Solar photovoltaic energy: Trends and status
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# Table of Content

Solar Photovoltaic Energy ................................................................. 1
Solar PV technologies ......................................................................... 1
Solar cell .......................................................................................... 1
PV module prices .............................................................................. 7
Share of technologies in Global PV market ........................................ 8
Applications ...................................................................................... 9
Global market scenario ....................................................................... 10
Global PV cell manufacturing status .................................................. 11
Major players .................................................................................... 12
R & D activities .................................................................................. 12
Forecasts ........................................................................................... 13
References ......................................................................................... 13
Bibliography ....................................................................................... 13
Annexure: Manufacturers’ details ....................................................... 14
SPV (solar photovoltaic) technology is primarily a semiconductor-based technology, which is used to convert solar radiation into direct electricity. A basic PV system comprises PV modules/solar cells and the BOS (balance of systems) that includes cabling, electronic controllers, storage batteries, inverters, and support structure.

**Solar PV technologies**

**Solar cell**

There are several ways of classifying the solar cell depending upon the type of absorbing material used, manufacturing technique/process adopted, type of junction formed etc.

- Solar cell technologies can be broadly classified into
  - Wafer based crystalline silicon solar cell technology
  - Thin-film solar cell technology, which includes, Copper Indium Gallium Diselenide (CIGS), Cadmium Telluride, Amorphous silicon (a-Si) etc.
  - Emerging technologies such as thin-film silicon dye sensitized solar cells; polymer organic solar cells, etc have come up in recent times.

**Wafer-based crystalline silicon solar cell technology**

This is further classified into two types as

a. Single-/ Monocrystalline silicon solar cell
b. Polycrystalline silicon solar cell

**Single-/Monocrystalline silicon solar cell (c-Si)**

This is the most efficient technology available till date. It has module efficiency of 15-18%. These cells are manufactured from single silicon crystal, by process called Czochralski process. As during manufacturing, c-Si crystals are cut from cylindrical ingots, they do not completely cover a square solar cell module. Hence most c-Si panels have uncovered gaps at the corners of four cells.

![Monocrystalline Si solar cell](image1.png)

*Figure 1: Monocrystalline Si solar cell*
Advantages
It is a reliable and well established technology

Concerns
1. As during manufacturing the wafers are cut from cylindrical ingots, these cells do not completely cover a square solar cell module so extensive amount of silicon is wasted.
2. It is requires expensive manufacturing process

Manufacturers

Multi-/Polycrystalline silicon solar cell (poly-Si or mc-Si)
These cells have module efficiency of around 12-14%. These are manufactured by cooling a graphite mold filled with molten silicon.

Advantages
1. It is less complicated and cost effective manufacturing method of Si-Wafer solar cell production.
2. Due to extensive research, gap between actual and laboratory efficiencies is reducing.

Concerns
Improvements in efficiency and cost reduction are major concern for poly-Si solar cell.

Manufacturers
Sharp, Q cells AG, Suntech Power, Mitsubishi Electric, Motech Industries, Schott, SolarWorld, BP Solar.

Thin film solar cell technology
Some of the thin film solar cells in use are as follows:
- a-Si
- CdTe
- CIS, CIGS (copper indium gallium di-selenide)
- Thin film crystalline silicon
The following section gives an overview of different thin-film solar cells in use.

**Amorphous silicon (a-Si) solar cell**
Amorphous silicon (a-Si) modules are the first thin-film solar module to be commercially produced and at present has the maximum market share out of all thin-film technologies.

![Amorphous silicon (a-Si) solar cell](image)

**Advantages**
- a-si solar cells can be fabricated at a lower deposition temperature thus permits the use of various low cost, flexible substrates by using easier processing technique.
- a-Si solar modules are easily integrated into facades, roofs and other structure. The lightweight substrates are also attractive for space application.

