ANKARA UNIVERSITY
DEPARTMENT OF ENERGY ENGINEERING
SOLAR ENERGY

INSTRUCTOR

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CONTENTS

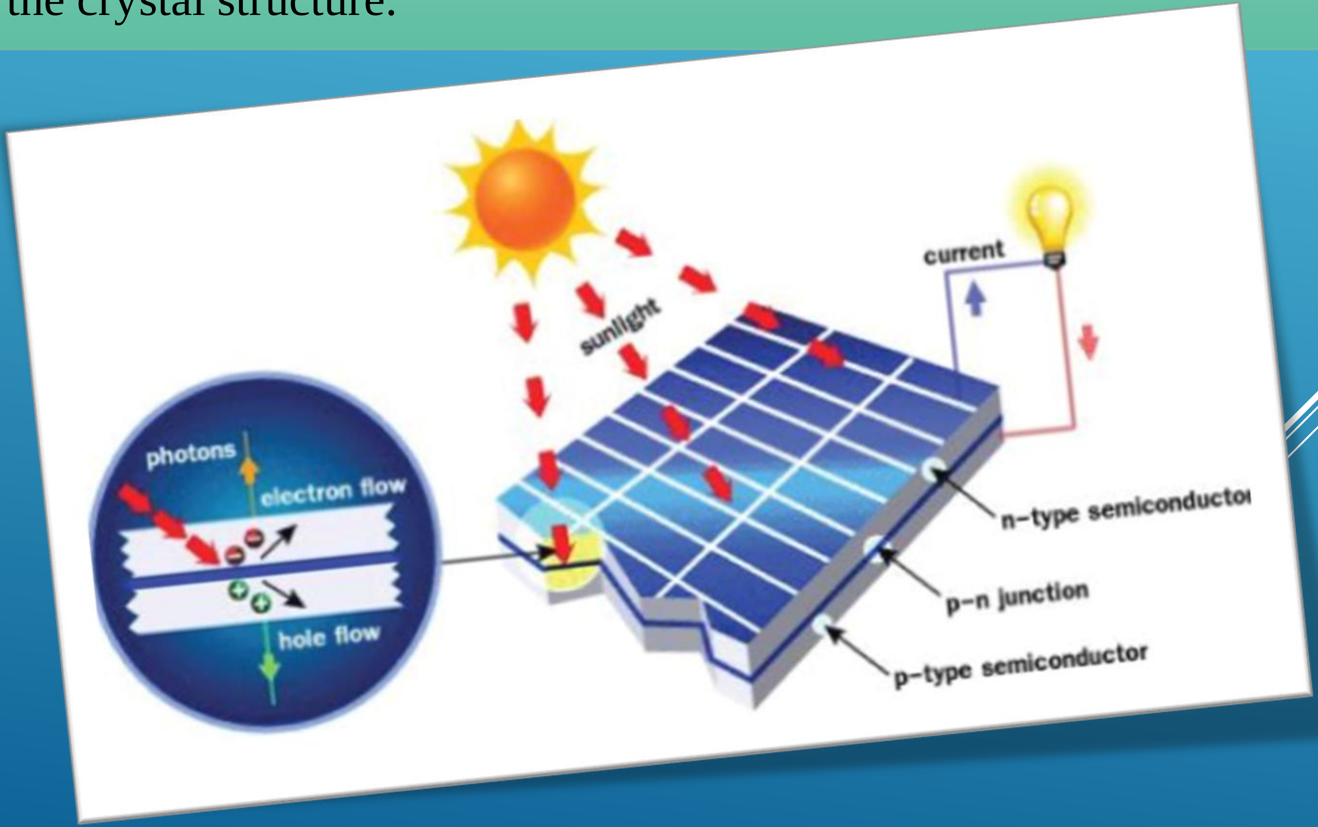
PHOTOVOLTAIC

Photovoltaic generation of power is caused by electromagnetic radiation separating positive and negative charge carriers in absorbing material. If an electric field is present, these charges can produce a current for use in an external circuit.

A solar cell is nothing but a PN junction diode under light illumination. Sun light can be converted into electricity due to photovoltaic effect. Sun light composed of photons (packets of energy). These photons contain various amount of energy corresponding to different wave lengths of light. When photons strike a solar cell they may be reflected or absorbed or pass through the cell.

How Do Silicon Solar Cells Work?

The most common PV cells are made of single-crystal silicon. An atom of silicon in the crystal lattice absorbs a photon of the incident solar radiation, and if the energy of the photon is high enough, an electron from the outer shell of the atom is freed. This process thus results in the formation of a hole–electron pair, a hole where there is a lack of an electron and an electron out in the crystal structure.



Incident solar radiation can be considered as discrete "energy units" called photons.

$$C = \lambda \nu$$

The energy of a photon is a function of the frequency of the radiation (and thus also of the wavelength) and is given in terms of Planck's constant h by

$$E = h\nu$$

The most energetic photons are those of high frequency and short wavelength.

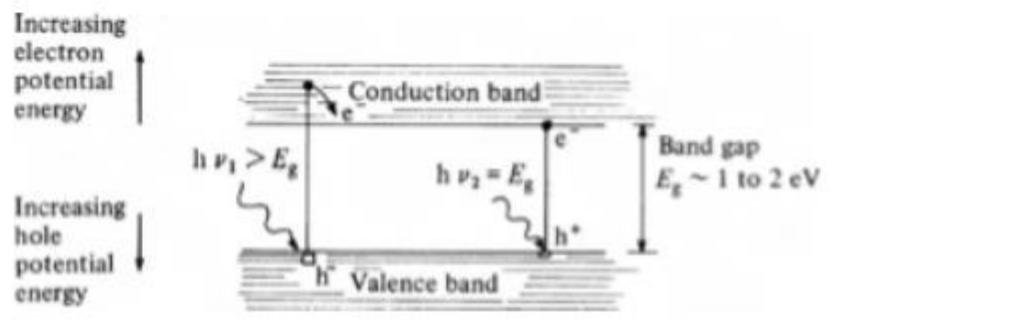
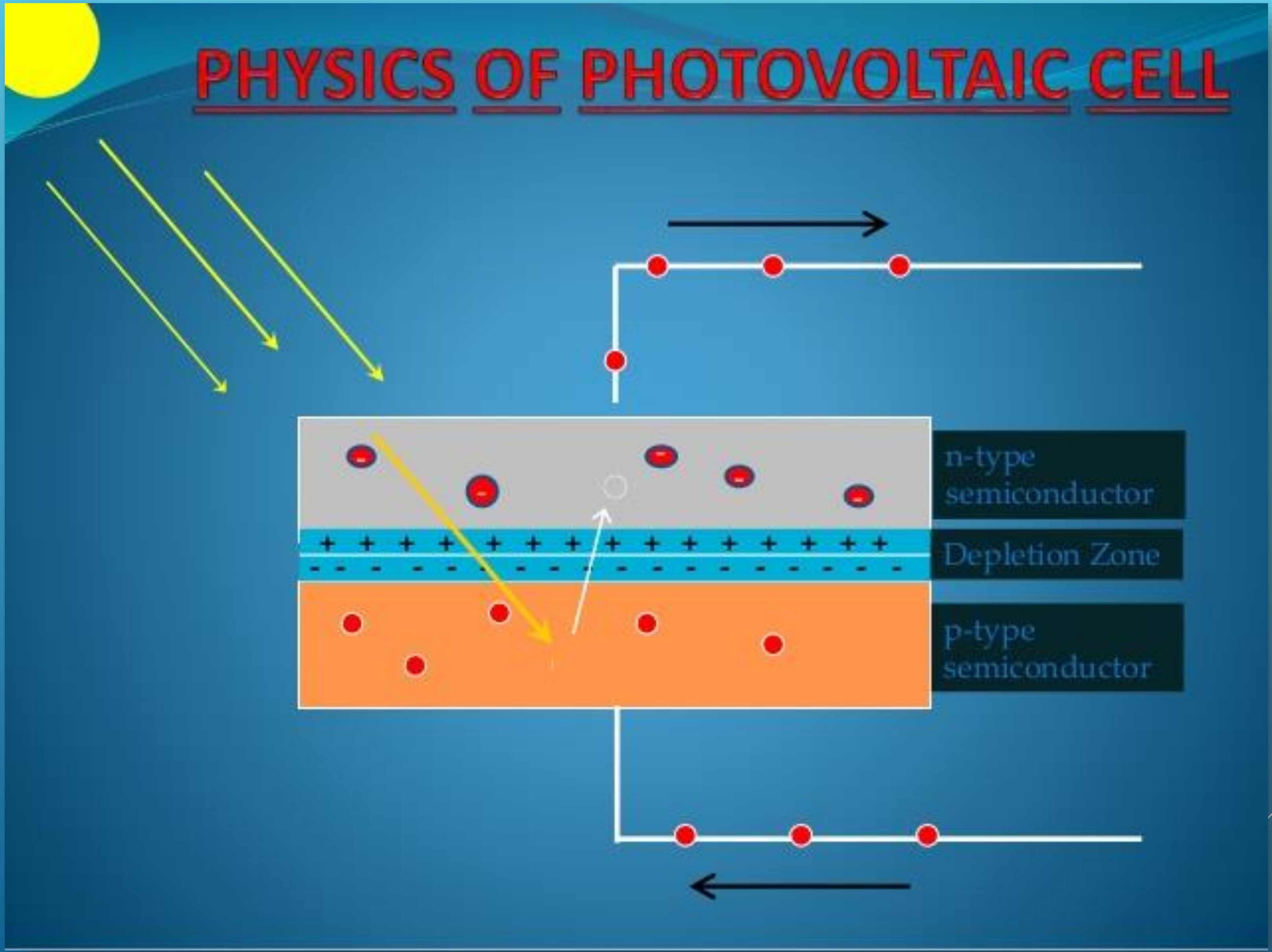
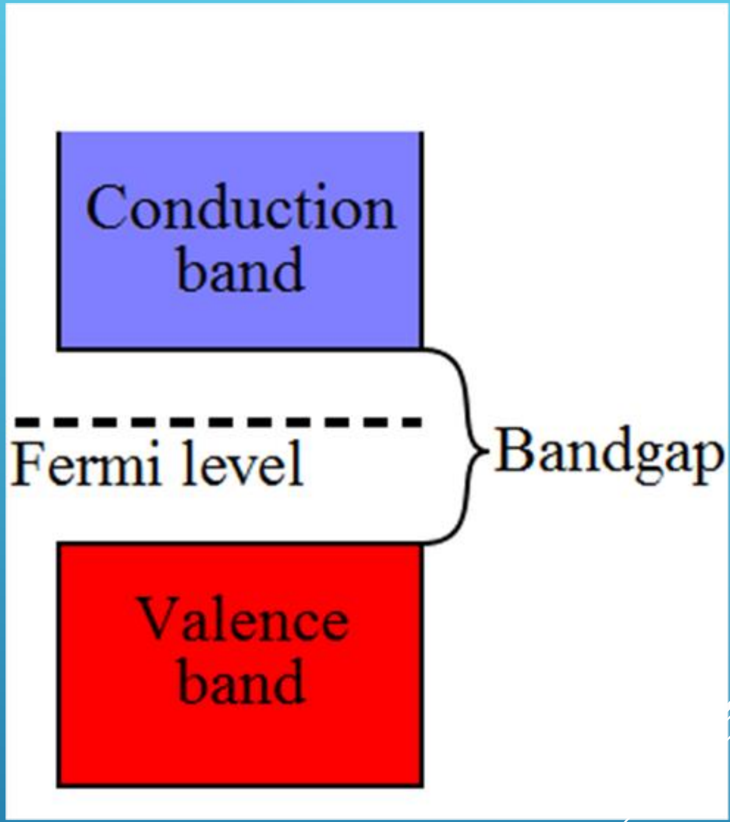


Figure 7.2 Semiconductor band structure, intrinsic pure material. Photon absorption; $h\nu_2 = E_g$, photon energy equals band gap; $h\nu < E_g$, no photovoltaic absorption; $h\nu_1 > E_g$, excess energy dissipated as heat.


