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Introduction to Photovoltaic

1.1 Photovoltaic

Solar power resources are abundant, widely available, one of the major renewable energy sources that have the greatest development potential. One important way to convert solar radiation into electricity occurs by the photovoltaic effect which was first observed by Becquerel. It is quite generally defined as the emergence of an electric voltage between two electrodes attached to a solid or liquid system upon shining light onto this system. Practically all photovoltaic devices incorporate a pn-junction in a semiconductor across which the photovoltage is developed. These devices are also known as solar cells. A cross-section through a typical solar cell is shown in **Fig. 1.1**. The semiconductor material has to be able to absorb a large part of the solar spectrum. Dependent on the absorption properties of the material the light is absorbed in a region more or less close to the surface. When light quanta are absorbed, electron hole pairs are generated and if their recombination is prevented they can reach the junction where they are separated by an electric field. Even for weakly absorbing semiconductors like silicon most carriers are generated near the surface. This leads to the typical solar cell structure of **Fig. 1.1**: the pn-junction which separates the emitter and base layer is very close to the surface in order to have a high collection probability for free carriers. The thin emitter layer above the junction has a relatively high resistance which requires a well designed contact grid also shown in the figure. The operating principles have been described in many publications, and will not be addressed further here.

For practical use solar cells are packaged into modules containing either a number of crystalline Si cells connected in series or a layer of thin-film material which is also internally series connected. The module serves two purposes, it protects the solar cells from the ambient and it delivers a higher voltage than a single cell which develops only a voltage of less than 1 V.

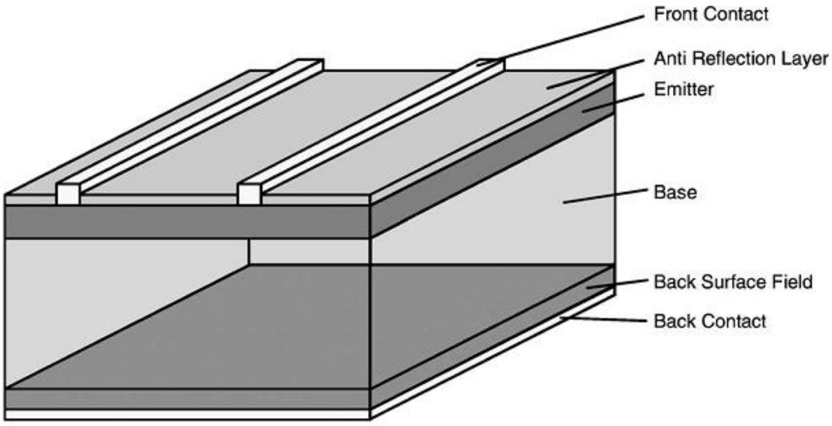

Fig. 1.1 Typical solar cell

Photovoltaic market in 2000 is about 277 MW corresponding to a value of over US$ 1 billion. This is a remarkable market but still far away from constituting a noticeable contribution to the world energy consumption. Market growth from 1990 to 2001 was between 15% and 25%. This market growth would be very satisfying for any conventional product but in the case of PV it is entirely insufficient if we consider the goals. The main motivation for developing solar energy is the desire to get away from depletable fossil fuels with their adverse effect on the environment. At the present growth rate, it will take us far into the second half of this century get a relevant contribution by PV to world energy demand. As will be pointed out below, support programs in several countries are already accelerating market growth. Besides the terrestrial market there is also the space market which has entirely different boundary conditions and also different materials requirements. In order to keep the volume of this paper at a reasonable size, space solar cell materials will not be included.

There are two major market sectors, grid connected and so called stand alone systems. The former delivers power directly to the grid. For this purpose the dc current from the solar modules is converted into ac by an inverter. The latter supplies power to decentralized systems and small scale consumer products. A major market currently being developed is in solar home systems supplying basic electricity demand of rural population in developing countries. The magnitude of this task can be appreciated if one is aware that about 2 billion persons are without access to electricity today. At present, both markets need subsidies, the grid connected installations because PV is much more costly than grid electricity, and solar home systems because the potential users lack the investment capital. On the other hand, there is also a significant industrial stand alone market which is today fully economical.

Because of its high potential the market is hotly contested and new companies are entering constantly. It is significant that several large oil companies have now established firm footholds in photovoltaic. Indeed, a recent study of possible future energy scenarios up to the year 2060 that was published by the Shell company predicts a multi-gigawatt energy production by renewable energies including photovoltaic. On the other hand, the strong competition leads to very low profit margins of most participants of this market.

In 2000, the market showed an accelerated growth of more than 30%. There are good chances that this growth will continue for at least some years because some countries have adopted aggressive measures to stimulate the grid connected market. Japan's very ambitious 70,000 roof program caused an astonishing increase by 63% of Japanese production in 1999. In Germany, a feed-back law was passed which sets a rebate rate of 0.5/kWh of PV generated electricity. If this rate is combined with the already existing 100,000 roof program, PV becomes (only moderately) economical. It can be expected that other countries will follow these examples. In order to meet the growing demand, many PV companies are in the process of setting up substantial new cell and module production capacities.

From Materials Science and Engineering R, by Adolf Goetzberger, 2003.

New Words and Expressions

1. photovoltaic [fəʊtəʊvɒl'teɪk] adj. [电子] 光电伏打的，光电的
2. resource [rɪ'sɔːs] n. 资源，财力；办法；智谋
3. renewable [rɪ'njuːəbəl] adj. 可再生的；可更新的；可继续的 n. 再生性能源
4. radiation [reɪdɪ'eɪʃ(ə)n] n. 辐射；发光；放射物
5. voltage ['vəʊltɪdʒ] n. [电] 电压
6. incorporate [ɪn'kɔːpəreɪt] vt. 包含，吸收；体现；把……合并 vi. 合并；混合；组成公司 adj. 合并的；一体化的；组成公司的
7. semiconductor [ˌsemɪkən'dʌktə] n. [电子][物] 半导体
8. resistance [rɪ'zɪst(ə)ns] n. 阻力；电阻；抵抗；反抗；抵抗力
9. grid [grɪd] n. 网格；格子，栅格；输电网
10. module ['mɒdjuːl] n. [计] 模块；组件；模数
11. crystalline ['krɪst(ə)laɪn] adj. 透明的；水晶般的；水晶制的
12. ambient ['æmbɪənt] adj. 周围的；外界的；环绕的 n. 周围环境
13. depletable adj. 可耗减的
14. boundary ['baʊnd(ə)rɪ] n. 边界；范围；分界线 复数 boundaries
15. current ['kʌr(ə)nt] adj. 现在的；流通的，通用的；最近的；草写的 n. （水，气，电）流；趋势；涌流 n. (Current)人名；(英)柯伦特
16. magnitude ['mægnɪtjuːd] n. 大小；量级；[地震] 震级；重要；光度

17. appreciate [ə'priːʃɪeɪt] vt. 欣赏；感激；领会；鉴别 vi. 增值；涨价
18. stimulate ['stɪmjʊleɪt] vt. 刺激；鼓舞，激励 vi. 起刺激作用；起促进作用
    过去式 stimulated 过去分词 stimulated 现在分词 stimulating
19. ambitious [æm'bɪʃəs] adj. 野心勃勃的；有雄心的；热望的；炫耀的
    比较级 more ambitious 最高级 the most ambitious
20. astonishing [ə'stɒnɪʃɪŋ] adj. 惊人的；令人惊讶的 v. 使……惊讶；使……诧异（astonish 的 ing 形式）

Notes

1. It is quite generally defined as the emergence of an electric voltage between two electrodes attached to a solid or liquid system upon shining light onto this system.

参考译文：这通常被定义为当光照在这个系统上时，在两个附属于固体或液体系统的电极之间产生的电压。

2. This is a remarkable market but still far away from constituting a noticeable contribution to the world energy consumption.

参考译文：这是一个引人瞩目的市场，但是离成为世界能源消费的重要组成部分还很远。

3. There are good chances that this growth will continue for at least some years because some countries have adopted aggressive measures to stimulate the grid connected market.

参考译文：这个增长将持续至少数年，这是很好的机遇，因为一些国家已经采取了积极的措施以促进电网连接市场。

1.2 Development of Photovoltaic in China

According to the China Meteorological Administration, China has abundant solar energy resources. The total potential for solar radiant energy of 1.7×10^{12} tce (tons of standard coal equivalent) per year for the entire country. More than two-third of the country has over 2000 h of sunshine each year, which provides an equivalent annual solar radiation of over $5.02\sim10^{6}$kJ/m^{2}. China's solar energy resource distribution is shown in **Table 1.1**. This illustrates the amount of solar radiation available. Compared with other countries in similar latitude, the solar radiant energy in China is superior to those in Europe and Japan, and similar to those in the United States. As can be seen in **Table 1.1**, provinces located in different latitudes and longitudes have different levels of solar irradiations. The country can be divided into five different regions from I to V. The distribution of China's solar energy resources in different areas varies significantly. In general, the solar resources in the western region (such as Ningxia, Gansu, Xinjiang, Qinghai, and Tibet) are higher than that in the eastern region (such as Guangdong, Shaanxi, Anhui, Heilongjiang, Zhejiang, Fujian, Hunan, and Hubei), and the resources in the northern region (such as Hebei, Shanxi, Inner Mongolia, Shandong, He nan, Jilin, Liaoning, and Shaanxi) are higher than in the southern region (such as Sichuan, Guizhou, Chongqing, Guangxi, and Jiangxi). This does not, however, correlate with the demand for energy. China's electricity loads are concentrated in the eastern and the southern regions, unfortunately, the solar resource-rich regions in the Qinghai-Tibet Plateau, North China and Northwest China are far from the regions which consume the greatest electrical power load.

