Global Solar Photovoltaic Industry Analysis with Focus on the Chinese Market

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ABSTRACT

As climate change is emerging as a manageable and predictable global problem, several industries are shifting the focus of their business to include the reduction of greenhouse gasses. This is seen in most power generation technologies, but none have shown the sustained level of growth as that of solar power. Year over year the photovoltaic industry continues to return growth rates around 30%. What is it about solar power that has attracted such a large amount of investment? An analysis on the growth rates, technological advancements and largest businesses in China will demonstrate how China is positioned to become the next world leader in photovoltaic manufacturing. The research was done mainly through literature review and data collection, focusing mainly on Chinese companies performance in the last decade. There has being a also a strong study in the European strategies to increase the use of PV technologies, from European manufacturing methods and technologies used, to local policies and government incentives.
1 Introduction and Background

1.1 Background

With global CO$_2$ emissions rising at an exponential rate, and the fact that 19 of the 20 hottest years on record have occurred since 1980, there is a global need for a shift in energy supply from fossil fuels to renewable energy.[1] Furthermore, as instability in the world's oil producing countries increases, it is becoming ever more important for developed nations to reduce reliance on fossil fuels. Of the sustainable energy technologies that currently exist, solar power has the most potential for growth in the long term, and if it is adopted at considerable levels, solar power could have a significant impact on the reduction of CO$_2$ emissions and increased energy security.[2]

For the past decade photovoltaics have enjoyed an average of 30% growth across the global spectrum with certain hot spots in Europe, the United States and Japan. There are many explanations as to why this is happening, such as government policy, the increase in fossil fuel prices and decrease in availability, and also enhancements in the technology due to research and development. But will this trend continue and in which region will we see the biggest development?

It is likely that China will soon become a world player in the PV sector since for the past 7 years, they have sustained a 70% annual growth in production capacity.[3] As with many other products, China has become the production hub of the world and photovoltaics is not an exception. However, there are many obstacles to overcome. China's ability to grow is somewhat hindered by the global silicon shortage as well as a lack of government support for the growth of the domestic market. Currently China does not possess the same level of manufacturing technology as the world leaders such as Germany, Japan and the United States. This results in higher costs and a less efficient products.

Yet there is a disconnect – even though there is considerable expansion capacity in China there is still uncertainty about whether China will be able to develop their own domestic market thereby increasing capacity and foreign investment. So in this case, will China remain a purely exporting country? Europe holds a tradition of dedicated research and development while China is a global leader in manufacturing and through a coordinated effort, a relationship between these two regions will form an almost limitless solar industry. There is certainly a need for investigation in the solar
energy market to get a better understanding of how the major players will shape the future of solar industry.

1.2 Objective of the study

The main goal of this study was to determine the market dynamics of solar energy worldwide with focus on China's potential for domestic and international expansion. The market development of solar energy is strongly dependent on the policy, technology development and transfer, and economics of solar energy products. Thus, state of the art of technologies were surveyed by analyzing public and academic documents. Policy incentives used stimulate the solar energy market were also reviewed. The needs for the cooperation between Europe and China was discussed to address the feasibility of the technology expansion.

1.3 Methodology

A combined methodology was employed, using both quantitative and qualitative instruments. Data was collected from a variety of European companies to gain a clear perspective on their approach to expansion into the Chinese market, as well as their business objectives within Europe. Next a literature review was performed to examine both the political climate in both regions of the study as well as social aspects affecting both Europe and China.


2 Introduction to Photovoltaics and Energy Economics

2.1 A History of Solar Energy

World Historical Overview

In 1839 a French physicist first discovered the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes.[4] After, the first intentional PV device was developed by the American inventor Charles Fritts in 1883. He melted selenium into a thin sheet of on a metal substrate and pressed gold-leaf film as the top contact. Later on, in 1954 researchers at Bell Labs accidentally discovered that p-n junction diodes generated a voltage when the room lights were on. Within a year they had produced a 6% efficient silicon p-n junction solar cell. The same efficiency was achieved the same year by the group at Wright Patterson air force base in the USA, only this time, they used a thin-film hetero-junction solar cell based on Cu2S/CdS. By the year 1960, several documents were written showing different solar cells built using different materials for the p-n junction, some key documents written by Prince, Loferski, Rappaport and Wysoski, Shockley and Queisser developed the fundamentals of p-n junction cell operation including the theoretical relationship between band gap, incident spectrum, temperature, thermodynamics and efficiency [5]. In the years to come the US and the USSR space programs played an important role in the R&D of solar cells, since they were the main energy source to power their satellites.

The year 1973 was very important for PV technological advancement. First the “violet cell” was developed, having an improved short wavelength response leading 30% relative increase in efficiency over the most advanced silicon cells at that time. Also, the same year an important event occurred called the Cherry hill conference. During this event a group of PV researchers and heads of US government scientific organizations met to evaluate the scientific merit and potential of photovoltaics. The outcome was the decision that photovoltaics was worthy of government support, resulting in the formation of the US Energy Research and Development Agency, the world's first government group setup whose mission included fostering research on renewable energy, which ultimately became the US dept of Energy. Finally in October, the first oil crisis pressed all the governments worldwide to encourage the use of renewable sources of energy, especially solar. [5]

From this point, solar research had the momentum and funding it needed from fuel providers, electric utilities and other interested parties to make a real impact on the energy industry. However,
this didn't last long because in 1982 the public funding was cut by the national governments worldwide. It is due to this withdrawal of support that has left the impression that solar power cannot succeed without substantial subsidies. Yet progress did not stop, it just switched direction and rapid changes in the technology and PV industry and parties interested took place to begin a transformation of the energy industry. All around the world energy sustainability was getting more attention because of energy security issues and climate change. But the reasons for these sustainable changes should not only be attributed to social environmental consciousness. The main driving factor, as with almost all emerging industries, is economic sensibility.

At the same time the fossil fuel industry was experiencing problems with supply and cost, China's economy was developing at incredible rates. As of 2005, for example, China accounted for almost 30% of global growth where the European community accounted for just 5%. And as China develops, the amount of oil needed for economic expansion is comparatively more per unit of growth [6]. All of this indicates that even with the most optimistic view of conservation programs, sustainable energy generation will have to increase if development is expected to continue at current rates. Fortunately a healthy mix of sustainable energy generation technologies along with the gradual phasing out of widespread fossil fuel use is one likely scenario for the future.

However, the most recent expansion of solar power is occurring mainly in Germany and Japan. At first glance this might seem surprising since neither Germany or Japan have a large amount of sunlight, but their lack of fossil fuel sources combined with a national government committed to sustainable energy programs have enabled solar power to thrive. Together these two countries, with Japan's sunshine program and Germany's 100,000 solar roofs program along with several government subsidies account for a full 69% of the world market for PV as of 2005. Also, the rate at which this market is expanding is encouraging - from 85 MW in 1995 to 1.1 GW globally in 2005. So the question here is: how can the PV industry take advantage of China's booming economy? It is clear that the proliferation of PV technology in China will not be routed in environmental policy so what will be the driving force?

**Chinese Historical Overview**

The first PV manufacturing companies were established in China during the late 1970’s mainly to help supply the demand of the first pilot space and terrestrial applications that where launched during these years [3].
Initially, these first companies were using waste raw material from the integrated circuit (IC) industry, but during the years 1985 to 1990, China used solar cell manufacturing equipment mainly from the USA. The first two large scale cell manufacturers in China were Ningbo and Kaifeng, with government support, they introduced key equipment into their cell manufacturing process. After, Qinghuangdao Huamei began production by purchasing new solar cell manufacturing equipment. Next, Yunnan Semiconductor started manufacturing with second-hand production equipment. Finally, Shenzhen Yukang and Haerbin Keluona set up a non-crystalline silicon solar cell manufacturing production, being the last ones of this period. By 1990 solar Chinese companies had established a total manufacturing production capacity of 4.5MWp [7].

During the next few years, the main companies began to innovate in solar technology, the production of solar cells increased and the manufacturing process improved. However, the first generation of manufacturers were very dependent upon the central government’s policies and by that time the government did not provide enough incentives to innovate and experiment with new technologies. Therefore, even though China had a total manufacturing capacity of around 5MWp, a lot less was actually produced due to serious equipment bottlenecks in different parts of these production lines. By 1998 3MWp of solar cells were actually produced [8].

After the year 2000 China experienced an era of very rapid growth within the solar market, in particular for solar thermal applications. New companies starting to appear, but in this case, with private/public partnerships, therefore all the producers were driven by a global market demand and were not dependent on the central government’s policies. Some of their manufacturing equipment still had to be imported, but in this case from Europe and not from the USA, while the rest of the equipment was produced domestically.

In 2001, Baoding Tianwei Yingli Solar became the first company to manufacture using single crystal instead of crystal silicon solar cell manufacturing technology and built a 3MWp polysilicon solar cell manufacturing production line. Another company, Wuxi Sun Tech built a 10MWp solar cell manufacturing production line [7].

Due to the rapid market demand in Europe (especially Germany) between 2003 and 2006 market Wuxi Sun Tech and Baoding Tianwei Yingli Solar expanded their capacity to meet demand, and more companies began to build solar cell manufacturing production lines.
In the R&D area, during the 2001-2005 period, between 5.2-6.2 M € were provided for PV research, development and demonstration projects. The public budget provided for the next five year plan (2006-2011) is 12.4 M €. As a comparison Germany's devoted a budget for R&D of 24.4M € while Japan invested 147 M € [3].

<table>
<thead>
<tr>
<th>Solar cell</th>
<th>Crystal-silicon solar cell</th>
<th>Non crystal-silicon solar cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>1673 MWp</td>
<td>1629 MWp</td>
<td>44 MWp</td>
</tr>
</tbody>
</table>

*Table 1. China solar cell capacity, year-end 2006 Source: THT Research*[7]*

Of all the material technologies that can be used to manufacture solar cells, only two are being produced in an industrial scale, mono crystalline silicon (mono-Si) and polycrystalline silicon (poly-Si). Amorphous silicon is also being produced but at a much lower scale (less than 10% of the total production). In this aspect, China follows the world's trend in PV manufacturing technology, where technologies based on crystalline silicon account for 93% of the world market share [7].

China has invested a very limited amount of money in R&D compared to some other countries, their main interest has been focused in decreasing the production cost per unit and increase the quantity of modules produced using the technologies available in the market rather than improving them or developing new ones that could achieve higher efficiencies or produce a noticeable decrease in the use of silicon [3].

<table>
<thead>
<tr>
<th>Category</th>
<th>China</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Efficiency (%)</td>
<td>Area (cm²)</td>
</tr>
<tr>
<td>Silicon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono-Si cell</td>
<td>20.4</td>
<td>4.00</td>
</tr>
<tr>
<td>Poly-Si cell</td>
<td>16.0</td>
<td>4.00</td>
</tr>
<tr>
<td>Si (thin film)</td>
<td>13.6</td>
<td>1.00</td>
</tr>
<tr>
<td>In-V Cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaAs (crystalline)</td>
<td>21.9</td>
<td>1.00</td>
</tr>
<tr>
<td>Thin-film chalcogenides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIGS (cell)</td>
<td>12.1</td>
<td>1.00</td>
</tr>
<tr>
<td>CdTe (cell)</td>
<td>13.36</td>
<td>0.5</td>
</tr>
<tr>
<td>Amorphous Si</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si (amorphous)</td>
<td>8.6</td>
<td>100</td>
</tr>
</tbody>
</table>

*Source: China's cells efficiency in laboratory: REDP21 world's solar cell efficiency: Green et al.22*

*Table 2.Best conversion efficiency of various solar cells developed in laboratories in China and in the world [3]*

7
Table 2. Commercial solar PV module efficiency in China and in the world

<table>
<thead>
<tr>
<th>Category</th>
<th>China</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Efficiency (%)</td>
<td>Module (model and dimensions)</td>
</tr>
<tr>
<td>Mono-Si module</td>
<td>14</td>
<td>Suntech STP175-24/Ab, 1580 × 808 × 50 mm</td>
</tr>
<tr>
<td>Poly-Si module</td>
<td>13</td>
<td>Suntech STP60-12/Nb, 955 × 453 × 30 mm</td>
</tr>
<tr>
<td>a-Si</td>
<td>5</td>
<td>Soltech PVS 60-24, 1549 × 787</td>
</tr>
</tbody>
</table>

Source: PV module manufacturer’s product specification on their corporate website [23, 24, 25, 26].
Note: Efficiency was calculated as module power divided by total module area.

Finally, the increase in Chinese production compared with the global trend is of great interest. While global PV production has been growing at an average rate of 36%, the annual growth capacity in China is nearly double that of the rest of the world with an average annual rate production of 70%. It remains to be seen if China will be able to continue with this incredible growth rate, however, there is much innovation and manufactures across the PV supply chain have come up with some interesting strategies which are explored later in this paper.[3]

2.2 PV Operation Principles

As its name implies, photovoltaics is a technology that converts light (photo) directly into electricity (voltaic). The name of the individual photovoltaic element is known as solar cell, which is made out of materials called semiconductors.

The most used semiconductor material is silicon, which in its naturally occurring state has the unique property of 4 electrons in its outer orbit, allowing them to form perfect covalent bonds with four neighbouring atoms, thus creating a lattice. The obtained crystalline form is a silvery, metallic-looking substance.

In its pure state, crystalline silicon is a poor conductor, due to the fact that all of the electrons in the outer orbit are bonded and cannot freely move. To change this behaviour, pure silicon has to go through a process called doping. In this process some “impurities” (eg. C, N, As, B) are added to the material [9].
According to the type of material added, the semiconductor receives the P or N classification.

- **N-Type**: Arsenic or phosphorous is added and since each element has 5 electrons in their outer orbit, there is one electron that has nothing to bond to, therefore is free to move within the material. By adding several atoms of arsenic or phosphorous, enough electrons will be able to move, allowing an electrical current to flow through the material. The name “n-type” comes from the electron's negative charge.

- **P-type**: Boron or gallium is added. In this case each one has only 3 outer orbit electrons, and when added to pure silicon, there is a hole in the structure where one silicon electron has nothing to bond to and is free to move. The absence of electrons creates the effect of positive charge, hence the “p-type” name [10].

These electrons are occupying a band of energy called the valence band. When some energy is applied and exceeds a certain threshold, called the band gap, these electrons are free to move in a new energy band called the conduction band, where they can conduct electricity through the material.

The energy required for the electrons to migrate to the conduction band can be provided by photons which are particles of light. Figure 1 shows the idealized relationship between energy (vertical axis) and the spatial boundaries (horizontal axis). When the solar cell is exposed to sunlight, photons hit the electrons in the valence band and give them enough energy to migrate into the conduction band. There, a n-doped semiconductor contact collects the conduction-band electrons and drives them to the external circuit where they can be used to create electricity. Then they are restored to the valence band at a lower (free) energy through the return circuit by a p-doped semiconductor contact.
This is all possible because sunlight is a spectrum of photons distributed over a wide range of energy. Photons with greater energy than the band gap can drive electrons from the valence band to the conduction band and can travel through the external circuit to produce work. Photons with less energy than the band gap cannot excite the free electrons, and instead, that energy travels through the solar cell and is absorbed as heat.

The voltage at which electrons are delivered to the external circuit are slightly less than the band gap. This voltage is measured in units of electron volts (eV), thus in a material with 1eV band gap the voltage delivered by a single cell is around 0.7V. Therefore multiple cells are connected together (usually 36) and encapsulated into units called PV modules which is the product usually sold to the customer.

2.3 Attempts at Commercialization

Solar power has certainly had chances in the past to commercialize but did not succeed on a large scale. In the first instance of interest, solar collectors at the beginning of the 20th century were widely being used for agricultural irrigation. Also, the American Southwest was a perfect testing ground for solar collectors, which by 1915, 30% of the homes in Pasadena California used solar energy to generate hot water. Aubrey Eneas, a solar entrepreneur in this Californian area, made a large effort to commercialize this technology and created a large truncated cone collector to heat water that powered a steam engine for running irrigation pumps. Unfortunately his designs were not
able to stand up to the unpredictable weather of this region such as dust devils, wind storms and hail. Eventually he gave up believing that this type of solar power would never become economically viable [2].