PHYSICS OF PHOTOVOLTAIC CELL
n-type semiconductor
Depletion Zone
p-type semiconductor

Semiconductor Energy-band Diagram

- Conduction band – top band, here electrons contribute to current flow
- Valence band –energy band where electrons are normally present
- An electron must acquire the band gap energy to jump across to the conduction band, measured in electron-volts eV
- Silicon band gap energy is 1.12 eV



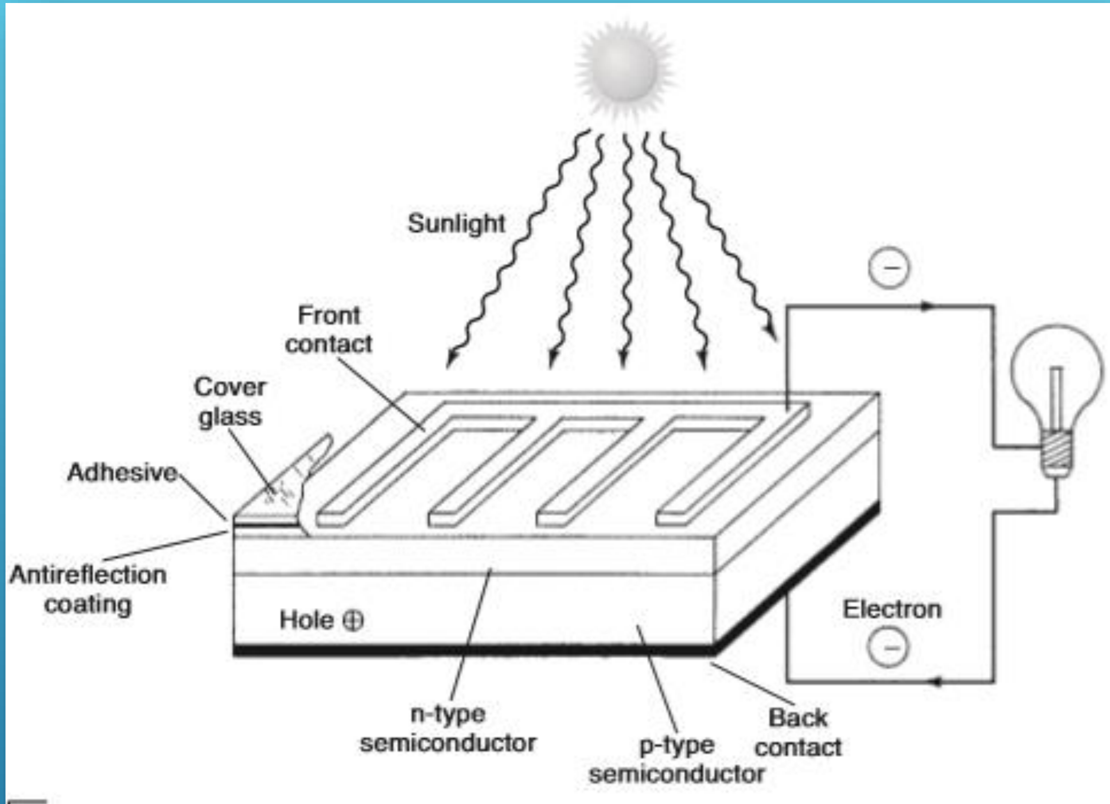
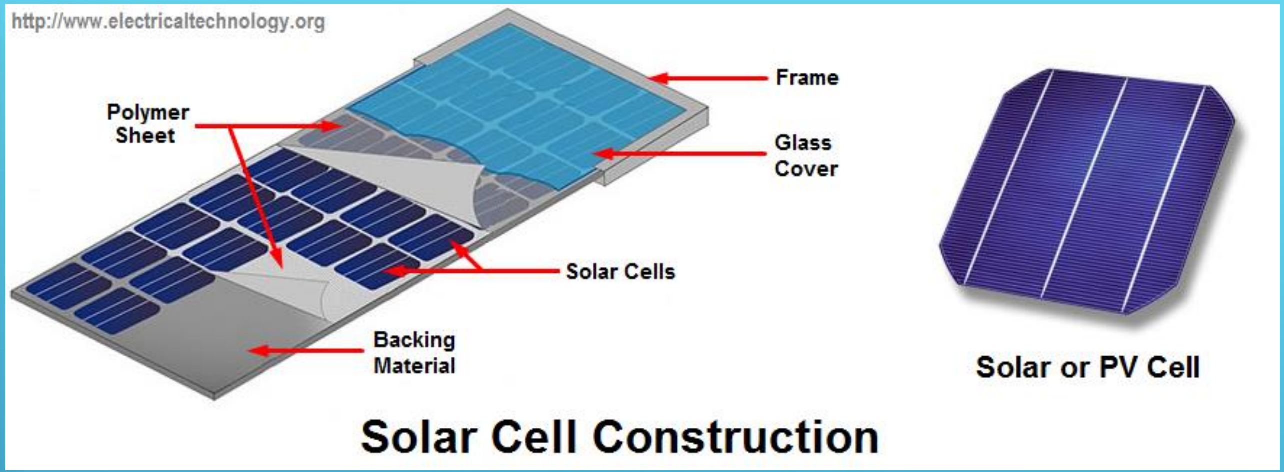


Figure 12.4 Solar cell construction. (Source: Solar Energy Research Institute)



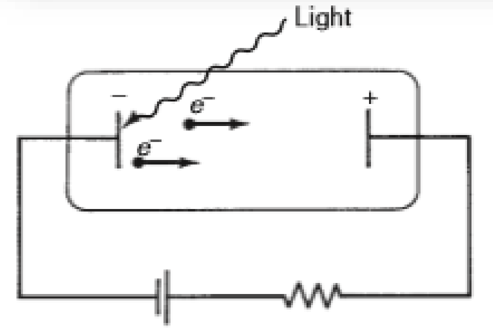
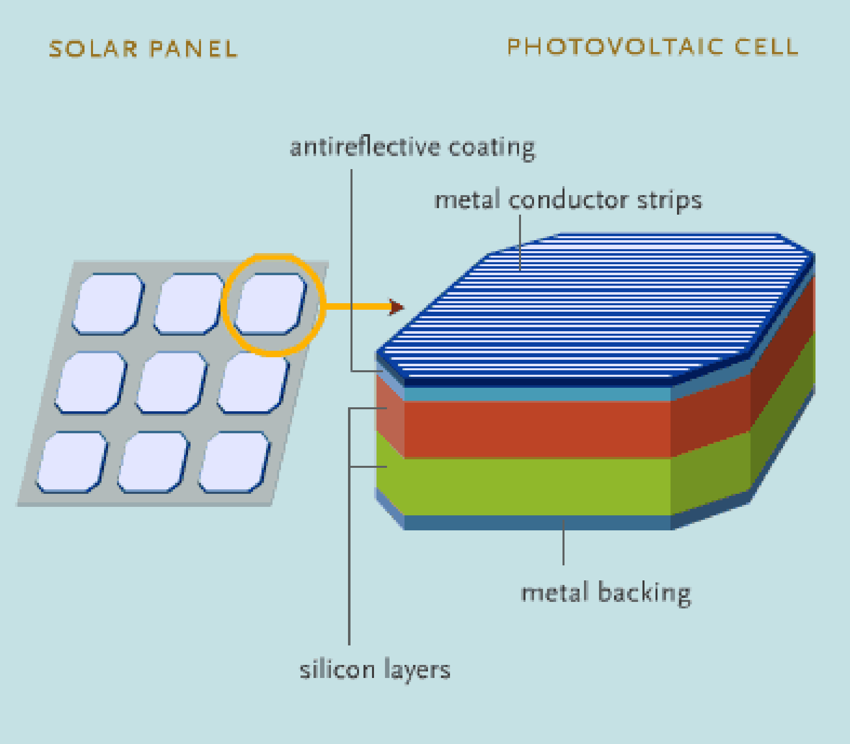


Figure 12.3 Apparatus for observation of the photoelectric effect. Light hits the metal plate (in the evacuated tube), and electrons are emitted.

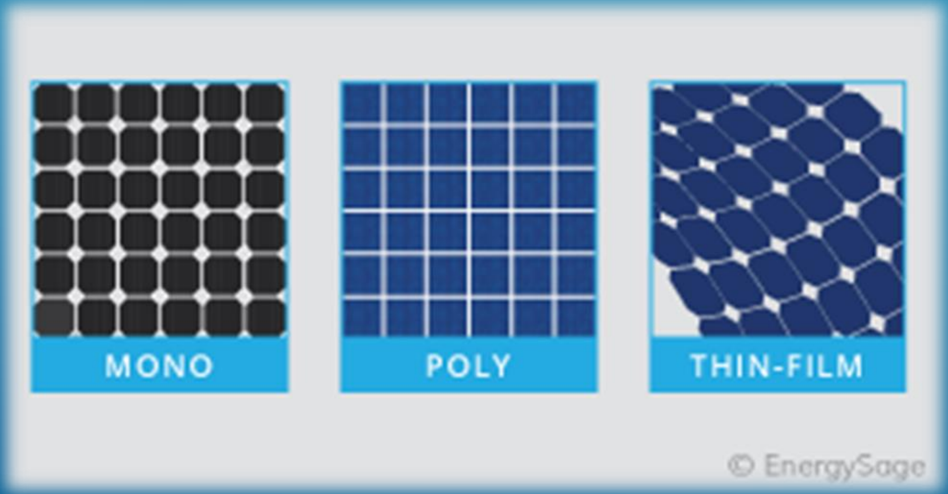


Types of Solar Cells

- ✓ Monocrystalline Solar Cells
- ✓ Polycrystalline Solar Cells
- ✓ Amorphous Solar Cells
- ✓ Thin Films

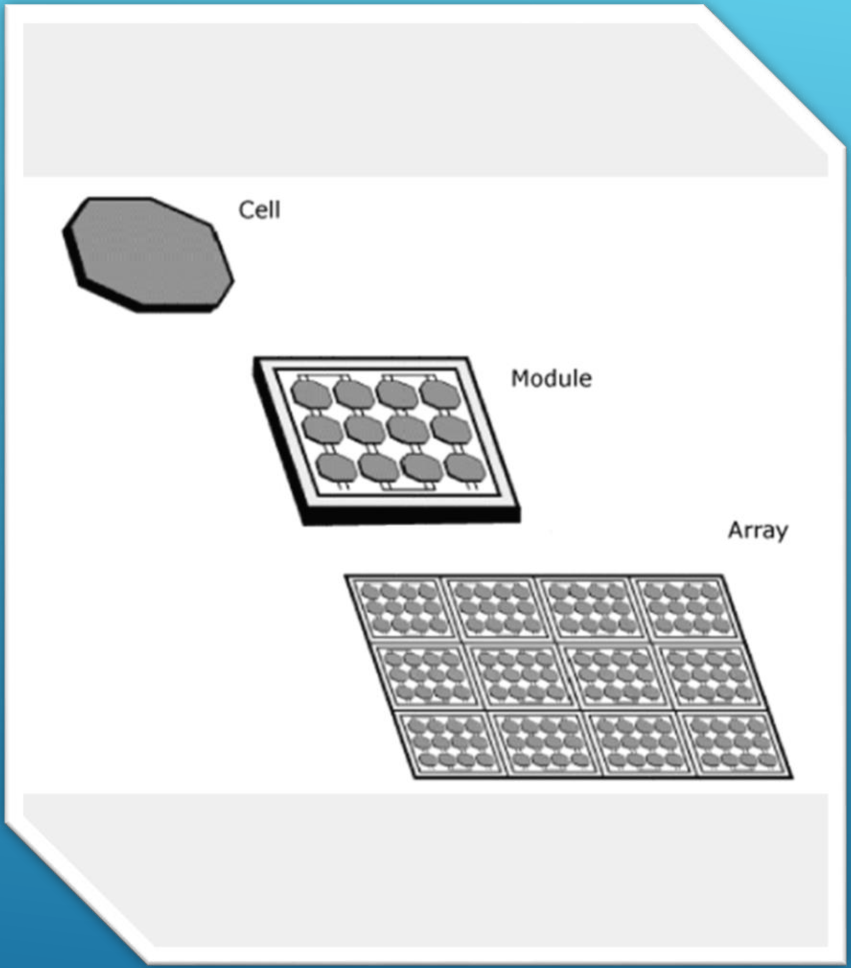
Table 1. Maximal efficiency reached for different types of solar cells [24].