Table 1.1 Solar energy resources in different regions of China

Type	Annual sunshine hours (h/a)	Total annual solar radiation (MJ/m^2 a)	Total annual solar energy per m^2 expressed in units of energy produced by kg of standard coal (kg)	Provinces
I	3200–3300	6680–8400	225–285	Northern Ningxia, Northern Gansu, Southeastern Xinjiang, Western Qinghai, and Western Tibet
II	3000–3200	5852–6680	200–225	Northwestern Hebei, Northern Shanxi, Southern Inner Mongolia, Southern Ningxia, Central Gansu, Eastern Qinghai, Southeastern Tibet, and Southern Xinjiang
III	2200–3000	5016–5852	170–200	Southeastern Shandong, Southeastern Henan, Northwestern Hebei, Southern Shanxi, Northern Xinjiang, Jilin, Liaoning, Yunnan, Northern Shaanxi, Southeastern Gansu, Southern Guangdong, Southern Fujian, Northern Jiangsu, Northern Anhui, Tianjin, Beijing, and Southwestern Taiwan
IV	1400–2000	4190–5016	140–170	Hunan, Hubei, Guangxi, Jiangxi, Zhejiang, Northern Fujian, Northern Guangdong, Southern Shaanxi, Southern Anhui, Heilongjiang, and Northeastern Taiwan
V	1000–1400	3344–4190	115–140	Sichuan, Guizhou, and Chongqing

Since the 1990s, China's PV power is developing rapidly and the installed capacity is increasing constantly. **Fig. 1.2** shows the annual installed capacity and the cumulative installed capacity from 1976 to 2009. Based on current trends, the cumulative PV power installations will reach 1.8 GWp by 2020 and 1000 GWp by 2050 nationwide in China.

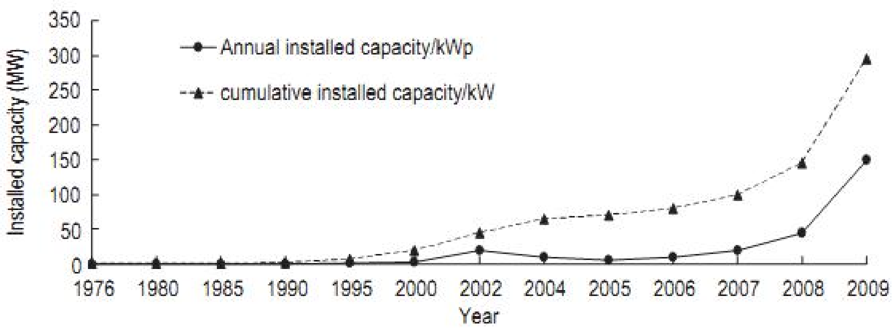

Fig. 1.2 Installed capacity of the solar PV power in China (1976-2009)

To encourage the development of renewable energy such as solar PV power, China has promulgated a series of laws, regulations and financial incentive policies, and has invested significant funds in PV power generation projects. The result of this investment is that China has a number of the world's leading PV companies as well as the successful establishment of research and development centers.

Table 1.2 Electricity sales in China from 2004 to 2010

Year	Sales (10^{13} kW h)	Annual growth rate (%)
2004	17,384	
2005	19,554	12.5
2006	22,825	16.7
2007	26,430	15.8
2008	28,418	7.5
2009	30,586	7.6
2010	35,289	13.3

Another factor that will increase the market for the solar PV power industry is China's demand for electricity, which continues to grow rapidly. The consumption of electricity in China from 2004 to 2010 is shown in **Table 1.2**. According to the statistics, the electricity sales value in China in 2010 is twice as much as that in 2004, and the average annual growth rate from 2004 to 2010 was more than 12%. This increasing demand for electricity, in addition to the shortage of fossil fuels and the negative impact of environmental pollution caused by the burning of fossil fuels, and the demand for renewable energy will increase which will create opportunities for the solar PV power industry.

In recent years, China has actively supported the development of PV power, and has constructed a series of PV power generation projects, mainly in China's western and northern provinces. **Table 1.3** lists the main large-scale PV power generation projects in China from 2004 to 2010. The installed capacities of these projects are in the range of 5–200 MW. However, most of these projects are located in developing regions (such as Qinghai, Gansu and Ningxia) where the grid structure is relatively weak and the distance to the load centers is significant. This poses a challenge to use the generated solar power fully and efficiently.

Table 1.3 The main large-scale PV power generation projects in China (2004-2010)

Year	Sales (10^{13} kW h)	Annual growth rate (%)
2004	17,384	
2005	19,554	12.5
2006	22,825	16.7
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The solar PV power supply chain consists of silicon materials, wafers, cells, components, and applications industries that utilize the power created by the solar PV power. The solar PV power industry has a close link with the raw material producers, power generating plants, and power supply companies. China's solar PV power industry chain and its influencing factors are shown in **Fig. 1.3**.

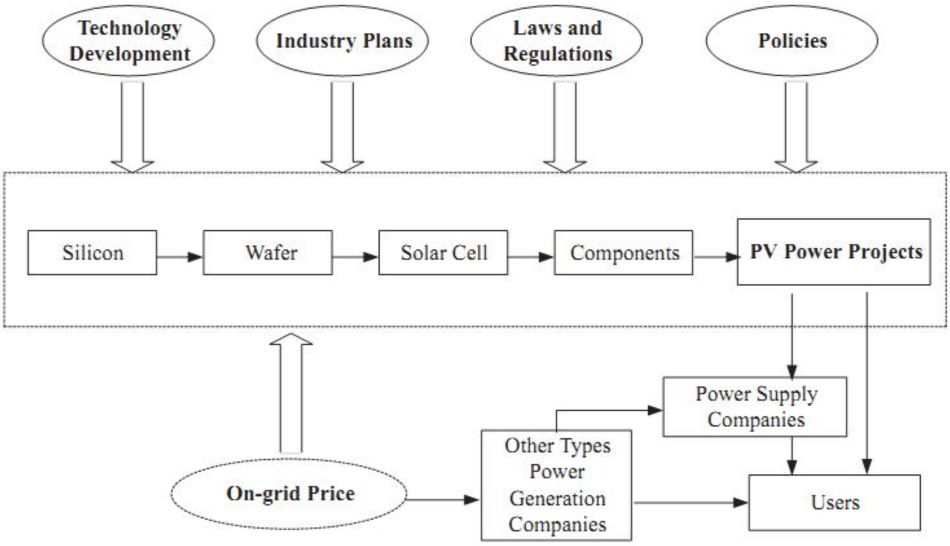

Fig. 1.3 Diagram of the solar PV power generation industry

In China, the main factors that affect the PV power industry are the technology, the industry plan, the laws, the price and the incentive policies. Technology is a key factor that affects the competitiveness of the PV power industry, especially the cost of solar PV power generation. The government plays a key role by regulating the renewable power market, especially since the current industrial environment is not mature. The Chinese government has formulated a series of industry plans for the PV power development. These industry plans serve as a strategic and directional guide to the development of PV power industry. In order to encourage the solar photovoltaic power, China also released supporting laws, policies and regulations. These laws, policies and regulations have an important impact and ensure a framework to sustain the stable, healthy and orderly operation of the PV power industry. Related policies, such as electricity price policies, tariff subsidy policies and project incentive policies, provide various advantages and favorable conditions that greatly improve the competitiveness of the industry. Therefore, this paper will review and examine the factors affecting the growth of the solar photovoltaic power industry in China based on the following five aspects: (1) the technology development, (2) the industry development plans, (3) the laws and regulations, (4) the electricity price policies, (5) the project incentive policies.

Since the successful development of the first crystalline silicon PV cell in 1958, China's PV power has evolved, going from small to large in scale, from single arrays to multiple arrays in type, from low to high in conversion efficiency. Milestone events in the development of China's solar energy technology, and in the growth, research and development of the solar PV power technology are shown in **Fig. 1.4**.

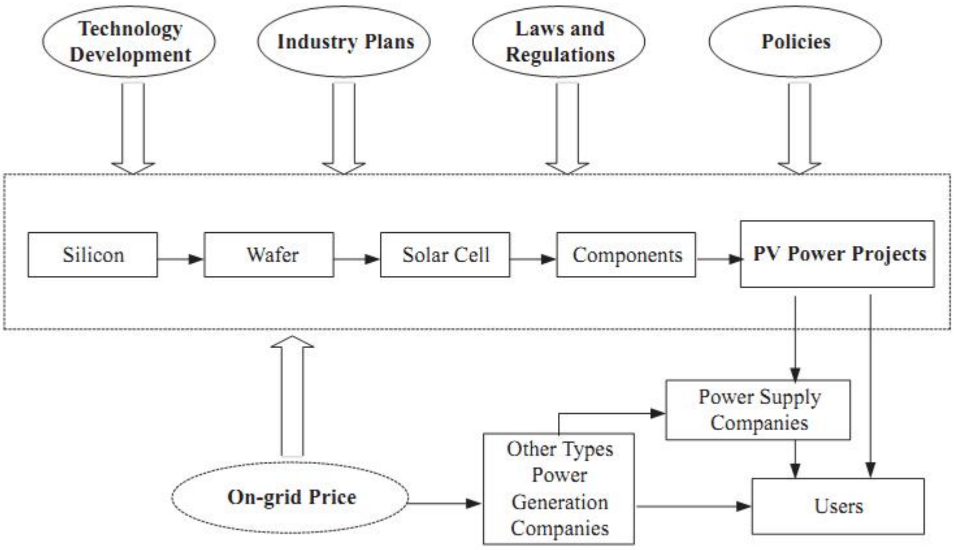

Fig. 1.4 Milestones in the development of the solar PV power technology development in China

In China, the technology development of solar PV power can be divided into three stages, germination stage, seedling stage and growth stage.

In the germination stage (from 1958 to 1970s), the development and manufacture of the solar cells was the key goal. In 1968, an institute in Tianjin developed and manufactured the first solar cell in China using satellite technologies. In the 1970s, a few solar cell factories were set up in the cities of Shanghai, Ningbo and Kaifeng.

In the seedling stage (from 1980s to 1990s), the State Scientific and Technological Commission set up China Optics and Electronics Technology Centre, which started the study of monocrystalline silicon solar cells, polysilicon silicon solar cells and the application of PV systems. In 1986, China's first 0.56 kW wind and solar hybrid system was established in Inner Mongolia. In 1989, China's first 10 kW PV power station began operation in Tibet. In the 1990s, the Institute of Electrical Engineering at the Chinese Academy of Sciences developed and constructed an independent PV station. A few production bases were formed in the Pearl River Delta areas and China began to export various PV products.

