Photovoltaics:
Past, Present and Future

A White Paper prepared
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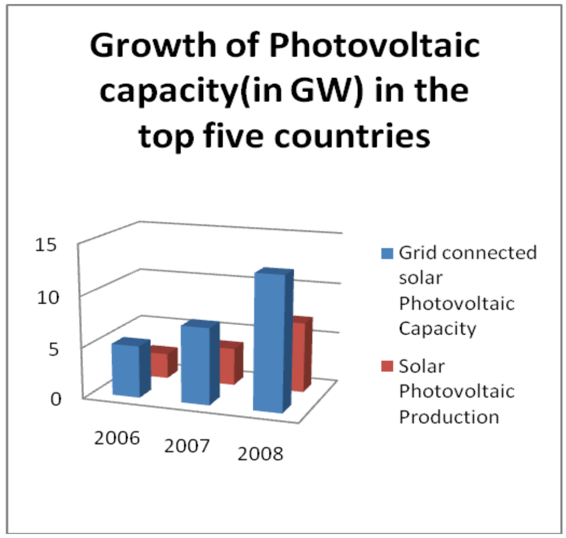
Photovoltaic (PV) technology uses direct sunlight to produce electricity. Today's solar PV panels are being installed on vehicles, ATMs, remote equipment stations, spacecrafts and on building envelope components. This white paper will focus on the fundamentals of photovoltaic energy production, and its integration with metal roofing materials.

Photovoltaic materials produce electricity with no moving parts, and without consuming any fossil fuels. Photovoltaics are one of the clean renewable energy sources that the world is developing with great interest. It presents particularly attractive features to building owners who are looking to reduce their electricity consumption.

Market Dynamics

The worldwide power generation capacity of photovoltaic systems grew from1.3 Giga Watts (GW) in the year 2001 to 15.2 GW by 2008. The solar industry as a whole is expected to grow to $51 billion in 2015 from $11 billion in 2005, according to forecasts from Clean Edge Inc. Thin-film PV is forecast to reach 20% of the overall solar market in 2010 – up from an 8% market share in 2006, according to Green Tech Media. According to NanoMarkets, thin film PV technology could grow from a $1 billion market today to $7.2 billion by 2015.

Grid-connected PV is the fastest growing power generation technology with a 70% growth in the year 2008 alone. Solar photovoltaic production in the top five countries has grown from 2.5GW to 6.9GW. The five countries with the highest photovoltaic capacity are Germany, Spain, Japan, United States, and South Korea.



This type of worldwide growth will continue in the coming years as many countries like Austria, China, Japan, Luxembourg, Netherlands and United States are adopting government subsidy programs to reduce the cost of solar photovoltaic installations.

New laws and policies which will encourage the growth of photovoltaic capacity are also being enacted in developing countries like Brazil, Chile, Egypt, Mexico, Philippines and South Africa.

The three major trends that are evolving are 1) the growth of building integrated photovoltaic (BIPV), 2) the development of thin-film solar photovoltaics, and 3) the growth in utility-scale solar photovoltaics. For example, during the 2007-08 time period the world added 800 more power generation plants using utility scale solar photovoltaic technologies.

Annual Installed Photovoltaic Power (MW) in Selected Countries (1997-2007)						
Country	1997	1999	2001	2003	2005	2007
Germany	14	15.6	80.9	153	863	1135
Spain	-	-	2	4	24	512
Japan	31.7	75.2	123	223	290	210
USA	11.7	17.2	29	63	103	206
Italy	0.7	0.8	1	4	6.8	70.2
Korea	0.4	0.5	0.8	0.6	5	42.9
France	1.7	1.5	2.6	3.9	7	31.3

According to Pike Research LLC, of Boulder, CO, distributed power generation using renewable energy, in general, grew 76% worldwide from 2007 to 2008, reaching $30 billion. The forecast for global revenue from power distributed from renewable sources is $60 billion by 2013 .

China has now become the leading country in photovoltaic cell production with a capacity of 1.8GW. Germany is the second largest with a capacity of 1.3GW, followed by Japan with a capacity of 1.2GW. Germany remains the world leader in operating PV capacity per capita at 46.8 W per citizen.

There are some notable and large manufacturing companies in the field of photovoltaics. Q-cell, a German based company, is the world leader in solar photovoltaic cell production. Its production for the year 2008 was 570 MW of cells. SunTech of China, First Solar of the US and Sharp Electronics of Japan are the next largest PV manufacturers. Large investments in R&D and new production capacities are expected to increase PV production figures even more.

The photovoltaic industry also creates many green jobs. The sector directly employees 20,000 people worldwide and also supports over 200,000 jobs indirectly in the areas of glass, steel manufacturing, electrical wires and equipment. The Pew Charitable Trust claims that the entire clean energy economy accounted for about 770,000 jobs in 2007 worldwide.

