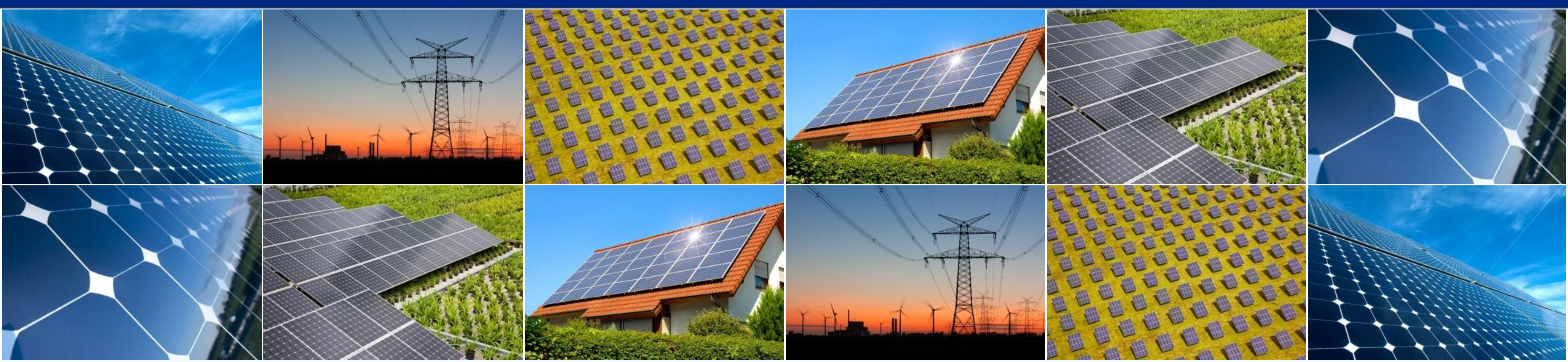
LEADING THE ENERGY TRANSITION

FACTBOOK

Solar Photovoltaic

SBC Energy Institute

September 2013



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Compiled by the SBC Energy Institute

About SBC Energy Institute

The SBC Energy Institute, a non-profit organization founded in 2011 at the initiative of Schlumberger Business Consulting (SBC), is a center of excellence for scientific and technological research into issues pertaining to the energy industry in the 21st century. Through its unique capability to leverage both Schlumberger's technological expertise and SBC's global network of energy leaders, the SBC Energy Institute is at the forefront of the search for solutions to today's energy supply challenges. It is overseen by a scientific committee comprised of highly experienced individuals in the areas of natural and applied sciences, business, and petroleum engineering.

About *Leading the Energy Transition* series

"Leading the energy transition" is a series of publicly available studies on low-carbon energy technologies conducted by the SBC Energy Institute that aim at providing a comprehensive overview of their development status through a technological and scientific prism.

About the Solar Photovoltaic Power factbook

This factbook seeks to capture the current status and future developments of Solar PV power, detail the main technological hurdles and the areas for Research and Development, and finally analyze the economics of this technology.

This factbook has been reviewed by Prof. Bernard Drévillon, Director of the Laboratory of Physics of Interfaces and Thin Films at the Ecole Polytechnique (France).

For further information about SBC Energy Institute and to download the report, please visit **http://www.sbc.slb.com/sbcinstitute.aspx**, or contact us at **sbcenergyinstitute@slb.com**

Solar photovoltaic (PV) generates electricity by exploiting the photovoltaic effect

Solar energy is one of the most abundant resources in the world. Solar rays can be categorized in terms of the wavelengths that determine visible light, infrared and ultraviolet. The energy available from sunlight is measured in kilowatt per square meter. This source of energy is good to excellent between 45° South and 45° North.

Solar PV is one of the four main solar-energy technologies, the others being concentrating solar power (CSP), solar thermal and solar fuels. Electricity is generated via direct conversion of sunlight to electricity by PV cells. Light shines onto a semiconductor (*e.g.* silicon), thereby generating electron-hole pairs separated spatially by an internal electric field that induces a voltage and direct current when connected to a load. PV cells are interconnected to form PV modules with a power capacity of up to several hundred watts. PV modules are then combined with a set of additional components (*e.g.* inverter, support rack, switch…), known as balance of system, to form PV systems.

There are several types of PV technology, differentiated by the type of material used in the cell's absorber. At present, crystalline silicon semiconductors are the most common commercial type of PV cell (with a market share of 85-90%), although thin-film cells (10-15% market share) are beginning to challenge their dominance. Aside from concentrated PV (CPV) cells, silicon semiconductors benefit from a higher efficiency (14-20%) and have a longer lifespan than other technologies, but lower-efficiency (4-17%) thin-film technology is cheaper. Emerging non-silicon organic technology has the advantage of not requiring rare materials, which brings down costs dramatically, at the expense of efficiency (5%+). Concentrated PV (CPV), which uses mirrors or lenses to concentrate and focus solar radiation on high-efficiency cells, is an alternative to concentrating solar power (CSP), but requires better solar irradiance and is, at present, far less common.

As the technology is highly modular, PV is well suited to distributed generation, either off-grid or grid-connected. The PV market is thus often viewed in terms of its four end-uses: residential on individual buildings; commercial/industrial; utility scale requiring 1 MW or more; and off-grid supply for remote communities or telecommunication facilities.

Solar PV was the fastest-growing renewable technology in the last decade

Solar PV development, which began in the 1970s, has taken place in relatively few countries and has mainly been deployed by small distributed installations in Europe. Capacity has grown at an average rate of 51% over the last seven years, reaching more than 96 GW at the end of 2012.

PV capacity is expected more than to double to 230 GW by 2017, with China taking over as market leader ahead of Germany and the US. At the same time, PV generation is likely to grow even faster, as a result of development in sunnier countries, which will increase the average load factor from 12% at present to almost 14% by 2017. Most PV projects are still based on Crystalline Silicon, despite the emergence of thin-film and organic technologies.

In the long run, the IEA estimates that PV would need to meet 6-12% of global electricity demand by 2050 in order to contribute to an energy system likely to limit the average global temperature increase to 2°C. In order to meet 6% of electricity demand, addition capacity of at least 2,000 GW would be required, with significant deployment outside the OECD and China.

Research, Development & Demonstration (R,D&D) is focused on improving efficiency and minimizing the cost of materials used to produce cells

R,D&D is focused on reducing costs, either by improving efficiency or by cutting the cost of components. High-risk but potentially high-reward technologies may yet emerge. It is also essential to improve the lifetime of balance-of-system and to develop more accurate systems for controlling and forecasting solar PV output. Finally, concentrated PV is currently moving from the pilot-plant stage to large-scale demonstration projects.

As a result, solar can rely on significant and increasing Research & Development (R&D) investments. Private investments in solar R&D have been maintained through the economic crisis at above $2 billion a year, which is substantially higher than any other renewables (wind ranks second with only $600 million). Public funding for PV R&D has more than doubled since 2008, and now accounts for 36% of all public funding for renewable energy R&D in the OECD.

PV has experienced significant cost reductions as a result of decreasing module prices

PV is a capital-driven technology. Annual operating and maintenance costs account for 0.8-1.6% of the initial investment. Modules are an important element, as they represent up to half of the overall investment. On average, module prices have fallen by 22% for each doubling of cumulative sales. The decline has accelerated since 2009 because of production overcapacity.

Depending on the cell-technology used, the manufacturer and the market conditions, PV investment ranges from $1.5 to $3.5/W for large-scale ground-mounted systems and from $2.4 to $6/W for small-scale rooftop systems. Module retail prices as low as $1.1/kW for multi-crystalline and $0.84/kW for thin films have been observed in China in 2012. Going forward, the costs of all PV system components are expected to continue to decrease, albeit at different rates, modifying the industry's overall cost structure. However, this trend may be disrupted by a scarcity of materials, especially in the case of thin films, which use rare metals such as indium and tellurium.

Depending on solar irradiance and application size, solar PV electricity prices range from $140 to $600 per MWh, making solar PV more expensive than most other renewables. Deployment in sunnier countries and further cost reductions are thus essential to make solar PV competitive. In addition, grid-integration costs have not been included in these cost estimates. However, distributed generation that defers or avoids network investment may partially offset intermittency-balancing costs in developing countries.

China changed market dynamics in 2010 by granting large loans to its PV manufacturers. As a result, Chinese manufacturers have become the main module suppliers and are likely to increase their market share because of overcapacity.

Solar PV is not facing significant environmental and social challenges despite concerns over rare materials

Since solar PV systems require relatively little land and almost no water, and no greenhouse gas (GHG) or other pollutants are emitted during the producing life of PV plants, they are considered environmentally benign and are usually accepted by the public.

However, a solar PV system does generate emissions over its lifetime. Median emissions range between 24 and 65 gram of CO_2 equivalent per kWh (gCO_2eq/kWh), but can reach 200 gCO_2eq/kWh. The level depends mainly on the material used in the cells, the manufacturing process, the power mix and recycling measures.

Recycling is crucial in ensuring the PV industry is sustainable, since it generates large amount of electronic waste. It is predicted that 80% to 96% of rare materials could be recycled. .

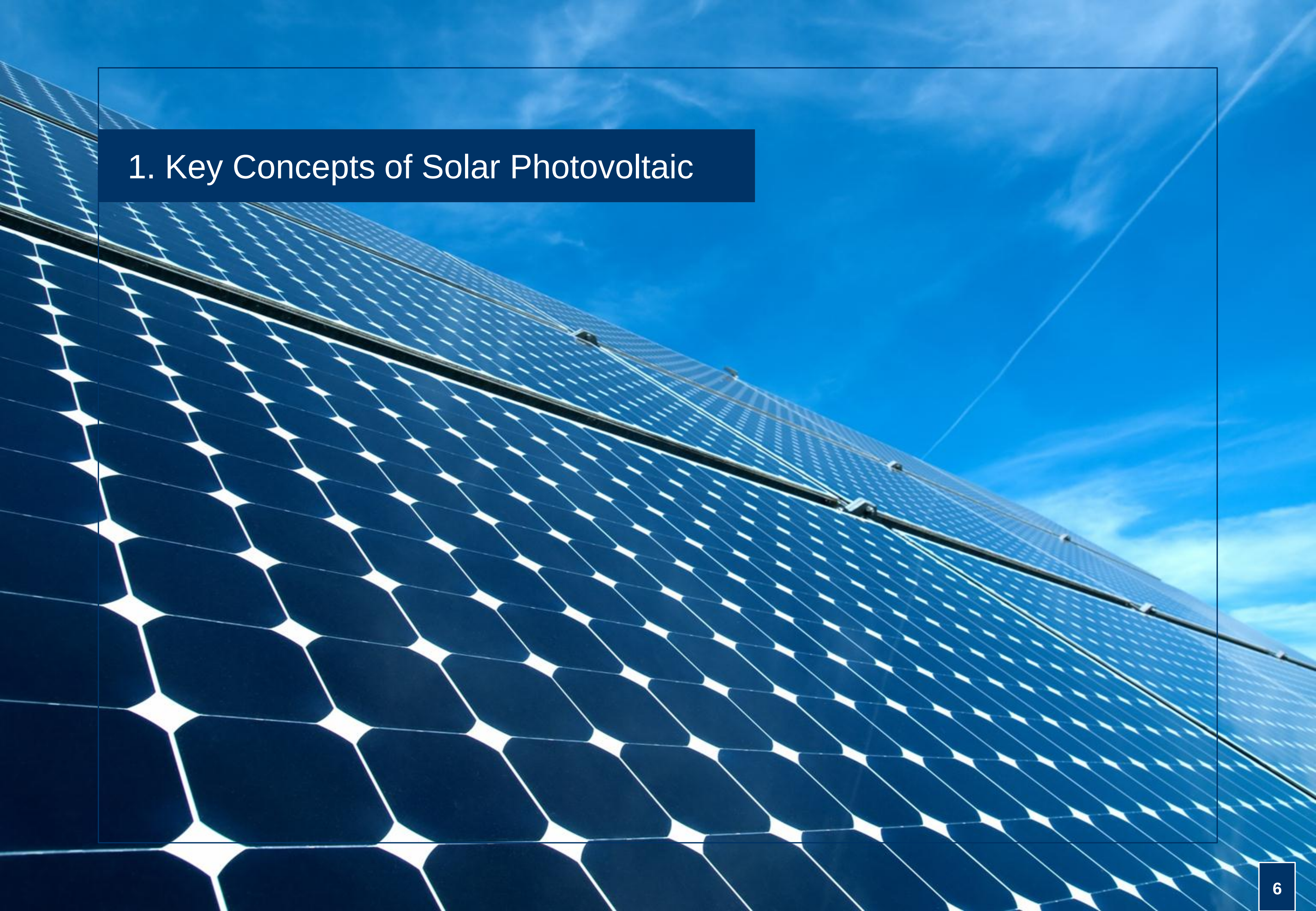
Solar energy raises system-specific network-integration issues

Solar is an intermittent energy: its output is variable, imperfectly controllable and predictable, and subject to sudden changes – in the event of a passing cloud, for example. However, solar output tends to be well correlated with demand, especially in areas where peak demand occurs during the sunniest hours and where it can mitigate the need for expensive power plants to meet marginal demand (*e.g.* in the Middle East or in the Southwestern United States, where the peak of demand is driven by air conditioning).

Distributed solar PV, like other distributed generators, requires enhancements in the distribution system to improve grid stability and ensure power reliability, although the need for long-distance transmission lines is limited.

Finally, the problem of grid-integration has been investigated less thoroughly in the PV sector than in the wind sector and is therefore difficult to assess. However, back-up resources will be required, in the form of dispatchable plants, energy storage capacity, interconnection with adjacent markets or demand-response.

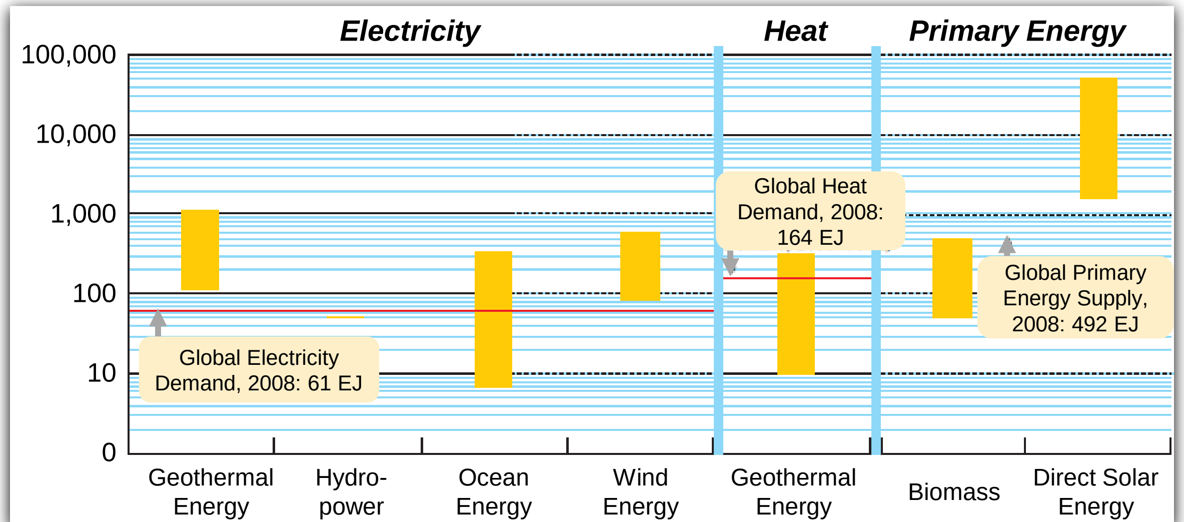
1. Key Concepts of Solar Photovoltaic



Solar is one of the most abundant resources in the world

GLOBAL TECHNICAL POTENTIAL OF ENERGY SOURCES

Exajoule (10^{18} Joules) per year, log scale

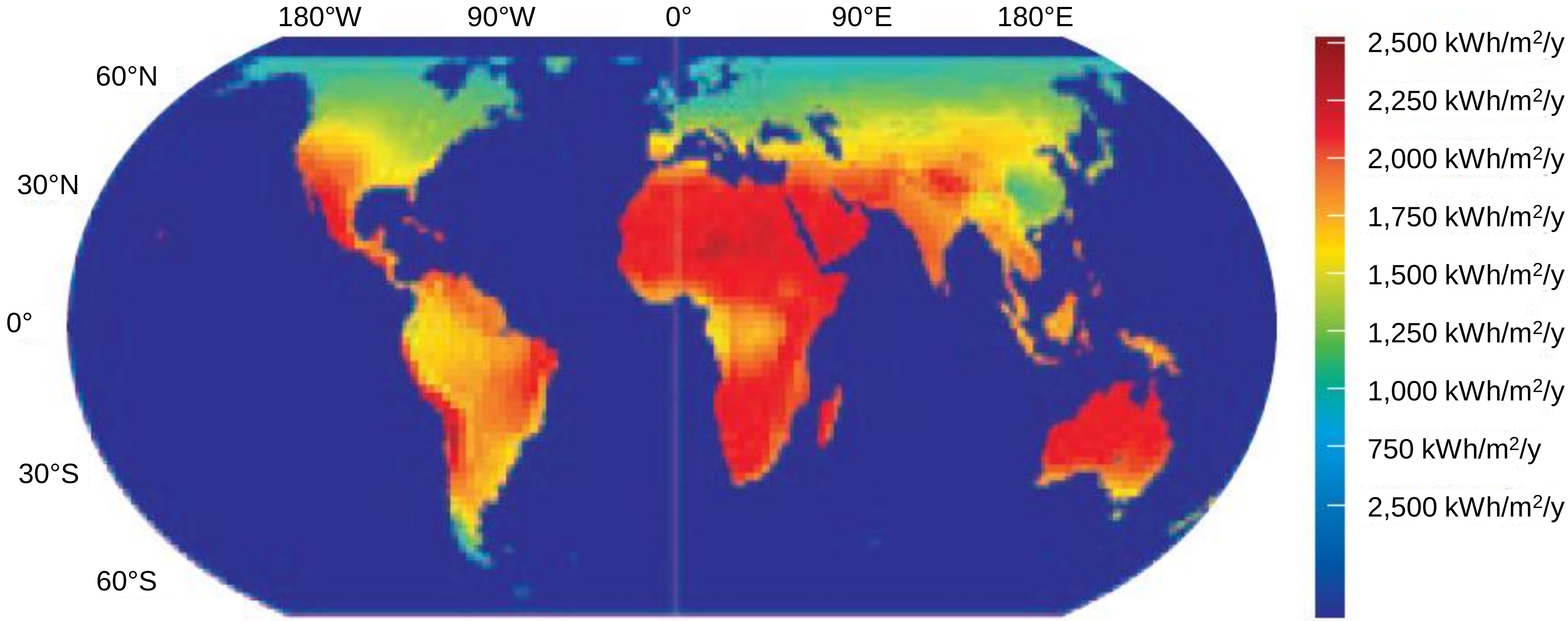


- The energy received from the sun in a single year, if entirely captured and stored, would represent more than 6,000 years of total energy consumption.
- Solar rays can be categorized in terms of the wavelengths that determine visible light, infrared and ultraviolet (respectively ~40%, 50% and 10% of the radiated energy).
- There are two main methods of capturing energy from the sun:
  - ***Heat***: irradiative solar energy is easily transformed into heat through absorption by gases, liquids or solid materials;
  - ***Photoreaction***: solar radiation can be viewed as a flux of elementary particles (photons) that can promote photoreactions and generate a flow of electrons.

Source: IPCC (2011), “Special report on renewable energy”

Solar irradiance is of fundamental importance and is deemed good to excellent between 10° and 40°, South or North

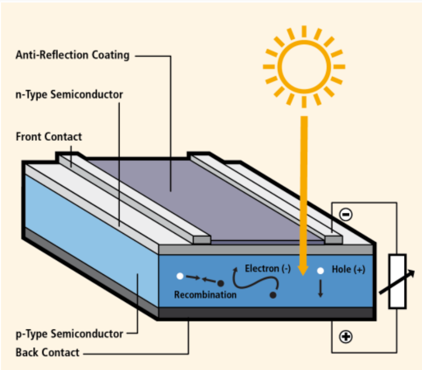
SOLAR FLUX AT EARTH SURFACE
kWh/m²/y, 2009



Source: Breyer and Schmidt (2010); IEA (2011), "Solar Energy Perspectives"

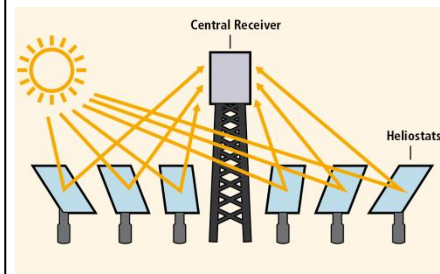
Solar Photovoltaic (PV) is one of the four main direct solar energy technologies

Solar Photovoltaic (PV)



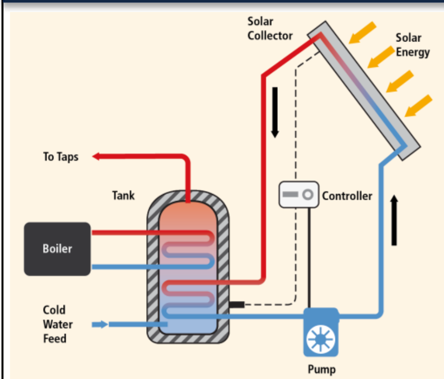
Electricity generation via direct conversion of sunlight to electricity by **photovoltaic cells** (conduction of electrons in semiconductors).

Concentrating Solar Power (CSP)



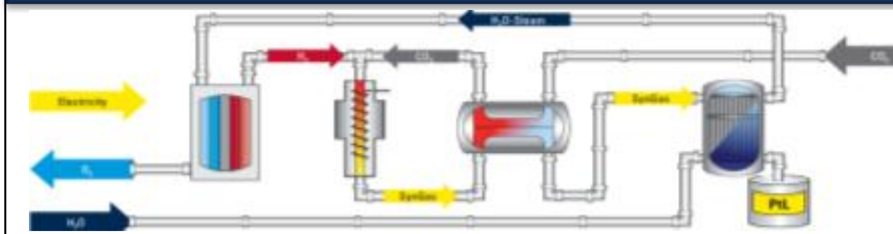
Electricity is generated by the **optical concentration** of solar energy, producing high-temperature fluids or materials to drive heat engines and electrical generators.

Solar Thermal



Solar panels made up of evacuated tubes or flat-plate collectors **heat up water stored in a tank**. The energy is used for hot-water supply and, occasionally, space heating.

Solar fuels



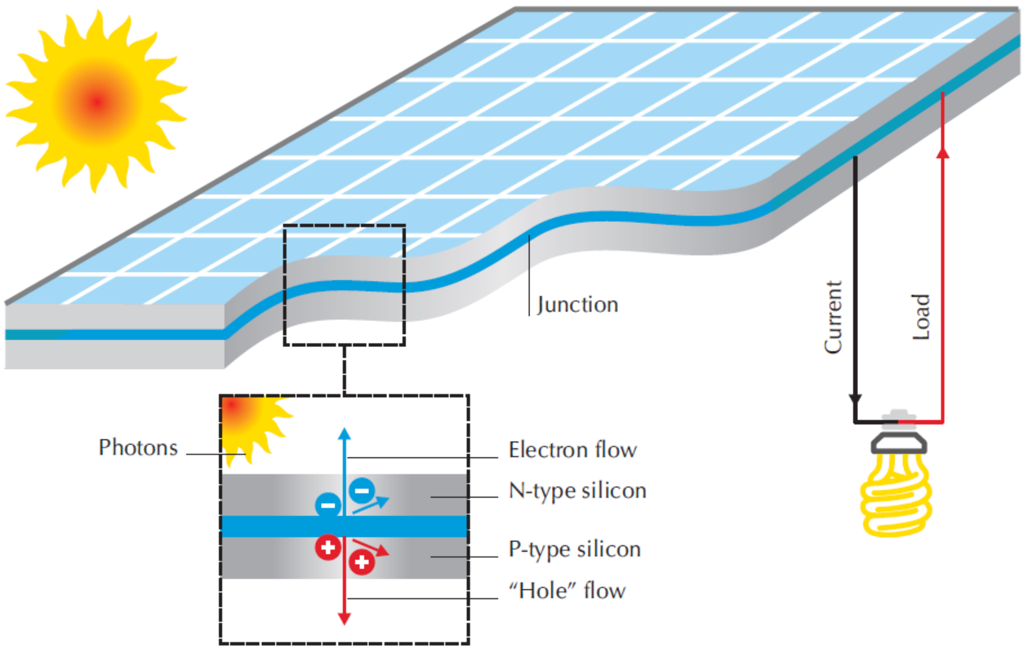
Solar Fuels processes are being designed to transform the radiative energy of the sun into chemical energy carriers such as hydrogen or synthetic hydrocarbons fuels (*e.g.* electrolysis, thermolysis, photolysis).

