital funds used for R&D are to be used for achievement, not to pay tuition fees, and to establish a competitive mechanism to encourage research on PV technologies. More practical work should be done to accelerate the commercialization of PV technology and catch up to the international level.

5. Establish basic standards, specifications, and technological requirements as soon as possible. Establish several state-authorized product-testing centers to ensure the quality of the products and strengthen the quality testing and technology inspection of PV systems and their components. Standardize and strictly supervise the PV market to prohibit the inflow of fake, low-quality products.

6. Distribute PV technologies and popularize the knowledge and use of PV. Help the public understand PV and be willing to take part in spreading the technology by taking advantage of popular education and science media such as television, cinema, broadcast, newspaper, magazines, books and internet access.

7. Find a subsidization method to enable people in poor areas to purchase PV equipment to meet basic electricity demands. This subsidization can come from the National Poverty Alleviation Program.

8. Through technological reform funds such as the "Double Push Project," give technological projects of PV companies preferential low-interest or discounted loans.

9. The state can support PV companies with a tax policy that would exempt or reduce the value-added tax (VAT) and income tax during a certain period.

10. Encourage competition within the PV industry, by encouraging PV companies that are strong both technologically and economically and can produce PV components as well as PV application systems with a production ability of 3–5 MW. This would increase the production scale and decrease the cost of the products. This encouragement could take several forms: large enterprise groups can annex small existing PV companies or invest in smaller companies (and hold most of the shares); undertake joint ventures with foreign companies; or unify and reorganize domestic PV companies.

11. An important developing tendency in the commercialization and application of PV technology is to connect PV systems to the power grid or integrate them into buildings. To catch up to the rest of the market, it is suggested that China invest in some demonstration projects to gain experience and perfect the technology. The state should give a 40%–50% subsidization to PV projects that are on-grid or integrated with buildings, which should encourage activity in this area.

12. Raising capital is an important part of accelerating the development and commercialization process of PV technologies. According to domestic and foreign experiences, it is suggested that "funds for the development and commercialization of PV technologies in China" should be established by adding 0.001 yuan per kWh to the price of power. If the power output in 2000 is 1.4 billion MWh, the annual funds raised will be 1.4 billion yuan. In five years, it will be 7 billion yuan.

13. The above two measures are just means of starting the commercialization of PV technologies, and are only supplementary steps for the state to establish the demand and

market. Excessive use of these measures may lead to unreasonable markets and dependence on the state, and give the profits to foreign companies. Healthy development will depend on the economic competition, quality, and service of domestic products, not on subsidization.

14. Develop and improve the scientific and manufacturing aspects of Chinese PV technology by means of international cooperation and technological interchange. This method is effective and requires a very small investment. It can help promote and accelerate the commercialized development of PV technologies in China.

15. Take advantage of the economic and technological assistance of international organizations, foreign governments, and foreign companies, as well as any experimental demonstrations of PV applications. This will open up the application and marketing of PV and promote commercialized development.

7. Appendix

7.1 Appendix Table

7.1.1 Seven Solar Regions in China

Region	Range	Annual Total Radiation KWh/m^2/yr	Conditions to Use Solar Energy
Northeast	Three provinces in Northeast	1,393–1,509	The winter is 4–5 months long, with low temperatures and low radiation intensity, fewer clouds, and more sun. Total radiation is more than 2,400 h/a.
North China	North China plain	1,509–1,626	The winter is shorter than in the northeast—about 100 days long. The temperature and radiation intensity is also higher. Total radiation hours are about 2,600–2,800 h/a.
Loess hills	Inner Mongolia plateau	1,5091,742	The winter is 3–5 months long. The terrain is higher, so the radiation intensity is high, about 2,600–3,200 h/a. The conditions are better than in North China.
Northwest arid regions	Xinjiang, northwest of Gansu, north of Ningxia, west of Inner Mongolia	1,626–1,856	It is dry, with fewer clouds. Total radiation is 3,200 h/a. The temperature is low on average, but with large fluctuations. Wind speed is high, and a lot of sand is blown around. Visibility is often poor.
South	South of north latitude 33°, including Taiwan, Hainan Island	1,161– 1,393	The temperature is high, but there are more clouds and more overcast and rainy days. Total radiation is about 2,200 h/a. The radiation intensity is high, but the amount is less.
Southwest	Sichuan, Guizhou, Yunnan	929–1,161	More cloudy, overcast, and rainy days. Total radiation is less than 1,400 h/a. This region has the worst conditions to use solar energy. However, the conditions are good in west Sichuan, and west Yunnan.
Xizang plateau	Xizang plateau	> 1,856	High elevation, with an atmosphere that is clear and thin. The radiation intensity is the highest. Total radiation is 3,000–3,200 h/a. This region has the best conditions to use solar energy.