The Impact of the Recession on the Photovoltaic Sector

The solar photovoltaic industrial sector has suffered the negative impacts of the global financial and economic downturn. Financing and investments in new research and development may be affected by this situation.

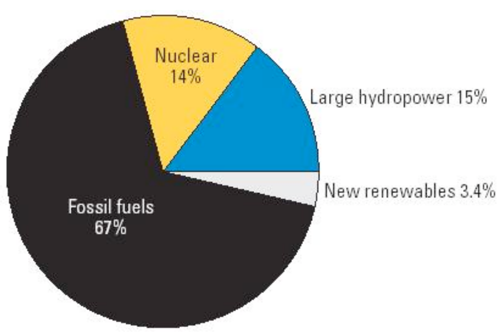
One estimate sees the photovoltaic market possibly contracting by 17% through the end of 2009, mostly due to the exit of some smaller manufacturers. At the same time, though, there are many signs of consolidation in this market as some larger companies are examining smaller organizations with weak cash flow.

One example of such consolidation was the acquisition of Germany's Business Institute Solar Strategy by SunEdison. A total of 61 such mergers and acquisitions have taken place since June 2008 in the solar sector.

In the US, the American Recovery and Reinvestment Act of 2009 has provided millions of dollars for state energy programs. That funding is targeting energy efficiency and renewable energy projects across the nation. The funds are directed toward plans that prioritize energy savings, create or retain jobs, increase the use of renewable energy, and reduce greenhouse gas emissions. Solar power generation is a recipient of that funding. The Act also is expected to produce 1-1.5 million jobs in the solar and wind energy fields, electrical grid upgrade projects and retrofitting of buildings.

Importance of Renewable Energy

More than 80% of the world's energy needs are fulfilled by fossil fuels. Coal, petroleum, and natural gas are the major fossil fuels consumed worldwide for energy requirements. Our dependence on fossil fuels raises concerns over the environmental impact that they have, their unstable and unpredictable pricing, and the national security issues that they create. In light of those concerns, the popularity of renewable sources of energy has never been greater.



Energy usage worldwide

(Source: www.iea-pvps.org)

The most commonly used renewable sources of energy are solar power, wind, hydro and geothermal energy. The solar energy from the sunlight, kinetic energy from the wind and water and the heat energy from the geothermal sources can be converted into electricity using different technologies.

Renewable sources of energy also help to reduce CO_2 emissions and other types of pollutants emitted during the burning of fossil fuels. That fact helps to encourage renewable energy for the mitigation of greenhouse emissions and factors affecting global climate change.

Incentives for Solar Energy

The US Energy Improvement and Extension Act of 2008 (a component of the Emergency Economic Stabilization Act) allows for rooftop solar installations to qualify for a 30% federal tax credit and an accelerated 5-year depreciation schedule. As of January 1, 2009 there is no longer a cap on the solar tax credit. The tax incentive extends through 2016. Details can be found in Section 25D of the US Tax Code.

For residential incentives, the federal tax credit applies to new equipment installed on a property that is used as a residence of the taxpayer. Almost 90% of residential photovoltaic systems are installations on existing homes. In addition to federal tax credits, many states are offering incentives of their own. For example, California's Solar Initiative offers residents in that state solar rebates based on actual output as well as expected performance.

Incentives also exist for commercial installations. The commercial federal solar tax benefit is described in Section 48A of the US Tax Code. The code states that a tax credit of 30% is available for solar property placed in service during the period of 2006-2016. The credit drops to 10% after 2016. Solar equipment that qualifies for the 30% tax credit can be depreciated over 5 years on an accelerated basis. Where the tax credit is claimed, only 85% of the equipment cost can be depreciated. Details of the commercial tax incentives are found in Section 168(e)(3)(B)(vi)(I) of the US tax code.

In either residential or commercial incentives, the federal tax credits can be combined with state rebates, buy downs, grants, loans or other incentive programs. An excellent database of statewide incentives can be found at www.DSIREUSA.org.

The American Recovery and Reinvestment Act of 2009 includes 19 provisions that are designed to stimulate the growth of solar energy. Solar technologies have access to $25 billion in government funded construction projects.

That funding is targeted toward federal grants, loan guarantees, tax incentives, state funding, solar on federal property, clean renewable energy bonds, "Solar for Schools" programs, green collar job training, Department of Interior funding, and "Solar for Military" projects.

Types of Photovoltaic Installations

Photovoltaic systems are used in four general types of applications:

A) **Grid connected distributed Photovoltaic systems** are used to supply electricity to the customers who are already on an electric supply network.

These are used for domestic as well as commercial systems.

B) **Grid connected centralized systems** generate a large amount of electricity from a centralized power station. The power is then distributed for domestic and commercial usage through an electric distribution network.

