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RESOR - **R**enewable **E**nergy **So**urces
as a Chance for Development for the
Rural Areas

RESOR PROJECT

Module 4:
Photovoltaic Energy

by Bursa Uludağ University

Presentation Content

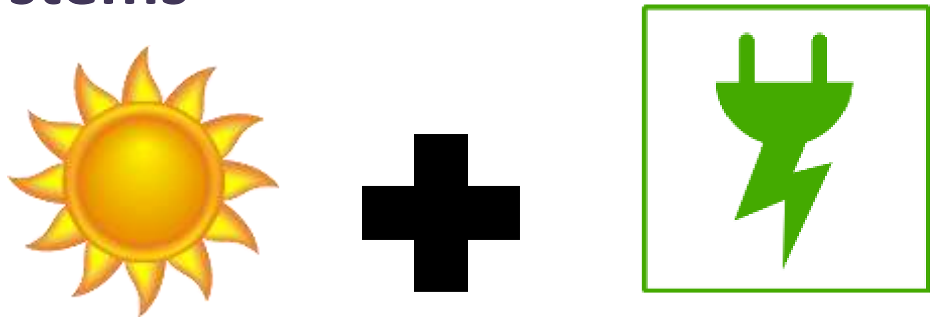
01 Photovoltaic systems & History

02 Light & PV Effect & System Components

03 Benefits & Challenges & Environmental Impacts of PV Technology

04 Economics & Case study

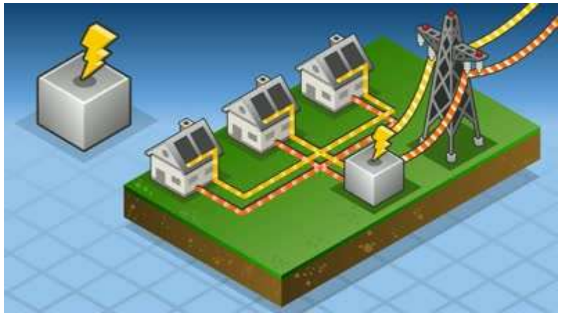
Photovoltaic Systems



Phos in Ancient Greek: Light

Volt: A measure of Electricity

Photovoltaic: Light-Electricity



Small PV systems: Small calculators, wristwatches, and outdoor lights etc.

Larger PV systems: Electricity for factories and warehouses, electricity for pumping water, powering communications equipment, and lighting homes and running appliances.

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A Brief History of Photovoltaic Technology

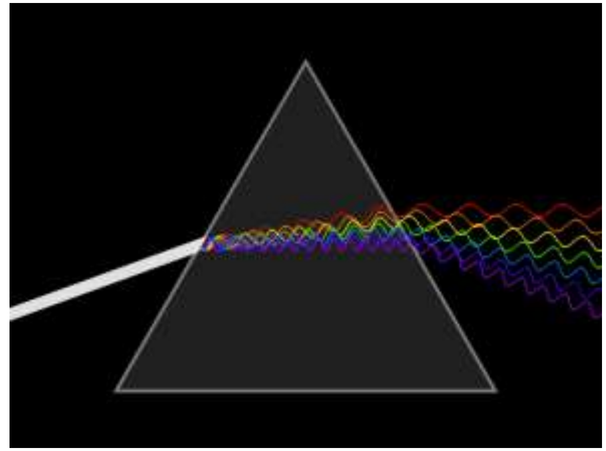
- **7th C. BC** — First use of solar power: used to light fires with a magnifying glass
- **1839** — Becquerel described photovoltaic effect: certain materials produce electric current when exposed to light

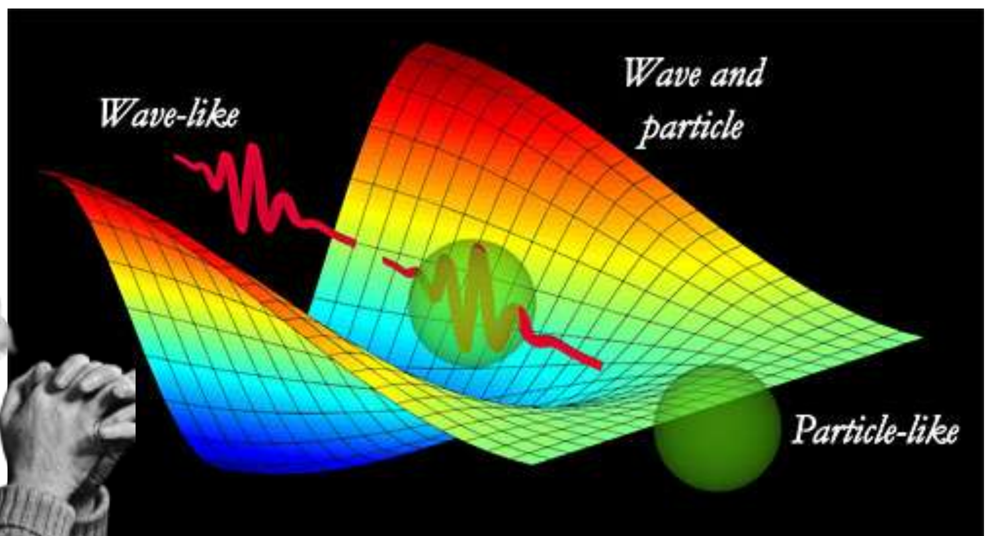
- **1873** — Selenium was discovered to have photoconductive potential (Adams& Day)
- **1883** — Charles Fritts produced the first solar cells made from selenium wafers (1% efficiency)
- **1954** — Creation of silicon photovoltaic cell at Bell Labs
- **1958** — Solar panels in outer space: Satellite used a one-watt panel to power its radio
- **1973** — First solar powered building at Delaware University
- **Today** — Many Innovations on Solar Tech

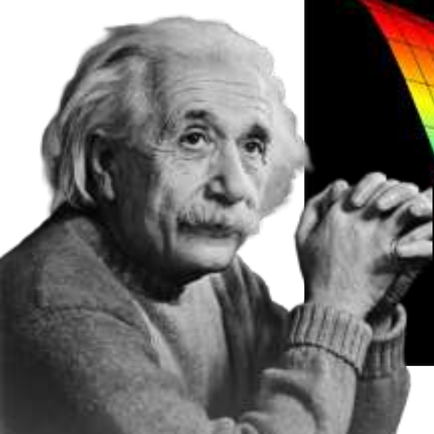
Source: https://www.goendlessenergy.com/brief-history-solar-power/

Light

- Initially **Maxwell's wave theory of light** predicted energy would be proportional to light intensity







- **Einstein** proved that light is a flow of **photons** and explained how a stream of photons can act both as a wave and particle.

