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Manufacturing Solar Modules—Clean Power with "Clean" Exposures?

by Oliver Stein, Gen Re, Cologne

Given the combination of global warming and limited fossil energy resources, finding renewable energy will be of key importance for our future power supply. In order to fight the climate change, the G8 countries are proposing serious reductions in global carbon dioxide (CO_2) emissions—50% by 2050.[1] In order to achieve this goal, further development of "clean energy" will be a major focus in many countries.

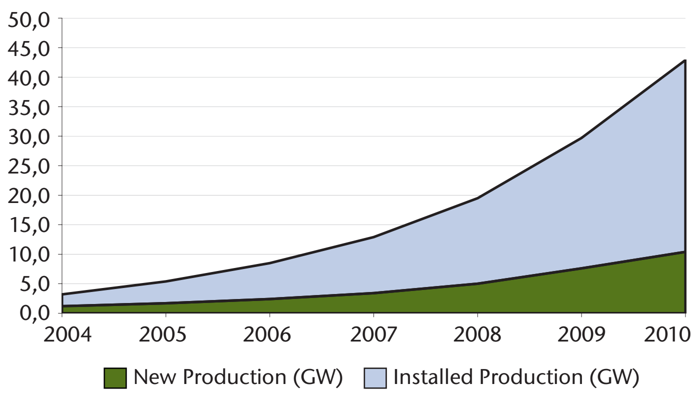
The direct conversion of light into electricity (photovoltaics) will play a major role, as power from photovoltaics is CO_2 free and virtually inexhaustible. On the other hand, photovoltaic power generating costs are presently around US$0.25 per kwh in most OECD countries,[2] which is still 3 to 10 times higher than other energy sources such as coal, nuclear, gas, oil, hydro and even wind.[3] As such, governmental support and incentives currently are critical for this application to be attractive.

There are estimates, however, that within the next few years, solar power generation costs will be reduced to US$0.10 – 0.15 per kwh. At this level, the cost will be at or below electricity grid parity for more than half of the residential customers in the OECD. Generating costs using conventional energy might increase further during the next decade due to limited fossil energy resources and environmental taxes. This would make solar power even more attractive.

Even today, the photovoltaic sector is booming. In 2006 solar modules with a nominal capacity of 2.4 megawatts have been produced worldwide—a growth of more than 40% compared to the year before. There are estimates that the production will quadruple within the next four years.[4]

The key producers of photovoltaic cells are located in Japan, Germany and the U.S. In order to meet future demand for solar modules, new production facilities and plants are currently being built.

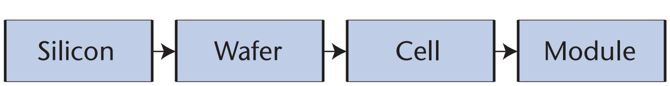
Installed Photovoltaic Power



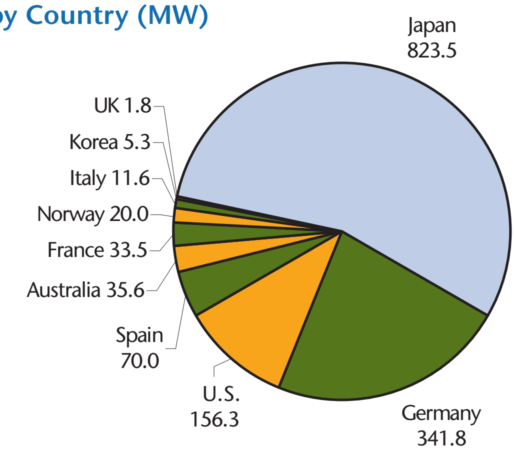
Source: *Gen Re calculations based on Photon-Consulting, July 2006 (www.photon-consulting.com/executive_summary.htm); and International Energy Agency (www.iea-pvps.org/isr/01.htm).*

Nine out of ten solar modules begin with silicon wafers and follow a process that is similar to semiconductor production (e.g., integrated circuit or chip manufacturing). This article will focus on the production process as well as the associated hazards and loss exposures for property insurers.

At first glance, a solar module doesn't look like a high tech product: a thin silver-blue shining plate lies behind glass in a metal frame. Also the raw material is nothing special—silicon, the second most abundant element on the planet following oxygen. It is in every grain of sand. But how do we get power out of sand? A complex and quite costly production process is necessary. Let's have a look at the supply chain of photovoltaics:



The Key Players—PV Cell Production in 2005 by Country (MW)



Source: *Trends in photovoltaic applications, Survey report of selected IEA countries between 1992 and 2005, page 16; www.ieapvps.org/products/download/rep1_15.pdf.*