C) **Off-Grid domestic systems** are used for household and other low electric consumption units. These systems are mainly used in locations that are not

connected by the electric supply networks. These systems are generally 1KW in size and are cost effective alternatives to the extension of the national electricity grid

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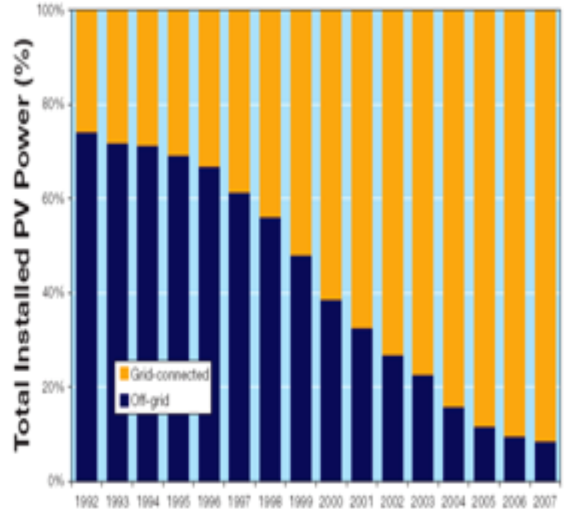
D) **Off-Grid Non-Domestic systems** are similar to the above mentioned Off-Grid domestic systems.

The electricity generated in this system is used for remote commercial purposes like telecommunication, water pumping, and lighting.



Percentage of Grid-Connected and Off-Grid PV Power in Reporting Countries

Most of the initiatives taken in 2007 in the solar energy sector were in grid-connected centralized systems. These systems have increased three times in the year 2006-07. This reflects the growth of investor-owned large scale PV power systems being developed and becoming better organized.

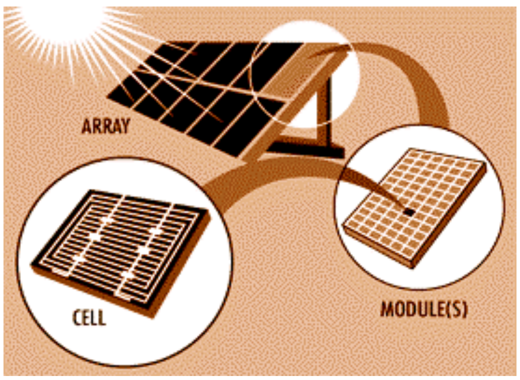
Fundamentals of Photovoltaic

"Photovoltaic", as the name suggests, is the technology of converting energy from sunlight. The energy is converted from energized photons to electrical energy by utilizing the inherent properties of semiconductors like silicon which conduct electricity in the presence of light.

Solar energy is the most abundant renewable energy source in our environment. And this source of energy is free, constant and does not fluctuate in price like other conventional fuels. Solar energy can be used to provide heat, lighting, mechanical power and electricity.

The photovoltaic effect was first observed in 1839 by French scientist Edmund Becquerel but its first commercial use was not until the 1950's when it was applied to powering US orbital satellites.

The building block of PV technology is the cell. A typical 4-inch silicon solar cell can produce up to two watts of direct current electricity. Solar cells are connected to form a PV module, and many modules are linked together to form a PV array.



While most photovoltaic (PV) cells were made of silicon since the earliest research, many other types of semiconductor PV cells have been found to surpass silicon in performance and cost. Crystalline silicon PV systems represent 90% of the market. They use approximately 20 kg of silicon per 1 kW of PV. Their sunlight-to-electricity conversion efficiency is typically 15-20%.

Crystalline Si modules are silicon wafers sandwiched between two layers of glass. The panels are relatively heavy and rigid but can be mounted to metal roofing with special fastening devices that do not penetrate the roof surface.

An alternative to crystalline silicon PV modules are thin-film amorphous silicon PV laminates. These flexible PV laminates are typically 0.12 inch in thickness. Their conversion efficiency is typically 6-10%.

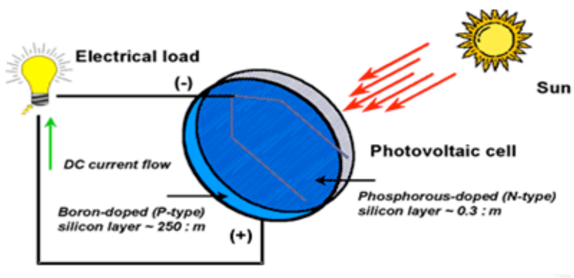
The flexible PV systems are made by depositing films of doped silicon-germanium alloys to a thin sheet of stainless steel and then encapsulating them with a strong and flexible polymer top layer. The PV sheets of material can be laminated to the flat pan surface of standing seam metal roof panel.