Note: Direct solar energy technologies exclude natural solar energy conversions, such as natural photosynthesis for biomass.

Source: IPCC (2011), “Special report on renewable energy”; IEA (2011), “Solar Energy Perspectives”; SolarFuel (http://www.solar-fuel.net/)

Photovoltaic solar technologies generate electricity by exploiting the photovoltaic effect

THE PHOTOVOLTAIC EFFECT



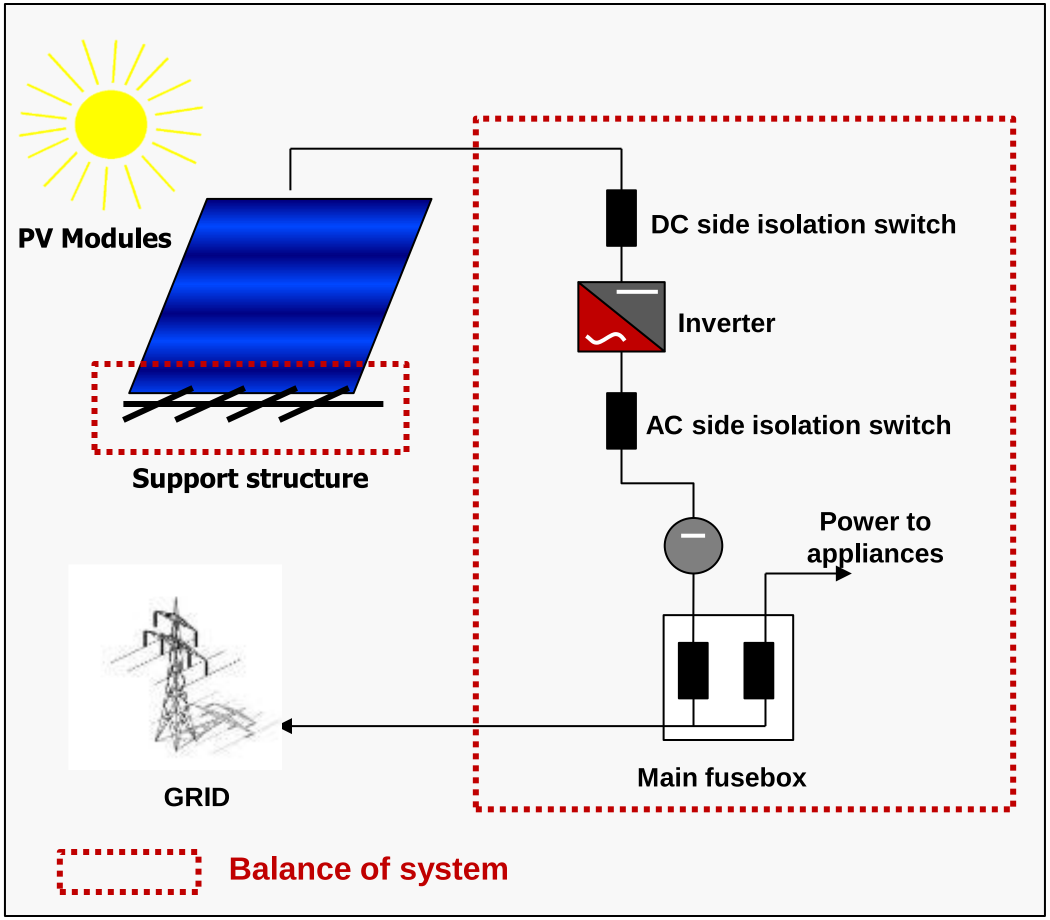
The conversion efficiency of a solar cell is defined as the ratio of the output power from the solar cell by unit area (W/cm^2) to the incident solar irradiance

- Light shining onto a semiconductor such as silicon (Si) generates electron-hole pairs.
- Electron-hole pairs are separated spatially by an internal electrical field created by introducing special impurities into the semiconductor.
- This separation creates negative charges on one side of the interface and positive charges on the other side, generating a voltage and direct current (DC) when connected to a load.
- Photovoltaic cells are interconnected to form PV modules with a power capacity of up to several hundred watts. Photovoltaic modules are then combined to form PV systems.
- The unit watt-peak is often used to express the costs or efficiency of Solar PV because the output of a PV cells varies according to solar irradiance and ambient temperature. For the sake of simplicity, the factbook uses the term watt to denote watt-peak.

Source: IPCC (2011), "Special report on renewable energy"; IEA (2011), "Solar Energy Perspectives"

PV modules combined with a set of additional application-dependent system components known as the Balance Of System form a PV System

GRID-CONNECTED PV SYSTEMS

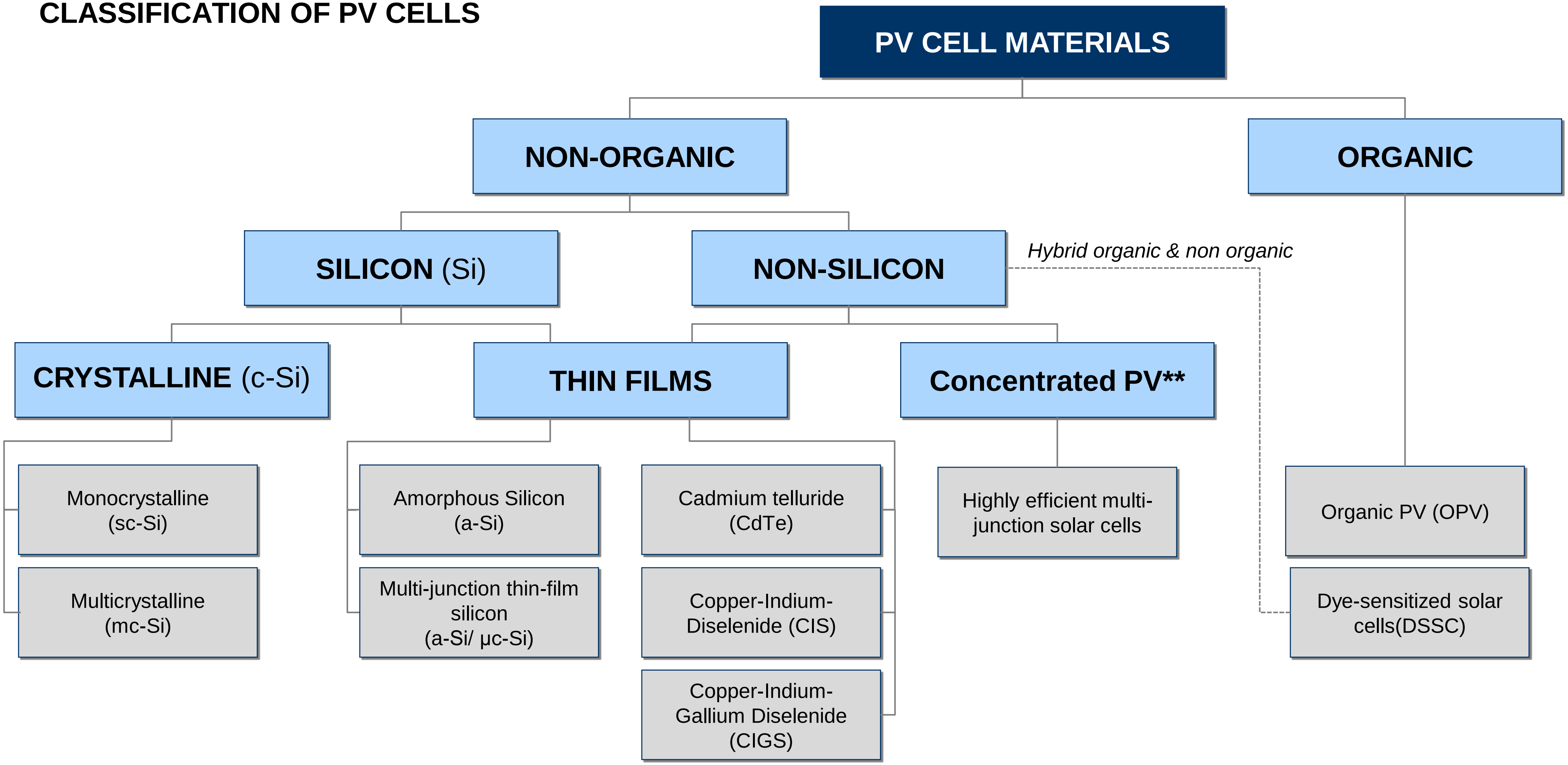


- **PV power systems are usually classified according to two major types**:
  - **Grid connected**: it is necessary to convert direct current (DC) to alternative current (AC) in order to connect to the grid;
  - **Off grid**: mainly to supply isolated areas, sometimes creating PV mini-grids, and usually with generator back-up. DC/AC conversion is not needed where system is only supplying a single point.
- **PV modules** are combined with application-dependent components such as a support rack, an inverter and switches to form a **PV system**.
- **Balance of system** (BOS) encompasses all components other than the PV module, including batteries when storage is included in the system.

Source: IPCC (2011), "Special report on renewable energy"; IEA (2011), "Solar Energy Perspectives"

There are several types of PV technology, varying by the type of material used in the cell's absorber

CLASSIFICATION OF PV CELLS



Note: * Crystalline silicon is also known as wafer-based. A wafer is a thin slice of semiconductor material such as silicon crystal.
** Some concentrated PV (CPV) systems with low-to-medium concentrations of sunlight can also use silicon solar cells.

Source: IPCC (2011), "Special report on renewable energy"

Crystalline silicon is the main commercial and the most efficient technology today

What is it?

- Wafer-based – also know as Crystalline silicon (c-Si) - is the dominant technology.
- Cells are made of highly purified silicon (5 grams per watt), which accounts for at least a quarter of their costs.
- A potential junction is created, and an anti-reflective coating and metal contacts are added.
- The cells are then grouped into modules, resulting in a slight loss of efficiency.
- Modules usually have:
  - Transparent glass on the front;
  - A weatherproof material on the back (usually a think polymer);
  - A frame.

KEY DATA

Efficiency:	**14 – 20%**	Advantage (dark green)
Module price (2012):	**$1.1 per watt peak**	Orange
Lifespan:*	**25-30 years**	Light green
Market share:	**85 – 90%**	Advantage (dark green)
Material issues:	**Silver**	Drawback (red)

Drawback → **Advantage**

PROS	**CONS**
- Higher efficiency than other technologies - Most mature technology, benefits from semi-conductor industry - High lifespan – currently 30 years, could increase to 40 years	- Efficiency decreases as temperature rises (-0.45% per °C) - Silver accounts for 5% of the cost and may have an impact on future cost reduction - Higher lifecycle GHG emissions than other technologies

Note: Manufacturers usually guarantee a product lifetime of 25-30 years for their modules, achieving at least 80% of original output.
Source: SBC Energy Institute; IPCC (2011), "Special report on renewable energy"; IEA (2011), "Solar Energy Perspectives"

Thin films made from semi-conductors deposited in thin layers on a low-cost backing are less efficient, but cheaper

What is it?

- Thin-film technologies include a range of absorber semi-conductor material systems:
  - Amorphous Silicon (a-Si), with efficiencies that range from 4 to 8%;
  - Multi-junction thin-film silicon (a-Si/ µc-Si), which can absorb more light, increasing the efficiency by up to 10% compared with a-Si;
  - Cadmium Telluride (CdTe) thin-film solar cells have lower production costs and reach efficiencies of up to 16.7%;
  - Copper-indium-(gallium)-(di)selenide (CIS-CIGS) have very high efficiencies, in the range 7 to 16%, and have achieved efficiency levels of up to 20.3% under laboratory conditions.
- These films are then deposited on low-cost backings, such as glass, metal or plastic substrates.

KEY DATA

Efficiency:	**4 – 17%**	Yellow
Module price (2012):	**$0.85 per watt peak**	Dark green
Lifespan:*	**15 – 20 years**	Yellow
Market share:	**10 – 15%**	Yellow
Material issues	**Rare earths**	Red

Drawback → **Advantage** (red, yellow, light green, dark green)

PROS	CONS
- Cheap when there is no land-use constraint - Flexible, available in many colors, shapes and sizes - Helps integration onto buildings	- Conversion efficiency is limited - Vulnerable to rare earth scarcity - Cadmium toxicity raises concerns

Note: Although manufacturers generally offer warranties of 15-20 years for their modules, guaranteeing a minimum of 80% initial output (or with a certain annual degradation rate), they have begun to offer longer warranties recently.

Source: SBC Energy Institute; IPCC (2011), "Special report on renewable energy"; IEA (2011), "Solar Energy Perspectives"

Non-silicon based materials are emerging to enable very low-cost modules without using exotic materials

What is it?

- Emerging technologies include advanced, low-cost thin films and organic solar cells.
- Organic solar cells are either:
  - Full organic cells: organic photovoltaic (OPV);
  - Hybrid: dye-sensitised solar cells (DSSC).
- OPV cells use stacked solid organic semiconductors, either polymers or small organic molecules.
- They hold the promise of a substantial module price reduction (over thin-film silicon), but their efficiency is very low.
- They have a place in niche markets such as consumer devices, but are still unproven.
- Research is under way on novel devices that may offer the possibility of breaking efficiency records (quantum dots and wells, and thermo-electric cells) to overcome the Shockley-Queisser 31% efficiency limit.

KEY DATA

Efficiency:	**5%+**	Drawback (red)
Module price (2011):	**$1.8 per watt peak**	Light green
Lifespan:*	**3 – 5 years**	Drawback (red)
Market share:	**1%**	Drawback (red)
Material issues	**None**	Advantage (dark green)

Drawback → **Advantage**

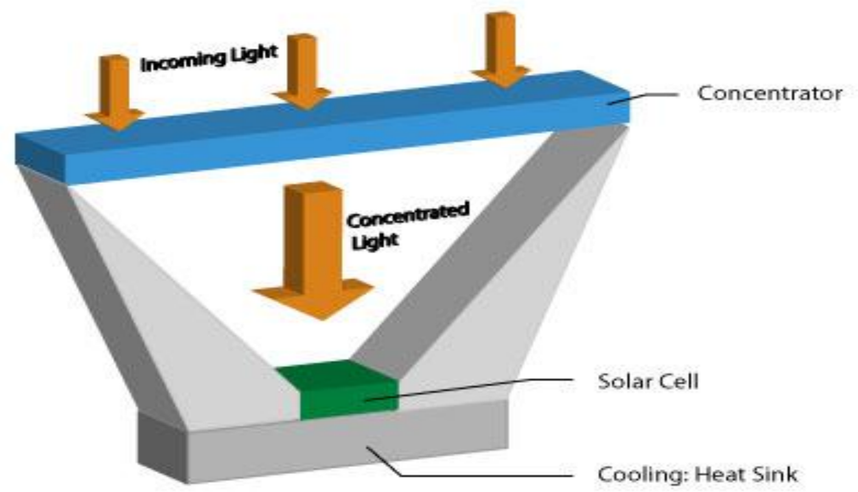
PROS	CONS
- Very low manufacturing costs - Not linked to silicon price - No use of rare materials - No pollutants	- Very low efficiency - Stability issues; UV light, irradiation, electrolyte leaking - Shorter lifespan than competing technologies

Note: Since organic cells stand at an early development stage, there are no standard lifespan figures. The 3-5 year range was derived based on test trials conducted in laboratories.

Source: SBC Energy Institute; IPCC (2011), “Special report on renewable energy”; IEA (2011), “Solar Energy Perspectives”

Concentrated PV (CPV) requires a better solar irradiance and is far less common today than non-concentrated technologies

CONCENTRATED PV BASICS



Concentration ratio	Low (2-10)	Medium (10-100)	High (>100)
Tracking	Not required	1 axis	Dual axis
Cooling	Not required	Passive	Active
PV Material	High quality Si		Multi-junction cells

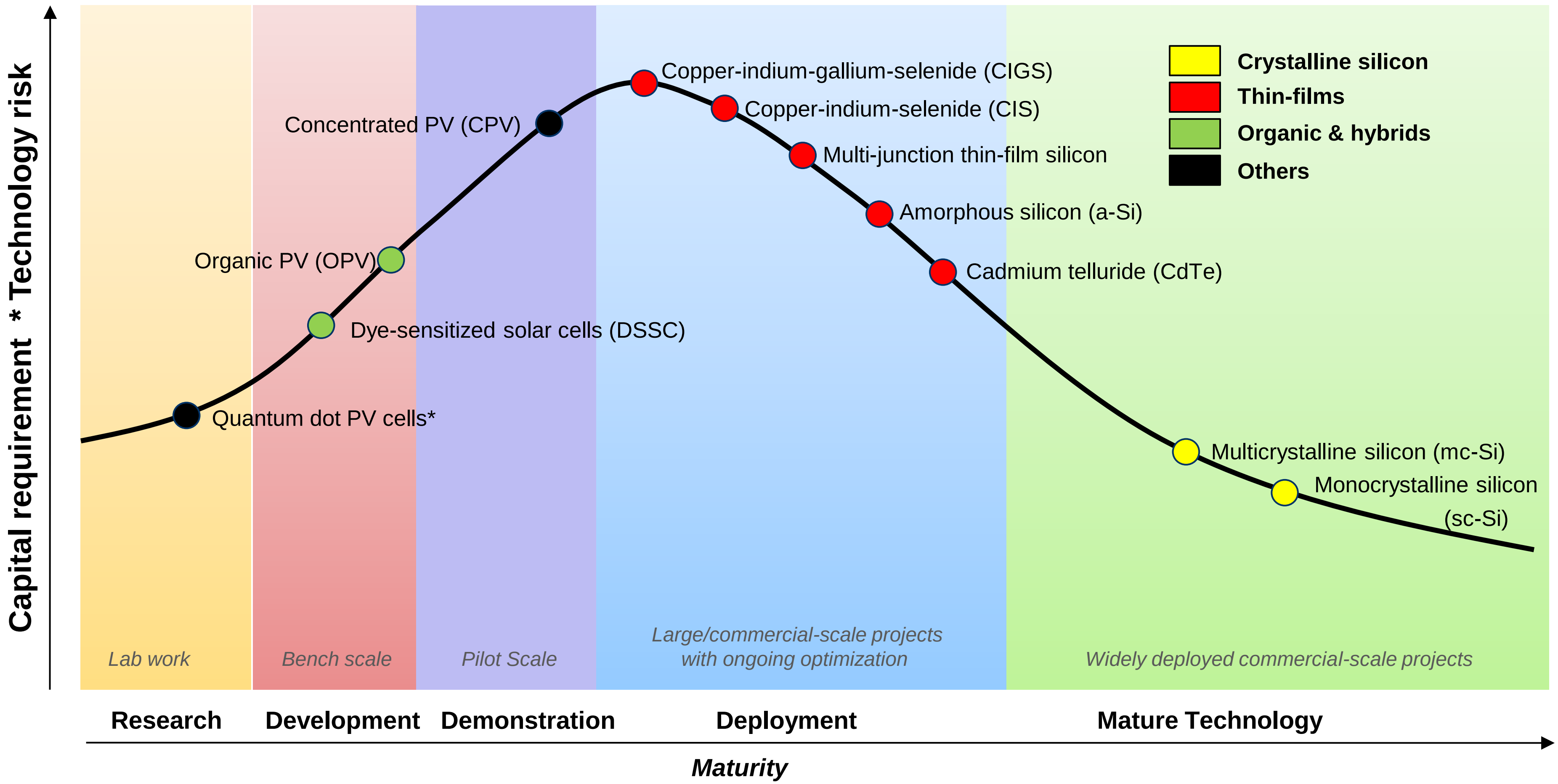
- CPV uses mirrors or lenses to concentrate and focus solar radiation on high-efficiency cells.
- As in CSP, several concentrator technologies can be used, either linear or point focus, mainly parabolic mirrors, Fresnel lenses, reflectors and luminescent concentrators.
- Ultra-efficient Solar Cells* (up to 50%) composed of different materials in several layers are used to capture most of the solar light spectrum. One assumption is that the higher cost of these cells is outweighed by their higher efficiency. They have been selected in the 10 breakthrough technologies 2013 by the MIT Technology Review.
- Contrary to PV, CPV requires:
  - Direct sunlight rather than scattered light, and is thus geographically limited (high direct normal irradiance areas, space);
  - Sun-tracking systems (more or less accurate);
  - Cooling (active if a fluid is needed, passive if not).
- As with concentrating solar power (CSP), CPV is well suited to steam uses such as desalinization due to heat production.

Note: * III-V multi-junction solar cells use multiple layers of semi-conductor material to absorb and convert more of the solar spectrum into electricity than a single-junction cell. According to MIT Technology Review, they could reached efficiencies of up to 50%.

Source: IPCC (2011), "Special report on renewable energy"; IEA (2011), "Solar Energy Perspectives", MIT (2013), http://www.technologyreview.com/featuredstory/513671/ultra-efficient-solar-power/

The various PV technologies are at different stages of maturity, from laboratory experiments to commercial systems

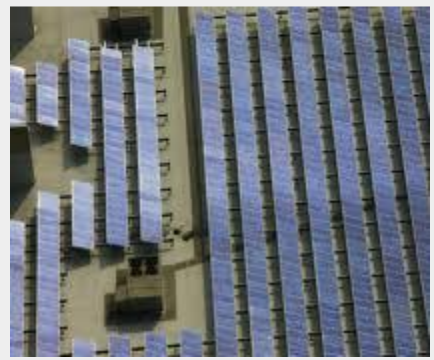
INVESTMENT-RISK CURVE: INTEGRATED PROJECTS



Note: * Quantum dot PV cells are an emerging technology that uses quantum dots as the absorbing PV material.
Source: SBC Energy Institute

PV has four end-use sectors with varying costs and performance requirements

GRID CONNECTED

Residential	Commercial / industrial	Utility	Off-grid
Up to 20 kW	Up to 1 MW	1 MW upwards	Varying sizes
			
▪ Individual buildings / houses	▪ Commercial office buildings, schools, hospitals and retail	▪ Starting at 1 MW ▪ Mounted on buildings or directly on the ground	▪ Telecommunication units, remote communities and rural electricity supply

Source: IEA (2010), "Solar Photovoltaic Technology Road Map"

Distributed generation is an important application of solar PV

DISTRIBUTED SOLAR GENERATION
Illustrative - Residential PV panels

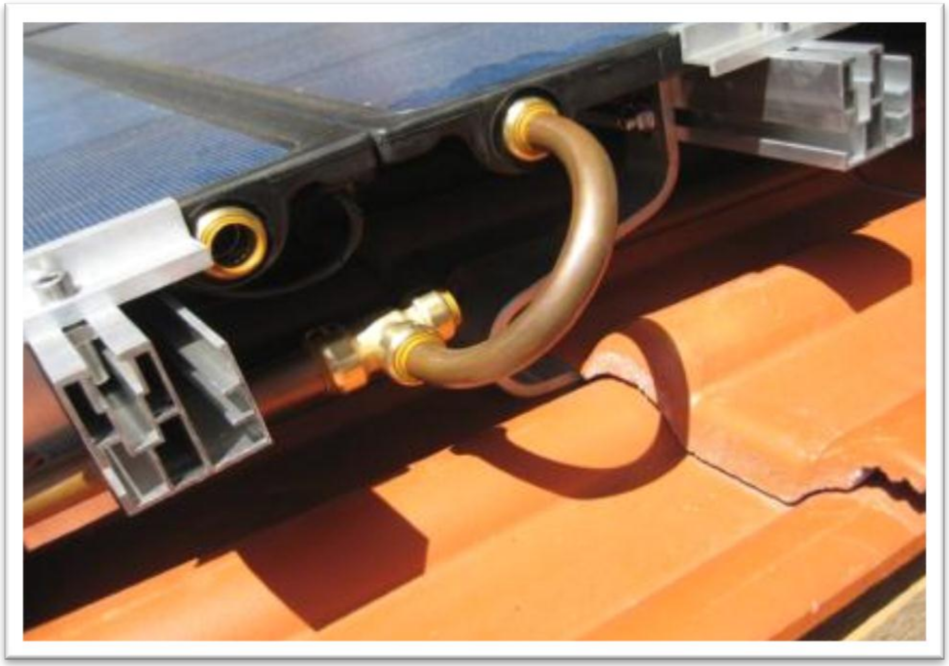
- **Distributed generation consists of generation units localized at the distribution end of the power system.**
- **Advantages of distributed generation:**
  - Transmission and distribution expansion deferral;
  - Reduced distribution losses in the network;
  - No extra land required for the PV system;
  - Mounting costs reduced if mounted on existing structure.
- Smart distribution and/or anti-islanding protection of solar inverters* is needed with distributed generation. **The flow of electricity in two directions in grids that have been designed and operated assuming a unidirectional flow not only** impacts reliability and quality of supply (*e.g.* overvoltage), but also raises safety concerns**. Distributed generation has long been classified, somewhat erroneously, as reduction in demand by system operators rather than additional supply. This classification will have to be adjusted for the penetration rate to increase substantially.

