Asia-Pacific
Economic Cooperation

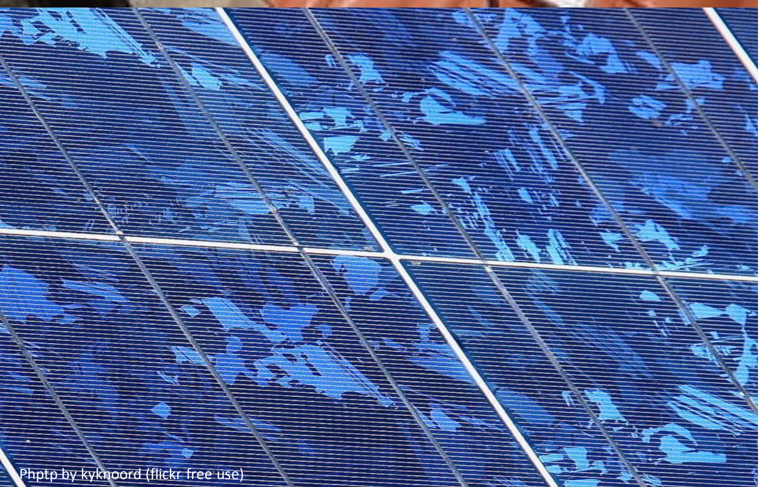
Rooftop Solar PV System Designers and Installers

Training Curriculum

APEC Secretariat

March 2015

Phptp by marufish (flickr free use)



Phptp by kyknoord (flickr free use)

Phptp by thomas kohler (flickr free use)

BASIC SOLAR PV SYSTEM TYPES

Training of PV Designer and Installer

Asia-Pacific Economic Cooperation

International Copper Association
Copper Alliance

castlerock consulting

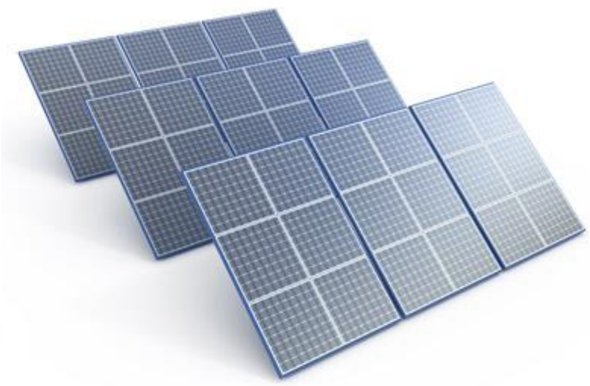
Contents

Asia-Pacific Economic Cooperation

A. Types of solar energy

These are all “solar panels”:

Solar thermal



Solar
PV

Solar thermo-electric

A. Types of solar energy

Asia-Pacific Economic Cooperation

- There are *two* common types of solar energy systems:
  - Thermal systems
  - Photovoltaic systems (PV)

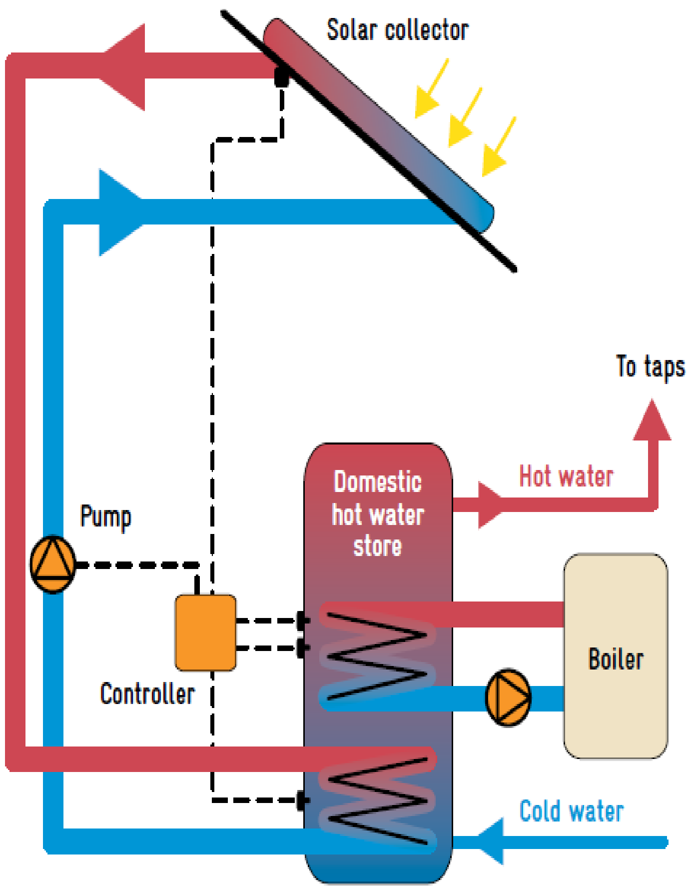
- **Thermal** systems heat water for domestic heating and recreational use (i.e. hot water, pool heating, radiant heating and air collectors). The use of thermal solar systems to produce steam for electricity is also increasing (Thermoelectric plants). Examples:
  - Solar Thermal Electric Plants
  - Pre-heating of feed water before turned into steam

- **Photovoltaic** (PV) systems convert sun's rays into electricity
  - Some PV systems have batteries to store electricity
  - Other systems feed unused electric back into the grid