**Concerns**
- One of the biggest concerns of a-Si cells is its low stabilized efficiency. Although the stabilized efficiency of a-Si based solar cells has been improved by the design of the cell structure such as multi junction solar cells, the highest lab efficiencies are in the range of 13-14.5%.
- Overall efficiency drops inevitably at module level and at present the efficiencies of commercial modules are in the range of 4-8%.
- The prices of a-Si are marginally lower than that of the crystalline silicon solar cells but due to lower efficiencies and initial stability problems these are not preferred for large scale applications.

**Manufacturers**
Sharp, Suntech power, Schott

**Cadmium telluride (CdTe) thin film solar cells**
Thin film cells based on CdTe technology is one of the oldest thin film technologies. CdTe with laboratory efficiency as high as 16.5% have been developed at NREL.
Advantages
- Multitude of manufacturing techniques, which are suitable for large-scale production

Concerns
- Limited availability of Cadmium and the cost associated with it.
- Pollution problems due to use of Cadmium which is one of the heavy metals.

Manufacturers
Suntech Power, Schott

Copper Indium Gallium Diselenide (CIGS) Solar cells
It is one of the most promising thin film technologies due to their high-attained efficiency and low material costs.

Advantages
- Amongst thin film solar cells, the advantage of CIGS solar cell is its extended operational lifetime without significant degradation. The inherent properties of CIGS also provide an opportunity for maximizing the efficiency.
- Module can be deposited on soda-lime glass substrate, polymers and metal foils, thus allowing the PV integration into buildings and space power applications.

Concerns
- Complicated and capital-intensive fabrication methods
- Availability of core elements (Indium)
- Toxicity of the CdS n-type buffer layer.
New and emerging technologies

**Thin film crystalline silicon solar cells**
Thin-film crystalline silicon solar cell is one of the new concepts developed in recent years. These cells are typically of 5-50 micrometer thickness and are substantially thinner than the conventional wafer based solar cells of 300 micrometer thickness. It is expected that these cells would have the advantage of high stable efficiency and longer life of crystalline silicon cells and low material requirement of thin film thus resulting in the reduction of the cost of the cells. Further the manufacturing process is supposed to be easier and cheaper.

**Advantages**
- Lesser use of silicon material with relatively easier manufacturing process.
- In these cells the active layer of silicon is 5-50 micrometer thick and can be supported either on lower grade Si or other substrates such as glass, ceramics or graphite.
- Efficiency of as high as 21% has already been achieved under ideal condition

**Concerns**
Some of the manufacturing processes/techniques used in the lab scale devices might not be economically viable for large-scale production.

**Other new emerging technologies**
Besides crystalline thin-film modules, Dye Sensitized Solar Cell (DSSC), organic polymer cells etc are emerging as new solar cell technologies.

Although DSSC is still at the pilot production stage, it is becoming popular because of its potential for high-energy conversion efficiencies at very low cost. Besides DSSC solar cells, and other organic solar cells such as polymer organic solar cells have shown the promise of ease of manufacturing at low temperature and at low cost. However the efficiency as well as the long-term stability has to be improved further in order to compete it with conventional solar cells.

Organic photovoltaic cells (OPVs) consist of organic semiconductor material. The Organic semiconductors are made from readily available and non-toxic precursors and can be deposited at atmospheric pressure in roll-to-roll coaters onto flexible substrate. OPVs using carbon nano-tube are an attractive alternative to traditional silicon-based solar cells because they are inexpensive and can be manufactured more
Solar Photovoltaic Energy: Trends and Status

A real challenge in OPVs is to increase its energy conversion efficiency from 3.5% to 8-12%. Intensive research is done in development of more efficient OPVs. Manufactures like, BASF, Schott, Bosch and Merck are promoting research and development activities in OPVs.

Companies like Bosch, Merck, Konarka, Schott and institutes like Princeton, Michigan, NREL are engaged in development of more efficient organic photovoltaic materials.

The chart below illustrates the various commercial large area module efficiencies and the best laboratory efficiencies obtained for various materials and technologies.

**Figure 1** Comparison of model efficiency and best laboratory efficiencies

Source: www.biocrawler.com
PV module prices

Figure 2 describes trends of PV module prices.