Solar cell type	Maximal efficiency reached	Solar cell type	Maximal efficiency reached
Multijunction Cells		*Thin-Film Technogies*	
• Three-junction	37.9–44.4 %	• CIGS	22.6–23.3 %
• Two-junction	31.6–34.2 %	• CdTe	22.10 %
• Four-junction or more	38.8–46.0 %	• Amorphous Si:H	14 %
Single-Junction GaAs		*Emerging PV*	
• Single crystal	27.5–29.3 %	•Dye-sensitized cells	11.90 %
• Thin-film crystal	28.80 %	• Perovskite cells	22.10 %
Crystalline Si Cells		• Organic cells (various)	11.50 %
• Single crystal	25.3–27.6 %	• Organic tandem cells	10.60 %
• Mylticrystaline	21.30 %	• Inorganic cells	12.60 %
• Silicon heterostructure	26.60 %	• Quantum dot cells	12.00 %
• Thin-film crystal	21.20 %		

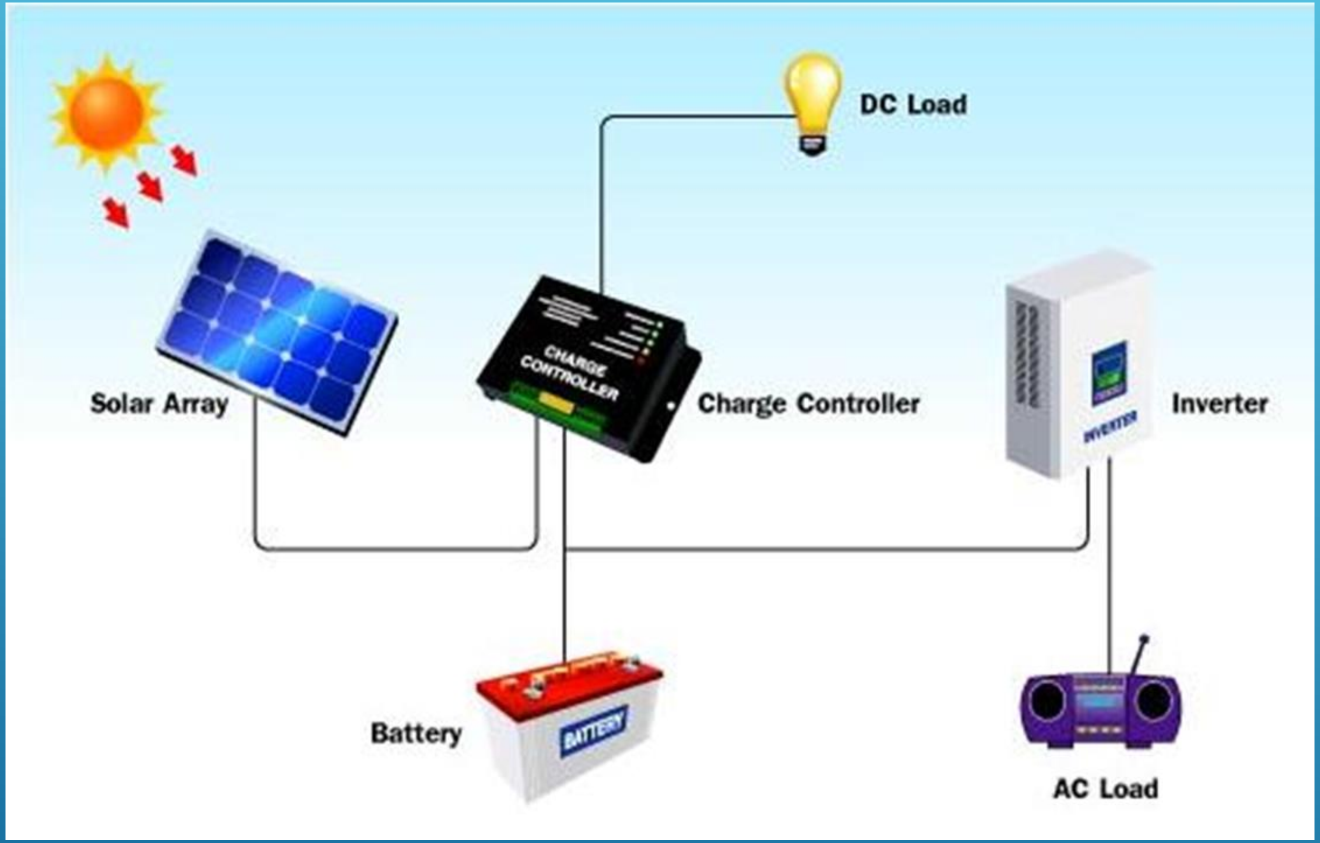


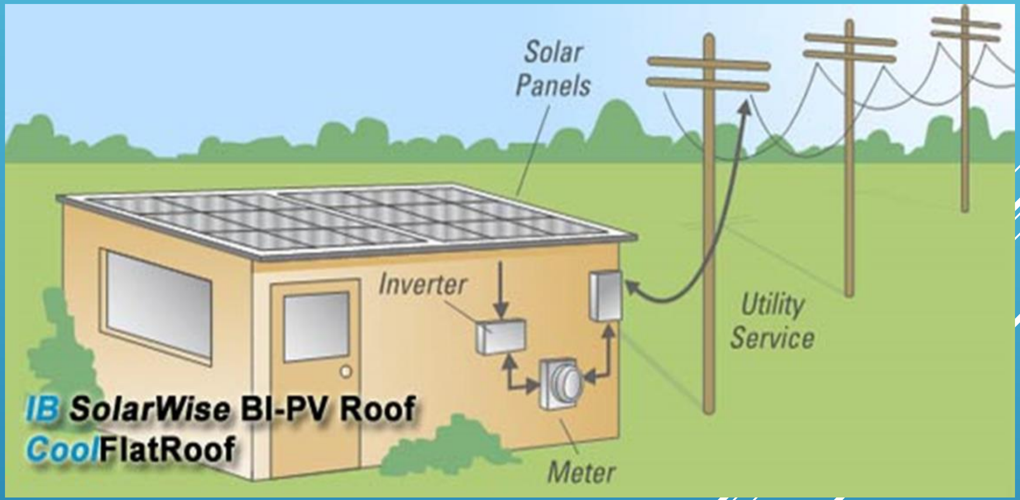
PV Array Components

- PV Cells
- Modules
- Arrays



PV System Components





PV Systems – 1.st configuration

- Grid-connected systems

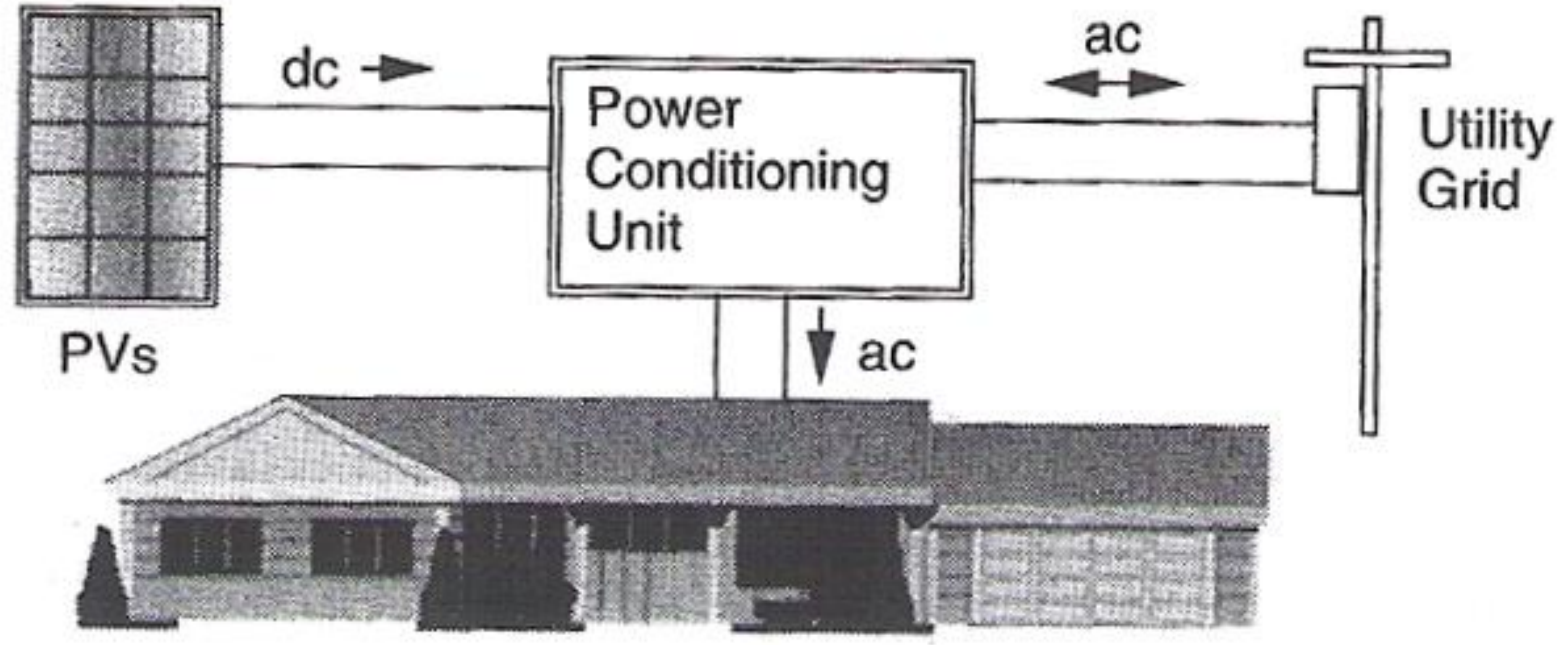


Figure 9.1 Simplified grid-connected PV system.