A. Types of solar energy

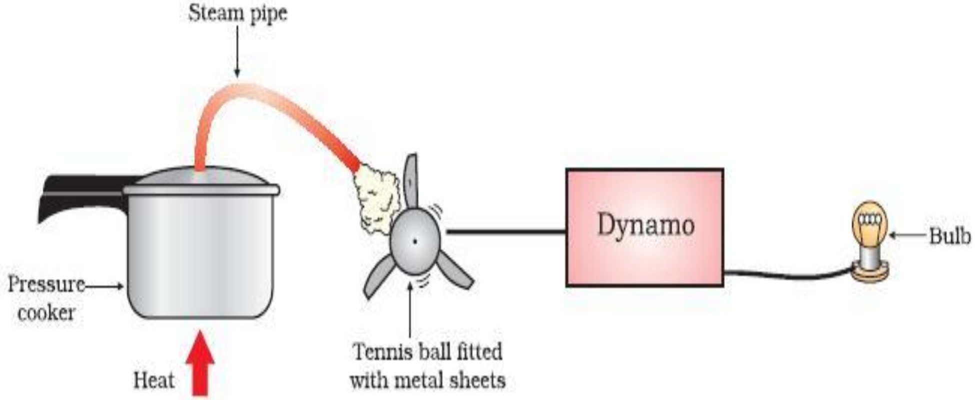
Asia-Pacific Economic Cooperation

Thermal system application



A. Types of solar energy

- Thermoelectric



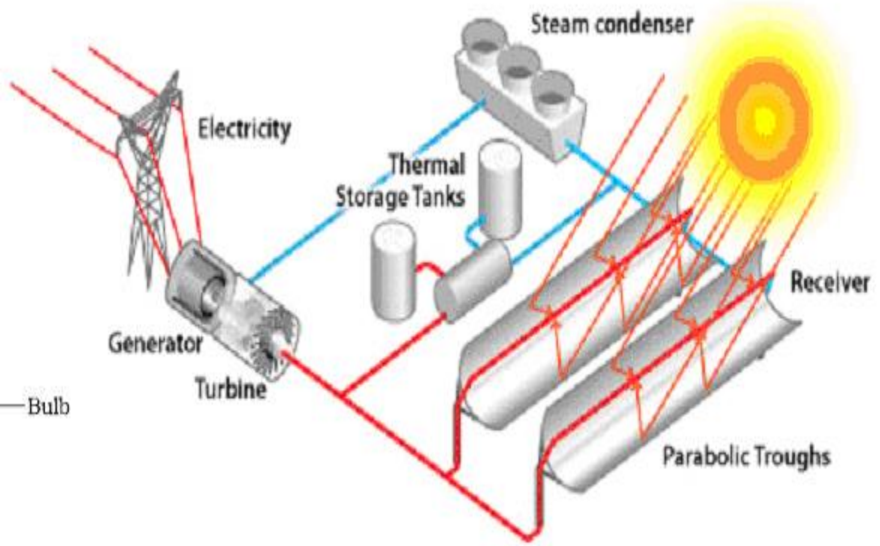


Diagram of a Parabolic Trough Power Plant

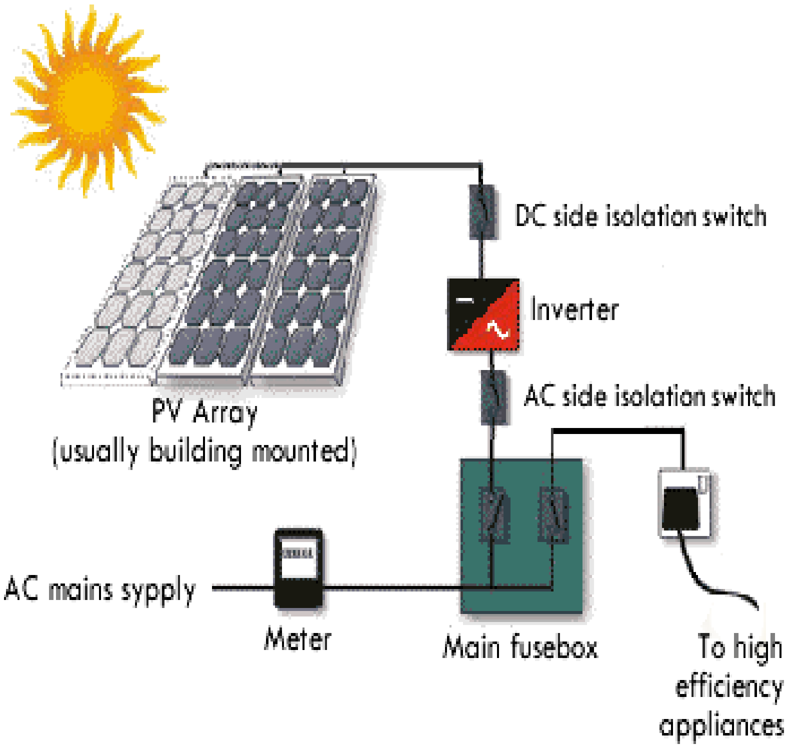
A. Types of solar energy

Asia-Pacific Economic Cooperation

Photovoltaic

Photovoltaic systems primary components:

- Modules
- Inverters



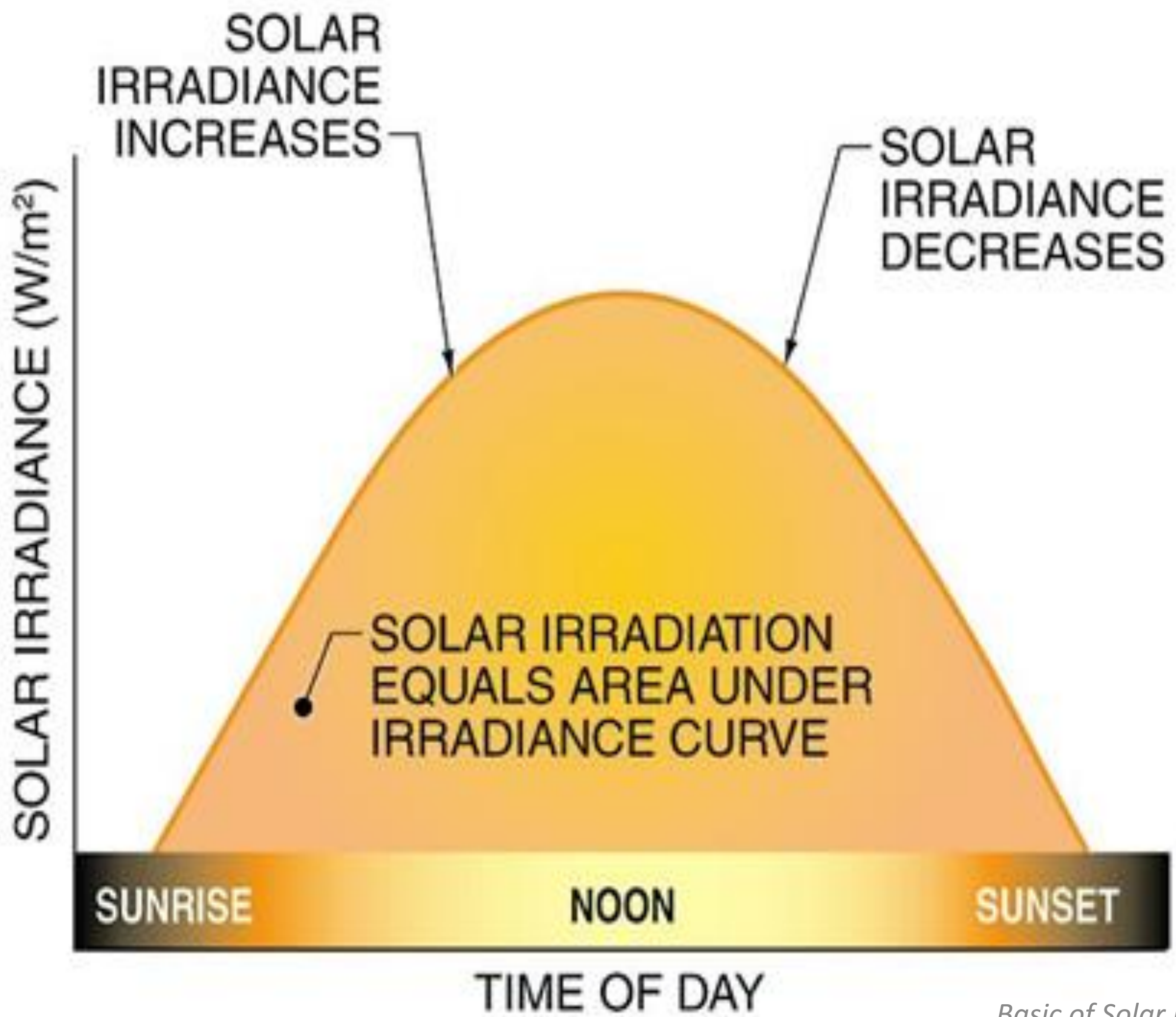
B. Basic terminology

- **Solar irradiance** is the intensity of solar power, usually expressed in Watts per square meter [W/m^2]
- PV modules output is rated based on Peak Sun Hours (equivalent to 1000 W/m^2).
- Since the proportion of input/output holds pretty much linearly for any given PV efficiency, we can very easily evaluate a system performance check by measuring irradiance and the PV module output (using a **pyranometer**)

B. Basic terminology

Asia-Pacific Economic Cooperation

Solar irradiance and irradiation



B. Basic terminology

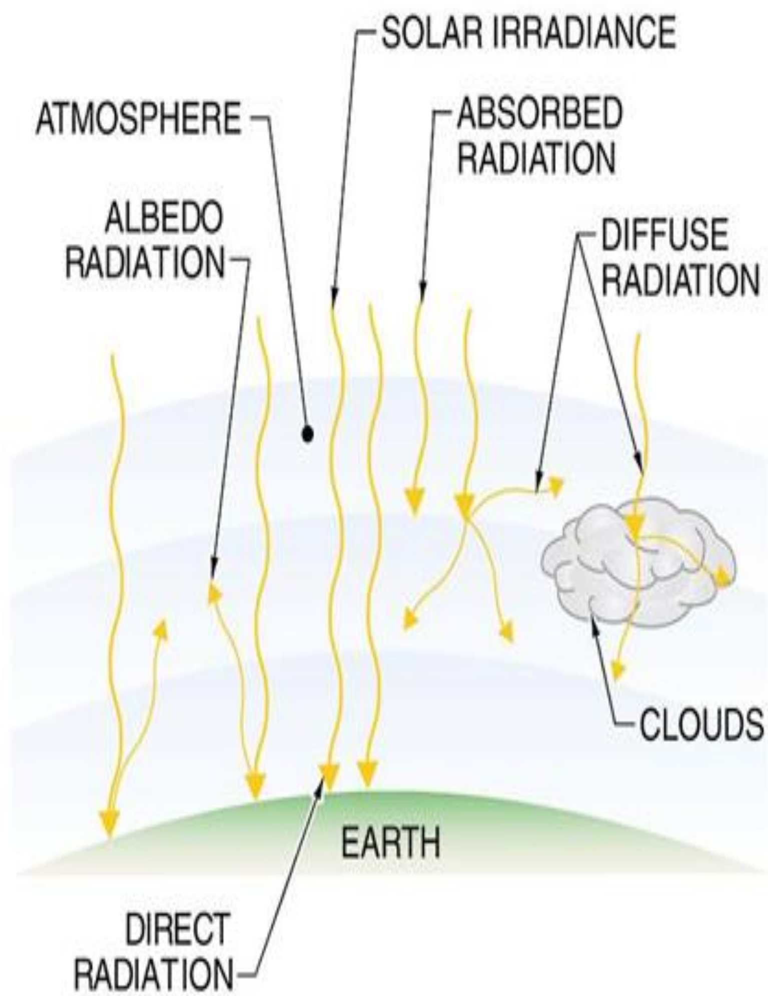
Solar Radiation

❑ **Atmospheric Effects**

Solar radiation is absorbed, scattered and reflected by components of the atmosphere

The amount of radiation reaching the earth is less than what entered the top of the atmosphere. The categories are:

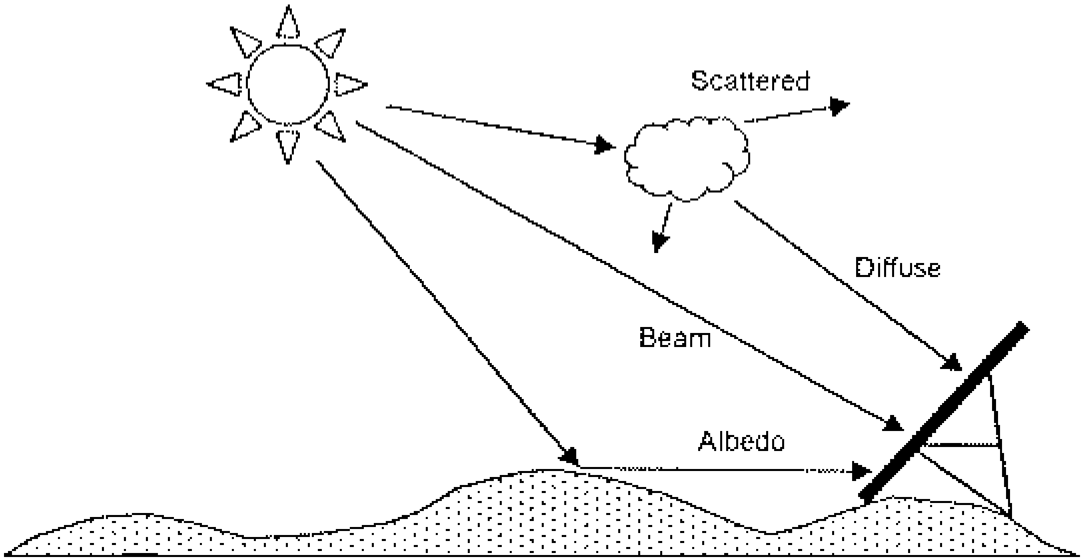
1. **Direct Normal Irradiance (DIN):** radiation from the sun that reaches the earth without scattering
2. **Diffuse Irradiance (DIF):** radiation that is scattered by the atmosphere, clouds, and may arrive from all directions.
3. **Albedo Irradiance:** a direct or diffuse radiation reflected from the soil or nearby surfaces (snow, lakes, etc)