Source: www.iea-pvps.org

It is seen that after 2003, there is significant increase in PV module prices, which may be due to shortage of silicon.
The market share of various technologies in the world markets in last eight years is shown below.

**Observation**

- Wafer based crystalline silicon technology (mono crystal and multi crystal) has been the dominating technology and its world market share is more than 80% for last eight years
- Out of crystalline Silicon based technology, share of multi-crystalline Silicon technology has increased from 42.1% in 1999 to 57.2% in 2003. It might be attributed to the relatively easier manufacturing process (than mono c-Si solar cells) with moderate stabilized efficiency. But from 2003, mono c-Si's share has increased from 32.2% in 2003 to 38.4% in 2005 and 43.4% in 2006. The increase in share might be because of the interest and demand for high efficiency cells for large scale grid interactive power projects. Such solar cells are used for various applications such as...
grid interactive as well as off grid electrification, communication and signaling systems, hybrid systems etc.

- The market share for a-Si was reduced from 12.3% in 1999 to 4.4% in 2004. It might be because
  (i) Earlier, small consumer market (watches, calculators) has a significant share in world PV market and a-Si was used mainly for such small application.
  (ii) Grid interactive power plants are becoming more popular in major markets like Japan, Europe and US. These plants use crystalline cells due to their high efficiency and long-term stability.
- In 2005 and 2006, the market share of a-Si solar cell increased from 4.4% in 2004 to 4.7% in 2005 and 2006. It could be because of
  (i) Effect of shortage of crystalline silicon feedstock required for wafer based silicon solar cell
  (ii) Commercialization of promising manufacturing technique for producing relatively low cost a-Si solar cells/module with moderate stabilized efficiency.
- With the expansion plan of several a-Si manufacturers especially of United Solar (increase its production capacity to 300MW by 2010) it is believed that the production will increase in 2007.
- It is far too early to say that Si-wafer technology will dominate overall PV market.
- Solar cell of material other than silicon (such as CIGS, CdTe) have negligible share in the world market, which implies that those solar cells are not found to be feasible even at the time of shortage of silicon feedstock. Although it is seen that CdTe is found more reasonable technology among CIS and CdTe technology. In 2006, share of this technology is increased by 90% to 2.7% over share of 1.4% in 2005.

Applications

Some of the major applications of solar photovoltaic are as follows

Building integrated PV

Building integrated PV is one of the fastest growing segment of photovoltaic industry. Many industrial as well as residential buildings incorporate PV systems as their principal or auxiliary source of electricity.

PV arrays can be retrofitted to existing building; usually in this case they are fitted on the top of existing roof structure. Also now PV cells can be incorporated to wall or roof of building.
PV for remote electrification

The regions where it is not possible to provide grid electricity can be electrified by means of PV. Solar PV street lights, lanterns, etc. can also be used for remote electrification.

Agriculture

PV can be used as source of electricity for applications like solar water pumping, electric fencing, electricity for agricultural buildings etc.

PV power plants

Solar PV power plants generate electricity directly which can be feed to the grid. Various solar PV power plants are generating electricity worldwide.

Industry

Solar PV applications can be effectively used to electrify industrial buildings. Many industries like watches, calculators, mobile phone manufacturers use solar PV systems to develop their products.

Communication

Remote communications systems incorporate PV systems as a source of electricity for transmitting and broadcasting the signals.

Commercial applications

Commercial buildings like hotels, hospitals etc. use solar PV as a source of electricity

Transportation

PV array is used as auxiliary power for space ships and satellites. Also PV arrays are used as source of ancillary electricity for ships and boats.