In the growth stage (from 2000 to present), the Suntech Company and Yingli Green Energy Company constructed the 10 MWp solar cells production lines in 2002 and 2003, respectively. During the last few years, the output of China's solar cells increased rapidly and accounted for 30% of the world's production in 2005. Advances have also been made in research and development. In 2007, the Shanghai Institute of Technical Physics of the Chinese Academy of Sciences invented and developed the physical purification method with which the purity of the solar cell silicon can reach 99.9999%. In 2010, the Shanghai Branch of the Chinese Academy of Sciences successfully developed a method of using physical process technology to produce solar cell grade polysilicon. While there have been numerous advances, China still strives to narrow the gap and make advances in selected aspects of solar power technology, including cell efficiency, components efficiency, production equipment technology and testing technology.

In recent years, China's government issued a series of renewable energy development plans, including the "Renewable Energy Mid and Long-term Plan", "Renewable Energy Development Eleventh Five-Year Plan" and the "Economic and Social Development Twelfth Five-Year Plan". These plans have a significant impact on the potential growth of the solar PV industry. Milestones in the development of solar power and how these milestones related to the national plans are shown in **Fig. 1.5**.

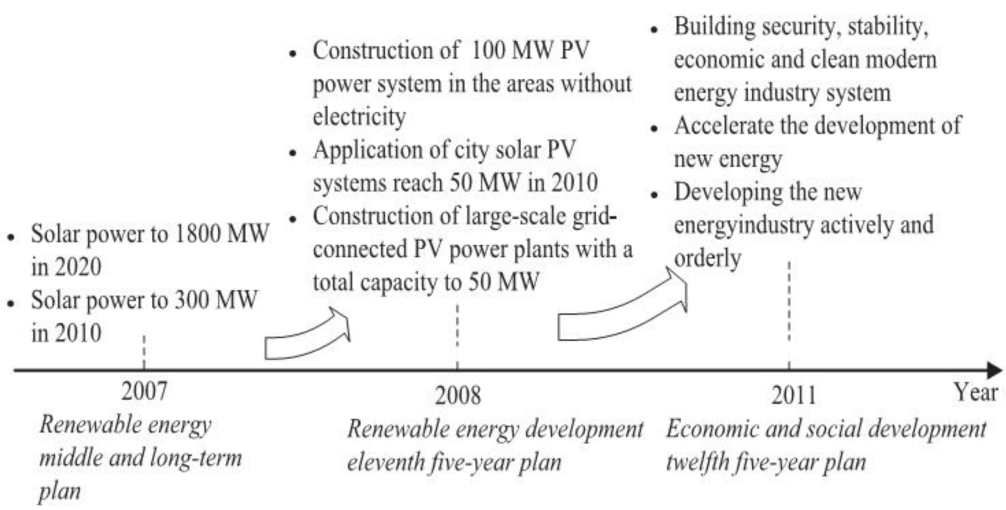

Fig. 1.5 Milestones in the growth of solar PV power industry program in China

In November 2007, the National Development and Reform Commission (NDRC) issued the "Renewable Energy Middle and Long-term Plan" which identified the long-term goal of solar power. In the plan, China's annual use of renewable energy will reach the equivalent of 2.7 hundred million tons of standard coal by 2010, with solar power contributing 300 MW to this goal. By 2020, the portion of China's energy use, that will be served by renewable energy, will increase to 16% (compared to 7% in 2007) and the amount of energy provided by solar power will reach to 1800 MW.

One year later, in March 2008, according to the requirements of the ‘‘Renewable Energy Mid and Long-term Plan’’ and the new development of renewable energy in China, the NDRC issued a “Renewable Energy Development Eleventh Five-Year Plan”. This plan proposed to establish national standards for public lighting in urban areas using PV, and technical standards to support PV construction, including the addition of building on-grid PV, large-scale on-grid PV and other technical standards. This plan identified the construction of the rooftop PV generating system in city housing and large scale on-grid PV power plant as key projects for solar energy utilization and development. The plan also outlined a development plan and technological categories for solar power in different regions.

In line with the rapid development of China's solar energy industry and the huge market potential, the State Council published the ‘‘Economic and Social Development Twelfth Five-Year Plan’’ in March 2011. This plan clearly stated that the country will:

- promote renewable energy production,
- build a safe, stable, economical and clean modern energy industrial system,
- accelerate the development of new energy projects,
- use the traditional energy by more clean and efficient ways.

This plan also proposed that the Chinese government support and fund the research and development of the key technologies for new energy and energy conservation.

Similarly, some provincial governments also released supporting policies to promote the solar PV power development. For instance, the Jiangsu provincial government issued implementing notices on solar PV industry in 2009. This policy stipulated that the government will develop the solar power industry through supporting policies, the development of relevant standards and the provision of incentives. Other provinces such as Hebei, Shanghai, Zhejiang, Shandong, and Fujian, are taking a similar approach. The goal for the development of solar PV power generation is shifting from an emphasis on the growth rate of installed capacity to a long-term program with orderly progress of the industry.

To encourage and promote the development of the solar energy industry, China has promulgated a series of supporting laws and regulations in recent years. **Fig. 1.6** illustrates the development of the laws related to the solar PV power generation. These laws created a framework of regulations and rules to protect the PV power industry.

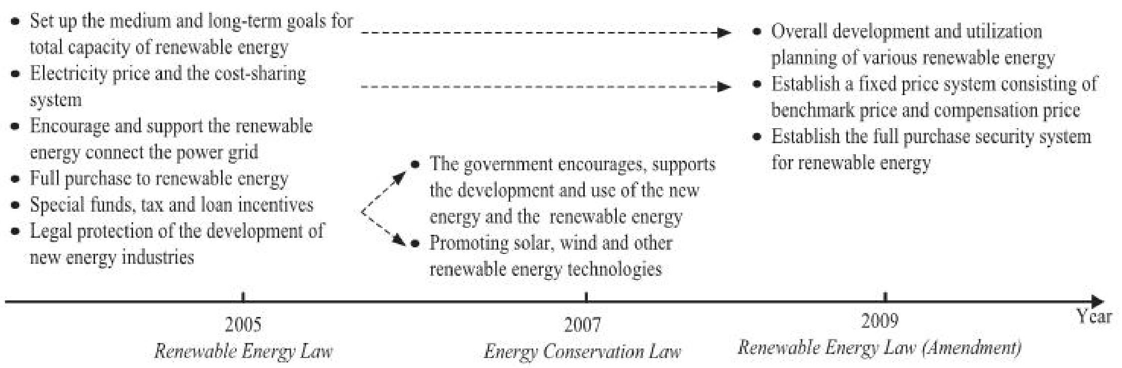

Fig. 1.6 Legislative milestones in support of solar PV power in China

The Renewable Energy Law was approved by the Tenth National People's Congress on February 28, 2005. This law requires the central government and each provincial government to identify medium and long-term goals for the use of renewable energy. The government encourages and supports renewable energy by regulating connections to the state power grid. The grid corporations must purchase all the electricity that is generated from renewable energy sources within the area served by their power grid. The law also promised to provide special funds, tax deduction and favorable loans as incentives for the development of renewable energy. According to the law, if the cost of renewable energy is higher than that of traditional energy sources, the gap shall be shared among the end users across the nation.

Although the full purchase of renewable energy had been regulated by the Renewable Energy Law, a conflict of interest existed between the power generation company and the grid company because the grid company was unwilling to purchase the electricity generated from renewable sources with a high price. As a result, the policy requiring the full purchase of renewable energy was difficult to implement fully. To solve this problem, in 2009, the Renewable Energy Law was amended and regulated the full purchase security system. According to the amended law, the NDRC together with the State Electricity Regulatory Commission and the Ministry of Finance shall determine the required ratio of renewable energy power to the total power generation capacity. This ratio shall be determined periodically according to the national medium and long-term plan, and shall formulate the implementation method for the grid companies, with priority to purchase the renewable energy power. This law also established a renewable energy development fund based on the experiences of the developed countries.

Furthermore, the Energy Conservation Law promulgated on October 28, 2007 explicitly stated that China recognizes saving resources as a basic long-term national strategy, and conservation and development are equally important with conservation as a top priority in the energy development strategy. The law learly states that China encourages and supports the development and use of new energy, renewable energy and the biomass in rural areas, and China will widely promote the biomass, solar and wind and other renewable energy technologies.

As a kind of renewable energy, solar PV power competes with and complements traditional energy and other kinds of renewable energy. In China, although the on-grid price of solar PV has gradually declined, still it is highly relative to traditional energy and relative to other kinds of renewable energy. As shown in **Table 1.4**, the price differences have greatly weakened the competitiveness of solar PV power generation and restricted the development of large-scale PV power generation.

Table 1.4 The on-grid prices of various power generation types in China (2010-present)

Type	On-grid power price (Yuan/kWh)	Equivalent to US cents (1 US$ ≈ 6.3 China Yuan)
Hydropower	0.265	4.21
Coal-fired power	0.35	5.56
Nuclear power	0.44	6.98
Liquefied natural gas	0.53	8.41
Wind power	0.56	8.89
Biomass power	0.75	11.90
PV power	1.00–1.50	15.87–23.81

The cost of solar cells constitutes the largest share of the total cost of PV power generation. Solar cells include crystalline silicon solar cells and amorphous silicon solar cells. The former includes monocrystalline silicon solar cells and polycrystal silicon solar cells. The development of monocrystalline silicon cells is still in the early stages, but the production cost is high due to the use of high-purity silicon, and the raw materials cost accounts for more than half of the total cost. Compared with the monocrystalline silicon cells, the cost of the polycrystal silicon cell is low because the production process is relatively simple. In recent years, the amorphous silicon solar cell has been mass produced for use as a low-cost solar cell.