B. Basic terminology

4. **Global Horizontal Irradiance (GHI):** Total amount of shortwave radiation received from above by horizontal surface. It includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI).

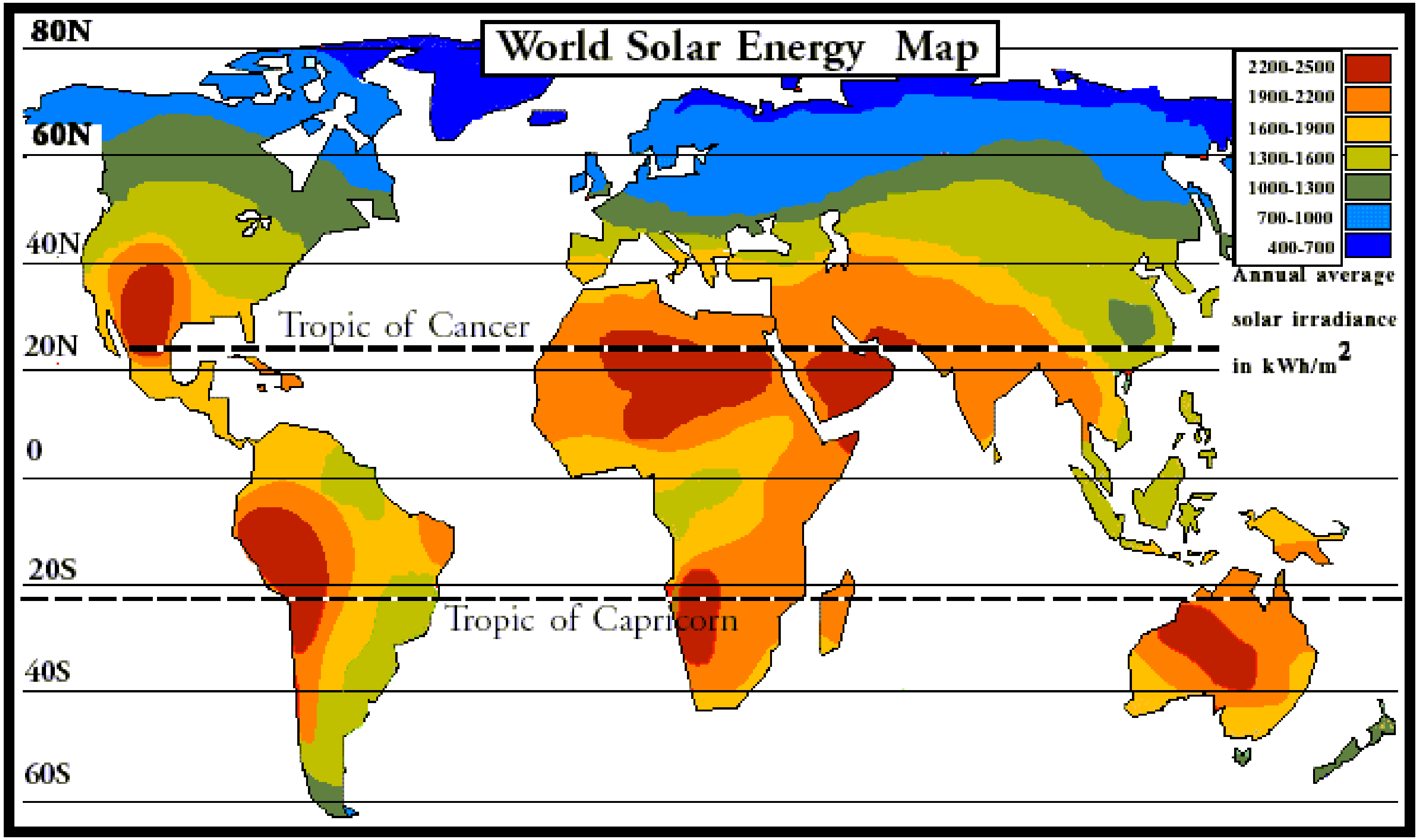
5. **Global In-Plane Irradiance:** total amount of radiation (both DNI and DHI) received from above by an inclined surface.