Science behind the concept

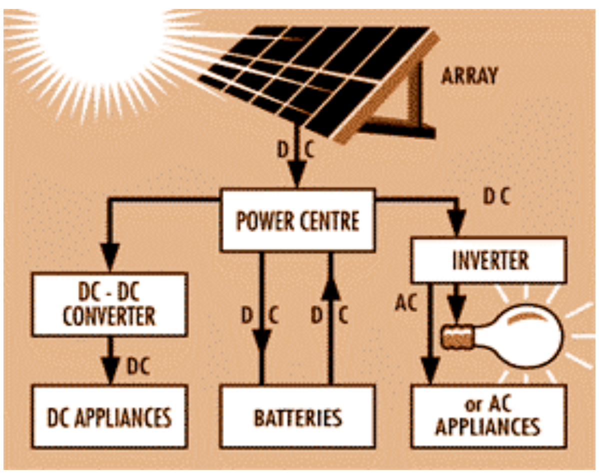
Electricity can be generated with PV technology through the interaction of photons in sunlight with certain "doped" semiconductor materials. All PV cells require a light absorbing material contained within the cell structure to absorb photons and generate electrons via the photovoltaic effect. If the electrons are sufficiently energized they are able to jump from the valence band to the conduction band where they are free to move within semiconductor material. The flow of electrons results in a current.

That direct current can then be converted to an alternating current with an inverter which provides electricity to power a building.

The movement of electrons and holes generate electricity. When not needed, this energy can be stored in specially designed batteries for subsequent use.



A complete PV system consists of the PV modules in an array, and the 'balance of system (BOS) comprised of the support structures, wiring, storage, and conversion devices as shown in the figure below.

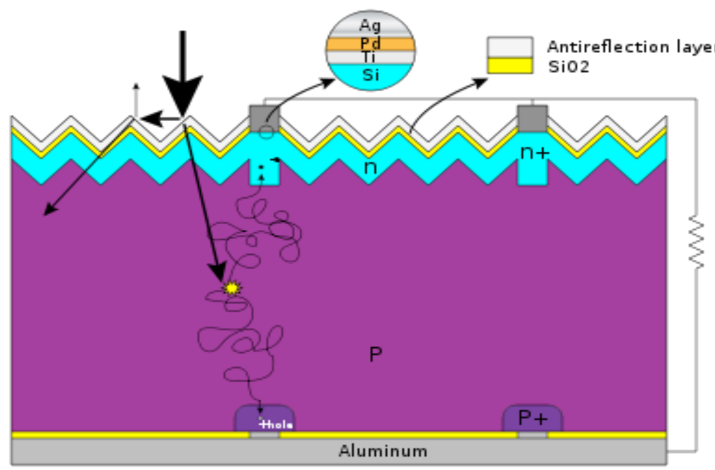


Types of Existing Photovoltaic Technology

There are two basic forms of crystalline silicon PV – poly crystalline and mono crystalline. Poly crystalline is less efficient at converting sunlight to electricity, but less expensive to manufacture. In contrast, mono crystalline is more efficient at creating electricity from sunlight, but relatively more expensive to manufacture. A comparison of the major PV technologies is shown in Appendix A.

Crystalline silicon

Crystalline silicon (c-Si) is the benchmark technology for PV cells. Crystalline technology was first launched in 1962. The highest reported commercial c-Si module conversion efficiency is 18% for mono-crystalline, and 15% for poly-crystalline. Silicon is classified into multiple categories according to crystallinity and crystal size in the resulting ingot, ribbon, or wafer.



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

Monocrystalline Silicon (c-Si)

Single crystal wafers are expensive to manufacture because they are cut from cylindrical ingots. As a result they do not cover a square PV module without a substantial amount of wasted areas of refined silicon. Hence, most c-Si panels have uncovered gaps at the four corners of the cells.

Ribbon silicon is a type of monocrystalline silicon formed by drawing flat thin films from molten silicon and retaining a crystalline structure. These cells have lower efficiencies than poly-Si but they save on production costs.

Polycrystalline Silicon

Poly- or multi-crystalline silicon is made from cast square ingots of molten silicon that are cooled and solidified under controlled conditions. This type of silicon is less expensive to produce than mono-crystalline silicon cells but their conversion efficiency is lower.

Gallium Arsenide (GaAs)

This is a semi-conductor material comprised of gallium (Ga) and arsenic (As). It has a crystal structure similar to that of silicon. One advantage of GaAs is its high level of sunlight absorptivity for a given thickness of material. It also has a higher conversion efficiency than crystal silicon, reaching about 25-30%. Its biggest disadvantage relative to other PV materials is its high cost of the single crystal substrate on which the GaAs is deposited.

Thin Films

A new market for PV is thin- film technology. Rather than growing crystalline silicon ingots, slicing them and treating them, thin-film PV is produced by sequentially depositing thin layers of different materials onto a very thin structure. The resulting device requires very little semiconductor material and is easier and less costly to manufacture than conventional silicon-based products.

The various thin-film technologies currently under development have a smaller amount of light absorbing material in the solar cell. This can lead to reduced processing costs compared to bulk materials (in the case of silicon thin films) but it also tends to reduce energy conversion efficiency (average 6 to 10%). However, there are reports of newly developed multi-layer thin films that have efficiency better than bulk silicon wafers. Flexible and thin film PV cells are now approaching 20% conversion efficiencies in some research programs.