The next instance, through some very fortunate laboratory accidents at Bell Labs, came in 1954 with the first working photovoltaic cell. Naturally, the prospect of limitless energy from the sun was of great interest to the international scientific community and governments alike. Progress was swift and consistent as the emerging PV industry enjoyed dedicated support from governments and private funding. This continued through the 1970's and as a result of the oil shock, the US President Carter's administration approved a $3 billion program for the development of solar energy. The White House even showed its support by installing solar panels on the roof. However, this was the extent of the progress that started in in 1954 and as Ronald Reagan entered office in 1981, research and funding slowed dramatically. By 1986 the solar panel showcase on the roof of the White House was removed, funding for alternative fuels was cut and oil prices began to drop. The message was clear that solar power was not priority of the moment and would have to wait. And at this point, as the United States accounted for 80% of the world's solar power, their actions affected the rest of the world and overseas governments in Europe and Asia followed in step [2].

The reasons for the past failures to commercialize this technology are access to a cheaper and more available alternative to solar energy (fossil fuels) and a drastic change in political motivation. These 2 elements are no longer present which is why solar power will finally have a real chance to commercialize on a massive scale. First, the price of oil has risen dramatically from it's recent low in 1998 at $15.24 to it's current high which is consistently in the $50-$60 range [11]. The next motivator is the serious environmental situation facing the world. Environmentally responsible nations see sustainable energy as the main tool for reducing green house gas emissions, which is one aspect that did not exist in the past. Finally, as PV technology is being proven cost effective in some areas of the globe, most notably Germany and Japan, many other national governments wish to remain competitive in this high-tech field and have begun to develop their own solar infrastructure. Simply put, the hindrances that existed in the past no longer exist and there are several new motivations that almost guarantee solar power will continue to grow and become competitive with other forms of more conventional energy.
2.4 Applications of PV Technologies

Another dramatic change that occurred to help the industry expand was the increased use of PV for grid-connected applications. Typically, in the past, PV was dominated by off-grid applications where PV provided a more economic means of delivering electricity than connection to the grid or the use of batteries. Off-grid applications can take many forms, such as the familiar PV power calculator or also irrigation pumps and freshwater distillers for example. However these systems are limited to delivering power only when the sun is shining. Other larger systems for home power use can store electricity in batteries for use at night or seasonal storage. Another market segment which is perfect for PV is that of remote industrial photovoltaics. Remote lighting, highway construction signs and parking ticket dispensers are examples of this. A third market segment exists in rural electrification. Often it is too expensive to power a house located far away from existing power lines so instead of extending connection, a PV system including a battery and charge controller can be installed at a much lower cost. In developing countries, for example, an installation of 50 Wp PV for 500 $US can replace the monthly cost of kerosene, batteries and candles through a low-interest loan from institutions such as the World Bank [12].

These PV applications are still expanding today, but in the mid to late 90's a dramatic shift of PV usage shifted towards grid-connected power. This is mainly due to the Japanese sunshine program and the German 100,000 solar roofs program. These initiatives were the result of increasing electricity prices, a will to escape dependence on foreign fossil fuels and environmental concern. While total solar applications have grown at a rate of 29% per annum, grid-connected applications have grown at a rate of over 50% per annum.

Another large PV application is centralized systems. In 2006, centralized PV systems only accounted for 2% of total installed power, but this is rapidly changing. In Sarnia, Canada, for example, the Ontario government has begun the process of installing 40MW of centralized PV power [13]. Furthermore, centralized PV systems have the potential to expand exponentially as about 1/3rd of the earth is covered by sun-rich deserts and if just 4% of this land area was used for PV, all of the world's energy needs would be covered (even with current efficiency levels) [2]. To achieve this, some some issues still have to be solved, such as electricity transmission, however the use of high voltage direct current (HVDC) transmission is likely to solve this problem since it can be cheaper than conventional AC transmission lines under certain conditions, and the losses in the system could also be significantly lower.
Also, a recent entrant and interesting business sector of PV is micro-scale PV systems. In the last few years, there has been a significant effort in the commercialization of these applications such as lightning systems for gardens, solar LED street lighting and some other stand-alone small applications. The price drop in PV systems and a more environmental global consciousness are helping these technologies spread fast and are becoming very common solutions for these very specific applications. Companies like China Technology Development Group currently offers have a wide range of this applications in their portfolio and are creating cooperation partnerships with companies in Europe to increase their position in the market [14].

2.5 Current Situation of Photovoltaic Industry

The current situation is positive, yet somewhat uncertain. As the silicon shortage is ending, there is some speculation about whether the companies who have committed to increase supply will follow through on their promises. The growth rate of the industry as a whole, although it has slowed a little in 2006 due to the shortage, is expected to increase again. Also, in lieu of the shortage, other technologies have stepped in to fill the gap. Thin-film technology is becoming much more competitive. A good example of this is the American company Nanosolar which is based in California. They have secured 100M US$ and are building a plant that will produce 430 MW of cells.[15] This number is extraordinarily large considering that in the year of 2006 only 1.520 MW were installed worldwide.[16]
The current worldwide capacity as of the end of 2006 was 5.737 MW where 588 MW was used for off-grid applications. The European Union accounts for more than half of the installed PV with 3.220 MW of which 112 MW is off-grid. If these figures are put over population, the EU also becomes the region with the highest per capita usage with 6,533 Wp/capita, mainly thanks to Germany which produces 34,8 Wp/capita. Japan produces 13,4 Wp/capita, but both Germany and Japan are behind the world leader: Luxembourg 50,54 Wp/capita. Yet, with a population of less than 500,000, Luxembourg does not have to face the same challenges of scale as Germany and Japan.[16]

The main driving force for the increased production of PV in recent years is the reduction in price thanks to both economies of scale and incentive programs. New incentive programs are appearing in many emerging markets as well, most of which are following the hugely successful German feed-in tariff program. For example, Canada has begun using a feed-in tariff under the Renewable Energy Standard Offer Program of 0.42 CAD/kWh for grid-connected PV and is expected to become a renewable energy hot spot for North America. France has an even higher tariff which can reach up to 0.55 EUR/kWh when used in the form of building integrated photovoltaics (BIPV). Italy also instituted their own version of the German system and offered 0.445 and 0.490 EUR/kWh, however they were not as successful in 2006, their launch year.[17]

The main players in the PV industry are divided across the supply chain, some focusing on the production and refining of feedstock materials, some involved in the fabrication of PV wafers, cells and modules and some have even stretched themselves across the chain and are involved everything from silicon extraction to the fabrication and installation of PV arrays. The leading companies involved in silicon production are Hemlock, Wacker and REC. All 3 of these companies have begun the process of expansion due to the increased need from the PV industry, but the extra output will not be ready to match the 2007 demand. The current leading cell manufacturers are Sharp, Q-Cells and Suntech. Each company has stated they plan to increase capacities even in the midst of the supply shortage. And it is this fact that has created some uncertainty in the market which is evident with falling stock prices from some of the major solar companies such as Sunergy, SunPower and Solarfun Power Holdings.[18]

Although the future of solar power looks bright, there are still many obstacles for solar companies world wide.
### 2.6 Causes for Photovoltaic Expansion

#### Political and Financial

Predicting any future scenario regarding future energy usage is a difficult task, and industry specialists from all forms of power generation have quite different opinions. However, one of the most cited models for predicting long term energy production originates from the U.S. Department of Energy's Energy Information Agency (EIA). This group is responsible for producing an annual forecast report for world energy use, titled the International Energy Outlook (IEO) as well as the Annual Energy Outlook (AEO) which includes predicted prices for fossil fuels and electricity. [19], [20].

![Figure 3. World energy consumption by region from 1970 to 2001 with forecast through 2025 (quadrillion Btu). Source: EIA (2004)[2]](image)

There are several problems with the assumptions made in these reports. Firstly, a critical mistake that has been made was the assumption that through productivity improvements, additional production and new pipelines, the inflation-adjusted price of energy will remain the same in 2025 as it is today even as the predicted need for fossil fuels will likely be 50% larger. Since peak production of oil has been reached and in 2004, the world required a full 99% of global capacity, there will likely be a sharp increase in price due to limited supply and increased demand. And to solidify
this point, in 2004 and 2005 when oil prices were 70% higher than 2002 levels, the increased price was higher than any point in the EIA forecast up to 2025. Naturally, a counter argument to this is that prices are cyclical and as the price of oil goes up, more is invested in infrastructure to increase supply and moderate the demand thereby lowering the price. However, at this stage, the scale and timeline do now allow for a significant price reversal. The reason for this is that investors are fully aware of the declining production and if growth rates are expected to be maintained, it is estimated that capital investment will have to increase to 500 billion $US annually between 2001 and 2030, a rate twice that of the 1990's. And to add to this, large new projects to increase production take years or even a decade to bring on-line, and in the meantime, as the early 2000's have shown, energy prices can fluctuate wildly during a project lifetime possibly making the net investment a loss.[2]

The second problem, which is a problem with all models about future energy scenarios, is the unforeseen political climate in the years to come. It has been proven recently how severely oil prices can be affected with conflicts in the Middle East. If instability continues, as it may well with the growing pressure between the United States and some middle eastern OPEC countries, oil prices could go up even higher if production levels are affected. This relates directly to a reliance on foreign energy, which is a major benefit of renewable energy, but since this threat is not quantifiable in financial term, this aspect is often overlooked in energy reports and only mentioned in a cursory manner. And with every international conflict involving oil supply, the case for solar power gains attention.

**Energy Payback Time**

One argument that has plagued PV power is that the energy payback time is too large, which is to say that the energy required to fabricate solar panel from silicon extraction and refining right up to installation and eventual decommissioning is too large to warrant the use of PV at all. The environmental question surrounding solar power indeed needs investigation, since currently the majority of energy generated is from unsustainable sources. After all, if solar panels required more energy in fabrication than they produced over their lifetime, there would be a net energy loss which would only contribute to environmental problems. Thankfully, although this was once the case, the gains in efficiency for solar panels have increased to a point where the energy payback period is just a fraction of a PV system's lifespan. Richards and Watt from the Centre for Photovoltaic Engineering at the University of New South Wales have rearranged the standard model and come up
with some modifications that put solar power on a more level playing field with conventional energy generation technologies.

The widely accepted but out of date formula for energy payback time is as follows:

\[
EPT = \frac{E_{\text{input}}}{E_{\text{gen}}}
\]

\[E_{\text{input}} = \text{PE requirement during module life-cycle (units of MJ)} = E_{\text{man}} + E_{\text{trans}} + E_{\text{inst}} + E_{\text{use}} + E_{\text{decomm}}\]

\[E_{\text{man}} = \text{PE requirement during module manufacturing including resource mining}\]

\[E_{\text{trans}} = \text{PE requirement during material and module transportation}\]

\[E_{\text{inst}} = \text{PE requirement during module installation}\]

\[E_{\text{use}} = \text{PE requirement during module operation}\]

\[E_{\text{decomm}} = \text{PE requirement during module decommissioning}\]

\[E_{\text{gen}} = \text{PE savings due to annual energy generation by PV module (units of MJ/y)}\]

This model misses one key factor, which is the lifetime of the module. The EPT in this form will yield a value that does not demonstrate the potential power generation after the full energy payback has been reached. Furthermore, using this type of indicator only serves to perpetuate the myth that PV is does not able to generate as much power as was needed to create it. Also, over the course of the lifetime of a PV system, there are several components that might need replacing such as an inverter, a battery bank or other structural components. This affects the EPT significantly and these factors are not as easily inserted into the original equations.[21]

The solution to this is relatively simple, but it completely shifts the objective of the calculation. Instead of looking at the amount of energy created versus the amount it required to build, the energy yield ratio, or EYR, can be used to show how many times the energy invested is paid back over the useful lifetime of the system. The equation for this is as follows:

\[
\text{EYR} = \frac{E_{\text{gen}}L_{\text{PV}}}{E_{\text{input}}}
\]

and a multi-component system is expressed as:
It can be seen here that if a product has a useful lifetime of 20 or 30 years (as is the case with many PV products today), the EYR reflects a much more useful figure to consumers.

\[
\text{EYR}_{\text{system}} = \frac{\sum_{i=1}^{n} \left( E_{\text{input}(i)} \frac{L_{\text{system}}}{L_i} \right)}{E_{\text{gen}} L_{\text{system}}}
\]

\[
= \frac{E_{\text{gen}} L_{\text{system}}}{\left[ \left( E_{\text{input}(\text{PV})} \frac{L_{\text{system}}}{L_{\text{PV}}} \right) + \left( E_{\text{input}(\text{inv})} \frac{L_{\text{system}}}{L_{\text{inv}}} \right) + \left( E_{\text{input}(\text{batt})} \frac{L_{\text{system}}}{L_{\text{batt}}} \right) \right]}
\]

It can be seen here that if a product has a useful lifetime of 20 or 30 years (as is the case with many PV products today), the EYR reflects a much more useful figure to consumers.

### Table 4: Calculated EPT and EYR (over both a 20 and 30 year period) for 3 selected scenarios[21]

<table>
<thead>
<tr>
<th>Scenario</th>
<th>EPT (y)</th>
<th>EYR_{20}</th>
<th>EYR_{30}</th>
<th>EPT (y)</th>
<th>EYR_{20}</th>
<th>EYR_{30}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1: mc-Si module</td>
<td>2.2</td>
<td>9.3</td>
<td>13.9</td>
<td>3.9</td>
<td>5.1</td>
<td>7.6</td>
</tr>
<tr>
<td>Scenario 2: 2 kWp rooftop mounted on-grid system</td>
<td>2.7</td>
<td>7.5</td>
<td>11.2</td>
<td>4.9</td>
<td>4.1</td>
<td>6.2</td>
</tr>
<tr>
<td>Scenario 3: 50 Wp solar home system (off-grid)</td>
<td>4.5</td>
<td>5.1</td>
<td>6.0</td>
<td>7.2</td>
<td>2.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>

In this table, taking scenario 1 as an example, where it would take 2.2 years to repay the energy input using the EPT calculation, there is a much higher ratio EYR of 9.3 and 13.9 for output to input energy for 20 and 30 year systems respectively. This is a much clearer demonstration of how the energy produced by PV can be repaid and does not mislead consumers to false conclusions about solar power.

**Environment**

As previously mentioned, for PV to have a positive net effect on the environment, it is important for PV systems not to require more energy in fabrication and maintenance than they produce. Since efficiencies have risen so much in the past decade, this is clearly possible. However, for this fact to remain true, it is important to consider how much sunshine is available for each system. Certain areas of the world have higher insolation levels and can rightly claim to have a larger net energy production such as China, Southern Europe, Australia and most equatorial regions. Unfortunately, some of these regions do not have the economic and political mechanisms needed to stimulate growth for the adoption of PV.
Yet this is the area where environmentalists and policy makers should be focusing their attention since the greatest gains can be accomplished in these regions. India and China are two of the most rapidly developing countries in the world and as their energy requirements grow, so too does their pollution of greenhouse gases. Thankfully, there is an array of incentives for more sustainable options that will likely curb the increase in GHG emissions, and although solar power currently accounts for less than 0.5% of global installed capacity, this will change drastically in the future because of solar power's impressive growth rates over the past decades.

For example, China has put in place several incentives which include favourable import customs duties for renewable energy products, various subsidy programs for all kinds of renewable energy technologies including wind, biogas and solar, which is investigated in greater detail in chapter 4 of this paper.
3 Technologies

3.1 Crystalline

Crystalline Silicon technology (c-Si) accounts for more than 90% of the actual PV systems in the market, the reason why its presence is so high is because it has use all the technology and R&D of the semiconductors for the electronics industry since the 1960's. Furthermore, silicon is one of the most abundant minerals in the earth's crust, giving refineries a virtually unlimited supply resources.

However, silicon is a very brittle material, requiring relatively thick cells (~300um, although 100um thick cells can be obtained using the latest sawing technology), therefore some of the electrons excited by the photons have to travel large distances inside the materials, losing energy in a process called recombination, where electrons return to their valence band. Consequently a material with high purity and structural perfection is required. To avoid this loss, the electrons must be highly mobile, as they are in pure silicon. Imperfections and impurities can absorb the electron's energy and convert it into heat, impeding the electron's ability pass through an electric circuit.