The evolution of the cost of solar cell power during the last 30 years in China is shown in **Fig. 1.7**. In the 1970s, the solar cell power cost was as high has 200Yuan/kWh. In the1980s, China's PV industry made progress and the cost of solar cell power reduced to 40–45 Yuan/kWh. By the end of 2000, China's amorphous silicon solar cell power cost was 23–25 Yuan/kWh. In 2008, the cost of solar cells in China was 10–75 Yuan/kWh. In 2010, China's solar PV cells power cost is down to approximately 1 Yuan/kWh.

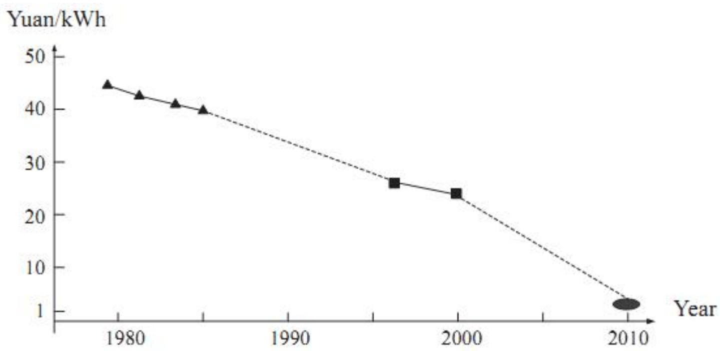

Fig. 1.7 Evolution route of the solar cells power cost in China

To support the solar PV power industry, the government has promulgated a series of policies to supply on-grid solar PV power.

The NDRC released the “Trial Measures on Renewable Energy Prices and Cost-sharing Management” in January 2006; this regulated the renewable energy prices and implemented the government pricing and government guiding prices. Solar power projects and prices for on-grid solar power are regulated by government pricing, with the standard price determined by the Bureau of Commodity Prices of the NDRC. In this framework, the price is based on the actual cost plus a reasonable profit. At present, the subsidy for solar power is 0.25 Yuan/kWh. The government encourages the users to buy renewable energy power. The Ministry of Finance promulgated the “Procedures for the Administration of Special Funds for Renewable Energy Development” in May 2006. This policy administers special funds that support the promotion and application of wind power, solar power, and ocean power, and also support the application of solar energy and geothermal energy for building energy conservation.

In January 2007, the NDRC issued the “Interim Measures on Renewable Energy Subsidy Management” to ensure rational use and distribution of the subsidy of renewable energy. It is stipulated that the range and standard rates of subsidy to solar PV shall be approved and announced by the Bureau of Commodity Prices of the NDRC. The subsidies for solar PV power generation projects include: (1) the excess of the on-grid price of renewable energy power over the standard on-grid price of the local desulfurized coal-fired units; (2) the excess of the operation and maintenance costs of the independent solar PV power systems by public investment over the local grid average sale price; (3) the grid connections costs of the solar power projects.

The Ministry of Finance of China issued the “Interim Measures on Management of Financial Fund for Solar Building” in March 2009, which regulates the subsidy standard for solar buildings that will be adjusted annually according to the actual cost. This policy gives full support to the solar energy and the building integration applications, and as a result the solar power cost will reduce to 1

Yuan/kWh through use of the subsidies.

In China, the PV power prices are not the same in all regions. Different regions and different projects have different PV power prices due to the different approved prices by the government. However, with the reduction in the cost and the subsidy support by various policies, the PV power price continued to decline. The PV power prices continue to become closer to traditional power prices steadily.

PV power generation includes independent PV power system (off-grid) and grid-connected PV power system (on-grid). In the 20th century, due to the high cost of PV cells, PV power generation is mainly used in island, mountain, desert and other remote areas where the public power grid cannot reached. In recent years, the PV power, including power generation and PV construction, have been gradually extended to include both on-grid and off-grid power systems in cities and rural areas. In 2002, China launched the "Electricity Plan for Remote Villages in Western Provinces", by establishing PV power and other power generation projects to provide electricity for poor and remote villages. In 2009, the government issued a series of project policies such as the "Golden Sun Demostration Projects" and the "Solar Roofs Plan" to support solar power development, and China was ranked in the top ten of PV markets throughout the world. In the next 10 years, China's solar PV power market will turn from independent power systems to grid-connected power systems, which will include desert power stations and city roof power systems.

In February 2006, the NDRC published "The Renewable Energy Power Administration Regulation" to stipulate the requirements for the power generation companies engaged in the solar PV power generation business. And power generation enterprises are encouraged to increase their investment in the renewable energy projects. Solar PV power projects are under the policies of the NDRC and can receive financial support from the NDRC. According to the regulation, the power grid companies shall invest in solar power and undertake to connect the solar power generation plants into the public grid system.

In March 2009, the Ministry of Finance and the Ministry of Housing and Urban–Rural Development issued the "Notice of Opinions on the Implementation of Accelerating the Solar PV Building Applications" to implement the "Solar Roofs Plan" which adopted a demonstration project to speed up the implementation of PV projects in urban and rural areas.

In April 2009, the Ministry of Finance and the Ministry of Housing and Urban–Rural Development published the "Application Guideline for Solar PV Building Demonstration Project". The guideline supports the solar PV building projects. The government will provide subsidies for solar PV building application demonstration projects, and the maximum subsidy is 20 Yuan/W.

In July 2009, the Ministry of Finance, the Ministry of Science and Technology, and the National Energy Board jointly issued the "Notice of Implementation of Golden Sun Demonstration Projects" which regulated that the government will provide subsidies to on-grid PV power projects at 50% of the total investment, and the subsidies for independent PV power systems will reach 70% of the total investment in remote areas without electricity.

This policy illustrates the strong support that the Chinese government provides to encourage the investment and operation of solar PV power projects. This policy also launched a series of incentives for PV power generation projects. The policies are gradually shifting from encouraging the large companies to invest in PV power generation projects to implement subsidies for PV projects. The subsidies for PV power generation projects have reached as much as half of the total investment for a project. In addition, the policies for the PV projects have expanded from supporting solar PV power plant projects to encouraging the construction of solar buildings.

From Renewable and Sustainable Energy Reviews, by Zhen-yu Zhao, 2013.

New Words and Expressions

1. equivalent [ɪ'kwɪvələnt] adj. 等价的，相等的；同意义的 n. 等价物，相等物
2. distribution [dɪstrɪ'bjuːʃ(ə)n] n. 分布；分配
3. latitude ['lætɪtjuːd] n. 纬度；界限；活动范围
4. superior [suː'pɪərɪə; sjuː'pɪərɪə] adj. 上级的；优秀的，出众的；高傲的 n. 上级，长官；优胜者，高手；长者
5. longitude ['lɒn(d)ʒɪtjuːd; 'lɒŋgɪtjuːd] n. [地理] 经度；经线
6. correlate ['kɒrəleɪt; kɒrɪleɪt] vi. 关联 vt. 使有相互关系；互相有关系 n. 相关物；相关联的人 adj. 关联的
7. capacity [kə'pæsɪtɪ] n. 能力；容量；资格，地位；生产力 复数 capacities
8. cumulative ['kjuːmjʊlətɪv] adj. 累积的
9. promulgate ['prɒm(ə)lgeɪt] vt. 公布；传播；发表
   过去式 promulgated 过去分词 promulgated 现在分词 promulgating
10. financial [faɪ'nænʃ(ə)l; fɪ'nænʃ(ə)l] adj. 金融的；财政的，财务的
11. consumption [kən'sʌm(p)ʃ(ə)n] n. 消费；消耗；肺痨
12. environmental pollution 环境污染
13. opportunity [ɒpə'tjuːnɪtɪ] n. 时机，机会 复数 opportunities
14. efficiently [ɪ'fɪʃəntli] adv. 有效地；效率高地（efficient 的副词形式）
15. formulate ['fɔːmjʊleɪt] vt. 规划；用公式表示；明确地表达
    过去式 formulated 过去分词 formulated 现在分词 formulating
16. strategic [strə'tiːdʒɪk] adj. 战略上的，战略的
17. monocrystalline silicon 单晶硅

18. polysilicon [pɔli'silikən]　n. [晶体] 多晶硅
19. rooftop ['rʊf'tɑp]　n. 屋顶　adj. 屋顶上的
20. utilization [ˌjuːtɪlaɪ'zeʃən]　n. 利用，使用
21. category ['kætɪg(ə)rɪ]　n. 种类，分类；[数] 范畴　复数 categories
22. implement ['ɪmplɪm(ə)nt]　vt. 实施，执行；实现，使生效　n. 工具，器具；手段
23. provision [prə'vɪʒ(ə)n]　n. 规定；条款；准备；[经] 供应品　vt. 供给…食物及必需品
24. conflict ['kɒnflɪkt]　n. 冲突，矛盾；斗争；争执　vi. 冲突，抵触；争执；战斗
25. periodically [ˌpɪərɪ'ɒdɪkəlɪ]　adv. 定期地；周期性地；偶尔；间歇
26. priority [praɪ'ɒrɪtɪ]　n. 优先；优先权；[数] 优先次序；优先考虑的事　复数 priorities
27. rural ['rʊər(ə)l]　adj. 农村的，乡下的；田园的，有乡村风味的
    比较级 more rural 最高级 the most rural
28. biomass ['baɪə(ʊ)mæs]　n. （单位面积或体积内的）[生态] 生物量
29. traditional [trə'dɪʃ(ə)n(ə)l]　adj. 传统的；惯例的
    比较级 more traditional 最高级 the most traditional
30. evolution [ˌiːvə'luːʃ(ə)n; 'evə'luːʃ(ə)n]　n. 演变；进化论；进展

Notes

1. Compared with other countries in similar latitude, the solar radiant energy in China is superior to those in Europe and Japan, and similar to those in the United States.

参考译文：与相似纬度的其他国家相比，中国接收到的太阳辐射能量比欧洲和日本多，与美国相似。

2. To encourage the development of renewable energy such as solar PV power, China has promulgated a series of laws, regulations and financial incentive policies, and has invested significant funds in PV power generation projects.