Amorphous silicon (a-Si) was the first thin-film material to become a commercial product. Initially, a-Si was mostly used in consumer items such as calculators. Amorphous silicon is under constant development with increasing efficiencies, economic manufacturability, and innovative product applications.

Thin-film PVs have become popular compared to wafer silicon due to lower costs and advantages including flexibility, lighter weight, and ease of integration with building materials.

Cadmium Telluride

Cadmium Telluride (CdTe) is used in some thin film solar cells. This material provides a cost effective solar cell design, but its conversion efficiency is less than that of poly-crystalline silicon materials. While the best CdTe modules are about 10% efficient, recently produced modules were measured by NREL with efficiency of 12.5%. Research into improved doping of CdTe and increased understanding of the processing steps are resulting in improved efficiencies.

Direct manufacturing costs for CdTe PV modules have reached $1.12 per watt. However, the reduced efficiency of CdTe modules requires more area to produce the same output of silicon-based modules.

A significant drawback to the use of CdTe materials is the fact that Cadmium is one of the six most toxic materials banned by the EU's RoHS regulations. In addition, Tellurium is an extremely rare element, and its supply for high volume production of PV cells is in question.

CIGS

CIGS (Copper Indium Gallium diSelenide) was first discovered in the 1970s. The material is a polycrystalline solid solution of copper indium selenide (often abbreviated as CIS) and copper gallium selenide. The chemical formula is $CuIn_xGa_{(1-x)}Se_2$. Presently, CIGS represent only 2% of the PV market.

CIGS convert more sunlight to electricity than other thin-film PV materials. Its conversion efficiency is stable over time, meaning its performance continues for many years. In contrast, the performance of conventional PV materials typically declines slightly each year.

CIGS films can be manufactured using several methods. The most common is a vacuum-based process that co-evaporates or co-sputters copper, gallium and indium, followed by an annealing process using a selenide vapor. Another method uses a non-vacuum based process whereby nanoparticles of the required materials are deposited onto a substrate and then sintered in place.

CIGS solar cells are generally not as efficient as crystalline silicon solar cells, but they are substantially lower in cost. However, it was recently reported that the National Renewable Energy Laboratory achieved a 19.9% conversion efficiency, a new world record, by modifying the CIGS surface slightly. Manufacturers are targeting production module efficiencies in the 10-12% range.

CIGS can be printed directly onto molybdenum coated glass sheets. Some CIGS producers are claiming a $1/Watt cost as compared to approximately $4.50/Watt for traditional solar cells.

Worldwide, five companies are presently offering commercial thin-film CIGS PV products: Würth Solar (Germany), Global Solar (USA), Honda (Japan), Showa Shell (Japan) and Sulfurcell (Germany). The production capacity ranges between 5 and 27 MW/year. However, there are 34 companies actively developing thin-film CIGS PV technologies, representing more than ten different deposition methods. A list of some US-based and international companies involved in CIGS research and/or pursuing full scale production is shown in Appendix B.

Inkjet Circuitry

Third-generation solar panels are being produced with specialized printers applying nano-size particles onto rolls of thin flexible material in a way similar to inkjet printing. These panels are being produced at a fraction of the cost (as little as $1/watt) of second generation PV panels which use a vacuum-based glass etching technology.

Flexible PV

Flexible thin-film cells are produced by depositing the photoactive layer and other necessary layers on a flexible substrate.

If the substrate is an insulator (e.g. polyester or polyimide film) then monolithic integration is used. If the substrate is a conductive material then another technique for electrical connection must be used.

The cells are assembled into modules by laminating them to a transparent fluoropolymer on the front side and a polymer suitable for bonding to the final substrate on the other side. The only commercially available (in MW quantities) flexible module uses amorphous silicon triple junction materials. Inverted metamorphic (IMM) multi-junction solar cells made with compound-semiconductor technologies became commercialized in July 2008

Typical Power Output

Independent of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions, a typical commercial PV cell with a surface area of 160 cm^2 (25 in^2) will produce about 2 watts peak power. If we consider sunlight intensity at 40 percent of peak, this cell would produce about 0.8 watts.

A solar cell's power output depends on a number of factors which include the sun's incidence angle for the given region, solar irradiance, air mass and temperature.

For comparison of power output of different kinds of PV cells, the measure of watts peak is used. The standard test conditions (STC) imply a solar irradiance of 1000 W/m^2, a solar reference spectrum AM (air mass) of 1.5 and a cell temperature 25°C. Ideally a 1 kWp system will produce 1 kW under STC.

A watt-peak of a cell is the DC power output in watts as measured under an industry standardized light test before the solar module leaves the manufacturer's facility. The standard light test measures the output power when illuminated under standard conditions of 1000 watts of light intensity per square meter, 25 °C ambient temperature and a spectrum similar to sunlight.

