

Renewable energy sources in automobility

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Abstract—This article gives an instruction into the basic guidelines for preparing an automobile for application of the renewable energy sources. The energy source is a sunlight uses the photovoltaic elements. In paper describe the history and materials of photovoltaic elements.

Index Terms – renewable energy sources, solar power, solar energy, electromobil, photon energy, electrical, photovoltaic elements, materials, solar cell efficiency.

I. INTRODUCTION

A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. What powers the electric motor and solar energy?

The idea that the drive uses a motor vehicle is not new. A charge of electric current through the battery, we get by using solar cells, the question is quite recent past, present and especially future. Large electric motors started back in the early nineties 20th century, unfortunately without much success. The electric motor is most efficient in city driving, where over 90% of the mileage driven at low speeds. Some of the first cars ever built were powered by electricity. These first-fueled cars electric appeared as early as the late 19th century (actually 1880), a step which the vehicle is driven on gasoline are held until the early 20th century, when oil was due to the increasing exploitation has become significantly cheaper and has developed infrastructure for its distribution. Today is the time that this technology back in a big way, because it offers many advantages, especially when it comes to ecology. In addition to ecology, electric range offers even more advantages as a fuel for vehicles. This is its excellent mechanical simplicity, eliminating the need for a complex currency exchange and transmission assembly makes this car extremely reliable. The electric motor has the advantage of being reversible, except that the energy transferred into kinetic energy, is able to transform kinetic energy into electricity to supplement the battery. Modern electric motors are much more advanced today were the direct switch to AC power, and electronic engine control was significantly improved, and from these aggregates can be drawn significantly better performance without increasing in size. Before the mass introduction of electric motor drives for passenger cars must be resolved some issues and concerns mainly energy driven by the electric motor. Current technology offers a couple of complete and several intermediate solutions that work in practice. The complete solution is still in development phase. Here it comes to batteries and fuel cells, while the transitional arrangements, or hybrids, largely in the sale and are available to customers. When charging the battery and fuel cell applications of solar energy has its own solutions, although the pilot testing phase.

A. History of solar cells

The term "photovoltaic" comes from the Greek $\phi\omega\varsigma$ (*phōs*) meaning "light", and "voltaic", from the name of the Italian physicist Volta, after whom a unit of electromotive force, the volt, is named. The term "photo-voltaic" has been in use in English since 1849.[1]

The photovoltaic effect was first recognized in 1839 by French physicist A. E. Becquerel. However, it was not until 1883 that the first photovoltaic cell was built, by Charles Fritts, who coated the semiconductor selenium with an extremely thin layer of gold to form the junctions. The device was only around 1% efficient. In 1888 Russian physicist Aleksandr Stoletov built the first photoelectric cell based on the outer photoelectric effect discovered by Heinrich Hertz earlier in 1887.

Albert Einstein explained the photoelectric effect in 1905 for which he received the Nobel prize in Physics in 1921.[2] Russell Ohl patented the modern junction semiconductor solar cell in 1946, [3] which was discovered while working on the series of advances that would lead to the transistor.

B. Solar energy

Assemblies of solar *cells* are used to make solar modules which are used to capture energy from sunlight. When multiple modules are assembled together (such as prior to installation on a pole-mounted tracker system), the resulting integrated group of modules all oriented in one plane is referred to in the solar industry as a *solar panel*. The general public and some casual writers often refer to solar modules incorrectly as solar panels; technically this is not the correct usage of terminology. Nevertheless, both designations are seen in regular use, in reference to what are actually solar modules. The distinction between a module and a panel is that a module cannot be disassembled into smaller re-usable components in the field, whereas a solar panel is assembled from, and can be disassembled back into, a stack of solar modules. The electrical energy generated from solar modules, referred to as *solar power*, is an example of *solar energy*.

C. Photovoltaic

Photovoltaics is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight.

Cells are described as *photovoltaic cells* when the light source is not necessarily sunlight. These are used for detecting light or other electromagnetic radiation near the visible range, for example infrared detectors, or measurement of light intensity.

D. Bell produces the first practical cell

The modern photovoltaic cell was developed in 1954 at Bell Laboratories.[4] The highly efficient solar cell was first developed by Daryl Chapin, Calvin Souther Fuller and Gerald Pearson in 1954 using a diffused silicon p-n junction.[5] At first, cells were developed for toys and other minor uses, as the cost of the electricity they produced was very high; in relative terms, a cell that produced 1 watt of electrical power in bright sunlight cost about \$250, comparing to \$2 to \$3 for a coal plant.