参考译文：为了鼓励太阳能光伏发电等可再生能源的发展，中国已经颁布了一系列法律、法规和财政激励政策，并已在光伏发电项目中投入大量资金。

3. In recent years, China has actively supported the development of PV power, and has constructed a series of PV power generation projects, mainly in China's western and northern provinces.

参考译文：近年来，中国大力支持光伏发电的发展，并在中国西部和北部省份建设了一系列光伏发电项目。

4. Technology is a key factor that affects the competitiveness of the PV power industry, especially the cost of solar PV power generation.

参考译文：技术是影响光伏发电竞争力的一个关键因素，尤其是太阳能光伏发电的成本。

5. The government plays a key role by regulating the renewable power market, especially since

the current industrial environment is not mature.

参考译文：政府对可再生能源市场的调控起着关键性的作用，尤其是在当前工业环境还尚未成熟时期。

6. Since the successful development of the first crystalline silicon PV cell in 1958, China's PV power has evolved, going from small to large in scale, from single arrays to multiple arrays in type, from low to high in conversion efficiency.

参考译文：自从 1958 年第一块晶体硅光伏电池问世以来，中国光伏发电经历了从小到大的规模、从单一阵列到多阵列型式、从低到高转化率的发展。

7. Although the full purchase of renewable energy had been regulated by the Renewable Energy Law, a conflict of interest existed between the power generation company and the grid company because the grid company was unwilling to purchase the electricity generated from renewable sources with a high price.

参考译文：尽管可再生能源全额收购已经由可再生能源法来规范，但是在发电公司和电网企业之间还存在利益冲突，因为电网公司不愿用高价格购买来自可再生能源生产的电力。

8. This ratio shall be determined periodically according to the national medium and long-term plan, and shall formulate the implementation method for the grid companies, with priority to purchase the renewable energy power.

参考译文：该比例应根据国家中长期计划定期确定，并应制定本公司的实施方法，以优先购买可再生能源生产的电力。

9. Different regions and different projects have different PV power prices due to the different approved prices by the government.

参考译文：由于政府批准的价格不同，不同地区和不同的项目有不同的光伏发电价格。

1.3 Status of Photovoltaic in China

The research and development of photovoltaic started from 1958 in China. It began to enter into application stage in the 1970s, but it was not actually industrialized until the middle of the 1980s when two single crystalline silicon solar cell production lines were introduced and the large-scale utilization period was coming. Since 1993, the output of domestic crystalline silicon solar cells soared by 20%–30% annually, the total installed capacity of photovoltaic systems in China was approximately 22MWp at the end of 2002. Through long time of hard work, production equipment, technology of cells and modules and balance-of-system components have been improved significantly.

Work on research and development of photovoltaics is carried out by various institutes and universities. The active research work in China includes single crystalline silicon solar cells with practical type, high efficiency single crystalline silicon solar cells, multicrystalline silicon solar cells, amorphous silicon solar cells, GaAs solar cells, $CuInSe_2$ and CdTe compound thin films solar cells, terrestrial silicon concentrator solar cells. The high conversion efficiencies of various solar cells in China are shown in **Table 1.5**.

Table 1.5 Efficiency of different solar cells for laboratory levels in China

Type	Highest efficiency (%)	Area (cm^2)
Single c-Si	20.4 14	2 × 2 10 × 10
GaAs	20.1	1 × 1
Multi c-Si	14.5 12	2 × 2 10 × 10
Si cell for concentrator	17.0	2 × 2
$CuInSe_2$	9	1 × 1
CdTe	7	3 mm^2
a-Si	8.6 7.9 6.2	10 × 10 20 × 20 30 × 30

At present, main products of photovoltaic are single crystalline silicon solar cells and amorphous silicon solar cells, multicrystalline silicon solar cells are in the small amount pilot production, the size of single crystalline silicon solar cells consists of mainly 100mm-diameter wafer, 100 × 100 mm^2 pseudosquare and 125×125 mm^2 pseudosquare. The thickness of wafer is between 280 and 400 um.

The conversion efficiency of single crystalline silicon solar cells ranges from 12% to 14% for production, the efficiency of 100×100 mm^2 multicrystalline crystalline silicon solar cells is 10%-12%. The photovoltaic industry uses cheap reject material from the micro-electronics industry. In 2001, multicrystalline silicon casting and wafer processing had been introduced to avoid front-end bottlenecks and reduce, to a certain extent, cell costs. In the laboratory, PESC, PERC, LGBC and MGBC solar cells, gettering and passivation technology have been studied extensively. The development of modules fabrication has progressed over the last 15 years to yield a highly reliable and durable package for the inter-connected cells, much of the technology used today was originated in the efforts of the US Department of Energy program active in the early 1980s. Only a few modules used for garden light are encapsulated by transparent resin. The silver inks and aluminium inks for metallization of crystalline silicon solar cells have been produced by some institutes with high quality. The ethylene vinyl acetate (EVA) used for encapsulation of crystalline silicon solar cells has been produced by native major factory, the adhesive intensity of EVA/Glass is 30 N/cm, the adhesive intensity of EVA/TPT is 20 N/cm. EVA has recently been shown to discolor, in some situations, after several years in the field, particularly when modules reach high temperatures. Discoloring is associated with the deterioration of ultraviolet absorbers added to the EVA. The tempered, low-iron content glass and the Tedlar-Polyester-Tedlar trilayer used in the rear surface of the modules mainly depend on import from abroad. The area of amorphous silicon solar modules is 305×915 mm^2, the conversion efficiency is 4%–6%, high degeneration is the key problem for this single junction module.

Development of production and research equipment for photovoltaic is still encouraged and supported by China government. In 2000, Institute of Solar Energy of Shanghai Jiaotong University developed own solar tester financed by the Ninth Five-Year Plan. Tianjin Institute of Power Sources is one of four laboratories in the world, who is qualified for World photovoltaic scale (WPVS).

Before 2000, China did not have capacity of making production equipment used for solar cells, The past equipments were imported from developed countries 15 years ago. Technologies and the equipment used for photovoltaic production have been out of date. In 2000, in collaboration with Institute of Solar Energy of Shanghai Jiaotong University, Shanghai GoFly Green Energy Co. Ltd., installed a production line of crystalline silicon solar cells. Some main equipment such as Solar cell Selector, Module Simulator, Laminator, RTP furnace, etc., are designed by themselves. The laminator is adapted to efficient mass production, and has a low maintenance cost, the effective lamination area is 1000 × 800 mm^2. The module simulator uses a PC with Windows 98, it has a high accuracy and fast data acquisition speed, light intensity uniformity is complied with the ASTM and JIS standards, light source is pulse-Xe lamp, the light uniformity is within 75%, the light spectrum is AM1.5, the effective area of module simulator is 1500 × 1000 mm^2. At present, Shanghai GoFly Green Energy Co., Ltd., is improving process integration and implementing statistical process control and data systems, the improvements are directed at reducing yield losses in areas of electrical and mechanical performance and reducing chemical waste. This progress reduces the gap between Chinese manufacturers and the world's leading manufacturers, in terms of technological advancement and production volumes.

The photovoltaic industry continues to rapidly expand at rates comparable to the telecommunications and computer industries, the massive growth in the industry is leading to many manufacturers installing new manufacturing capacity. In 2002, some manufacturers expand their volumes, and five new module assembly plants have emerged out.

In summary, China has a capacity of building photovoltaic production line, this is a significant development for future photovoltaic industry in China. **Table 1.6** shows the information of main solar cell manufacturers in China.

Table 1.6 The information of main solar cell manufacturers in China

Manufacturer	Equipment origin	Technology	Capacity (MWp)
GoFly Green Energy Co. Ltd.	Themselves	c-Si and multi-Si ($125 \times 125\,mm^2$)	2
Qinhuangdao Huamei Co. Ltd.	Whole line imported (Spire, USA)	c-Si (Diamter 100 mm)	1
Yunnan Semiconductor Devices Factory	Whole line imported (TPK, Canada)	c-Si (Diameter 100 mm)	1
Ningpo Solar Cell factory	Key equipment imported (Spire, USA)	c-Si (Diameter 100 mm)	1
General Institute for Non-Ferrous Metals	Key equipment imported (Spire, USA)	multi-Si	0.15
Harbin-Chronar	Whole line imported (Chronar, USA)	a-Si	1
Tuori	Whole line imported (Chronar, USA)	a-Si	1

Batteries are used in solar electric systems to store electricity generated during daylight hours for later use, the operation of a battery used in a photovoltaic system can be summarized by two types of cycling: a shallow cycle each day and deep cycles over several days or weeks during cloudy weather or winter. The deep cycles occur when charging during the day is not enough to replace the amount of charge used by the appliances over the whole day. Therefore, the state of charge after each daily cycle is reduced slightly and this builds up to a deep cycle over a period of several days. When the weather improves or the days lengthen, there is extra charging and the state of charge after each daily cycle gets higher. Most solar electric systems use lead-acid batteries for storage, today in China, there are hundreds of small sealed and starter battery manufacturers, but there is no deep cycle and long lifetime lead-acid battery specially designed for photovoltaic systems, the most frequent problem comes from photovoltaic and hybrid system is the battery failure.

A power inverter is used in a photovoltaic system to convert low-voltage DC to mains voltage AC. This is needed when using appliances that only work from a mains voltage AC supply. At present, the small and middle power compact inverter developed for photovoltaic have been used widely, most of them have high efficiency and reliability. Inverter with large capacity were developed, supported by State Science and Technology Commission (SSTC). 15-20 kVA inverters have been provided to the photovoltaic plants with capacity of 20 kVA in Gaize and Cuoqin counties, in Tibet. 90% of conversion efficiency is available with less than 5% of harmonic deformation. The inverters were provided working normally in bad ambient temperature. And now, we plan to complete design enhancements to produce 100–1000 kVA inverters, that are easily manufactured and are suitable for use in residential applications, these products will use the transformerless, phase-leg topology.

A controller is used to provide these protections: risk of cable damage and fire from short circuits, over-discharge of lead-acid batteries, excessive charging of batteries. Micro-controller-based charge controllers for photovoltaic system have been developed and used. Charge controllers used for solar-powered communication systems have data-acquisition system. And now, there are some specialized controller manufactures in China, their products are cost-effective.