Once silicon of the desired purity is obtained, it is then put together into ingots and then cut into wafers using a saw. Wafers stand for about 65% of the module cost, equally divided between purification, crystallization and sawing. For many years the PV industry have used scrap silicon from the IC industry, but the increase of PV demand has nearly exhausted this market. The Siemens method for obtaining silicon is the most used worldwide but it has been considered ultimately too expensive for its use in PV. The purity it provides, however, is well above what is necessary for the fabrication of solar cells.

During the 80's, an attempt to fabricate low-cost solar silicon (Sol-Si) did not succeed due mainly to the low demand at that time. Today, some new attempts are being made, from just simplifying the Siemens method, or by using totally different techniques to purify and process the silicon. A very important advance in solar cell fabrication has been the demonstration of cells with high efficiency made from wafers containing hundreds of large-grain multicrystals (1-10mm), called multicrystalline (multi-Si), or polycrystalline (poly-Si). The multi-Si growth procedure is much faster and the wafer is cheaper. Because of the random orientation of the crystals, there's an efficiency drop of a few percent (absolute) compared to a mono-Si wafer, but taking into account that the cells are cheaper, the price per watt peak remains the same on a per-module basis. The simplicity of the multi-Si wafer-growing equipment and process offers a clear trend towards the use
of this option for mass scale production.

Although the solar cell manufacturing process represents a relatively small fraction of the total cell cost it strongly affects the overall cost in $/Wp, because it determines the cell and module efficiency. The efficiency depends of the wafer and ribbon utilized, but it also greatly depends on the manufacturing process itself.

Efficiencies over 25% have been achieved for laboratory cells in a long complex manufacturing process, where every possible efficiency-improving factor has been taken into account to obtain a nearly-ideal device structure. When transferred to commercial mass producing scenarios, the efficiencies obtained are around 15% for single-crystal cells and 13% for multi-crystal cells. In modules these efficiencies are reduced to 14% or 12% due to the redefinition of the area that now includes the module frame.

The existence of this big efficiency gap between laboratory and commercial cells together with an increased market demand suggest that new higher efficiency cells will appear in the years to come, some companies have achieved 17-18% efficiency cells in production. There are some other factors that can also be improved, the manufacturing yield, for instance, is around 95% giving some gap for improvement, and finally, at the end of the process, the interconnecting and encapsulating process can be done using better automation and using cheaper materials helping reduce the overall cost of crystalline cell modules. [5]

### 3.2 Thin Films

Around 10 times more crystalline silicon is needed to absorb a given fraction of sunlight compared to other semiconductors like GaAs, CdTe, Cu(InGa)Se2 since silicon is the weakest absorbing semiconductor used for solar power. Therefore, thicker wafers have to be made when working with crystalline technologies and, because of the size, higher quality material has to be used because of the longer paths the high-energy electrons have to travel before reaching the external circuit.

During the same years c-Si PV cells were developed, it was shown that other semiconductors could be used for electricity production. When this material is used to make solar cells, so little of this material is required that a foreign material is needed to physically support the cells. During the first years of thin-films development, 4 technologies achieved higher efficiencies than 10%, Cu2S/CdS,
a-Si, CuInSe2/CdS and CdTe/CdS. Cu2S/CdS disappeared soon due to stability problems related to electrochemical decomposition.

The main advantage of the thin films is the lower price they could achieve once set into a mass production scheme.

The lower price of thin films derive from the following characteristics:

- They are typically 100 times thinner than Si wafers (between 1 to 3 um) deposited on low-cost substrates such as glass, metal foils, and plastics.
- The temperatures used to place the material on the substrates is much lower (200 to 500 C vs 1400 for c-Si).
- They can tolerate higher impurities, therefore needing cheaper purification of raw material.
- They are integrated into a monolithic interconnected module reducing the module connection costs.

Even though price is a very good reason for thin films to take a big portion of the market share, crystalline-based PV still dominates around 94% of the market because thin films still have lower efficiencies and there's much less developed technology for their manufacture. Consequently, high amounts of capital are required to build manufacturing plants due to the fact that the techniques used have to be developed some times from scratch. Thin films industry couldn't adopt a mature technology like the Si PV community did from the Si electronics industry.

Analyzing the most used technologies, the first one, with Amorphous Silicon (a-Si) films are typically deposited between 150 to 300 centigrades allowing the use of low cost substrates, such as glass, steel foil, or plastic. All practical a-Si solar modules contain multiple junction devices where two or three junctions are grown on top of each other, allowing more efficient use of sunlight. Even though a-Si has showed efficiencies up to 15% for triple junctions under laboratory conditions, it usually presents a lower efficiency when compared to other PV technologies but has the advantage of being temperature-independent, when other technologies can lower their efficiencies up to 4% when exposed to high temperature outdoor conditions (eg. summer). a-Si technology is the most common used in the thin-films area, but it still has to overcome certain factors such as:

- Improve its efficiency
- Minimize the self-limited degradation (reduced a-Si panels efficiency by 2 to 3%)
- Increase the faster, low-cost manufacturing process by increasing the deposition rate of the layers and the utilization of gases.

Another Thin Films technology is the Cu(InGa)Se2 alloys, that have achieved the highest efficiencies (between 12 and 15%) but were limited by the low band gap. By using different empirical methods, the maximum achieved efficiency has been 19%, by adding different alloys that increase the band gap and increase the efficiency of delivering the electrons to the circuit. The three major challenges for this technology are:

- Control the composition of the alloy through the film in a manufacturing environment on a moving substrate.
- Find alternative junction partners to replace CdS
- Find new alloys or new deposition methods to increase the efficiency by achieving higher band gaps.

Finally there are the thin films of CdTe, they have been studied since the 1970's, one main difference this last type of thin films has compared to the mentioned ones, is that there are over 10 methods to deposit the CdTe films that have produced CdTe solar cells exceeding 10% efficiency. There are 4 available commercially are: Spray Pyrolisys (SP), Electrodeposition (ED), Vapor Deposition (VD) and close space sublimation (CSS). The highest reported efficiency for cells based on this technology has been 16%. Even though some CdTe modules have been in outdoor field-testing for over 10 years without major degradation, some other CdTe modules have degraded considerably. Of all the mentioned Thin Film technologies, CdTe is the one that presents the more amount of challenges as follows:

- Cu seems to produce a high efficiency device, but affect the long-term stability.
- Various optimization methods should be better understood so they can be simplified and transferred into a mass scale production scheme.
- CdTe modules are more sensitive to outdoor interaction (O2, H2O) requiring better encapsulation methods.
- Safe and cost-effective strategies of Cd usage in the workplace and recycling should be addressed. [5]
3.3 Concentration PV Systems

Due to the cost of solar cells, focusing concentrated light onto a small area have been always considered a way of reducing costs. In order to make it profitable the concentrators required should be cheaper than the area of solar cells they are replacing, another condition that has to be taken into account is that the solar cells efficiency should not decrease under concentrated sunlight. The first condition is usually easily fulfilled because the concentrators can be made using low-cost optical devices, the second one is a little bit trickier due to the fact that in order to keep the cells permanently in focus, active tracking systems are required, significantly adding costs to the modules. Also, even though the cells efficiency should increase with increase luminous flux, in practice due to the high currents in very small areas, the ohmic losses make this efficiency drop, therefore additional care have to be put into solar cells used in concentration systems to minimize this effect.

Another effect present when using concentration PV systems, is that only direct sunbeam is collected since diffuse light is not focused, this reduces the electrical output by 15% approximately. This can be fixed when using 2-axis tracking systems to keep the solar concentrators facing the sun directly all the time.

Analyzing all the gains and losses, and taking into account that the cells efficiency keeps getting higher, the tendency is that concentration PV systems are more efficient than conventional c-Si technologies and it is also believed that concentration systems should ultimately be cheaper than module silicon solar cells, however, due to the lack of real market, this statement cannot be confirmed in practice.

Currently, concentration systems are suitable for large installation rather than for domestic use because there is not a large amount of companies manufacturing concentration PV systems, therefore they have large general cost for small production volumes. However, the situation may change, and with the help of cheap optics, and efficient and low-cost tracking systems, this concentration PV systems can make a very good use of high-efficient solar cells.

Even though of the three reviewed technologies, a-Si has the lowest efficiency, it was commercialized much earlier, and therefore now has a much greater manufacturing capacity compared to its thin films competitors. One of the reasons for this to happen is that CdTe and Cu(InGa)Se2 have no real application outside photovoltaics, so, just independent research groups
and laboratories have been working in developing these technologies during the last few years, but it has to be taken into account that translating research-grade cell performance into commercial production line modules is a very challenging task, delays from 6 to 8 yeas are typical to achieve the same lab-obtained efficiency in production lines. [5]

3.4 Under Development

As previously mentioned in section 2, the energy that comes from the sun as a light form is very hight but spread over a wide spectrum, therefore presenting a low energy density.

The energy that can actually be converted by solar panels is the one provided by those photons with higher amount of energy than the band gap, all the remaining energy from the photons that hit the panel with low-energy levels are transformed into heat in the back of the panel.

For this reason, there is strong development being done to increase the utilization of the different energy levels provided by sunlight's photons. A way to achieve this is by stacking cells of semiconductors with different band gaps. The cells with higher gap semiconductors are placed on top, therefore absorbing the higher energy photons and letting pass through the lower energy ones so they can be absorbed by inner cells of lower band gap semiconductors.

The theoretical limit for an infinite number of cells stacked together with different band gaps is 86% while with a single junction cell only 40% maximum efficiency can be obtained. [5]

Since multijunction cells are considerably more expensive than single junction cells, their application niche is mainly for spacial applications where price is less relevant than performance in most cases. However, they can be used for terrestrial applications using concentrators to reduce the amount of cells required. There is a trend to develop cells operating at 1000 suns [5].

The prospects for this technology are very promising, since they predict in the long-term, to produce electricity competitive with conventional sources.

Multijunction cells are also crucial for the thin-films, the highest cell and module efficiencies reported for a-Si thin-film PV technology are for triple junctions. The band gap of various polycrystalline alloys can be varied with alloying.
Another technology that is getting a lot of attention is called Dye-sensitized Solar Cells (DSSC). Instead of working based on the photovoltaic effect, they work on charge between molecular orbitals, as in photosynthesis. They consist of a photo-sensitized anode and an electrolyte forming a photoelectrochemical systems.

Even though, this technology has been previously studied, cells had poor stability, until 1991, when Michael Grätzel and Brian O'Regan at the École Polytechnique Fédérale de Lausanne[22] developed drastic improvements in the performance of DSSC. Therefore this solar cells are also known as Grätzel Cells.

The Grätzel cell follows the same photosynthesis principles plants employ. A layer of dye molecules, where light absorption is performed, is added to a mesh of nano-particles of a semiconductor, TiO$_2$ (titanium oxide) placed on the bottom of a glass substrate acting as a transparent conducting coating. When a photon hits the dye's surface, an electron is transferred to the semiconductor (TiO$_2$) in a process called injection. This excited electron moves to the anode on top of the cell where it can be extracted and transferred to the load. A positive charge is then transferred now from the dye's surface to an electrolyte between the two layers of glass substrate that encapsulate the cell and then to the counter electrode connected after the load. With this last electron transfer, the charge in the electrolyte returns to its reduced state thus closing the circuit.

The operation principle is represented in the figure shown below:

![Figure 4: DSSC Operation Principle Diagram](image)
DSSC is a promising technology mainly because of the low cost of the materials used and its assembly process is simple and easy. Some “do it yourself” kits are even available for educational purposes [23].

There are, however, some barriers to overcome before DSSC can compete with conventional ways of producing electricity:

- Efficiencies are usually around 10% or below, where low-cost PV commercial applications are around 12-15%.
- Dealing with a liquid electrolyte, instead of solid-states devices, such as in traditional c-Si panels, inserts a set of new limitations. Under low temperatures the electrolyte can freeze, stopping therefore the power production, and during hot conditions, it can expand, break the sealing system and start to leak.

Once these limitations have been solved, mass production of DSSC can become a reality, specially because with the high silicon prices we've experienced in the last few years, this technology can offer already a better power/price production ratio. Also, because of its operation principle, DSSC panels can work under cloudy or low sunlight conditions in such a great way, that even some indoor applications are being considered.
4 Policies

4.1 Subsidies and PV Policy

Incentives and Subsidies

The feed-in-tariff (FiT) which has fueled the German market over the recent years is an explicit monetary reward for producing PV electricity, at a rate per kWh somewhat higher than retail electricity rates being paid by consumers. The incentive does not help directly with the high initial cost of a PV system, unless the producer can use this tariff in a proposal to more easily secure financing. There are several ways the FiT can be applied: the first is where the FiT is applied to all power produced by the PV system and the second is where the FiT is only applied to any additional power above the needed of the customer. The FiT itself is usually funded sustainably, whereby it is paid for by a tax levied to all electricity users instead of from the government budget (which can change as the direction of government changes). Some countries, such as Italy, have opted for the latter method, but the incentive program put into place is too recent to draw conclusions about its effectiveness.

The core benefit of the FiT is that it can be used as a temporary mechanism to stimulate growth that is not a burden for taxpayers since the entire funding for the program is taken from a tax levied on the electricity bill of all consumers. In this way, investors can be assured that PV systems are of high quality and perform well since funding for the system is guaranteed. This incentive also forces the industry to improve performance since the annual reduction of the benefit will only encourage investors to acquire the best technology that will give them the greatest return. The FiT is also regarded as the main driver for further cost reductions and a transition to economies of scale.[24]

The reward of such a tariff varies - calculations can be made to determine the cash flow required for a certain PV installation to become competitive and provide a certain return on investment. Also, externalities can be estimated from the costs of pollution associated with traditional energy supply. Or the tariff can be based on the benefits that PV will add to the grid, peak demand of electricity or line support. And even in some cases a government might decide a standard reward will be a certain multiple of the retail electricity price.

In any case, the main targets for this kind of subsidy are groups such as housing developers,
investors or commercial entities. Specifically it will attract groups that have limited capital such as households, public organizations and small businesses if the FiT is combined with a direct capital subsidy. Alternatively, countries such as Japan, the USA, Switzerland and Australia have decided to use direct capital subsidies, renewable portfolio standards, green electricity schemes, tax breaks or some combination instead of the FiT. Generally, using a type of subsidy other than the FiT, progress in the industry is generally slower but more constant and predictable. Countries currently using the FiT include Austria, Germany, Italy, Korea, France, Portugal, Spain, the Netherlands and Canada. There are some drawbacks with this type of subsidy since industry growth might not always be consistent due to overly complex administrative requirements, caps on PV capacity or even the exclusion of large-scale plants.

Some countries, such as Germany, have avoided this situation by providing a high subsidy with a decreasing amount over time which rewards early investment. But if prices for systems do not come down as the technology expands, or if the program itself is not directly helping the target economy (instead of the foreign economy supplying the systems) progress could stagnate.

Also, the issue of where exactly to set the FiT is a major problem. Setting the FiT too high will result in overheated markets and if it is set too low the investment in PV will be negligible. Policy makers aim to set the FiT at just the right level, which with careful scrutiny of existing markets and foreign PV FiT schemes is possible, but with changing governments, lengthy pay-back periods and fluctuating energy prices, FiT rates should be constantly under revision. One solution is to only apply the FiT to a specific market segment at the beginning, and later expand to other segments. This will alleviate the need to put a cap on the FiT in terms of installed capacity.[25]

Furthermore, as the Core Group along with the European PV Industry Association have found through policy framework analysis, high levels of FiT rewards are not proportional to market size, but rather are sensitive to an incentive threshold that investors must be comfortable with. More generally speaking, the Core Group mentions that the two most important ingredients in a sound FiT plan are longevity and stability. If there is mistrust of government support for a PV subsidy, especially because of the high initial cost and predicted length of operation of the PV system, investors will not become as involved. Also a good mix of incentive instruments with well defined time frames which are contained in simple administrative packaging can be quite attractive for investment.[26]
Germany

The German subsidy system for PV is considered by the European Photovoltaic Industry Association to be the best in Europe. It has been praised as very easy to use with little administrative requirements. Because of this, the growth in the German PV market has been the best in Europe as well.

