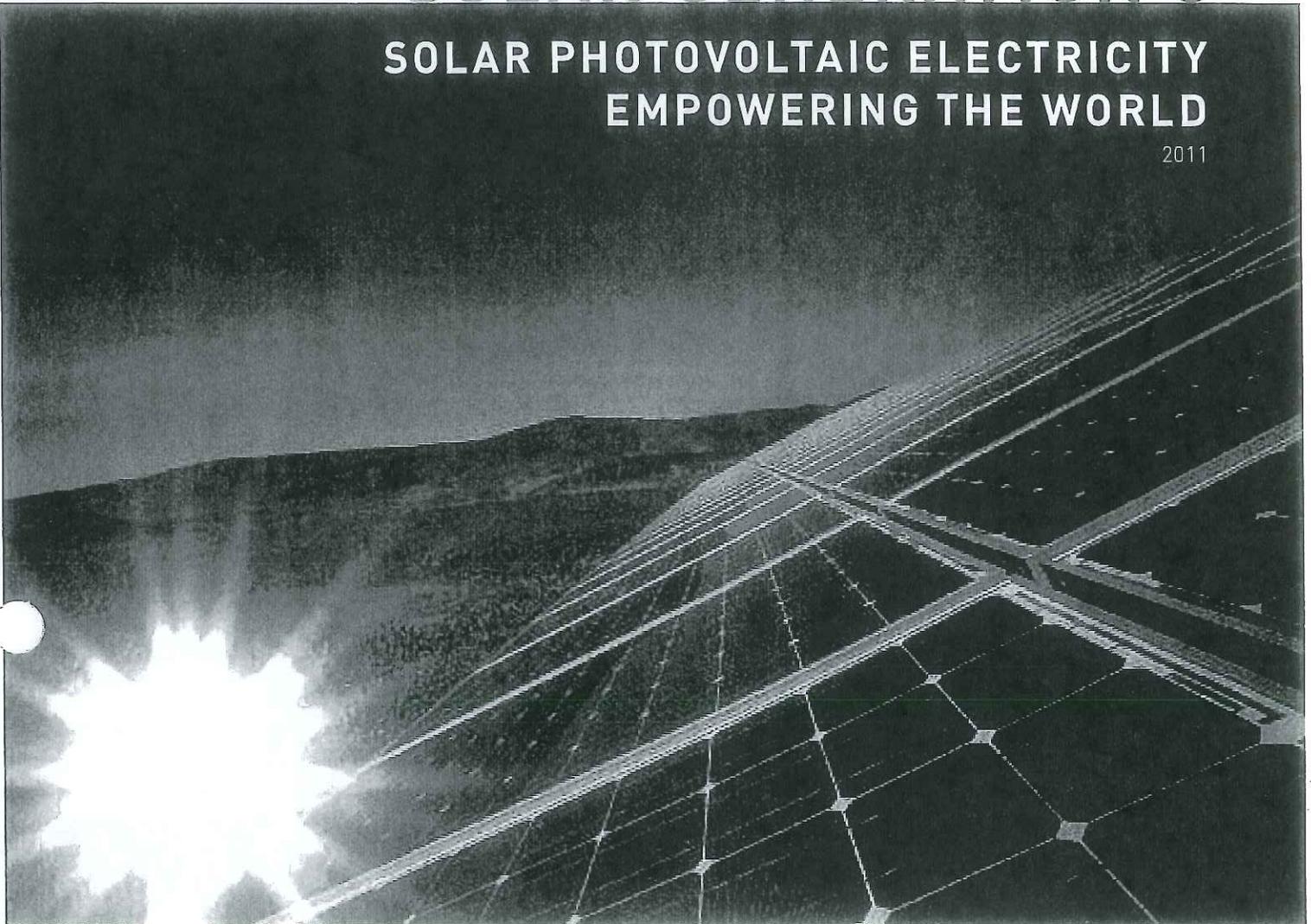


SOLAR GENERATION 6

SOLAR PHOTOVOLTAIC ELECTRICITY
EMPOWERING THE WORLD

2011



GREENPEACE

**EPIA**
European Photovoltaic Industry Association

SOLAR GENERATION 6

SOLAR PHOTOVOLTAIC ELECTRICITY EMPOWERING THE WORLD

2011

FOREWORD

The European Photovoltaic Industry Association and Greenpeace International are pleased to present this 6th edition of the report "Solar Generation: Solar Photovoltaic Electricity Empowering the World".

This report aims to provide a clear and understandable description of the current status of developing Photovoltaic power generation worldwide, and also of its untapped potentials and growth prospects in the coming years.

During 2010, the Photovoltaic (PV) market has shown unprecedented growth and wide-spread use of this environmentally friendly and distributed source of power generation. On a global basis, new PV installations of approximately 15,000 MW have been added during 2010, taking the entire PV capacity to almost 40,000 MW. This result is even above the optimistic forecast contained in the report, and it also translates into investments of over 50 bn€ in 2010, again ahead of the report's forecast.

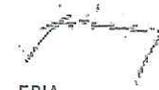
The most impressive result is however the number of installations and therefore of individuals, companies, and public entities participating in this development: nearly 2 million single PV installations produce photovoltaic power already today.

The cumulative electrical energy produced from global PV installations in 2010 equals more than half of the electricity demand in Greece, or the entire electricity demand in ten central African countries.*

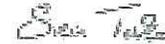
* Angola, Benin, Botswana, Cameroon, Congo, Cote d'Ivoire, Eritrea, Ethiopia, Gabon and Ghana.

The strong growth in PV installations is currently driven in particular by European countries, accounting for some 70% of the global market, and accompanied by the promising key markets of North America, Japan, China and Australia. At the same time, the PV arena has importantly widened its number of participating countries and also increased their specific weight. Major new areas for development lie also in the Sunbelt region, with Africa, Middle East and South America just starting to create new growth opportunities, almost always dedicated to covering local demand.

FOREWORD



EPIA
Ingmar Wilhelm
President European Photovoltaic
Industry Association (EPIA)



Greenpeace
Sven Teske
Renewables Director
Greenpeace International



Installing thin film modules.

The major competitive advantages of PV technology lie in its versatility, i.e. the wide range of sizes and sites, resulting into proximity to electricity demand, in the value of its production profile concentrated during peak-load hours, and in its enormous potential for further cost reduction.

PV technology has reduced its unit costs to roughly one third of where it stood 5 years ago, thanks to continuous technological progress, production efficiency and to its wide implementation. The trend of decreasing unit cost will continue also in the future, just like in

comparable industries such as semiconductors and TV screens. Adding the important feature of integrated PV solutions in particular in building architecture, the potential of further growth is simply enormous.

This edition of the Solar Generation report combines different growth scenarios for global PV development and electricity demand until 2050. It is built on the results of several reference market studies in order to accurately forecast PV growth in the coming decades. In addition, the economic and social benefits of PV, such as employment and CO₂

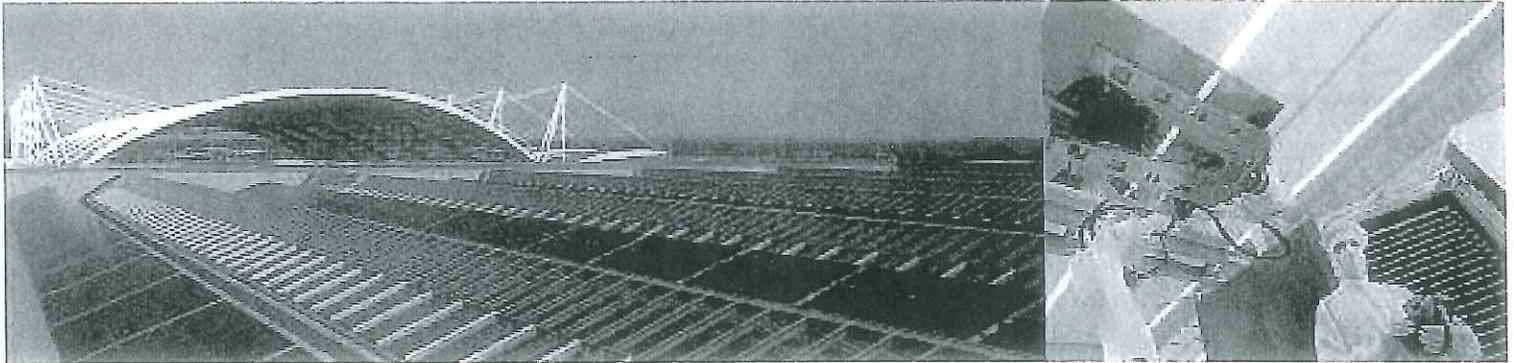
emissions reduction, are also worked out. With PV becoming a cost competitive solution for producing power, it will open up an increasing variety of new markets and contribute more and more significantly to cover our future energy needs.