7.1.2 *Monthly Average Radiation (kWh/m^2/month) and Annual Total Radiation (kWh/m^2/year) in China, in 1961-1977*

City	Radiation Type	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Harbin	Scattering	24.6	31.3	47.8	59.9	69.9	70.6	70.3	60.0	42.8	31.7	22.9	20.7	553.8
	Direct	28.9	42.5	67.9	77.0	88.3	94.6	81.5	79.0	74.85	55.1	32.5	23.7	746.0
	Total	53.5	73.8	115.8	136.9	158.2	165.2	151.8	139.0	117.7	86.8	55.5	44.4	1299.8
Shenyang	Scattering	28.2	35.7	51.8	63.3	73.6	72.5	73.6	63.4	48.2	36.0	26.5	25.0	597.8
	Direct	33.6	48.7	76.9	89.3	104.6	93.3	73.6	77.2	81.6	63.3	38.2	29.6	809.8
	Total	61.9	84.4	128.7	152.6	178.2	165.8	147.1	140.6	129.8	99.3	64.7	54.6	1407.5
Beijing	Scattering	33.4	40.9	62.0	76.8	86.0	76.0	79.8	69.5	53.4	42.7	79.4	30.1	683.7
	Direct	45.7	54.0	79.4	81.0	108.1	110.4	82.5	81.8	84.7	67.6	44.3	38.3	877.5
	Total	79.1	94.9	141.4	157.8	194.2	186.4	162.3	151.3	138.1	110.3	123.6	68.4	1561.1
Huhehaote	Scattering	34.8	38.3	59.5	75.8	84.3	82.1	76.6	61.2	52.8	39.8	32.7	28.1	665.3
	Direct	45.9	63.0	84.5	85.7	111.7	124.0	112.8	114.4	98.0	80.6	48.7	44.3	1012.9
	Total	80.6	101.3	142.0	161.5	196.0	206.1	189.4	175.5	150.9	120.4	81.5	72.4	1678.2
Urumqi	Scattering	25.8	33.6	51.7	60.6	71.8	62.3	56.7	50.1	40.7	32.2	23.9	20.5	529.8
	Direct	29.5	42.3	63.4	88.5	115.1	124.5	136.5	124.4	96.0	68.3	34.4	20.1	943.7
	Total	55.3	75.9	115.1	149.1	186.9	186.8	193.2	174.5	136.8	100.4	58.3	40.6	1473.5
Xining	Scattering	36.3	47.1	73.2	83.8	88.4	79.4	73.2	62.7	56.9	91.2	35.4	32.4	713.5
	Direct	59.4	63.1	76.4	85.0	100.8	112.6	112.9	115.3	75.3	74.8	62.2	55.4	992.9
	Total	95.7	110.3	149.7	168.8	189.2	192.0	186.1	177.9	132.1	166.1	97.6	87.8	1706.4
Lanzhou	Scattering	41.2	50.6	75.2	85.2	93.7	84.3	76.4	66.6	60.1	50.4	42.3	38.4	764.3
	Direct	28.1	38.7	52.1	66.9	86.2	100.1	102.4	98.9	58.9	54.9	35.4	24.9	759.2
	Total	69.2	89.3	127.4	152.1	179.9	184.4	178.8	165.6	119.0	105.3	77.8	63.3	1511.9

7.1.2 Monthly Average Radiation (kWh/m²/month) and Annual Total Radiation (kWh/m²/year) in China, in 1961-1977 (continued)