![Development of the German PV Market](image)

**Figure 5: German PV market expansion thanks to the feed-in-tariff[27]**

Since their innovative Renewable Energy Law (REL) was introduced in 2000 which provided a buyback rate of 0,50 €. In 2004 this law was revised to and the new buyback rate ranged from 45,7 – 62,4 Euro cents which is reduced by 5% annually to avoid overheated markets.[27]

The German system itself is treated as the standard for hopeful governments worldwide to use as a model. To name a few, countries such as France and the state of California in the US have taken much of the German approach and made small changes to adapt the system to their own needs. This has not been done in China as of yet, but currently China is focusing on the international market and domestically PV is used for rural electrification – something that will be discussed in greater detail in chapter 6 and 7. For the moment, France and California will be investigated to provide a general sense of how the feed-in tariff works on a local scale.
France

The federal subsidy in France is currently the highest in the EU with a FiT of 0,55 €/kWh for Building Integrated PV (BIPV). This is composed of an initial 0,30 €/kWh which applies to all new PV installations, with an additional 0,25 € for BIPV which should last for 20 years. This benefit structure is also available outside of Continental France, in Overseas departments (DOM) and Corsica, but in this case, the initial FiT is actually 0,40 € and a BIPV addition of 0,15 €. One reason for the especially high tariffs formed in 2006 is that in 2000 the government decided on very low tariffs of 15.25 €/kWh which left PV as an unattractive option from an economic standpoint. This is especially unfortunate because France is a highly motivated country when it comes to energy reform and exploring new alternatives to their long history of nuclear power. A press release from Invest in France and the French Solar Energy Association, Enerplan, a full 98% of French people are interested in the promotion of energy alternatives and over 40% of the population believe that PV has a key role.

The future of PV in France is looking good, although they have started a bit late. Government predictions have planned for installed PV of 200MW by 2010 but after that it becomes less clear. The government is predicting growth rates less than the industry which would reach a goal of 500MW by 2015 with an annual growth rate of 10%, whereas the PV industry itself is predicting a full 1 GW with a growth rate of 25%. Investors believe the latter is more likely for 2 reason: the first is that the development of the French infrastructure will take the lessons learned from the successful German industry, and second, never before has the French public been so supportive of renewable energies, specifically solar energy.

However, there are obstacles that are not easily overcome. The amount of administration work slows down the system and as an example, 1 out of every 10 installed systems in 2006 were never connected to the grid because of administrative problems. There is a lack of expertise in this developing market and the French will have to watch out for competition coming from abroad.

Currently, the French market is dominated by 3 companies: Tenesol (co-owned by the previous state-run power company, EdF and the power company Total), Apex BP Solar (whose parent company is of course British Petroleum) and Photowatt (subsidiary of the Canadian Automation Tooling Systems Inc.). However, with the onset of neighbouring Germany's solar power experience, these French companies will have to fight hard to keep their market share. Tenesol, for example, having only sold 1.5MWp in 2006 expects to boost their sales to a full 7 MWp for 2007 thanks to
the greatly improved government aid. Many in the industry feel that companies that existed in the French market prior to the government incentives will have a better shot at capturing a greater market share. Currently there is a lack of qualified engineers and complicated bureaucracy is still a prevalent issue. To magnify these problems the installation of many small systems inherently requires more personnel.

Thankfully, the latter problem will correct itself thanks to the influx of new players in the French market. Conergy AG and Schüco International KG are examples of 2 German companies that have already established training centres in the Paris area to train new installation engineers. Specifically, training will include the new quality system "Quali-PV" program under the supervision of Enerplan that has been active since July 2007. By the end of 2007, this certification could potentially be possessed by 1000 trade companies. Also, another certification that has more to do with solar bureaucracy called "Centre Scientifique et Technique du Bâtiment" (CSTBat) has already proven it's need. A survey conducted by European Press Service shows that the major hindrance to the advancement of the PV industry is bureaucracy, which specifically refers to delays in processing feed-in contracts with new installations and lengthy approval processes.

Other companies entering the market have specialized their involvement. Biohaus, a German PV wholesaler has decided to limit their customers to continental France where the FiT is more heavily weighted towards building integrated systems (BIPV). Soleos Solar France is taking the opposite strategy and is focusing their effort in off-shore regions (DOM/TOM) where few companies operate. And even further from the mark is Donauer Solar, another German wholesaler who has decided to focus their attention on large-scale projects that will not benefit from the full availability of the FiT. [28]

It seems that there are a variety of ways to make use of this type of subsidy. In the future, the Chinese should look not only to the German market, but also the French market to learn from their somewhat different approach to the expansion of their domestic market. Next a more capitalist approach will be investigated to see what kind of incentives and programs are being used.

**California**

In recent history California has been a net importer of electricity. In the year 2000, at times the state had to import 50% of its power. Today that figure has fallen to 25% but the need still remains. Local
power generation cannot seem to keep up with demand even though California has proven to be energy efficient: the per capita electricity usage is only 6500 kW/h, which is even lower than Germany which consumes 6800 kW/h per capita.

In the 1990's California underwent a shift whereby the federal government liberalized the electricity market which wiped out the state-wide electricity price in favour of market based pricing. Initially this was reported as a great step forward in conservation and it was thought that with market forces controlling the grid, pricing will become more competitive and fair. This did not happen for several reasons, but mainly the power supply companies simply put off planned investments into new power stations and grid capacities which resulted in massive black-outs around the state. As these companies were whispering notions of bankruptcy, electricity suppliers out of state were reluctant and sometimes completely unwilling to sell electricity to California.

This problem has still not been rectified, but the trends have changed at least. Investment in power generation and grid improvements are on track again, but more importantly, the public has woken up to the fragility of the electric grid and realized their dependence on it.

Contrary to the official line of the US federal government, much of the US, with California leading the way, are becoming more ecologically educated. This can be seen with the sales of hybrid vehicles even with the limited selection that currently exists compared to the internal combustion engine. Even the republican governor of California, Arnold Schwarzenegger, is using his political strength to steer the state in a new direction: soon California will pass a bill which bans electricity generated from coal-fired power plants. California also has the strictest exhaust emission standards in the country and very soon a zero-emission vehicle will be announced. Schwarzenegger also filed claims against 6 major vehicle manufactures for environmental pollution and destruction to the climate which could quickly turn into a billion dollar law-suit. Finally, the governor has said that to reach the Californian goal of reducing GHG emissions by 25% by 2020 the industry will undergo a positive change that will create billions in new investment and tens of thousands of jobs, something which the federal government has ferociously denied is possible.

Certainly the incentives are there for an upcoming solar boom in California: there is a need for energy expansion, over 340 days of sunshine per year and the political support needed to encourage PV usage. [29]
However, one immediate drawback of installing a PV system in the US is the upfront cost of the system. In 2006 the average cost of a system was $9.24 US/Wp for a system around 5 kW. At the same time, comparable German systems were in the range of $5 - $6 US/Wp. Therefore, there was certainly a need for a new incentive program. Under the old subsidy system which expired at the end of 2006, customers were paid upfront to help with the high cost of installing a system, but received no money on a per kWh basis. Under the previous system, the Emerging Renewables Programme, installations under 30 kW were paid $2.80 US/Wp. Installations over 30 kW were under a different program called the Self Generation Incentive Programme had similar subsidies from $2.50 to 2.80 US/Wp.

The subsidy system that California has put in place which began in January 2007 is aggressive, but somewhat complicated compared to European systems. There are two options available to consumers and some even have a choice as to which subsidy option they would prefer. The first option, dubbed the Performance Based Incentive (PBI), is straightforward and applies to all systems larger than 100 kW. This incentive program will provide continuous returns for the consumers unlike the second option. For this reason customers can opt out of this system and apply under other option which will provide a lump sum based on the size of the system as well as some other factors.

The second option that is available, the Expected Performance-Based Buydown (EPBB), applies to systems less than 100 kW. This system is based on factors such as equipment ratings and geographical factors such as location, tilt, orientation and even shading. Because of this, it is very difficult for installers to make accurate predictions for subsidy financing, especially for systems closer to 100 kW.

Below are 2 tables which outlines the incentives:

<table>
<thead>
<tr>
<th>Customer Group</th>
<th>Monthly Payment</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>0.26 US$/kWh</td>
<td>Five Years</td>
</tr>
<tr>
<td>Residential</td>
<td>0.39 US$/kWh</td>
<td>Five Years</td>
</tr>
<tr>
<td>Government/Non Profit*</td>
<td>0.37 US$/kWh</td>
<td>Five Years</td>
</tr>
</tbody>
</table>

*Table 5. Programme 1: Performance Based Incentives*
<table>
<thead>
<tr>
<th>Customer Group</th>
<th>Up-Front Incentive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial/Residential</td>
<td>up to 2.50 US$/Wp</td>
</tr>
<tr>
<td>Government/Non Profit*</td>
<td>up to 2.35 US$/Wp</td>
</tr>
</tbody>
</table>

Table 6. Programme 2: Expected Performance-Based Buydowns

Yet this new legislation has been met with some skepticism. However to compare the Californian incentive program to the German version is not worthwhile. The question of how the German market will develop has been answered and now the question is how will the German PV market be financed. In California, since the subsidy levels are not nearly as high, nor will they likely become, the state will have to rely on its traditional strength that lies in the high-tech industry as well as its excellent climactic conditions which can deliver more than 2000 hours of sunshine each year. Another attractive area that is specific to California is the expanding catalog housing construction industry. And if this can be combined with photovoltaics into an attractive option for buyers interested in zero energy housing, solar installations would become quite commonplace.[29]

Canada

The growth in the Canadian sector has been constant over the past 14 years at about 20%, reaching 20,50 MW of installed power, significantly less per capita than other IEA countries of similar insolation levels. Still the market is continuing to grow despite the low price for conventional energy - mainly in the off-grid sector (93% is used in applications such as transport route signaling, navigational aides, remote homes, telecommunications and remote sensing and monitoring).

The interesting point here is that much like China, Canada has historically focused on rural electrification much more than grid connected PV. And Canada, much like China, has no focused their efforts on the development of a domestic market. Recently, the Canadian RESOP program which employs a feed in tariff of 0,42 $CDN will likely increase PV installations at a predictable rate. This is certainly an area China could monitor to gain knowledge for the future.
Japan

The Japanese market is another good example of the effectiveness of subsidies. But now that Japan has a PV industry which is subsidy free, will the government have to step in once again to stimulate growth? Japan initiated the PV subsidy system under the direction of the Ministry of Economy, Trade and Industry (METI) back in 1994. Initially the program covered 50% of the installation cost and then in 1997 the system changed to pay a price depending on the size of the system installed. In 1997 the subsidy offered compensation of ¥340,000/kW (US$3223/kW at current rates) and steadily decreased to the end of the program's life in 2003 with a subsidy of ¥90,000/kW ($865/kW). What is left is a healthy PV industry which is continuing to grow at sustainable rates.

Because of this subsidy program, Japan was able to secure its position at the top of the worldwide PV industry for both installed systems and export of solar power equipment. The interesting aspect to Japan's situation is how their PV market is now sustained with no more subsidies and PV is competing with conventional energy. Granted they have very high electricity prices which is necessary for PV to become competitive, therefore Japan can serve as another model for policies much further in the future.

4.2 Chinese Energy Policy

China plans to increase their renewable energy consumption to a full 10% by 2010. This is the main goal of China's Renewable Energy Law that was implemented in the beginning of 2006. This new law requires grid operators to electricity from registered renewable energy producers. Also, a fund has been set up to offer financial incentives to encourage the development of renewable energy projects. And finally, the law includes some very clear penalties for non-compliance. Considering that in 2003 China used only 3% renewable energy, this is a major step and has been recognized as such by many environmental critics around the world, most notably, Greenpeace.[30]

Yet a Chinese feed-in tariff still does not exist. Experts in the field do not believe the Chinese government will seek to institute this kind of incentive in the near term. For the moment they are relying on sever different kinds of financial support from the government. For example, during the Tenth Five Year Plan (2001-2005), the central government invested between 5,2 – 6,2 M € in PV R&D and the Eleventh Five Year Plan is projected to double that figure to 12,4 M €. However, a comparison to Germany and Japan is a bit discouraging since respectively they invested 24,4 M and
In any case, the programs that do exist are certainly pushing the market forward. The Brightness Programme that began in 1996 and is scheduled to run until 2010 aims to provide 100 watts of PV electricity to about 23 million people. Another venture connected with the Brightness Programme called the Township electrification programme completed in 2004 and installed about 24 MWp. In 2006 several other projects such as the Township Electrification Programme and the rooftop programmes in Shanghai and Wuxi have substantial government investment. Thanks to the government support through subsidies and direct funding of some projects, China's 2004 capacity was 40 MWp.[3]

But the question remains if China has directed their research funding to the right areas. Currently the majority of funding is aimed at improving material quality of PV cells and the accompanying manufacturing process. While they have focused their efforts, they have neglected some important areas such as system components like inverters, batteries and control electronics which typically make up about 25% of a systems costs. Another area that has not attracted attention from PV developers is the integration of R&D into energy policy and domestic market deployment. This might seem in line with the national approach to grow quickly and take advantage of the current cheap labour availability but in the medium to long term, to capitalize on domestic markets, China will need to innovate in more areas of the supply chain in much the same way that Germany has.[3]

The major contributor to the development of the PV market is the Renewable Energy Law that took effect at the beginning of 2006. The law is divided into several sections covering how programs will be funded, how they will be monitored and what concrete goals are expected to be achieved. The interesting aspect to this law is the section where legal requirements are outlined: any criminal activity is pursued in a direct manner and the failure of utilities to purchase all electricity from a renewable producer is also punishable. This type of law, with the appropriate monitoring, could certainly make it easier for renewable energy startup companies as well.[31]

Furthermore, if the present government actions on renewable energy as a whole are any indication, PV will likely receive much more attention in the future since the production of certain components in the PV supply chain parallels China's history of large scale manufacturing and OEM production. There is no doubt that China's main strength lies in their ability to increase manufacturing levels quickly, and with the proper government policy and support, this is likely to occur for the PV
industry just as it has for so many other product lines.
5 Silicon and the Supply Chain

5.1 Silicon Bottleneck

Over the past 5 years, there has been a seven-fold price increase for PV-grade silicone. The cause of this is simple: the rapidly expanding PV market is overwhelming the available supply of silicon which is shooting up the price. Previously, PV the industry was satisfied with the excess or rejected silicon from the semiconductor industry, but currently the demand of the industry has increased to a point where over one third of silicon is being sold to the PV industry. 11 000 tonnes of silicon were sold to the PV industry out of a total 30 000 tonnes produced in 2005. In actuality, about 15000 tonnes were used for solar cell production which is enough to make 1.15 GW of solar cells, with the excess coming from remaining inventories and rejects from the semiconductor industry.

Yet, with such a steep price increase, subsidies and technological improvements alone will not be able to sustain such high market growth although silicon producers are doing their best to keep up with demand. Currently, an additional 20 000 tonnes of silicon are projected to come on the market in 2008-2009 from the world's leading PV-grade silicon producers: Hemlock, USA, REC Silicon, USA, and Wacker, Germany. A variety of strategies are being used.[32]

The current strategy that is being used by most facilities is the long established Siemens process which produces highly pure PV-grade silicon but at high prices. It is due to this fact that a global discussion about the upper impurity levels of solar silicon has begun as a means to help reduce the constantly increasing price of silicon. However, to achieve efficiencies upwards of 18%, a very high purity is needed (in ppm, O:1, C:1, B:0.5, B:0.025, As:0.025, Fe,Al,Cr,Ni,Ti,Mo,V,Cu,Zn sum to less than 0.1) and using the current Siemens process, cost reductions are very difficult.