B. Basic terminology

Asia-Pacific Economic Cooperation

Solar Irradiation around the world

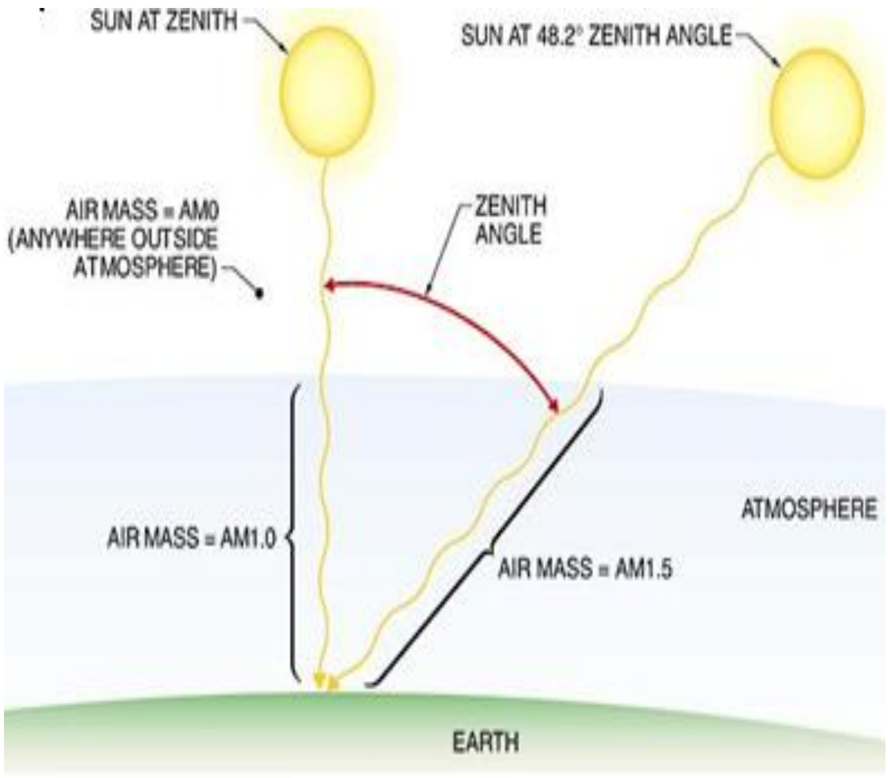


B. Basic terminology

Solar Radiation

- **Peak Sun Hours** is the number of hours required for a day's total radiation to accumulate at peak sun condition.
- **Zenith** is the point in the sky directly overhead a particular location – as the Zenith angle **ϴz** increases, the sun approaches the horizon.

AM = 1/ Cos ϴ



B. Basic terminology

- **Example problem of Peak sun hours per day**:

  If during the day we have 4 hours at 500 Wh/m^2 and 6 hours at 250 Wh/m^2 we should compute the peak sun hours per day as follows:

  First, multiply 4hs x 500 W/m^2 and add to it 6hs x 250 W/m^2 – Equal 3500 Wh/m^2

  Second, by definition Peak Sun is 1000 W/m^2, divide the total irradiation for the day by Peak Sun we will obtain Peak Sun hours,

  Peak Sun Hours = Total Irradiation [Wh/m^2] / Peak Sun [W/m^2] = Peak Sun hours

  <u>In our case above:</u>

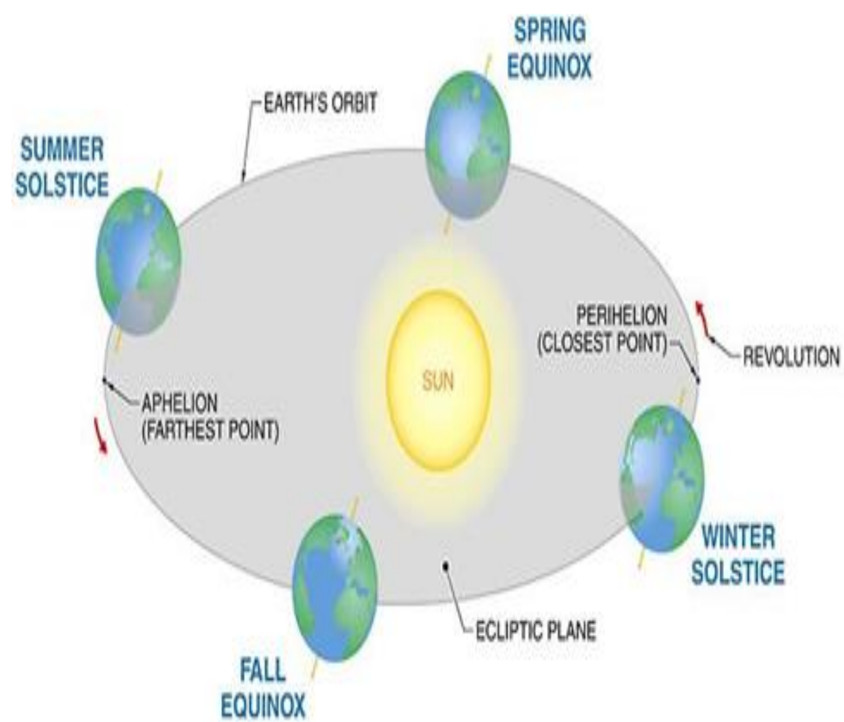
  Peak Sun Hours = 3500 Wh/m^2 / 1000 W/m^2 = 3.5 Peak Sun hours

- **Note:** solar irradiation data is often presented in Peak Sun Hours units

B. Basic terminology

Solar Radiation

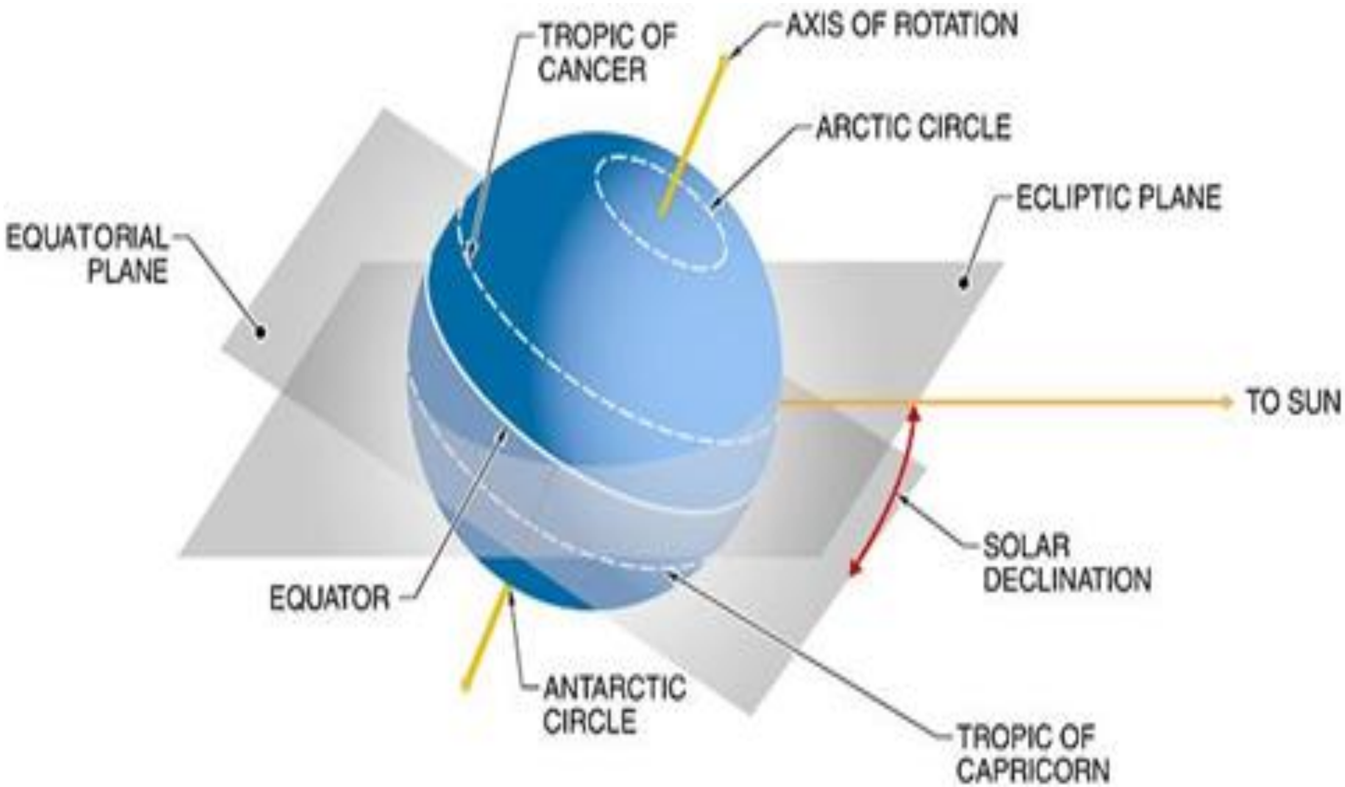
- Major motions of Earth affect the apparent path of the sun across the sky:
    1. Yearly revolution around the sun
    2. Daily rotation about its axis
- **Ecliptic Plane** is the plane of Earth's orbit around the sun
- **Equatorial Plane** is the plane containing Earth's equator and extending outward into space