Note: * A solar inverter converts the direct current output of a PV panel into alternating current. Islanding protection of solar inverters refers to the tools used in the inverter to detect an islanding situation (when a power outage occurs on the grid and some solar panels keep feeding a small part of the grid), which can be risky both for utility workers and equipment.
** For instance, distributed generators can "threaten the safety of utility workers were it to keep a line energized after a fault when the line is thought to be broken" (MIT 2011).

Source: IPCC (2011), "Special report on renewable energy"; IEA (2011), "Solar Energy Perspectives"; MIT (2011), "The Future of Electric Grid"

As a cogeneration technology, hybrid PV/thermal (PV/T) is more energy efficient than PV and thermal systems operating separately

PV/T COVERED MODULES



- **PV/T generates both electricity and heat** from PV modules with the use of a thermal collector. Collectors can be either:
  - Covered with heat pipes on the back of PV Modules;
  - Non-covered: PV modules are placed inside a flat-plate heat collector.
- **It is more energy efficient than PV and thermal systems operating separately:**
  - As in cogeneration, the aim is to maximize energy (heat and power) efficiency, in this case per surface area of panel. Energy efficiency is higher because waste energy from the PV effect is collected.
- PV/T may be combined with concentrated PV (CPV) to generate high-temperature steam for use in desalinization or enhanced oil recovery (EOR).

Source: IPCC (2011), "Special report on renewable energy"; IEA (2011), "Solar Energy Perspectives"

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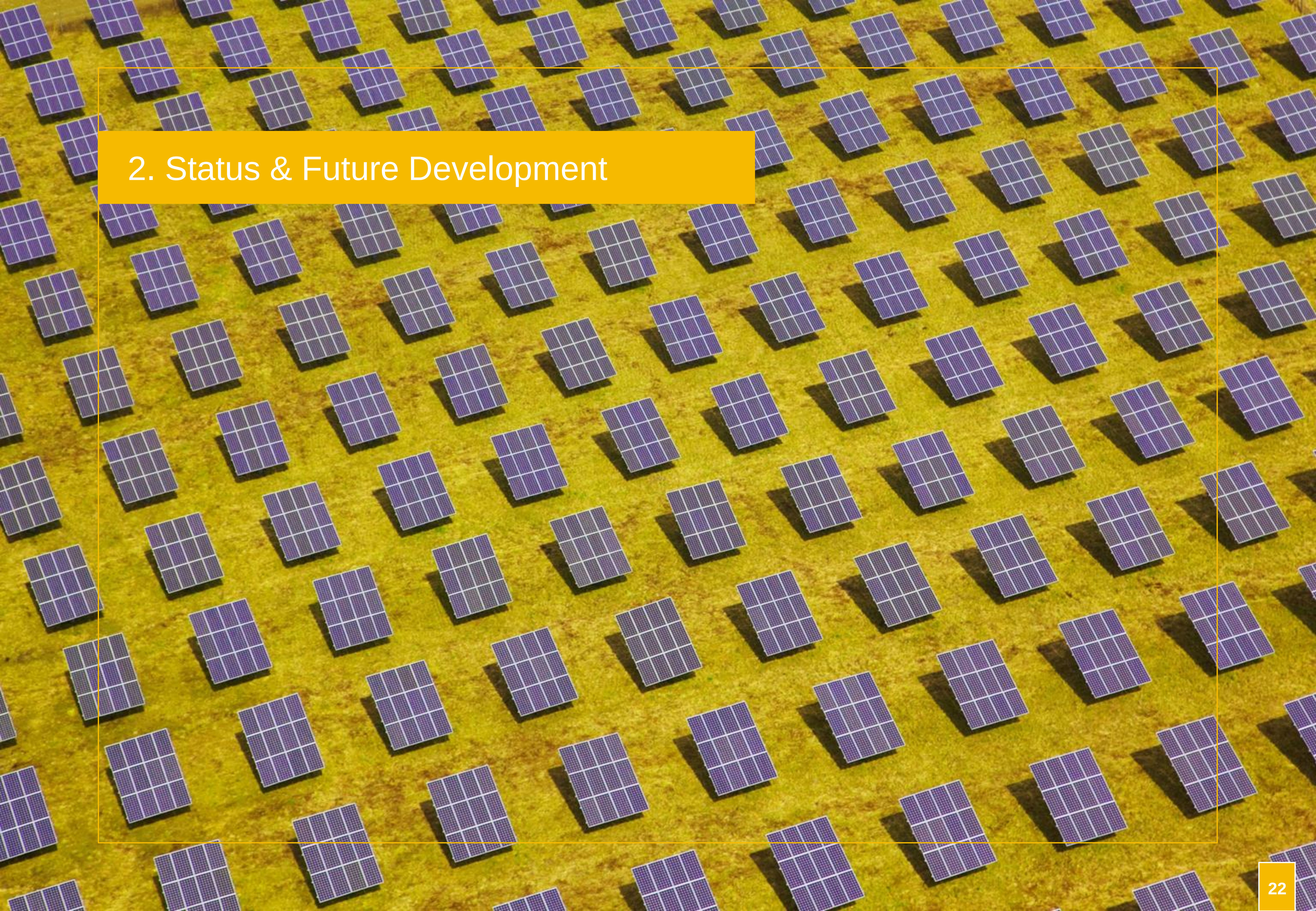


2. Status & Future Development

PV development has taken place in relatively few countries

SOLAR PV DEVELOPMENT TIMELINE

1970s
- Terrestrial applications
- Niche off-grid applications
- Mostly rural electrification

1980

1990

1990s
Various countries introduced incentives to support early development of PV systems

1995

Japan's 70,000 solar roofs program began, initially providing a 50% subsidy of the cost of installed grid-tied PV systems

1999

Start of Germany's 100,000 solar-roofs program

2000

Germany passes a renewable energy law establishing a feed-in tariff for PV systems

2003

Germany overtakes Japan as market leader. Japan had previously surpassed the US in 1998

2005

2000s
The end of the decade saw a massive expansion in European installed PV capacity as a result of a combination of falling module prices and generous feed-in tariffs, especially in Germany & Italy

2010

2012

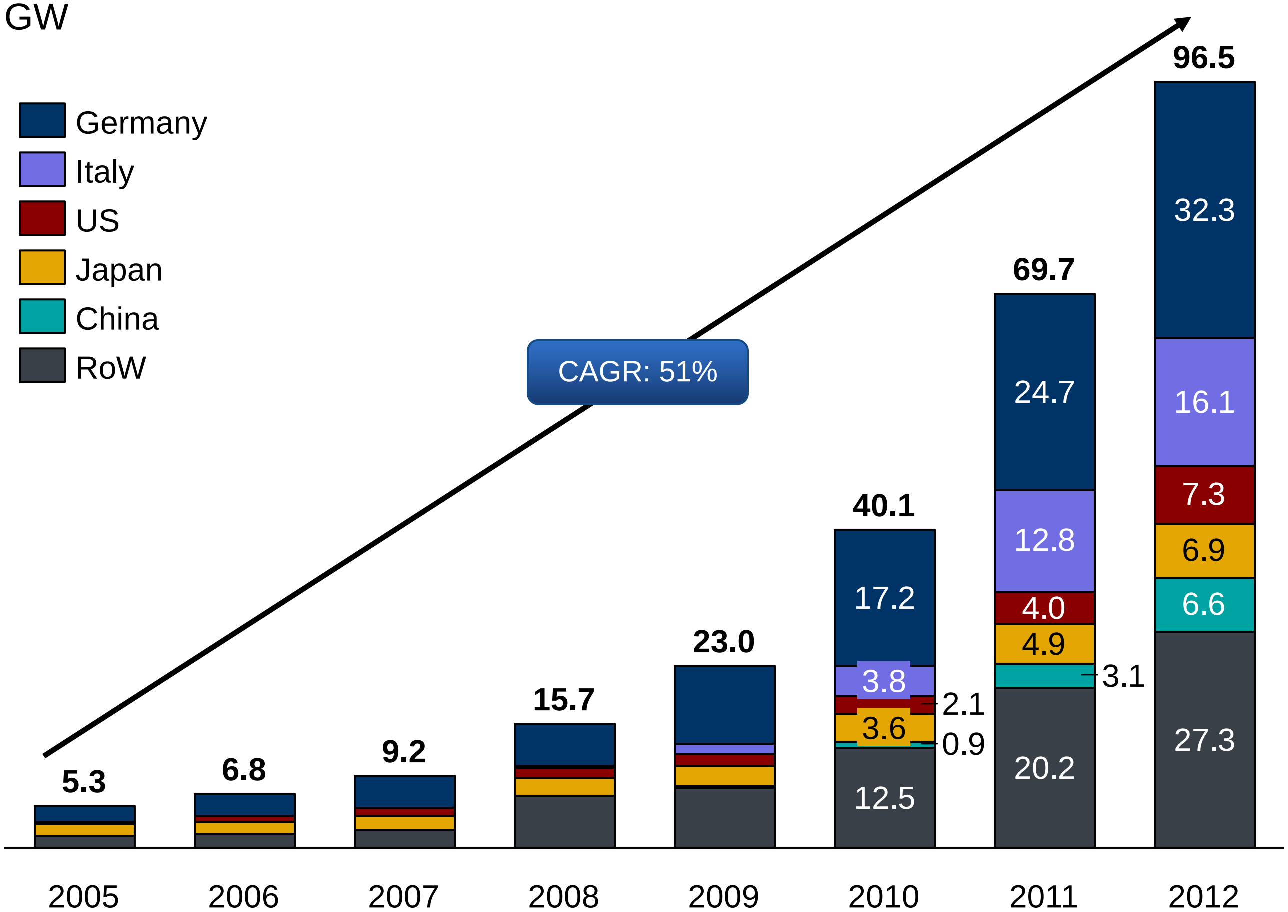
96.5 GW of grid connected capacity

Source: IEA (2012), "Renewable Energy , Medium-term market report"; IEA (2012), "A Snapshot of Global PV 1992-2012"

PV capacity has grown at an average annual rate of 51% over the last seven years, propelled by small distributed installations in Europe

GLOBAL CUMULATIVE GRID-CONNECTED PV CAPACITIES

GW

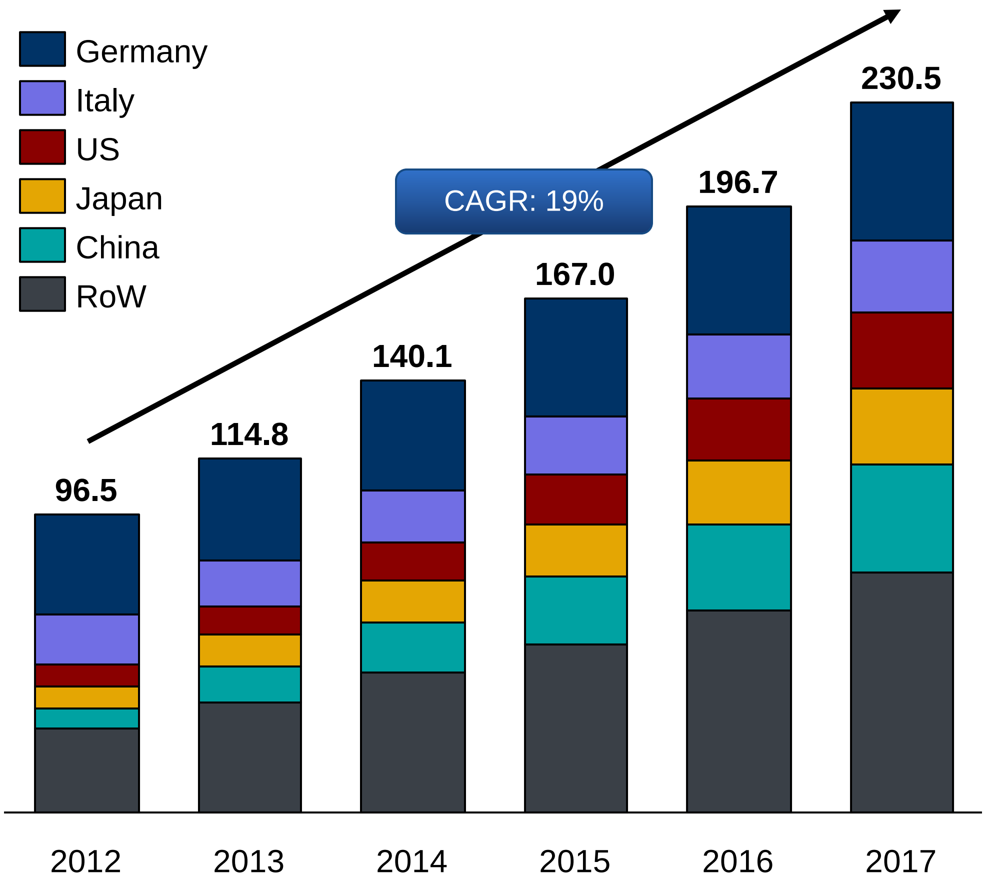


- **PV was the fastest-growing renewable technology in the 2000s,** with an average annual growth rate of 51% over the last seven years, compared with 25% in the case of onshore wind.
- **The market is dominated by Germany**, with 32 GW grid-connected PV modules – mainly in the form of small, distributed capacity. After Germany, Italy is the second-largest country for installed capacity, despite a slow-down in growth in 2012 (3.3 GW of additional capacity, compared with 9 GW in 2011).
- In 2012, China made the world's second-largest capacity additions, of 3.5 GW, confirming its role as a leader in renewable technologies.
- Recent rapid growth in Europe has been the result of a **combination of generous feed-in-tariffs and falling module prices**.

Source: IEA (2011), "Solar Energy Perspectives"; IEA (2012), "Renewable Energy , Medium-term market report"; IEA (2013), "A Snapshot of Global PV 1992-2012"

Installed PV capacity is expected to more than double by 2017, with China becoming the principal engine of market growth

PROJECTED MID-TERM CUMULATIVE PV CAPACITY
GW

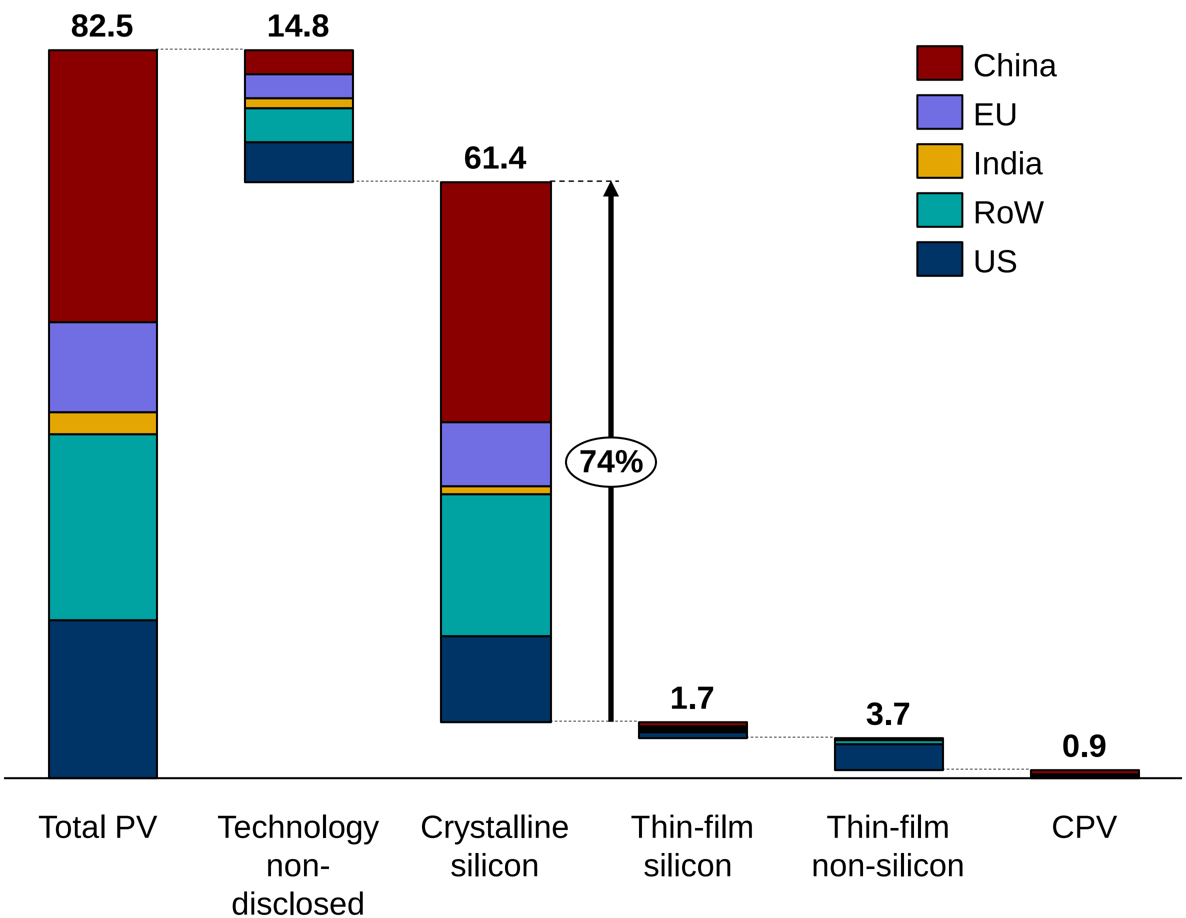


- **PV should maintain a strong growth rate to 2017,** with an expected annual average growth rate of 19%.
- **PV deployment will spread to more countries.** A slow-down in European capacity growth will be offset by growth in China, the US and other countries:
  - **China will take over Germany** as the fastest-growing solar PV market in 2013. The US will overtake Germany in 2016;
  - **Japanese growth is expected to recover,** with a steady 3.5 GW of annual growth forecast;
  - PV capacity outside the OECD and China should reach 35 GW by 2017 – more than total world capacity at the end of 2009.

Source: IEA (2011), "Solar Energy Perspectives", IEA (2012), "Renewable Energy , Medium-term market report"

Most PV projects are still based on Crystalline Silicon technology despite the emergence of thin film and non-silicon technology

PROJECTS UNDER CONSTRUCTION OR ANNOUNCED
GW

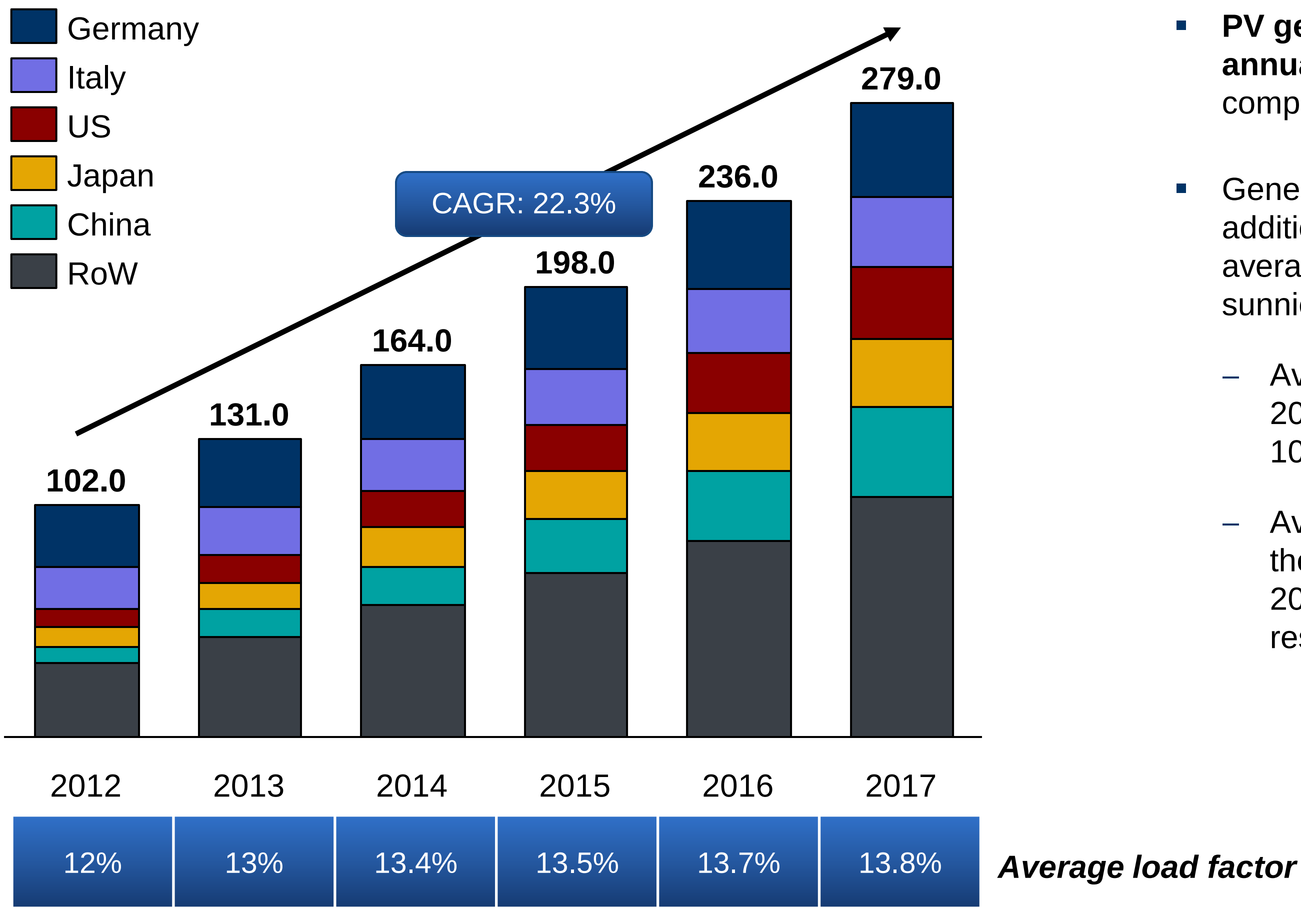


- **Of projects announced or under construction, 74% will deploy crystalline silicon PV cells**.
- **91% of projects** announced or under construction that have disclosed their technology **will deploy crystalline silicon PV cells** - similar to the present market share.
- There are more than twice as many non-silicon thin-film projects in development as **silicon thin-film projects, in which growth appears to have stopped.**
- **The US are especially active in novel technologies,** with 84% of non-silicon thin-film projects and 20% of CPV projects.