PV technology has all the potential to satisfy a double digit percentage of the electricity supply needs in all major regions of the world. Going forward, a share of over 20% of the world electricity demand in 2050 appears feasible, and opens a bright, clean and sunny future to all of us.

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EXECUTIVE SUMMARY

“Solar can and must be a part of the solution to climate change, helping us shift away from fossil fuel dependence.”

Status of solar power today

At the end of 2009 the world was running 23 GW of photovoltaic (PV) electricity, the equivalent of 15 coal-fired power plants. At the end of 2010, this number should reach more than 35 GW. We have known for decades that just a portion of the energy hitting the Earth's surface from the Sun every day could power all our cities several times over.

Solar can and must be a part of the solution to combat climate change, helping us shift towards a green economy. It is also a potentially prosperous industry sector in its own right. Some industry indicators show just how far photovoltaic energy has already come.

- The cost to produce solar power has dropped by around 22% each time world-wide production capacity has doubled reaching an average generation cost of 15c€/KWh in EU.
- Average efficiencies of solar modules have improved a couple percentage points per year. The most efficient crystalline silicon modules, go to 19.5% in 2010 with a target of 23% efficiency by 2020, which will lower prices further. That increase in efficiencies is seen in all PV technologies.
- Solar power booms in countries where the boundary conditions are right.
- Over 1,000 companies are involved in the manufacturing of the established crystalline silicon technology and already more than 30 produce Thin Film technologies.

- The energy pay time back the electricity it took to create them in one to three years. The most cutting-edge technologies have reduced this to six months depending on the geographies and solar irradiation, while the average life of modules is more than 25 years.

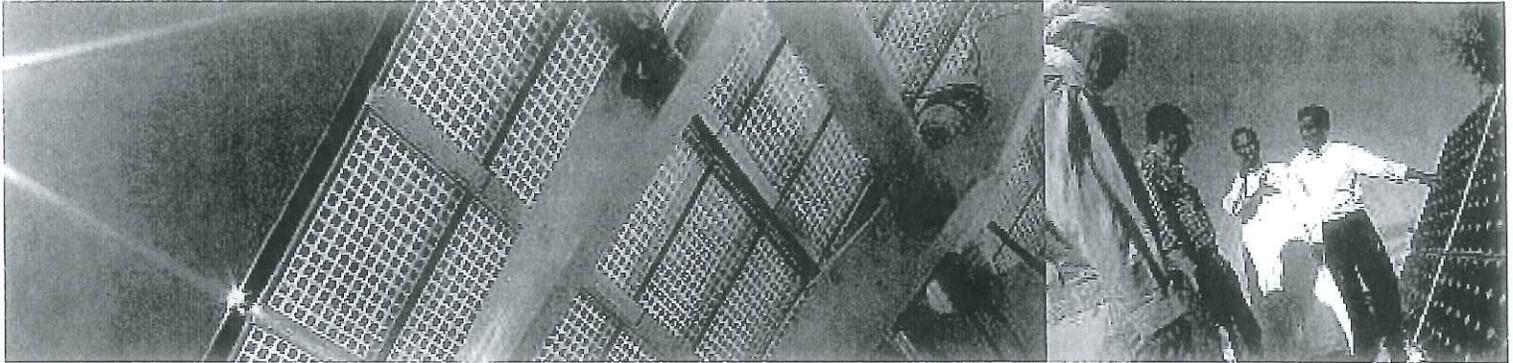
Imagining a future with a fair share of Sun

The European Photovoltaic Industry Association (EPIA) and Greenpeace commissioned updated modelling into how much solar power the world could reasonably see in the world by 2030. The model shows that with a Paradigm Shift scenario towards solar power, where real technical and commercial capacity is backed-up by strong political will, photovoltaics could provide:

- 688 GW by 2020 and 1,845 GW by 2030.
- Up to 12% of electricity demand in European countries by 2020 and in many Sunbelt countries (including China and India) by 2030. Around 9% of the world's electricity needs in 2030.

Under an Accelerated scenario, which follows the expansion pattern of the industry to date and includes moderate political support, photovoltaics could provide:

- 345 GW by 2020 and 1,081 GW by 2030
- Around 4% of the world's electricity needs in 2020.



What are the benefits?

The benefits of a Paradigm Shift towards solar electricity as described in this model include:

- Provide clean and sustainable electricity to the world.
- Regional development, by creation of local jobs. New employment levels in the sector – as many as 1.62 million jobs as early as 2015, rising to 3.62 million in 2020 and 4.64 million in 2030.
- Clean electricity that contributes to international targets to cut emissions and mitigate climate change.
- Avoiding up to 4,047 million tonnes of CO₂ equivalent every year by 2050. The cumulative total of avoided CO₂ emissions from 2020 to 2050 would be 65 billion tonnes.

How can we get there?

A Paradigm Shift for solar is possible. While the PV sector is committed to improve efficiency of products and reduce costs, these aspects are not the major issues either. In fact, solar power is due to reach grid parity in a number of countries, some as early as 2015. Lessons from real examples show there are some key approaches to getting it right in solar power support schemes. These include:

Using Feed-in Tariffs (FIT) that guarantee investment for 15 to 20 years. FIT schemes have been proven to be the most efficient support mechanisms with a long, proven ability to develop the market world-wide.

Assessing PV investment profitability on a regular basis and adapting FIT levels accordingly. A fair level of FIT can help the market take-off and avoid over heated markets.

Assessing profitability through IRR calculations. All aspects of a support scheme including FIT, tax rebates and investment subsidies must be considered when calculating the internal rate of return (IRR) of a PV investment.

Controlling the market with the upgraded “corridor” concept. The corridor is a market control mechanism that allows to adjust FIT levels to accelerate or slow the PV market in a country. The FIT level can be increased or decreased regularly in relation to how much PV is in the market against predefined thresholds at regular intervals (for example, annually).

Refining FIT policies for additional benefits. The way a scheme is designed can encourage specific aspects of PV power. For example; systems that are integrated into buildings and substitute building components.

Drawing a national roadmap to grid parity. Financial incentives can be progressively phased-out as installed PV system costs are decreased and conventional electricity prices are increasing.

“The solar PV market has outpaced ‘Solar Generation’ predictions by nine years.”

Learning from the pioneers

Some nations have taken a lead with support schemes that encourage market creation and industry growth.

Germany: The first country to introduce a FIT, has shown the rest of the world how countries can achieve environmental and industrial development at the same time.

Japan: More than 2.6 GW of solar power were installed in 2009, almost 99% of which were grid-connected thanks to incentives administered by the Ministry of Economy, Trade and Industry.

Italy: Uses a FIT with higher rates for building integrated systems (guaranteed for 20 years) accompanied with net metering to encourage solar power.

USA: Allows a tax credit of 30% for commercial and residential PV systems that can be used by utilities. Several States offer very attractive schemes and incentives.

China: The world's largest PV manufacturer with unlocked its PV market potential. The country is discussing FIT to meet a goal of 20 GW of solar power installed by 2020, 5 GW of this by 2015 which is of course negligible considering its huge potential.