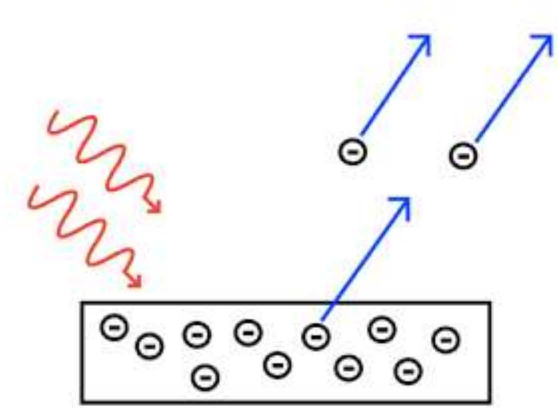
"Grains" of energy : photons

Source: https://www.photonics.com/Articles/Photons_Observed_as_Particles_Waves/a52250

Light & Photovoltaic Effect

- **A photon above a certain threshold frequency (energy) is able to eject a single electron.**

= The Photovoltaic Effect

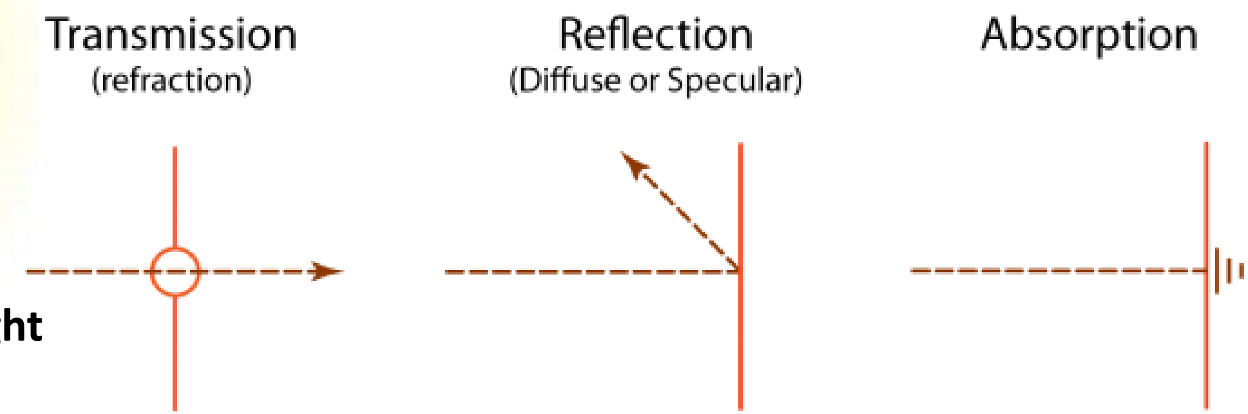


•Creation of voltage and electric current in a material upon exposure to light.
•It is a physical and chemical phenomenon.

•PV technology works any time the sun is shining, but more electricity is produced when the light is more intense and when it strikes the PV modules directly—when the rays of sunlight are perpendicular to the PV modules.

Light & Photovoltaic Effect

- Unlike solar systems for heating water, PV technology does not produce heat to make electricity.
- Instead, PV cells generate electricity directly from the electrons freed by the interaction of radiant energy with the semiconductor materials in the PV cells.



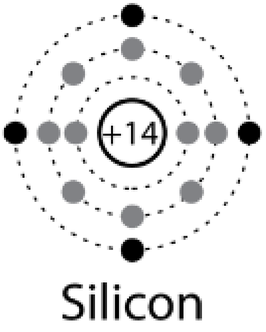
- When photons of the sunlight strike a PV cell, they may be reflected, absorbed, or transmitted through the cell.

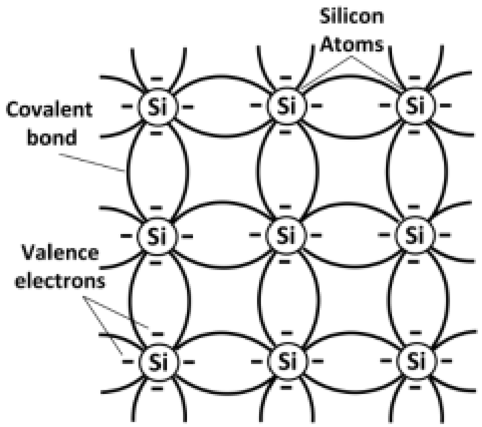
- Only the absorbed photons generate electricity.
- When the photons are absorbed, the energy of the photons is transferred to electrons in the atoms of the solar cell.

Photovoltaic Effect

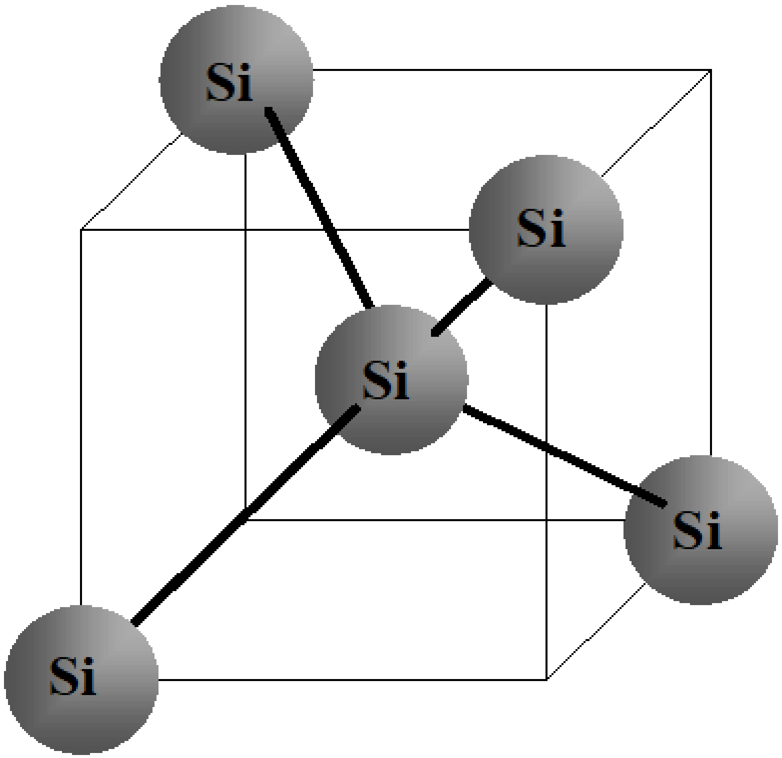
- **Photovoltaic effect:** **A process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight.**
- **Solar cell is the elementary building block of the photovoltaic technology.**
- **Solar cells are made of semiconductor materials, such as silicon.**