Besides the expansion of the current production from the Siemens process promised by silicon producers, three companies are working on developing new processes that promise to reduce PV-grade silicon production costs. Wacker Chimie, a German company is developing a process called fluidized bed decomposition of trichlorosilane. Tokuyama Corporation is working on hot wall decomposition of trichlorosilane and melting of the formed silicon. Also, Joint Solar Silicon has a two-step process where the decomposition of monosilane to silicon powder in a free space reactor is subsequently compacted into denser silicon pieces. All methods produce the necessary purity for PV production and research is ongoing to reduce costs and increase efficiency within the
In 2005, a full 95% of solar cells produced used silicon-based technologies. Recent breakthroughs in thin-film technologies are encouraging, but as The Prometheus Institute for Sustainable Development, of Cambridge, Massachusetts remarks: "Thin films, while promising, will not increase their market share fast enough to keep the PV industry from relying almost entirely on the polysilicon supply through 2010. Understanding the supply of silicon, therefore, is essential to understanding the prospects for the PV industry as a whole."[34] So in the interim, with government incentives at a point where solar electricity can be competitive with conventional power, silicon companies are scrambling to sell as much as they can. Yet, what will happen when thin-films begin to capture their share of the market and the silicon bottle neck that exists disappears?

To being with, competition will increase. The current state is one of partnerships and acquisitions Schott and Wacker have joined in wafer production until 2012 investing 370 € over the next couple years. Also, Solaria of California have signed a deal for 1,35 GW of solar cells from Germany's Q-Cells. Finally, SunPower has entered into a contract with NorSun, a German startup for 2 GW of silicon ingots and also they have acquired Powerlight, a large solar integrator in November 2006.

5.2 Geographic Distribution of Silicon Suppliers

In 2005, more than 50% of the world's silicon suitable for PV use was produced in the United States. Japan and Europe shared the rest with Germany making up the largest portion in Europe. This uneven ratio is slowly changing however, and in the years to come a more market share will be taken up by China. The European increase is mainly due to Germany again, but Norway is also expected to contribute a significant portion.

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>2005</th>
<th>2010 (projected)</th>
<th>2010 (potential)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>54,2%</td>
<td>40,7%</td>
<td>27,6%</td>
</tr>
<tr>
<td>Japan</td>
<td>24,3%</td>
<td>14,8%</td>
<td>9,6%</td>
</tr>
<tr>
<td>Europe</td>
<td>21,1%</td>
<td>32,6%</td>
<td>30,2%</td>
</tr>
<tr>
<td>China</td>
<td>0,4%</td>
<td>7,5%</td>
<td>18,8%</td>
</tr>
<tr>
<td>Russia/FSU</td>
<td>N/A</td>
<td>1,2%</td>
<td>10,4%</td>
</tr>
<tr>
<td>RoW</td>
<td>N/A</td>
<td>3,1%</td>
<td>3,3%</td>
</tr>
</tbody>
</table>

Table 7: Geographic distribution of polysilicon production as a percent of total production [34]
Also, given the low cost of shipping silicon, it is interesting to see where companies will choose to place their factories. There is very large potential in both China and the former Soviet Union but at present, China has shown the most dedication in this area. Above is a table demonstrating the potential and projected outcomes for 2010. In 3 years time, according to projections, China could see the biggest relative increase since formerly their polysilicon production was almost non-existent.

In China, the largest monosilicon producer is the Jinglong Group, with a production capacity of 3000 tons. Its is located in north China's Hebei Province. Its monosilicon output made up 50% of China's total in 2006. Jinglong has joined in the expansion plan of the world's largest polysilicon producer Hemlock Semiconductor Corporation (HSC) and signed a long-term supply contract, with may ensure a certain part of its raw material supply, according to Jinglong's Chairman. [35]

5.3 Silicon Processing

Silicon Refining

The refining process for silicon is not very complicated, but since the level of purity required by the PV industry is 99,9999 %, there are several steps along the way to achieve this result. The first step in the production of polysilicon is mining. Here the quartz rock is extracted from the mine and
added into a furnace with coal and woodchips or charcoal and headed to produce a liquid. Once the liquid is cooled, the silicon can reach a level between 96 - 99.0% purity. At this stage, the aluminum industry used about half of the global production. This is a very large amount respectively - in 2005, global metallurgical silicon (MG-Si) production was above 1000000 MT while the PV industry accounted for just 15 000 MT.

To increase the purity of the silicon, there are several methods that can be used. In 2005, 91% of PV grade silicon was made using the traditional Siemens process with the remaining 9% created from the fluidized bed reactor process. The Siemens process reacts HCl with MG-Si which forms a liquid which is subsequently vaporized. This gas is then deposited onto silicon rods that are heated to 1100 C. The use of the trichlorosilane (TCS) has the advantage of high deposition rates and high volatility which helps remove the problematic impurities, specifically boron and phosphorous. However the reason why much research is going into other methods of purification is due to the high electricity consumption for maintaining the process temperature. Another process to further refine the silicon deposits monosilane gas onto heated silicon rods. The higher purity of the monosilane in comparison to the TCS increases the purity, but of course, this also increases the overall cost.

The fluidized bed reactor (FBR) has the advantage over the Siemens process for capital cost and electricity consumption, but since the technology is still relatively new the associated economics are not well understood. The process itself was developed by Ethyl Corporation and they used silicon fluoride instead of MG-Si. In the process, the silicon seed is put into the reactor and silane and hydrogen gases pass through to allow deposition. Another experimental process called Vapor-to-Liquid Deposition (VLD) which is gaining attention is that of Tokuyama. They have developed a process which uses the same feedstock as the Siemens process, but the deposition occurs in a heated tube where the vapor condenses to liquid allowing for faster final product formation.

With current trends in the industry, producers are moving away from the Siemens process and towards the FBR process. Also, many producers who have traditionally focused on providing high-purity silicon for both the Integrated Circuits (IC) and PV industry have decided to focus on the latter since IC requires purity levels which are thousands of times greater and incur higher costs for production. It is predicted that in 2010, the Siemens process will only account for 75% of production with the FBR process increasing to 13% and specialized PV-MG production AT 11%. Experimental processes will account for the remaining 1%. [7]
However, with all the different types of silicon refining, there remains the problem of high electricity costs and the need for a highly trained labour force. With a general analysis of the Siemens process, the Prometheus Institute estimates that a average figure of about $100/kg for the construction of a polysilicon factory. With today's average efficiency rates, a large factory that can process 10 000 MT of polysilicon can produce enough silicon for about 900 MW of annual PV cell production. And assuming capital cost recovery and operating costs, the cost of silicon is at least $0,60 to $0,75 per watt which is about 15 to 18 percent of the total cost of a solar modules today ($3,50 per watt). For solar power to reach competitive levels the price must reach the $2,00 threshold.

**Ingots**

There are several forms which silicon can take after the refining process: ingot, block, sheet or ribbon. Furthermore, certain processes are only for creating monocrystalline ingots such as the Czochralski and float zone methods. Polysilicon is made using directional/solidification casting or ribbon/sheet methods.

The Czochralski method begins with a silicon seed attached to a rod which is dipped into a large crucible which contains molten silicon. As the seed is drawn up, a monocrystaline ingot is grown. In 2005 this method accounted for a full 35% of all global production, and although it takes comparatively longer and is more costly than other methods, the resulting cells have very high efficiencies. The Float Zone method is similar to the Czochralski method in that a silicon seed is still used at the beginning of the process, but instead, a heating coil is passed along the forming ingot to separate the input silicon from the newly crystallized ingot. This type of crystalization is even more costly than the Czochralski method, but it can be worth it if very high efficiencies are necessary since this method is produces silicon very low in oxygen.

**Wafers**

Transforming the purified and shaped silicon into wafers is very wasteful process. When using standard techniques to saw the ingots, somewhere between 200 - 230 µm worth of silicon are lost to make wafers that are between 200 - 300 µm. New techniques are under research to reduce waste and also laser cutting is sometimes used but in this case there is material degradation because of heat produced from the laser. Yet, because some losses with wire cutting are inevitable, a reduction
in silicon usage is the main focus of research. In 2005 it took about 12 grams of silicon to create 1 watt of electricity, including losses from wire cutting. For this to be reduced which would in turn lower overall costs of solar modules, three main goals must be achieved: wafers should be sliced thinner, ribbon and sheet methods need to be more widely used and cell efficiencies need to improve.

5.4 Polysilicon Capacity

The current shortage that exists in the polysilicon industry can be attributed to two main factors: first, after the semiconductor industry crash of 2001, there was excess semiconductor grade silicon that was suitable for the PV industry and secondly, after the PV industry had used up the excess silicon new capacity had not been planned due to the uncertainty that is inherent in the rapidly growing PV industry. In fact, the PV industry grew so quickly and relied so heavily on the excess silicon capacity from the semiconductor industry, that very few PV companies decided to pursue plans to secure polysilicon specifically for solar use. Also, when looking at the growth of the PV industry as a whole over the past ten years, the industry had an annual growth rate of about 30%, whereas new capacity added only grew by less than 4%. This will change though, several of the larger companies are dedicating many resources to polysilicon production now. In 2005, the 7 largest polysilicon producers were Hemlock (7700MT), Wacker (5500MT), REC (5300MT), Tokuyama (5200MT), MEMC (3800MT), Mitsubishi (2850MT) and Sumitomo (800MT). Two other companies in China were able to provide an additional 130MT as well.[34]

The future of the aforementioned companies looks bright. All of them are planning expansion of polysilicon production - the largest being the current industry leader, Hemlock, which plans to increase production to 19 000 from their 2005 level of 7 000. Here is a table which outlines the projected growth of these companies (These estimates also take into account potential productivity improvement, construction delays and reductions in plant size.)
In this summary of the top polysilicon producers, Hemlock and Wacker share a similar outlook for the future. Both companies expect to expand to 2 and a half times their current production capacity and in 2005 they sold 40% of their product to the PV industry. Renewable Energy Corporation (REC) differs from the previous 2 companies in that they are one of the few PV companies that are fully-integrated. From silicon production to distribution and installation, REC has full or part ownership of subsidiaries throughout the PV supply chain. Tokuyama has chosen a different approach as well - although they only plan to increase their capacity by 200 MT, this full amount is expected to come from the promising new technology called vapor-to-liquid deposition which allows for much faster production and produces a product more appropriate for PV applications due to its reduced purity. If their new 200 MT VLD plant can achieve expectations, the company believes they could become the world's 2nd largest polysilicon producer.[34]

MEMC, with 2 factories, one in Texas and the other in Italy, are currently the only company producing granular polysilicon at an industrial scale. This has given them a competitive advantage as some companies prefer polysilicon in this form. Wacker and Hemlock have pilot projects to produce granular silicon as well so this advantage could be short-lived, but with planned expansion in 2008 which would almost double their current production rates, MEMC is keeping pace with the larger companies. The remaining 2 companies on this list are expanding but have not shown the same level of commitment. Mitsubishi has planned only minor expansion in relation to their current capacity, while Sumitomo is expanding only in relation to the increased demand from the semiconductor industry.[34]
5.5 New Entrants to the Silicon Industry

New and emerging companies entering the PV industry definitely have competition. Although the past decade saw polysilicon capacity increases lower than 4% versus an average of almost a 30% increase for PV production, the shortage of silicon will soon be over. However, there is a stark difference in the projected amount of polysilicon that will come online and the potential production amounts. Also of interest is the level of commitment new companies have shown to the newer and less established technologies involving metallurgical silicon processing to solar grade silicon (MG-SoG).

<table>
<thead>
<tr>
<th>Company</th>
<th>2005 Production Capacity (MT)</th>
<th>2010 Production Capacity (MT) (projected/potential)</th>
<th>Technology (Siemens, FBR, VLD, MG to SoG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Chemical</td>
<td>--</td>
<td>3,000/--</td>
<td>Siemens</td>
</tr>
<tr>
<td>Hoku Scientific</td>
<td>--</td>
<td>1,500/--</td>
<td>Siemens</td>
</tr>
<tr>
<td>Isophoton et al.</td>
<td>--</td>
<td>2,500/--</td>
<td>Siemens</td>
</tr>
<tr>
<td>French Consortium</td>
<td>--</td>
<td>2,000/3,000</td>
<td>Siemens</td>
</tr>
<tr>
<td>Crystal</td>
<td>--</td>
<td>1,200/--</td>
<td>Siemens</td>
</tr>
<tr>
<td>Russia/FSU</td>
<td>--</td>
<td>--/14,500</td>
<td>Siemens</td>
</tr>
<tr>
<td>M.Setek</td>
<td>--</td>
<td>6,000/--</td>
<td>Siemens</td>
</tr>
<tr>
<td>Elkem</td>
<td>--</td>
<td>5,000/10,000</td>
<td>MG to SoG</td>
</tr>
<tr>
<td>JSSI</td>
<td>--</td>
<td>850/--</td>
<td>Silane to SoG</td>
</tr>
<tr>
<td>ARISE</td>
<td>--</td>
<td>--/2,000</td>
<td>MG to SoG</td>
</tr>
<tr>
<td>JFE Steel</td>
<td>--</td>
<td>100/--</td>
<td>MG to SoG</td>
</tr>
<tr>
<td>Solar Value</td>
<td>--</td>
<td>5,300/10,000</td>
<td>MG to SoG</td>
</tr>
<tr>
<td>Global PV Specialists</td>
<td>--</td>
<td>--/2,000</td>
<td>MG to SoG</td>
</tr>
<tr>
<td>Total China</td>
<td>130</td>
<td>7,300/22,100</td>
<td>Siemens</td>
</tr>
</tbody>
</table>

*Table 9: New Silicon producer capacity in 2005, projected and potential in 2010, and technology employed [34]*

Of these companies listed, DC chemical, Hoku Scientific, Isophoton, a French consortium and M.Setek have chosen to use the conventional Siemens process in their expansions. DC Chemical has received a $250 million investment from SunPower to make a 3,000 MT polysilicon facility. Hoku Scientific, a fuel cell company based in Hawaii, has chosen to diversify and has secured investments of $250 million, some of which is from other solar companies in the form of contracts for feedstock material. This will fund a 1,500 MT polysilicon facility as well as a 30 MW module plant. Isophoton, which is a public company from the Andalusian government has joined with Endesa, a Spanish utility to form the first Spanish polysilicon plant. The plant will be 2,500 MT and it is positioned perfectly as this region is expected to be a solar installation hot spot. Finally, the collaboration of the French companies Econcern, NorSun and Photon Power Technologies, have planned to build a solar polysilicon plant dedicated to the solar industry. The consortium is still
unsure of the size of the plant, which will be somewhere between 2,000 and 3,000 MT, but they expect it to be operational in 2008. Finally, M.Setek, a Japanese silicon-wafer company has planned to enter the market and by 2010 they will produce 6,000 MT of polysilicon.

These previously mentioned companies have all posted reliable information concerning their expansions or they have proven reliability in the past in similar industrial practices. Furthermore, since they are all employing the Siemens process to produce polysilicon, their capacities and future potential can be easily tabulated. Other companies entering the market, although having some experience in silicon production, are either less reliable because they have not secured all necessary funding, have not provided a timeline, or have chosen alternative technologies to the Siemens process so for this reason, their production levels are not as concrete. The major companies of interest here are Elkem Solar, ARISE, SolarValue, Global PV Specialists, GiraSolar and Dow Corning.