Solar cells were rescued from obscurity by the suggestion to add them to the Vanguard I satellite, launched in 1958. In the original plans, the satellite would be powered only by battery, and last a short time while this ran down. By adding cells to the outside of the body, the mission time could be extended with no major changes to the spacecraft or its power systems. There was some scepticism at first, but in practice the cells proved to be a huge success, and solar cells were quickly designed into many new satellites, notably Bell's own Telstar.

Improvements were slow over the next two decades, and the only widespread use was in space applications where their *power-to-weight ratio* was higher than any competing technology. However, this success was also the reason for slow progress; space users were willing to pay anything for the best possible cells, there was no reason to invest in lower-cost solutions if this would reduce efficiency. Instead, the price of cells was determined largely by the semiconductor industry; their move to integrated circuits in the 1960s led to the availability of larger boules at lower relative prices. As their price fell, the price of the resulting cells did as well. However these effects were limited, and by 1971 cell costs were estimated to be \$100 per watt.[6]

E. Berman's price reductions

In the late 1960s, Elliot Berman was investigating a new method for producing the silicon feedstock in a ribbon process. However, he found little interest in the project and was unable to gain the funding needed to develop it. In a chance encounter, he was later introduced to a team at Exxon who were looking for projects 30 years in the future. The group had concluded that electrical power would be much more expensive by 2000, and felt that this increase in price would make new alternative energy sources more attractive, and solar was the most interesting among these. In 1969, Berman joined the Linden, New Jersey Exxon lab, Solar Power Corporation (SPC).[7]

His first major effort was to canvas the potential market to see what possible uses for a new product were, and they quickly found that if the price per watt were reduced from then-current \$100/watt to about \$20/watt there would be significant demand. Knowing that his ribbon concept would take years to develop, the team started looking for ways to hit the \$20 price point using existing materials.[7]

The first improvement was the realization that the existing cells were based on standard semiconductor manufacturing process, even though that was not ideal. This started with the boule, cutting it into disks called wafers, polishing the wafers, and then, for cell use, coating them with an anti-reflective layer. Berman noted that the rough-sawn wafers already had a perfectly suitable anti-reflective front surface, and by printing the electrodes directly on this surface, two major steps in the

cell processing were eliminated. The team also explored ways to improve the mounting of the cells into arrays, eliminating the expensive materials and hand wiring used in space applications. Their solution was to use a printed circuit board on the back, acrylic plastic on the front, and silicone glue between the two, potting the cells. The largest improvement in price point was Berman's realization that existing silicon was effectively "too good" for solar cell use; the minor imperfections that would ruin a boule (or individual wafer) for electronics would have little effect in the solar application.[8] Solar cells could be made using cast-off material from the electronics market.

Putting all of these changes into practice, the company started buying up "reject" silicon from existing manufacturers at very low cost. By using the largest wafers available, thereby reducing the amount of wiring for a given panel area, and packaging them into panels using their new methods, by 1973 SPC was producing panels at \$10 per watt and selling them at \$20 per watt, a fivefold decrease in prices in two years.

F. Navigation market

SPC approached companies making navigational buoys as a natural market for their products, but found a curious situation. The primary company in the business was Automatic Power, a battery manufacturer. Realizing that solar cells might eat into their battery profits, Automatic had purchased a solar navigation aid prototype from Hoffman Electronics and shelved it.[9] Seeing there was no interest at Automatic Power, SPC turned to Tideland Signal, another battery company formed by ex-Automatic managers. Tideland introduced a solar-powered buoy and was soon ruining Automatic's business.

The timing could not be better; the rapid increase in the number of offshore oil platforms and loading facilities produced an enormous market among the oil companies. As Tideland's fortunes improved, Automatic Power started looking for their own supply of solar panels. They found Bill Yerks of Solar Power International (SPI) in California, who was looking for a market. SPI was soon bought out by one of its largest customers, the ARCO oil giant, forming ARCO Solar. ARCO Solar's factory in Camarillo, California was the first dedicated to building solar panels, and has been in continual operation from its purchase by ARCO in 1977 to 2011 when it was closed by SolarWorld.