Reference for the future

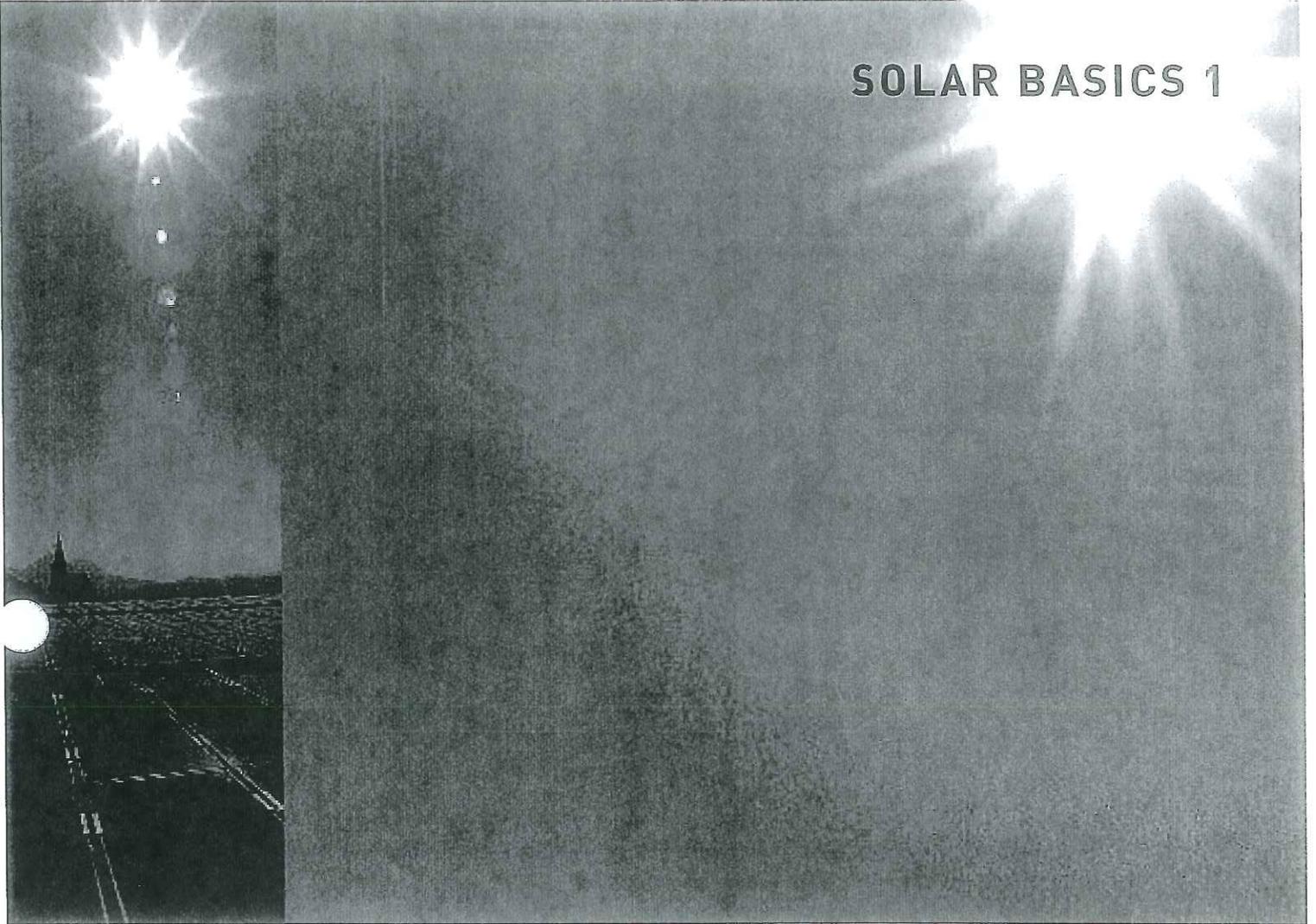
This publication is the sixth edition of the reference global solar scenarios that have been established by the European Photovoltaic Industry Association and Greenpeace jointly for almost ten years. They provide well documented scenarios establishing the PV deployment potential World-wide by 2050.

The first edition of Solar Generation was published in 2001. Since then, each year, the actual global PV market has grown faster than the industry and Greenpeace had predicted (see table 1).

TABLE 1
ANNUAL PV INSTALLED CAPACITY
MW

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Market Result MW	334	439	594	1,052	1,320	1,467	2,392	6,090	7,203	
SG I 2001	331	408	518	659	838	1,060	1,340	1,700	2,150	2,810
SG II 2004					985	1,283	1,675	2,190	2,877	3,634
SG III 2006						1,883	2,540	3,420	4,630	5,550
SG IV 2007							2,179	3,129	4,339	5,650
SG V 2008								4,175	5,160	6,950
SG VI 2011										13,625

SOLAR BASICS 1



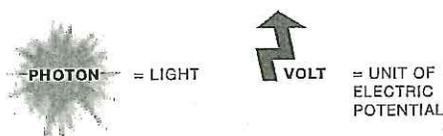
1 SOLAR BASICS

1.1. What does photovoltaic mean?

Photovoltaic systems contain cells that convert sunlight into electricity. Inside each cell there are layers of a semi-conducting material. Light falling on the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates.

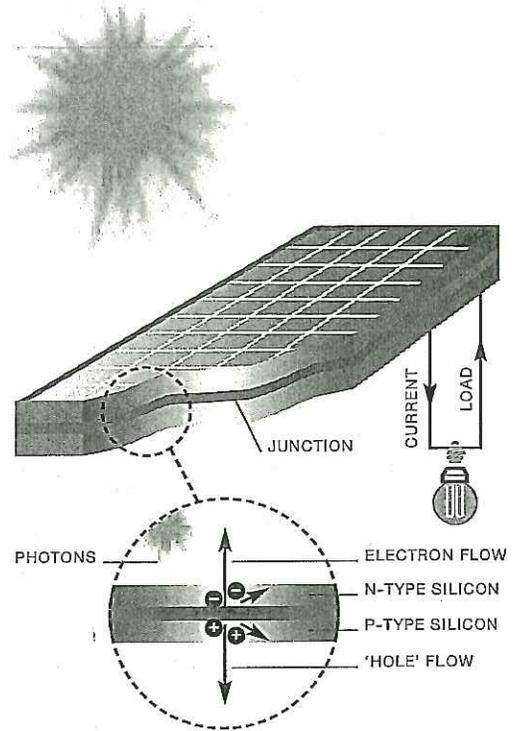
“PV technology exploits a virtually limitless source of free power from the sun.”

FIGURE 1
THE MEANING OF THE WORD “PHOTOVOLTAIC”



source: EPIA.

FIGURE 2
EXAMPLE OF THE PHOTOVOLTAIC EFFECT



source: EPIA.

A photovoltaic system does not need bright sunlight in order to operate. It can also generate electricity on cloudy and rainy days from reflected sunlight.

1.2. Benefits of PV technology

PV technology exploits the most abundant source of free power from the Sun and has the potential to meet almost all of mankind's energy needs. Unlike other sources of energy, PV has a negligible environmental footprint, can be deployed almost anywhere and utilises existing technologies and manufacturing processes, making it cheap and efficient to implement.

a. Environmental footprint of PV

The energy it takes to make a solar power system is usually recouped by the energy costs saved over one to three years. Some new generation technologies can even recover the cost of the energy used to produce them within six months, depending on their location. PV systems have a typical life of at least 25 years, ensuring that each panel generates many times more energy than it costs to produce.

b. Improving grid efficiency

PV systems can be placed at the centre of an energy generation network or used in a decentralised way. Small PV generators can be spread throughout the network, connecting directly into the grid. In areas that are too remote or expensive to connect to the grid, PV systems can be connected to batteries.

c. Making cities greener

With a total ground floor area over 22,000 km², 40% of all building roofs and 15% of all facades in EU 27 are suited for PV applications. This means that over 1,500 GWp of PV could technically be installed in Europe which would generate annually about 1,400TWh, representing 40% of the total electricity demand by 2020. PV can seamlessly integrate into the densest urban environments. City buildings running lights, air-conditioning and equipment are responsible for large amounts of greenhouse gas emissions, if the power supply is not renewable. Solar power will have to become an integral and fundamental part of tomorrow's positive energy buildings.

d. No limits

There are no substantial limits to the massive deployment of PV. Material and industrial capability are plentiful and the industry has demonstrated an ability to increase production very quickly to meet growing demands. This has been demonstrated in countries such as Germany and Japan which have implemented proactive PV policies.

