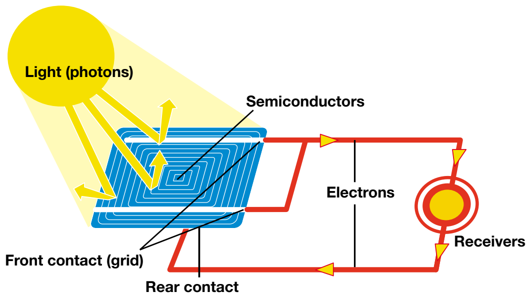
Principles and Applications

Operating principles

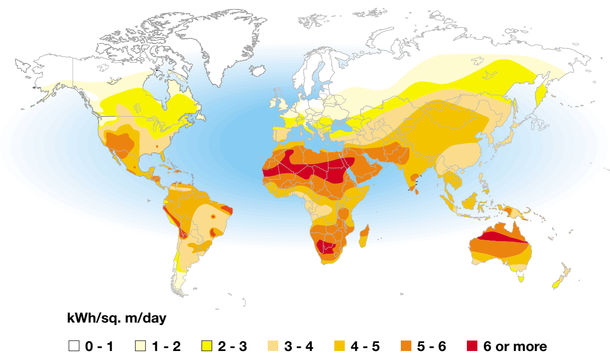
Solar energy is one of the Earth's most abundant renewable resources. The solar energy that blankets the planet's surface each year is equal to approximately 15,000 times world energy consumption. Some of that energy can be converted directly into electricity using solar collectors, and is called photovoltaic energy or solar power.

The direct conversion of light energy into electricity

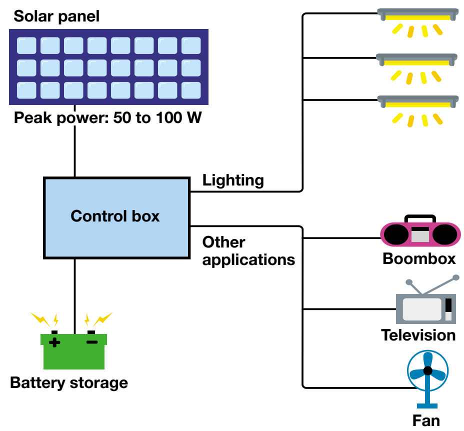


The average efficiency of a polycrystalline silicon photovoltaic cell is roughly 12 to 15%. Consequently, a square meter of photovoltaic collectors can supply 100 W of power and produces an average of 80 to 150 kWh a year, depending on its location. The photovoltaic electricity generated is either fed directly into the power grid or stored in batteries, for retrieval at night.
An installation with 20 to 30 square meters of panels could supply enough electricity for an average household in southern Europe.

Annual average sunshine



Individual solar energy system for rural electrification in developing countries



Applications

The primary developing markets for solar power are:

1. Niche markets that are economically viable:

• Beacons, radio relay receivers, time clocks, cathode protection, etc.

• Off-grid, decentralized power in developed countries, such as for mountain shelters.




2. Subsidized applications:

• Grid connections in some developed countries, including Germany, Japan and Spain, which pay high prices to purchase solar kWh. For instance, the rate in Germany is €0.48 per kWh.

• Water pumps and decentralized rural electrification in developing countries. The latter receive multilateral aid, via the World Bank, or bilateral aid from such organizations as the Fonds Français pour l'Environnement Mondial and L'Agence Française de Développement.

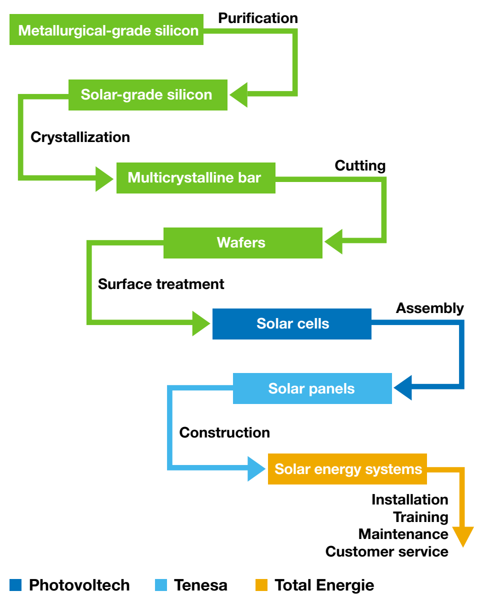
Cutting costs through technological breakthroughs

Silicon is a reliable, proven technology that currently supplies almost 90% of the world's solar panels. Semiconductor-grade, or impurity-free, silicon is melted and formed into monocrystalline bars or polycrystalline blocks with a cross-section of 100 to 200 square centimeters. The bars or blocks are then sawed into 200 to 300-micron-thick wafers. After careful cleaning, the plates are converted into light-sensitive cells by modifying their electron balance through the diffusion of doping agents such as boron and phosphorus. A grid of conductors is deposited on the surface to collect the current. After the cells are checked to make sure they perform to specifications, they are interconnected and encapsulated in glass panels featuring powers of between 100 and 200 W. The panels use about 12 kilograms of silicon per kilowatt of generating capacity and wholesale for about €3,500 per kilowatt. They are guaranteed for up to 25 years.