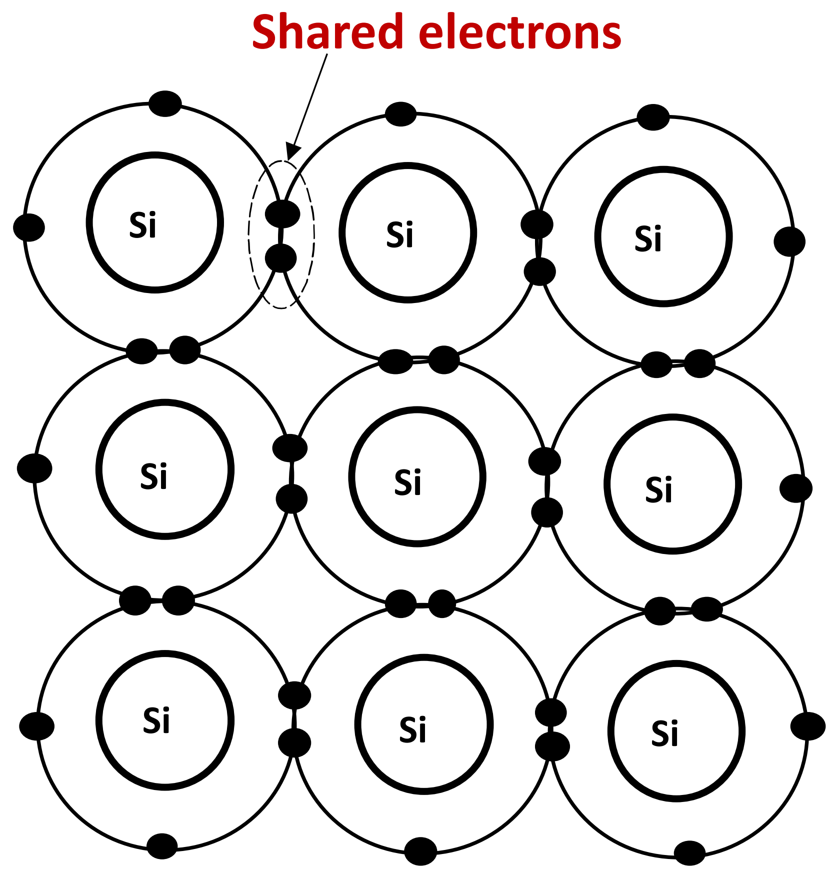
- **Conductivity of semiconductors may easily be modified by introducing impurities into their crystal lattice.**
- **Silicon, with four valence electrons, is treated to increase its conductivity.**





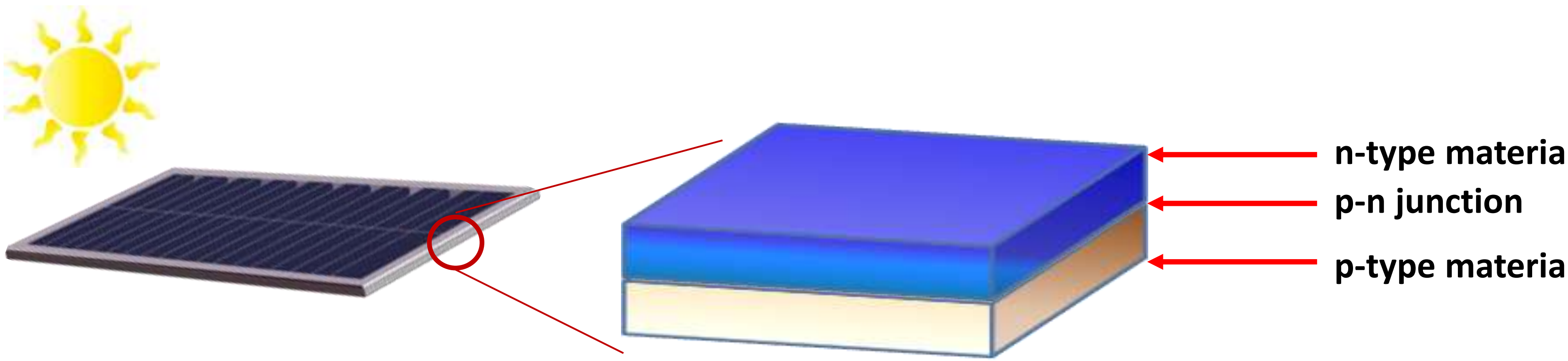
Silicon



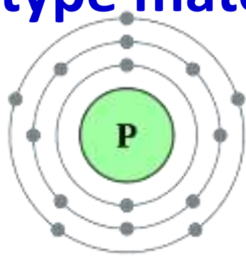


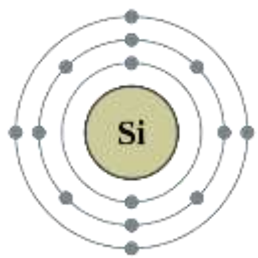
- Silicon is group IV element – with 4 electrons in their valence shell.
- When silicon atoms are brought together, each atom forms covalent bond with 4 silicon atoms in a tetrahedron geometry.

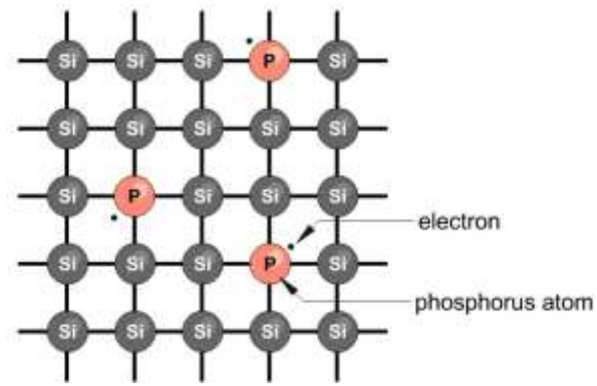
Photovoltaic Systems



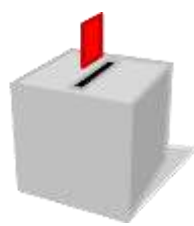
n-type material







Phosphorus donates electrons



to silicon

Phosphorus doped silicon

(5 valence electrons)

e^- e^- e^- e^- e^-

(4 valence electrons)

e^- e^- e^- e^-

e^- An extra electron, negative charge carrier created

One electron is not involved in bonding. Instead, it is free to move inside the silicon structure.

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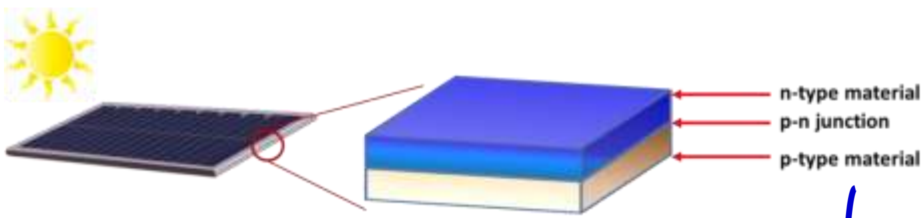
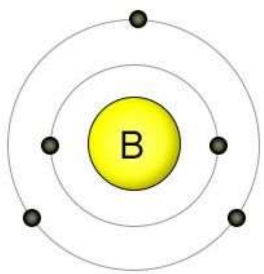


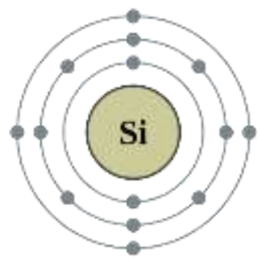
p-type material



Boron shares electrons

(3 valence electrons)

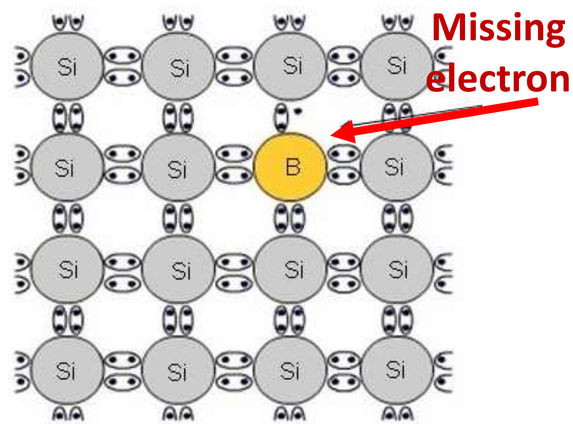
e^- e^- e^-



with silicon

(4 valence electrons)

e^- e^- e^- e^-



Boron doped silicon

An electron vacancy or «hole» is created.