City	Radiation Type	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Xi'an	Scattering	40.5	45.6	65.5	74.3	79.5	80.2	75.1	66.8	52.6	45.4	38.1	36.5	700.1
	Direct	27.9	28.9	39.4	46.7	66.6	84.0	87.3	92.7	47.0	37.6	29.6	26.3	613.9
	Total	68.4	74.5	104.9	121.0	146.1	164.2	162.4	159.5	99.6	83.0	67.8	62.8	1314.0
Shanghai	Scattering	35.6	38.2	54.3	60.3	70.6	73.6	70.6	64.6	58.1	48.0	37.8	32.2	644.8
	Direct	37.6	39.9	51.5	52.6	60.6	54.5	95.0	98.1	51.6	50.2	41.2	36.8	668.9
	Total	73.1	78.1	105.8	112.9	131.2	128.1	165.5	162.7	109.8	98.1	79.0	69.0	1313.7
Nanchang	Scattering	39.1	40.2	53.0	61.1	71.6	75.3	68.1	65.2	63.2	53.9	40.7	36.2	667.4
	Direct	31.8	30.2	35.7	40.9	53.3	55.0	109.0	111.6	77.3	55.7	44.4	34.6	679.4
	Total	70.9	70.4	88.7	102.0	124.8	130.3	177.1	176.8	140.5	109.6	85.1	70.7	1346.8
Fuzhou	Scattering	33.7	35.2	48.9	58.5	62.8	59.4	62.2	61.6	53.4	45.9	38.3	33.1	593.0
	Direct	39.3	32.7	42.8	46.3	46.6	53.4	97.1	88.7	65.2	49.1	36.4	34.7	632.2
	Total	73.0	67.9	91.7	104.7	109.4	112.8	159.2	150.3	118.7	95.0	74.6	67.8	1225.2
Guangdong	Scattering	41.7	42.5	53.6	61.4	71.7	72.3	71.8	68.8	62.9	54.5	44.6	41.7	687.6
	Direct	44.2	26.4	27.6	22.7	40.4	38.8	62.1	61.9	58.4	66.6	59.0	48.2	556.3
	Total	85.8	69.0	81.2	84.1	112.1	111.1	133.9	130.7	121.3	121.1	103.7	89.9	1243.9
Guiyang	Scattering	32.6	36.5	55.5	62.2	70.7	67.6	76.4	70.1	57.6	45.2	34.7	32.3	641.3
	Direct	14.9	19.6	31.4	42.3	37.6	37.3	58.2	61.0	44.0	28.2	23.3	16.0	413.7
	Total	47.4	56.1	87.0	104.5	108.4	104.9	134.6	131.1	101.6	73.3	58.0	48.4	1055.0
Kunming	Scattering	32.6	33.6	51.3	64.2	67.3	72.1	72.2	71.6	59.9	50.5	36.6	31.7	643.4
	Direct	77.4	87.6	104.7	98.2	76.4	43.9	46.6	45.1	50.2	44.0	53.6	68.8	796.2
	Total	110.0	121.2	156.0	162.1	143.7	116.0	118.8	116.7	110.1	94.5	90.2	100.5	1439.7
Lhasa	Scattering	30.5	40.4	66.7	73.9	73.2	73.2	85.9	82.8	61.3	36.1	26.7	25.2	671.6
	Direct	113.2	108.0	125.0	119.6	155.7	150.5	129.4	116.2	118.7	146.4	124.1	112.6	1519.0
	Total	143.7	148.5	191.6	193.5	228.8	223.6	215.4	199.0	180.0	182.5	150.8	137.8	2190.5

7.1.3 Annual Average Sunshine, and Relative Sunshine of 19 Cities in Seven Chinese Provinces

Area		Northeast Area			Inner Mongolia and Xijiang			Huanghe River Valley			Changjiang River Valley			South China			Yunnan Plateau and Traverse Mountain Area		Qinghai-Tibet Plateau	
City		Changchun	Shenyang	Dalian	Xilinhaote	Urumqi	Hami	Beijing	Taiyuan	Jinan	Shanghai	Wuhan	Chengdu	Fuzhou	Guangzhou	Kanding	Kunming	Xining	Changdu	Lhasa
Sunshine	Average sunshine hours/year	2739.9	2642.8	2739.6	2882.8	2802.8	3205.8	2700.0	2800.9	2668.0	1885.2	1958.0	1152.2	1850.2	1891.0	1727.2	2527.0	2647.3	2262.4	2982.8
	Relative sunshine	62%	58%	62%	65%	63%	75%	61%	64%	60%	43%	45%	26%	41.7%	43%	39%	57%	61%	52%	68%

