PHOTOVOLTAIC TECHNOLOGY
SUNNY SIDE UP

The solar photovoltaic (PV) market – the green energy source par excellence – is booming. Production has doubled every two years since 2002, making it the fastest-growing energy sector. Buoyed by government incentives, the industry is thriving and research is opening new avenues and bringing costs down. The number of solar energy-related patent applications filed under the Patent Cooperation Treaty (PCT) tripled from 2004 to 2008, rising from 460 to 1,411.

The photovoltaic effect – a phenomenon allowing light-to-electricity conversion – was first described by the French physicist Edmond Becquerel in 1839. Albert Einstein was awarded a Nobel Prize for his theoretical work on the subject, published in 1904. Intensive research, spurred by the race to space from 1950 to 1969, led a number of companies to develop and bring solar cells, or PV cells, to the marketplace as of 1955. *Vanguard I*, the first solar-powered satellite, launched in 1958 and ran for eight years. Others followed. Solar power continues to be used as an auxiliary energy source on spacecrafts and to power orbiting satellites.

Photo: NASA

Vanguard I

When it came to earthbound applications, the technology was slower to take off. The return on investment in the PV market did not justify the expense: grid electricity from virtually any other source – coal, hydro or nuclear – was, and still is, much less expensive. But over the last decade climate change issues have modified our perspective. The environmental problems associated with carbon dioxide (CO_2) buildup have sounded an alarm: there is now a pressing need for new, non-polluting technologies as well as revived interest in older technologies that were passed over when cost and mass production were the primary considerations. And so, photovoltaic technology has risen from the dust of patent information stored and all but forgotten years ago.

PV market

The "Global Photovoltaic Market Analysis and Forecasts to 2020" highlights that worldwide PV capacity grew from 1.3 gigawatts (GW) in 2001 to 15.2GW in 2008. If investments and efficiency gains continue to grow at their current rate, a joint EPIA* and Greenpeace study forecasts that by 2030, PV systems will provide 2,600 terawatt hours (TWh) of electricity or some 14 percent of the electricity needs of the world's population.

Germany, Japan and the U.S. seem to be leading the market in PV installations, but the figures differ from one report to the next. Spain, having completed the installation of several large PV power plants, with a total generating capacity of 226.3 megawatts (MW) in 2008, laid claim to the number one position in January. But with individual installations and PV power plants mushrooming, the PV landscape is evolving at such a pace that the position of leader is a constantly shifting one. Most of the increase is due to financial incentives, which often come in the form of investment subsidies that refund part of the installation costs or in the form of feed-in tariffs where local electric utility companies buy PV electricity from producers.

The PV market is not out of the grasp of the developing world. Research is bringing prices down and developing countries are benefiting. Solar power offers an excellent solution in remote areas too expensive or impossible to connect to the grid (see *Barefoot College, Teaching Grandmothers to be Solar Engineers*, page 5). In these areas, an important market has developed for solar power-charged batteries.

* European Photovoltaic Industry Association

From the Sun

- In *one hour*, the sun provides more than enough energy to supply the earth's energy needs for one year.
- In *one day*, it provides more energy than the world's population could consume in 27 years.

Source: BIPV Technology

Photovoltaics – the drawbacks

One big disadvantage of photovoltaics is the land area required for a solar power plant. California's planned 550MW solar installation will cover a surface area of some 25 km². Not many countries have such quantities of barren, unused land to set aside for power plants.

Installation can also be relatively expensive, so it might take some time – up to 20 years – to recoup its cost.

It may seem obvious, but solar panels do not produce electricity on overcast days or at night, so user must either stay hooked-up to the regular grid electricity or install a storage system.

Scarcity threatens the market

Standard PV modules are made from mono and polycrystalline silicon. Some 50 percent of the price of a module is due to the cost of processed silicon wafers. The solar panel industry benefited from a major breakthrough when Emanuel Sachs invented string ribbon crystal growth in 1980 (U.S. patent 4661200). The process enabled the production of continuous thin strips of multi-crystalline wafers, eliminating the waste and heavy expense previously incurred sawing through blocks of silicon. The reduction in manufacturing cost made wider adoption of the solar technology more feasible.

Photo: Anna Regelsberger

A photovoltaic tree in Gleisdorf, Germany.

But crystalline silicon has major drawbacks: its production is energy-intensive and leaves the PV industry dependent on silicon – an expensive and scarce material for which PV manufacturers must compete with the micro-electronic industry. There are only 12 factories producing PV-grade polycrystalline silicon in the world and when both the micro-processor and PV markets boom, silicon prices skyrocket. In 2004, for example, the cost of silicon significantly increased because demand was high in the electronics industry. So while silicon research continues, the threat that shortages might pose to the PV industry has stimulated a search for alternative materials.