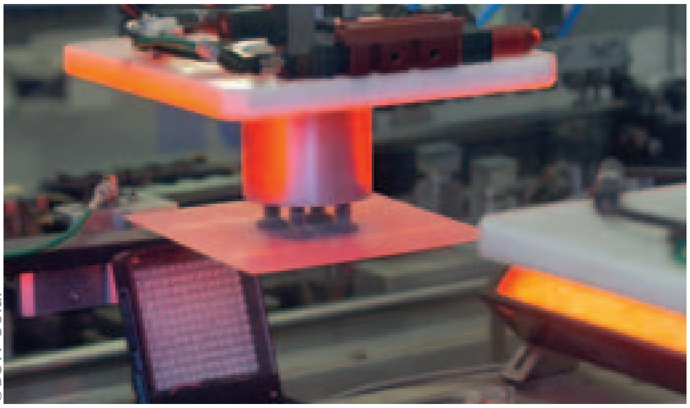
Silicon Production

The raw material is quartz (silica). For usage in solar cells or semiconductor chips, it has to be processed into high purity silicon, so clean that on one trillion silicon atoms only one foreign part is allowed. It is done in a complex chemical-thermal process. In a first step silica is reduced in an arc furnace at over 1,900°C (3,450°F) into silicon that is 98% pure. Further purification is mostly done with the so-called "Siemens process." Here, the silicon is transformed with hydrogen chloride into trichlorsilane gas, which is then exposed to silicon rods at 1,150°C (2,100°F). The end product is high purity silicon in a granulate form. This is the raw material for either solar cells or computer chips. It is produced only by a few companies worldwide. Most solar cell manufacturers do not produce the silicon on their own. Due to increasing demand in the solar industry, there is currently a shortage of this material.

Exposures—The silicon production is a hazardous chemical process. The main insurance exposures are the furnaces and reactors with high temperatures. Trichlorsilane is self-igniting, toxic and caustic when exposed to the air. Major fire and explosion losses have already occurred. (See the Major Losses box on page 5.)

Wafer Production

Silicon producers supply the granulate to the wafer manufacturers. At a temperature of 1,410°C (2,570°F) this material is smelt into bars, the so-called "ingots." These ingots can be grown mono- or multicrystalline. Monocrystallines are more expensive to manufacture; however, they have a slightly higher efficiency than the multicrystalline ones that are mostly used in mass production. The ingots are cut into very thin slices, the wafers. Today, they are only 0.18 millimeters thin. As the cutting is done with wire-saws, for each wafer created one wafer is lost as sawdust. While there is a shortage of high



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purity silicon, the producers are working hard on further decreasing the thickness of the wafers and developing new sawing methods that reduce the lost silicon amount.

Exposures—Major hazards are the melting ovens with very high temperatures. Explosions and fires have occurred with losses up to several million U.S. dollars. (See the Major Losses box on page 5.)

Cell Production

In the first production step, the wafers are cleaned in wet benches using caustic baths. In order to make a solar cell, "doping" of the wafer is necessary. Chemicals change the conductivity of the silicon so that the front side has a positive charge and the back side a negative—or vice versa. This is done using diffusion furnaces with around 900°C (1,650°F) with phosphorous gas.

To reduce optical losses of the wafers, a blue anti-reflexion coating of silicon nitride is applied. This is done in an oven with ammonia and silane gas using Plasma Enhanced Chemical Vapour Deposition (PECVD).

The wafer is then metallized, whereby a full area metal contact is made on the back surface, and a grid-like metal contact made up of fine "fingers" and larger "busbars" are screen-printed onto the front surface using a silver paste. This is then burnt into the semiconductor in an oven at 900°C (1,650°F).

The processes are highly automated, including automatic transportation and conveyor systems. Robots place the wafer magazines into the machines. As solar cells are semiconductor devices, they share many of the same processing and manufacturing techniques and exposures as, for example, computer chip manufacturing.[5]

Main exposures are:

> Ovens with high temperatures.

> Use of flammable and/or aggressive liquids and flammable and toxic gases such as silane, phosphine, chlorine, methanol, alcohol, acetone, sulphuric, nitric and hydrofluoric acid.
  – In case of even a small fire, large smoke damage potential would have to be expected.

> Wet benches with baths of heated degreasing liquids (e.g., acetone).
  – The heating of these liquids can produce explosive vapors. Electrostatic charges can ignite them.
  – Overheating can also be a problem, if the heating controls fail. Heating controls may not be of the redundant type, and as such, a single point failure may result in uncontrolled overheating. Frequent testing of low level liquid switches as well as heating controls is essential.

> Silane is a self-igniting, toxic and caustic gas when exposed to air.