7.1.4 Location, Annual Sunshine Time, and Annual Sunshine Rate in Key Chinese Cities

City	**Location**		**Annual sunshine time (Hours)**	**Annual sunshine rate (%)**	**City**	**Location**		**Annual sunshine time (Hours)**	**Annual sunshine rate (%)**	**City**	**Location**		**Annual sunshine time (Hours)**	**Annual sunshine rate (%)**
	North latitude	East longitude				North latitude	East longitude				North latitude	East longitude		
Manzhouli	49°35´	117°26´	2,750.5	62	Dalian	38°54´		2804.1	63	Wuhai	30°38´	114°17´	1,967	45
Hailaer	49°13´	119°45´	2,763.1	62	Baoding	38°53´	115°34´	2678.1	60	Hangzhou	30°20´	120°10´	1,902	43
Qiqihaer	47°20´	123°56´	2,902.9	65	Yingchuan	38°25´	106°16´	3022.1	68	Ningbo	29°54´	121°32´	2,020	46
Harbin	45°45´	126°38´	2,636.1	59	Shijiazhuang	38°04´	114°26´	2664	60	Lhasa	29°43´	91°02´	3,005	68
Changchun	43°32´	125°20´	2,653.4	61	Taiyuan	37°55´	112°34´	2756	67	Chongqing	29°30´	106°33´	1,258	28
Urumuqi	43°47´	87°37´	2,802.7	63	Jinan	36°41´	116°58´	2776	63	Nanchang	28°40´	115°58´	1,968	44
Sipin	43°11´	124°20´	2,751.8	63	Xining	36°35´	101°55´	2670	61	Changsa	28°15´	112°50´	1,815	41
Tulufan	42°58´	89°14´	3,126.9	70	Yan'an	36°34´		2373	54	Zunyi	27°41´	106°55´	1,237	28
Hami	42°50´	93°27´	3,310.4	75	Qingdao	36°04´	120°19´	2500	57	Hengyang	26°58´	112°30´	1,711	39
Fushun	41°50´		2,532.2	57	Lanzhou	36°01´	103°59´	2571	58	Guiyang	26°34´	106°42´	1,404	32
Shenyang	41°46´	123°26´	2,546.9	57	Kaifeng	34°50´	114°20´	2328	53	Fuzhou	26°05´	119°18´	1,860	43
Jingzhou	41°08´		2,761.7	62	Zhenzhou	34°43´	113°39´	2451	55	Guilin	25°15´	110°10´	1,676	38
Anshan	41°07´		2,535.5	57	Luoyang	34°40´	112°30´	2247	51	Jilong	25°09´	121°45´	1,370	31
Zhangjiakou	40°50´	115°15´	2,832.1	65	Xuzhou	34°19´	117°22´	2400	54	Kunming	25°02´	102°43´	2,522	57
Huhehaote	40°90´	111°41´	2,906.7	67	Baoji	34°16´	106°58´	1758	44	Xiamen	24°27´	118°04´	2,239	51
Yumen	40°16´	97°11´	3,216.4	73	Xi'an	34°15´	108°55´	1966	44	Guangzhou	23°00´	113°13´	1,951	44
Datong	49°00´	113°18´	2,855.8	64	Bangbu	32°56´	117°27´	2179	49	Nanning	22°48´	108°18´	1,843	41
Beijing	39°57´	116°11´	2,763.7	63	Nanjing	32°04´	118°47´	2182	49	Hengchun	22°00´	120°45´	2,396	54
Tangshan	39°40´	119°07´	2,656.2	60	Hefei	31°35´	117°15´	2287.9	51	Zhanjiang	21°02´	110°28´	1,983	45
Tianjing	39°06´	117°10´	2,850.3	64	Shanghai	31°12´	121°26´	1986	45	Dongshadao	20°42´	116°43´	1,745	39
Zhangye	38°56´	100°37´	3,026.7	68	Chengdu	30°40´	104°04´	1211	27					