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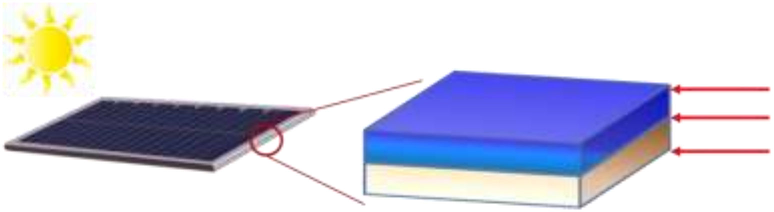
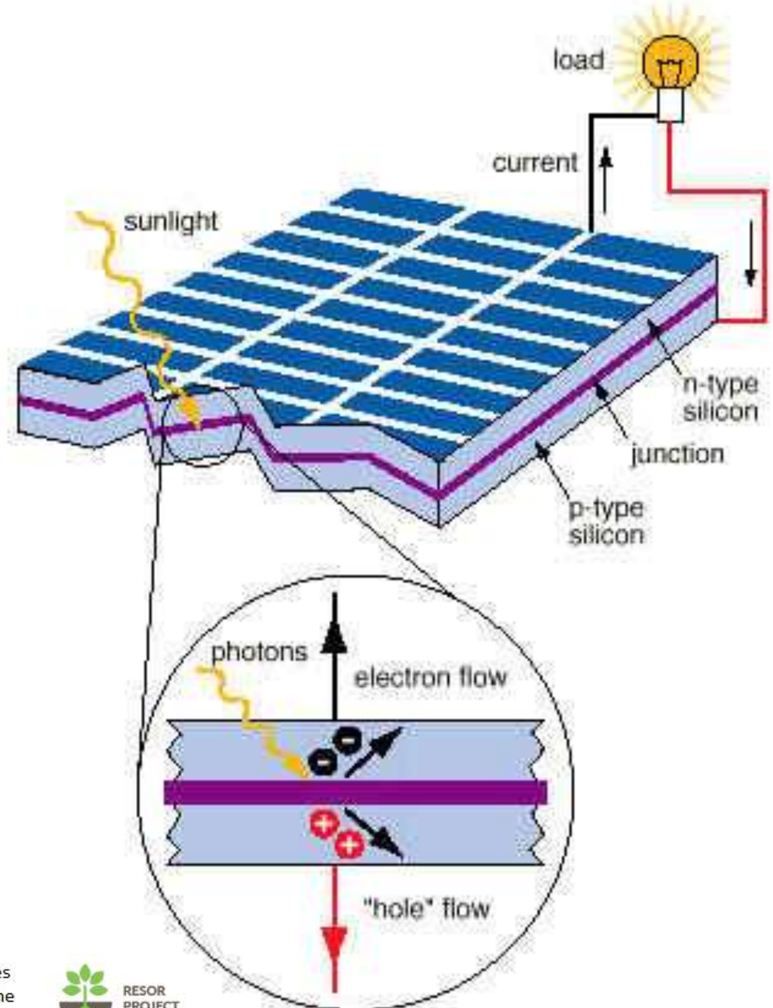


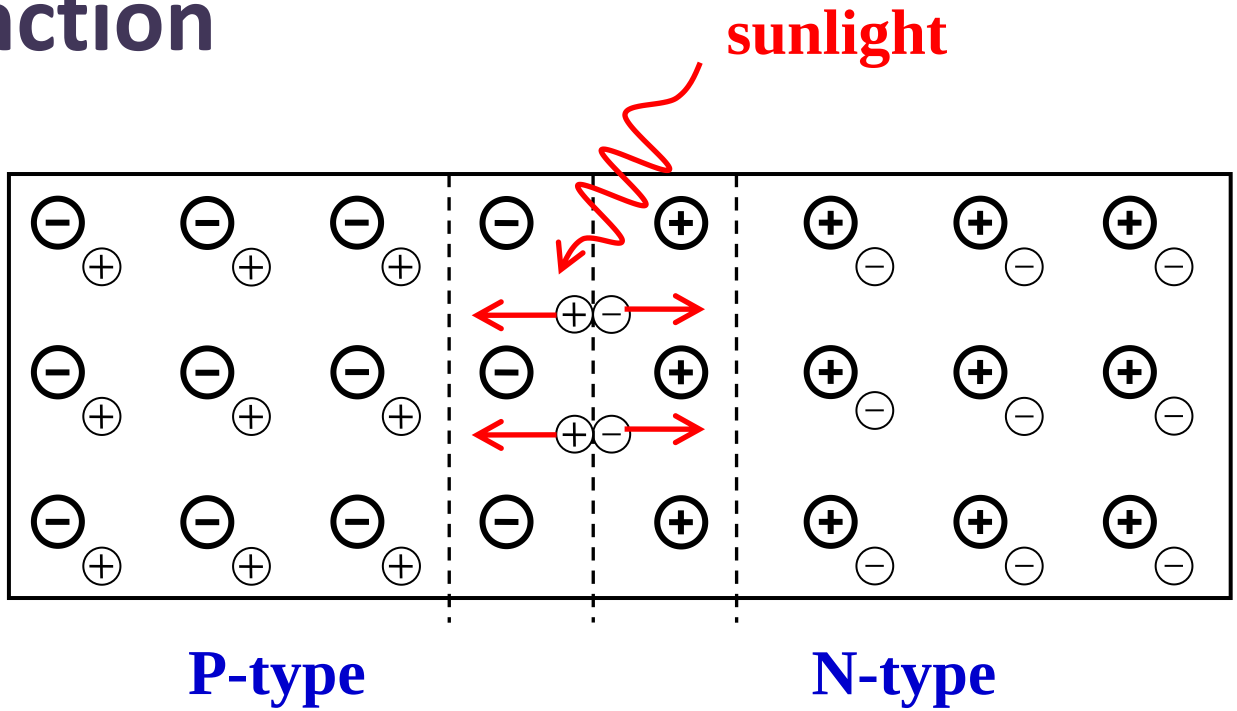
p-type and n-type materials are joined together to create a p-n junction.

p-n junction

- **n-type : an excess of electrons, p-type : excess of positively charged holes**
- **p-n junction of the two layers: the electrons on one side (n-type) move into the holes on the other side (p-type) (Diffusion of electrons).**
- **Area around the junction: Depletion zone (in which the electrons fill the holes)**
- **Sunlight will create an electric field across photovoltaic systems, causing electrons & electricity (Direct current- DC) to flow.**