Note: Within the 134 GW expected by the IEA by 2017, 82.5 GW have been announced or are in the planning or construction phases.
Source: Bloomberg New Energy Finance, extracted from database 13th May 2013

As a result of development in sunnier countries, PV electricity generation should grow at a higher rate than PV capacity

PROJECTED PV ELECTRICITY GENERATION AND AVERAGE LOAD FACTOR
TWh

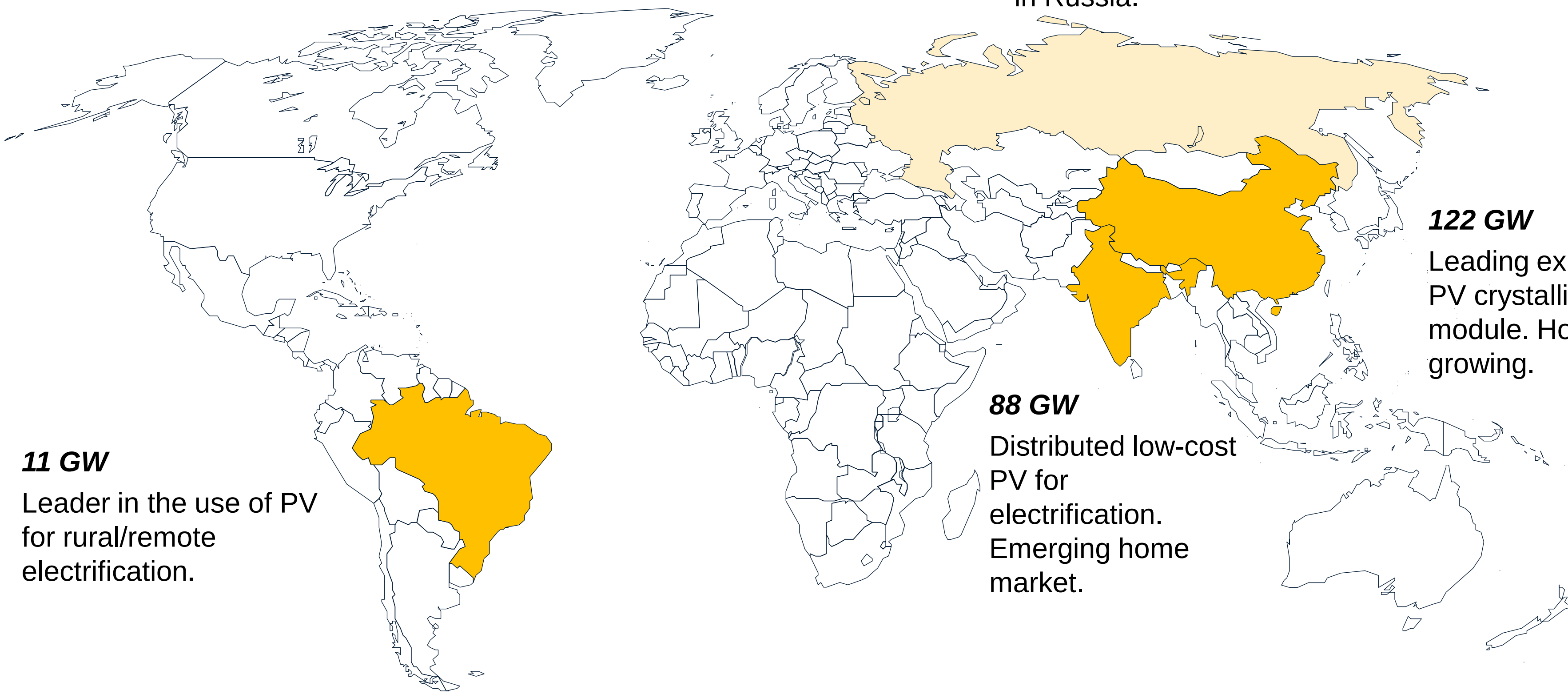


- **PV generation should grow at an average annual rate of 22.3%** from now to 2017 compared to 19% for capacity growth.
- Generation growth can be explained by the addition of new capacity and increases in average load factors as plants are built in sunnier countries:
  - Average load factor in Germany was 8.8% in 2011 and should remain stable, at around 10.5%, between 2013 and 2017;
  - Average load factors in Italy and the Rest of the World are expected to exceed 15% by 2017, reaching 15.2% and 15.5% respectively.

Source: IEA (2011), “Solar Energy Perspectives”, IEA (2012), “Renewable Energy , Medium-term market report”

The BRIC countries – Russia apart – are at the forefront of PV development and are expected to account for 34% of capacity additions between now and 2035

SOLAR PV – FORECAST CAPACITY ADDITIONS BY 2035 IN IEA'S *NEW POLICIES SCENARIO*
GW



2 GW
Negligible development in Russia.

122 GW
Leading exporter of PV crystalline silicon module. Home market growing.

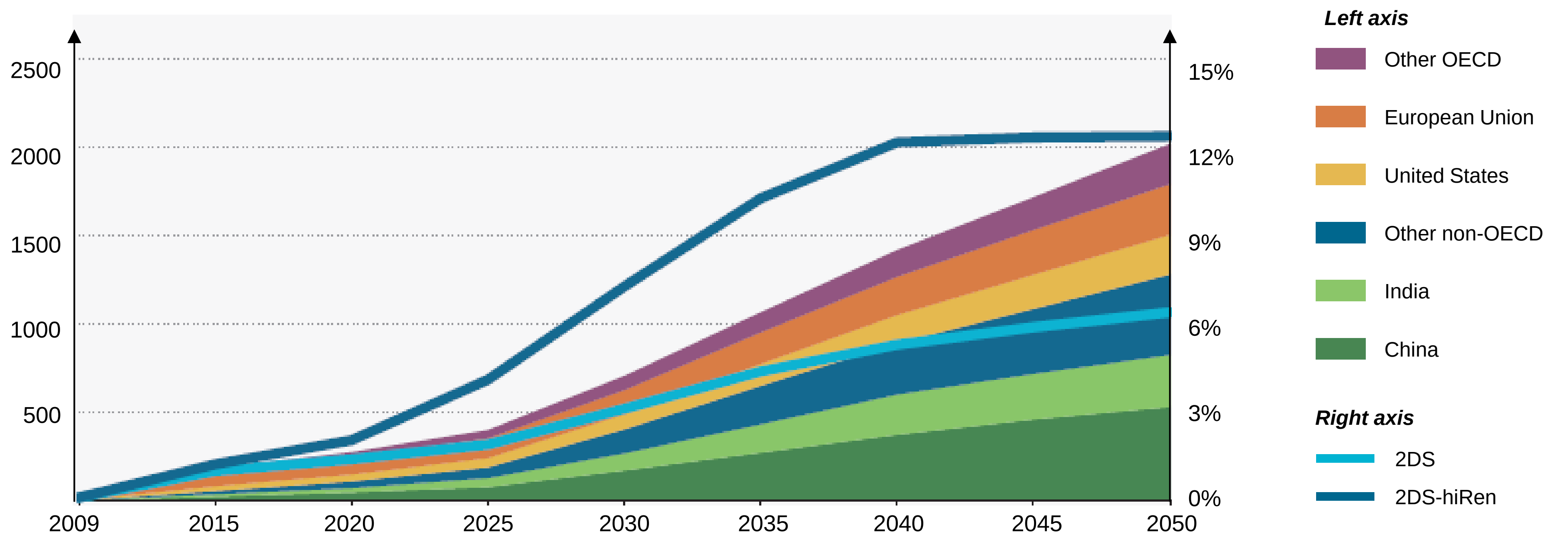
88 GW
Distributed low-cost PV for electrification. Emerging home market.

11 GW
Leader in the use of PV for rural/remote electrification.

Note: New Policies Scenario is the central scenario of IEA's World Energy Outlook 2012, in which recent government policy commitments are assumed to be implemented in a cautious manner – even if they are not yet backed up by firm measures.
Source: IEA (2012), "World Energy Outlook"

If its most ambitious climate-change mitigation scenario is to be met, the IEA believes solar PV would need to account for 6%-12% of global electricity generation in 2050

IEA *2DS SCENARIO* FOR SOLAR PV CAPACITY
GW and % of global electricity generation



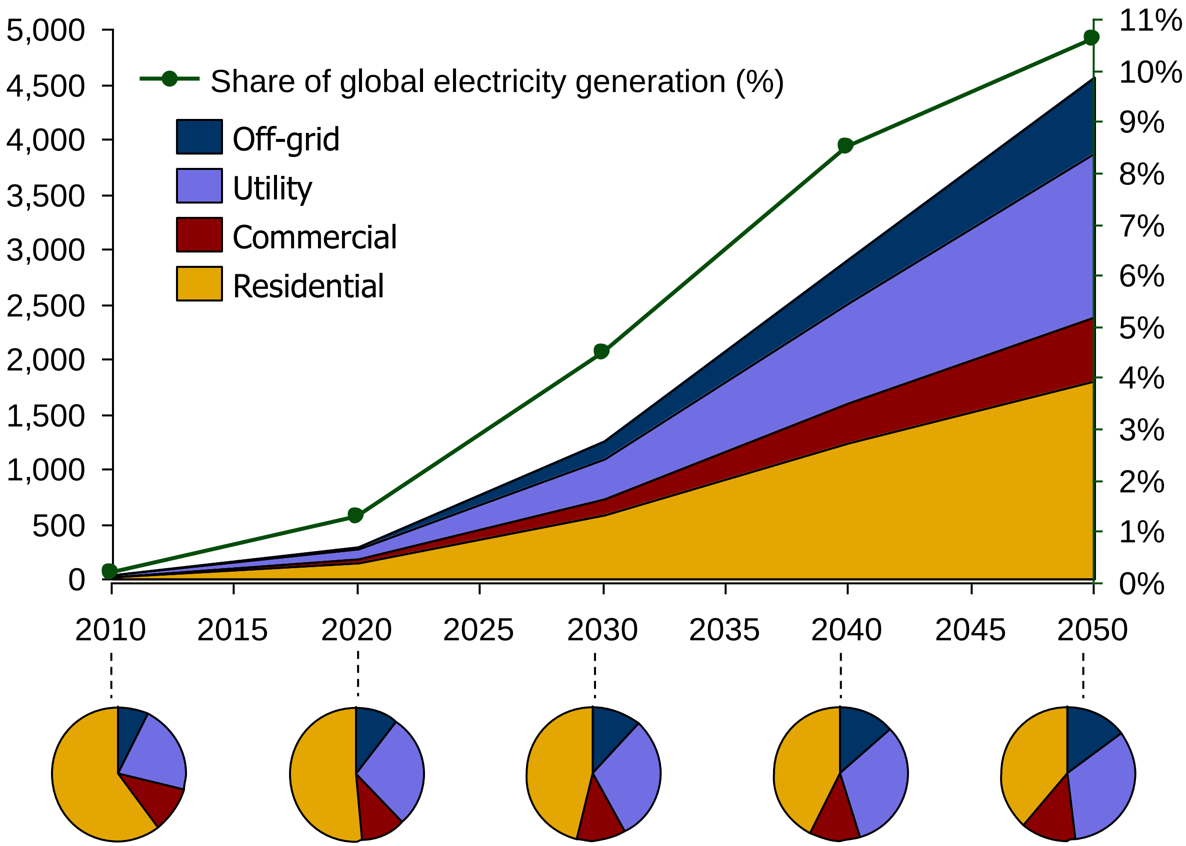
- Solar PV would need to account for 6%-12% of global electricity supply by 2050 in order to meet the IEA's 2°C Scenario (2DS), compared with 0.1% in 2010.
- For solar to attain a 6% share of consumption in 2050, capacity would need to increase by at least 2000 GW – a 20-fold increase from installed capacity at end-2012. As a result, the expansion of solar capacity in developing countries is vitally important.

Note: The 2DS Scenario corresponds to 'an energy system consistent with an emissions trajectory that recent climate-science research indicates would give an 80% chance of limiting the average global temperature increase to 2°C'. 2DS-hiRen is a variant of the 2DS with a higher share of renewables and a lower share of nuclear and carbon capture and storage. Colored areas showed in the graph represent the 2DS scenario.

Source: IEA (2012), "Energy Technology Perspectives"

All four PV end-use markets would have to coexist and expand rapidly after 2020 for PV's share of global electricity generation to exceed 10% by 2050

IEA TECHNICAL ROADMAP FOR PV POWER GENERATION BY END-USE SECTOR
TWh per year and % of global electricity generation



- Residentially applications of PV will prevail in the medium term but utility-scale PV systems will become more and more important.
- Off-grid applications make up just 10% of the total today but should remain important in remote areas and developing countries that lack infrastructure.

Note: The IEA *Technical Roadmap* scenario shown here is an older version (2010) of the IEA 2DS Scenario (2012).
Source: IEA (2010), "Solar Photovoltaic Technology Road Map"

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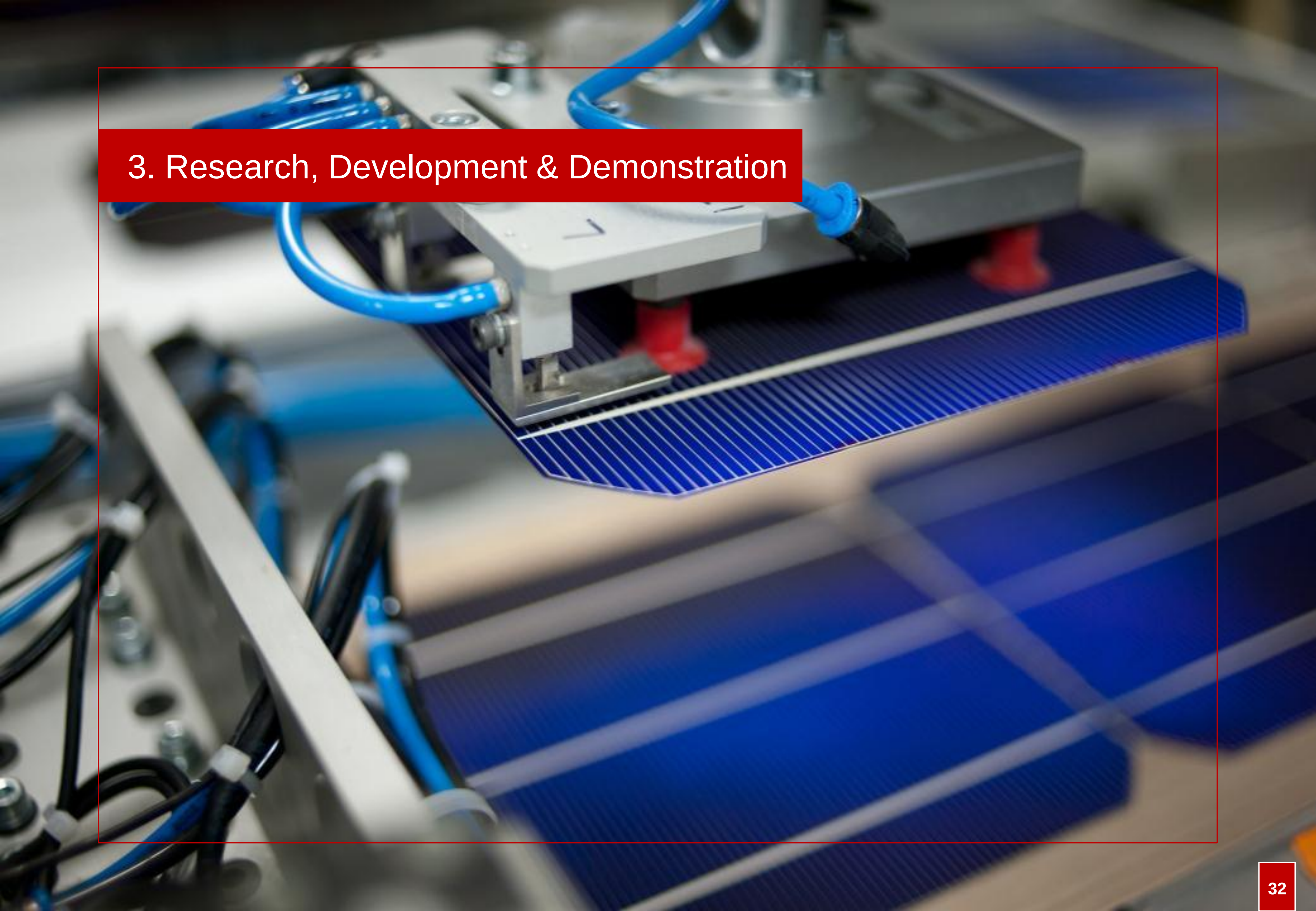
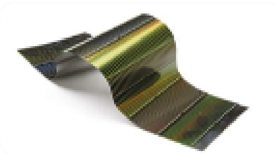
3. Research, Development & Demonstration



Most R&D is focused on improving the cost & efficiency of cell materials

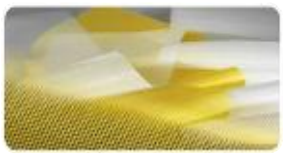
Crystalline silicon

- Improve efficiency and reduce resource consumption (especially silver and silicon)
- Develop new silicon materials and processing (including recycling)
- Seek wafer-equivalent technologies



Thin films

- Simplify production processes
- Improve device structures and substrates
- Roll to roll manufacture and packaging



Novel concepts and technologies

- Develop advanced inorganic thin-film technologies
- Reduce costs and improve efficiencies of new technologies

Concentrator technologies

- Improve optical systems
- Develop better module assembly and higher-efficiency devices
- Improve manufacturing and installation

Balance of system

- Improve lifetime of BOS components to reach same life expectancy as module
- Develop more accurate solar forecast and control systems

Source: IEA (2011), "Technology Roadmaps Concentrating Solar Power"; Chatham House (2011) "Patent Landscapes of Individual Energy Sectors"

Balance of system needs further R&D advances to increase lifespan and to reduce costs

BALANCE OF SYSTEM (BOS) R&D PRIORITIES TO 2020

	Component level	System level
Industry and manufacturing aspects	1. Increased inverter reliability 2. General-purpose tracking platforms 3. Lower-cost support structures and electrical components 4. Lower-cost components through new designs and semiconductors	1. Standardization of components 2. Prefabricated ready-to-install units
Advanced technology and installation	1. Component development for minimization of system losses 2. AC PV modules with integrated inverters 3. Self-cleaning constructions	1. Tools for early fault detection 2. Integration with energy-storage plants 3. Align lifetimes of different components
Fundamental research	1. PV inverters optimized for different PV technologies	1. Development of technology of high-voltage systems (>1000 v)

- To enable high PV penetrations, balance of system cost reductions and reductions in module prices are necessary.
- BOS costs can be broken down into component and system level costs:
  - Installation accounts for 30-70% of BOS costs at present;
  - As array area depends on module efficiency, increasing this can help to reduce BOS costs significantly.

Source: European Photovoltaic Technology Platform (2007), “A Strategic Research Agenda for Photovoltaic Solar Energy Technology”

Monitoring, control and forecasting are attracting more attention as PV penetration increases

MONITORING, CONTROL AND FORECASTING R&D PRIORITIES TO 2020

	Component level	System level
Industry and manufacturing aspects	N/A	N/A
Advanced technology and installation	1. Development of efficient incentive-management for PV 2. Management of island micro-grids with a high share of PV 3. Billing and metering in off-grid systems 4. Low-cost control and monitoring of system output and use of appropriate measurement protocols 5. Strategies for centralized system monitoring	1. Development of new methods and algorithms for solar forecasting 2. Computer programs to forecast output and validation of forecast outputs 3. Incorporating forecasts into real-time power-system operations
Fundamental research	1. Development of power electronics and control strategies for improving the quality of grid electricity at high PV penetrations	1. Improving accuracy of solar forecasting (0-6 hours and day-ahead timeframes) 2. Establishing a standard set of metrics for solar-forecast accuracy assessment

- Monitoring and control systems will increase in importance as penetration of PV increases.
- They can help to maximize the output of the system in addition to allowing the smooth integration of PV into the grid.
- Likewise, accurate solar forecasting and output predictions will enable the successful integration of solar power.

Note: N/A: Not applicable.
Source: European Photovoltaic Technology Platform (2007), “A Strategic Research Agenda for Photovoltaic Solar Energy Technology”

Concentrated PV has the ability to reach very high efficiencies and could build on R&D carried out for CSP technologies

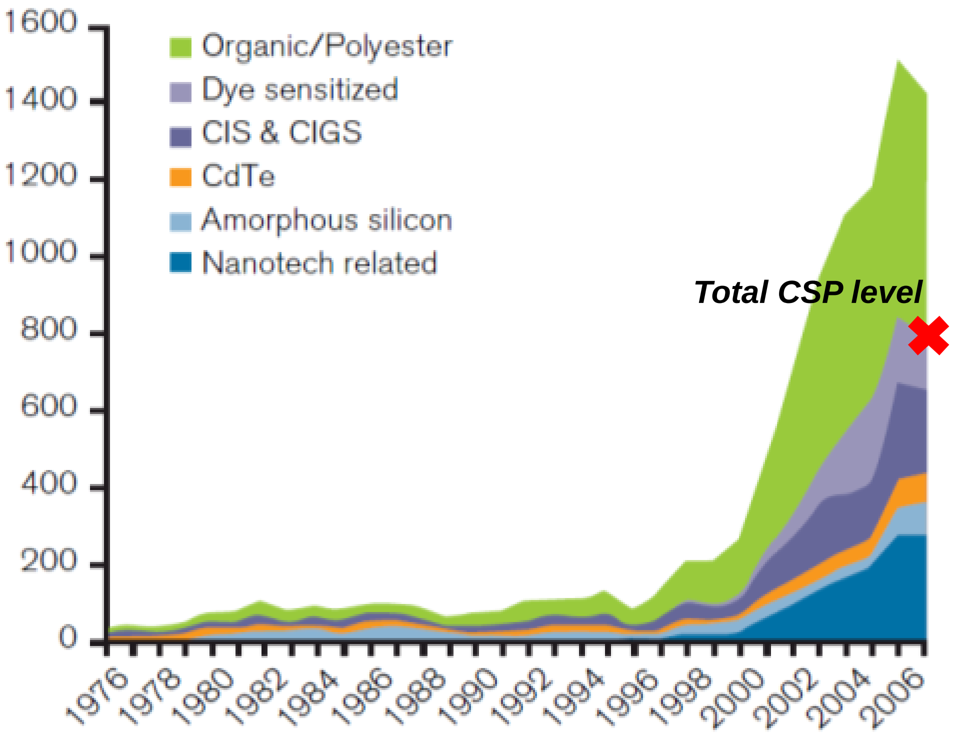
CONCENTRATED PV (CPV) R&D PRIORITIES TO 2020

	Optical components	Module & system components
Industry and manufacturing aspects	1. Cost reduction of lenses and mirrors 2. Improving optical efficiency* to 85-90% 3. Increased process automation	1. Concepts for automated mounting and sealing of modules 2. Concepts for very large-scale systems
Advanced technology and installation	1. Improved alignment of optical components 2. Development of optics giving higher concentrations with wider acceptance angles 3. Films and coatings on plastic or glass and new technologies for wide-area coatings 4. Ultra-high concentration (>2500 suns)	1. Recycling concepts 2. Concepts for fully automated production 3. Effective passive cooling 4. Combined CPV and solar thermal plants
Fundamental research	1. Solving heat-transfer problems	1. New combinations of technologies in the CPV module; *e.g.* PV and electrolyzer to produce hydrogen

Note: * Optical efficiency refers to the amount of radiation absorbed by the panel.
Source: European Photovoltaic Technology Platform (2007), "A Strategic Research Agenda for Photovoltaic Solar Energy Technology"

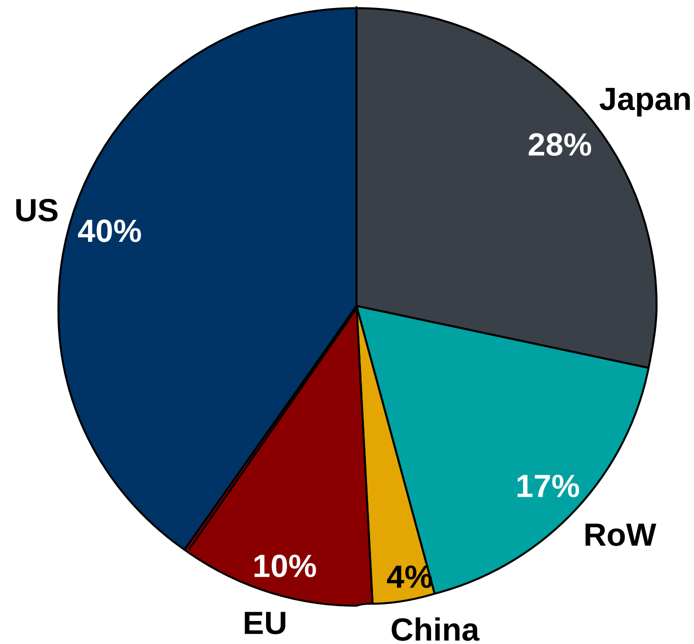
PV innovation is being driven by thin films and new cell materials in the US, Japan and Europe

PATENTING RATES BY PV SUBSECTOR
Annual number of patents filed, 1976-2006



- **New cell materials**, either organic, dye-sensitized or nanotech-related, form the bulk of patent filing since 2000.

PATENT FILING LOCATION
Cumulated patents filed, 1976-2006

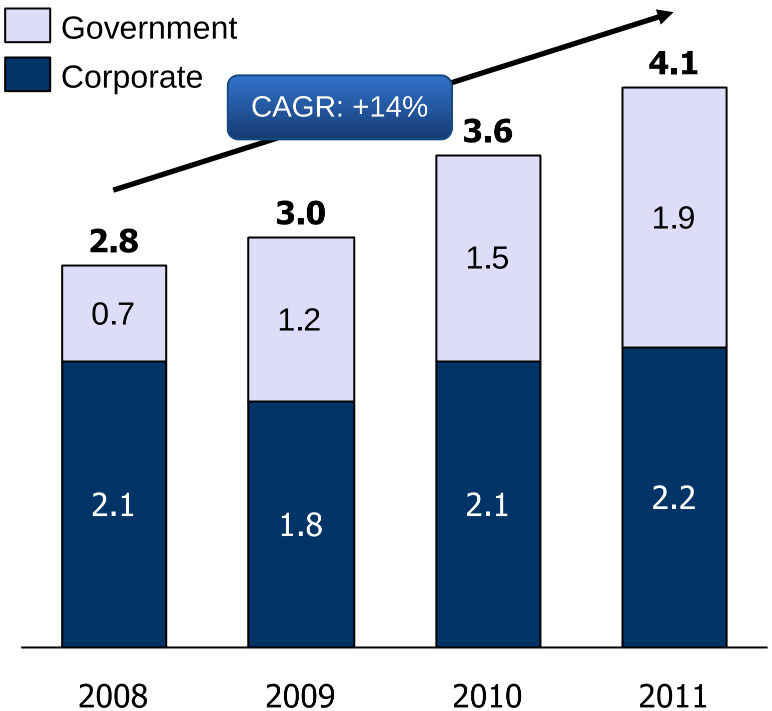


- **The US and Japan** are the most important locations for patents filing, while Europe and China are lagging behind.