Global market scenario

Table 1 gives brief idea about global PV installation trends by the end of 2005.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>8,768</td>
<td>33,073</td>
<td>6,860</td>
<td>1,880</td>
<td>60,581</td>
<td>2.97</td>
</tr>
<tr>
<td>Austria</td>
<td>2,895</td>
<td>19,973</td>
<td>1,153</td>
<td>24,021</td>
<td>2.93</td>
<td>2,961</td>
</tr>
<tr>
<td>Canada</td>
<td>5,903</td>
<td>9,719</td>
<td>1,059</td>
<td>65</td>
<td>16,746</td>
<td>0.52</td>
</tr>
<tr>
<td>Switzerland</td>
<td>2,930</td>
<td>320</td>
<td>21,240</td>
<td>2,560</td>
<td>27,050</td>
<td>3.66</td>
</tr>
<tr>
<td>Germany</td>
<td>29,000</td>
<td>1,400,000</td>
<td>1,429,000</td>
<td>17.32</td>
<td>635,000</td>
<td>632,000</td>
</tr>
<tr>
<td>Denmark</td>
<td>70</td>
<td>225</td>
<td>2,355</td>
<td>0</td>
<td>2,650</td>
<td>0.49</td>
</tr>
<tr>
<td>Spain</td>
<td>15,800</td>
<td>41,600</td>
<td>57,400</td>
<td>1.32</td>
<td>20,400</td>
<td>18,600</td>
</tr>
<tr>
<td>France</td>
<td>13,844</td>
<td>6,232</td>
<td>12,967</td>
<td>0</td>
<td>33,043</td>
<td>0.54</td>
</tr>
<tr>
<td>UK</td>
<td>227</td>
<td>697</td>
<td>9,953</td>
<td>0</td>
<td>10,877</td>
<td>0.18</td>
</tr>
<tr>
<td>Israel</td>
<td>809</td>
<td>210</td>
<td>11</td>
<td>14</td>
<td>1,044</td>
<td>0.15</td>
</tr>
</tbody>
</table>
As on April 2006, in India, total installed capacity of grid connected as well as off grid solar PV is 88.6MWp while as estimated potential is 20MW/sq. km [1].

### Global PV cell manufacturing status

Table 2 describes global PV cell manufacturing scenario. It is seen that in 2006, Asia is contributing around 63% of total PV cell manufacturing, which may be due to lower manufacturing cost here.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>5,300</td>
<td>7,000</td>
<td>8,500</td>
<td>6,700</td>
<td>37,500</td>
<td>0.64</td>
<td>6,800</td>
<td>6,500</td>
</tr>
<tr>
<td>Japan</td>
<td>1,148</td>
<td>85,909</td>
<td>1,331,951</td>
<td>2,900</td>
<td>1,421,908</td>
<td>11.13</td>
<td>289,917</td>
<td>287,105</td>
</tr>
<tr>
<td>Korea</td>
<td>853</td>
<td>4,810</td>
<td>8,028</td>
<td>1,330</td>
<td>15,021</td>
<td>0.31</td>
<td>6,487</td>
<td>6,183</td>
</tr>
<tr>
<td>Mexico</td>
<td>14,476</td>
<td>4,178</td>
<td>40</td>
<td>0</td>
<td>18,694</td>
<td>0.17</td>
<td>513</td>
<td>30</td>
</tr>
<tr>
<td>Netherlands</td>
<td>4,919</td>
<td>43,377</td>
<td>2,480</td>
<td>50,776</td>
<td>3.12</td>
<td>1,697</td>
<td>1,547</td>
<td></td>
</tr>
<tr>
<td>Norway</td>
<td>6,800</td>
<td>377</td>
<td>75</td>
<td>0</td>
<td>7,252</td>
<td>1.58</td>
<td>362</td>
<td>0</td>
</tr>
<tr>
<td>Sweden</td>
<td>3,350</td>
<td>633</td>
<td>254</td>
<td>4,237</td>
<td>0.47</td>
<td>371</td>
<td>0</td>
<td></td>
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<tr>
<td>USA</td>
<td>100,000</td>
<td>133,000</td>
<td>219,000</td>
<td>27,000</td>
<td>479,000</td>
<td>1.62</td>
<td>103,000</td>
<td>70,000</td>
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<tr>
<td>Estimated total</td>
<td>202,276</td>
<td>311,199</td>
<td>3,022,416</td>
<td>160,909</td>
<td>3,696,800</td>
<td>1,092,851</td>
<td>1,039,917</td>
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</tr>
</tbody>
</table>