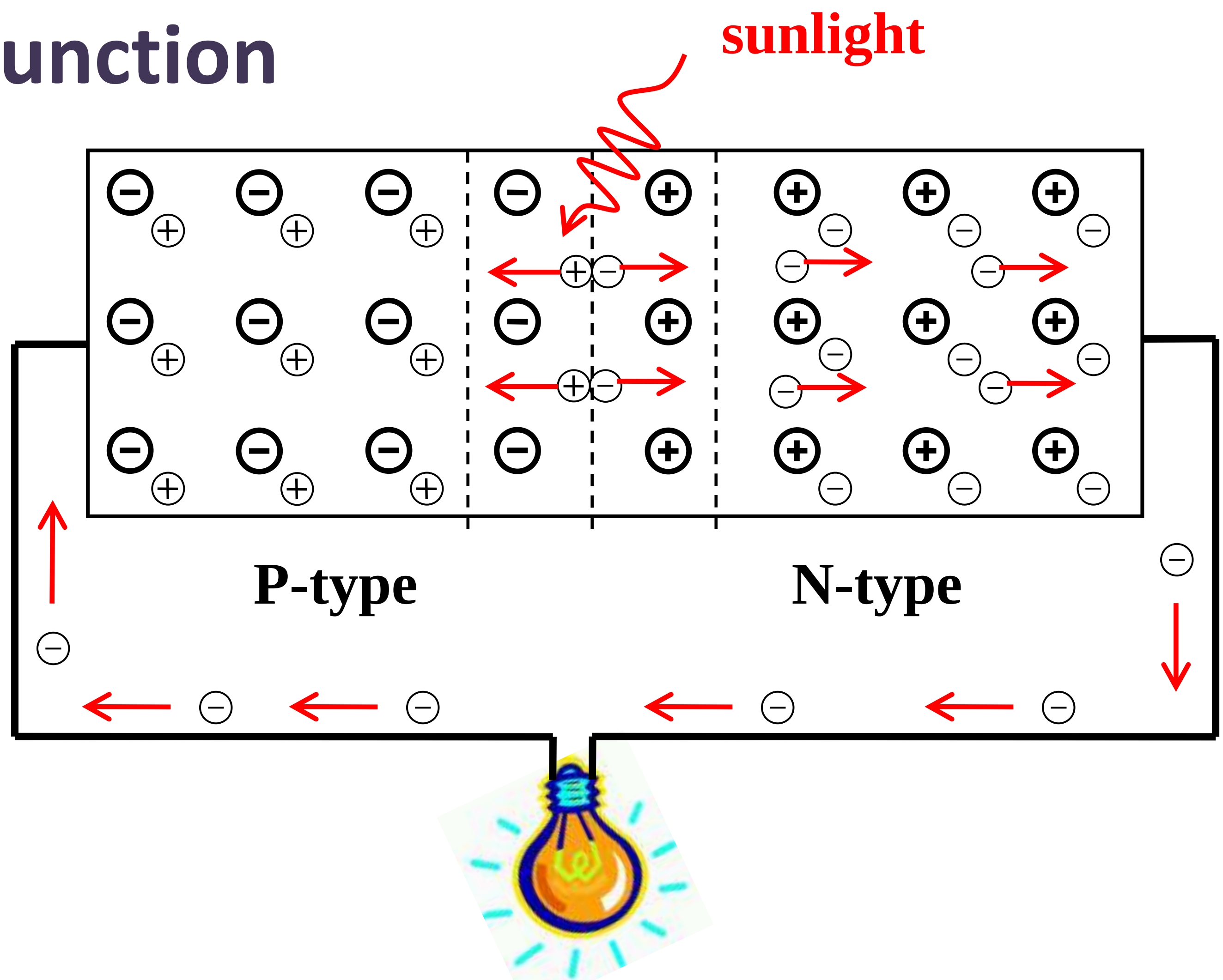


p-n junction



When sunlight strikes atoms in the P-N Junction, the free electrons on the P-type side move towards the N-type side.

p-n junction



•When sunlight strikes atoms in the P-N Junction, the free electrons on the P-type side move towards the N-type side.

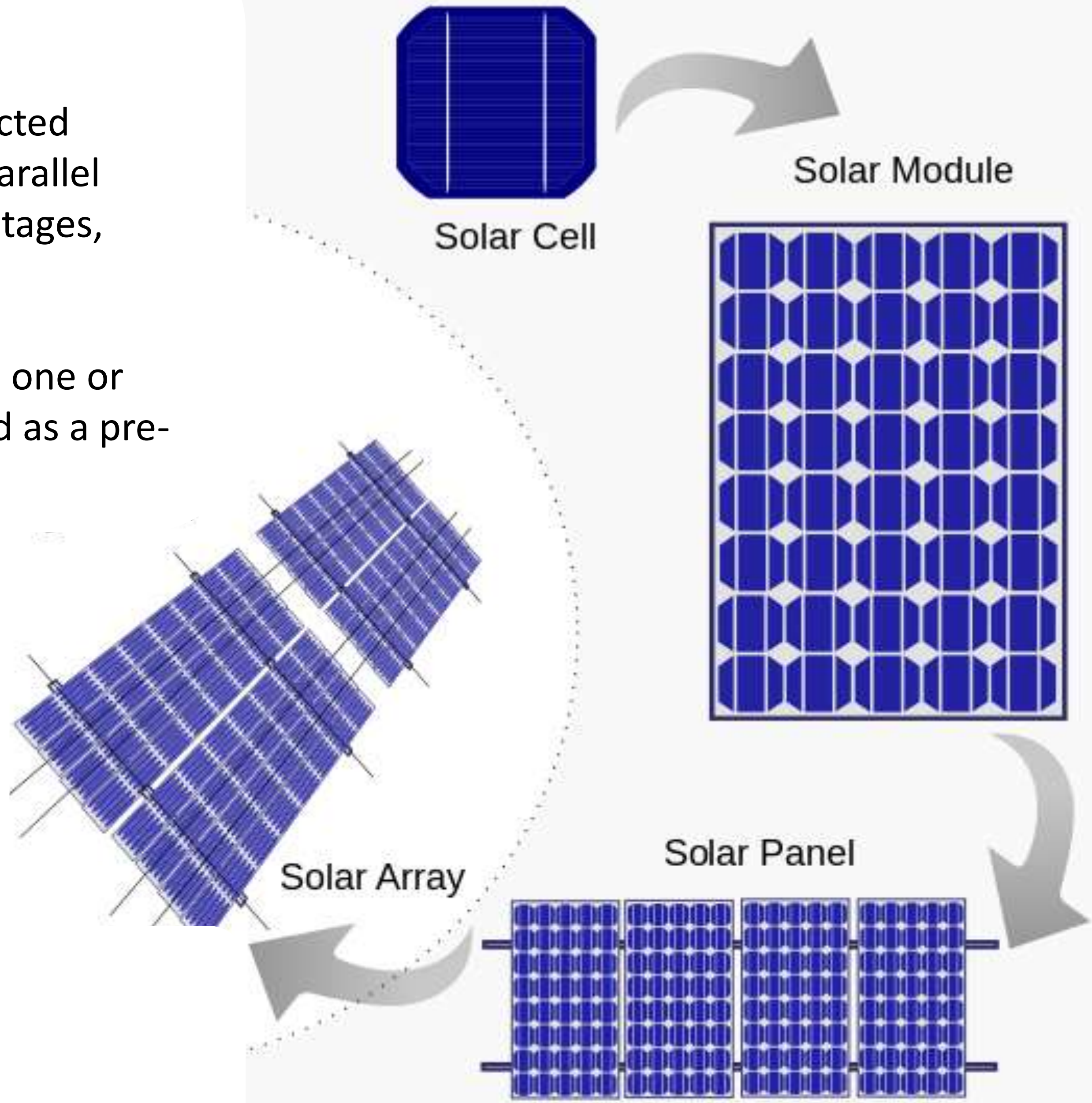
•If a load is connected across the cell, electric current is formed and the energy is transmitted to the load.