PV Systems – 2.nd configuration- Stand-alone system

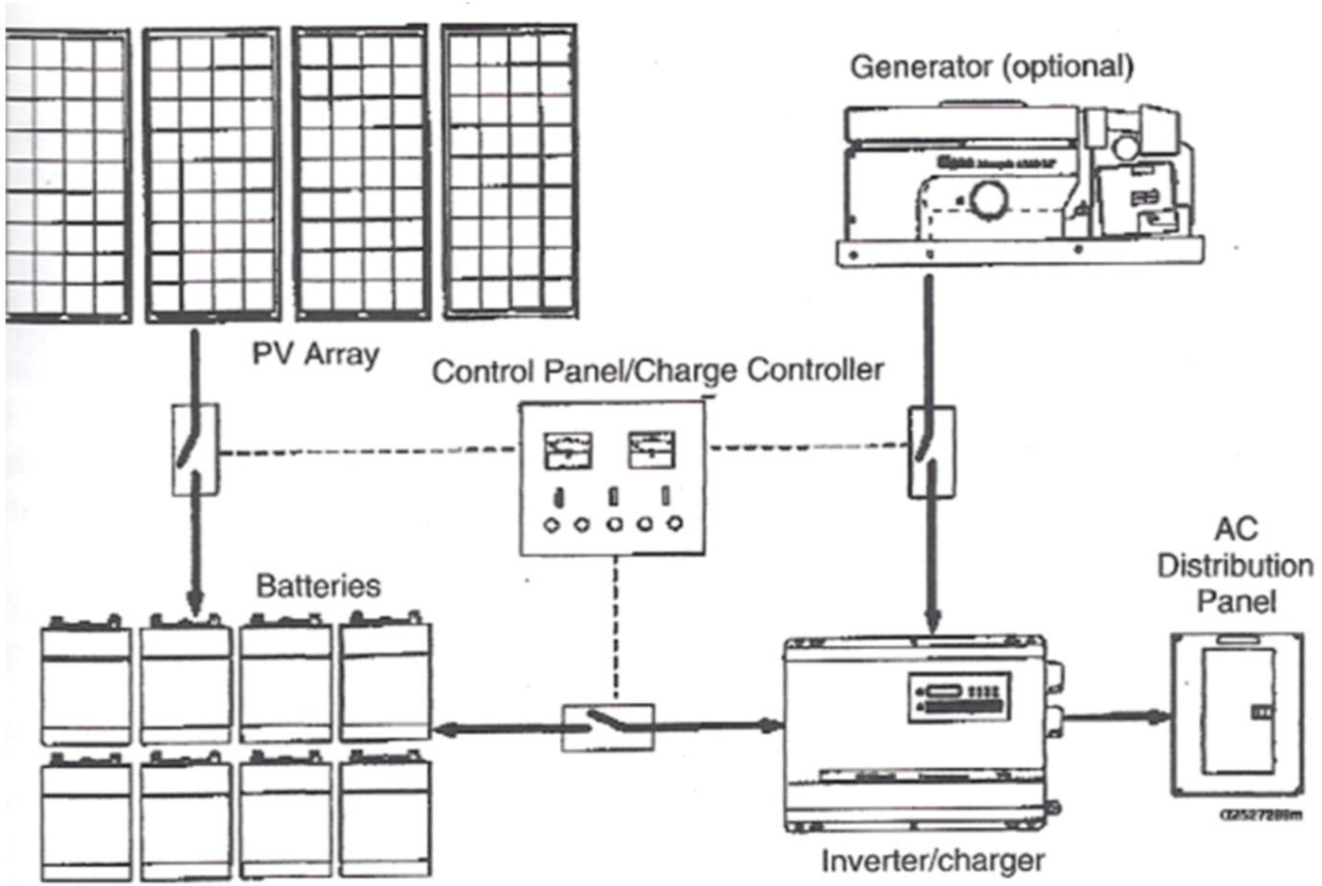


Figure 9.2 Example of a stand-alone PV system with optional generator for back-up.

Stand-alone systems which charge batteries

PV Systems – 3.rd configurations

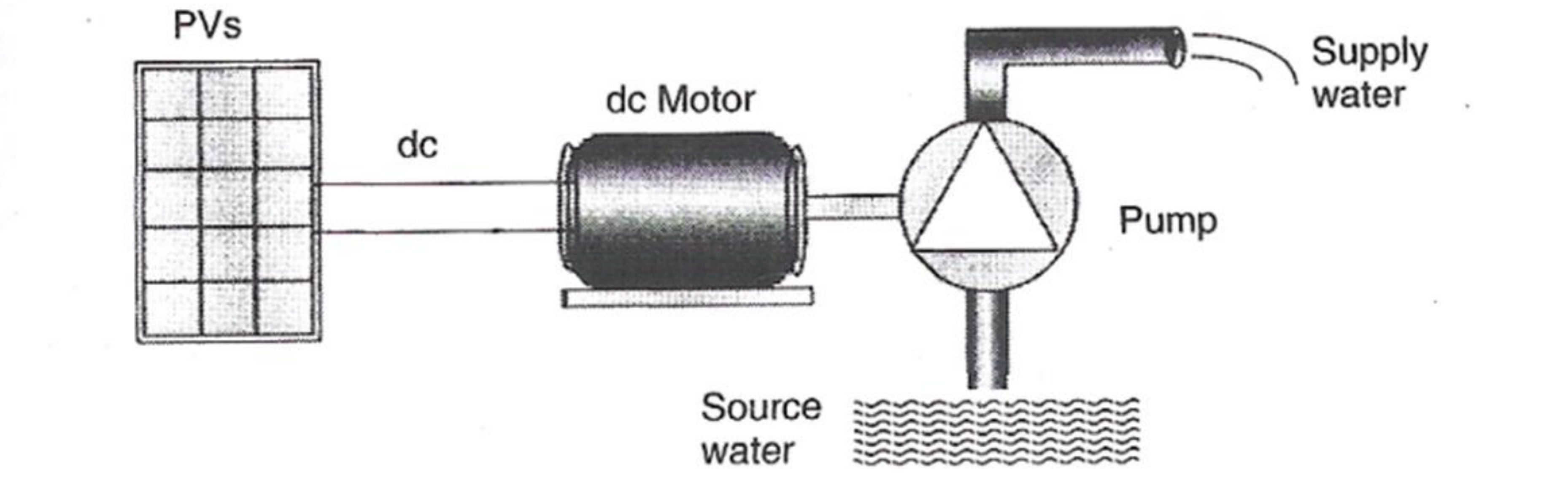


Figure 9.3 Conceptual diagram of a photovoltaic-powered water pumping system.

Stand-alone systems with directly-connected loads

Load I-V Curves

- *PV panels have I-V curves and so do loads*
- *Intersection of the two curves to tell where the system is actually operating*
- *Operating point – the intersection point at which the PV and the load I-V curves are satisfied*

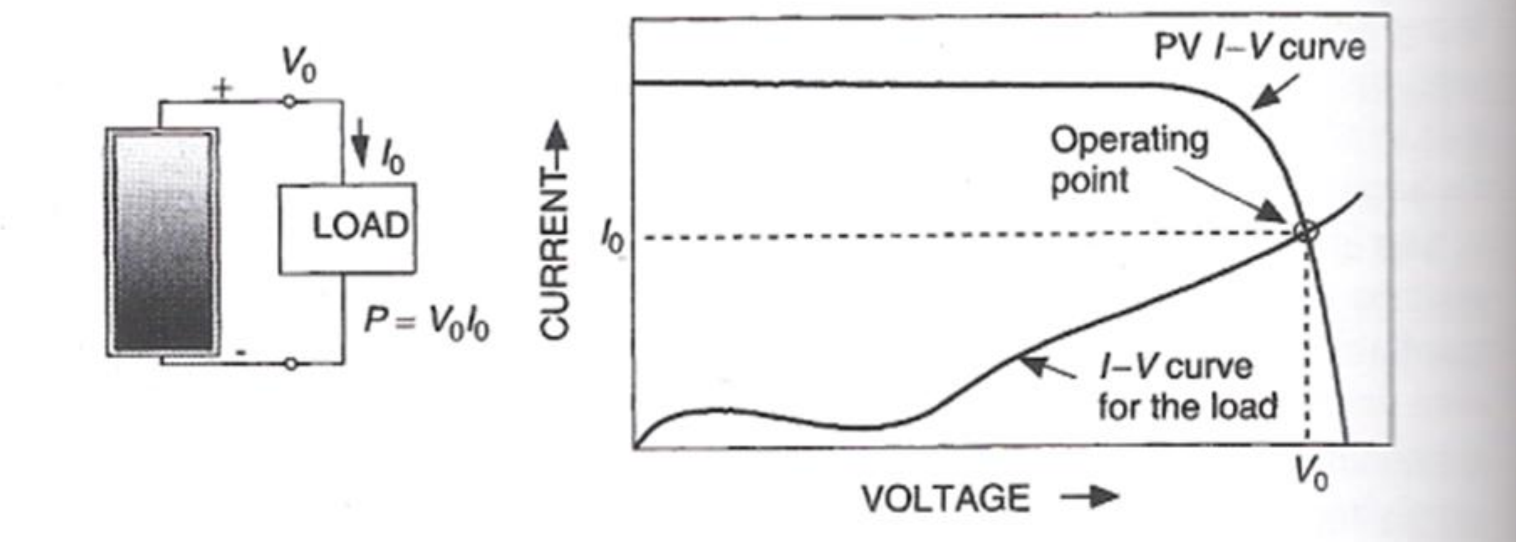
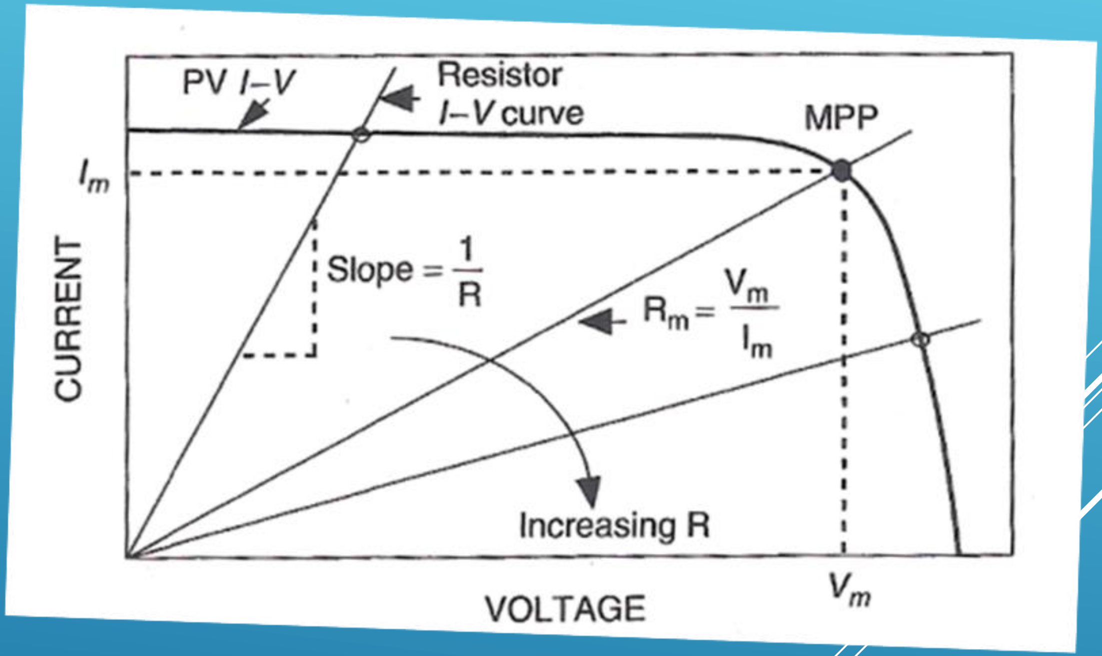


Figure 9.4 The operating point is the intersection of the current–voltage curves for the load and the PVs.