Greenpeace has supported solar power as a clean way to produce power for 20 years. This is mainly because it avoids the harmful impact on the environment caused by carbon dioxide. Carbon

dioxide is emitted during the burning of oil, coal and gas to generate electricity. The European Photovoltaic Industry Association has been actively working for the past 25 years to promote a self-sustaining PV industry.

1.3. Types of PV systems

PV systems can provide clean power for small or large applications. They are already installed and generating energy around the world on individual homes, housing developments, offices and public buildings.

Today, fully functioning solar PV installations operate in both built environments and remote areas where it is difficult to connect to the grid or where there is no energy infrastructure. PV installations that operate in isolated locations are known as stand-alone systems. In built areas, PV systems can be mounted on top of roofs (known as Building Adapted PV systems – or BAPV) or can be integrated into the roof or building facade (known as Building Integrated PV systems – or BIPV).

Modern PV systems are not restricted to square and flat panel arrays. They can be curved, flexible and shaped to the building's design. Innovative architects and engineers are constantly finding new ways to integrate PV into their designs, creating buildings that are dynamic, beautiful and provide free, clean energy throughout their life.

“There are no substantial limits to the deployment of PV.”

Why solar ticks all the boxes:

- Free energy direct from the Sun
- No noise, harmful emissions or gases are produced
- Safety and reliability are proven
- Each module lasts around at least 25 years
- Systems can be recycled at the end of their life and the materials re-used
- PV is easy to install and has very low maintenance requirements
- Power can be generated in remote areas that are not connected to the grid
- Solar panels can be incorporated into the architecture of a building
- The energy used to create a PV system can be recouped quickly (between six months and three years) and that timeframe is constantly decreasing as technology improves
- Solar power can create thousands of jobs
- Solar contribute to the security of energy supply in every country.

a. Grid connected systems

When a PV system is connected to the local electricity network, any excess power that is generated can be fed back into the electricity grid. Under a FIT regime, the owner of the PV system is paid according to the law for the power generated by the local electricity provider. This type of PV system is referred to as being 'on-grid'.

Residential and commercial systems

Most solar PV systems are installed on homes and businesses in developed areas. By connecting to the local electricity network, owners can sell their excess power, feeding clean energy back into the grid. When solar energy is not available, electricity can be drawn from the grid.

Solar systems generate direct current (DC) while most household appliances utilise alternating current (AC). An inverter is installed in the system to convert DC to AC.

Industrial and utility-scale power plants

Large industrial PV systems can produce enormous quantities of electricity at a single point respectful of the environment. These types of electricity generation plants can produce from many hundreds of kilowatts (kW) to several megawatts (MW).

The solar panels for industrial systems are usually mounted on frames on the ground. However, they can also be installed on large industrial buildings such as warehouses, airport terminals or railway stations. The system can make double-use of an urban space and put electricity into the grid where energy-intensive consumers are located.



grid-connected BIPV system on the roof and façade of a commercial building.



Large ground-mounted system in Germany.

TABLE 2
TYPICAL TYPE AND SIZE OF APPLICATIONS PER MARKET SEGMENT

Type of application	Market segment			
	Residential < 10 kWp*	Commercial 10kWp - 100kWp	Industrial 100kWp - 1MWp	Utility scale >1MWp
Ground-mounted			✓	✓
Roof-top	✓	✓	✓	
Integrated to facade/roof	✓	✓		

* Wp : Watt-peak, a measure of the nominal power of a photovoltaic solar energy device.

b. Stand-alone, off-grid and hybrid systems

Off-grid PV systems have no connection to an electricity grid. An off-grid system is usually equipped with batteries, so power can still be used at night or after several days of low irradiation. An inverter is needed to convert the DC power generated into AC power for use in appliances.

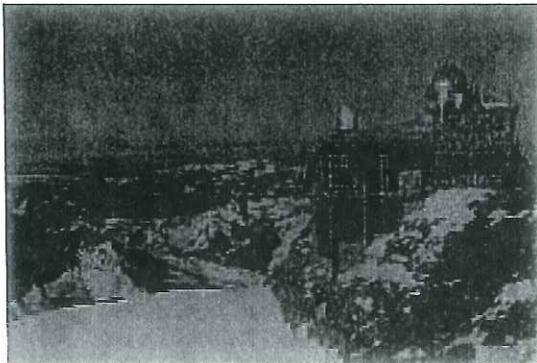
Most standalone PV systems fall into one of three main groups:

- Off-grid industrial applications
- Off-grid systems for the electrification of rural areas
- Consumer goods.

Off-grid industrial applications

Off-grid industrial systems are used in remote areas to power repeater stations for mobile telephones (enabling communications), traffic signals, marine navigational aids, remote lighting, highway signs and water treatment plants among others. Both full PV and hybrid systems are used. Hybrid systems are powered by the Sun when it is available and by other fuel sources during the night and extended cloudy periods.

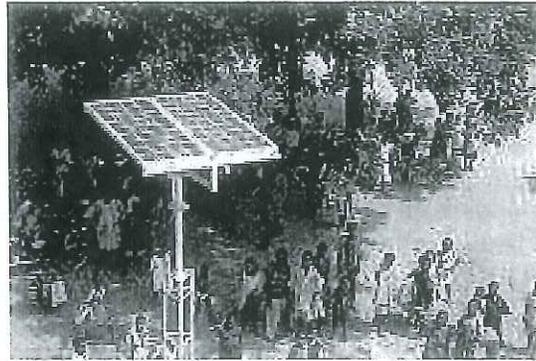
Off-grid industrial systems provide a cost-effective way to bring power to areas that are very remote from existing grids. The high cost of installing cabling makes off-grid solar power an economical choice.



Off-grid industrial application.

Off-grid systems for rural electrification

Typical off-grid installations bring electricity to remote areas or developing countries. They can be small home systems which cover a household's basic electricity needs, or larger solar mini-grids which provide enough power for several homes, a community or small business use.

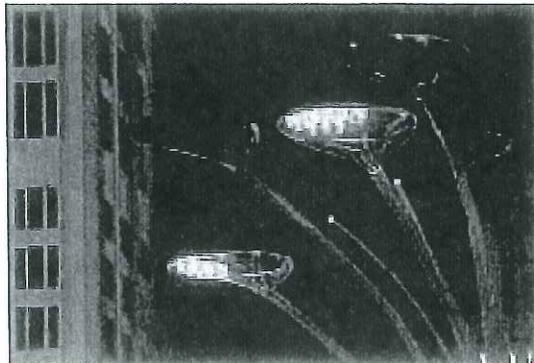


Rural electrification system in an African village.

“Off-grid systems provide a cost-effective way to bring power to remote areas.”

Consumer goods

PV cells are now found in many everyday electrical appliances such as watches, calculators, toys, and battery chargers (as for instance embedded in clothes and bags). Services such as water sprinklers, road signs, lighting and telephone boxes also often rely on individual PV systems.



Public lights in Berlin.

1.4. The Solar potential

There is more than enough solar irradiation available to satisfy the world's energy demands. On average, each square metre of land on Earth is exposed to enough sunlight to generate 1,700 kWh of energy every year using currently available technology. The total solar energy that reaches the Earth's surface could meet existing global energy needs 10,000 times over.