Major strides have been made in the last decade in cell efficiency and industrialization of the crystalline silicon segment. Continued efforts should bring down the cost of solar panels by 20 to 30% over the next several years.

However, it would take a 1,200 MW photovoltaic plant to deliver the generating capacity of a 300 MW gas-fired plant. And the photovoltaic plant would use 15,000 tons of semiconductor-grade silicon, or all of the silicon produced annually worldwide. Moreover, the electricity generated would be ten times more expensive.

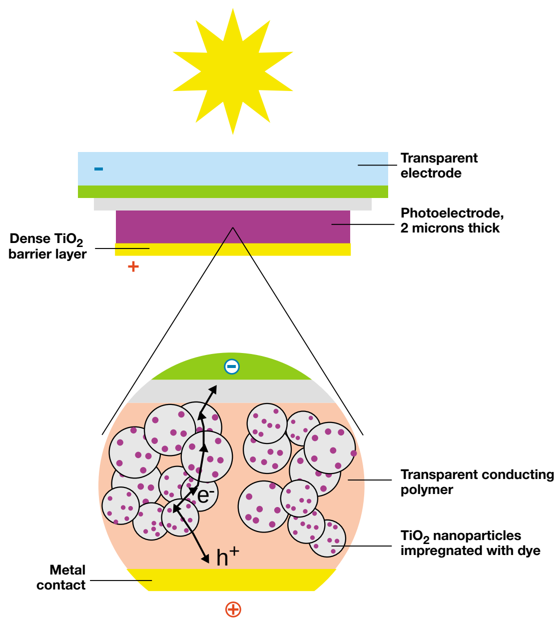
The photovoltaic chain



So the large-scale development of solar energy will have to wait for technological breakthroughs that can cut costs and drastically reduce the amount of material used.

The industrial challenge of thin films

A sensitized titanium dioxide/conducting polymer hybrid cell



The photoelectrode consists of surface-dyed, nanocrystalline titanium dioxide, which is impregnated with a transparent conducting polymer that serves as the electrical contact. Metal is deposited on the back to complete the cell.

For the last 20 years, researchers have been tackling the challenge of industrializing thin films by studying every aspect of their structure. Thin films are created by depositing layers several microns thick directly onto a glass plate. The layers form a collector grid and light-sensitive semiconductor. Thin films require much less active material and can be used alone to create a panel of 30 to 60 W. However, the difficulty of controlling the deposition of thin, uniform films using reliable, inexpensive industrial processes has so far prevented this technology from coming into its own. If future efforts prove successful, the cost of manufacturing solar panels would be €2,000 a kilowatt initially, a figure that could gradually drop to €1,000 a kilowatt.

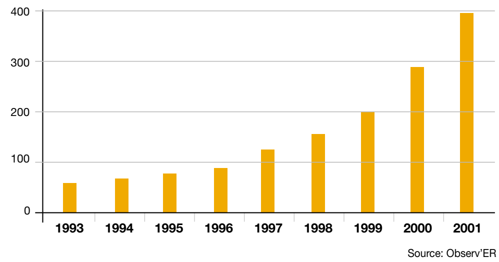
The success of thin film technology will determine the future growth of the photovoltaic industry. It will need to replace current silicon technology by around 2010 if the solar industry is to get off the ground.

More recently, progress in mastering nanostructures and conducting polymers has paved the way for photovoltaic systems that use only 0.5 kilograms of material per kilowatt of rated capacity.

An industry poised for success?

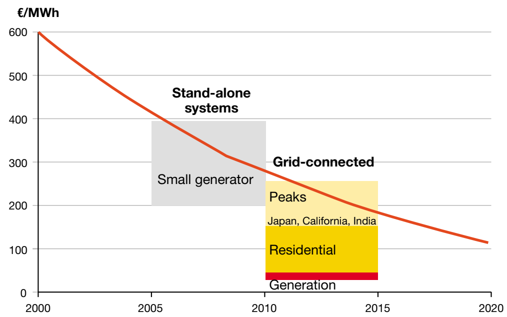
Since its beginnings in the 1970s, the solar power industry has reduced its costs by about 20% each time aggregate panel production has doubled. Before the introduction of major grid-connected programs in 1997, installed capacities rose by 15 to 18% annually, a figure that has since topped 25% a year. If identified and projected technological strides are realized, the trend could continue and an annual growth rate of 20 to 30% would cut costs by an average of 8% a year. Competitive solar power supply would then be available sometime between 2015 and 2020.