Resistive Load I-V Curve

$$V = IR \quad \Rightarrow \quad I = \left(\frac{1}{R}\right)V$$

- Straight line with slope 1/R
- As R increases, operating point moves to the right



- Can use a potentiometer to plot the PV module’s IV curve
- Resistance value that results in maximum power

$$R_m = \frac{V_m}{I_m}$$

Grid-Connected Systems

- Can have a combiner box and a single inverter or small inverters for each panel
- Individual inverters make the system modular
- Inverter sends AC power to utility service panel
- Power conditioning unit (PCU) may include
  - MPPT
  - Ground-fault circuit interrupter (GFCI)
  - Circuitry to disconnect from grid if utility loses power
  - Battery bank to provide back-up power

Components of Grid-Connected PV

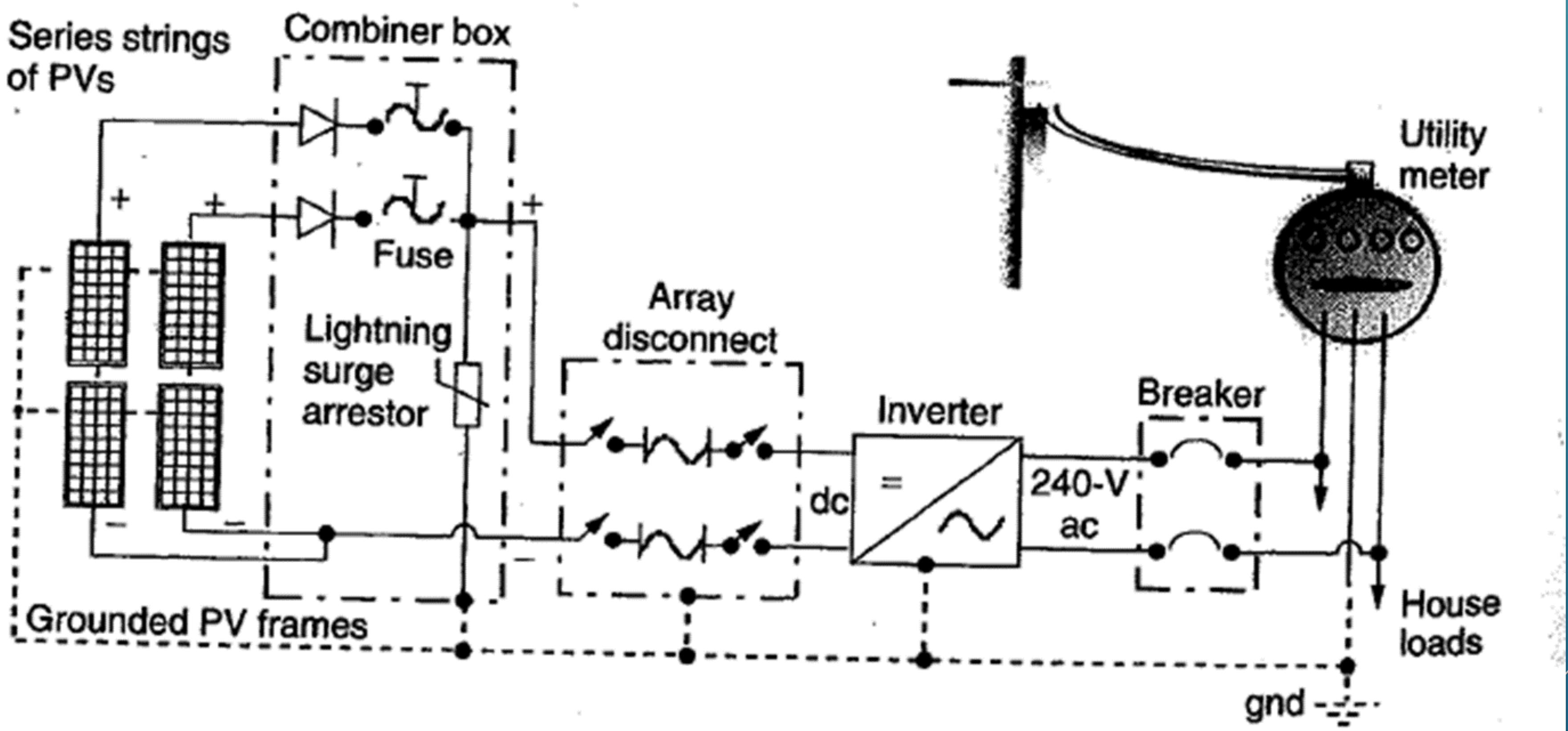


Figure 9.20 Principal components in a grid-connected PV system using a single inverter.

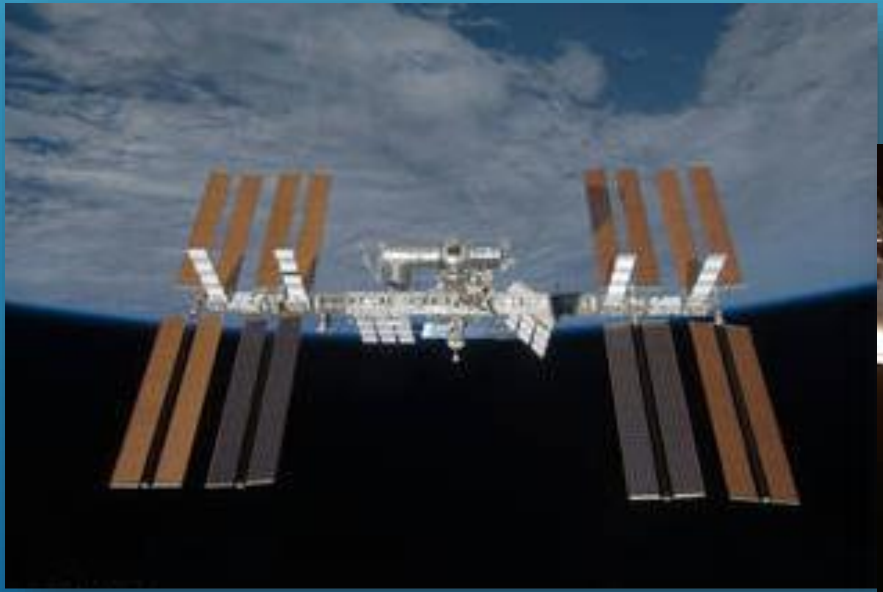
SPACE APPLICATIONS

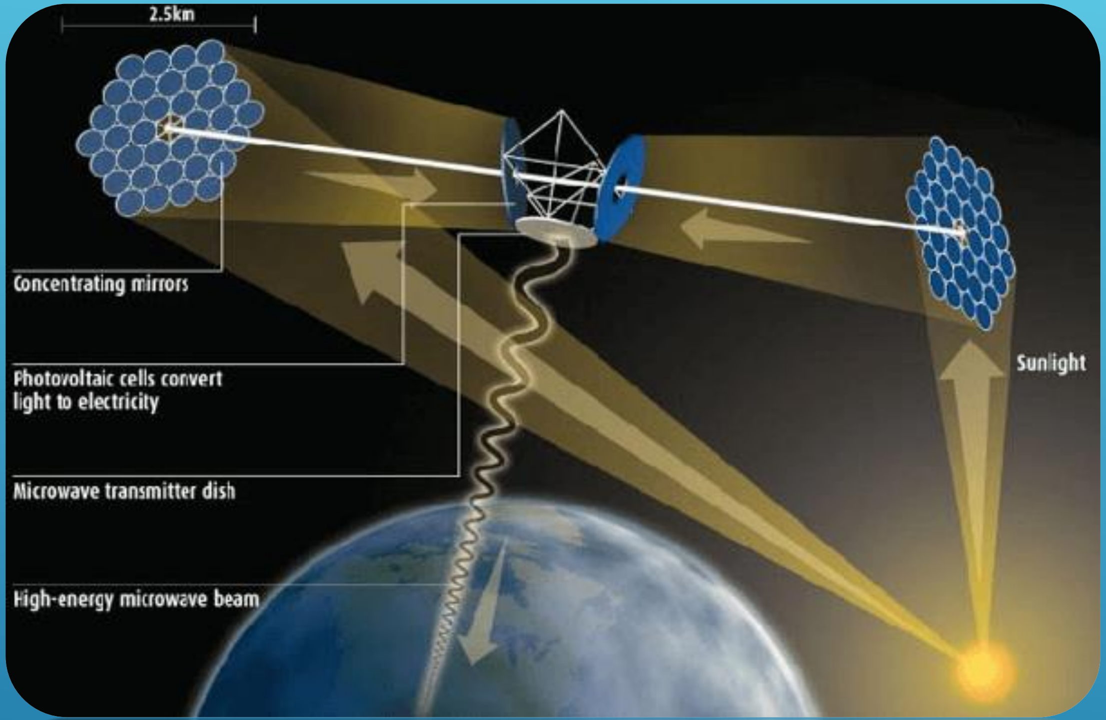
On earth, solar power is greatly reduced by night, cloud cover, atmosphere and seasonality. Some 30 percent of all incoming solar radiation never makes it to ground level. In space the sun is always shining, the tilt of the Earth doesn't prevent the collection of power and there's no atmosphere to reduce the intensity of the sun's rays. This makes putting solar panels into space a tempting possibility.

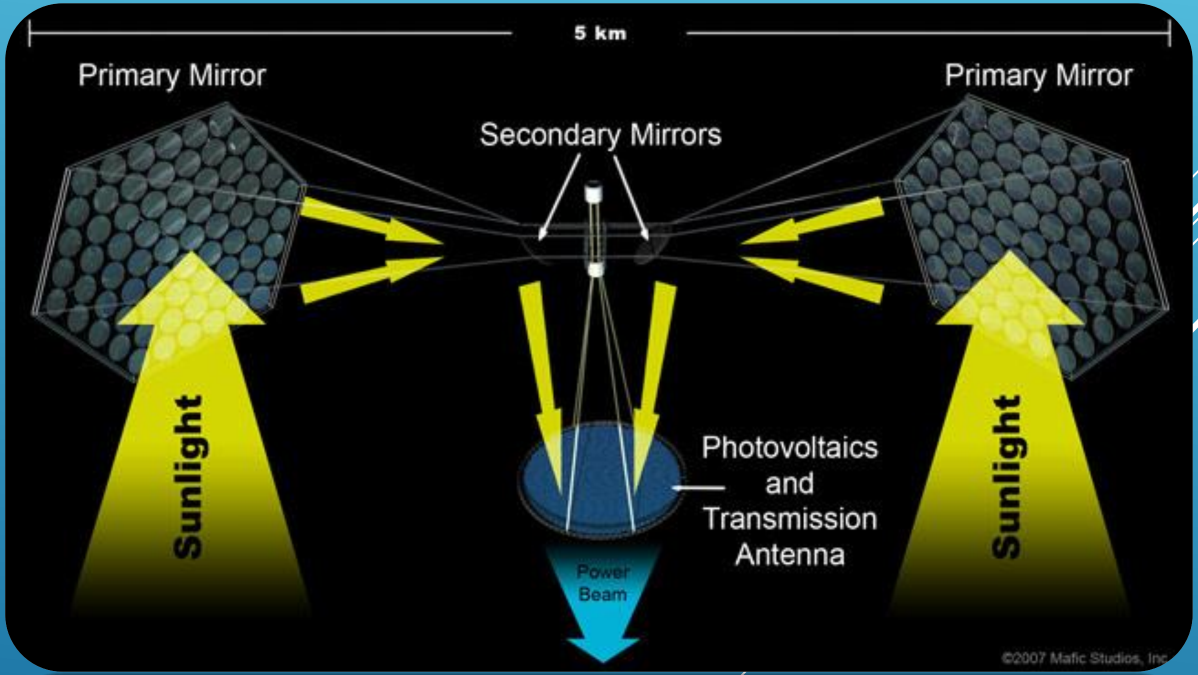
Space Solar Power (SSP)

The best source of energy for spacecraft is sunlight. Engineers have developed technologies to convert solar energy to electrical power efficiently. Solar arrays that convert energy to electricity on the International Space Station are made of thousands of solar cells, made from purified chunks of the element silicon. These cells directly convert light to electricity using a process called photovoltaics.