B. Basic terminology

Asia-Pacific Economic Cooperation

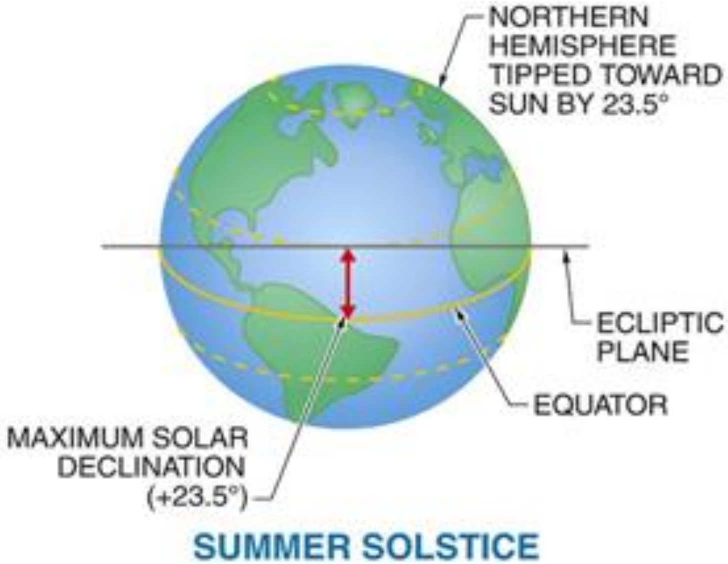
- **Solar Declination** is the angle between the equatorial plane and the ecliptic plane
- The **solar declination angle** varies with the season of the year, and ranges between –23.5º and +23.5º

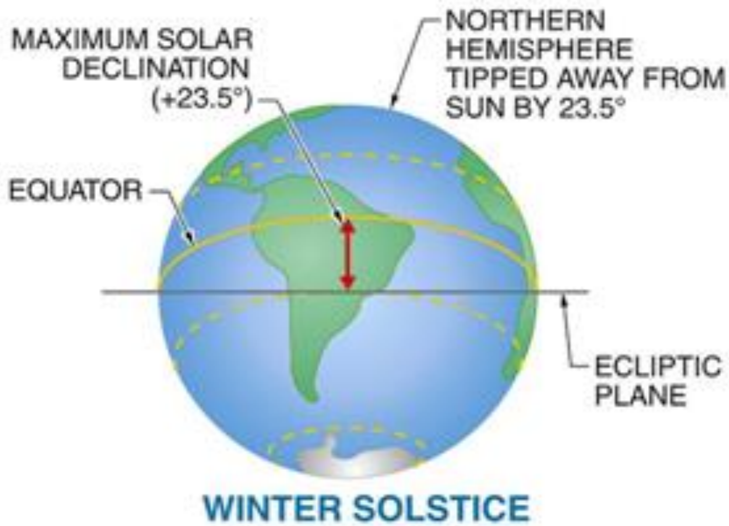


B. Basic terminology

- **Summer Solstice** is at maximum solar declination (+23.5º) and occurs around June 21st –Sun is at Zenith at solar noon at locations 23.5º N latitude
- **Winter Solstice** is at minimum solar declination (-23.5º) and occurs around December 21st.

At any location in the Northern Hemisphere, the sun is 47º lower in the sky at noon on winter solstice than on the summer solstice – Days are significantly shorter than nights