China is perhaps the largest potential market for photovoltaic in the world, China has untapped solar resources, particularly in its western region which boasts about 3000 h of sunshine annually, taking into account the vast areas and the low population density, small energy units such as photovoltaic form a more cost-effective solution than expansion of the electricity grid. So, there are many encouraging signs, as well as many critical challenges, for both the international and indigenous photovoltaic industries in the energy markets in China. The terrestrial markets are very diverse, using different products and often with different criteria for defining the “best” product. To analyze the market for photovoltaic, it is essential to divide it into market segments, that are consumer products, industrial markets, remote communities.

Consumer products include domestic power supplies, individual power supplies, indoor applications. Domestic power supplies are used to provide power for houses remote from the grid, holiday homes, mobile homes, boats, and so forth. In this category, the purchaser is the homeowner using his or her own money. Individual power supplies include garden lights, fountains, home security systems, fans for cars, battery chargers, and personal electronics. In this category the consumer is buying a product in order to enjoy a specific services, the manufacturer of the product has incorporated photovoltaic because it makes the product cheaper, enhances its market appeal, or allows a novel product to be developed. Indoor applications include calculators, watches and clocks, toys, instruments, and novelties. In this category, sizing photovoltaic to provide even tens of milliwatts can be difficult because of the small areas available and the low power in indoor lighting, however, many of these applications call for microwatts at a few volts, and a few integrally interconnected cells each of a small area are sufficient. Consumer products are market-led in a purely commercial environment, the growth of the market is influenced by general economic factors.

The industrial market is not homogeneous, and there are three broad categories that need to be considered: communications, cathodic protection, and remote power. Photovoltaic is cost-competitive in these markets because of the high costs associated with refuelling and maintaining internal combustion engines or in changing batteries or liquid gas cylinders. Communications application includes relay and repeater stations for telecommunications, monitoring control and reporting stations, and so on. The market of remote power includes applications such as electrified fencing, intruder detection, perimeter security at large sites. The customers for this category are companies and military.

Photovoltaic can provide electricity for remote communities in China, the range of services supplied is very wide and includes water pumping and water treatment, village supplies for domestic and small industry use, medical uses, educational uses, and communications via telephone, television, and radio, and so forth. In this case, the equipment is purchased by a utility, government agency, or international agency for deployment in the community.

A large amount of experience has been gathered on technical, economic, social and management issues, an analysis of the experience shows that solar photovoltaic technology can be a viable alternative to extension of grid lines to electrify villages, especially in remote and difficult areas. Organizations such as railways, telecommunication, oil and natural gas commission in very specialized applications are using photovoltaic systems as the most viable option.

There is still a large gap between the potential of photovoltaic based on available resources and current levels of market development. Factors contributing to commercialization barriers for photovoltaic in China include government policy and planning, at the national government level there is a lack of a systematic and comprehensive policy structure tailored for photovoltaic development, coordination among agencies responsible for photovoltaic planning is weak. Other factors include the high cost. Costs remain high and the photovoltaic industry is only now making the jump from niche markets which is difficult and expensive. Low customer density in a given service territory makes sales, installation service and payment collection expensive and difficult, resulting in transaction costs that are about 30% of the total system costs. This reduces afford-ability, undermines sustainability of systems and reduces the market impact of even dramatic cost reduction in photovoltaic modules.

After the UN summit conference on Global Environment and Development held in Reo de Janeiro, 1992, China developed a quick response towards implementing a sustainable development strategy. They issued “Agenda of China 21st century”, a white paper of China’s sustainable development strategy in the 21st century. In this programmatic document, it is stressed that ‘‘renewable energy is the basis of future energy pattern’’. It is also stated that: ‘‘priority should be given to the development of renewable energy in the state energy development strategy’’, and ‘‘to encourage energy-saving, energy efficiency and developing renewable energy should become the fundamental state policy’’.

The policy of government is clearly directed towards a greater thrust on all aspects of photovoltaic technology and application. Under the framework of National Sixth, Seventh, Eighth, Ninth and Tenth Five-Year Plan, the government has been actively supporting the development of photovoltaic in China. In 1996, the Chinese State Development Planning Commission launched the Brightness Program, with the overall objective of providing renewable power for 20 million Chinese without electrification by the year 2010. In 2002, China government accelerates this plan, about 1.8 billion RMB yuan will be provided for rural electrification at remote town level by installing photovoltaic and wind systems, 4.25 MWp photovoltaic systems of the first batch bidding will be installed in five provinces or autonomous regions (1.03 MWp for Gansu, 0.206 MWp for inner Mongolia, 1.68 MWp for Qinghai, 0.2 MWp for Shaanxi, 1.13 MWp for Xinjiang).

In addition to financial support from the government of China, various international funding agencies have supported the photovoltaic program from time to time. One example is a 10 MWp solar home system program being developed by the World Bank for western China. The Shell Company is implementing a large-scale solar home system project in the Province of Xinjiang. The systems are expected to be purchased mainly by households and institutions living in isolated rural areas without access to electricity, subsidies come from different organizations. The previous National Photovoltaics Program Plan placed heavy emphasis on cell research, and now, major government programs have been focused on reducing the production costs associated with crystalline silicon module production and were instrumental in financing programs in thin-film technologies.

Such efforts have resulted in the emergence of a commercial sector for photovoltaic systems and have opened up a market for many enterprises to sell their innovative designs and products. Marketing in true commercial sense has emerged, a lot of small enterprises is joining. The "Risk business" has been doubted by more and more people.

From Energy Policy, by Hong Yang, 2003.

New Words and Expressions

1. industrialized [ɪn'dʌstrɪəlaɪzd] adj. 工业化的 v. 使工业化；将……组成产业（industrialize 的过去分词）
2. utilization [ˌjuːtɪlaɪ'zeɪʃən] n. 利用，使用
3. output ['aʊtpʊt] n. 输出，输出量；产量；出产 vt. 输出
   过去式 outputted 或 output 过去分词 outputted 或 output 现在分词 outputting
4. domestic [də'mestɪk] adj. 国内的；家庭的；驯养的；一心只管家务的 n. 国货；佣人
5. annually ['ænjʊəlɪ; 'ænjʊlɪ] adv. 每年；一年一次
6. approximately [ə'prɒksɪmətlɪ] adv. 大约，近似地；近于
7. component [kəm'pəʊnənt] adj. 组成的，构成的 n. 成分；组件；[电子] 元件
8. carry out 执行，实行；贯彻；实现；完成
9. institute ['ɪnstɪtjuːt] vt. 开始（调查）；制定；创立；提起（诉讼）n. 学会，协会；学院 过去式 instituted 过去分词 instituted 现在分词 instituting
10. thin films solar cells 薄膜太阳能电池
11. terrestrial [tə'restrɪəl] adj. 地球的；陆地的，[生物] 陆生的；人间的 n. 陆地生物；地球上的人
12. single crystalline silicon solar cells 单晶硅太阳能电池
13. wafer ['weɪfə] n. 圆片，晶片；薄片，干胶片；薄饼；圣饼 vt. 用干胶片封

14. reject material　剔除料
15. micro-electronics industry　微电子行业
16. cast [kɑːst]　vt. 投，抛；计算；浇铸；投射（光、影、视线等）n. 投掷，抛；铸件，[古生] 铸型；演员阵容；脱落物 vi. 投，抛垂钓鱼钩；计算，把几个数字加起来
17. bottleneck ['bɒt(ə)lnek]　n. 瓶颈；障碍物
18. passivation [pæsi'veiʃən]　n. [化学] 钝化；钝化处理
19. fabrication [fæbrɪ'keɪʃ(ə)n]　n. 制造，建造；装配；伪造物
20. reliable [rɪ'laɪəb(ə)l]　adj. 可靠的；可信赖的　n. 可靠的人
比较级 more reliable 最高级 the most reliable
21. durable ['djʊərəb(ə)l]　adj. 耐用的，持久的　n. 耐用品
22. encapsulate [ɪn'kæpsjʊleɪt; en'kæpsjʊleɪt]　vt. 压缩；将……装入胶囊；将……封进内部；概述　vi. 形成胶囊
23. transparent resin　透明树脂
24. adhesive intensity [əd'hiːsɪv; əd'hiːzɪv]　n. 粘合剂；胶黏剂　adj. 粘着的；带粘性的
25. deterioration [dɪˌtɪərɪə'reɪʃn]　n. 恶化；退化；堕落
26. in the rear surface of　在后面的表面
27. degeneration [dɪˌdʒenə'reɪʃ(ə)n]　n. 退化；[医] 变性；堕落；恶化
28. junction ['dʒʌŋ(k)ʃ(ə)n]　n. 连接，接合；交叉点；接合点
29. data acquisition　数据采集
30. uniformity [juːnɪ'fɔːmɪtɪ]　n. 均匀性；一致；同样　复数 uniformities
31. simulator ['sɪmjʊleɪtə]　n. 模拟器；假装者，模拟者
32. manufacturer [ˌmænjʊ'fæktʃ(ə)rə(r)]　n. 制造商；[经] 厂商
33. telecommunications ['telɪkəˌmjuːnɪ'keɪʃənz]　n. 通讯行业：服务类型变更，缴纳话费，账户总览等所有业务均可通过移动设备完成
34. battery ['bætri]　n. [电] 电池，蓄电池　n. [法]殴打　n. [军]炮台，炮位
35. transformerless [trænz'fɔməlɪs]　adj. 无变压器的；不使用变压器而产生的
36. short circuit　短路；漏电
37. remote [rɪ'məʊt]　adj. 遥远的；偏僻的；疏远的　n. 远程
比较级 remoter 最高级 remotest
38. domestic [də'mestɪk]　adj. 国内的；家庭的；驯养的；一心只管家务的　n. 国货；佣人
39. perimeter security　周边安全
40. viable ['vaɪəbl]　adj. 可行的；能养活的；能生育的
41. sustainable development strategy　可持续发展战略
42. innovative design　创新设计

Notes

1. Work on research and development of photovoltaics is carried out by various institutes and universities.

参考译文：各个研究院所和高校正开展对太阳能电池的研究和开发工作。

2. Only a few modules used for garden light are encapsulated by transparent resin.

参考译文：花园的灯只用几个由透明树脂包裹的模块制成。

3. The photovoltaic industry continues to rapidly expand at rates comparable to the telecommunications and computer industries, the massive growth in the industry is leading to many manufacturers installing new manufacturing capacity.