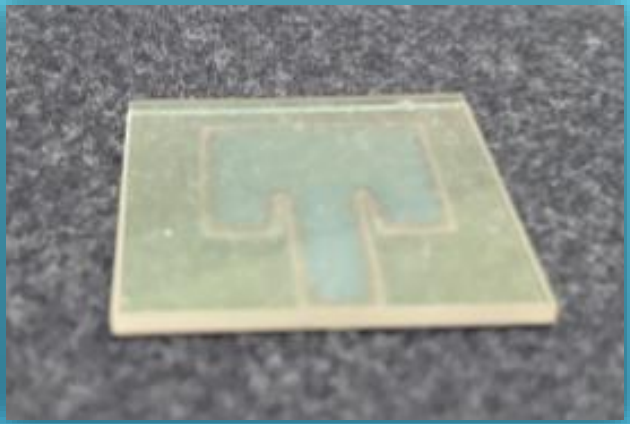
The solar arrays produce more power than the station needs at one time for station systems and experiments. When the station is in sunlight, about 60 percent of the electricity that the solar arrays generate is used to charge the station's batteries. The batteries power the station when it is not in the sun.




2.5km
Concentrating mirrors
Photovoltaic cells convert light to electricity
Microwave transmitter dish
High-energy microwave beam
Sunlight


5 km
Primary Mirror
Primary Mirror
Secondary Mirrors
Sunlight
Sunlight
Photovoltaics and Transmission Antenna
Power Beam
©2007 Mafic Studios, Inc

Cubesat



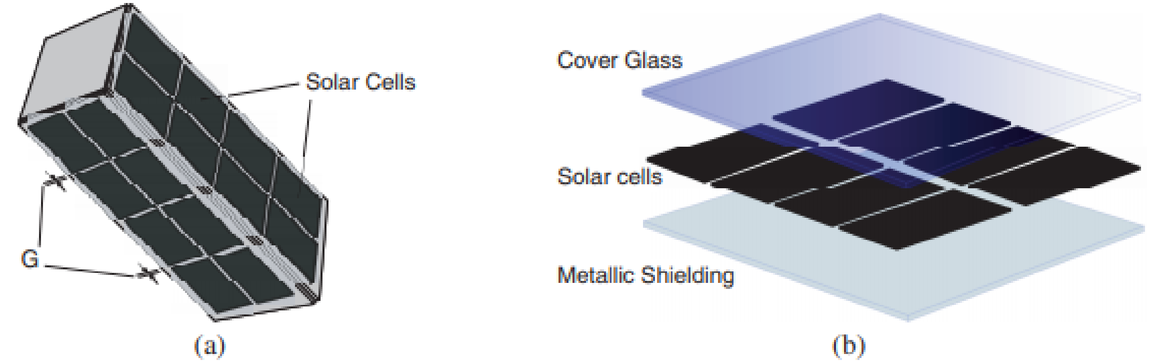
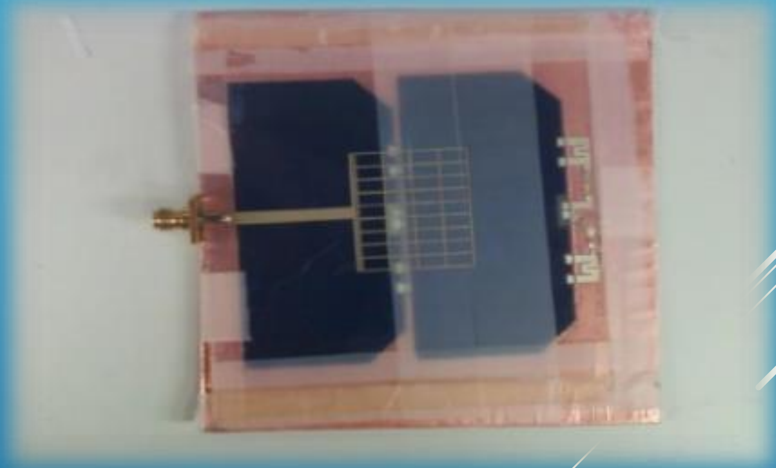
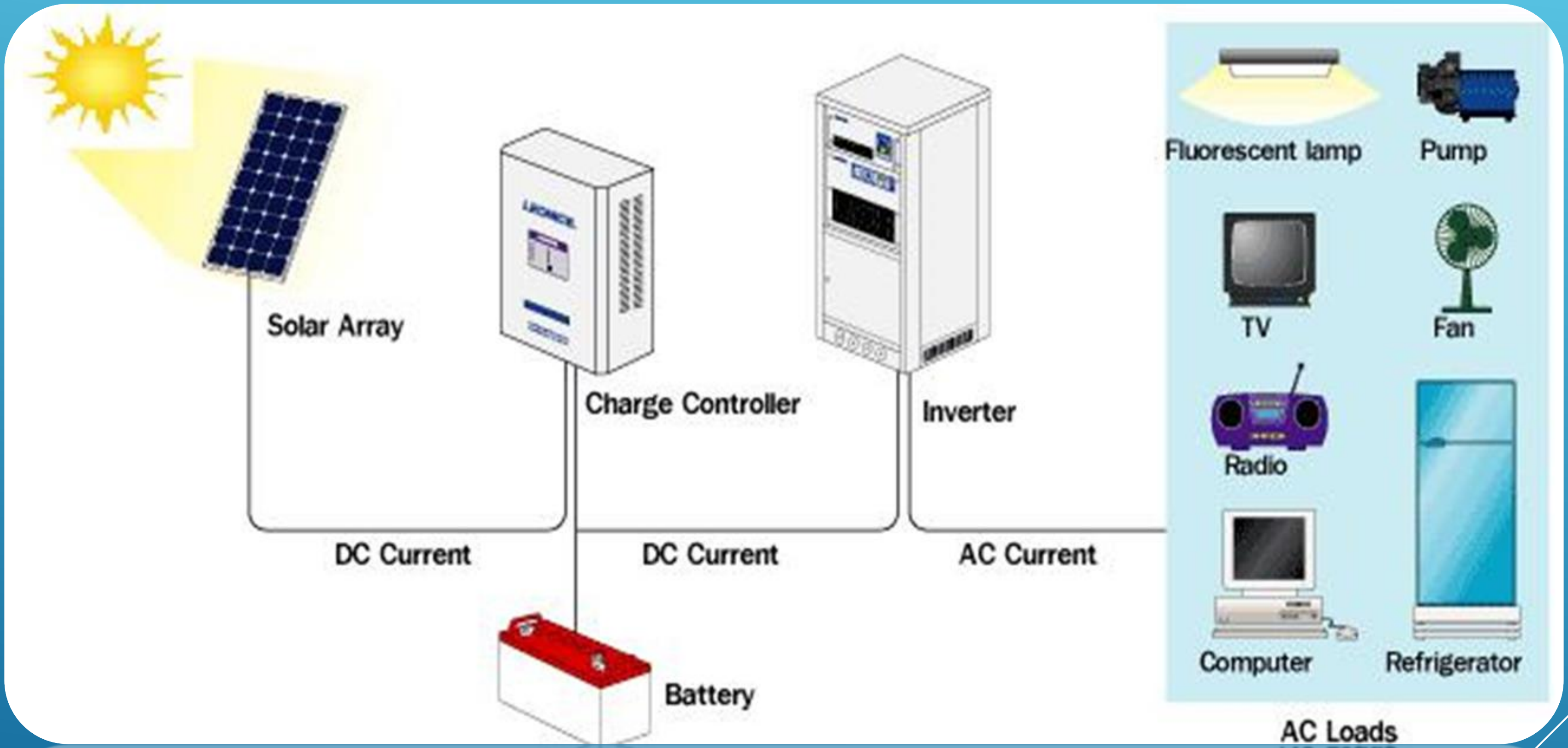


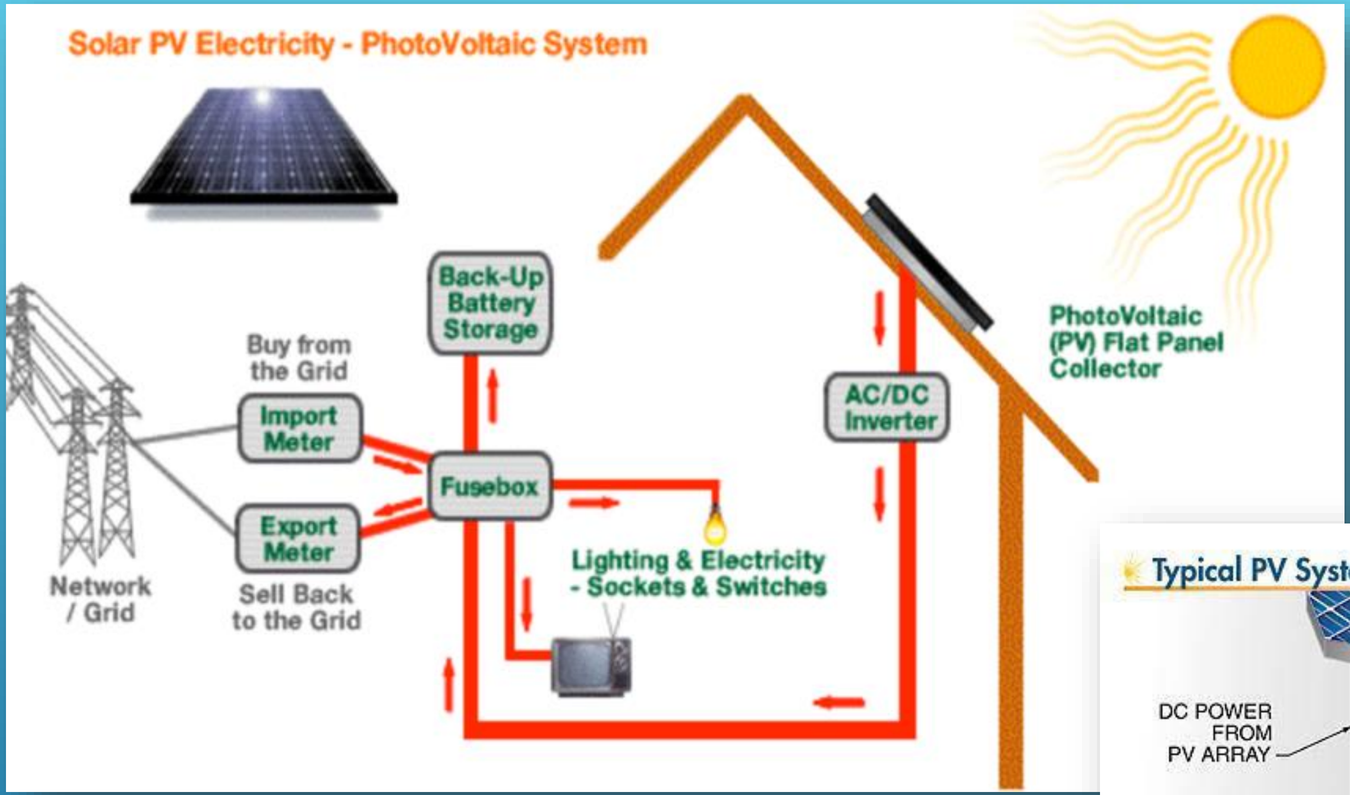
Figure 1. Solar panel of a CubeSat: (a) isometric view of a CubeSat; (b) solar panel structure.