Some simple examples are that a 1kWp system will produce approximately:

· 1800 kWh/year in Southern California

· 1600 kWh/yr in India and Australia

. 850 kWh/yr in Northern Germany

General Cost

The solar energy industry typically uses price per Watt Peak (Wp) as its primary unit of measurement. The solar module represents nearly 40-50% of the total installed cost of a "solar system". This percentage will vary according to the nature of the application. A complete solar system includes the other components required to create a functioning system, whether it be to feed energy in to the grid or to be used in stand-alone off-grid applications.

Labor and installation costs can represent 15-25% of the total cost of a crystalline Si PV system. The PV inverters can represent another 10-20% of the total cost of PV installation.

Solar PV costs today are around 2-5 times the average residential electricity rates.

Average Nati onal Electricity Rates (1999)	
Country	Cents/kWh
Australia	8.0
Austria	16.8
Brazil	12.8
France	12.9
Germany	15.2
India	3.4
Japan	21.2
Mexico	5.9
Spain	14.3
UK	11.7
USA	8.1

(Source: Energy Information Administration)

PV installed costs are now in the $3,000-$10,000 per kW range, which is down significantly from 1998. That cost is before incentives, rebates or credits are applied.

A 3000 Watt system can reduce a typical home's electricity bill by $50-$60 per month. A typical residential system provides power for ½ to ¾ of the home's electricity needs. Generally a PV array that covers one square foot can produce about 10 watts.

When installing a PV system on a metal roof, compared to other types of roof materials, there are significant cost savings. The PV cost advantage with metal is about $0.80/watt. An average PV system is warranted for 25 years. Many conventional roofing products' service life is 15-20 years. If a PV system is installed on the conventional roofing materials, the likelihood of the roof requiring removal and re-roofing while the PV system is still functioning is high. In that scenario, the PV equipment would have to be removed, the original roof would have to be removed, a new roof installed, and the PV equipment re-installed. The material and labor cost for this is significant. In contrast, the need to replace a metal roof used with a PV installation is minimal.

In addition, attaching a PV system to metal roofing can be done without penetrating the roof surface, thereby eliminating the cost and labor to waterproof penetrations that result with other types of roof materials.

As the PV industry grows and incentives become available, the installation costs are expected to drop. According to USA Today, the cost of rooftop PV arrays, including installation, is expected to drop 20% in 2009.

Next Generation Products

There is much research and development in the field of photovoltaic materials. Two "next generation" products that should be closely monitored include copper-based materials and systems that perform at the nano-size scale.

Copper-Based Products

Photovoltaic materials based on copper/indium/selenide ($CuInSe_2$) include several elements from groups I, III and VI in the periodic table. These semiconductors are commonly referred to as CIS films. They are especially ideal for thin-film solar cell applications because of their high optical absorption coefficients and versatile optical and electrical characteristics. Research is showing that their properties can be adjusted for specific performance needs.

Recent reports claim that CIS films (with no Ga) have achieved greater than 14% conversion efficiency. However, manufacturing costs of CIS solar cells at present are high when compared with amorphous silicon solar cells. Continuing research is leading to more cost-effective production processes. Manufacturing techniques vary and include the use of ultrasonic nozzles for material deposition.

Researchers are experimenting with CIS and CIGS to boost their efficiencies even more by using optics to concentrate the incident light on the surface. Other approaches include using multi-junction tandem solar cells.

Nanotechnology

Nanocrystalline solar cells make use of some of the same thin-film light absorbing materials but they are deposited as an extremely thin absorber. The film is normally deposited on a supporting matrix of conductive polymer or metal oxide materials having a very high surface area to increase internal reflections. With more reflections, the probability of light absorption increases, thereby boosting their conversion efficiency.

Using nano-crystals allows scientists to design the junction circuitry on the scale of nanometers, which is the typical excitation diffusion length within the cells. At that scale, sunlight to electricity conversion rates could become significantly higher.

Synergy with Metal Roofing

Building-integrated photovoltaic (BIPV) are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, windows, skylights, or wall surfaces. They are increasingly being incorporated into the construction of new buildings as a principal or ancillary source of electrical power, although existing buildings may be retrofitted with BIPV modules as well.

Fastening techniques

Improvements are continuously being made to lower the installed cost and boost the efficiencies of PV systems. Crystalline silicon solar arrays and thin-film amorphous silicon systems are the two common types of BIPV. Today's mounting techniques allow c-Si PV systems to be fastened to metal roofing panels directly without penetrating the roof. Thin-film silicon PV modules can be laminated directly to the flat pan surface of a standing seam metal roof. With both types of PV products on metal, there is no need for additional waterproofing of attachment points, and no maintenance required around those areas. This represents a lower life cycle cost for the PV/metal roof system.