A large amount of statistical data on solar energy availability is collected globally. For example, the US National Solar Radiation database has 30 years of solar irradiation and meteorological data from 237 sites in the USA. The European Joint Research Centre (JRC) also collects and publishes European solar irradiation data from 566 sites¹.

Where there is more Sun, more power can be generated. The sub-tropical areas of the world offer some of the best locations for solar power generation. The average energy received in Europe is about 1,200 kWh/m² per year. This compares with 1,800 to 2,300 kWh/m² per year in the Middle East.

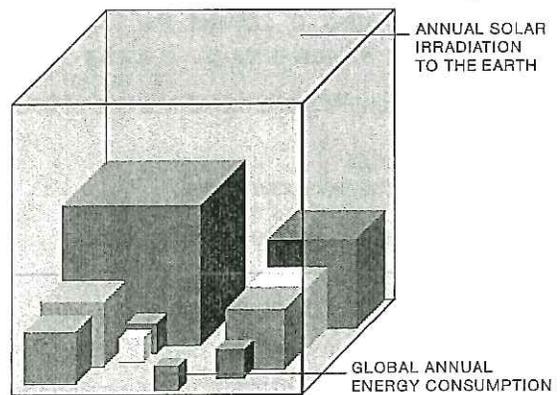
While only a certain part of solar irradiation can be used to generate electricity, this 'efficiency loss' does not actually waste a finite resource, as it does when burning fossil fuels for power. Efficiency losses do, however, impact on the cost of the PV systems. This is explained further in Part 3 of this report.

EPIA has calculated that Europe's entire electricity consumption could be met if just 0.34% of the European land mass was covered with photovoltaic modules (an area equivalent to the Netherlands). International Energy Agency (IEA) calculations show that if 4% of the world's very dry desert areas were used for PV installations, the world's total primary energy demand could be met.

There is already enormous untapped potential. Vast areas such as roofs, building surfaces, fallow land and desert could be used to support solar power generation. For example, 40% of the European Union's total electricity demand in 2020 could be met if all suitable roofs and facades were covered with solar panels².

"The total solar energy that reaches the Earth's surface could meet existing global energy needs 10,000 times over."

FIGURE 3
SOLAR IRRADIATION
VERSUS ESTABLISHED
GLOBAL ENERGY
RESOURCES

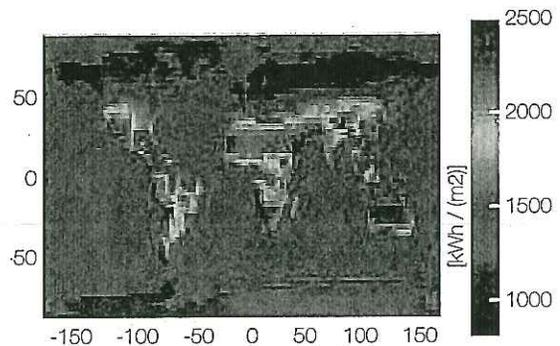


- | | |
|----------------------|------------------------------|
| ■ SOLAR (CONTINENTS) | ■ COAL |
| ■ WIND | ■ GAS |
| ■ BIOMASS | ■ OIL |
| ■ GEOTHERMAL | ■ NUCLEAR |
| ■ OCEAN & WAVE | ■ PRIMARY ENERGY CONSUMPTION |
| ■ HYDRO | |

FOSSIL FUELS ARE EXPRESSED WITH REGARD TO THEIR TOTAL RESERVES WHILE RENEWABLE ENERGIES TO THEIR YEARLY POTENTIAL.

source: DLR, IEA WEO, EPIA's own calculations.

FIGURE 4
SOLAR IRRADIATION
AROUND THE WORLD



source: Gregor Czisch, ISET, Kassel, Germany.

1.5. Example: How PV can meet residential consumption

Electricity produced by a PV installation on a house over a year can generally cover the demands of a typical family. The graph in Figure 5 shows the daily electricity needs for a household of 2-3 people, compared to the electricity generated from a 20 m² PV installation in a sunny region (about 1200 kWh/kWp). Electricity demand is largely met and exceeded during spring and summer. In winter more electricity is used for lighting and heating, and there is a shorter daytime period. In this period the house can draw additional power from the grid.

The model assumes that the PV system uses modules with efficiency of 14%, and that it is installed on a roof at the optimum inclination angle. The Sunrise Project toolbox has been used for calculations.

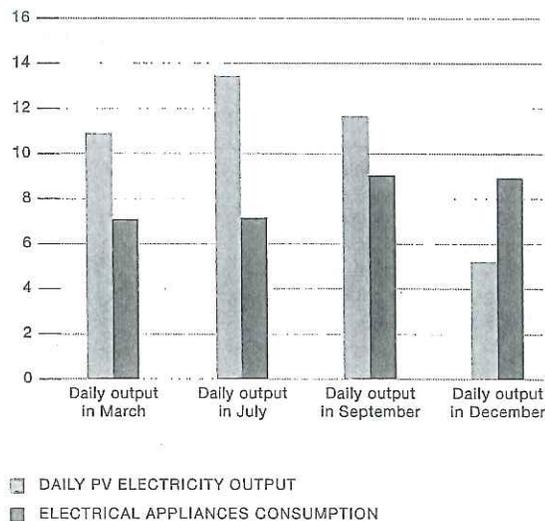
TABLE 3
POTENTIAL FOR SOLAR POWER
IN THE EU-27 IN 2020

European population	497,659,814
Total ground floor area	22,621 km ²
Building-integrated solar potential (roofs and facades)	12,193 km ² or 1,425 TWh/a
Expected electricity demand	3,525 TWh/a
Potential share of electricity demand covered by building-integrated PV	40%

source: Sunrise project/EPIA.

“Electricity demand is largely met and exceeded during spring and summer.”

FIGURE 5
COMPARISON OF THE AVERAGE DAILY ELECTRICITY NEEDS OF A 2-3 PEOPLE HOUSEHOLD WITH THE ELECTRICITY OUTPUT OF A 20M² PV SYSTEM.
kWh/day



source: Sunrise project/EPIA.

“Solar energy must be implemented together with responsible energy consumption and energy efficiency.”

Table 3 shows the electricity demand of typical households in nine different countries. The table also shows the area that would need to be covered in PV modules to cater to this demand. The numbers are averages, so large deviations are possible for individual households. These depend on factors such as the energy efficiency of the dwelling, the number of household appliance, and the level of insulation against heat loss and intrusion.