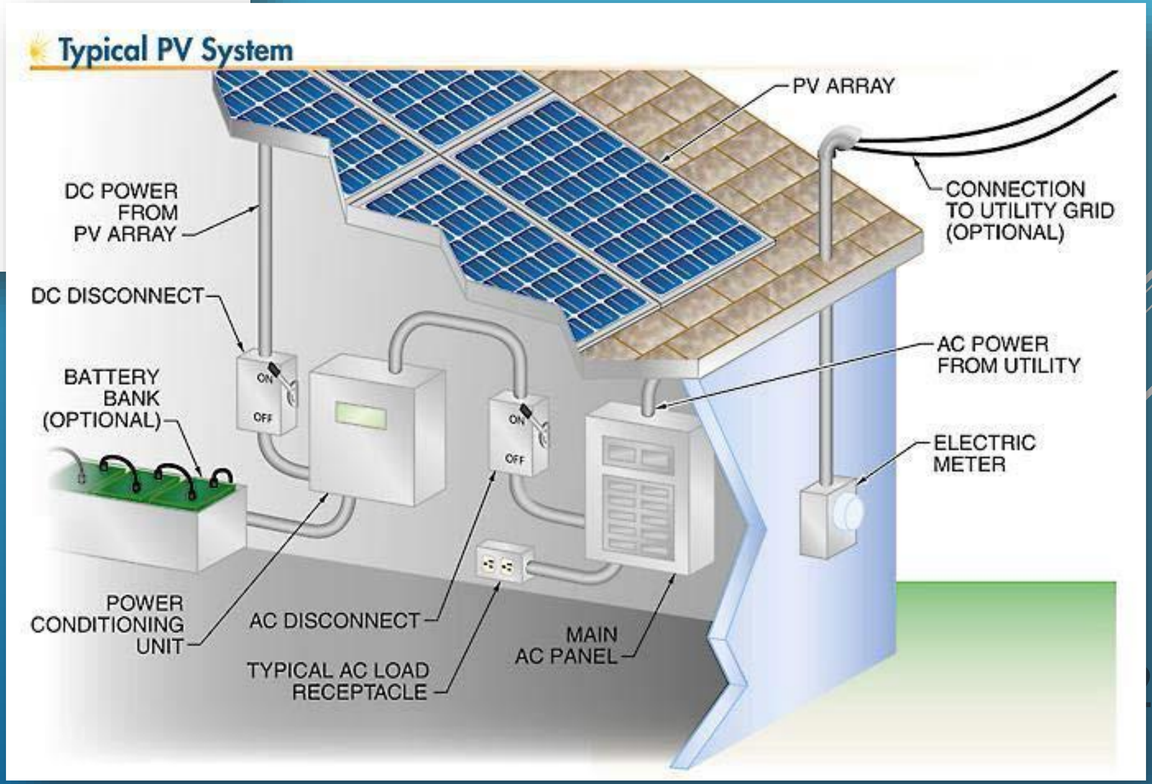


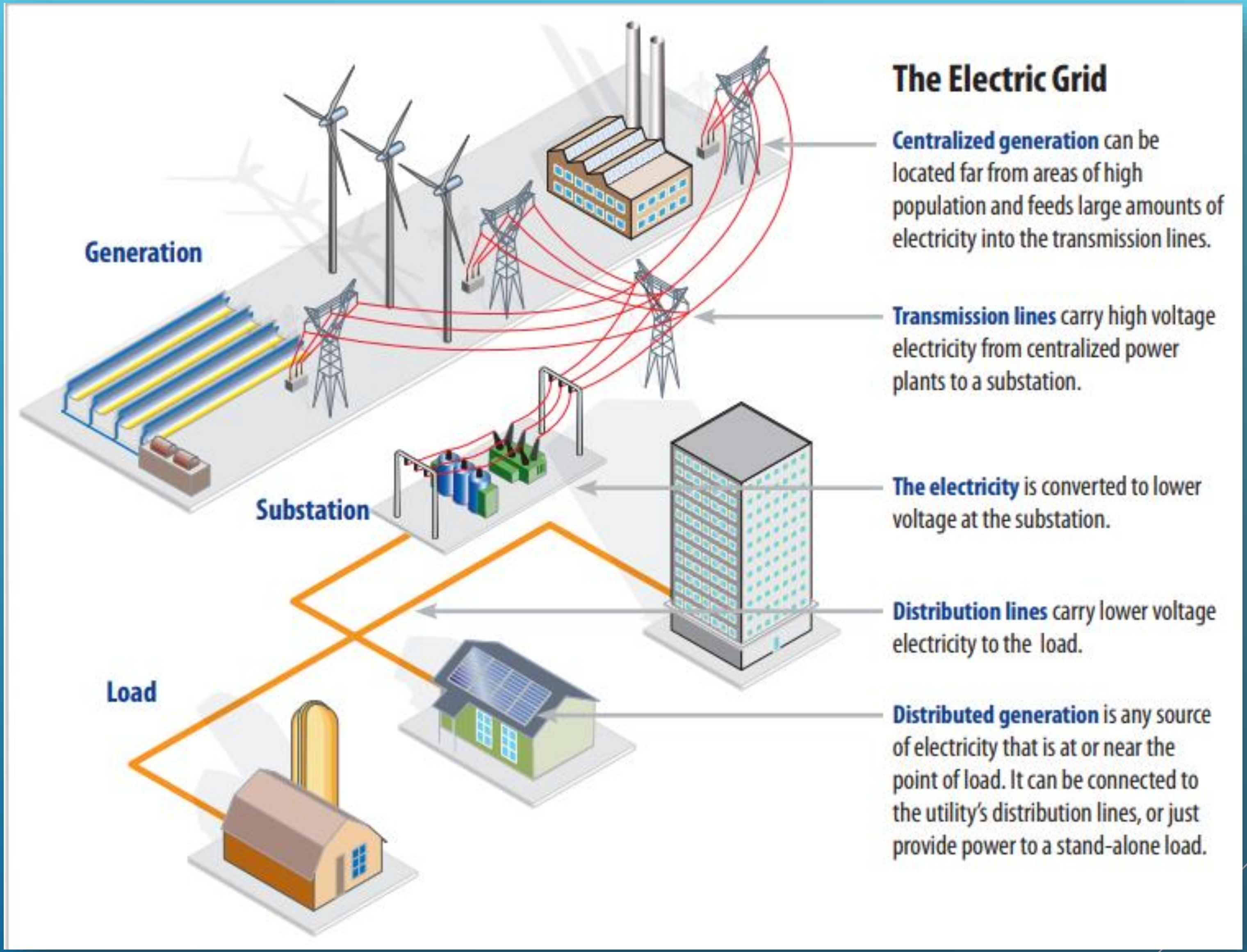
Metallic grid antenna with integrated solar cell

Energy Distribution/Transmission – Electricity & Smart Technologies

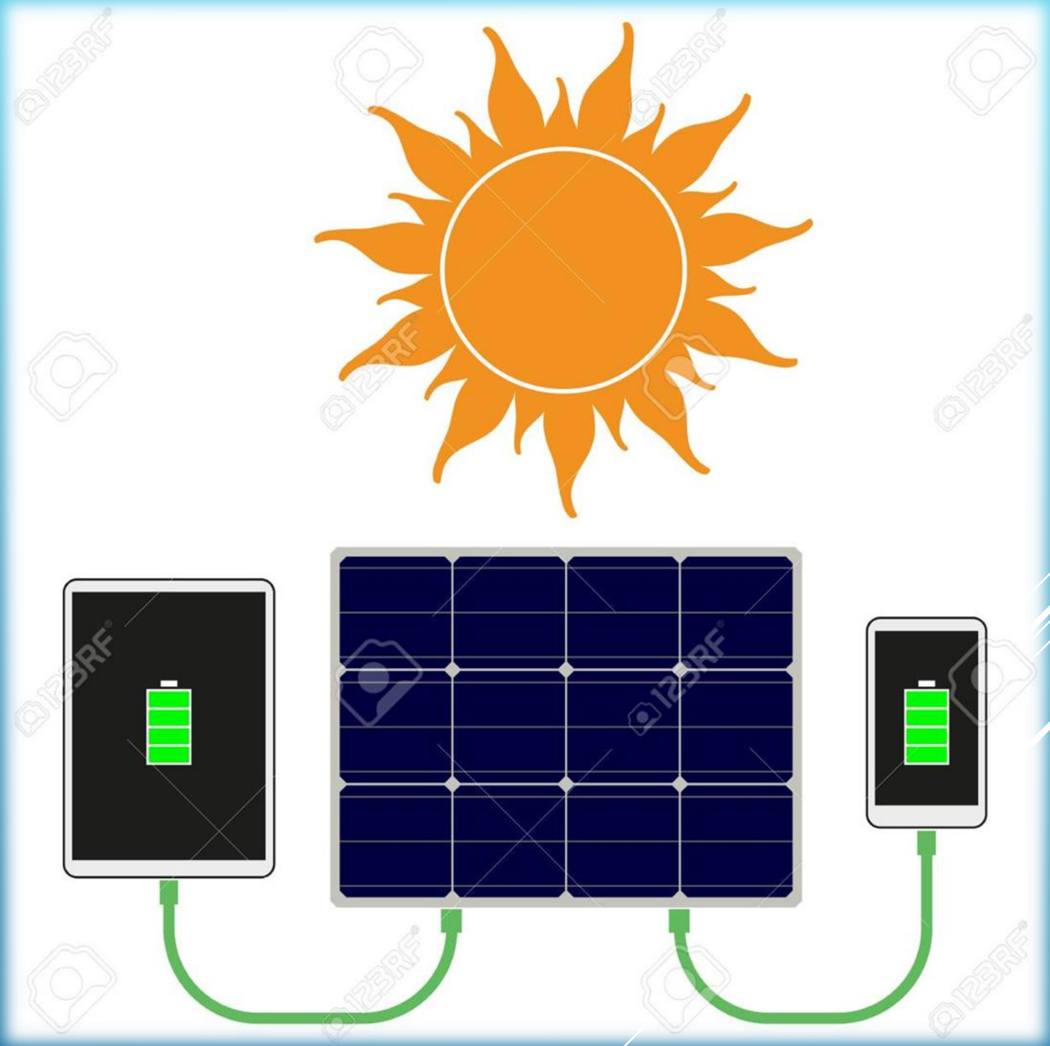



Solar PV Electricity - PhotoVoltaic System
Back-Up Battery Storage
Buy from the Grid
Import Meter
Fusebox
Export Meter
Network / Grid
Sell Back to the Grid
AC/DC Inverter
PhotoVoltaic (PV) Flat Panel Collector
Lighting & Electricity - Sockets & Switches


Typical PV System
PV ARRAY
DC POWER FROM PV ARRAY
CONNECTION TO UTILITY GRID (OPTIONAL)
DC DISCONNECT
BATTERY BANK (OPTIONAL)
AC POWER FROM UTILITY
ELECTRIC METER
POWER CONDITIONING UNIT
AC DISCONNECT
TYPICAL AC LOAD RECEPTACLE
MAIN AC PANEL


The Electric Grid
Generation
Substation
Load
Centralized generation can be located far from areas of high population and feeds large amounts of electricity into the transmission lines.
Transmission lines carry high voltage electricity from centralized power plants to a substation.
The electricity is converted to lower voltage at the substation.
Distribution lines carry lower voltage electricity to the load.
Distributed generation is any source of electricity that is at or near the point of load. It can be connected to the utility's distribution lines, or just provide power to a stand-alone load.

Smart Technologies



Solar Chargers

Solar Light Systems

Solar Road

Smart Security Device

Music Speakers

Rechargeable Flashlights

ELECTRIC CAR

In 1955, William G. Cobb of the General Motors Corp. (GM) demonstrates his 15 inch long "Sun-mobile", world's first ever solar-powered automobile at the General Motors Powerama Auto show held in Chicago, Illinois. Cobb's Sunmobile introduced the field of Photovoltaics - the process by which the sun's rays are converted into electricity when exposed to certain surfaces.