Solid-state physics has demonstrated that silicon is not the ideal material for light-to-electricity conversion. In applications for outer space, where technology is most advanced and the very purest, high performance silicon is available, efficiency hovers around 30 percent. But most PV modules on the market average between 12 to 18 percent. Improvements in efficiency are a high priority for the industry.

Efficiency gains on the horizon

Previous advances in conversion efficiency relied on concentrating sun rays, in the same way that a magnifying glass concentrates sunlight to ignite a fire. The results were heavy, unwieldy devices with lenses up to 30 centimeters thick. Using innovative thin-film technology, researchers are breaking efficiency records while building ever less cumbersome solar cells. Their goal is to define the ideal architecture for the solar cell – keeping in mind the objectives of lowering costs, minimizing size and facilitating mass production.

In 2007, 21 months into a project aimed at developing the technology basis for a new highly efficient crystalline silicon solar cell, a research consortium led by the University of Delaware achieved a record 42.8 percent conversion efficiency. Their unique solar cell architecture integrates the optical design with that of the solar cell, resulting in a small, portable device that can easily fit on a laptop computer (for more information see PCT WO2008/091290). The consortium aims to break the 50 percentile marker by 2010.

Promising new materials technologies

In addition to new developments in the use of silicon for manufacturing solar cells, design breakthroughs have been achieved involving non-

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silicon materials including alternative semiconductors and organic chemical compounds. Using materials other than silicon can lead to cost reductions because the production process is simpler and less expensive, and does not compete for the use of silicon. However, further research into the use of these advanced materials is needed to obtain and surpass the efficiencies of silicon-based solar cells. That research is evolving quickly as shown by the examples below.

The ThinPV research consortium, in which the Swiss Federal Institute of Technology in Lausanne (*Ecole polytechnique fédérale de Lausanne* (EPFL)) participates, aims to increase the efficiency of non-silicon thin-film solar cells, specifically copper indium gallium selenide (CIGS), organic and so-called dye-sensitized solar cells. At the launch of the project in 2006, conversion efficiency rates of around 11 percent were reached for CIGS thin-film solar cells. Using CIGS and the EPFL's patented dye-sensitized PV technology, ThinPV has already achieved 15 percent efficiency in laboratory tests. But the consortium believes it can achieve much better results.

Similar to silicon-based thin-film solar cells, CIGS solar cells use nano-thin layers of semiconductor material that can be applied to a low-cost backing, such as glass, flexible metallic sheets or foils, or high-temperature polymers. Contrary to conventional PV technologies, dye-sensitized solar cells separate the task of light absorption from that of charge carrier transport. In dye-sensitized solar cells, photogenerated electrons from the light-absorbing dye are passed on to thin layers of semiconductor materials that transport the electrical charge. The possible applications for this technology include dye-sensitized solar cell paints that could be applied directly onto steel sheets, which are being developed by a U.K. research team. It hopes to bring them to market by 2011.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) surpassed the ThinPV record in March 2008, reaching 19.9 percent efficiency with CIGS thin-film. This puts thin-film technology at par with crystalline silicon. The NREL claims that it is the quality of the materials applied during the manufacturing process that boosted the power output. The Laboratory sees a bright future for CIGS cells; they can be used both in space applications and the portable electronics market because of their light weight. They are also suitable for special architectural uses, such as photovoltaic roof shingles and windows.

Photo: www.treehugger.com

Thin-film solar technology

Though still in the early phases of research, non-silicon thin-film technology has already made the transition from the laboratory to the market. Expectations are high in the PV industry. Thin-film materials are easy and cheap to manufacture, have low environmental impact, and are compatible with flexible materials, making their application possible in packaging and clothing and for recharging cell phones and laptops.

Evolution of the PV market

Several new solar technologies now co-exist on the market with mono and polycrystalline solar cells, including thin-film which has already captured 7 to 10 percent of the PV market. The Prometheus Institute for Sustainable Development forecast that non-silicon thin-film applications will take over 40 percent of the market by 2012.

At present, U.S. manufacturing is more concentrated on various thin-film technologies and Europe and Asia more on mono and polycrystalline silicon solar cells. As research progresses, efficiencies will further increase and a growing number of promising non-silicon alternatives should start being brought to market. As shown in a forthcoming WIPO study on alternative energy technologies, the number of patent applications filed for solar power inventions at major industrial property offices has nearly tripled during the past 20 years.

The financial crisis is slowing down the PV market, but there will be no stopping it. The increasing number of PCT patents registered in the solar energy-related field – for technical improvements as well as new breakthrough inventions – attests to the advances being made in the industry. Here we have only glimpsed at the potential.