This market, combined with the 1973 oil crisis, led to a curious situation. Oil companies were now cash-flush due to their huge profits during the crisis, but were also acutely aware that their future success would depend on some other form of power. Over the next few years, major oil companies started a number of solar firms, and were for decades the largest producers of solar panels. Exxon, ARCO, Shell, Amoco (later purchased by BP) and Mobil all had major solar divisions during the 1970s and 1980s. Technology companies also had some investment, including General Electric, Motorola, IBM, Tyco and RCA.[10]

G. Further improvements

In the time since Berman's work, improvements have brought production costs down under \$1 a watt, with wholesale costs well under \$2. "Balance of system" costs are now more than the panels themselves. Large

commercial arrays can be built at below \$3.40 a watt,[11] [12] fully commissioned.

As the semiconductor industry moved to ever-larger boules, older equipment became available at fire-sale prices. Cells have grown in size as older equipment became available on the surplus market; ARCO Solar's original panels used cells with 2 to 4 inch (51 to 100 mm) diameter. Panels in the 1990s and early 2000s generally used 5 inch (125 mm) wafers, and since 2008 almost all new panels use 6 inch (150 mm) cells. Another major change was the move to polycrystalline silicon. This material has less efficiency, but is less expensive to produce in bulk. The widespread introduction of flat screen televisions in the late 1990s and early 2000s led to the wide availability of large sheets of high-quality glass, used on the front of the panels.

H. Current events

Other technologies have tried to enter the market. First Solar was briefly the largest panel manufacturer in 2009, in terms of yearly power produced, using a thin-film cell sandwiched between two layers of glass. Since then Silicon panels reasserted their dominant position both in terms of lower prices and the rapid rise of Chinese manufacturing, resulting in the top producers being Chinese. By late 2011, efficient production in China, coupled with a drop in European demand due to budgetary turmoil had dropped prices for crystalline solar-based modules further, to about \$1.09[12] per watt in October 2011, down sharply from the price per watt in 2010.

I. Applications, photovoltaic system

Solar cells are often electrically connected and encapsulated as a *module*. Photovoltaic modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain, hail, etc. Solar cells are also usually connected in *series* in modules, creating an additive *voltage*. Connecting cells in parallel will yield a higher current; however, very significant problems exist with parallel connections. For example, shadow effects can shut down the weaker (less illuminated) parallel string (a number of series connected cells) causing substantial power loss and even damaging excessive reverse bias applied to the shadowed cells by their illuminated partners. As far as possible, strings of series cells should be handled independently and not connected in parallel, save using special paralleling circuits. Although modules can be interconnected in series and/or parallel to create an *array* with the desired peak DC voltage and loading current capacity, using independent MPPTs (maximum power point trackers) provides a better solution. In the absence of paralleling circuits, shunt diodes can be used to reduce the power loss due to shadowing in arrays with series/parallel connected cells.

To make practical use of the solar-generated energy, the electricity is most often fed into the electricity grid using inverters (grid-connected photovoltaic systems); in stand-alone systems, batteries are used to store the energy that is not needed immediately. Solar panels can be used to *power or recharge* portable devices.

II. THEORY OF SOLAR CELLS

The solar cell works in three steps:

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.

2. Electrons (negatively charged) are knocked loose from their atoms, causing an electric potential difference. Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.

3. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

III. SOLAR CELL EFFICIENCY

Solar panels on the International Space Station absorb light from both sides. These Bifacial cells are more efficient and operate at lower temperature than single sided equivalents.

The efficiency of a solar cell may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of each of these individual efficiencies.

Due to the difficulty in measuring these parameters directly, other parameters are measured instead: thermodynamic efficiency, quantum efficiency, integrated quantum efficiency, V_{OC} ratio, and fill factor. Reflectance losses are a portion of the quantum efficiency under "external quantum efficiency". Recombination losses make up a portion of the quantum efficiency, V_{OC} ratio, and fill factor. Resistive losses are predominantly categorized under fill factor, but also make up minor portions of the quantum efficiency, V_{OC} ratio.

The *fill factor* is defined as the ratio of the actual maximum obtainable power, to the product of the open circuit voltage and short circuit current. This is a key parameter in evaluating the performance of solar cells. Typical commercial solar cells have a fill factor > 0.70 . Grade B cells have a fill factor usually between 0.4 to 0.7. The fill factor is, besides efficiency, one of the most significant parameters for the energy yield of a photovoltaic cell.[13] Cells with a high fill factor have a low equivalent series resistance and a high equivalent shunt resistance, so less of the current produced by light is dissipated in internal losses.