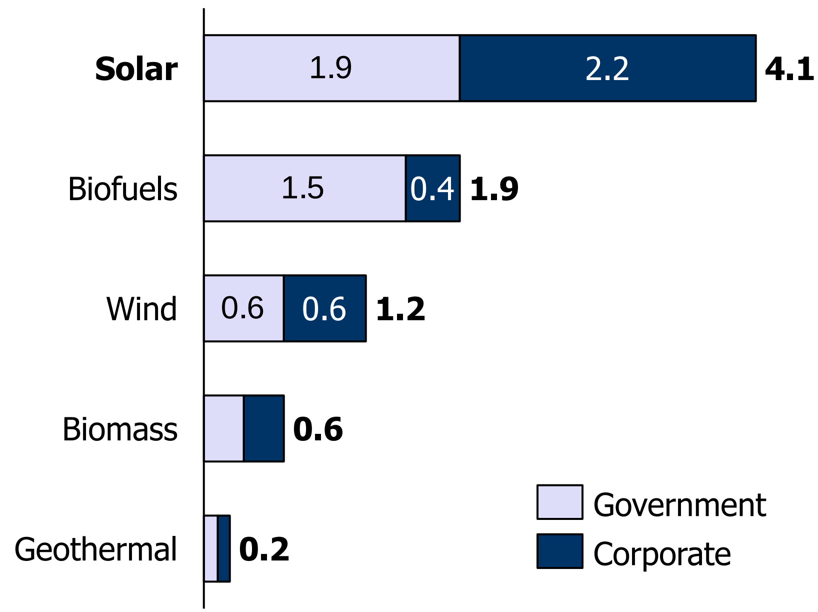
Source: Chatham House (2009), "Who Owns Our Low Carbon Future? Intellectual Property and Energy Technologies"

Investment in solar R&D is substantially higher than in other renewables

R&D INVESTMENTS IN SOLAR
$ billion, 2008 - 2011



2011 R&D INVESTMENTS
$ billion

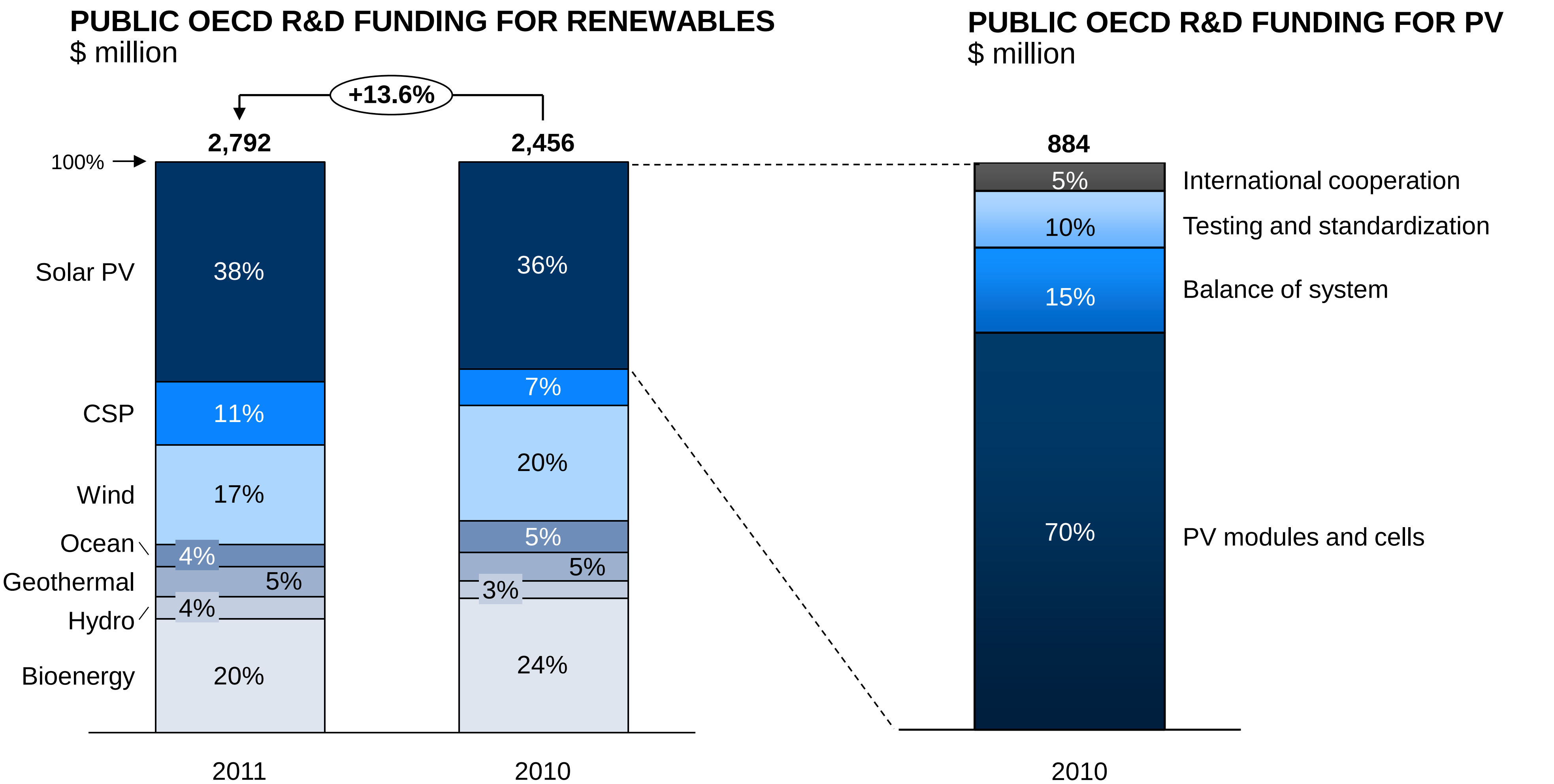


- Solar R&D funding has increased every year since 2008, benefiting from strong public support.
- Solar R&D funding is significantly higher than investment in other renewable technologies.

Note: Caution: global breakdown of solar R&D investment between PV and CSP is not available. The ratio of public R&D funding for PV and CSP in the OECD is 5:1, in favor of PV.

Source: UNEP (2012, 2011, 2010, 2009) "Global Trend in Renewable Energy Investment". Results based on Bloomberg, Bloomberg New Energy Finance, IEA, IMF, and various government agencies

In the OECD, PV receives the largest share of public R&D funding for renewables, in particular for the development of modules and cells

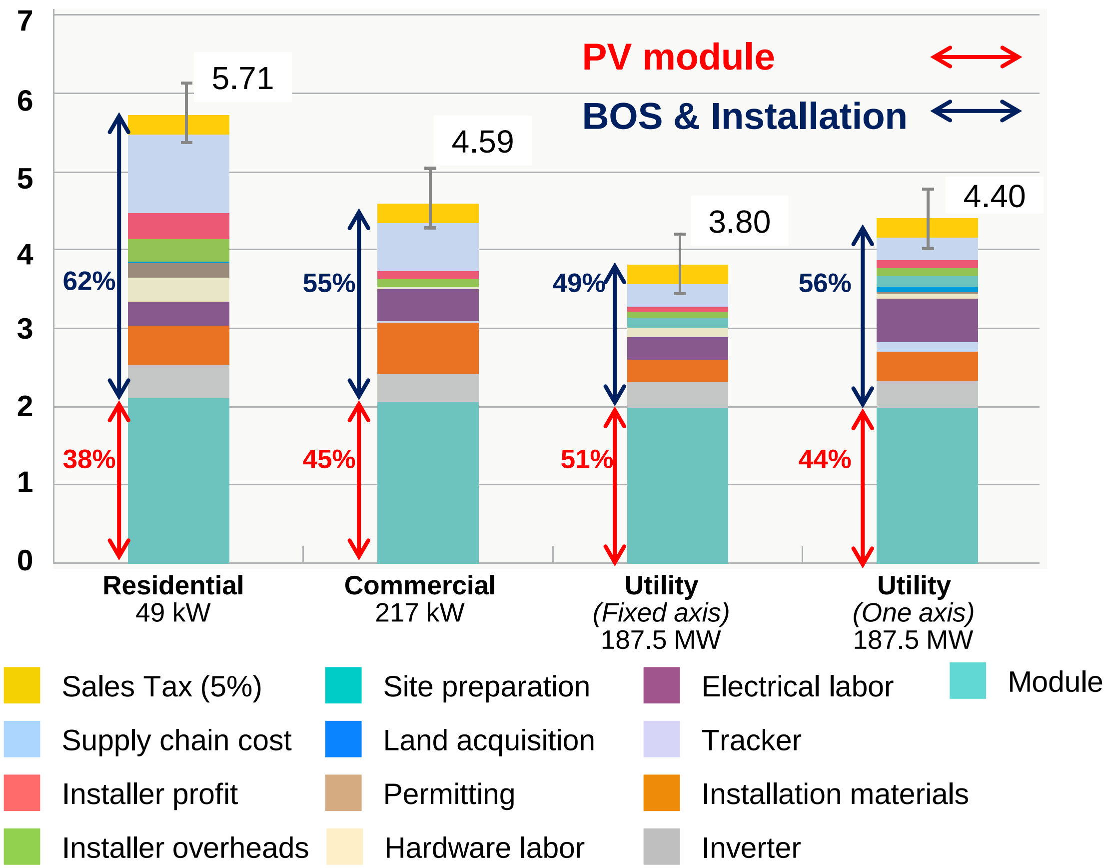


Source: IEA (2012), "Tracking Clean Energy Progress"; IEA (2013), "Tracking Clean Energy Progress"

4. Economics, financing & key players

While total investment requirements are highly sensitive to system scale, module price remains the main cost driver across all applications

US PV SYSTEM PRICE* BREAKDOWN BY APPLICATION
$/W



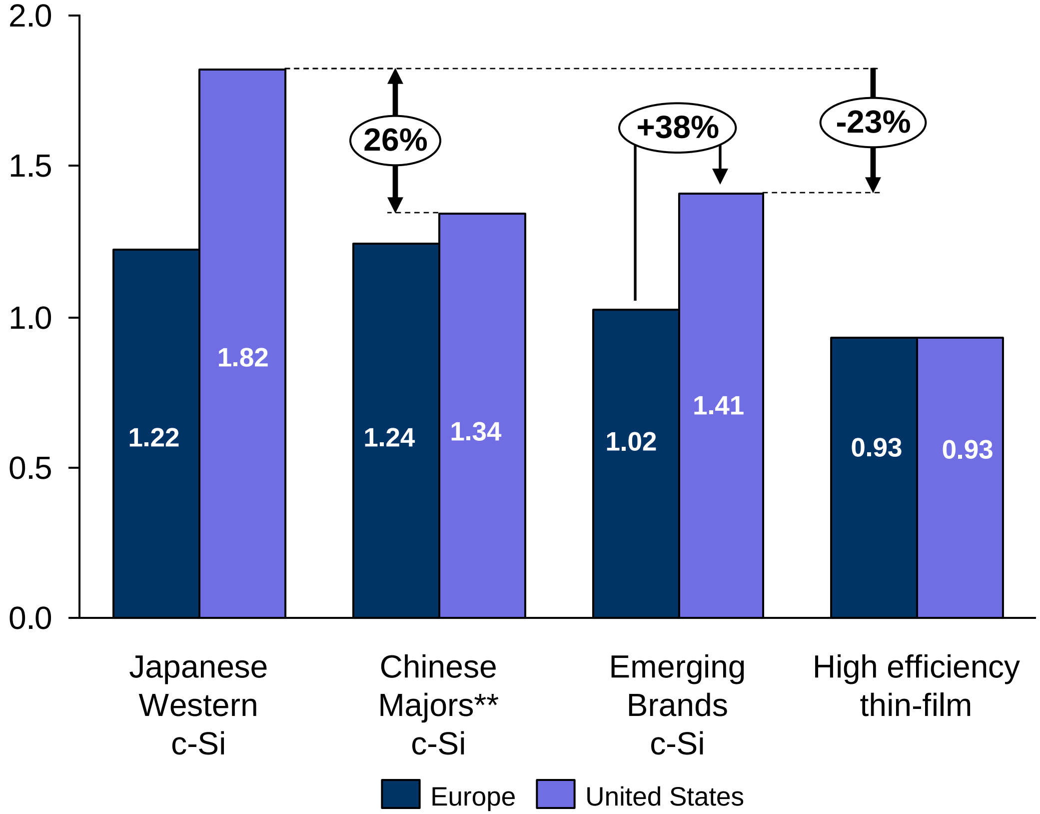
- The system size of a solar photovoltaic (PV) generator has a strong impact on its costs. Large PV systems significantly reduce the cost per unit of capacity. PV module costs slightly decrease with system size but most of the economies of scale are achieved as a result of reductions in balance of system (BOS) costs and installation costs.
- Despite declines in PV module costs and prices over recent decades, modules still account for the largest share (38%-51%) of PV system costs. PV module costs comprise raw materials, cell processing/manufacturing and module assembly. Costs vary according to the technology used, the manufacturer and market conditions.
- Balance of systems costs also depend on where PV modules are mounted (on the ground or on rooftops) and on their ability to track the sun. For instance, in the US, implementing a tracking system increases the cost of a PV system by 13% per unit of capacity, assuming all other variables (module technology, size, cell manufacturer) are unchanged. However, it is estimated that they increase energy production by 25 to 30% per year.

Note: * Prices correspond to installed crystalline silicon (c-Si) PV system prices in 2010 in the US. Residential and commercial systems are rooftop while utility-scale systems are ground-mounted.** BOS & installation costs include the inverter, racking and mounting components, combiner box and miscellaneous electrical components, site preparation and installation, storage if required.

Source: NREL (2012), "Residential, Commercial and Utility-Scale PV System Prices in the US"

PV module prices are very sensitive to manufacturer and market conditions

PV MODULE FACTORY-GATE PRICES BY BRAND
$/W, 2012 price in Europe & US

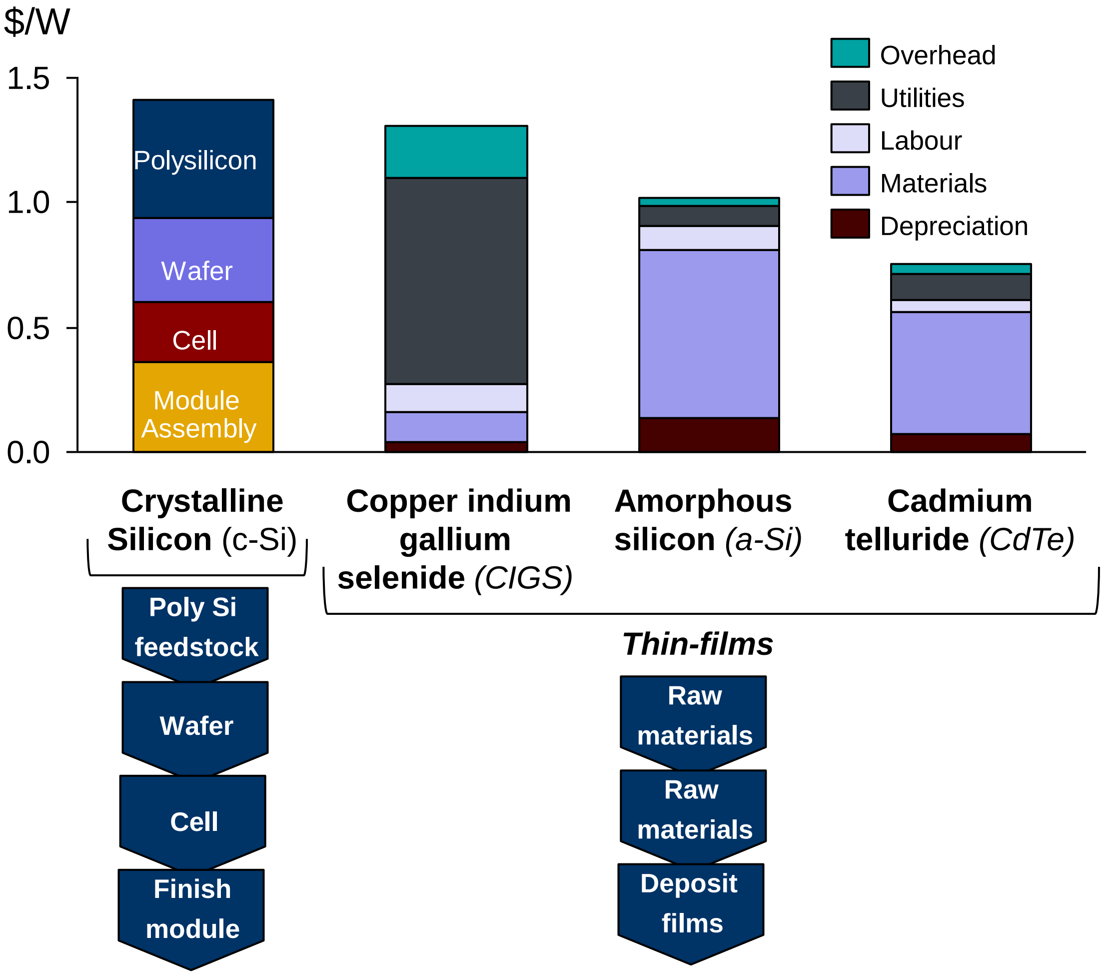


- PV module prices do not just reflect cell costs. They are also influenced by market conditions (*e.g.* the level of competition, the supply-demand balance, the strategy of market players) and the origin of the manufacturing. PV modules are easier to ship over long distances than wind turbines, which are difficult to transport.
- Chinese majors and emerging brands** are significantly cheaper than incumbent players from Japan and Western countries. In the US, crystalline silicon modules supplied by Chinese majors are 26% cheaper than those of Japanese, US or European suppliers. Emerging brands are 23% cheaper. This is the result of lower labor, processing and raw-material costs, and of market-penetration strategy.
- PV module factory-gate prices also vary according to end-market prices. At present, prices are higher in the US than in the EU (except for thin films). This is perhaps the result of the greater financial support offered in the US and of the larger-than-average size of systems deployed in Europe***.
- Retail prices are 35%-45% higher than factory-gate prices, reflecting the margins of the distributor (15%) and the retailer (20% to 30%, depending on the system size).

Note: * c-Si for crystalline silicon.
** Emerging brands include Chinese, Korean and Indian manufacturers, Chinese majors means established Chinese companies.
*** Average system size in 2010 for utility scale PV plants was 2 MW in US while it was 11 MW in Germany and 12.5 MW in Italy.
Source: IRENA (2012), “Renewable energy technologies: cost analysis series”; NREL (2011), “2010 Solar Technologies Market Report”

PV module costs vary strongly depending on technology and efficiency

PV MODULE COST STRUCTURE BY TECHNOLOGY *



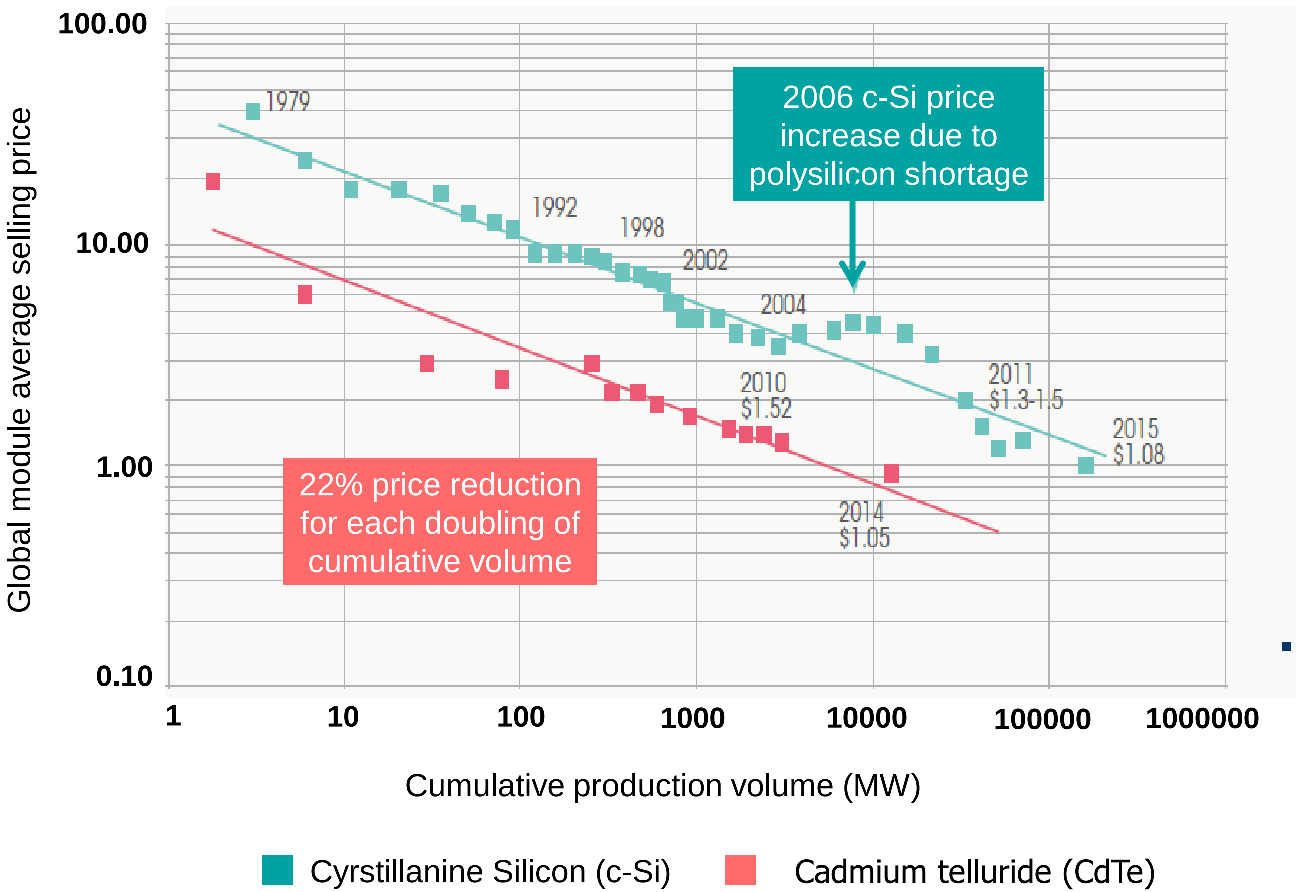
- The cost of a PV module varies primarily according to the cell technology used. There is a considerable difference between the costs of crystalline silicon (c-Si) and thin-film technologies. There is also a wide variance in costs within the thin-film technology family (*e.g.* copper indium gallium selenide, amorphous silicon a-Si and cadmium telluride).
- This variance is largely the result of differences in the costs of materials and fabrication. The supply chain for crystalline silicon modules is a disaggregated and consists of multiple players, while thin-films can be produced in a single factory. Crystalline silicon modules also require a higher quantity of expensive materials than thin films, which is reflected in the difference in costs (*e.g.* $1.41/W and $1.31/W in 2011 for c-Si and CIGS respectively).
- However, different levels of efficiency also affect costs. For a given technology, it is estimated that a 1% increase in efficiency implies a $0.1 increase in costs, all other things being equal. In general, c-Si cells are significantly more efficient than thin-film cells. The arbitrage depends on whether the superior efficiency offsets the cost premium.