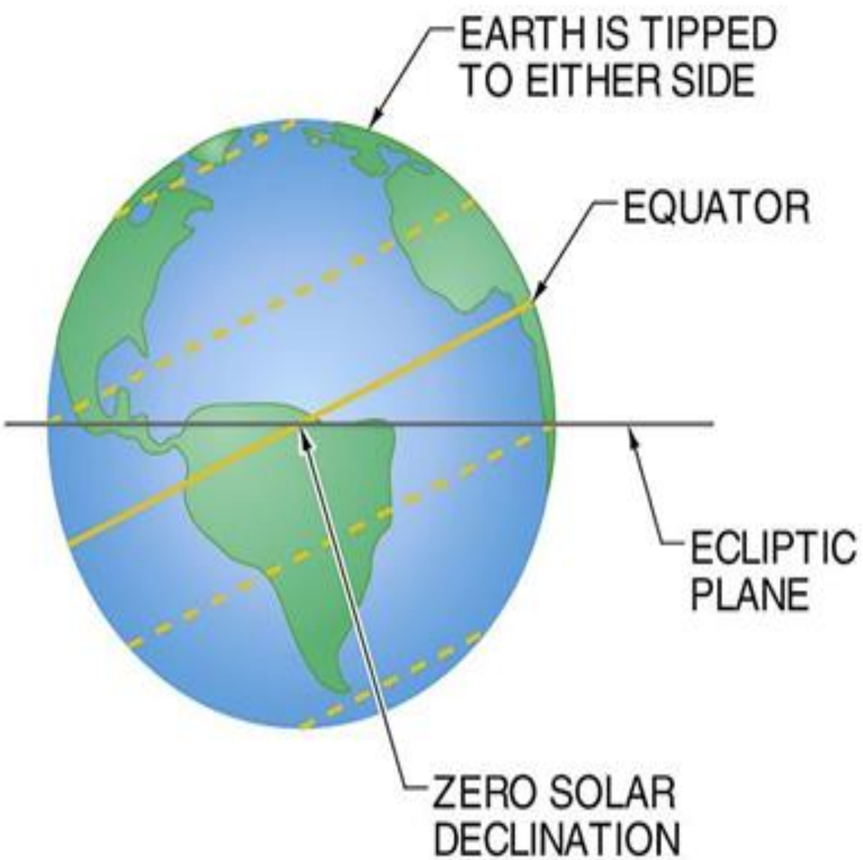




B. Basic terminology

Asia-Pacific Economic Cooperation

- **Equinoxes** occur when the solar declination is zero. Spring equinox is around March 21st and the fall equinox occurs around September 21st –Sun is at Zenith at solar noon on the equator.
- Around the equinoxes the daily [rate of] change is at maximum as oppose to change of declination during the solstices when it is at its minimum