Figure 1Sun-mobile


Solar-Powered Drive

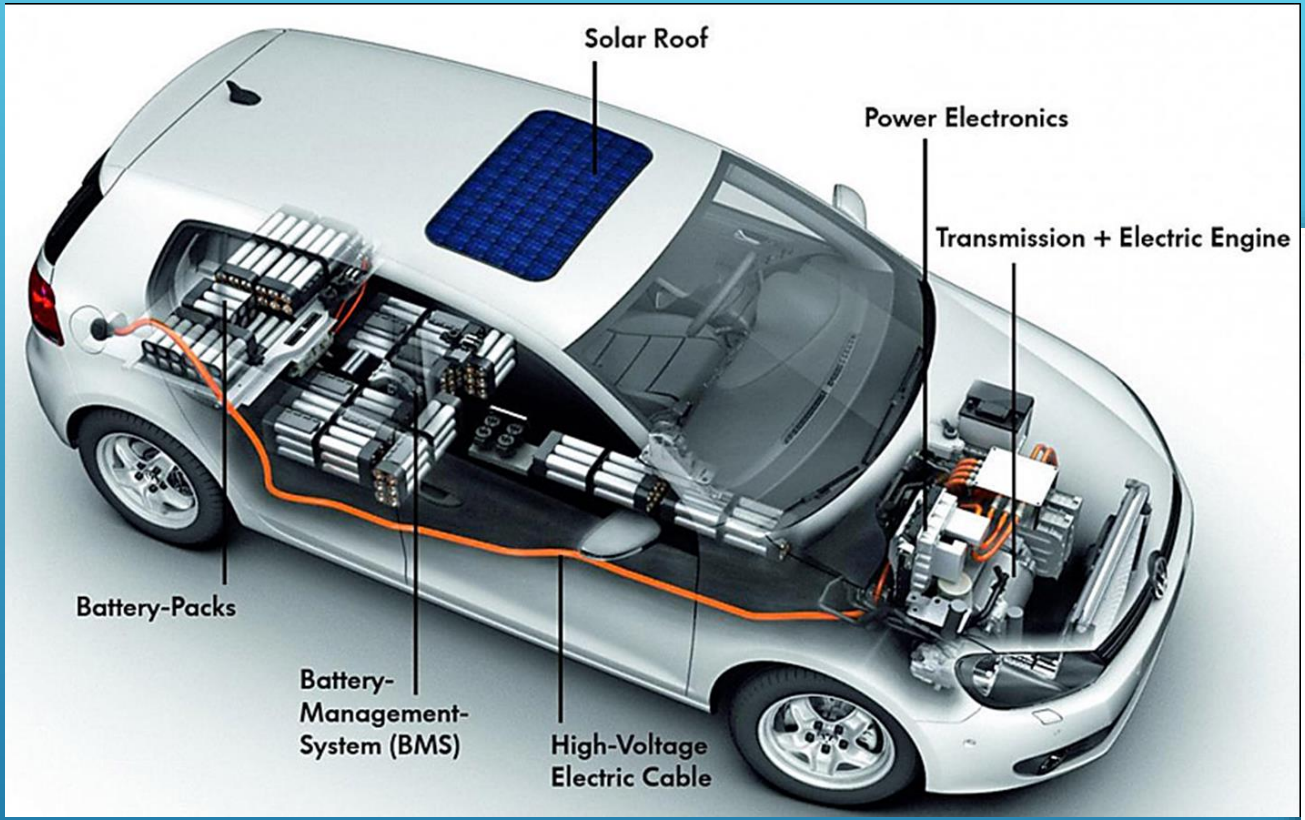


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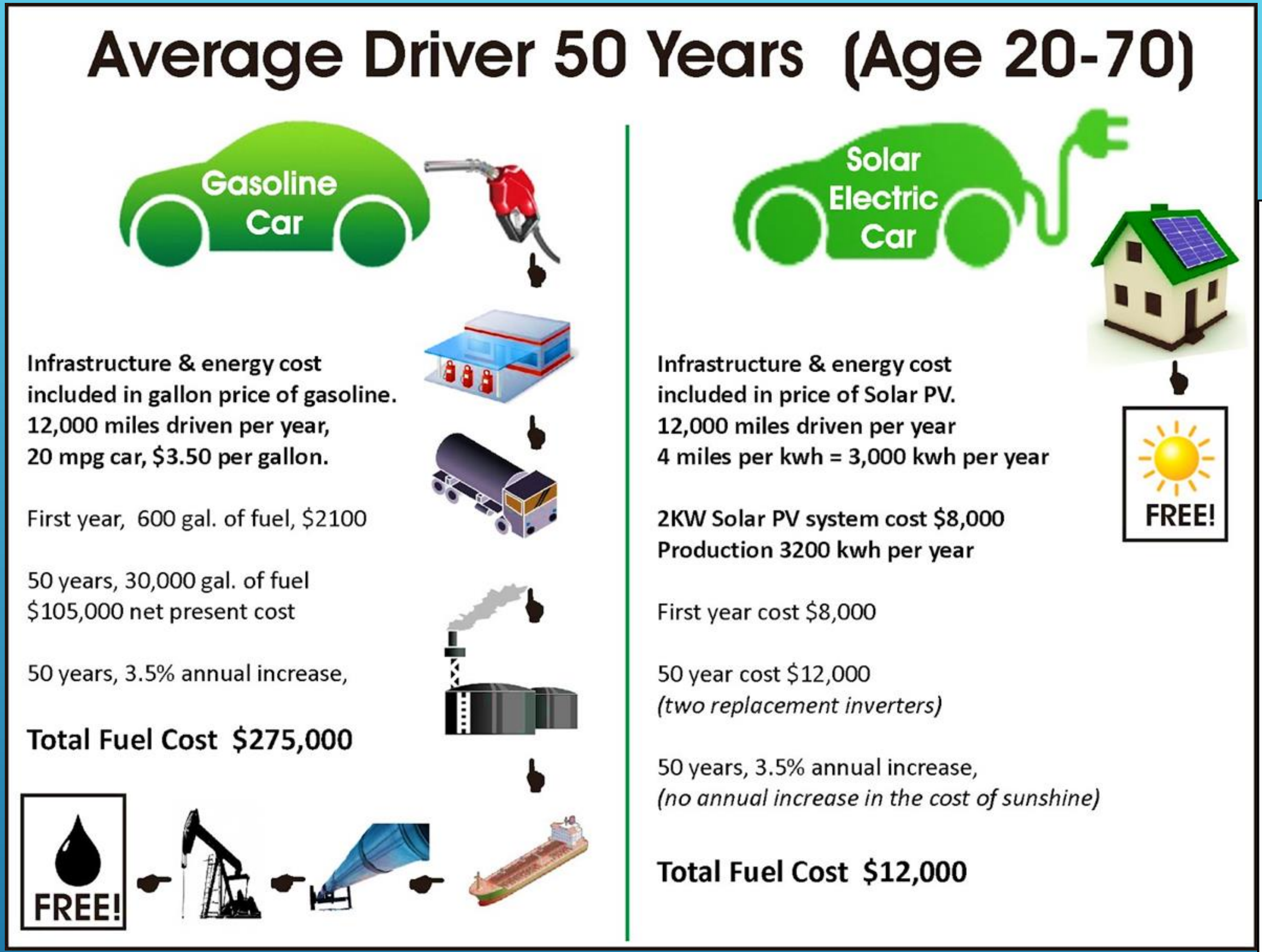
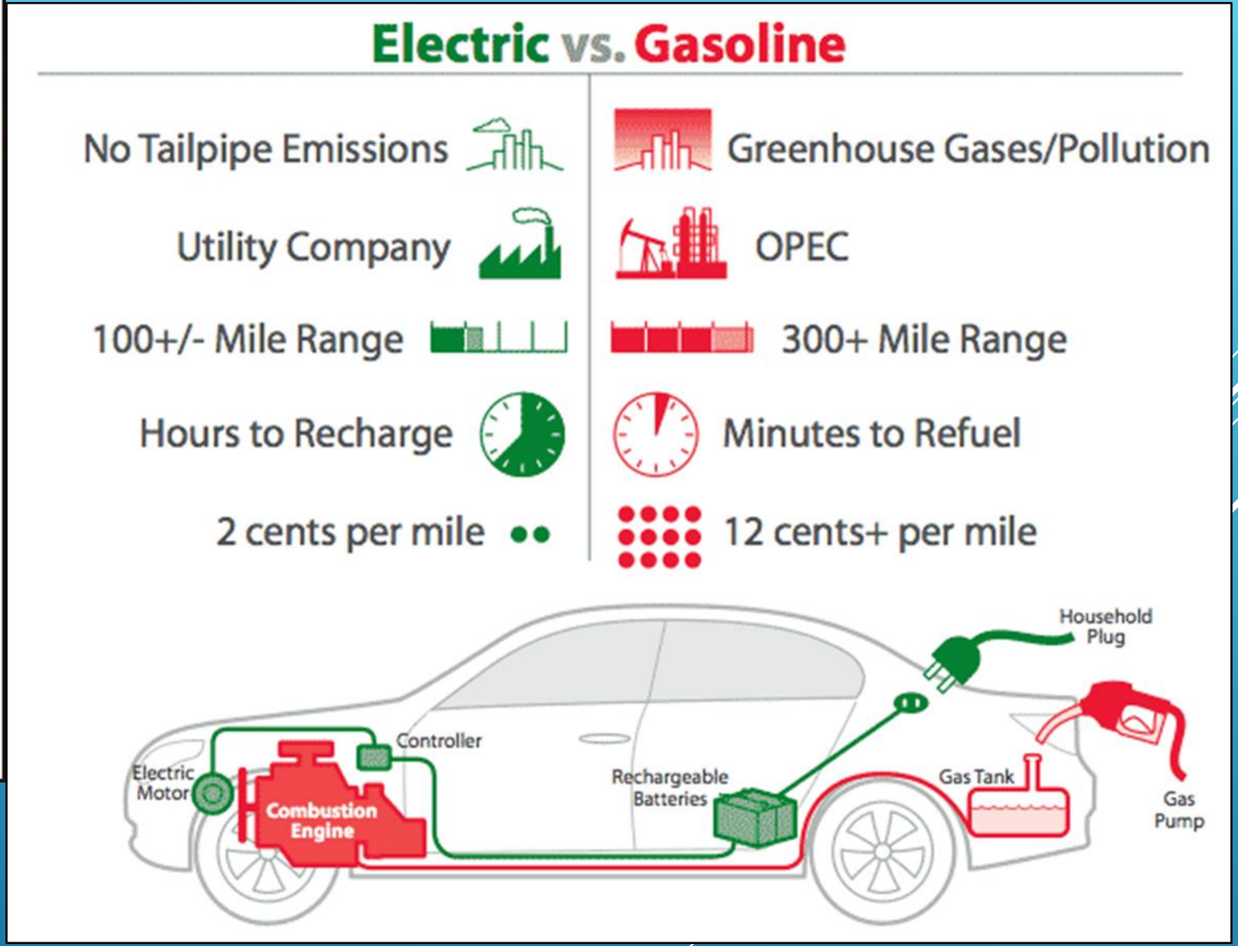
Figure 6. 1 Representation of the solar panel EV charging station and EV chassis components


Average Driver 50 Years (Age 20-70)
Gasoline Car
Infrastructure & energy cost included in gallon price of gasoline.
12,000 miles driven per year,
20 mpg car, $3.50 per gallon.
First year, 600 gal. of fuel, $2100
50 years, 30,000 gal. of fuel
$105,000 net present cost
50 years, 3.5% annual increase,
Total Fuel Cost $275,000
FREE!
Solar Electric Car
FREE!
Infrastructure & energy cost included in price of Solar PV.
12,000 miles driven per year
4 miles per kwh = 3,000 kwh per year
2KW Solar PV system cost $8,000
Production 3200 kwh per year
First year cost $8,000
50 year cost $12,000
(two replacement inverters)
50 years, 3.5% annual increase,
(no annual increase in the cost of sunshine)
Total Fuel Cost $12,000


Electric vs. Gasoline
No Tailpipe Emissions
Greenhouse Gases/Pollution
Utility Company
OPEC
100+/- Mile Range
300+ Mile Range
Hours to Recharge
Minutes to Refuel
2 cents per mile
12 cents+ per mile
Household Plug
Controller
Electric Motor
Combustion Engine
Rechargeable Batteries
Gas Tank
Gas Pump

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