Note: * c-si and CIGS prices are based on 2011 data, while a-si and CdTe prices are based on 2010 data.
Source: IRENA (2012), "Renewable energy technologies: cost analysis series"; NREL (2011), "2010 Solar Technologies Market Report", "Solar PV Manufacturing Cost Analysis: U.S. Competitiveness in a Global Industry""

Schlumberger SBC Energy Institute

PV module prices have fallen by an average of 22% for each doubling of cumulative sales, with an acceleration since 2009 due to overcapacity

PV LEARNING CURVE – PV MODULE PRICE
2010 $/W, Log scale

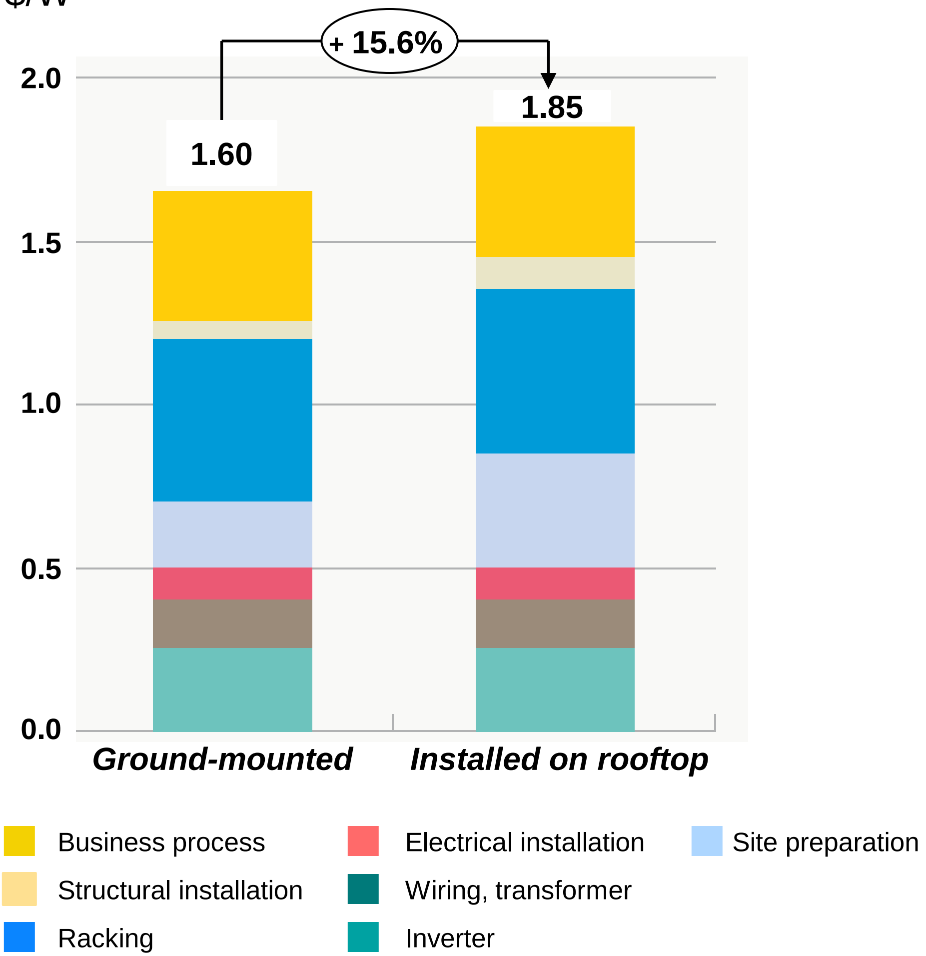


- Since 2009, solar photovoltaic (PV) modules have experienced very significant declines in prices, which have exceeded the historical learning rate (the price of crystalline silicon cells has fallen by 75%). This has been caused by a combination of lower production costs and different market conditions (price):
  - A drop in the silicon price since the 2008 recession (-75% since 2008, with no sign of an increase);
  - Overcapacity resulting from an increase in China's module-production capacity. In 2011, estimated annual production capacity was 50 GW, but only 29.7 GW of that capacity was utilized in that year.
- Lowest observed retail module prices in 2012 were:
  - $1.10/W for multicrystalline;
  - $1.06/W for monocrystalline;
  - $0.84/W for thin films.

Source: IRENA (2012), "Renewable energy technologies: cost analysis series"; IEA (2011), "Solar Energy Perspectives"; Breyer and Gerlach (2010)

The costs of the balance of system (BOS) of PV farms depend whether the installation is ground mounted or installed on rooftop

PV BOS COSTS BREAKDOWN COMPARISON
$/W



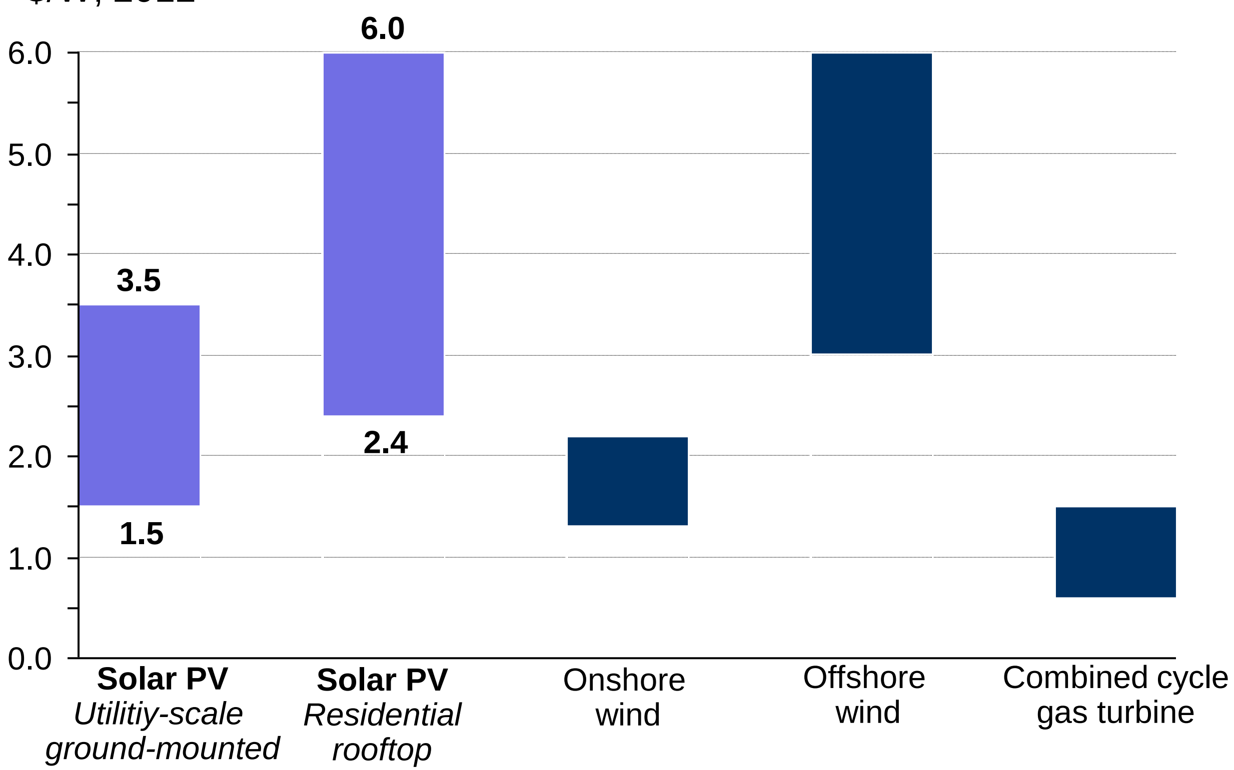
- Balance of system (BOS) costs include the cost of the structural system (structural installation, racking and site preparation), and also of the electrical system (inverter, transformer, wiring, electrical installation) and of the storage system, if required.
- Balance of system costs per unit of capacity depend strongly on the nature of the installation:
  - Whether it is ground-mounted or installed on a rooftop;
  - Whether it includes a system to follow the sun (tracking) or whether it is fixed.
- Rooftop BOSs are around 15% more expensive than ground-mounted systems because of additional costs incurred in roof preparation and installation. Tracking systems also add also around 15% to the initial investment per watt. This is due to the price of the tracking system and additional, as well as higher land acquisition and site preparation costs, given that modules need sufficient space between each others to avoid row-to-row shadowing.
- Site preparation and installation are major components of BOS & installation costs and cause the largest variance in costs between ground-mounted and rooftop systems. This aspect of project costs consists mainly of labor costs and, as a result, varies significantly by project and country.

Source: IRENA (2012), “Renewable energy technologies: cost analysis series”

Total PV investment costs range between $1.5 and $6 per watt, depending on project location, scale and market conditions

SOLAR PV INVESTMENT COSTS*

$/W, 2012



- Mirroring module and installation price dynamics, the full investment costs of PV systems vary significantly depending on their scale, their installation structure and their location.
- The investment costs of utility-scale, ground-mounted PV systems range from as low as $1.5/W, to $3.5/W (*i.e.* $1500 to $3500/MW). In favorable locations, capital requirements are thus similar to those of onshore wind.
- The investment costs of residential rooftop PV systems are significantly higher, ranging up to $6/W. It is difficult to compare these systems with other technologies because of their distributed nature.
- In all cases, PV investment ranges are higher than combined cycle gas turbine investment ranges.

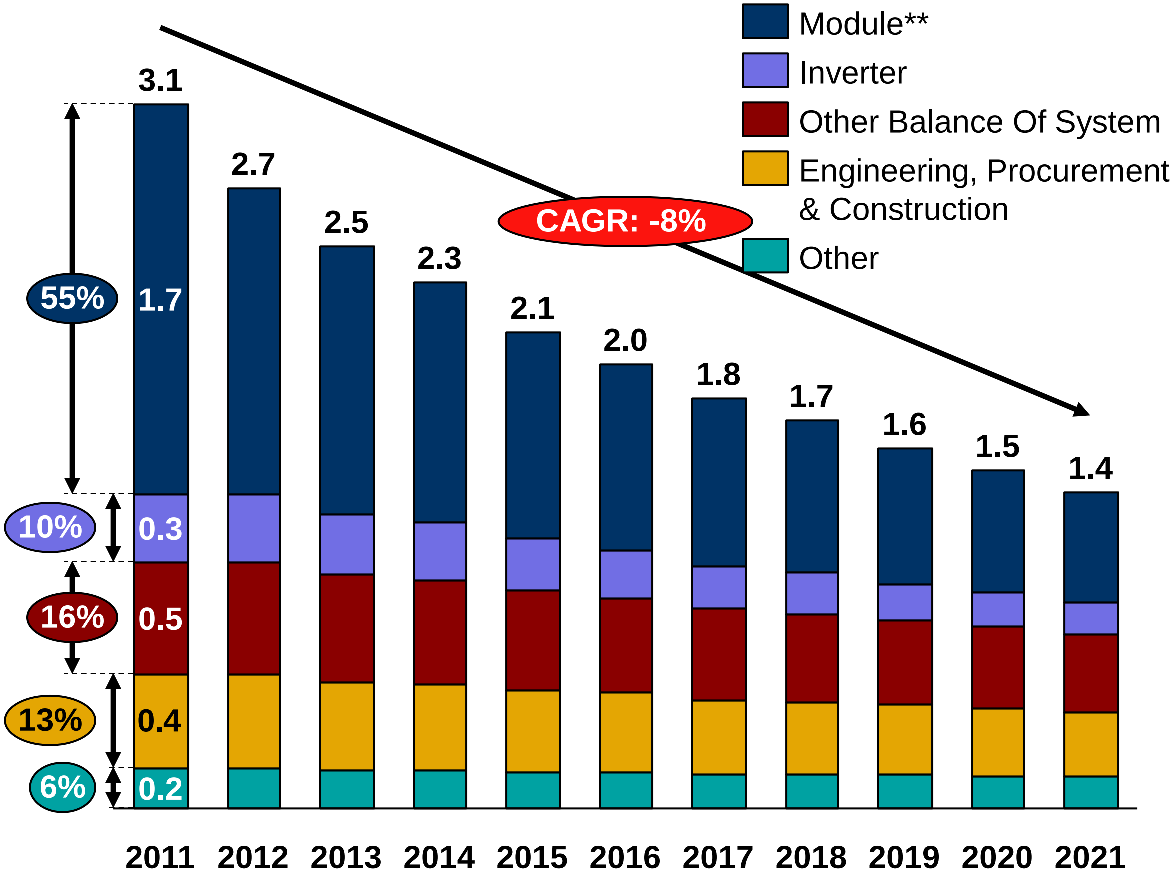
Note: * Comparing the investment cost per kW does not reflect the competitiveness of the technologies. It does not take into account the load factor, nor the lifetime or required transmission and distribution costs, which will have a significant impact on the competitiveness of the technologies.

Source: SBC Energy Institute Analysis adapted from IEA (2013), "Tracking Clean Energy Progress" and IRENA (2012), "Renewable energy technologies: cost analysis series"

Schlumberger SBC Energy Institute

The costs of all PV system components are expected to continue to fall, but at different rates, modifying the sector's overall cost structure

PRICE FORECAST FOR UTILITY-SCALE C-SI* PV PLANT
$/W



- Decreases in module costs are expected to reduce the cost of PV systems. In 2011, modules accounted for around 55% of the total system cost of utility-scale, crystalline silicon (c-Si) plants; this is expected to fall to 35% by 2021, reducing the total cost to $1.4/W.
- In parallel, balance of system (BOS) & Installation costs will account for a rising share of overall costs and limiting them will become the main challenge. This will be more difficult to achieve than reducing module costs because BOS and installation costs fluctuate according to local labor costs, and involve different components and a range of suppliers. The most promising approach is improving the design of the inverter (*e.g.* micro-inverters directly included in the PV modules), and manufacturing lighter and cheaper structures. Greater competition in installation markets and increases in the volume of BOS components could also reduce prices.
- The US DoE's Sunshot initiative has set a target for the system cost of utility-scale applications of $1/W PV by 2020 (50% module, 50% BOS). This looks hard to achieve.

Note: * C-Si for crystalline silicon.
** Module price is derived from experience curve and margin; system price in markets with cost-based, rather than value-based pricing.
Source: IPCC (2011), "Special report on renewable energy"; DOE (2012), "$1/W Photovoltaic Systems"

Capacity may be limited by a scarcity of materials and a commensurate rise in costs

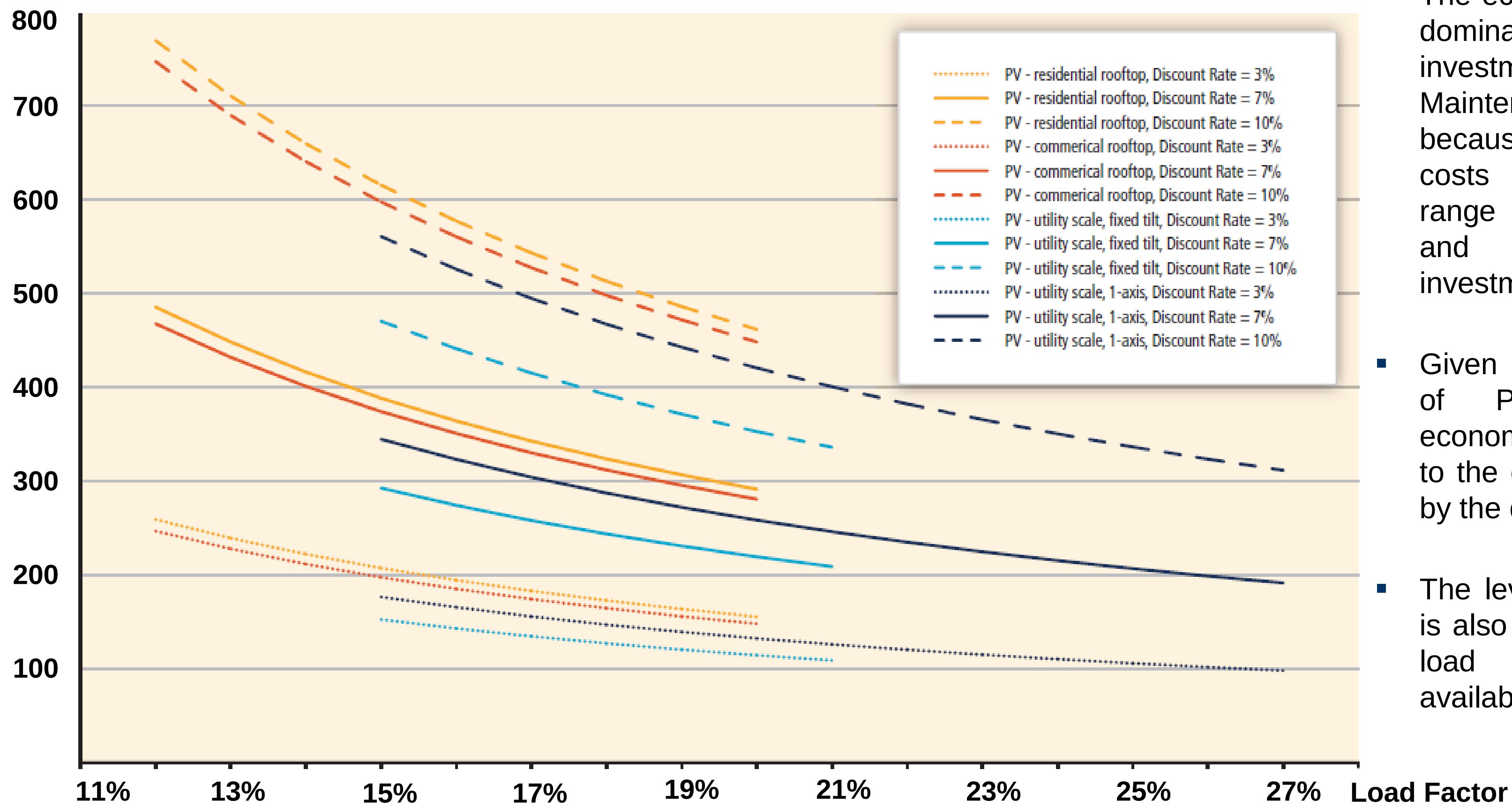
MATERIAL	SUPPLY CHAIN
1 SILICON	– Silicon accounts for ~27% of module price in crystalline silicon applications – Average silicon requirement per watt of capacity has direct impact on PV costs – Silicon is the second most widespread element on earth, available in sand and quartz rocks – Demand outstripped supply between 2004 and early 2008, causing the spot price of silicon to rise – Extreme price hike triggered the massive capacity expansion (by incumbents and new entrants) – Silicon prices have dropped since 2009 and are expected to remain low in the next few years
2 SILVER	– Silver accounts for ~5% of module price in crystalline silicon applications – PV accounts for ~ 10% of global demand for silver, the price of which doubled in 2010 – Rapidly expanding PV industry could become price-maker for silver – Some manufacturers already provide Si-PV systems with no silver contacts
3 OTHER MATERIALS INC. RARE EARTH	– Cadmium telluride (CdTe) depends on cadmium and tellurium respectively by product of zinc and copper mining respectively. The long-term availability of tellurium will depend on the copper industry's ability to optimise extraction, refining and recycling yields – CIS and CIGS need selenium, gallium and indium, the prices of which could increase – Rare earth elements are used by thin films and many start-ups to reduce cost. The availability and costs of the materials are highly dependent on China (which accounts for 95% of production)

Source: IPCC (2011), “Special report on renewable energy”; IEA (2011), “Solar Energy Perspectives

The levelized cost of electricity (LCOE) from solar plants is sensitive to solar irradiance, discount rate and application size

LCOE DEPENDING ON INVESTMENT COST & LOAD FACTOR

$\$_{2005}$/MWh, in 2009



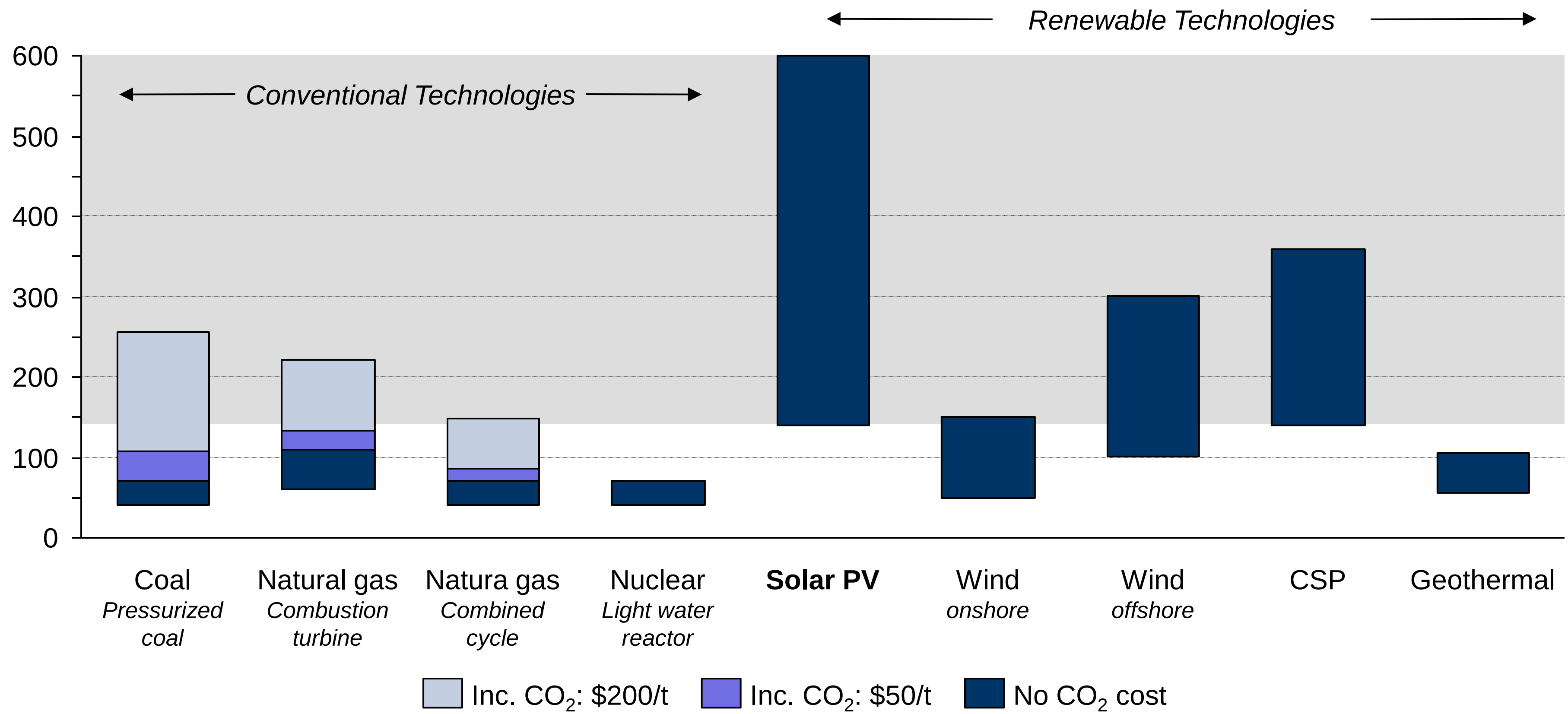
- The economics of Solar PV are dominated by the initial investment cost. Operation & Maintenance costs are low because of the absence of fuel costs and moving parts, and range annually between 0.5% and 1.5% of the initial investment.
- Given the investment structure of PV systems, project economics are highly sensitive to the cost of capital measured by the discount rate.
- The levelized cost of electricity is also highly dependent on the load factor and thus the availability of sunlight.

Note Investment costs assumed at \$5,500/kW for residential, \$5,150/kW for commercial, \$3,650/kW for utility-scale fixed tilt and \$4,050/kW for utility-scaled one-axis, annual O&M from \$41 to \$64/kW and a lifetime of 25 years.