Solar Array

•Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels.

•Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit.

•A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.



Source: Wikimedia commons, From a solar cell to a PV system.svg|thumb|From a solar cell to a PV system

Components of a typical solar cell

Cover: A clear glass provides outer protection

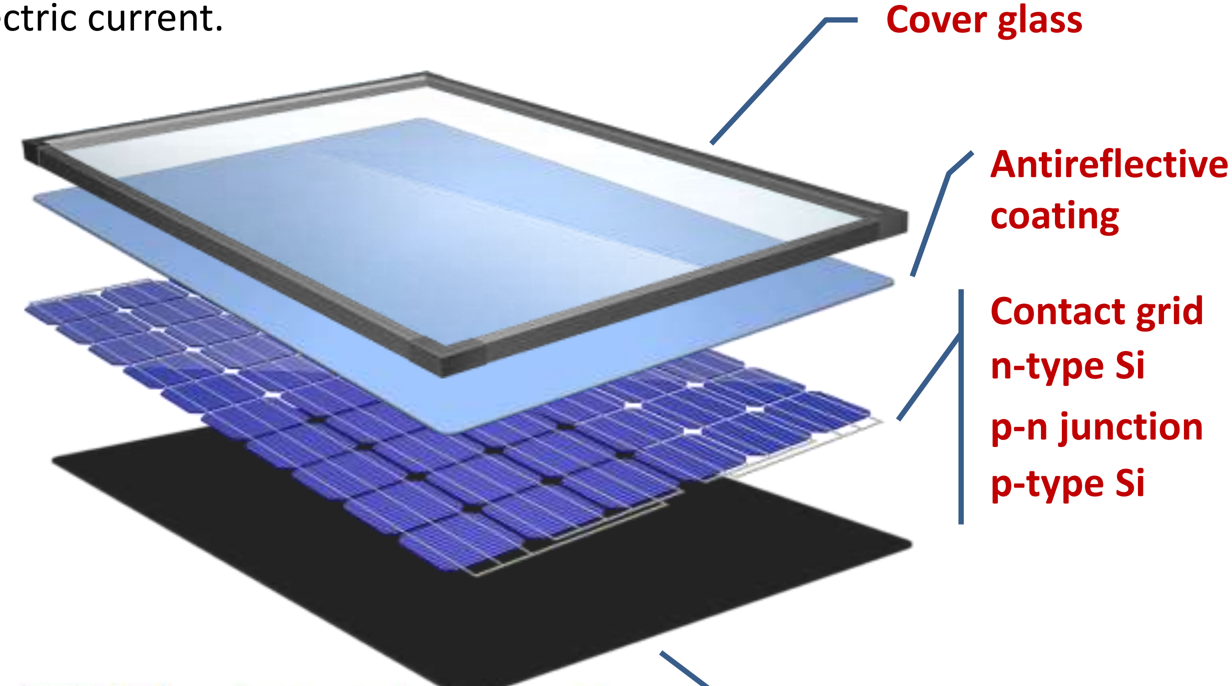
Anti-reflective Coating: Prevents the light that strikes the cell from bouncing off so that the maximum energy is absorbed into the cell.

Front Contact: Transmits the electric current.

N-Type Semiconductor Layer: Thin layer of silicon doped with phosphorous.

P-Type Semiconductor Layer: Thin layer of silicon doped with boron.

Back Contact: transmits the electric current.



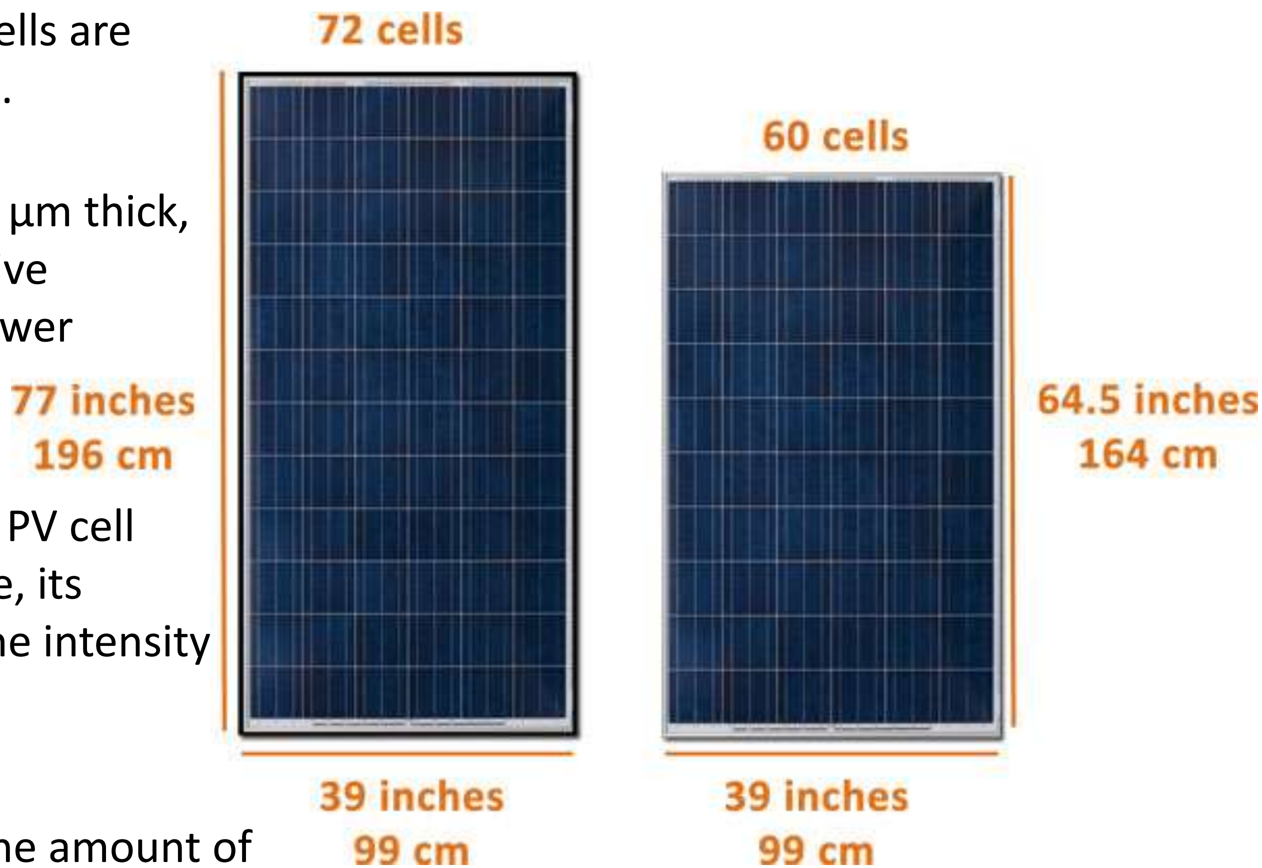
Dimensions of solar cells

•Wafer-based silicon solar cells are approximately 200 µm thick.