Longevity

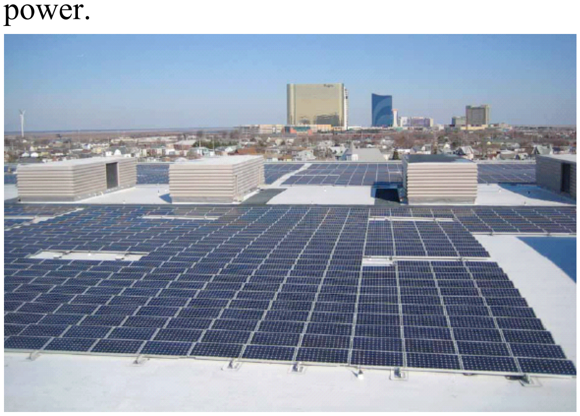
The endurance of PV modules is a crucial factor for economic competitiveness of solar installations. The systems that are used with metal roofing are often warranted for more than 25 years, but all BIPV systems have some degradation from exposure of the modules to constant sunlight. This causes them to lose approximately 1% of their original conversion efficiency every year. The performance degradation is the result of two main factors—1) the slow breakdown of a module's encapsulant (typically ethylene vinyl acetate [EVA] and back sheet [typically polyvinyl fluoride films], and 2) the gradual degradation of the layer between the module's front glass and the cells themselves. However most PVs that are warranted for 20-25 years have high probability of working well beyond 30 years.

Metal roofing has synergy with PV systems in that the expected useful life of metal roofing is 30 - 35 years or more. Hence, a durable metal roof will out-last the service life of a PV system. This eliminates the need and cost of re-roofing before the PV has reached the end of its useful life. The expected useful life of some conventional roof materials' used with PV installations is 15-20 years. When the conventional roof material needs to be replaced, the PV equipment must first be removed, and later re-installed after the new roof has been installed.

Major Rooftop Photovoltaic Installations and Applications

The world's largest single roof solar panel array is on the General Motors plant near Zaragoza Spain. Over 85,000 PV laminates were installed in September 2008 to provide 11.8 MegaWatt of power.

In the United States, the largest PV roof mounted array is on the Atlantic City, NJ Convention Center. I3,321 crystalline Si PV panels were installed over 290,000 ft^2 of roof space to provide 2.4 MegaWatts of power.



Australia witnessed 12.2 MW of PV installation in the year 2007. Half of that installation was grid-connected systems. However, the largest PV installation in Australia is off-grid and used for industrial and agricultural purposes. The PV market there is supported by government grants through the Renewable Remote Power Generation Program. There has been a noticeable increase in PV systems in public and commercial buildings as a part of government greenhouse gas reduction program.

Canada installed 5.3 MW of PV power in the year 2007. More than half of their market is represented by off-grid non-domestic PV applications. Their grid-connected PV market is also expected to rise because of the government policy support.

Germany had the highest PV installation worldwide in 2007 with 1100 MW. This expansion is mainly fueled by the country's promotion programs of grid-connected rooftop systems and large PV power plants.

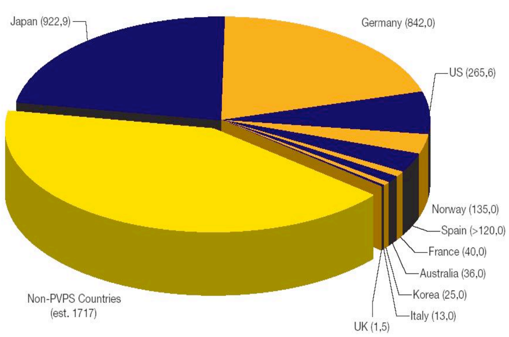
Trends

The PV industry is maturing at a fast pace. New measures like integration of the entire supply chain, mergers and acquisitions, and joint ventures can be seen. An example and possible model for this trend may be Norway's Renewable Energy Corporation which is presently in the entire PV supply chain. It has long-term supply agreements with Taiwan and other countries.

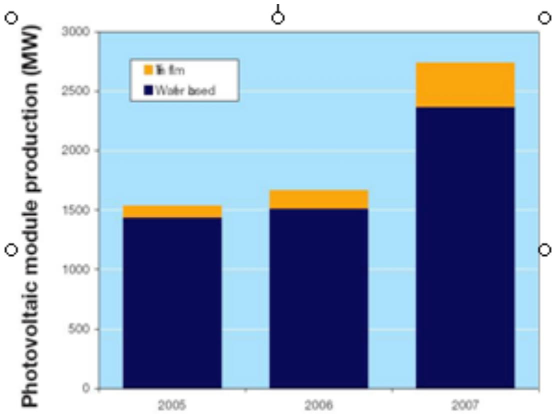
The growing demand for specialized equipment in the PV manufacturing industry is having an impact on supporting industries. Those include the chemical and gas industry, abrasives and equipment for cutting wafers, pastes and inks for the cells, encapsulation material for the modules and specialized measurement equipment for the use in production processes.