Single p-n junction crystalline silicon devices are now approaching the theoretical limiting efficiency of 37.7%, noted as the Shockley–Queisser limit in 1961. However multiple layer solar cells have a theoretical limit of 86%.

In October 2010, triple junction metamorphic cell reached a record high of 42.3%.[14] This technology is currently being utilized in the Mars Exploration Rover missions, which have run far past their 90 day design life.

The Dutch Radboud University Nijmegen set the record for thin film solar cell efficiency using a single junction GaAs to 25.8% in August 2008 using only 4 μm thick GaAs layer which can be transferred from a wafer base to glass or plastic film.[15]

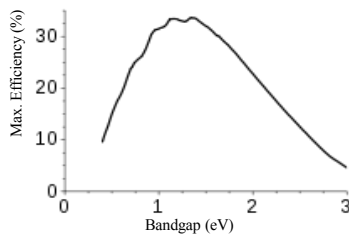
IV. MATERIALS

Different materials display different efficiencies and have different costs. Materials for efficient solar cells must have characteristics matched to the spectrum of available light. Some cells are designed to efficiently convert wavelengths of solar light that reach the Earth surface. However, some solar cells are optimized for light absorption beyond Earth's atmosphere as well. Light absorbing materials can often be used in *multiple physical configurations* to take advantage of different light absorption and charge separation mechanisms.

Materials presently used for photovoltaic solar cells include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide.[16]

“Picture 1.” The Shockley-Queisser limit for the theoretical maximum efficiency of a solar cell. Semiconductors with band gap between 1 and 1.5eV, or near-infrared light, have the greatest potential to form an efficient cell. (The efficiency “limit” shown here can be exceeded by multijunction solar cells.) Many currently available solar cells are made from bulk materials that are cut into wafers between 180 to 240 micrometers thick that are then processed like other semiconductors.

Other materials are made as thin-films layers, organic dyes, and organic polymers that are deposited on supporting substrates. A third group are made from nanocrystals and used as quantum dots (electron-confined nanoparticles). Silicon remains the only material that is well-researched in both *bulk* and *thin-film* forms.



Picture 1. Shockley - Queisser full curve

A. Crystalline silicon

By far, the most prevalent *bulk* material for solar cells is crystalline silicon (abbreviated as a group as *c-Si*), also known as “solar grade silicon”. Bulk silicon is separated into multiple categories according to crystallinity and crystal size in the resulting ingot, ribbon, or wafer.

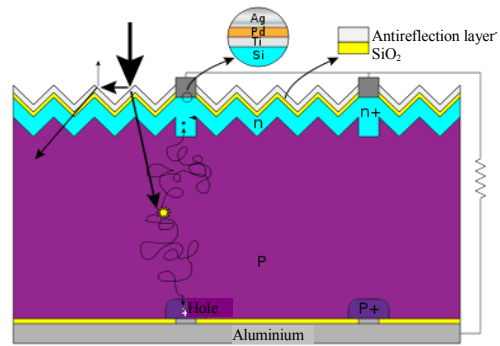
“Picture 2.” show basic structure of a silicon based solar cell and its working mechanism.

1) Monocrystalline silicon (*c-Si*)

Often made using the Czochralski process. Single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most *c-Si* panels have uncovered gaps at the four corners of the cells.

2) Polycrystalline silicon, or multicrystalline silicon, (*poly-Si* or *mc-Si*)

Made from cast square ingots — large blocks of molten silicon carefully cooled and solidified. Poly-Si cells are less expensive to produce than single crystal silicon



Picture 2. Basic structure of a silicon based solar cell and its working mechanism.

cells, but are less efficient. United States Department of Energy data show that there were a higher number of polycrystalline sales than monocrystalline silicon sales.

3) Ribbon silicon

Is a type of polycrystalline silicon: it is formed by drawing flat thin films from molten silicon and results in a polycrystalline structure. These cells have lower efficiencies than poly-Si, but save on production costs due to a great reduction in silicon waste, as this approach does not require sawing from ingots.[17]

B. Thin films

In 2010 the market share of thin film declined by 30% as thin film technology was displaced by more efficient crystalline silicon solar panels (the light and dark blue bars).

Cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and amorphous silicon (A-Si) are three thin-film technologies often used as outdoor photovoltaic solar power production. CdTe technology is most cost competitive among them.[18] CdTe technology costs about 30% less than CIGS technology and 40% less than A-Si technology in 2011.

1) Cadmium telluride solar cell

A cadmium telluride solar cell uses a cadmium telluride (CdTe) thin film, a semiconductor layer to absorb and convert sunlight into electricity. The cadmium present in the cells would be toxic if released. However, release is impossible during normal operation of the cells and is unlikely during fires in residential roofs.[19] A square meter of CdTe contains approximately the same amount of Cd as a single C cell Nickel-cadmium battery, in a more stable and less soluble form.[19]

2) Copper indium gallium selenide

Copper indium gallium selenide (CIGS) is a direct band gap material. It has the highest efficiency (~20%) among thin film materials (see CIGS solar cell). Traditional methods of fabrication involve vacuum processes including co-evaporation and sputtering. Recent developments at IBM and Nanosolar attempt to lower the cost by using non-vacuum solution processes.

3) Gallium arsenide multijunction

High-efficiency multijunction cells were originally developed for special applications such as satellites and space exploration, but at present, their use in terrestrial concentrators might be the lowest cost alternative in terms of \$/kWh and \$/W.[20] These multijunction cells consist

of multiple thin films produced using metalorganic vapour phase epitaxy. A triple-junction cell, for example, may consist of the semiconductors: GaAs, Ge, and GaInP₂. [21]

Each type of semiconductor will have a characteristic band gap energy which, loosely speaking, causes it to absorb light most efficiently at a certain color, or more precisely, to absorb electromagnetic radiation over a portion of the spectrum. The semiconductors are carefully chosen to absorb nearly all of the solar spectrum, thus generating electricity from as much of the solar energy as possible.

GaAs based multijunction devices are the most efficient solar cells to date.

Tandem solar cells based on monolithic, series connected, gallium indium phosphide (GaInP), gallium arsenide GaAs, and germanium Ge p-n junctions, are seeing demand rapidly rise.

4) *Light-absorbing dyes (DSSC)*

Dye-sensitized solar cells (DSSCs) are made of low-cost materials and do not need elaborate equipment to manufacture, so they can be made in a DIY fashion, possibly allowing players to produce more of this type of solar cell than others. In bulk it should be significantly less expensive than older solid-state cell designs. DSSC's can be engineered into flexible sheets, and although its conversion efficiency is less than the best thin film cells, its price/performance ratio should be high enough to allow them to compete with fossil fuel electrical generation. The DSSC has been developed by Prof. Michael Grätzel in 1991 at the Swiss Federal Institute of Technology (EPFL) in Lausanne (CH).

Typically a ruthenium metalorganic dye (Ru-centered) is used as a monolayer of light-absorbing material. The dye-sensitized solar cell depends on a mesoporous layer of nanoparticulate titanium dioxide to greatly amplify the surface area (200–300 m²/g TiO₂, as compared to approximately 10 m²/g of flat single crystal). The photogenerated electrons from the *light absorbing dye* are passed on to the *n-type* TiO₂, and the holes are absorbed by an electrolyte on the other side of the dye. The circuit is completed by a redox couple in the electrolyte, which can be liquid or solid. This type of cell allows a more flexible use of materials, and is typically manufactured by screen printing and/or use of Ultrasonic Nozzles, with the potential for lower processing costs than those used for *bulk* solar cells. However, the dyes in these cells also suffer from degradation under heat and UV light, and the cell casing is difficult to seal due to the solvents used in assembly. In spite of the above, this is a popular emerging technology with some commercial impact forecast within this decade. The first commercial shipment of DSSC solar modules occurred in July 2009 from G24i Innovations. [22]

5) *Organic/polymer solar cells*

Organic solar cells are a relatively novel technology, yet hold the promise of a substantial price reduction (over thin-film silicon) and a faster return on investment. These cells can be processed from solution, hence the possibility of a simple roll-to-roll printing process, leading to inexpensive, large scale production.

Organic solar cells and polymer solar cells are built from thin films (typically 100 nm) of organic semiconductors including polymers, such as

polyphenylene vinylene and small-molecule compounds like copper phthalocyanine (a blue or green organic pigment) and carbon fullerenes and fullerene derivatives such as PCBM. Energy conversion efficiencies achieved to date using conductive polymers are low compared to inorganic materials.