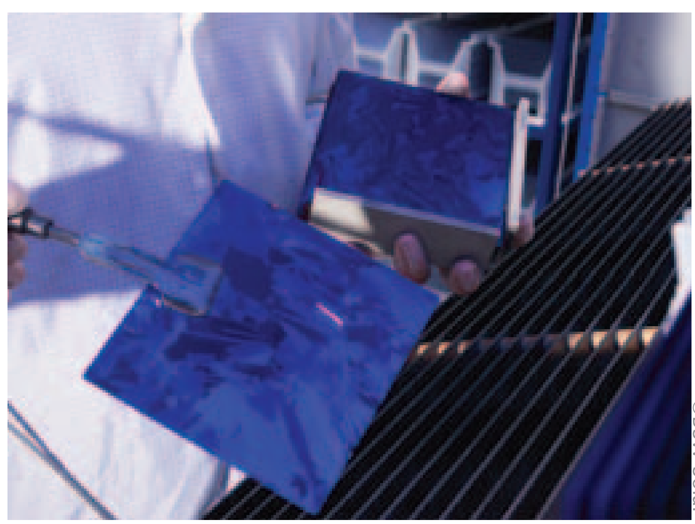
> Usually a cleanroom atmosphere (e.g., classification of 10,000–100,000) is necessary.
  – Smoke can cause severe damage to the high-value equipment and machines, and business interruption losses can quickly mount. The clean environment must be rectified in order to produce a product of appropriate yield (purity).

> Air ducts as well as equipment (such as wet benches, etc.) are made of combustible, often plastic materials.

Modules Manufacturing

Cells are soldered and connected to a matrix unit. The unit is embedded in a glass-foil sandwich. This is done in a large heated vacuum oven called a "laminator" at 150°C (300°F). Finally the laminates are grouted with an aluminium frame, and the solar modules are manufactured. In the end, the modules or panels are tested for their capacity and then packed.

Exposures—This is basically an automated assembly process of electronic components. The processes are highly automated, using specialized machinery and equipment developed for this industry. Cleanrooms are not required. The concentration of machinery and equipment values is less than during cell manufacturing. Fire exposures can result from the soldering and lamination processes using combustible encapsulants (e.g., polyethylene) and combustible packaging materials.



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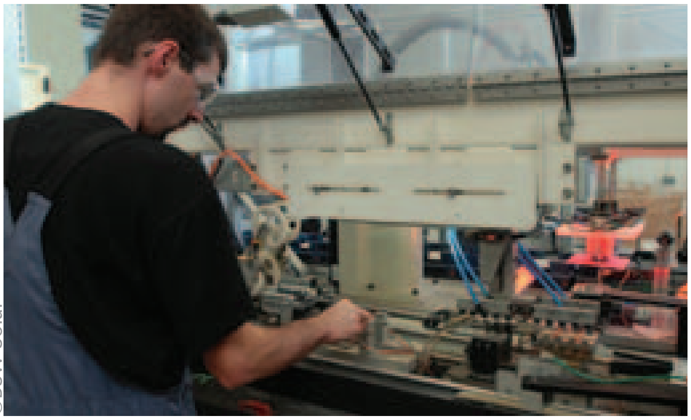

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Underwriters' Checklist

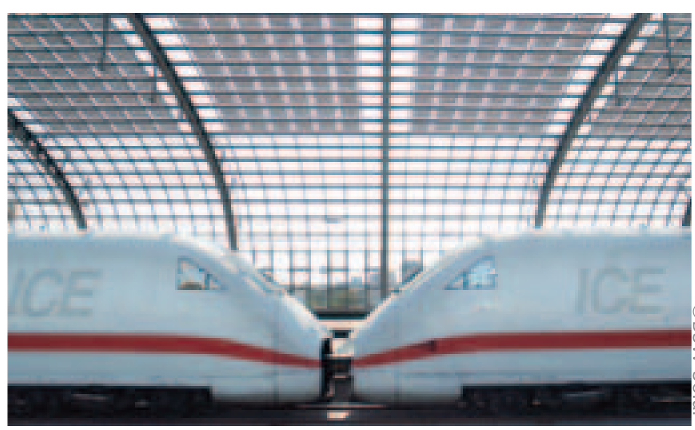
> Production steps—What production steps in the supply chain are performed at the risk to be insured? Often specialized companies perform only certain production steps (i.e., only cell or modules manufacturing). Exposures of the individual steps in the supply chain are quite different, as mentioned before.