The total PV cell production volume has been increasing and is expected to continue growing. Countries like Germany, Japan, and the United States should lead the world in production. Developing countries are seeing more need for PV installations, especially in off-grid applications.

New innovations and modifications to traditional PV production techniques will emerge. Already we are seeing specially designed modules coming from Italy and other European countries.



The production of thin-film materials has increased rapidly. The shortage of PV grade silicon feedstock continues to threaten the worldwide markets. As the US market witnessed high prices of PV grade silicon feed stock in 2007, the thin-film producers used this as an advantage and increased their production. In many cases the foreign price and products continue to dominate the US domestic market dynamics.



Trends in PV Module Technologies

(Source: www.iea-pvps.org)

Wafer-based crystalline silicon technology continues to be the dominent technology. It accounts for almost 90% of the market for the PV modules. However, the dominance of wafer based crystalline technology is diminishing each year because of the incresing populariy of thin- film technology

Tax credit and direct capital subsidies in different countries have had a major positive effect on the market. The growth of PV is expected to continue as long as incentives are being offered.

Summary

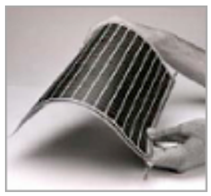
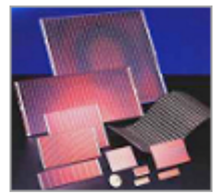
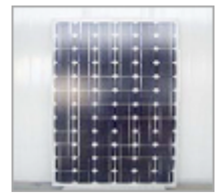
Photovoltaic technology is a significant part of today's renewable clean energy market. Its growth has been spurred by government subsidized financial incentives and a renewed interest in sustainable energy sources.

Silicon-based photovoltaic materials continue to dominate the market. However, the growth of thin film technologies, and development of new semi-conductor materials will change the landscape in the near future. Improvements to sunlight-to-electricity conversion efficiencies continue to be made in research programs worldwide.

Building-integrated rooftop installation of photovoltaic systems is a major application. The use of metal roofing as a platform for solar technologies such as photovoltaics is synergistic. The useful life of metal roofing equals or exceeds that of PV equipment, resulting in a lower life cycle cost for the entire roof installation when compared to other types of roof platforms.

The size and power output of rooftop installed photovoltaic systems continues to grow around the world. As the use of PV materials grows, the manufacturing costs are being reduced, and more incentives are being offered.

Appendix A
Comparison of Major PV Technologies

	A-SI	CIS / CIGS	CdTe	Standard
Full name	Amorphous silicon	Copper Indium(Gallium) Diselenide	Cadmium Telluride	Crystalline silicon
Example of application				
Module efficiency	5-8%; triple junction up to 10%	9-12%	7-10%	13-18%
Capital costs(US$/Watt)	US$ 2-3	US$ 2-3	US$ 1.5	US$ 0.80 ±
Manufacturing cost(US&/Watt)	US$ 1.5-2	US$ 1.5-2	US$ 1.3-2	US$ 2.5-3 ±
Share of solar market(06)	4.7%	0.2%	2.7%	92.4%
Pros	More mature, similar process to familiar TFT-LCD panels, uses 1/100 silicon of crystalline solar cells	Thin and flexible, more efficient than A-SI	Low manufacturing costs, relatively high efficiency in non-peak conditions	Very mature technology, with well-established supply chains and technologies
Cons	Low efficiency, durability	Potential indium shortage	Cadmium is toxic, potential tellurium shortage	Raw material shortage has prevented natural price declines
Representative companies	Energy Conversion Devices, Sharp, Kanaka, China Solar, United Solar Ovonic	Nanosolar, DayStar, Miasole, Honda, Shell	First solar, Antec	Motech, E-Ton, Trina Solar, Suntech, Sharp, Q-Cells

Appendix B

Companies Involved in CIGS Research and Production

US-Based

DayStar Technologies (http://www.daystartech.com)

Global Solar, Inc. (http://www/globalsolar.com)

Miasolé (http://www.miasole.com)

Nanosolar, Inc. (http://www.nanosolar.com)

Ascent Solar and ITN Energy Systems (http://www.ascentsolar.com/x.php?)

Konarka (http://www.konarka.com)

International Solar Electric Technology, Inc. (http://www.isetinc.com)

HelioVolt (http://www.heliovolt.net)

SoloPower (http://www.solopower.com)

PowerFilm Solar (http://www.powerfilmsolar.com)

Solexant (http://www.solexant.com)

PrimeStar Solar (http://www.primestarsolar.com)

Innovalight (http://www.innovalight.com)

International

Aleo AG (Germany) (http://www.aleo-solar.com)

Honda Motor Company (Japan) (http://www.world.honda.com)

Shell Solar (http://www.shell.com/shellsolar)

Showa Shell Sekikyu (Japan) (http://www.showa-shell.co.jp)

Würth GmbH (Germany) (http://www.wuerth-solar.com)

Flexcell (Switzerland) (http://www.flexcellint.com)

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