Elkem Solar of Norway is probably the most influential in this grouping. They currently provide about 50% of the world's metallurgical silicon and with their experience in this area, they plan to employ metallurgical silicon refining methods to produce solar grade silicon. Their contribution to the polysilicon market is important for 2 reasons. First, the size of their expansion from 5,000 MT to a full 10,000 MT by 2010 would make them the fourth largest polysilicon producer in the world and would have about 9.8% of the market share. Second, because the silicon will be solar grade, this will greatly reduce costs compared to traditional processing methods. For some time traditional polysilicon made with the Siemens method may need to be blended to attain the required purity for solar applications, but as the technology will undoubtedly improve, costs will continue to decrease. ARISE Technologies of Canada has recently entered the silicon market - in the past they focused on the downstream end of the supply chain. Cash and donations from a consortium including the Canadian government have made their entry into the market possible with almost $20 million in funding. ARISE plans to conduct joint research to form a proprietary solar grade polysilicon production process with help from the University of Toronto and the University of Waterloo. By 2010 they hope to have a 2,000 MT plant in operation.[34]

SolarValue has added to their business by purchasing a metallurgical silicon company from Slovenia. They will use this company as feedstock for their MG to SoG operation that they hope will reach 10,000 MT by the year 2010. For this to happen, several improvements from research will need to be implemented, but this expansion is only in the planning stages at the moment. The
California based Global PV Specialists have chosen to enter the market to produce silicon solely for their own customers. Their business is mainly consulting and setting up turnkey factories for cell manufacturing and adding a polysilicon supply to these factories will certainly make their core business more attractive to prospective clients. GiraSolar is another company showing promise. They are an umbrella company operating out of the Netherlands and control several different types of solar energy companies at several levels in the supply chain. Although they have no estimates on when they will be able to produce their pilot factory, they have applied for patents for a proprietary process they believe could cut up to $12/kg off the current cost of producing solar grade silicon. Finally, Dow Corning has come up with their own unique type of polysilicon which they have called PV 1101. DC makes this silicon by purifying metallurgical silicon and then sells this its customers who then mix it in to their own feedstock at 10% or more. Resulting blend ratios and efficiencies have not been given due to non-disclosure agreements, but a rise in demand would be a clear indicator to the quality of the product and as of yet, no reports have surfaced of reduced cell quality or efficiency.[34]

5.6 Projections for the Future

Future of Polysilicon in the Western World

For the next few years up to 2010, the top three companies, Hemlock, Wacker and REC will maintain their positions in the market as they did in 2005. They have all added significant capacities with 2008 being the first year where all 3 companies will have their expansion plants fully operational. In 2009 Hemlock and REC will increase production yet again while in Wacker will come online with another facility in 2010 totaling 47 000 MT of capacity. The fourth largest producer, Tokuyama, will be overtaken in the years to come. Speculation on why this will occur has 2 arguments, the first being that the Japanese company is not as committed to future PV sales as the industry leaders are, or its possible that expansion plans are under consideration but have not been made public. This also brings up the interesting point that the many in the industry are now talking of oversupply. This would be detrimental to companies employing processes that purify silicon to levels only suitable for PV use as any excess solar grade silicon could not be used by the semiconductor industry without further processing.[34]

The most dramatic change here is coming from both China and companies comprised in the Other section. These companies, either new entrants to the industry or an expansion of current PV
activities to include silicon processing will make up over 25% of production in 2010. Also, if China can fully realize their potential, they could seize upwards of 18% by 2010.

Here is a table showing the predicted usage of silicon by year and by sector. It is believed that 2008 will be the year where the PV industry overtakes the semiconductor industry in terms of silicon needs.

<table>
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<th></th>
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</thead>
<tbody>
<tr>
<td>2003</td>
<td>26700</td>
<td>17000</td>
<td>9700</td>
<td>11000</td>
<td>20700</td>
<td>671</td>
<td>80</td>
<td>751</td>
</tr>
<tr>
<td>2004</td>
<td>28800</td>
<td>19350</td>
<td>9450</td>
<td>11700</td>
<td>21150</td>
<td>1142</td>
<td>114</td>
<td>1256</td>
</tr>
<tr>
<td>2005</td>
<td>31080</td>
<td>20627</td>
<td>10453</td>
<td>7118</td>
<td>17571</td>
<td>1523</td>
<td>170</td>
<td>1693</td>
</tr>
<tr>
<td>2006*</td>
<td>35800</td>
<td>22277</td>
<td>13523</td>
<td>-</td>
<td>13523</td>
<td>1610</td>
<td>258</td>
<td>1868</td>
</tr>
<tr>
<td>2007*</td>
<td>40210</td>
<td>24282</td>
<td>15928</td>
<td>-</td>
<td>15928</td>
<td>1828</td>
<td>449</td>
<td>2277</td>
</tr>
<tr>
<td>2008*</td>
<td>57220</td>
<td>26710</td>
<td>30510</td>
<td>-</td>
<td>30510</td>
<td>3162</td>
<td>720</td>
<td>3882</td>
</tr>
<tr>
<td>2009*</td>
<td>71370</td>
<td>27245</td>
<td>44125</td>
<td>-</td>
<td>44125</td>
<td>4641</td>
<td>918</td>
<td>5559</td>
</tr>
<tr>
<td>2010*</td>
<td>77370</td>
<td>28062</td>
<td>49308</td>
<td>-</td>
<td>49308</td>
<td>6035</td>
<td>1098</td>
<td>7133</td>
</tr>
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</table>

*Table 10: Pipper Jaffray solar industry production estimates [34]*

**Chinese Polysilicon Production**

Currently, polysilicon manufacturing is dominated by seven global leaders. In the year 2006, 36,000 tons of silicon were produced. Over 50% of the silicon was supplied to the solar industry, with the rest supplying the semiconductor industry. Of the total amount, only 500 tons were produced in China while 5260 were required in this country.

This clearly shows how 95% of the used silicon in China has to be imported, increasing their solar cells manufacturing costs and limiting their production capacity. Even though new silicon manufacturing plants are being built, the 7 global leaders hold the patents for the process technology, leaving China with inefficient processes that consume from 2 to 3 times the amount of energy required to manufacture the same amount of silicon.

On the other hand, the biggest silicon manufacture plants in China produce up to 300 tons of silicon per year, 800 tons below the required 1000 tons per year to reach minimum economy of scale making it harder for China to keep up with international silicon prices. In the following tables, China's polysilicon industry actual status can be appreciated:
Regardless the technical limitations previously mentioned, China's local polysilicon supply is growing, companies like Luoyang Zhonggui and Emei semiconductor have been increasing their manufacturing capacities, another company, Sichuan Xinguang who began manufacturing solar and semiconductor polysilicon, has now the largest polysilicon production line in China. Actually China is the fourth country to achieve polysilicon manufacturing capacity over 1000 tons per year.

If all the planned projects become a reality, China's estimated polysilicon manufacturing capacity in 2011 will reach 12,660 Tons per year, and China's polysilicon shortage will be solved. Even though the situation looks promising for the polysilicon supply within China, companies like Suntech, the biggest solar panels manufacturer in the country, has secured his position in the market through long-term contracts with several international silicon suppliers such as REC (Norway), MEMC (USA), Comtec (USA) and Sunlight (USA). The same scheme is being followed by other Chinese companies such as Trina and Ja Solar who secured their silicon supply with silicon suppliers from Germany and South Korea.[36]

<table>
<thead>
<tr>
<th>Company</th>
<th>Capacity (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luoyang Zhonggui</td>
<td>300</td>
</tr>
<tr>
<td>Sichuan Emei Semiconductor</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 11: China Polysilicon Capacity (2006)

<table>
<thead>
<tr>
<th></th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semiconductor demand</td>
<td>575</td>
<td>80</td>
<td>230</td>
</tr>
<tr>
<td>Solar industry demand</td>
<td>910</td>
<td>1060</td>
<td>1260</td>
</tr>
<tr>
<td><strong>Total Demand</strong></td>
<td><strong>1495</strong></td>
<td><strong>2656</strong></td>
<td><strong>5260</strong></td>
</tr>
<tr>
<td>Polysilicon production</td>
<td>57.5</td>
<td>80</td>
<td>230</td>
</tr>
<tr>
<td><strong>Polysilicon shortage</strong></td>
<td><strong>1437.5</strong></td>
<td><strong>2576</strong></td>
<td><strong>5030</strong></td>
</tr>
</tbody>
</table>

Table 12: China Polysilicon Production and Demand 2004-2006 (tons). Notes: Solar cell polysilicon demand is calculated as: 2004: 12 tons/MW; 2005: 11 tons/MW; 2006: 10 tons/MW. 2006 crystal-silicon solar cell production is about 400MW [36]
6 Market Analysis

6.1 Costs of Different Technologies

As mentioned in section 3, there are mainly three available technologies for commercial PV: single-crystal, polycrystalline and thin films.

Crystalline-based technologies, are the oldest, and since 1976, they have experienced a price drop of around 5% per year. However, due to the silicon shortage, cost rose considerably between years 2004 and 2006. This price rise have encouraged the develop of new silicon-free technologies with great potential for a further price reduction.

With the aggressive entering of China into the PV market, one of the approaches required for an effective price reduction of solar modules has been addressed, mass production. However, some different approaches could also help PV technology finally reach a price where it can compete with traditional non-renewable technologies.

Crystalline-Based Technologies

A crystalline-based solar cell requires around 40% silicon for its construction, therefore this technology is highly dependant on fluctuations of the market price for this semiconductor. A price reduction on silicon would immediately drop the price of these solar cells. Up until a few years ago, solar cells where using IC-grade-silicon for its construction, this grade of silicon (1E-09% impurities allowed) is more pure than the required for solar cells (1E-06), and the efficiency improvement it allows, does not justify its price increase. To address this price-reduction approach, some companies are producing solar-grade-silicon at lower prices than the one required for integrated circuits.

Once a low-price supply of silicon has been achieved, it should be used in a very efficient way. Actual solar wafers thickness is around 240um, therefore having a production efficiency of around 45 wafers per kg of silicon (~100W at 10g/W) [37]. If thinner cells can be produced, such as the 180um thick cell Sharp's prototype, a considerably increase in production efficiency can be achieved. Some research has been done to reduce cell's thickness down to 100um, but the cells become to brittle, and represent a significant problem for the manufacturing process of modules.
Another strategy for price reduction in use is to produce more polycrystalline-based solar cells than single-crystal solar-cells. Even though these last ones provide a better efficiency, are considerably more expensive, and it is possible to achieve commercial panels based on polycrystalline cells with efficiencies of 18.5% (Kyocera).

Finally, once the usage of raw materials has been highly optimized, the remaining cost to reduce the production of c-Si-based modules is to optimize the manufacturing process of modules itself. In this area, 2 different approaches are in use today: most European companies, such as Q-cells, are working extensively in automate the PV manufacturing process as much as possible, therefore reducing broken cells, increase energy consumption and reduce production time. China, on the other hand, possess certain characteristics that makes the country more competitive from an economic point of view. First, labor costs can be less than $200/month per worker, and its companies also benefit from lower SG&A (Sales, General, and Administration) R&D and tax rate costs. Therefore Chinese PV manufacturing lines tend to be more labor-intensive instead of using automated assembly equipment.

In 1975 the price of PV technology was about $30/Watt, and has gone down to around $3/W in more than 30 years by using all the approaches mentioned before. The lowest price the PV industry has experienced was $2.60/W in 2003 using Sharp's solar modules. After that, due to the shortage of silicon it rose again during the years 2004-2006 but started to show a reduction during middle of 2006, due to the introduction of several new silicon manufacturing facilities. In figure 7 this effect could be appreciated when analyzing the price per watt peak for commercial modules of 125W or more.

![Figure 7: Retail price per Watt peak in Europe][38]
**Thin-Films**

Even though it lags behind c-Si technologies when it comes to efficiency analysis, thin-films have got greatly stimulated during the silicon shortage of the last years. A-Si, thin-films technology leader, have the advantage of requiring only around 1% of the silicon required for building a c-Si module, therefore not depending of the silicon supply.

Also as explained before in section 3, thin-films offer several advantages that make the technology more flexible than c-Si based PV technologies, specially in the manufacturing process, therefore they can achieve a very low price when set into mass production scheme. First, since the temperatures required to place the material on the substrates is considerably lower than the ones required for the same process when using c-Si, the substrates required are cheaper and even some flexible materials can be used, allowing thin-films to be used for several specific applications where c-Si can not. Second, the purity of the materials required is lower, therefore the raw material obtaining process becomes cheaper than obtaining highly pure silicon. And finally, since they are integrated into a monolithic interconnected module the connection costs reduces the overall module price.

Also, there are some different approaches that can be followed, besides reductions in the manufacturing process of thin-films. An important one is its integration in buildings (BiPV), since it integrates the building structure in a better way than c-Si modules, the price of the materials that are being replaced by thin-films modules can be deducted from the module price.

Thin-films still account for less than 10% of the modules installed worldwide, however, the increase in the price of silicon, has boosted up the development and manufacturing of thin-films technologies, and thin-films account for almost half of the installed PV systems in the US, mainly due to the introduction of very succesful thin-films manufacturing companies such as First Solar. This company, by using CdTe thin-films, achieved the lowest cost per manufactured watt in the PV industry at a production scale of only 100MW in 2006, and the company announced costs of $1.25 per watt today, but it expects for costs to drop per watt below $1 by 2009. A price very hard to get for c-Si based technologies if a there is not a drastic price drop of silicon in the months to come.

Just as First Solar, many new companies will start appearing in the next few months, and the old ones will start manufacturing some type of thin-film-based technology. The main reason for this is because there are typically shorter lead times for building thin-films solar manufacturing facilities.
Companies like First Solar take between nine and 15 months to build a new plant, while it takes around 3 years to build polysilicon plants. This means that thin-films companies can respond faster to quick changes in the PV market demand, such as the changes we have experienced in the last two years. As an example, the biggest solar cells manufacturer, Sharp, announced the construction of their 1GWp thin-films manufacturing facility.

On the other hand big players, Suntech for example, do not seem as interested in manufacturing thin-film solar cells as the previously mentioned companies. By the end of 2007, Suntech only had announced a production capacity of 50MWp of thin-film based solar cells. Instead, they drastically increased their production capacity on c-Si based technologies, and signed large long-term contracts with silicon suppliers. The reason for this is that although thin-film based technologies are already commercially available, they are still under intense research and development. A trend not very often followed by Chinese manufacturers, they instead, tend to optimize the production scale of the most used technology available at the moment.

6.2 Major Players

With the world's five leader manufacturers in the PV industry controlling more than 50% of the total production, analyzing their strategies and plans for the future, can give us a clear perspective of what to expect in the future to come.

As explained before, companies formed in USA leaded the market during the first years of the PV sector, mainly thanks to the great boom of the spacial industry. Later on, Japan's companies production capacity increased at a very remarkable rate and have been leading the world's PV production then since. However, mainly thanks to government subsidies and environmental policies, Europe have gained more and more market each year.

In the following figure, the PV manufacturing share by country by the year 2005, is shown.
As it can be clearly seen, the major players were Japan (45% Share) and Europe (28%). However, China has had the fastest growth in the past two years in the history of PV (In production capacity increase in MWp). By year 2005, China's production was 150.7 MW and by end of the third quarter of year 2007, just Suntech alone (China's biggest PV manufacturer) was 420 MW, and it is projected to be 1GW in 2008 [40]. With an estimated current amount of 160 module and over 40 cell manufacturers in the People's Republic of China [41], China's future PV manufacturing share is definitely going to be considerably higher.

Now, a brief description of some of the world's leader PV manufacturers will be performed, showing their biggest milestones in the past years and their successful strategies.

**Suntech**

Founded in 2001 by Dr Shi Zhengrong, Suntech is definitely the major player of the moment, after opening their 1 gigawatt facility in Wuxi, China, Suntech became the second largest solar modules manufacturer in the world. Suntech started in september of 2002 their first production line with 10MW capacity, expanding constantly per year, reaching 50MW in august of 2004 and becoming in 2005 the largest PV manufacturer in China with the start of their 120MW production plant, China's
first mega-scale PV manufacturing facility. [42]

After an impressive growth production rate, Suntech entered New York's stock market in August of 2005, where, thanks to investor's money, the company kept its expansion, by several acquisitions and joint ventures: 66.88% in August 11, 2006 of MSK Corporation (PV Manufacturer specialized in BIPV). On February 7, 2007, the company established a 80% owned subsidiary, Shenzhen Suntech Co., Ltd, with Shenzhen New Photovoltaic Technology Development Co., Ltd and Shenzhen Yutong Investment Co., Ltd. On February 15, 2007, the Company established a 90% owned subsidiary, Jiangsu Suntech Co., Ltd, with Wuxi New & Hi-Tech Venture Investment Co., Ltd. [43]

During year 2007, Suntech increased its capacity target three times, first from 390 MWp to 420 MWp, then to 480 MWp [41], and finally during their third quarter report results in November 15, the final target was 540 MWp. In this report, it was also announced their target for 2008, 1 GWp, 2 years ahead of schedule[40]. Due to this results, its stock price has increase drastically during the past few months, as it can be seen in the following figure, and its trend is to keep raising.