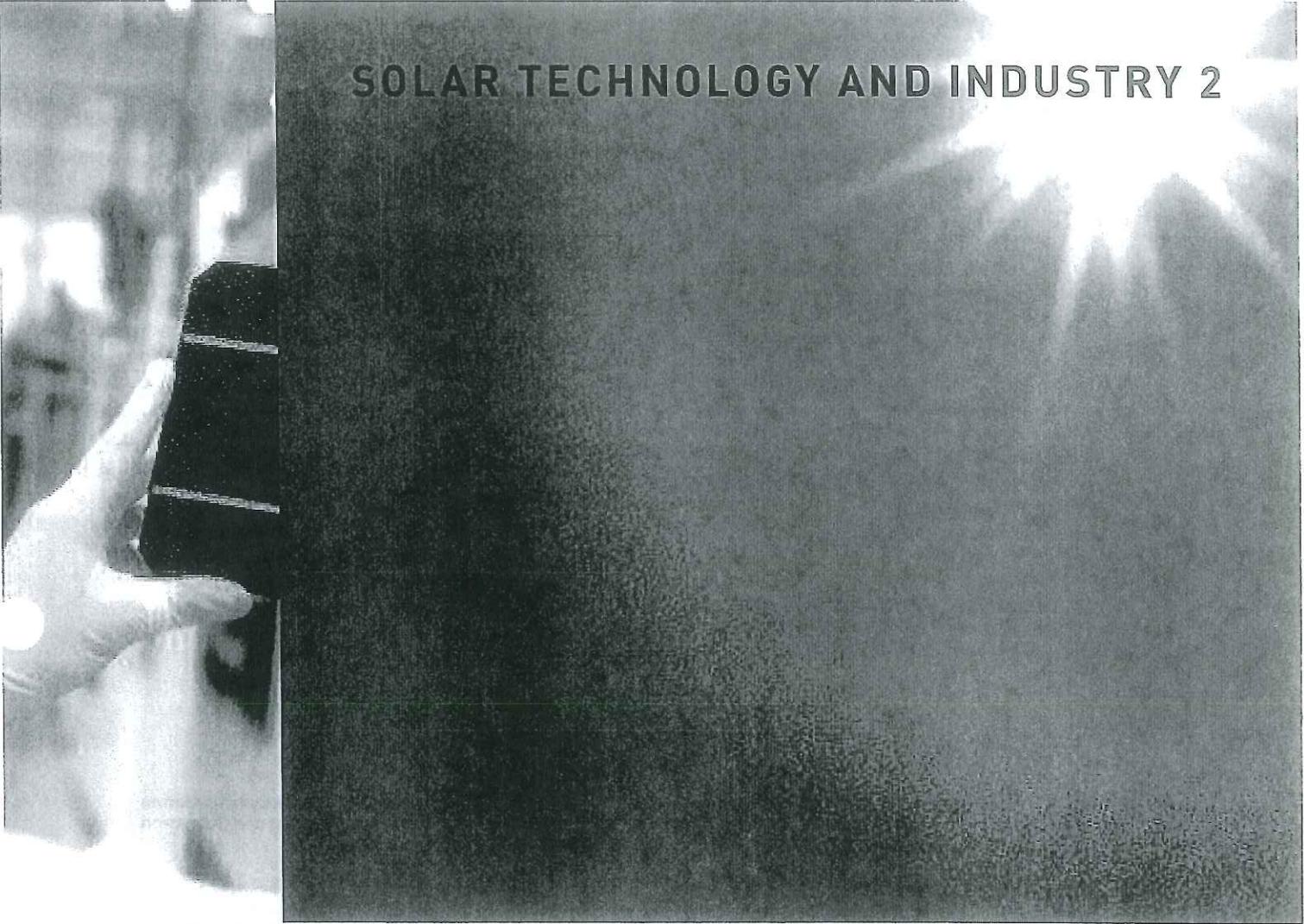
Depending on solar irradiation levels in each city and the electricity consumption pattern of a typical home, the required area for solar power ranges from 14 m² in Rome, to 45 m² in New York. The amount of roof space available for solar power generation varies by country. The average rooftop area needed per household in Tokyo or Seoul is significantly lower than that in Munich.

For solar energy to be truly effective, it must be implemented together with responsible energy consumption and energy efficiency. Measures such as improved insulation and double glazing will significantly improve energy consumption. Better energy efficiency makes it possible to meet electricity demand with sustainable solar power, using significantly lower coverage areas than those shown in Table 4.

**TABLE 4
AVERAGE HOUSEHOLD
CONSUMPTION AND PV COVERAGE
AREA NEEDED TO MEET DEMAND
IN NINE COUNTRIES**

City, Country	Annual Consumption (kWh)	Area of PV modules needed (m²)
Copenhagen, Denmark	4,400	33
Kuala Lumpur, Malaysia	3,700	15
London, UK (2008)	3,300	24
Munich, Germany (2008)	4,000	25
New York, USA	11,000	45
Rome, Italy	2,700	14
Seoul, South-Korea	3,600	16
Sydney, Australia	8,000	30
Tokyo, Japan	3,500	20

source: EPIA, IEA PVPS.

A black and white photograph showing a hand holding a small, dark, rectangular solar cell. The background is a large array of solar panels under a bright sun, with rays of light visible. The text "SOLAR TECHNOLOGY AND INDUSTRY 2" is overlaid on the top right of the image.

SOLAR TECHNOLOGY AND INDUSTRY 2

2 SOLAR TECHNOLOGY AND INDUSTRY

2.1. PV systems

The key parts of a solar energy generation system are:

- Photovoltaic modules to collect sunlight
- An inverter to transform direct current (DC) to alternate current (AC)
- A set of batteries for stand-alone PV systems
- Support structures to orient the PV modules toward the Sun.

The system components, excluding the PV modules, are referred to as the balance of system (BOS) components.

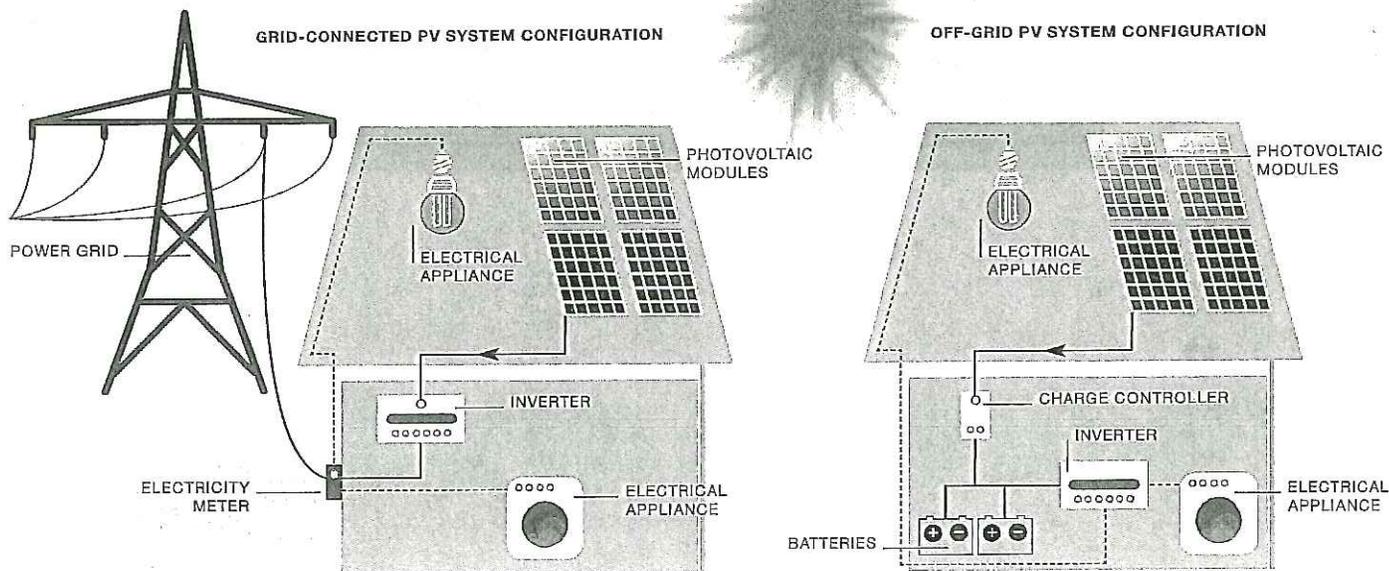
a. PV cells and modules

The solar cell is the basic unit of a PV system. PV cells are generally made either from:

- crystalline silicon, sliced from ingots or castings,
- from grown ribbons or
- from alternative semiconductor materials deposited in thin layers on a low-cost backing (Thin Film).

Cells are connected together to form larger units called modules. Thin sheets of EVA* or PVB** are used to bind cells together and to provide weather protection. The modules are normally enclosed between a transparent cover (usually glass) and a weatherproof backing sheet (typically made from a thin polymer). Modules can be framed for extra mechanical strength and durability. Thin Film modules are usually encapsulated between two sheets of glass, so a frame is not needed.

FIGURE 6
DIFFERENT CONFIGURATIONS
OF SOLAR POWER SYSTEMS



source: EPIA.

* Ethyl Vinyl Acetate.
** Polyvinyl Butyral.

Modules can be connected to each other in series (known as an array) to increase the total voltage produced by the system. The arrays are connected in parallel to increase the system current.