Source: IPCC (2011), "Special report on renewable energy"

Despite recent cost declines, the LCOE of PV power remains more expensive on average than fossil-fuel energy and the LCOE of other renewables

CURRENT LCOE RANGE FOR TECHNOLOGIES WITH SEVERAL CARBON PRICE SCENARIO
$/MWh

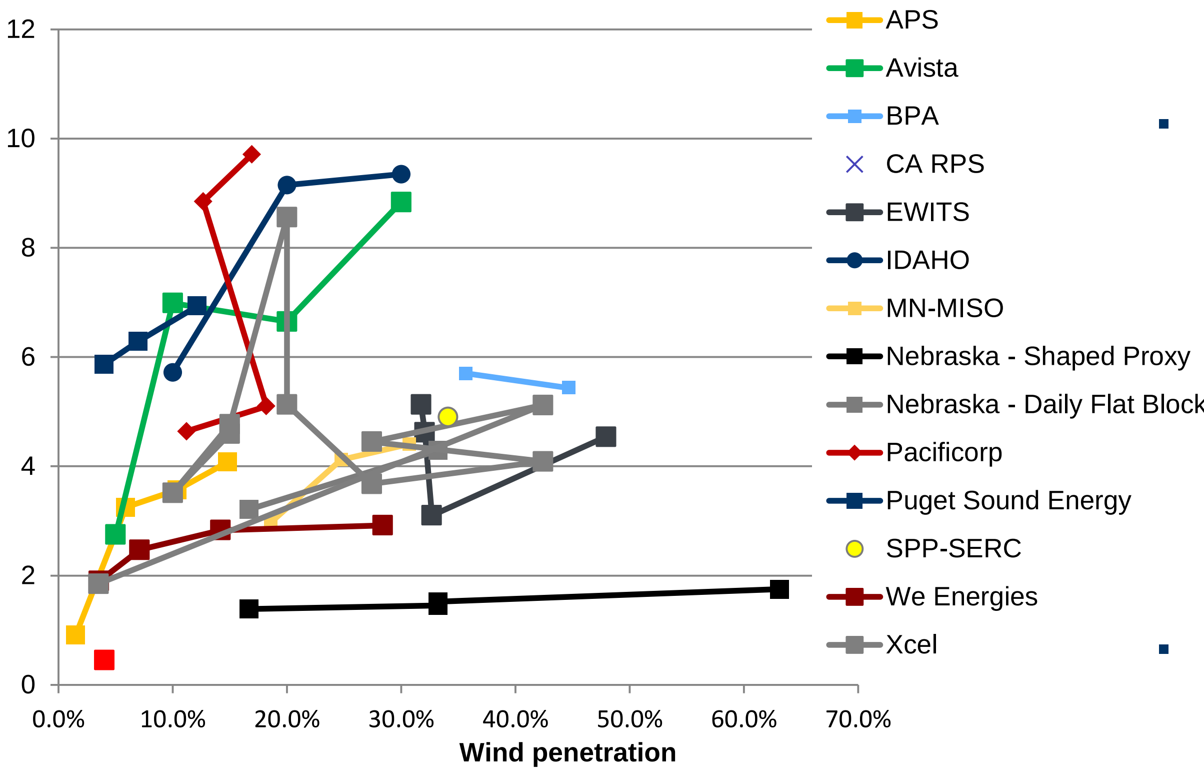


Note: Levelized cost of electricity (LCOE) ranges reflect differences in resources available, local conditions and choice of sub-technology. Calculations are based on a 7% discount rate and may not reflect differences in financing costs between countries. Coal carbon intensity is estimated at 740 gCO_2/kWh, Natural gas combustion turbine at 400g CO_2eq./kWh and natural gas combined cycle at 310 gCO_2eq./kWh. Nuclear and renewable technologies are considered carbon neutral.

Source: SBC Energy Institute Analysis based on IEA (2012), "Energy Technology Perspectives", IRENA cost reports series and US DoE & NREL transparent cost database

Expenditure on grid integration to compensate for the intermittent nature of PV will add to the cost of PV, but this is difficult to assess and is highly system specific

INCREASE IN BALANCING COSTS FOR WIND
$/MWh



- **The full cost of PV comprises levelized costs and incremental system costs of matching intermittent output with demand.**
- **Additional system costs depend on:**
  - **The penetration rate**: costs are negligible when penetration rates are low, as other flexible resources can accommodate variations in the availability of solar, but rise as the share of intermittent capacity in the generation mix grows;
  - **Power system**: costs depend on the structure of the power system, especially on the existence of low-cost resources that enhance system flexibility, such as market interconnections, storage capacity, demand response potential and dispatchable power plants.
- **There is a lack of data for solar-integration costs due to the low maturity and penetration rate.**

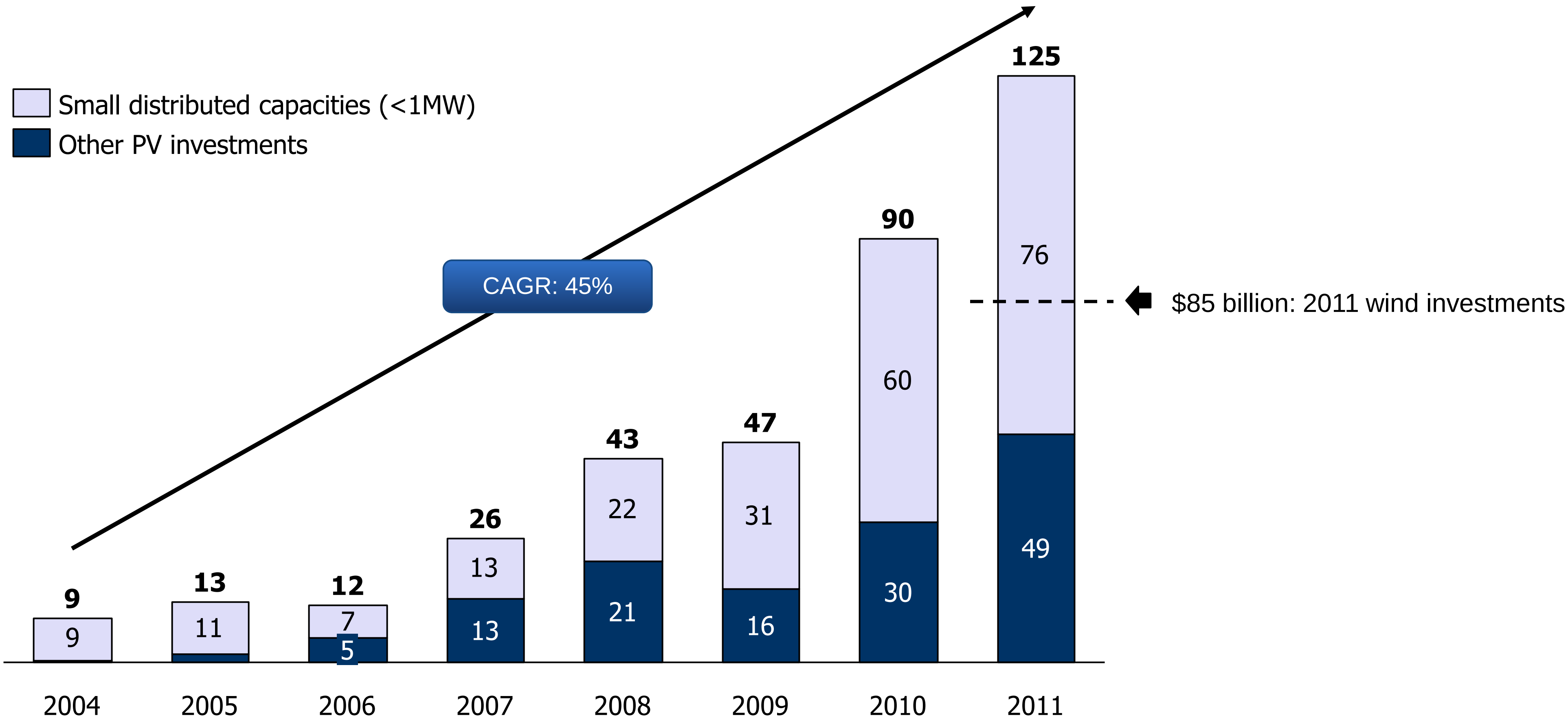
Results from wind must be analyzed with caution as solar PV production tends to be more closely correlated with demand, especially in locations with high use of air conditioning.

Note: Balancing costs mean costs resulting from matching supply with demand on a relatively short timescale, ranging from minutes to days. Additional transmission costs (*e.g* .new long-distance transmission lines to sunniest regions if distant from major load center) and adequacy costs (*i.e.* cost of matching supply and demand on a month-to-year timescale) are not included in the figures above.

Source: IPCC (2011), "Special report on renewable energy"; US DOE LBNL (2012), "2011 Wind Technologies Market Report"

Solar PV investment boomed in the late 2000s, driven by growth in small, distributed capacity

TOTAL PV INVESTMENTS
$ billion

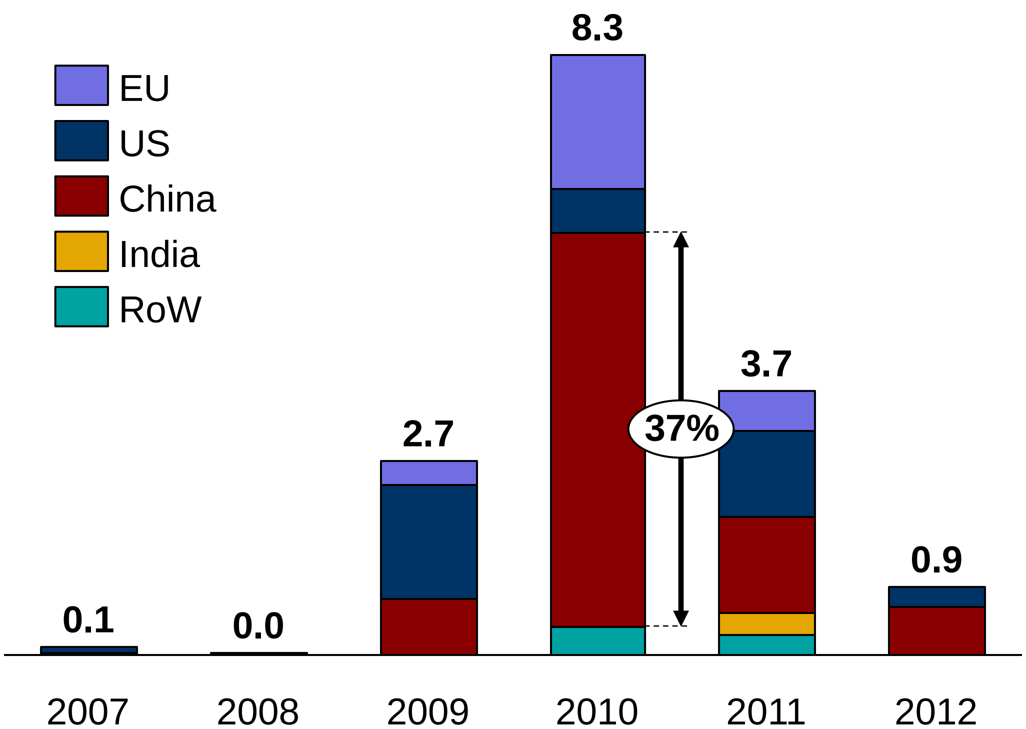


Note: Total PV investments include large project-financing deals, equipment-manufacturing scale-up, R&D and small distributed capacity.
Source: Bloomberg New Energy Finance, extracted from database July 27 2012

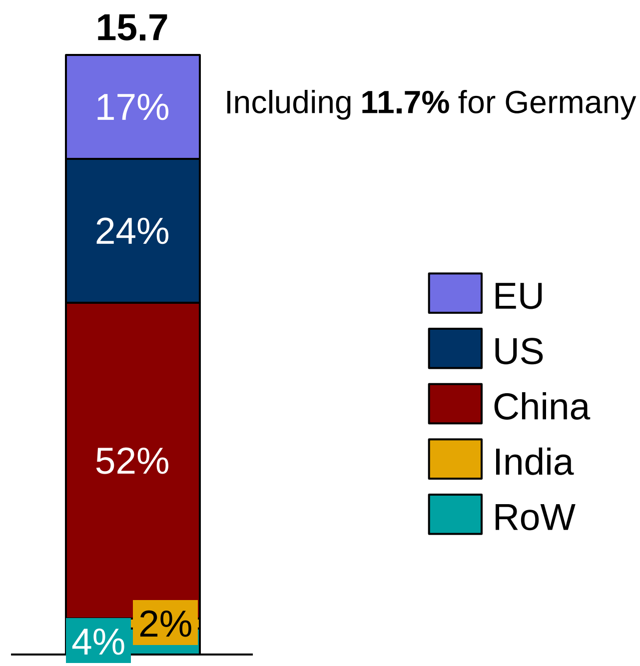
Schlumberger SBC Energy Institute

China has changed market dynamics by granting large loans to its PV manufacturers

CORPORATE DEBT GRANTED TO PV
$ billion, 2007-2012



CUMULATIVE CORPORATE DEBT GRANTED TO PV
$ billion, cumulated over 2007-2012



Note: Corporate debt is a component of PV investment mainly dedicated to upscaling manufacturing capacity. It can be issued by selling bonds on securities exchanges or by applying for loans with banks or private investors.

Source: Bloomberg New Energy Finance, extracted from database 23rd May 2013

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Asian companies are the main players in the silicon value chain

VALUE CHAIN: CRYSTALLINE SILICON

Raw feedstock	Ingots and wafer	Cells	Modules	Balance of System	Project development and installation
- Mitsubishi	- Solarworld	- Suntech Power**	- JA Solar	- Sharp	- Phoenix Solar
- JFE Steel	- Sharp	- Motech Solar	- Sharp	- Power One***	- Mitsubishi
- REC*	- JFE Steel	- Sharp	- Hanwah SolarOne	- Nitto Kogyo	- Hanwha SolarOne
- Hanwha SolarOne	- Hanwha SolarOne	- Canadian Solar	- Solon	- SMA Solar Technology	- Ralos solar
- OCI	- Motech Solar	- Trina Solar	- Canadian Solar		- Reis Solar
- Tokuyama	- Canadian Solar	- Yingli Green	- Trina Solar		- Mohring Energie
- GCL Solar	- GCL Solar	- AUO SunPower	- First Solar		- Colexon
- Leshan electric	- Yingli Green		- Yingli Green		- YHS Co
- Wacker Polysilicon	- Trina Solar				- Green Tec Co
	- REC				- First Solar
					- Leshan Electric
					- Saferay

Note: * REC = Renewable Energy Corporation, which has shut down its crystalline silicon division.
** The main subsidiary of Suntech Power announced bankruptcy in March 2013.
*** Power One was been bought by ABB (Switzerland) for about $1 billion in April 2013.

Source: Bloomberg New Energy Finance (2012)

Chinese and Japanese firms dominate the thin-film industry

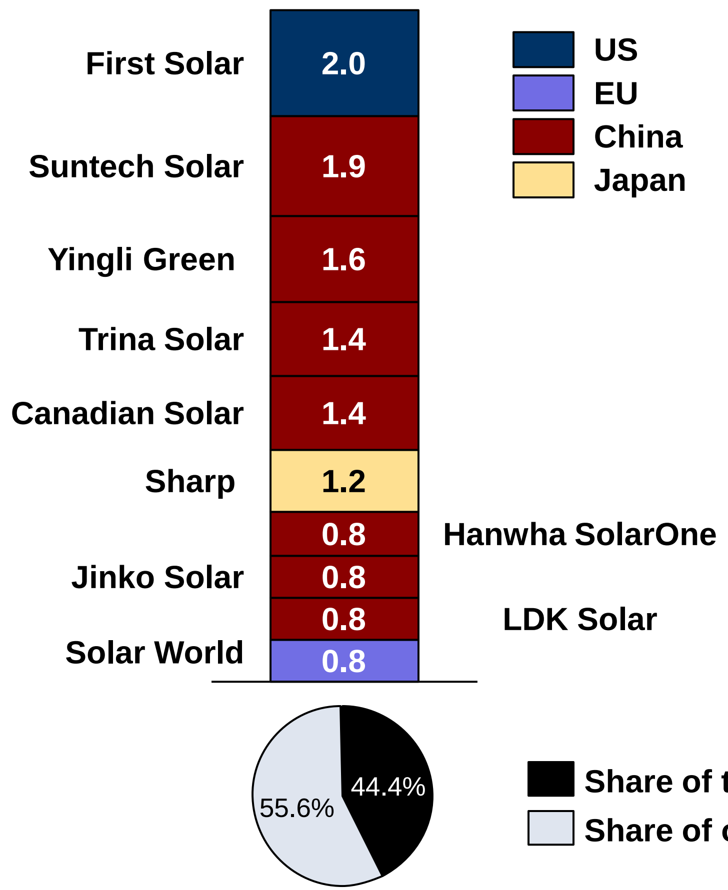
VALUE CHAIN: THIN FILM

CEM	Raw Material	Cells, monolithic integration and modules	Balance of System	Project development	Installation
- Dai-Ichi Kiden	- Jinzhou Xuloing	- Jinzhou Xuloing	- Phoenix Solar	- Mitsubishi	- Phoenix Solar
- Covalent Materials	- Mitsubishi	- Kaneka Solar	- Tindo Solar	- Hanwha SolarOne	- Mitsubishi
- Ulvac	- Ulvac	- Sharp	- Dainippon	- Ralos Solar	- Hanwha SolarOne
- Iwasaki Electric	- Hebel Dongxu	- Xinyi Solar	- Iwasaki electric	- Reis Solar	- Ralos solar
- TEL Solar	- Jiangsu Akcome	- Gintech	- SunPower	- Mohring Energie	- Reis Solar
- Toshiba	- Toppan Printing	- Sanyo	- Siemens	- Colexon	- Mohring Energie
- SiC Processing	- MEMC Electronic	- Scheuten Solar*		- Scheuten Solar	- Colexon
- Manz Asia	- Taiyo Nippon	- First Solar		- Phoenix Solar	- YHS Co
- Dainippon Screen Manufacturing	- Sumitomo	- Bosh		- SunPower	- Green Tec Co
		- Zhejiang Shuqimeng		- Siemens	- LG Solar Energy
					- Seohan E&C
					- Daesung

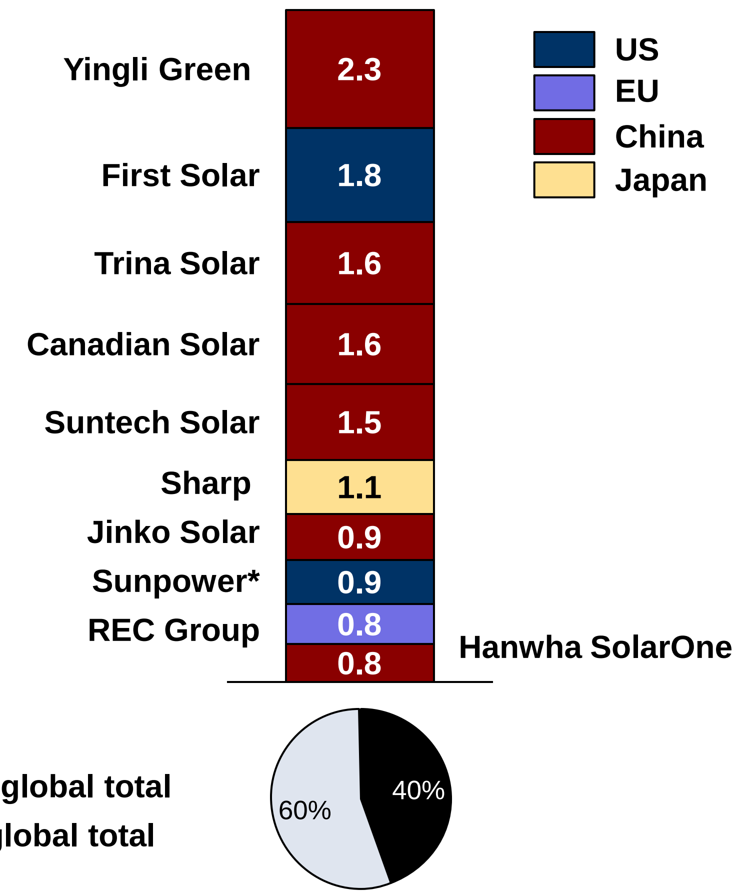
Note: * Scheuten Solar filed for insolvency in March 2012 and was bought by Aiko Solar a few months after.
Source: Bloomberg New Energy Finance (2012)

While many of the top-10 module manufacturers lost market share in 2012, China remains the leader and has the greatest overcapacity

TOP-10 PV MODULE MANUFACTURERS
Module production in GW - 2011



TOP-10 PV MODULE MANUFACTURERS
Module production capacity in GW - 2012



Share of top-10 manufacturers of global total
Share of other manufacturers of global total

Note: * Despite Tota's (France) majority stake, US-based Sunpower is considered as an American company.
Source: IMS research (2013), "PV Integrated Market Tracker – Q1'13"

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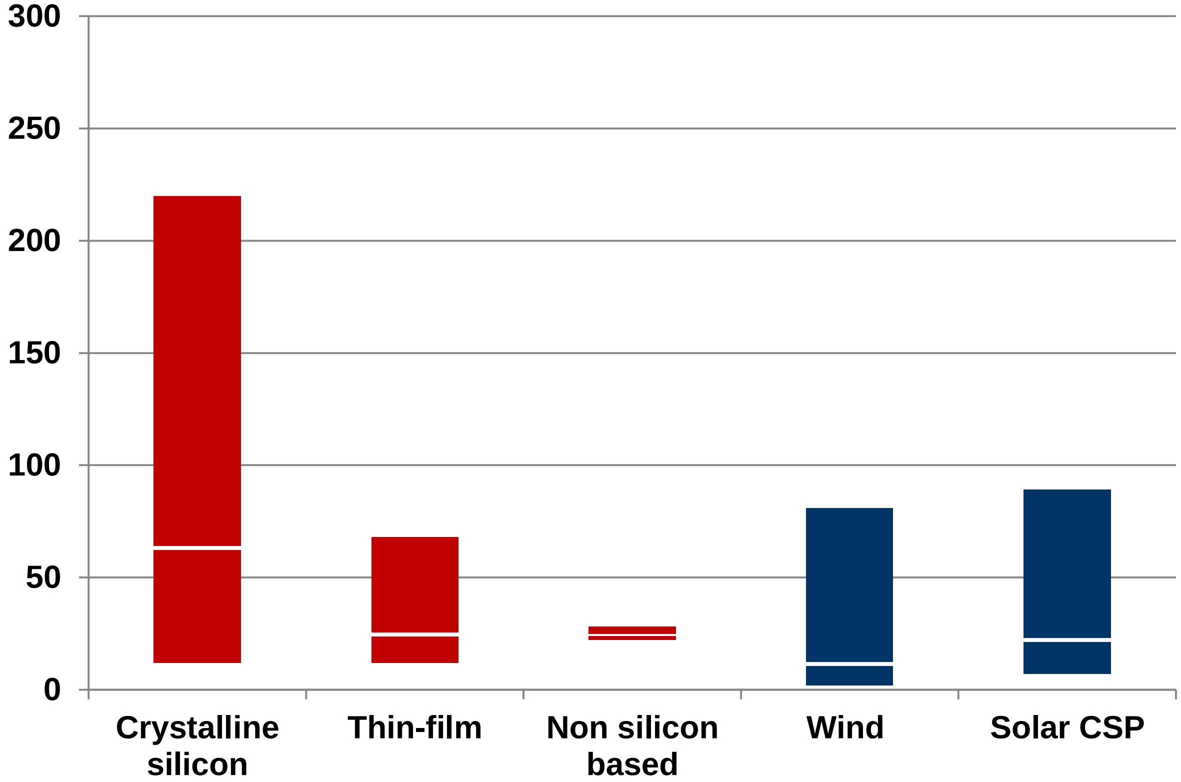
5. Environmental & Social impacts

Greenhouse gas (GHG) emissions from solar PV are low, but the technology's overall environmental impact depends on power-system integration

LIFECYCLE GREENHOUSE GAS (GHG) EMISSIONS
g CO_2eq/kWh



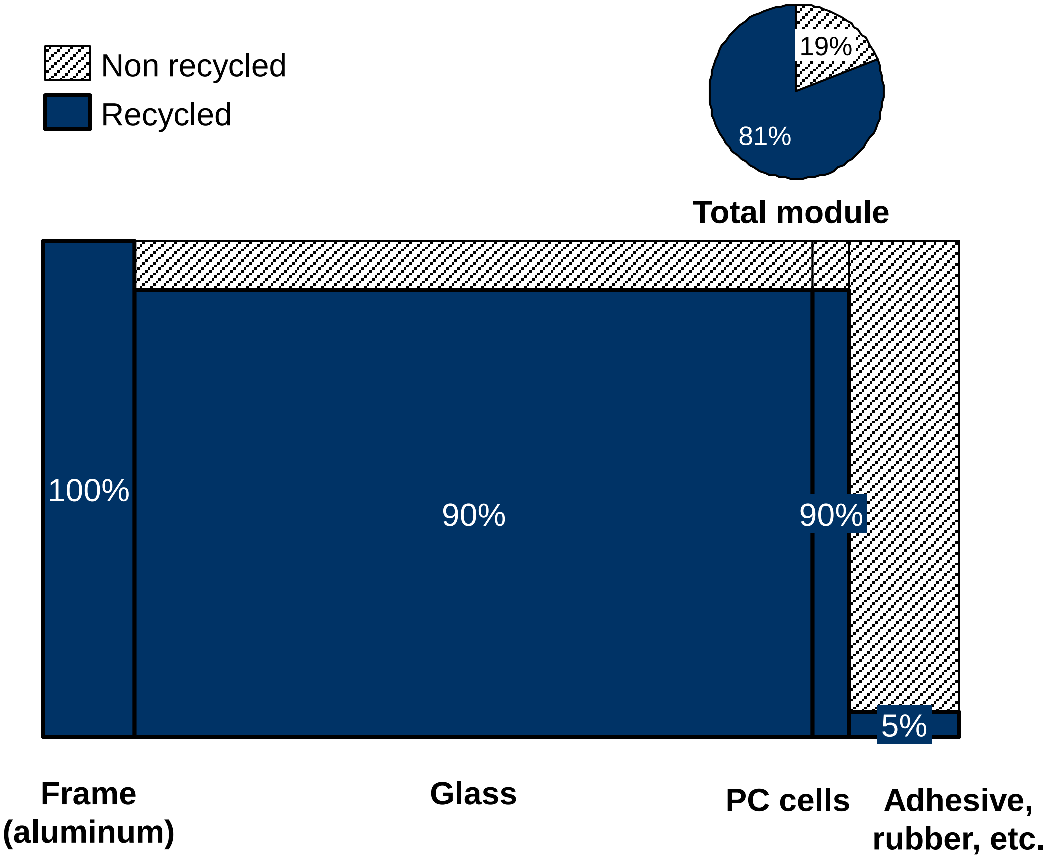
	Crystalline silicon	Thin-film	Non silicon based	Wind	Solar CSP
Median *g CO_2 eq / kWh*	65	24	24	12	22

- Solar photovoltaic (PV) does not directly emit GHGs or other pollutants. However, median solar PV emissions range between 24 and 65 g CO_2 equivalent per kWh over the entire lifecycle, depending upon the material used for the cells. This range is close to concentrating solar power and wind, and significantly lower than natural gas and coal-fired power plants that range from 500 to 1,000 gCO_2eq/kWh, respectively, for conventional combustion turbines in the US*.
- Lifecycle emissions depend on control and recycling measures during the manufacturing process, as well as installation, Operation & Maintenance, and disposal procedures.
- Crystalline silicon production is electricity intensive, so lifecycle emissions depend on the carbon content of the electricity used.
- Replacing fossil-fuel power capacity with solar PV may result in an increase in the use of flexible back-up plants. This could lead to a rise in GHG emissions, although the impact would be highly system specific. In general, however, greater use of solar PV should reduce significantly pollutants and GHG emissions.