参考译文：光伏产业继续以与电信和计算机行业相媲美的发展速度高速增长，行业的大规模增长使得众多制造商安装新设备以提高生产能力。

4. This is needed when using appliances that only work from a mains voltage AC supply.

参考译文：当使用的设备只从一个交流电源得到电力供应的情况下这样是必要的。

5. In addition to financial support from the government of China, various international funding agencies have supported the photovoltaic program from time to time.

参考译文：除了中国政府的资金支持外，各种国际基金机构也时常对光伏项目进行资助。

1.4 The Future of Photovoltaic

Though the photovoltaic industry has experienced a phenomenal annual 20% growth rate over the last decade, it has just started to realize its potential. While over a million households in India alone get their electricity from solar cells, more than two billion still have no electrical service. The continuing revolution in telecommunications is bringing a greater emphasis on the use of photovoltaics. As with electrical service, the expense of stringing telephone wires keeps most of the developing world without communication services that people living in the more developed countries take for granted. Photovoltaic-run satellites and cellular sites, and a combination of the two, offer the only hope to bridge the digital divide. Photovoltaics could allow everyone the freedom to dial up at or near home and of course, hook up to the Internet.

Opportunities for photovoltaics in the developed world also continue to grow. In the U.S. and Western Europe, thousands of permanent or vacation homes are too distant for utility electric service. If people live in a vacation home that is more than 250 yards from a utility pole, paying the utility to string wires to their place costs more than supplying their power needs with photovoltaics. Fourteen thousand Swiss Alpine chalets and thousands of others from Finland to Spain to Colorado get their electricity from solar energy.

Many campgrounds now prohibit recreational vehicle (RV) owners from running their engines to power generators that run appliances inside the campground. The exhaust gases pollute, and the noise irritates other campers, especially at night. Photovoltaic panels, mounted on the roofs of RVs, provides the electricity needed without bothering others.

Restricting carbon dioxide emissions to help moderate global warming could start money flowing from burning fossil fuels to photovoltaic projects elsewhere. The damage wrought by the 1997-1998 El Nino gives us a taste of the harsher weather expected as the Earth warms. The anticipated increase in natural disasters, brought about by a more disastrous future climate, as well as the growing number of people living in catastrophe-prone regions, make early warning systems essential.

The ultimate early warning device may consist of pilotless photovoltaic-powered weather surveillance airplanes, the prototype of which is the Helios. The Helios has flown higher than any other aircraft. Solar cells make up the entire top of the aircraft, which consists of only a wing and propellers. Successors to the Helios will have fuel cells on the underside of the wing. They will get their power from the photovoltaic panels throughout the day, extracting hydrogen and oxygen from the water discharged by the fuel cells the night before. When the sun sets, the hydrogen and oxygen will power the fuel cells, generating enough electricity at night to run the aircraft. Water discharged in the process will allow the diurnal cycle to begin the next morning. The tandem use of solar cells and fuel cells will allow the aircraft to stay aloft forever, far above the turbulence, watching for and tracking hurricanes, and other potentially dangerous weather and natural catastrophes.

Revolutionary lighting elements called light-emitting diodes (LEDs) produce the same quality of illumination as their predecessors with only a fraction of energy. LEDs therefore significantly reduce the amount of panels and batteries necessary for running lights, making a photovoltaic system less costly and less cumbersome. They have enabled photovoltaics to take over from gasoline generators the mobile warning signs used on roadways to alert motorists about lane closures and other temporary 16 John Perlin cis Group, LLC Copright 2005 by Taylor & Francis Group, LLC problems that drivers should know about. The eventual replacement of household lighting by LEDs will do the same for photovoltaics in homes.

To bring photovoltaics to mainstream will require further reductions in their cost. Many researchers believe that greater demand could do the trick because for every doubling of production, the price drops 20%. Others believe that new methods of producing silicon solar cells will drop the price significantly. Some researchers are exploring the development of producing less expensive silicon feed stock. At present, most photovoltaic material is made from silicon grown as large cylindrical single crystals or cast in multiple-crystal blocks. Cutting cells only 300 or 400 mm thick from such bulky materials demands excessive cutting, and half of the very expensive starting material ends up on the floor as dust.

New less costly and wasteful ways of manufacturing solar cells promise much lower prices. A number of companies, for example, have begun producing cells directly from molten silicon; the hardened material, only about 100 mm thick, is then fitted into modules. Other companies have developed processes to spray photovoltaic material onto supporting material. All these new techniques have potential for mass production. There are skeptics, however, who believe that today's techniques will never reach a low enough price for mass use. Some optimists see emerging nanotechnology as the answer. Authors contributing to this book are working with organic compounds that can absorb light and change it into electricity. They envision depositing these compounds on film-like material, which would cost very little to produce, and could be easily adhered to building surfaces. Commercialization is yet to begin.

In truth, the number of potentially inexpensive ways to make solar cells being pursued is dazzling. When Bell Laboratories first unveiled the silicon solar cell, their publicist made a bold prediction: The ability of transistors to operate on very low power gives solar cells great potential and it seems inevitable that the two Bell inventions will be closely linked in many important future developments that will influence the art of living.

Already, the tandem use of transistors and solar cells for running satellites, navigation aids, microwave repeaters, televisions, radios, and cassette players in the developing world and a myriad of other devices has fulfilled the Bell prediction. It takes no great leap of the imagination to expect the transistor and solar cell revolution to continue until it encompasses every electrical need from space to Earth.

From Organic Photovoltaics, by Sam-Shajing Sun, 2005.

New Words and Expressions

1. phenomenal [fi'nɒmɪn(ə)l] adj. 现象的；显著的；异常的；能知觉的；惊人的，非凡的
2. potential [pə t enʃl] n. 潜能；可能性；[电] 电势 adj. 潜在的；可能的；势的
3. households ['haʊshəʊld] adj. 家庭的；日常的；王室的 n. 家庭；一家人
4. emphasis ['emfəsɪs] n. 重点；强调；加强语气 复数 emphases
5. expense [ɪk'spens; ek'spens] n. 损失，代价；消费；开支 vt. 向…收取费用 vi. 被花掉 过去式 expensed 过去分词 expensed 现在分词 expensing
6. permanent ['pɜː m(ə)nənt] adj. 永久的，永恒的；不变的 n. 烫发（等于 permanent wave） 比较级 more permanent 最高级 the most permanent
7. utility [juː t ɪləti] n. 实用；效用；公共设施；功用 adj. 实用的；通用的；有多种用途的 复数 utilities
8. campgrounds ['kæmpgrəʊnd] n. 露营场所；野营地

9. recreational vehicle 野营旅游车；休闲车
10. appliance [ə'plaɪəns] n. 器具；器械；装置
过去式 applianced 过去分词 applianced 现在分词 appliancing
11. mount [maʊnt] vt. 增加；爬上；使骑上马；安装，架置；镶嵌，嵌入；准备上演；成立（军队等） vi. 爬；增加；上升 n. 山峰；底座；乘骑用马；攀，登；运载工具；底座 n. （英）芒特（人名） v. 登上；骑上
12. disaster [dɪ'zɑːstə] n. 灾难，灾祸；不幸
13. discharge [dɪs'tʃɑːdʒ] vt. 解雇；卸下；放出；免除 vi. 排放；卸货；流出 n. 排放；卸货；解雇 过去式 discharged 过去分词 discharged 现在分词 discharging
14. diurnal cycle [植] 昼夜循环
15. tandem ['tændəm] n. 串联；串座双人自行车 adj. 串联的 adv. 一前一后地；纵排地
16. aloft [ə'lɒft] adv. 在空中；在高处；在上面 prep. 在……之上；在……顶上 adj. 在空中的；在高处的；在上面的
17. turbulence ['tɜːbjʊl(ə)ns] n. 骚乱，动荡；[流] 湍流；狂暴
18. natural catastrophe 自然灾害
19. light-emitting diodes (LEDs) 发光二极管
20. cumbersome ['kʌmbəs(ə)m] adj. 笨重的；累赘的；难处理的
21. adhere to 坚持；粘附；拥护，追随
22. commercialization [kəˌmɜːʃəlaɪ'zeɪʃən] n. 商品化，商业化
23. dazzling ['dæzlɪŋ] adj. 耀眼的；眼花缭乱的 v. 使……眼花（dazzle 的 ing 形式）
24. unveil [ʌn'veɪl] vt. 使公之于众，揭开；揭幕 vi. 除去面纱；显露
25. transistors [træn'zistəz] n. [电子] 晶体管；晶体三极管（transistor 的复数）
26. navigation aid 助航设备；导航设施
27. encompass [ɪn'kʌmpəs; en'kʌmpəs] vt. 包含；包围，环绕；完成

Notes

1. As with electrical service, the expense of stringing telephone wires keeps most of the developing world without communication services that people living in the more developed countries take for granted.

参考译文：就像用电服务一样，延伸电话线的成本使得大部分发展中国家没有通讯服务，而这样的通讯服务在发达国家被认为是理所应当的。

2. To bring photovoltaics to mainstream will require further reductions in their cost.

参考译文：让光伏发电成为主流能源需要进一步降低其成本。

3. There are skeptics, however, who believe that today’s techniques will never reach a low enough price for mass use.

参考译文：然而怀疑论者认为，当前的科技水平无法支持光伏发电达到大规模应用的低价格。

Reading Material

Survey of photovoltaic industry and policy in Germany

Technology improvements and cost reductions result from the exploration of improvement opportunities and the search for alternatives by individual actors. The industry structure impacts on their incentives and ability to pursue innovative activities and is therefore characterized for Germany (late 2009).