The power generated by PV modules varies from a few watts (typically 20 to 60 Wp) up to 300 to 350 Wp depending on module size and the technology used. Low wattage modules are typically used for stand-alone applications where power demand is generally low.

Standard crystalline silicon modules contain about 60 to 72 solar cells and have a nominal power ranging from 120 to 300 Wp depending on size and efficiency. Standard Thin Film modules have lower nominal power (60 to 120 Wp) and their size is generally smaller. Modules can be sized according to the site where they will be placed and installed quickly. They are robust, reliable and weatherproof. Module producers usually guarantee a power output of 80% of the Wp, even after 20 to 25 years of use. Module lifetime is typically considered of 25 years, although it can easily reach over 30 years.

b. Inverters

Inverters convert the DC power generated by a PV module to AC power. This makes the system compatible with the electricity distribution network and most common electrical appliances. An inverter is essential for grid-connected PV systems. Inverters are offered in a wide range of power classes ranging from a few hundred watts (normally for stand-alone systems), to several kW (the most frequently used range) and even up to 2,000 kW central inverters for large-scale systems.

c. Batteries and charge controllers

Stand-alone PV systems require a battery to store energy for future use. Lead acid batteries are typically used. New high-quality batteries, designed specifically for solar applications and with a life of up to 15 years, are now available. The actual lifetime of a battery depends on how it is managed.

Batteries are connected to the PV array via a charge controller. The charge controller protects the battery from overcharging or discharging. It can also provide information about the state of the system or enable metering and payment for the electricity used.



Antireflection coating based on nitride to optimize light penetration into solar cell.



PV modules integrated into flat roof.

2.2. Photovoltaic technologies

PV technologies are classified as first, second or third generation. First generation technology is the basic crystalline silicon (c-Si). Second generation includes Thin Film technologies, while third generation includes concentrator photovoltaics, organics, and other technologies that have not yet been commercialised at large scale.

a. Crystalline silicon technology

Crystalline silicon cells are made from thin slices (wafers) cut from a single crystal or a block of silicon.

The type of crystalline cell produced depends on how the wafers are made. The main types of crystalline cells are:

- Mono crystalline (mc-Si):
- Polycrystalline or multi crystalline (pc-Si)
- Ribbon and sheet-defined film growth (ribbon/sheet c-Si).

The single crystal method provides higher efficiency, and therefore higher power generation. Crystalline silicon is the most common and mature technology representing about 80% of the market today. Cells turn between 14 and 22% of the sunlight that reaches them into electricity. For c-Si modules, efficiency ranges between 12 and 19% (see Table 7).

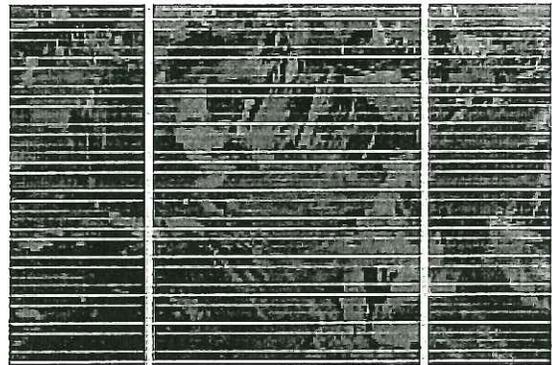
Individual solar cells range from 1 to 15 cm across (0.4 to 6 inches). However, the most common cells are 12.7 x 12.7 cm (5 x 5 inches) or 15 x 15 cm (6 x 6 inches) and produce 3 to 4.5 W – a very small amount of power. A standard c-Si module is made up of about 60 to 72 solar cells and has a nominal power ranging from 120 to 300 Wp depending on size and efficiency.

The typical module size is 1.4 to 1.7 m² although larger modules are also manufactured (up to 2.5 m²). These are typically utilised for BIPV applications.

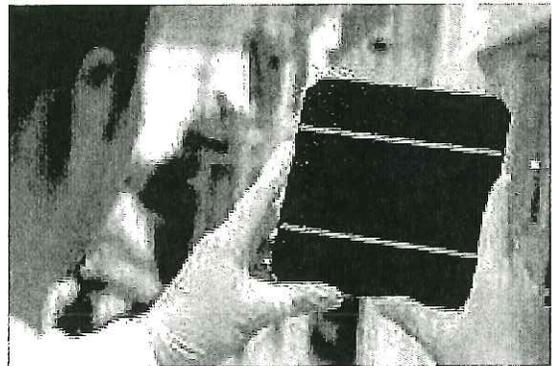
Manufacturing process

The manufacturing process of c-Si modules takes five steps (see Figure 8).

FIGURE 7
CRYSTALLINE SILICON CELLS



Polycrystalline silicon
PV cell.



Monocrystalline
solar cell.

FIGURE 8
CRYSTALLINE SILICON
MANUFACTURING PROCESS



The steps, in detail are:

1. *Convert the metallurgical silicon into high purity polysilicon (known as solar grade silicon).*

Silicon is the second most abundant element in the Earth's crust after oxygen. It is found in quartz or sand. Metallurgical silicon is 98 to 99% pure. The polysilicon required for solar cells can be up to 99.999999% pure. The most common process for converting raw silicon into solar grade silicon is the Siemens process.

2. *Form the ingots.*

The polysilicon is melted in large quartz crucibles, and then cooled to form a long solid block called an ingot. The type of wafer that will be cut from the ingot depends on the process used to form the ingot. Monocrystalline wafers have a regular, perfectly-ordered crystal structure, while multicrystalline wafers have an unstructured group of crystals. The level of structure affects how electrons move over the surface of the cell.

3. *Slice the ingot or block into wafers.*

A wire saw is used to slice the wafer from the ingot or block. The saw is about the same thickness as the wafer. This method of slicing produces significant wastage – up to 40% of the silicon (known as kerf loss). Using a laser cutter reduces kerf loss; however, this can only be done on ingots formed by string ribbon or sheet/edge-defined film growth.

4. *Transform the wafer into a solar cell.*

The cell is the unit that produces the electricity. It is created using four main steps:

- a. *Surface treatment:* The wafer's top layer is removed to make it perfectly flat.

- b. *Creation of the potential difference (p-n) junction:* A potential difference between two points gives rise to an electromotive force that pushes electrons from one point to the other. A solar wafer needs to have a p-n between the surface and the bottom of the cell. This step takes place in a diffusion oven.

- c. *Deposition of an anti-reflective coating:* The coating enables the cell to absorb the maximum amount of light. It also gives cells their typical blue colour.

- d. *Metallisation:* Metal contacts (usually silver) are added to the cell so the electrons can be transported to the external circuit. A thin metal grid, known as a finger, is attached to the front surface of the cell. Wider metal strips, known as busbars, are connected to the front and back surfaces of the cell.

The fingers collect the current generated by the cell, while the busbars connect the fingers and provide external connection points to other cells. The entire back surface of the cell is coated with aluminium to create a reflective inner surface.

5. *Connect and coat the cells to form a module.*

The cells are effectively sandwiched between layers of coating material to protect them from the environment and breakage. Transparent glass is used for the front, while a weatherproof backing (typically a thin polymer) is applied to the back of the module. The cover is attached using thin sheets of EVA or PVB. Frames can be placed around the modules to increase their strength. For some specific applications, such as integration into a building, the back of the module is also made of glass to allow light through.

“Silicon is the second most abundant element in the earth’s crust after oxygen.”

Alternative cell manufacturing technologies

Advances and alternatives in cell manufacturing methods are producing cells with higher levels of efficiency. Some of the most promising emerging technologies include:

- *Buried contacts:*

Instead of placing the fingers and busbars on the front of the cell, they are buried in a laser-cut groove inside the solar cell. The change makes the cell surface area larger, enabling it to absorb more sunlight.

- *Back contact cells:*

The front contact of the cell is moved to the back. The cell's surface area is increased and shadowing losses are reduced. This technology currently provides the highest commercial cell-efficiency available on the market.