•Thin-film solar cells are 1-2 µm thick, require significantly less active semiconducting material (lower efficiencies)

•The amount of electricity a PV cell produces depends on its size, its conversion efficiency, and the intensity of the light source.

•Efficiency is a measure of the amount of electricity produced from the sunlight a cell receives.



•A typical PV cell produces 0.5 volts of electricity.

•It takes just a few PV cells to produce enough electricity to power a small watch or a solar calculator.

https://sunmetrix.com/solar-panel-size-for-residential-commercial-and-portable-applications/

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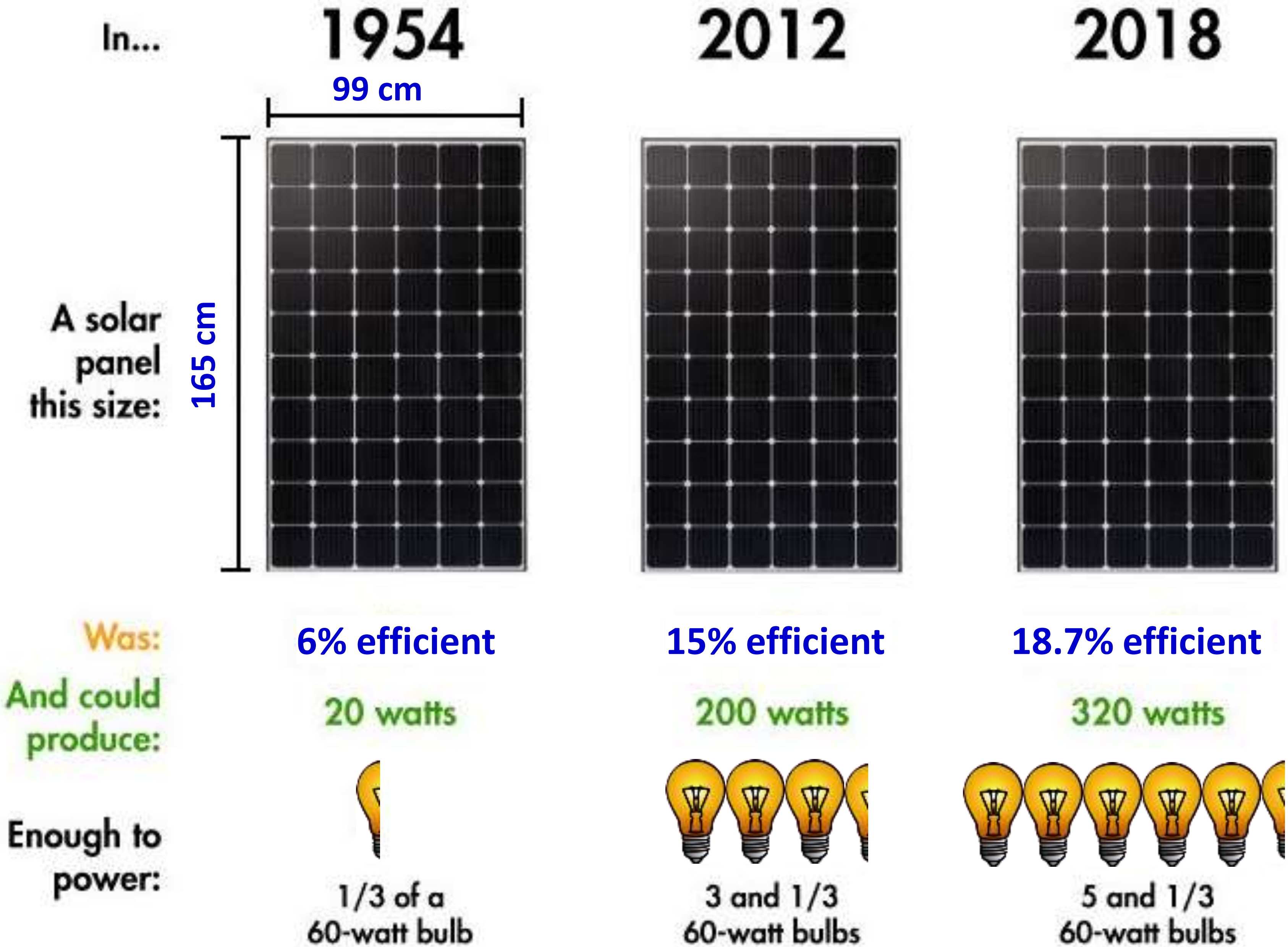
Technology improves…

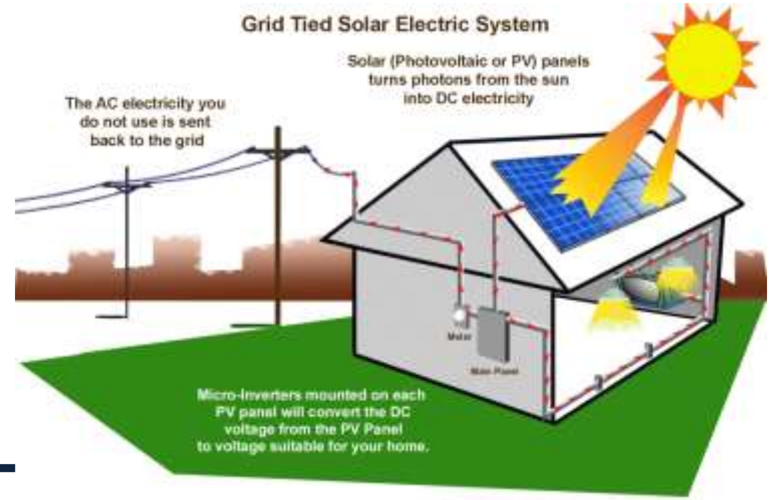


Source: American Physics Society, National Renewable Energy Laboratory
https://www.solarpowerrocks.com/solar-basics/how-much-electricity-does-a-solar-panel-produce/

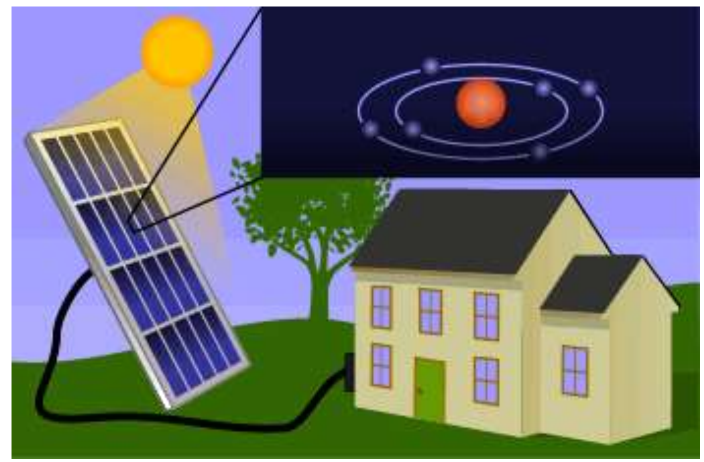
PV Systems

PV

Connected to grid



Off grid (stand-alone)



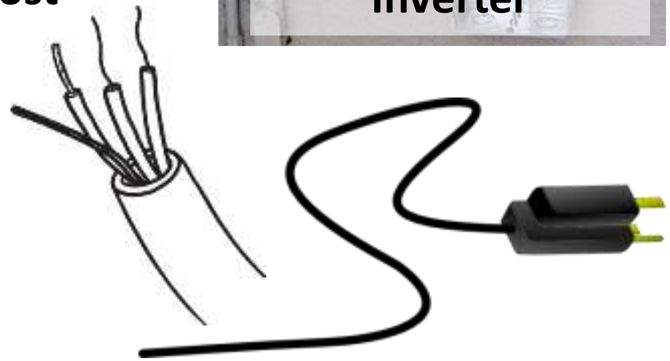
- PV generates DC electricity
- DC can be used to charge batteries.
- To supply power DC needs to be converted to AC.