Note: *Figures aim to provide an order of magnitude, as lifecycle emissions are inherently specific to location and technology.
Source: IPCC (2011), "Special report on renewable energy"; IEA (2012), "Energy Technology Perspectives"

Recycling is crucial in ensuring the PV industry is sustainable

RECYCLABILITY OF A TYPICAL CRYSTALLINE PV MODULE
% of total mass

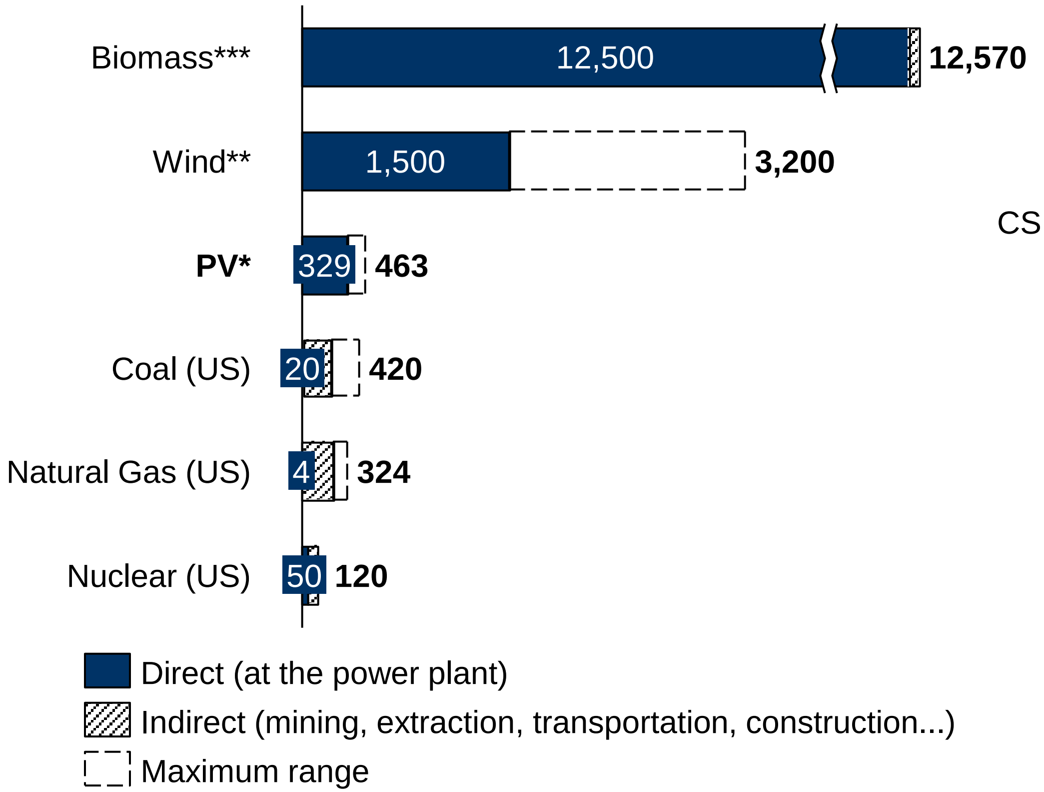


- Production of crystalline silicon modules generates a large amount of electronic waste, as in the semi-conductor industry.
- Recycling and disposal processes are therefore essential and will be even more crucial for thin films because of the use of rare metals.
- Recycling is already a core part of the PV industry as:
  - It is economically viable for large-scale applications. It is predicted that 80%-96% of glass, ethylene vinyl acetate and metals will be recycled;
  - Modules are being designed to aid recycling;
  - Solar PV manufacturers are increasingly being held responsible for the lifecycle impact of their products.

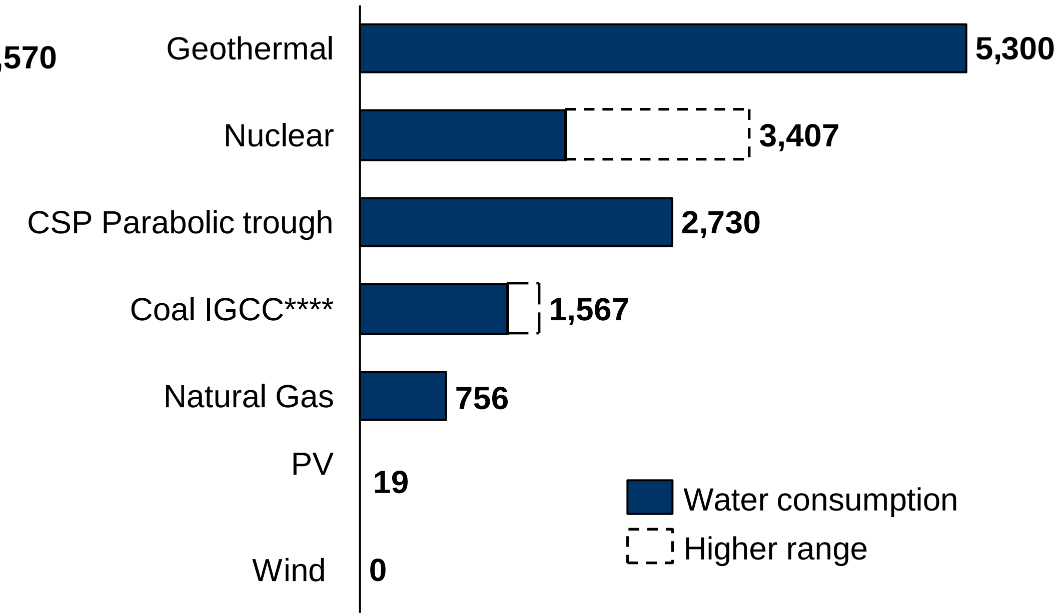
Source: IPCC (2011), "Special report on renewable energy"

Although there are concerns about lifecycle pollutants, PV technologies appear to have a limited social and environmental impact

LIFECYCLE LAND TRANSFORMATION REQUIREMENT
m^2/GWh



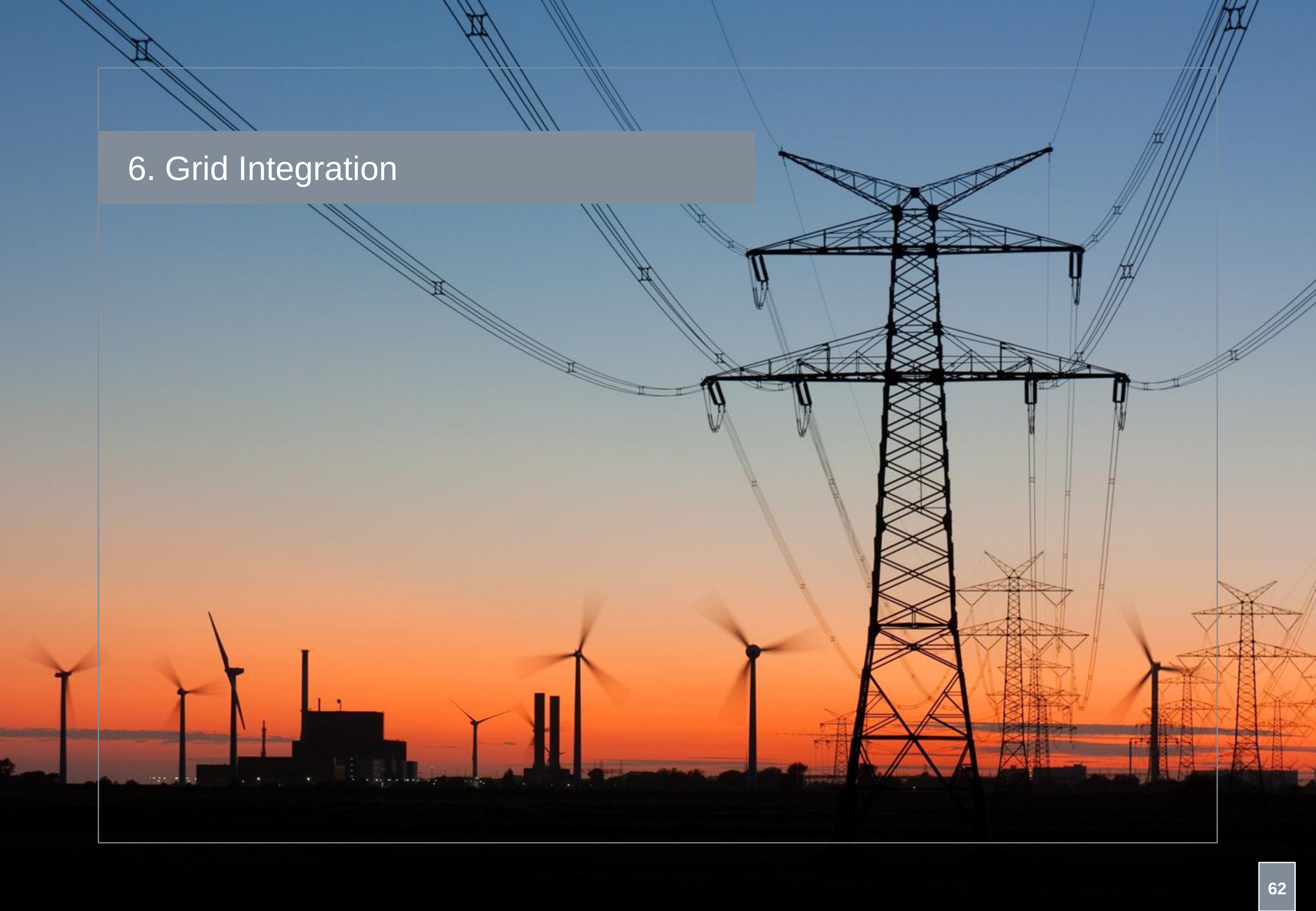
PLANTS' WATER CONSUMPTION
L/MWh



Note: Land transformation is assessed over a 30-year lifetime. * PV Multi crystalline technology. Range is based on current US and European PV farms. ** California ~1500m²/GWh; Denmark Taendpibe: ~3200m²/GWh. *** Willow gasification, New York. Water consumption refers to water that disappears or is diverted from its source. **** Integrated Gasification Combined-Cycle.

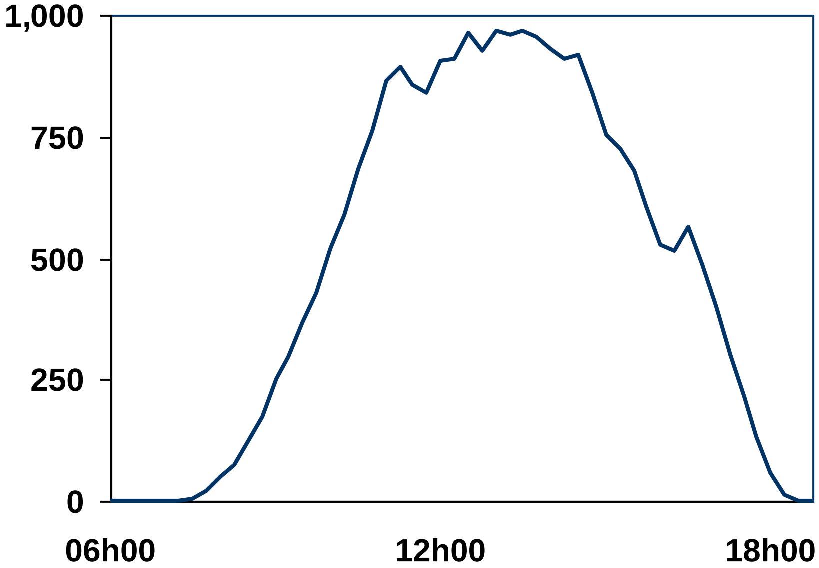
Source: Fthenakis, V & Kim, H (2009), "Land use and electricity generation: A life-cycle analysis"; World Policy Institute (2011), "The Water-Energy Nexus"; Campbell (2009), "Water issues of Concentrating Solar Power Electricity in the U.S. Southwest"

6. Grid Integration



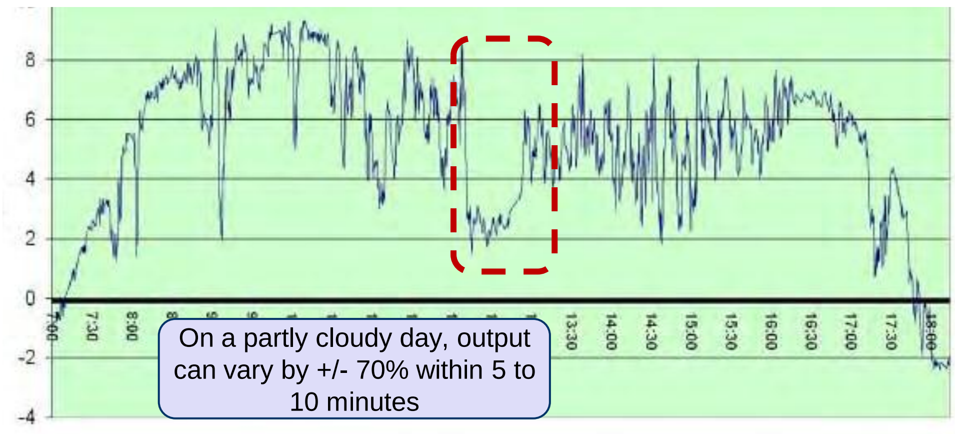
Solar PV output varies during the day, the season and the year, as a result of solar irradiance and the weather

DAILY PV OUTPUT IN GERMANY
MW, 07/10/10



- Unlike wind, solar has a clear **day/night production pattern.**

DAILY PV PLANT OUTPUT IN NEVADA
MW, 3/25/2008 on a partially cloudy day



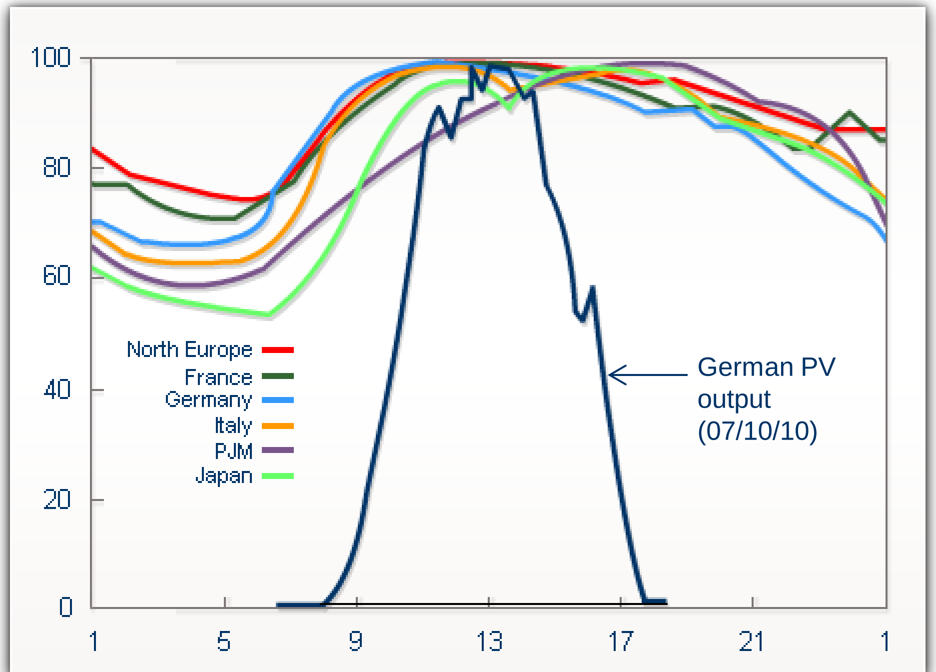
- **Sudden variations** can have a significant impact on voltage stability and the power flow in the local T&D grid.
- **Generation from numerous systems over a wide area is likely to reduce disruption to grid stability by having a smoothing effect** on the flow of electricity: a five-minute change in output can exceed +/-50% within an individual system in Germany but this cannot result in a change greater than +/- 5% in the country as a whole.

Source: IPCC (2011), "Special report on renewable energy"

PV faces the usual intermittent renewable grid-integration challenge of ensuring power quality, and matching supply and demand

DAILY LOAD CURVE IN VARIOUS COUNTRIES AND DAILY PV OUTPUT IN GERMANY

% of daily peak



- **PV supply pattern tends to be closer to demand pattern than wind.**

- **Seasonal and annual variations are more extreme at higher latitudes**, making it more difficult to balance supply and demand. Nearer the equator, however, **Solar PV could prove beneficial in warm and sunny regions**, where peak demand is driven by air conditioning, and therefore coincides with peak times for solar irradiance. This partially negates the need to compensate for large volumes of marginal demand with capital-intensive power plants. This is currently the case in the Middle East and North Africa and in the Southwestern US, although potentially this applies to vast equatorial regions and Oceania. Finally, **wind and solar could be complementary**, smoothing out variations in supply, as wind output does not have a day/night pattern and may be higher during winter.

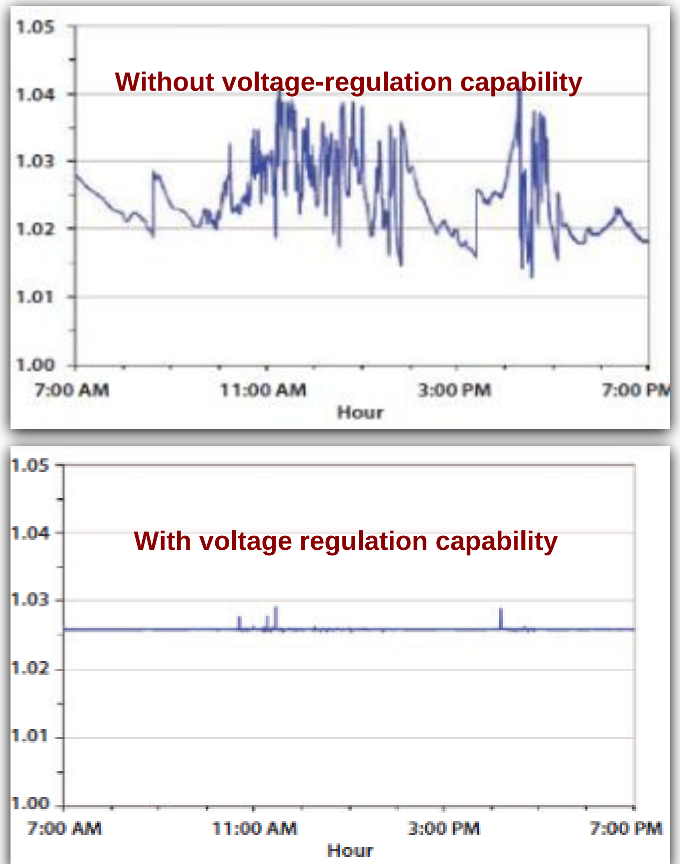
- **There is a shortage of data on the generation characteristics of and the grid-integration requirements for solar.** More data are available for wind, with several studies already undertaken (*e.g.* in Ireland, Spain).

- **Solutions exist to help meet the integration challenge:**
  - Back-up capacity;
  - Storage;
  - Grid development;
  - Demand-side management;
  - Forecast and operation improvement;
  - Technology advances.

Source: IPCC (2011), “Special report on renewable energy”; IEA (2011), “Solar Energy Perspectives”

Distributed solar PV requires distribution-system enhancements to improve grid stability and ensure reliable power flows

VOLTAGE AT THE POINT OF INTERCONNECTION OF A SOLAR PV SYSTEM WITH THE GRID
Normalized measure, relative to the nominal voltage of the connection line



- If the penetration of distributed generation (DG) grows, DG cannot continue to be regarded simply as a reduction in load. The 'fit & forget'* approach that drove the creation of today's distribution system will no longer apply.
- DG can have an adverse impact on an electricity-supply system and requires:
  - Power quality (voltage and frequency control);
  - System reliability (fault detection);
  - Safety (islanding operation).
- **Voltage regulation:** DG can complicate the regulation of voltage along distribution feeders. Advanced power electronics could help DG units play an active role in voltage regulation (*e.g.* power-conditioning modules within units).
- **Islanded operations**: system operators may require DG units to be disconnected during system outages, preventing DG from providing reliability benefits. Distributed monitoring and control overcome this hurdle (only possible for mid-sized DG or micro-grids for cost reasons).
- **Management system**: DG can disrupt the operation of system-protection schemes by making it harder to detect a fault and to coordinate protection devices. New sensors, communication equipment and management systems could help reduce costs.

Note: * The fit and forget approach means that distributed generations are built on the basis of present technologies where centralized control is applied to transmission systems and passive control to distribution systems.
Source: MIT (2011), "The Future of Electric Grid"

Appendix & Bibliography

Acronyms

- **AC**: Alternative current
- **a-Si**: Amorphous silicon
- **BOS**: Balance of system
- **BRIC**: Brazil, Russia, India and China
- **CAGR**: Compound annual growth rate
- **CdTE**: Cadmium telluride
- **CIS**: Copper-indium-selenide
- **CIGS**: Copper-indium-gallium-diselenide
- **CPV**: Concentrated photovoltaic
- **c-Si**: Crystalline silicon
- **CSP**: Concentrating solar power
- **DC**: Direct current
- **DG**: Distributed generation
- **DNI**: Direct normal irradiance
- **DoE**: US Department of Energy
- **DSSC**: Dye-sensitized solar cells
- **EJ**: Exajoules (10^{18} Joules)
- **EOR**: Enhanced oil recovery
- **gCO_2eq**: Gram of CO_2 equivalent
- **GHG**: Greenhouse gas
- **IEA**: International Energy Agency
- **IGCC**: Integrated gasification combined cycle
- **IPCC**: Intergovernmental Panel on Climate Change
- **LBNL**: Lawrence Berkeley National Laboratory
- **LCOE**: Levelized cost of electricity
- **Mc-si**: Multi-crystalline silicon
- **N/A**: Not Applicable
- **OECD**: Organisation for Economic Co-operation and Development
- **O&M**: Operation and maintenance
- **OPV**: Organic photovoltaic
- **PV**: Photovoltaic
- **PV/T**: Photovoltaic/Thermal
- **R&D**: Research & Development
- **R,D&D**: Research, Development & Demonstration
- **Sc-Si**: Single-crystalline silicon
- **Si**: Silicon
- **W**: Watt
- **Wp**: Watt peak*

Note: * Watt-peak is often used for Solar PV in order to present cost and efficiency performance under standard conditions. The output of a PV cell varies according to solar irradiance and ambient temperature.

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