Now, in order to keep its actual position in the market, Suntech can't stop it's aggressive expansion scheme, that's why one of their key strategies is to reduce the cost of silicon. This can be achieved by creating long-term contracts with silicon manufacturers, buying silicon for prices below the actual market price and fixing that price for several years. This strategy has been already used by the company, and in November 14, the company announced they had entered a two silicon-wafer supply agreements that last through 2016. [45]
Suntech's current leader products are monocrystalline and multicrystalline silicon PV cells with 16.8% and 15.6% efficiencies respectively. That explains the amount of effort put into reducing the cost of silicon supply, so the company can increase its gross margin.

On the thin-films area, with the constant development of this technology and its increase in efficiency and decrease in price, Suntech wants to be also an important player in the supply of thin-films in the future to come. To achieve this, the construction of their R&D and manufacturing thin-film factory in the Caohejing High Tech park in Shanghai already begun. Production will begin in 2008 and will reach a capacity of 50MWp in 2009. [41]

**Q-Cells**

With a production of 256.6 MWp by the third quarter of 2007 [46], Q-cells is the biggest PV manufacturer in Europe and is currently ranking number 3 worldwide.

Established in 1999, Q-Cells AG is a Germany based company, focused on production and sale of monocrystalline and polycrystalline silicon solar cells. During 2007 Q-Cells had a growth of 47% compared to 2006[47]. During the company's 2007 third quarter report, in november 14, Q-Cells meeting 2007's expectations and increased the expectations for 2008 and 2009. [48]

Q-Cell's main strategy is, rather than just follow a pure expansionary scheme, research and development is a key element of their management policy. By having several subsidiaries, Q-Cells make sure the company plays an important role in the development and implementation of the best technologies available in the market. Calyxo, Brilliant 234, Solibro, CSG Solar and Flexcell in the thin-films area. EverQ for String Ribbon Technology and finally Solaria for low concentration PV technology.

Even though Suntech showed a bigger expansion capacity increase during the company's third-quarter financial report, Q-Cells presented a higher gross margin (37% vs Suntech's 24%[49]). The difference mainly was because Suntech had to pay higher prices for silicon, since Q-Cells, with more experience in the market had already long-term low-costs contracts with silicon suppliers.

This same experience that helped Q-Cells have such a high gross margin in 2007, added to their
constant innovation policy and efficient use of silicon, have allowed the company to have a constant increase in the stock market, as shown in the figure below.

![Q-Cell's Stock Chart][50]

Q-cells is confident with their growth strategy, and even though Suntech have recently overtaken the company for the number 2 spot in the market by using a very aggressive expansionary strategy, Q-Cells's commitment to invest in new technologies less dependant on silicon without stopping their continuous growth, could help them gain their position back. In 2010 Q-Cells expects a production of more than 1GWp in their core business and between 400 and 600MWp in their thin-films business.

**Kyocera**

The Japanese company Kyocera, has had a very important presence in the PV market for the last few years. By year 2005, Kyocera was ranking 3 with an annual production of 180MW[51], now, with the inclusion of Suntech in the top 3 worldwide, Kyocera moved to position number 4. During year 2006, Kyocera's solar sales increased by 33%, and in april 2007, the company announced plans to expand its solar module manufacturing capacity to 500MW.[52]

To keep a high positioned status in the actual PV market, some of Kyocera's strategies are similar to Suntech's, such as keep a constant expansion capacity, although not as aggressive, and ensure their silicon feedstock by creating long-term contracts with silicon suppliers. However, Kyocera has been in the PV market for longer, therefore it has been consolidated as a global company with established local production and supply systems for solar modules in Japan, Europe, the United
States and China. Therefore, its strategies are more focused in growing each plant according to its area needs, increasing their efficiency and responding to local specific demands. Also, Kyocera's commitment to R&D makes them hold the world's record for energy conversion efficiency in 15x15 polycrystalline silicon solar cells, at 18.5%. [53]

With companies such as Suntech, already predicting production's capacities of 1GW by 2008, Kyocera's 500MW production capacity plan by 2011 does not seem big enough, but, its experience and distributed production scheme has guaranteed the company a close relationship with governments and customers in the past, so it is possible that these same relationships added to its competitors pressure, can stimulate Kyocera's growth rate beyond their actual predictions.

**Sharp Solar**

Sharp Corporation is a global electronics manufacturer and one of the oldest solar cells manufacturer, beginning researching solar cells in 1959, and its mass production in 1963. [54]

During the last 7 years, Sharp has been the number 1 PV systems manufacturer in the world. Starting in 2000 with 50.4MW PV modules shipped, Sharp has kept a continuous growth rate, and by the end of year 2007, its annual production reached 710MWp. [39]

Sharp has been in the solar market for over 50 years, first providing solar power for satellites and lighthouses (1000 by year 2000), but then moving into every possible PV application available. Sharp holds most of the patents for technologies and manufacturing methods giving the company a clear advantage over its competitors. Also, its experience and production capacity, have given the company a very respectable status in the market, allowing them great relationships with governments and major private companies. Therefore the company holds most of the biggest large-scale PV installations worldwide, including the largest commercial PV system in the US to date, at Google's corporate headquarters in Mountain View, California (1.6MW) installed in June 18, 2007. [55]

Sharp's product line include all the technologies previously mentioned, from the traditional monocristalline and polycrystalline silicon solar cells, up to specialized high-efficiency solar cells for spacial applications.
One of the products line Sharp has put an special effort on, is their thin-films one. The company presented their latest modules during Intersolar's exhibition held in Freiburg, Germany in 2007. Their latest modules are triple-layered with two layers of amorphous silicon and one of microcrystalline silicon. The modules efficiency is just below 10% (very high for thin-film modules) and with a peak output of 105Wp per module. Also, the company announced in november of 2007 the construction of a 1GWp thin-films manufacturing facility in Japan.

Even though Suntech's expansion strategy makes the company Sharp's actual main commercial competitor, Sharp's experience and technology guarantees their competitiveness in the future.

**Companies Review**

Since PV technology has been considered as an option to help supply the demand of electricity for both commercial and domestic applications, the main issue that has been around this technology is its high price per watt produced. This last one has been, until now, considerably higher, compared to traditional technologies, or even compared with some renewable ones, such as windpower and biomass.

Thanks to its “clean” nature, and a world trying to be less dependent on fossil fuels, supportive policies used by several governments have been vital to help this technology develop dramatically during the last decade.

However, this trend is changing, 2006 and 2007 showed the highest growth rate in PV technology in history, only this time, not just due to supportive governments, but due to a growing PV market. PV technology is today a ready-to-implement option that would help shifting electricity production from fossil fuels. One of the most significant changes that have helped such a high growth, is the introduction of China as a major player in this area. For many years, China's PV production was very limited and the market was ruled by Japan, Europe and US.

Suntech, China's biggest PV manufacturer, has changed this, and just within 6 years, has become the world's second largest PV products manufacturer, projecting a production capacity of 1GW in 2008.

Germany has still the world's largest PV market, (estimated 1260 MW installed in 2007) [56] and
some of the most successful PV companies in the industry. However, China's aggressive introduction into the market is forcing prices to drop dramatically, while in Europe production costs for PV modules are around 3.2€/Wp[57], China is entering the market at prices of 2.74€/Wp[41].

One of the reasons why the price is still higher in Europe is because they have invested a lot of money in PV R&D during the last decade. China, on the other hand, is highly focused on manufacturing processes expansion and price reduction. China's strategy can be clearly appreciated in Suntech, putting a great effort in increasing the manufacturing amount of modules based on the traditional monocrystalline and polycrystalline silicon-based solar cells. Also, to make sure events like the silicon shortage we have experienced since year 2004 do not affect their production rate, Suntech has made large long-term contracts with silicon suppliers. On the thin-films area, even though the company has announced the construction of a thin-films research, development and manufacturing plant, its 50MWp capacity falls short when compared to their 1GWp crystalline-based silicon solar cells production capacity.

The german-based company Q-Cells, on the other hand, is truly committed to innovation and work with state-of-the-art technology. The company's projections of 400 to 600MWp by 2010 of thin-films production capacity clearly shows a trend of using less silicon-dependant technologies. Instead of just focusing on immediate price reduction, the company is more interested in increasing their cells and manufacturing process efficiency. This strategy may seem slower in terms of increased production capacity, but more stable in terms of market longevity.

However, even though there is a lot of effort in increasing the production of thin-films-based modules, c-Si still accounts for over 90% of all the modules being sold worldwide, but the trend is for thin-films to grow. Obtaining silicon is a very expensive and energy intensive process, and, as proven since year 2005, there could be a shortage of it, therefore increasing the production costs of PV modules.

This shortage of silicon, reminded the PV industry of the incident that happened during the oil crisis in 1972. Depending on a raw product which price can fluctuate so drastically can generate a very big impact on a whole industry. But at the same time, just like the oil crisis stimulated the growth of renewable energy sources in the past, the shortage of silicon is now stimulating the development of new PV technologies less silicon-dependant.
Of all the low silicon-dependant technologies available, thin-films is definitely the most important at this moment, and that is why companies based on this technology, such as First Solar, have shown an impressive growth, only compared to very innovative successful companies such as Google. First Solar is a US-based company formed in 1999. Unlike the previously mentioned companies, this one is only focused on manufacturing thin-films modules. The company started production in 2002 and achieved the lowest cost per manufactured watt in the PV industry at a production scale of only 100MW in 2006 [58].

Thanks mainly to the silicon shortage, First Solar has received a great recognition, and of course, lots of investors interested in this new technology. The company entered the public market at $20 per share, and it has gone up in value by 11 times in less than 1 year. Google entered the market a few years ago and is now over $600, the numbers are bigger but the multiple is not. [59]

Right now is the best time for thin-films developing, however, with an increasing number of silicon suppliers appearing, the shortage of silicon is not to be considered a problem anymore, and in case the opposite effect happens and there could be an over-production of silicon, c-Si based technologies could drop their prices and put thin-films into great trouble. Therefore thin-films researchers should concentrate their efforts on rapidly increase their conversion efficiencies up to c-Si levels without sacrificing their price per watt, therefore guaranteeing their future role in the PV market.
7 Chinese Market Penetration

7.1 Commercialization

Chinese PV companies are expanding rapidly. Since the beginning of China's significant entry into the PV market which occurred around the beginning of the decade, China has production capacity growth almost double that of the rest of the PV producing world with a growth rate of 70% to 36% respectively. However the important point to notice is that although China is producing more and more every year, most of it is exported. This graph demonstrates this fact.

With 80% of the PV products in 2005 being exported, it is clear that Chinese government was not able to spark much interest into the domestic PV market up to date. This due to the lack of environmental legislation that would require utilities to purchase renewable energies prior to the Renewable Energy law that took effect in January of 2006.

Domestic Market

As of 2004, China had a very small domestic market considering their large potential market and

Figure 11: Total Chinese PV production capacity[3]
high solar radiation levels (much of the country averages above 2000 hours of sunlight per year). And although the domestic market has grown consistently since its meaningful inception about a decade ago, progress is slow due to low levels of government support and higher profits available in foreign markets.

Several useful programs, such as the Township Electrification Programme and other rooftop programs have demonstrated China's ability to provide some stimulation in domestic markets, but this has been on a limited scale. The government's projection of 2 GWp installed capacity by 2020 also suggests that the government is not doing enough to promote favourable conditions for the development of internal markets. Other advocates of Chinese solar R&D have predicted an increase to 10 GWp by 2020, but for this to happen, a complete shift in government policy, industry focus and R&D funding will be needed.

To begin with, the implementation of a feed-in tariff that has worked so well in Japan and Germany will be needed. A good example of how much impact the feed-in tariff has on a domestic market can be seen in Canada, where to date upwards of 90% of PV is used in non-grid connected installations which is similar to Chinese levels. With Ontario's new feed-in tariff under the Standard Offer Programme, which provides a benefit of 0.42 $CAD available to both commercial and residential customers. Canada is still in its infancy for grid-connected PV, but much like

Figure 12: PV annual production and cumulative installation capacity in MWp in China by year[60]
Germany and Japan, this will certainly spark interest in domestic producers.[61] Currently China is focusing on bringing electricity to the millions of households that are without power, and although this is a worthwhile endeavor for the development of the country, the market potential in this segment is limited compared to grid-connected PV.

![Figure 13: Extrapolation of the consolidated PV production capacity trend in China over the last decade][3]

Furthermore, although Chinese producers are currently focused on reducing costs of wafer and cell manufacturing, companies in China plan to increase their presence in the higher value added segments of the production chain. Historically, foreign competitors in Europe, North America and Japan have led controlled these segments, but as China moves forward with their plans, they will gain the potential to reduce costs which could be economical on the domestic market. However, producers are still not investing enough in implementation and application research therefore growth is not likely to increase in the domestic market as much as it has internationally.

Finally, probably the most important reason why China will not grow a significant domestic market is because Solar Power is still too expensive to compete with conventional power. China will continue to invest in their primary energy source, coal, as seen in the table below:
Table 13: China: Electricity generation capacity by type of fuel in GW and as a percentage of total generation[3]

<table>
<thead>
<tr>
<th>Mode of electricity generation</th>
<th>2002</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>266</td>
<td>400</td>
<td>592</td>
</tr>
<tr>
<td>Hydro</td>
<td>86</td>
<td>135</td>
<td>220</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4.5</td>
<td>12.5</td>
<td>36</td>
</tr>
<tr>
<td>Renewables</td>
<td>0.5</td>
<td>37</td>
<td>102</td>
</tr>
<tr>
<td>Total</td>
<td>357</td>
<td>584.5</td>
<td>950</td>
</tr>
</tbody>
</table>

International Market

China PV companies have generated a lot of interest as of late. Numerous Chinese companies have made headlines with dramatic plans for future expansion, exceptional profits and large contracts with other companies in different areas of the production chain. Now one of China’s richest men, Dr Shi Zhengrong, founded China’s most successful PV company, Suntech, in 2001. As discussed later in this paper, part of China’s strength has been to take advantage of the low cost labour that is currently available. This had made expansion in this industry much faster than other countries. However, companies in China seem to realize that to add value to the production chain and to increase profit margins they need to invest heavily in wafer and cell production and move away from the traditional module assembly segment that has characteristically been their main focus.

Figure 14: China: capacity along the crystalline silicon production chain (2005)[3]
Clearly China is attempting to reduce cost through economies of scale. However, the cheap labour that had such an impact in module production is not nearly as pronounced for cell and wafer manufacturing. To bring cost savings to this segment, high-tech improvements need to be made and it is in this area that companies have invested the most money. China is also moving away from imported technology and trying to develop their own solutions, which in the medium to long term will produce significant cost savings.

Expansion plans exist with most companies and contracts for silicon are being signed very quickly as the silicon becomes available. Most companies predict that when the silicon shortage is over in the coming years, there will be dramatic price reductions in solar cells. The overall cost of the modules will not decrease as dramatically since the silicon contained in the whole operation only accounts for about 30% of the total cost.

To summarize, a recent report has been issued by Global Sources breaks down the ambitions and concerns of 60 PV suppliers in China. The report states that the main 3 strategies being used to cut costs are: reducing waste, increasing automation and upgrading management systems. Clearly the silicon shortage is taking a heavy toll on Chinese producers and reducing waste was listed as a primary goal for 28% of respondents. Increased automation and management system reforms ranked at 27% and 25% respectively. For the next 12 months, 60 % of suppliers cited price competition as their primary concern. Another 25% said raw material costs could hinder their growth while 7% were concerned about overseas standards. However, a full 97% said they expected exports to increase over the next 12 months.[62] This is overly optimistic considering the fierce competition and the dominance of the Chinese market's giants like Suntech who are able to offer more competitive prices, but the ambition of the industry itself is clear.

7.2 Current Barriers

**Lack of Silicon Production and Refining**

Since the beginning of the solar industry, the silicon needed for fabricating solar cells came exclusively from the oversupply of the integrated circuit industry. Year over year, however, growth in the solar industry has risen about 30% to a point where more silicon was required by the solar industry than the IC industry. But as always, IC producers were able to pay more for the refined silicon material and because of their longer business ties with silicon producers and higher margins
on their final products. But now with the PV industry proving a certain amount of staying power, they have started to secure long term contracts with silicon producers, as well as gaining a certain amount of silicon from producers designed specifically at a purity only usable by the PV industry.