In addition, these cells could be beneficial for some applications where mechanical flexibility and disposability are important.

These devices differ from inorganic semiconductor solar cells in that they do not rely on the large built-in electric field of a PN junction to separate the electrons and holes created when photons are absorbed. The active region of an organic device consists of two materials, one which acts as an electron donor and the other as an acceptor. When a photon is converted into an electron hole pair, typically in the donor material, the charges tend to remain bound in the form of an exciton, and are separated when the exciton diffuses to the donor-acceptor interface. The short exciton diffusion lengths of most polymer systems tend to limit the efficiency of such devices. Nanostructured interfaces, sometimes in the form of bulk heterojunctions, can improve performance. [23]

6) *Silicon thin films*

Silicon thin-film cells are mainly deposited by chemical vapor deposition (typically plasma-enhanced, PE-CVD) from silane gas and hydrogen gas. Depending on the deposition parameters, this can yield: [24]

a) *Amorphous silicon (a-Si or a-Si:H)*

An amorphous silicon (a-Si) solar cell is made of amorphous or microcrystalline silicon and its basic electronic structure is the p-i-n junction. A-Si is attractive as a solar cell material because it is abundant and non-toxic (unlike its CdTe counterpart) and requires a low processing temperature, enabling production of devices to occur on flexible and low-cost substrates. As the amorphous structure has a higher absorption rate of light than crystalline cells, the complete light spectrum can be absorbed with a very thin layer of photo-electrically active material. A film only 1 micron thick can absorb 90% of the usable solar energy. [25]

Amorphous silicon has a higher bandgap (1.7 eV) than crystalline silicon (c-Si) (1.1 eV), which means it absorbs the visible part of the solar spectrum more strongly than the infrared portion of the spectrum. As nc-Si has about the same bandgap as c-Si, the nc-Si and a-Si can advantageously be combined in thin layers, creating a layered cell called a tandem cell. The top cell in a-Si absorbs the visible light and leaves the infrared part of the spectrum for the bottom cell in nc-Si.

b) *Protocrystalline silicon or Nanocrystalline silicon (nc-Si or nc-Si:H), also called microcrystalline silicon.*

It has been found that protocrystalline silicon with a low volume fraction of nanocrystalline silicon is optimal for high open circuit voltage. [26] These types of silicon present dangling and twisted bonds, which results in deep defects (energy levels in the bandgap) as well as deformation of the valence and conduction bands (band tails). The solar cells made from these materials tend to have lower *energy conversion efficiency* than *bulk* silicon, but are also less expensive to produce. The quantum efficiency of thin film solar cells is also lower due to

reduced number of collected charge carriers per incident photon.

V. CONCLUSION

Analysts have predicted that prices of polycrystalline silicon will drop as companies build additional polysilicon capacity quicker than the industry's projected demand. On the other hand, the cost of producing upgraded metallurgical-grade silicon, also known as UMG Si, can potentially be one-sixth that of making polysilicon.[27]

Manufacturers of wafer-based cells have responded to high silicon prices in 2004-2008 prices with rapid reductions in silicon consumption. According to Jef Poortmans, director of IMEC's organic and solar department, current cells use between eight and nine grams of silicon per watt of power generation, with wafer thicknesses in the neighborhood of 0.200 mm. At 2008 spring's IEEE Photovoltaic Specialists' Conference (PVS'08), John Wohlgemuth, staff scientist at BP Solar, reported that his company has qualified modules based on 0.180 mm thick wafers and is testing processes for 0.16 mm wafers cut with 0.1 mm wire. IMEC's road map, presented at the organization's recent annual research review meeting, envisions use of 0.08 mm wafers by 2015.[28]

Thin-film technologies reduce the amount of material required in creating the active material of solar cell. Most thin film solar cells are sandwiched between two panes of glass to make a module. Since silicon solar panels only use one pane of glass, thin film panels are approximately twice as heavy as crystalline silicon panels. The majority of film panels have significantly lower conversion efficiencies, lagging silicon by two to three percentage points.[29] Thin-film solar technologies have enjoyed large investment due to the success of First Solar and the largely unfulfilled promise of lower cost and flexibility compared to wafer silicon cells, but they have not become mainstream solar products due to their lower efficiency and corresponding larger area consumption per watt production.

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