**Source:** www.iea-pvps.org

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### Table 2 Global PV cell manufacturing status

<table>
<thead>
<tr>
<th>Region</th>
<th>% share</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>61.00</td>
<td>63.40</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>45.40</td>
<td>36.40</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>8.30</td>
<td>15.10</td>
<td></td>
</tr>
<tr>
<td>Taiwan</td>
<td>4.2</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>1.50</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>Rest of Asia</td>
<td>1.60</td>
<td>3.70</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>28.10</td>
<td>28.20</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>18.90</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>Rest of Europe</td>
<td>9.20</td>
<td>8.20</td>
<td></td>
</tr>
<tr>
<td>America</td>
<td>8.60</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>8.60</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>1.90</td>
<td>1.30</td>
<td></td>
</tr>
<tr>
<td>Africa and Middle East</td>
<td>0.40</td>
<td>0.30</td>
<td></td>
</tr>
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</table>

**Source:** Photon 3/2007
Major players

Table 3 gives details of key players in global PV market and their market share by 2006.

<table>
<thead>
<tr>
<th>Manufacturers</th>
<th>Technology</th>
<th>Market share (%) in 2005</th>
<th>Market share (%) in 2006[2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp</td>
<td>Mono, Multi</td>
<td>23.5</td>
<td>17.1</td>
</tr>
<tr>
<td>Q-Cells</td>
<td>Mono, multi</td>
<td>9.1</td>
<td>10.0</td>
</tr>
<tr>
<td>Kyocera</td>
<td>Multi</td>
<td>7.8</td>
<td>7.1</td>
</tr>
<tr>
<td>Sanyo</td>
<td>HIT</td>
<td>6.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Suntech</td>
<td>Multi, Mono</td>
<td>4.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Motech</td>
<td>Multi, Mono</td>
<td>3.3</td>
<td>4</td>
</tr>
<tr>
<td>Mitsubishi Electric</td>
<td>Multi</td>
<td>5.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Schott Solar (formerly RWE schott)</td>
<td>EFG cells (Crystalline)</td>
<td>5.2</td>
<td>3.8</td>
</tr>
<tr>
<td>BP Solar</td>
<td>Multi, LGBC</td>
<td>4.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Deutsche cell (incl shell)</td>
<td>CIS, multi, mono</td>
<td>3.2 (shell)</td>
<td>N.A.</td>
</tr>
</tbody>
</table>


R & D activities

Over the coming years there is a drastic need of improvements in performance, convenience and cost-effectiveness of PV material. Following R & D concepts are being undertaken in order to achieve the afore mentioned objectives [3].

- Technologies to improve the efficiency of CIS-based thin film solar cells and elemental technologies to form solar cells on light weight
- Technology to enable higher productivity and to improve efficiency of thin-film silicon solar cells
- Technologies to enable highly efficient, modular and double die sensitised solar cells
- Technologies and associated processes to produce highly efficient next generation ultra-thin crystalline silicon solar cells
- Technologies to improve the efficiency and durability of organic thin film solar cells
- Search for next generation technologies that would enable significant cost reductions, improved performance, and extend the usable life of solar generation systems.
- Fundamental understanding and implementation of performance-enhancing features of low-cost, high-efficiency crystalline silicon (c-Si) and thin-film silicon solar cells.
- Explore new process approaches such as combinatorial science, ink-based electronic materials deposition and hybrid nanostructures for solar energy conversion.
- Adapt high-efficiency copper indium gallium diselenide (CIGS) and cadmium telluride (CdTe) solar cell materials
and systems to allow implementation in low-cost manufacturing.