- *Pluto™:*

Developed by Suntech, Pluto™ features a unique texturing process that improves sunlight absorption, even in low and indirect light.

- *HIT™ (Heterojunction with Intrinsic Thin Layer):*

Developed by Sanyo Electronics, the HIT™ cell consists of a thin, single-crystal wafer sandwiched between ultra-thin amorphous silicon (a-Si) layers. Using both amorphous and single crystal silicon improves efficiency.

TABLE 5
COMMERCIALISED CELL
EFFICIENCY RECORDS

Technology	Commercialised cell efficiency record
Mono (back contact)	22%
HIT™	19.8%
Mono (Pluto™)	19%
Nanoparticle ink	18.9%
Mono	18.5%

source: Greentech Media, July 2010.

b. Thin Films

Thin Film modules are constructed by depositing extremely thin layers of photosensitive material on to a low-cost backing such as glass, stainless steel or plastic. Once the deposited material is attached to the backing, it is laser-cut into multiple thin cells.

Thin Film modules are normally enclosed between two layers of glass and are frameless. If the photosensitive material has been deposited on a thin plastic film, the module is flexible. This creates opportunities to integrate solar power generation into the fabric of a building or end-consumer applications.

Four types of Thin Film modules are commercially available:

1. *Amorphous silicon (a-Si)*

The semiconductor layer is only about 1 µm thick. Amorphous silicon can absorb more sunlight than c-Si structures. However, a lower flow of electrons is generated which leads to efficiencies that are currently in the range of 4 to 8%. With this technology the absorption material can be deposited onto very large substrates (up to 5.7 m² on glass), reducing manufacturing costs. An increasing number of companies are developing light, flexible a-Si modules perfectly suitable for flat and curved industrial roofs.

2. *Multi-junction thin silicon film (a-Si/µc-Si)*

This consists of an a-Si cell with additional layers of a-Si and micro-crystalline silicon (µc-Si) applied onto the substrate. The µc-Si layer absorbs more light from the red and near-infrared part of the light spectrum. This increases efficiency by up to 10%. The thickness of the µc-Si layer is in the order of 3 µm, making the cells thicker but also more stable. The current maximum substrate size for this technology is 1.4 m² which avoids instability.

3. *Cadmium telluride (CdTe)*

CdTe Thin Films cost less to manufacture and have a module efficiency of up to 11%. This makes it the most economical Thin Film technology currently available.

The two main raw materials are cadmium and tellurium. Cadmium is a by-product of zinc mining. Tellurium is a by-product of copper processing. It is produced in far lower quantities than cadmium. Availability in the long-term may depend on whether the copper industry can optimise extraction, refining and recycling yields.

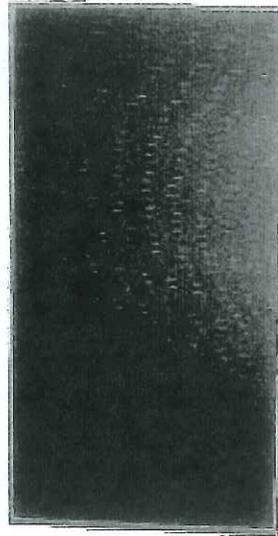
4. *Copper, indium, gallium, (di)selenide/(di)sulphide (CIGS) and copper, indium, (di)selenide/(di)sulphide (CIS)*

CIGS and CIS offer the highest efficiencies of all Thin Film technologies. Efficiencies of 20% have been achieved in the laboratory, close to the levels achieved with c-Si cells. The manufacturing process is more complex and less standardised than for other types of cells. This tends to increase manufacturing costs. Current module efficiencies are in the range of 7 to 12%.

There are no long-term availability issues for selenium and gallium, Indium is available in limited quantities but there are no signs of an incoming shortage. While there is a lot of indium in tin and tungsten ores, extracting it could drive the prices higher. A number of industries compete for the indium resources: the liquid crystal display (LCD) industry currently accounts for 85% of demand. It is highly likely that indium prices will remain high in the coming years.

Typical module power ranges from 60 to 350 W depending on the substrate size and efficiency. There is no common industry agreement on optimal module size for Thin-Film technologies. As a result they vary from 0.6 to 1.0 m² for CIGS and CdTe, to 1.4 to 5.7 m² for silicon-based Thin Films. Very large modules are of great interest to the building sector as they offer efficiencies in terms of handling and price.

FIGURE 9
THIN FILM MODULE



Thin Film CdTe Module.

TABLE 6
SUMMARY OF RECORD
EFFICIENCIES OF THIN
FILM TECHNOLOGIES

Thin Film technology	Record commercial module efficiency	Record Lab efficiency
a-Si	7.1%	10.4%
a-Si/ μ -Si	10%	13.2%
CdTe	11.2%	16.5%
CIGS/CIS	12.1%	20.3%

source: A. Green et al., 2010³, Lux Research Inc., EPIA research

FIGURE 10
STEPS IN MAKING THIN
FILM SOLAR CELLS



Thin Film manufacturing processes

Thin Films are manufactured in five common steps:

1. *A large sheet of substrate is produced.* Typically this is made of glass although other materials such as flexible steel, plastic or aluminium are also utilised.
2. *The substrate is coated with a transparent conducting layer (TCO).*
3. *Semiconductor material (absorber) is deposited onto the substrate or superstrate.* This layer can be deposited using many different techniques. Chemical and physical vapour depositions are the most common. For some technologies (usually CIGS, CIS and CdTe), a cadmium sulphide (CdS) layer is also applied to the substrate to increase light absorption.
4. *The metallic contact strips on the back are applied using laser scribing or traditional screen-printing techniques.* The back contact strips enable the modules to be connected.
5. *The entire module is enclosed in a glass-polymer casing.*

For flexible substrates, the manufacturing process uses the roll-to-roll (R2R) technique. R2R enables manufacturers to create solar cells on a roll of flexible plastic or metal foil. Using R2R has the potential to reduce production time, and both manufacturing and transport costs. R2R can be used at much lower temperatures in smaller, non-sterile production facilities.

c. Concentrator photovoltaics

Concentrator photovoltaics (CPV) utilise lenses to focus sunlight on to solar cells. The cells are made from very small amounts of highly efficient, but expensive, semi-conducting PV material. The aim

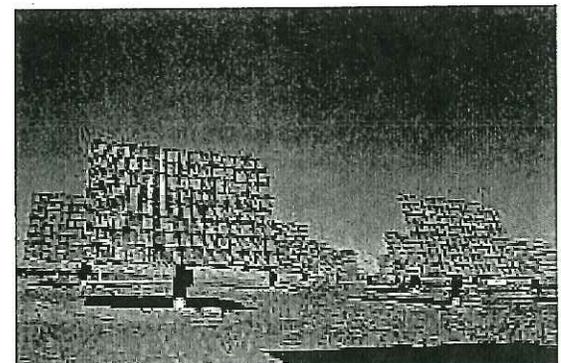
is to collect as much sunlight as possible. CPV cells can be based on silicon or III-V compounds (generally gallium arsenide or GaAs).

CPV systems use only direct irradiation.* They are most efficient in very sunny areas which have high amounts of direct irradiation.

The concentrating intensity ranges from a factor of 2 to 100 suns (low concentration) up to 1000 suns (high concentration). Commercial module efficiencies of 20 to 25% have been obtained for silicon based cells. Efficiencies of 25 to 30% have been achieved with GaAs, although cell efficiencies well above 40% have been achieved in the laboratory.

The modules have precise and accurate sets of lenses which need to be permanently oriented towards the Sun. This is achieved through the use of a double-axis tracking system. Low concentration PV can be also used with one single-axis tracking system and a less complex set of lenses.

FIGURE 11
CONCENTRATOR PV
MODULES



Concentrator Photovoltaics installed on trackers to follow the sun.

* Sunlight consists of both direct and diffuse irradiation. Diffuse irradiation occurs because of the reflection and refraction of sunlight when it comes into contact with the Earth's atmosphere, clouds and the ground.