This is good news for Chinese producers because at the moment their technological strengths do not lie in polysilicon manufacturing. Yet, as their capacity for solar cells expand, the deficit of domestic silicon produced and used expends in step. This puts a lot of pressure on new entrants to polysilicon based PV companies if they are not able to secure silicon in the next few years while the silicon shortage continues. Furthermore, if thin film R&D has a breakthrough in China (increasing efficiency or exceptional cost reductions for example), a slight shift away from silicon based cells towards cheaper third and fourth generation PV technology could help mitigate the silicon shortage. At the very least, China will undoubtedly become much more competitive in the international market when the silicon shortage is over in a couple years. Although they have some barriers to overcome, the silicon shortage will only slow their progress, not stagnate it.

**Lack of Government Support**

The Chinese government has laid out clear strategies for increasing solar power and supportive environmental programs which were mentioned throughout the paper. However this will not be enough to stimulate growth for a domestic market. The history of China has shown their unique ability to maximize production and profit margins though the use of cheap labour, relaxed environmental laws, and their ability to encourage foreign capital investment. This will certainly translate to the PV market as well, but without proper domestic incentives, the domestic market will not grow at the same rate. However, there are several market segments to consider. The first goal of China is to provide power to millions that currently go without.

A web interview with Emil ter Horst, director of Horison, senior PV consultant and China PV expert is somewhat more optimistic and mentions that "the "Renewable Energy Law' was approved in February last year and has been actively enforced since this year. The effect for the development of the PV market is not yet clear." When asked by SolarPlaza the Shanghai 100,000 Solar Roofs Program, ter Horst said “I also think that provincial incentives/policies such as the Shanghai 100,000 roof programme will be decisive for the prevalent PV market segment in the province.” Therefore, there is reason to believe that very small scale PV installations (on the order of 10 to 40 Wp) will pick up and provide electricity. But larger segments in the high kilowatts and megawatts
will have to wait for more generous subsidy offers in the next round of incentives from the
government.[63]

More recently China held the bi-annual International Solar Energy Society (ISES) Conference
which was held between the 18th and 21st of September, 2007 and over 600 participants including
300 Chinese trade investors attended. Although the mood was very optimistic about the future of
the Chinese PV industry, the general consensus was that the national government was not ready to
support the domestic market in the same way that Germany has. Specifically, the Chinese
government currently views solar power as a solution for rural electrification needs, not for large
scale alternatives to fossil fuel energy production. This is understandable since the situation in
China is quite different to Germany. In China, income levels compared to electricity prices are
quite significant and this doesn't lend itself as easily to a feed-in tariff. Instead, the government, for
the foreseeable future will continue to rely on subsidising the current state-run energy companies to
help lessen the impact of high electricity prices.[64]

Finally, because new PV projects are too expensive for the general population in China, and
considering there are still unfulfilled needs in rural electrification, the government is focused on
new roof-top projects. The Brightness Program which expired in 2005 is now replaced by a new
project for 3 million households. Until prices can come down and rural electrification is no longer
the main focus in development, there will not be any sizeable feed-in tariffs to stimulate the
domestic market.

Inaccurate Projections for PV

Up to date, expansion has been fairly predictable in the PV industry. This has been a big advantage
to interested parties since they were able to invest in confidence. Companies producing cells and
modules historically have never had problems securing silicon but now with the shortage, many
companies are expanding silicon production. Also, because the silicon supplied to the PV industry
was from a reliable source - the semiconductor industry - now the need has out grown the supply
and there is a flood of promised silicon expected to come onto the market, not all of which has been
verified.

Also, because competition is so fierce at the moment in China and producers are worried about
competitors price reductions, companies are doing their best to attract investment. Some of this will
undoubtedly be rooted in overly optimistic projections for the future. This is a dangerous business
tactic because planning production expansion before securing the necessary feedstock means a PV
producer would have to rely on the expansions promised by the silicon refining industry, which are
also not entirely concrete either.

**Solar Cell Efficiency and Product Quality**

The highest efficiency for a commercial solar PV module current available is 18.4% (Kyocera)
using polycrystalline technology, and in the thin-films area it is possible to find panels with
efficiencies of around 10%. Although, under laboratories conditions it has been possible to reach
efficiencies of up to 40%. With an expected time delay between laboratories and manufacturing
production lines of about 8 years, it is possible to predict an inevitable efficiency increase in the
electrical conversion of PV modules.

With the great advances the PV industry has experienced during the last 2 years, it is possible that
the considered time delay from laboratories to production lines could be shortened. However, with
an increased effort put into PV development, new technologies are appearing constantly, making it
harder for manufacturing companies to decide which technology to choose to bring to the
production line. In the years to come, we will have a variety of technologies that would fit many
different specific needs. However the bottom line will continue to be the $/Wp of the installed
system.

In this area, Chinese companies's PV modules efficiency has always been slightly lower compared
to those of Japanese and European companies. This is a trend that is likely going to continue
because Chinese companies do not seem as interested in developing new technologies. They would
rather enhance the manufacturing process of the existing ones - c-SI based PV cells for instance -
since this last approach provides a faster economic payback time (EPT). This approach does not
necessarily guarantee market longevity. Technologies like thin-film based solar cells have shown a
steeper learning curve, leading to faster and more efficient manufacturing processes that could
allow them to have the best $/Wp ratio in the future.

To achieve this point, quality is another factor besides efficiency that has to be taken into account.
At the very beginning of the PV industry, its application field was considered too specific and just a
few companies manufactured solar cells. This resulted in many companies having the power to
choose their own quality standards based on customer needs. Although there exist several certification organizations worldwide trying to address this situation, there are new companies and technologies entering the market every day, making this task a very complicated one. This could become a real problem in the future, where customers would have to “trust” the companies quality control process. For a product with a life time expectancy of 20 years, for consumers, is a big leap of faith to take, considering most of this new entrants have not being in the industry for that long, and there is no guarantee that they will be 20 years in the future.

Chinese companies have had a history of being able to enter the market of different industries very fast, and in an aggressive way. That is why they have gained a reputation of being the manufacturers of the world. The Chinese regulation system allows companies to grow really fast in a very short amount of time, but while this is vital for their ability to enter the market, sometimes it has lead to low quality control policies. Many companies have had legal conflicts for not complying with the safety and quality regulations of western countries. This negative image can affect Chinese manufacturers, and it is quite possible that companies in western markets could wait until the Chinese PV industry matures. Therefore, because of the negative image that China has for the quality of their manufactured products, it is even more important that PV manufacturers focus on quality assurance and control.

7.3 Suggestions and Recommendations

Competition is fierce in the Chinese solar industry. Companies are aggressively securing contracts and expanding their production because of the incredible growth rates around the world. New markets are opening on an almost quarterly basis with governments world wide installing new tariff schemes or other types of subsidies. Clearly there is a lot of profit to be made. But with so many entrants into the industry, how can China position themselves as a world leader?

Beginning with the strengths of the Chinese market, the expansion of production seems inevitable, although in the past it occurred in fits and starts. And no doubt will China continue its history of massive exports compared to domestic sales. But the real future potential for China lies in their untapped domestic market. Increased PV presence in China would result in more experience for the industry itself, and efficiency and quality improvements naturally follow. Certainly China has their obstacles to overcome, beginning with overcoming the silicon shortage and increasing cell efficiency and quality to remain competitive with the rest of the world, but they have the unique
advantage of a cheap labour force. And as China develops in the decades to come, this comparative advantage will diminish. Therefore, for China to maximize their advantage sooner rather than later, several key factors need to be addressed.

First, the view that the Chinese government considers PV as a technology used primarily for rural electrification needs to be changed. As mentioned earlier, this is certainly a worthwhile cause and the results from these programs throughout China have been quite successful, but these programs should be running alongside grid-tied PV. To make PV more mainstream, startup projects will be needed in urban areas and some centralized PV plants should be created.

This seems to be a tough idea to sell to the Chinese government for several reasons. Mainly because there is simply not enough public money available to justify large scale expansion for domestic PV when coal represents a much cheaper alternative. Another reason is the lack of support from more advanced countries like Germany when it comes to the transfer of knowledge and technology. Recently at the ISES conference in China, Frank Haugwitz from the German Agency for Technical Cooperation mentioned that “[Chinese] PV manufacturers have a problem in obtaining [European] technology. Foreign technology suppliers are not so willing to sell them know-how and machinery.”[64] Instead, China has oriented themselves more towards Russian expertise, which is certainly inferior to the well-developed German and Japanese industry. And the most fundamental reason is that there are very few incentives, politically, socially and financially, to motivate Chinese companies to concentrate their efforts within their borders.

The first solution to transform the domestic industry would seem to be a synthesis of the German Renewable Energy Act as many other countries have already done (France, provinces with Canada, states within the US for example). In China this would only work with some significant changes which would address their specific obstacles. Since China has relatively high electricity prices as it is, introducing a feed-in tariff similar to the German tariff would not transfer the cost of electricity away from the consumers in any meaningful way. In Germany, the rebate received for green energy produced is derived from all consumers in the form of a tax. This could be modified in China by instead placing the tax burden on unsustainable energy producers, thus promoting solar power as a cleaner technology, providing financial incentive for PV adopters which would essentially create a level market on which PV can compete with conventional types of energy.

Following this stage, a certain amount of public education is needed to increase national support for
clean energy within China. This is not easily quantifiable, but there is certainly a correlation with an educated public and a more sustainable and efficient energy market. Many European countries have succeeded in this respect which is apparent in the environmental platforms that exist for political parties up for election. France, for example, has placed a high importance on energy security and the reduction of GHG emissions.

Finally, for China to maintain their growth rates and increase their domestic market size, they need to increase their product quality, continue research and development to remain competitive with the rest of the world.

As previously mentioned, Chinese companies tend more to focus more on the manufacturing process than on the PV technology development itself. This is still true, and can be easily appreciated when analyzing some of the biggest Chinese PV manufacturers expansion strategies. This should not be confused as lack of R&D from Chinese companies, as there is a growing development on PV manufacturing equipment such as module laminators, wafer eth/bath and mono-crystalline wafer pullers. This equipment is being designed and built in China for a fraction of the price it would cost to purchase this technology from western countries.

With this in mind, China is technologically reaching the most efficient per dollar manufacturing process of the market, by combining a highly-skilled cheap labor force and local low-priced manufactured automation equipment. But even though this is giving China a great competitive advantage over western companies at present, Chinese PV companies currently lack the necessary level of development that could change their market position in the future. Furthermore, thin-film technology's steeper learning curve may change the market situation very fast, leaving behind those who did not enter this technology market soon enough.

7.4 Solar Energy Forecast for China

The future of solar power in China is still in great debate. Although growth rates have averaged about 70% since 2000, the coming years will be quite decisive for the future of PV in China. On the conservative side, the government believes that an installed capacity in China will reach 400 MWp by 2010 and 2 GWp by 2020. On the optimistic end of the spectrum, some Chinese solar R&D representatives believe that up to 10 GWp is possible by 2020, but for this to happen, policy needs to be completely reworked.[3][64]
The likely scenario is probably somewhere above the lower projection. Chinese producers have certainly proven their ingenuity when the proper motivations are there, and if the next 5 year plan for China includes some more interesting incentives, a sharp increase in domestic PV will likely occur in the beginning of the next decade. Furthermore, as economies of scale are added to the picture, and considering the likely price decreases that will come after the silicon shortage is over, the case for Chinese domestic PV becomes ever more realistic. Not to mention the climatic advantage that China possesses due to the large amount of sunshine available in this region of the world.

Internationally, it seems that China will continue keeping a steady production capacity expansion. Product improvements with efficiency and quality will allow them to capture more market share. Continued use of their cheap labour force will allow them to maintain market dominance in the less skilled segments of the production chain such as module assembly.

It looks like the shortages of silicon are finally disappearing and production prices for c-Si based technologies are starting to drop, turning the market from a market of suppliers to a market of buyers again. With China's PV production capacity over 2GWp by 2010, this ensures their important role in supplying the world's PV demand.

And finally, although China is unevenly distributed in the production chain, new entrants to the market are filling the gaps and older companies are showing interest in vertical integration. This fact will create a more secure market for the future since they will become more self reliant.
8 Conclusions

The Chinese energy industry consumption is estimated to reach 1629 Million Tons of oil equivalent in year 2006. Fossil fuels, most significantly coal, accounted for 69% of the total energy consumption in 2005 and oil at 21%, were the major sources for energy in China. With the Chinese objective to secure energy for their future, their investment in coal is still overshaddowing all attempts at growing a domestic renewable energy market. However, in the photovoltaics sector, China registered rapid growth in solar cell production for export. In only 2-3 years (roughly from 2003 to 2005), solar cell production share of the country increased from 1.07% to 8% with respect to the world, only after Japan and Europe.

The growth strategy China has followed in the PV industry has been very similar to every other manufacturing sector, by using cheap qualified labour and low administrative costs several Chinese companies have been able to build large PV manufacturing plants and being able to position one of them (Suntech) as the second largest PV panels manufacturer in the world.

There are, however, several barriers China must overcome in order to keep such an impressive grow rate in the industry. First, there has been a high price for silicon for the last 5 years, and taking into consideration that this is the raw material for c-Si-based solar panels, that account for 90% of the the total ammount of installed panels, this has a serious impact on the entire industry. Some companies, such as Q-cells and Sharp, have migrated from a c-Si based production to make large investments in Thin-films development, mainly to rely on a less silicon-dependant technology in the short-term. Suntech - the Chinese leader solar manufacturer - on the other hand, just expanded to 1GWp c-Si based manufacturing capacity, maintaining a strong dependency on silicon. In order to keep prices competitive, c-Si based panels manufacturers will keep long-term contracts with silicon suppliers in order to have a silicon price per kg lower than the retail market price.

There are two main ways to make it cheaper to produce electricity from solar panels, having a high conversion efficiency so you use less panels to produce the same amount of electricity or to make them cheaper so it is possible to buy more, this whole balance goes down to analyzing PV modules price in $/Wp. China's approach tends to be the second one, less efficient panels but cheaper due to the manufacturing strategies already mentioned (cheap labour, large-scale producion, etc.). However, with thin-films technology holding the lowest manufacturing price per watt, c-Si based technologies should increase their efficiency in order to hold its market position. Chinese PV panels
conversion efficiency is usually 2-3% lower compared to the conversion efficiency found in European and Japanese panels, showing that there is an important need for investing in R&D into wafer and cell production.

R&D would also benefit Chinese companies in terms of quality standards, there is still the worldwide mentality of Chinese companies having low-quality standards, it could not be so important when it comes to analyzing short-lifetime products, but when it comes to analyze solar panels, -with a guaranteed lifetime of 20 years but expected to last for 25-30- quality standards becomes an important issue. This quality standards increase would at the end increase consumer "trust" and help Chinese companies keep holding their solar PV panels manufacturing growth.

Even after solving these barriers, some additional effort should be put into the chinese PV industry in order to guarantee their important participation in the field. In order to prepare for rising labour costs, Chinese companies need to invest more heavily in automation and optimization of their manufacturing processes. Also, there is a large potential for the PV local market, but low public awareness is actually present, therefore increased awareness campaigns should be addressed.

In the state-of-the-art technologies, Thin-films have proven so far their large potential in the PV industry, but Chinese companies participation in this area have been minimal compared to the efforts made to increase the production of c-Si based panels. With a manufacturing price of 1.25 USD/Wp -the lowest of all the commercial PV technologies available- Thin-films technology becomes a very serious option Chinese companies should consider more heavily.

In the present project it was found that although China is speeding ahead to become the world leader, they are not taking a sustainable approach. Partnerships with European companies to secure more efficient technology is slim and the use of the inexpensive Chinese labour force continues to allow Chinese businesses to remain competitive with foreign producers. Finally, as China is and will remain a net exporter of solar power products in the decades to come, the domestic market will not grow due to the lack of government support and higher profits available outside Chinese boarders. The implications of these findings are that as China is showing signs of a young market undergoing rapid expansion, they appear sustainable only in the short to medium term. As this market matures and development drives up labour costs and stricter environmental standards, the lack of investment in solar infrastructure and more efficient technologies will hinder China’s ability to complete globally in the medium to long term.
9 References

References