World photovoltaic cell production (in MW)



Future markets

Competitiveness of solar power in relation to the electricity market



A 20-square-meter solar roof has a rated capacity of 2.5 kW and produces 2 to 4 MWh a year, depending on the amount of sunlight. In California, half of the state's residential consumption, or 36 TWh a year, could be supplied by seven million solar roofs, for a total rated capacity of 18 GW.

Lower costs could make photovoltaic electricity competitive in ever-larger niches:

• Reduced consumption of expensive-to-supply fuels in small, distributed generating systems in remote areas by 2005-2010.

• Lower peaks in air-conditioning demand in California, Japan and India by 2010-2015.

Annual sales would rise from 0.3 GW in 2000 to 2 to 3 GW in 2010. At least a third of the new capacity would have to come from thin film technology. World capacity would jump from 1 GW to more than 10 GW.

Annual sales could reach 20 to 40 GW for every 100 GW of rated capacity worldwide by 2020. Yet solar power is not expected to supply more than 1% of the total market for electricity.

The value of the photovoltaic chain would rise from €2 billion in 2000 to €5 to €10 billion in 2010 and €30 to €40 billion in 2020. For that to happen, the industry would have to invest several billion euros between now and 2010 and several tens of billions by 2020.

Total Energie

Created in 1983, Total Energie supplies original equipment for photovoltaic systems.

Total and French utility Electricité de France each have a 35% interest in Total Energie, which posted consolidated sales of €55 million in 2001.

Total Energie's many assets include:

• A solid reputation and positive image in the solar power and housing worlds, recognized by a number of architectural prizes.

• Installation, training and customer service know-how available to customers.

• Assertive distribution and maintenance networks in West Africa, the Caribbean and Germany.

• Pioneering skills and expertise in deploying decentralized rural electrification projects, in conjunction with its shareholders Total and Electricité de France.

Lastly, Total Energie began manufacturing solar panels at its Tenesa subsidiary in South Africa in 1999. The plant, located in Cape Town, employs around 100 people. Its production capacity was boosted to 8 MW-peak in early 2002.

For more information, go to www.total-energie.fr

Architects Jacques Ferrier and Jean-François Irissou designed Total Energie's headquarters, which won the Observatoire des Energies Renouvelables (Observ'ER) "solar habitat, contemporary habitat" competition.

Increasing integration

Total, Electrabel, IMEC and Soltech set up Photovoltech in late 2001 to produce solar panels and cells. Their equity interests are 42.5% for Total, 42.5% for Electrabel, including Soltech's stake, and 15% for IMEC.

Photovoltech is currently building a photovoltaic cell and panel manufacturing plant in Tienen, Belgium. The new manufacturing process, developed by IMEC, will be able to produce photovoltaic cells using multicrystalline silicon. Simplified processes such as carrying out certain steps concurrently and round-the-clock operation will support high industrial output and competitive prices. Based in Leuven, Belgium, IMEC is Europe's largest independent microelectronics research center. Production is slated to begin in mid-2003. The plant will have an annual capacity of 6 to 9 MW and will employ around 50 people.

Thanks to its subsidiaries Total Energie and Photovoltech, Total is active in many segments of the photovoltaic chain, giving it solid expertise in solar power applications.

At the same time Total has partnered with Electricité de France to implement a number of decentralized rural electrification programs, particularly in Morocco and South Africa, in areas not connected to the grid.

Total subsidiaries involved in photovoltaic energy

	Specialty	Other Major Partners
TOTAL ENERGIE	System design and sale	Electricité de France
TENESA	Panel encapsulation	Total Energie
Photovoltech	Cell manufacture	Electrabel, IMEC
Temasol	A Moroccan decentralized electric utility	Electricité de France, Total Energie
KES Kwazulu Energy Services	A South African decentralized electric utility	Electricité de France

Personal View

Philippe Costerg

Solar Power Manager, Renewable Energies Department, Total

"Our goal is to be more active across the photovoltaic chain and to number among the European leaders in the solar power industry. But without ever losing sight of the dynamics of the markets, which are still highly dependent on government aid.

"Besides expanding Total Energie and creating Photovoltech, we gather intelligence about the technologies of the future. Atofina helps us do that in its areas of expertise, notably thin film deposition technologies and the preparation of semiconducting polymer systems.

"Finally, we want to expand the decentralized electric utility concept in the field of decentralized rural electrification. In most cases, we would be partnering with Electricité de France, to reach our goal of electrifying 100,000 households (500,000 to 800,000 inhabitants) in developing countries by 2010."

Dr. Toby Meyer

Solaronix S.A.

"A new way of producing low-cost solar power is hybrid photovoltaic cells, which use dyed nanocrystalline titanium dioxide and a transparent conducting polymer. The advantage of hybrid cells is that they are easy to make and require very little in the way of deposition materials. Thin film technology lends itself especially well to continuous production, since it is essentially based on printing processes, especially when flexible substrates are used.

"Current research is focused on developing new conducting polymers, which can improve the photovoltaic efficiency of hybrid cells."