The German photovoltaic industry includes around 70 manufacturers (of silicon, wafers, solar cells, and modules), more than 100 PV equipment manufacturers, and employs more than 57,000 people. German PV industry sales surpassed the €9.5 billion mark in 2008, while PV equipment supplier sales accounted for an additional €2.4 billion(GTAI, 2009c). **Fig. 1.8** shows the biggest PV manufacturers in Germany, with their respective capacities in 2009, along the (crystalline) PV production chain. The number of companies in the first stage of the PV production chain (dominated by Wacker Chemie AG) is small, polysilicon production and processing require intensive technical knowledge and substantial investment. Towards the end of the production chain, the number of manufacturers is larger, due to lower investment requirements and less knowledge-intensiveness required. There are also fully integrated companies combining wafer, cell, and module manufacturing, such as Solar World, Conergy and Sovello.

Fig. 1.8 PV manufacturers in Germany along production chain. Excluding companies active in thin film technologies, based on data from GTAI (2009a).

Fig. 1.9 shows PV equipment manufacturers in Germany active in different stages along the crystalline production chain, in the field of thin film technologies, as well as in the areas of automation and laser processing. While some companies offer turnkey lines for thin film devices, crystalline cells or modules, other equipment producers supply specific tools, for instance tabbers and stringers for crystalline modules.

Fig. 1.9 PV equipment manufacturers in Germany. The legend shows only companies with 400þ employees, based on data from GTAI (2009b).

Equipment suppliers that have developed their skills in supporting manufacturing of semiconductors, chemicals, optics and glass, have devoted their expertise to PV manufacturing and have been instrumental in the successful development of the German photovoltaic cluster. **Fig. 1.10** shows the activities of equipment manufacturers in the related semiconductor, medical, and automotive industries.

Since 1991, systematic governmental support schemes for PV installations have been implemented in Germany. The Electricity Feed-in Act (Stromeinspeisegesetz 1991–1999/2000) was the first policy to provide incentives for renewable electricity generation. The “1000 Solar Roofs Initiative”, which was applied between 1991 and 1995, was the first PV-specific support scheme, and was followed in 1999–2003 by the “100,000 Solar Roofs Initiative”, which similarly provided loans at low interest rates for PV installations. These loans were granted by the state-owned German development bank (KfW). A feed-in tariff scheme with PV-specific support levels was established in

2000 (Renewable Energy Sources Act, EEG), and was amended in 2004 and 2009.

Fig. 1.10 PV equipment manufacturers in Germany—sector background (activity insectors). Based on data from GTAI (2009b).

Fig. 1.11 gives an overview of the current PV support measures applicable in Germany. Within the German strategy of fostering the deployment of renewable energy sources, the feed-in tariff scheme is the core element, supported by additional measures such as public support of R&D for PV technologies and investment support schemes for manufacturing plants.

Fig. 1.11 PV support measures in Germany (with main criteria applied to allocate support) and their target groups.

The Renewable Energy Sources Act Erneuebaren-Energien-Gesetz (EEG) is applied to power generation from renewable energy sources, including wind, water, biomass, landfill-, firedamp- and biogas, as well as geothermal and solar energy. Among the supported technologies, it grants the highest feed-in tariffs to electricity produced by photovoltaic devices. These tariffs are graded according to PV system capacity (with thresholds of 30 kW, 100 kW and 1000 kW) and installation types (roof-top and field installations). The feed-in tariffs are paid for a time period of 20 years. **Table 1.7** gives an overview of the recent German PV feed-in tariffs.

Table 1.7 PV feed-in tariffs according to German EEG. Sources: (EEG, 2008; BMU, 2010b; BNetzA, 2010b)

At the beginning of 2010, the tariffs saw a reduction of 11% and 9% (for roof-top installations ≤ 100 kW), respectively, in comparison to 2009 levels. However, as system prices fell much faster in 2009 than originally expected, the German government decided additionally to cut back the feed-in tariff in July 2010 and October 2010, as shown in **Table 1.7**. The feed-in tariff for ground-mounted systems on agricultural fields was stopped in July 2010 (IEA, 2010). Between 2003 and 2009, the present value of the PV feed-in tariff subsidy in Germany amounted to €4270 quintillion per year on average. New PV installations increased strongly in 2008 and 2010 (see **Fig. 1.12**), after the PV feed-in tariff was raised in 2008, and after system prices decreased strongly in 2010. The total system expenditure for PV installations represented this development in the respective periods, as shown in **Fig. 1.13**. Additional national market stimulation schemes are provided by the state-owned German development bank (KfW) through the following loan programs for PV investments (IEA, 2009):

- “Erneuerbare Energien Standard”: Loans for private PV investments;
- “Kommunal investieren”: Loans for PV investments by communities and their enterprises;
- “KfW—Kommunalkredit”: Loans for investment in the infrastructure of communities to save energy and change to renew- able energies.

Germany offers different investment incentive programs which can be categorized into three groups:

- grants/cash incentives (including the Joint Task program and the Investment Allowance program);

- reduced-interest loans(at national and state level); and
- public guarantees (at state and combined state/federal level).

Fig. 1.12 World Annual PV Installations

Fig. 1.13 Total system expenditure for PV installations in Germany

The same conditions apply to German and foreign investors. Funding is provided by the German federal government, the European Union (EU), and the individual federal states of Germany. The EU provides the legal and financial framework for public funding in all EU Member States.

Eligible industries, forms of investment and general program requirements are defined by each incentives program. Specific criteria within each program determine individual investment incentives rates. The highest incentive levels are usually offered to small and medium-sized enterprises (SMEs). In the following sections, we will focus on incentive levels for large enterprises, because that is the typical scale of PV manufacturers (the following criteria specify the size of large enterprises in the European Union: staff headcount ≥ 250 and annual turnover > €50 m or annual balance sheet total > €43 m).

Responsibility for renewable energies within the German Federal Government belongs to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Research and Development on different aspects of PV is supported by the BMU, as well as the BMBF (Federal Ministry of Education and Research). While BMBF supported for PVR&D projects amounted to €19.5 million in 2008 (8 co-operative R&D projects were granted), the BMU's R&D budget for PV totaled €39.9 million, shared between130 projects (IEA, 2009). In comparison to these public PVR&D budgets, industrial R&D investments amounted to €163 millionin 2008 (BSW-Solar, 2010).

Within the BMU funding activities, selection criteria for PV research projects are (BMU, 2010a):

- industry participation and networking structure, with preference on collaborative projects;
- development risk and implementation time;
- the possibility to spread research findings, while considering the protection of findings through patents.

Table 1.8 shows the distribution of the BMU funding. While wafer-based silicon technologies received more than half of total funding, around one-fifth was allocated to thin-film technologies. Support is also provided for alternative concepts such as concenrating photovoltaics.

Table 1.8 Newly approved PV funding from BMU.

In 2008, the BMBF setup networks aiming for the development of thin-film PV cells with a focus on topics such as material sciences and the use of synergies with other research fields, such as microelectronics. Meanwhile, the development of organic PV cells is being addressed by a joint initiative with the industry. As part of the Federal High-Tech Strategy, BMBF also supports the development of the "Solarvalley Mitteldeutschland" cluster, which covers most of the German PV industry.

Within the initiative "Innovationsallianz Photovoltaik," which was announced in 2010, BMU and BMBF will provide €100 million for new R&D projects during the next four years. The focus of this initiative is on improving production costs and efficiencies of photovoltaics. The European Union's main instrument for funding research in Europe is the Seventh Framework Programme for Research and Technological Development (FP7). This program runs from 2007 until 2013.

From Energy Policy, by Thilo Grau, 2012.

New Words and Expressions

1. exploration [eksplə'reɪʃ(ə)n]　n. 探测；探究；踏勘
2. alternative [ɔ：l'tɜ：nətɪv; ɒl'tɜ：nətɪv]　adj. 供选择的；选择性的；交替的　n. 二中择一；供替代的选择
3. innovative activity　创新活动
4. equipment [ɪ'kwɪpm(ə)nt]　n. 设备，装备；器材
5. surpass [sə'pɑ：s]　vt. 超越；胜过，优于；非……所能办到或理解
6. account for　对……负有责任；对……做出解释；说明……的原因；导致；（比例）占
7. devote [dɪ'vəʊt]　vt. 致力于；奉献
   过去式 devoted 过去分词 devoted 现在分词 devoting
8. automotive industry　汽车工业；汽车制造业
9. applicable [ə'plɪkəb(ə)l; 'æplɪkəb(ə)l]　adj. 可适用的；可应用的；合适的
10. foster ['fɒstə]　vt. 培养；养育，抚育；抱（希望等）　adj. 收养的，养育的
11. deployment [di：'plɒɪmənt]　n. 调度，部署
12. feed-in tariff　固定价格
13. agricultural field　农田
14. eligible ['elɪdʒɪb(ə)l]　adj. 合格的，合适的；符合条件的；有资格当选的　n. 合格者；适任者；有资格者
15. medium-sized ['mi:diəm'saizd]　adj. 中型的，中等大小的；普通型的
16. allocate ['æləkeɪt]　vt. 分配；拨出；使坐落于　vi. 分配；指定
   过去式 allocated 过去分词 allocated 现在分词 allocating
17. synergy ['sɪnədʒɪ]　n. 协同；协同作用；增效　复数 synergies
18. joint [dʒɒɪnt]　n. 关节；接缝；接合处，接合点；（牛，羊等的腿）大块肉　adj. 共同的；连接的；联合的，合办的　vt. 连接，贴合；接合；使有接头　vi. 贴合；生节

Notes

1. Towards the end of the production chain, the number of manufacturers is larger, due to lower

investment requirements and less knowledge-intensiveness required.

参考译文：在生产链的终端，制造商的数量是比较多的，因为在此阶段需要的投资较少、知识储备较少。

2. As part of the Federal High-Tech Strategy, BMBF also supports the development of the ‘‘Solarvalley Mitteldeutschland’’ cluster, which covers most of the German PV industry.

参考译文：作为联邦政府的高技术战略的一部分，德国联邦教研部也支持“德国太阳谷”集群的发展，它涵盖了大部分的德国光伏产业。