- Grid transmits AC power over long distances.
- Once AC reaches the end-user, it can be converted back if needed.

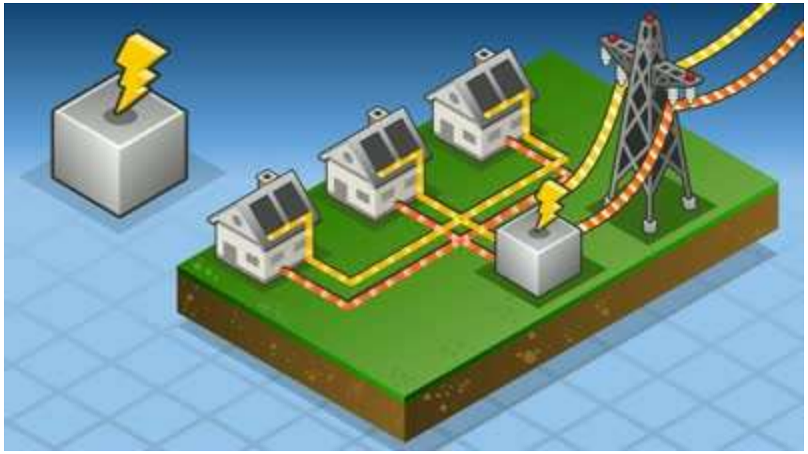
Other components

•Most of today's PV systems are modular; they allow the user to add or remove power capacity to the system at any time.

•These components distribute and store electricity safely and efficiently and can account of up to half of the total cost of a photovoltaic system.



- Solar panels
- Electrical connections between solar panels
- Output power lines
- Power inverter (converts DC to AC electricity)
- Mechanical mounting equipment
- Charge controller
- Wiring
- Batteries for energy storage
- Electrical meter (for grid-connected systems)
- Overcurrent and surge protection devices
- Power processing equipment
- Grounding equipment



CHALLENGES

- At present the costs of solar cells are high. Large numbers of solar cell modules and large spaces are required to generate power for large scale generation.
- As solar energy is intermittent, some electrical energy storage is required.
- Surface area requirement is high.
- The process to make PV technologies can have harmful effects on the environment.

BENEFITS

- No moving parts, are modular, easily expandable and even transportable .
- Energy independence and environmental compatibility
- The fuel (sunlight) is free, and no noise or pollution is created from operating PV systems.
- PV systems that are well designed and properly installed require minimal maintenance and have long service lifetimes.

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Electricity of a PV system

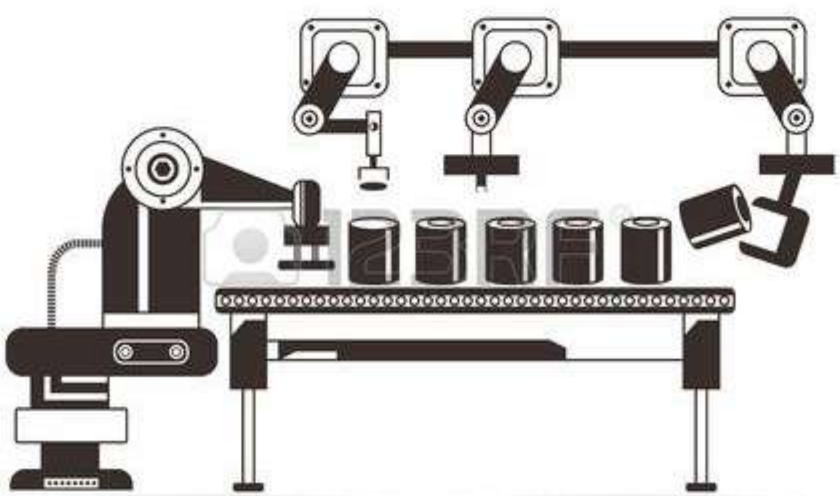
The global formula to estimate the electricity generated in output of a photovoltaic system

$$E = A \times r \times H \times PR$$

E = Energy (kWh)
A = Total solar panel Area (m2)
r = Solar panel yield or efficiency(%)
H = Annual average solar radiation on tilted panels (shadings not included)
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)
r is the yield of the solar panel given by the ratio: electrical power (in kWp) of one solar panel divided by the area of one panel.

Environmental Impacts of using PV systems

- **The use of land**
- **The use of water**
- **The use of natural resources**
- **The use of hazardous materials**
- **The life-cycle global warming emissions**
- **The visual impact**



Economics of Photovoltaic Energy

Economics depends on the following parameters:

- Total cost of installing a PV System
- Electricity price
- Feed-in tariffs
- Energy payback time

- Photovoltaic power plant (PVPP) costs can be divided into photovoltaic (PV) module costs and the costs for balance of system (BoS) components.
- Module costs typically represent only 40-60 % of total PV system costs.
- In 2010 the cost of installing a PV system with a power of 1 kW was about 3000 €/kWp.
- About half of this investment would be for the PV modules and the inverter. PV array support structures, electrical cabling, equipment, and installation would account for the rest.
- The life cycle cost (LCC) of a PV system may also include costs for site preparation, system design and engineering, installation labor, permits and operation, and maintenance costs.
- Photovoltaic systems have an anticipated 25-year lifetime.

Case Study: House in Paros Island-An on-roof PV system with slide-in mounting base

Site/building type: The On-Roof system is installed on a wooden shading construction using slide-in mounting base in order to improve the aesthetic of the system

Duration of installation works: 2 days

Total installed power: 4.8kWp

Area needed per kW: 6.87m²

PV technology used: Polycrystalline silicon with "Stay-Powerful" grid interconnection technology

Total cost: €12,700, (PV: 2.65 €/Wp)

Feed-in tariffs, subsidies, grants: The system feeds into the public grid and paid 0.55€/kWh by the Public Power Corporation (PPC).

The system is estimated to produce approximately 6.19MWh/year which means that **the total investment will be paid back in 4 years**.

CO^2 emissions savings: 3.7 t/year

Source: By U.S. Department of Energy from United States - Children of the Sun Solar Initiative, Public Domain, https://commons.wikimedia.org/w/index.php?curid=79977287

Thank you