7.1.5 Annual Radiation in Key Cities of the World

City	Annual Radiation ($kWh/m^2/yr$)	City	Annual Radiation ($kWh/m^2/yr$)
Helsinki	918	Milan	1,244
Stockholm	988	Venice	1,337
Moscow	1,034	Bucharest	1,430
Hamburg	953	Sofia	1,522
Potsdam	1046	Lisbon	1,918
Warsaw	976	Athens	1,615
London	1,011	Tokyo	1,174
Prague	1,011	Fushan	1,325
Paris	1,116	New York	1,313
Vienna	1,081	Washington	1,453
Budapest	976	Singapore	1,592

7.1.6 List of PV Companies

	Company Name	Address	Characteristics	Telephone	Fax	E-mail	Post Code
1	Inner Mongolia Huade New Technology Company	No. 506 Zhaowu Road, Hohut, Inner Mongolia	State owned	(0471) 4913805 4962211-219 013804710357	(0471) 4968471	Huadecom@public.hh.nm.cn	010010
2	Inner Mongolia Huanyu Wind and Solar Energy Company	No. 38 Sinsinglu, Chengguanzhen, Shangdu County, Inner Mongolia	State owned	(0474) 6901231 (0474) 9062918	(0474) 6902461	Lizzg@mail.impu.edu.cn	013450
3	Gansu Zhongxing Electronics Manufacture	No. 150 Majiazhuang, Anning Qu, Lanzhou	State owned	(0931) 7675754	(0931) 7675735	Gnery@sun20.gsinfo.sti.ac.cn	730070
4	Gansu Genaiyong Solar Energy Power Company	No.177 Dingxi Nanlu, Lanzhou	Limited company	(0931) 8619562 8616615-2061	(0931) 8616243		730000
5	Gansu Lanxing Wireless Equipment Company	No.1681 Donggang Donglu, Lanzhou	Collective owned	(0931) 8497615-180	(0931) 8497530		730020
6	Gansu Solar PV Company	No.12 Nanchang Road, Lanzhou	Joint venture	(0931) 8842317	(0931) 8616405		730000
7	Qinghai Solar PV Company	No. 22 Wusi xilu, Xigning	Stock company	(0971) 6154741 6154763	(0971) 6135523		810008
8	Qinghai Xining Tianpu Solar Energy and Technological Co. Ltd.	No. 14 Hutai E. Lane, Xining	Stock company	(0971) 6107969 013909717834	(0971) 8215430		810008
9	Qinghai Xining New Energy Development Company	No. 26 Yongjunxiang, Xining	Stock company	(0971) 8141965 (0971) 9009954	(0971) 8214416		810007
10	Qinghai Xining Dawa Solar Energy Company	No.12-1 Changjiang Road, Xining	Stock company	(0971) 8213315 013909783564	(0971) 8213315		810000
11	Qinghai Xining Solar Energy Development Center	No. 4 Weboxiang, Xining	Stock company	(0971) 6139601 013909785308			810001
12	Qinghai Xining Gesun Solar Energy Co. Ltd. (Qinghai Xining Gesun Solar Energy Company)	No. 12-1 Changjiang Road, Xining	Limited company	(0971) 6130963 8246514 013909717935	(0971) 8246514		810000
13	Xinjiang Solar Energy Development Company	No. 40 Beijing South Road, Urumqi	State owned	(0971) 3855922	(0971) 3835920		830011
14	Xinjiang Wind Energy Company	No.19 Heilongjiang Road, Urumqi	State owned	(0991) 3714095 013909924572	(0991) 5816456	Xjwind@public.wl.xj.cn	830000
15	Xinjiang Lida New Energy Electronic Co. Ltd (Xinjiang Urumqi Lida Satellite TV Receiver Equipment Company)	No.12-6 Tuanjie Road, Urumqi		(0991) 2864425	(0991) 2867449		830001
16	Xinjiang Urumqi Solar Energy Engineering Company	No.2 Shengli Road, Urumqi	State owned	(0991) 2866602	(0991) 2862274		830001
17	Beijing Jike Energy New Technology Company	No.25 Qinghua Donglu, Beijing	State owned	(010)62344485 013901388270	(0991) 62347144	Jike@public.bta.net.cn	100083

7.2 Appendix Chart