- Electro-optical characterisation
- Hybrid amorphous/crystalline cells for high-efficiency cells and low-temperature processing
- Hot-wire chemical vapor deposition of hydrogenated amorphous silicon (a-SiGe:H) alloys for better conversion of red light in amorphous multijunction cells
- Inexpensive approaches to high-purity feedstock for silicon crystal growth
- New combinatorial approaches to device optimization

Forecasts

Current research is broadly focused on thin film single junction polycrystalline module and thin film multifunction amorphous silicon module. Some research is carried out in flat plate silicon module and power conditioners, where as there is very less focus on medium concentration silicon cell, high concentration silicon cell, advanced thin film multijunction polycrystalline module, options for concentrators, electronic controllers for trackers and sensors for trackers.

For flat plate silicon cell, the research goal is to achieve 15% efficiency at cost of $100/m². For high concentration silicon cell, goal is to achieve system efficiency of 25% at array cost of less than $250/m². Research in amorphous silicon thin film is aiming to enhance the efficiency from current level of 7-15% to more than 15% at array cost of $50/m². Research in thin film single junction polycrystalline is projecting to achieve equivalent field performance to a-Si at lower cost. Advanced polycrystalline multijunction thin film research focuses on achieving 25% module efficiency at cost of $60/m².

References


Bibliography

www.biocrawler.com
www.nrel.gov
www.iea-pvps.org
## Annexure  Manufacturers’ details

<table>
<thead>
<tr>
<th>Name of Manufacturer</th>
<th>Contact Details</th>
<th>E-mail</th>
<th>Website</th>
</tr>
</thead>
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<tr>
<td><strong>1</strong> Sharp</td>
<td>5901 Bolsa Avenue Huntington Beach, CA 92647, USA</td>
<td><a href="http://www.sharpusa.com/solar">www.sharpusa.com/solar</a></td>
<td></td>
</tr>
<tr>
<td><strong>2</strong> Q-Cells</td>
<td>Guardian Str. 16, 06766 Thalheim, Germany</td>
<td><a href="mailto:q-cells@q-cells.com">q-cells@q-cells.com</a></td>
<td><a href="http://www.q-cells.com">www.q-cells.com</a></td>
</tr>
<tr>
<td><strong>3</strong> Suntech Power</td>
<td>17-6 Chang Jiang South Road, New District Wuxi Jiangsu, Province, China, 214028</td>
<td><a href="mailto:sales@suntech-power.com">sales@suntech-power.com</a></td>
<td><a href="http://www.suntech-power.com">www.suntech-power.com</a></td>
</tr>
<tr>
<td><strong>4</strong> Kyocera Corporation</td>
<td>6F, No. 248, Sec-3, Pei-Shen Rd., 222, Shenkeng Hsiang, Taipei, Taiwan</td>
<td><a href="mailto:se@kyocera.co.jp">se@kyocera.co.jp</a></td>
<td><a href="http://www.kc-solar.co.jp">www.kc-solar.co.jp</a></td>
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<tr>
<td><strong>5</strong> Motech</td>
<td></td>
<td>t&amp;<a href="mailto:m@motechind.com">m@motechind.com</a></td>
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<tr>
<td><strong>6</strong> Sanyo</td>
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<td><a href="mailto:info.solar@sanyo-component.com">info.solar@sanyo-component.com</a></td>
<td><a href="http://www.sanyo.co.jp">www.sanyo.co.jp</a></td>
</tr>
<tr>
<td><strong>7</strong> SolarWorld</td>
<td>D-53113 Bonn, Germany Phone:+49-228-55920</td>
<td><a href="mailto:service@solarworld.de">service@solarworld.de</a></td>
<td><a href="http://www.solarworld.de">www.solarworld.de</a></td>
</tr>
<tr>
<td><strong>8</strong> Baoding Tianwei Yingli</td>
<td>No. 3055 Middle FuXing Road, Boarding, China</td>
<td><a href="mailto:commerce@yinglisolar.com">commerce@yinglisolar.com</a></td>
<td><a href="http://www.yinglisolar.com">www.yinglisolar.com</a></td>
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