> Protection—Adequate risk protection is essential. A lot can be learned from the semiconductor manufacturing plants. Fire, explosion, smoke, and escaped liquids are key exposures. The following are highly-desirable design features and protection measures:

- Entirely non-combustible construction with fire separations between major production units, technical rooms and offices. Alternatively, if use of plastic material is unavoidable (e.g., due to inherent process needs/ requirements such as corrosion resistance, etc.), material should meet dedicated special standards (such as the FMRC cleanroom Materials Flammability Test Protocol[6] or some equally acceptable test method).
- Automatic sprinklers (if possible on a pre-action system) including protection within air ducts, if made out of combustible material.
- Automatic smoke/containment control systems with fire dampers in air-conditioning systems (with annual functional testing).
- Automatic shut off values in pipe systems for combustible gases.
- Local fixed protection at the wet benches with combustible liquids and ovens (e.g., CO_2, argon or an approved clean agent suitable for the individual application).
- Redundant temperature controls of ovens, wet benches as well as low level liquid switches—for example, if flammable liquid baths are heated above their flashpoint during normal operation and combustible containments are used.
- Very good housekeeping.
- Strict controls of outside contractors.
- Well- and regularly-trained private emergency organization and a high level of contingency planning.
- Double-walled gas piping for process liquids that are routed below ground rather than ceiling level.
- Wet benches made out of non-combustible, or specially approved material.
- Flammable gas cabinets located outside of the production area and well-protected.
- Very Early Warning Fire Detection Systems (VEWFD), such as smoke sampling systems like VESDA or similar systems.
- Emergency power should be provided for any vital equipment, such as process pumps, ventilation, furnaces equipped with HEPA or ULPA filter assemblies, smoke control/removal systems, etc.
- Mineral oil filled transformers and associated oil filled power supply units present also a potential increased hazard. If possible, this type of equipment should be replaced by cast resin dry-type transformers and Motor-Generator (MG) sets.

> Values—Specialized machines and equipment are used. Values for machinery and equipment are high. Smoke damage does cause high clean up costs. Equipment suppliers often withdraw or restrict their guarantees following smoke contamination, leading to replacement rather than repair. Business interruption values are usually large. Due to the high demand, production capacities are often increased in short periods of time (e.g., doubled in two years). This should be taken into consideration for Maximum Loss Calculations and Loss Limits.

> Business Interruption—Lead times for replacement machinery and equipment might be longer than typically observed in other industries due to the strong growth of the industry and limited production capacities of the machine manufacturers. There are large interdependencies between individual production steps of the supply chain. The



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interruption of one production step might have enormous effects on the whole production. Outsourcing and back up capacities are scarce. Therefore, exposures to external suppliers and customers can be large. As there are only a few players, and because demand is increasing, alternatives might be difficult to find. Business continuity management of the insured is of high importance.

Manufacturing solar modules requires complex and difficult processes. Substantial fire and explosion hazards are inherent to them. High-value machinery and equipment along with large business interruption values lead to significant loss potential. With thorough underwriting, these exposures can be managed and priced. Nevertheless, accidents will occur.

It is our hope that insureds and insurers will benefit from adequate exposure management and adequate pricing. Then, we can all benefit from clean power. ■

Oliver Stein is a Second Vice President and Senior Underwriting Specialist in the Global Property Facultative department in Cologne. For more information about this topic, we encourage you to contact either your local Gen Re underwriter or Oliver at +49 221 9738 1613 or ostein@genre.com.

Endnotes

[1] The G8 countries are: Canada, France, Germany, Italy, Japan, Russia, United Kingdom and United States.

[2] Organization of Economic Co-operation and Development, currently 30 member countries.

[3] Photon-Consulting, Solar Power in Focus, April 2007, www.photon-consulting.com/studie_the_true_cost_2007_executive_summary.htm.

[4] Photon-Consulting, Solar Annual, July 2006, www.photon-consulting.com/executive_summary.htm.

[5] For a video of cell manufacturing, see www.q-cells.com/cmadmin_2_512_0.html.

[6] Factory Mutual Research Corp., www.fmglobal.com/approvals/approved/categories/materials-cleanroom.asp.

Major Solar Modules Losses

February 2007, Germany—Explosion at a solar plant in Germany; reserved loss amount of US$13 million for PD and BI combined.

Source: *GDV (German Insurance Association), Rundschreiben Sach-Statistik (Circular Property Statistics), 33/2007.*

December 2006, Taiwan—An explosion at a Taiwanese plant producing solar cell raw materials left two dead and disrupted some of the company's output. The explosion occurred at one of the company's 26 crystal growing systems; two other crystal growing systems were also affected.

Source: *Explosion disrupts Taiwan solar cell material plant, Reuters News, 18 December 2006.*

October 1998, State of Washington—An explosion and fire at Advanced Silicon Materials Inc. in the State of Washington sent potentially lethal fumes into the air and injured six workers. The explosion caused a cloud of silicon tetrachloride gas that dissipated into fume silica and hydrogen chloride when it made contact with air. Silicon tetrachloride gas can burn the skin and eyes on contact. The products of this plant are used to produce silicon computer chips.

Source: *Six Injured in Washington State Computer-Equipment Plant Fire, Dow Jones Business News, 9 October 1998.*

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