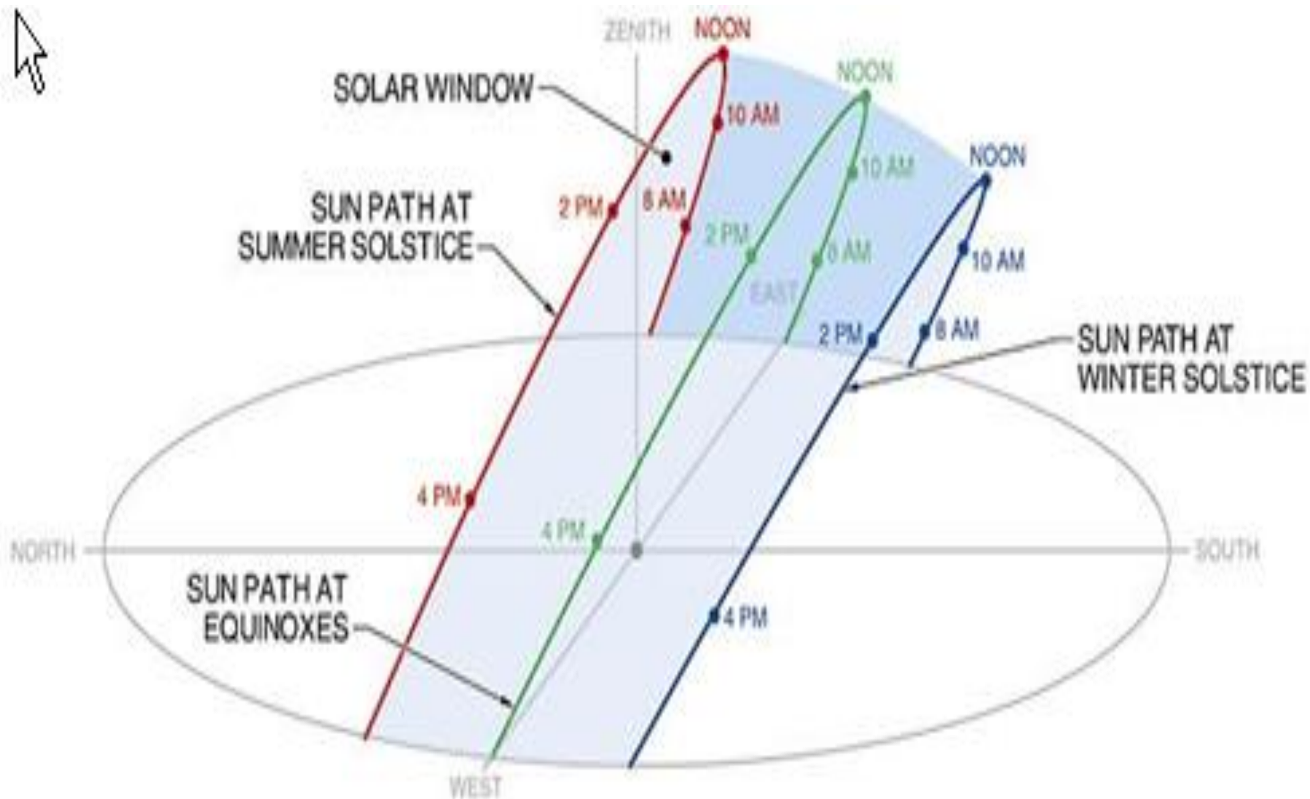


FALL OR SPRING EQUINOX

B. Basic terminology

Asia-Pacific Economic Cooperation

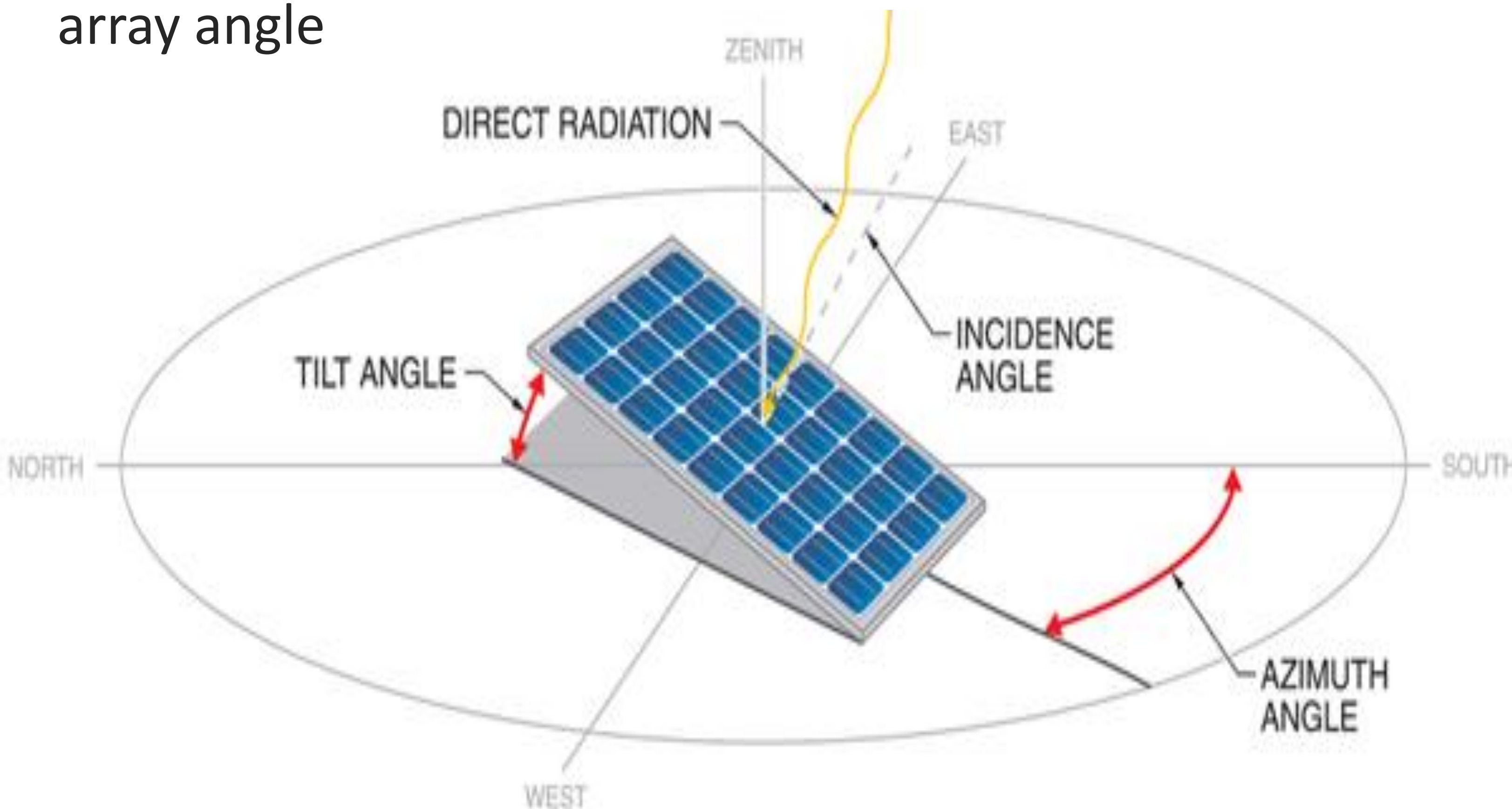
Solar Window is the area of sky between sun paths at summer solstice and winter solstice for a particular location



International Copper Association
Copper Alliance

B. Basic terminology

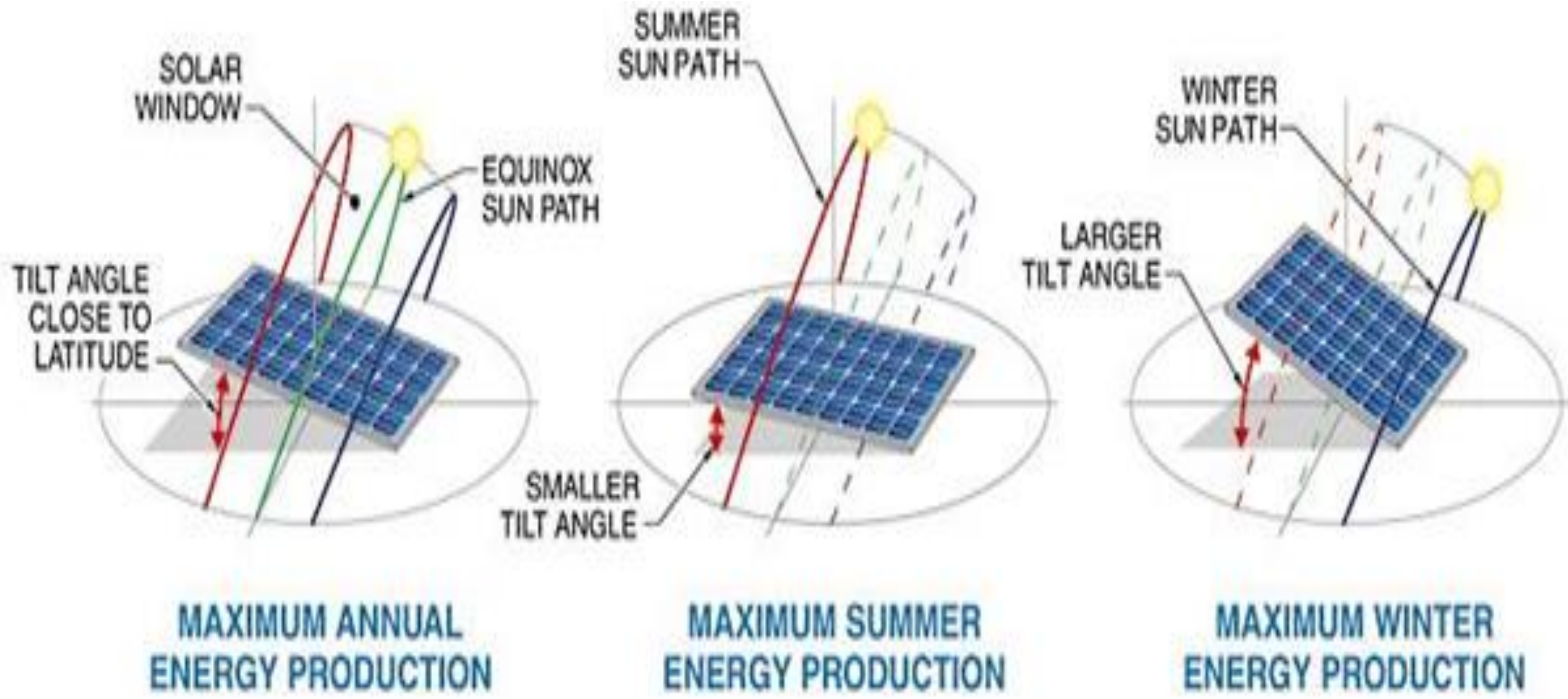
Incidence Angle is the angle between the direction of direct radiation and a line exactly perpendicular to the array angle



B. Basic terminology

Array orientation is defined by two angles:

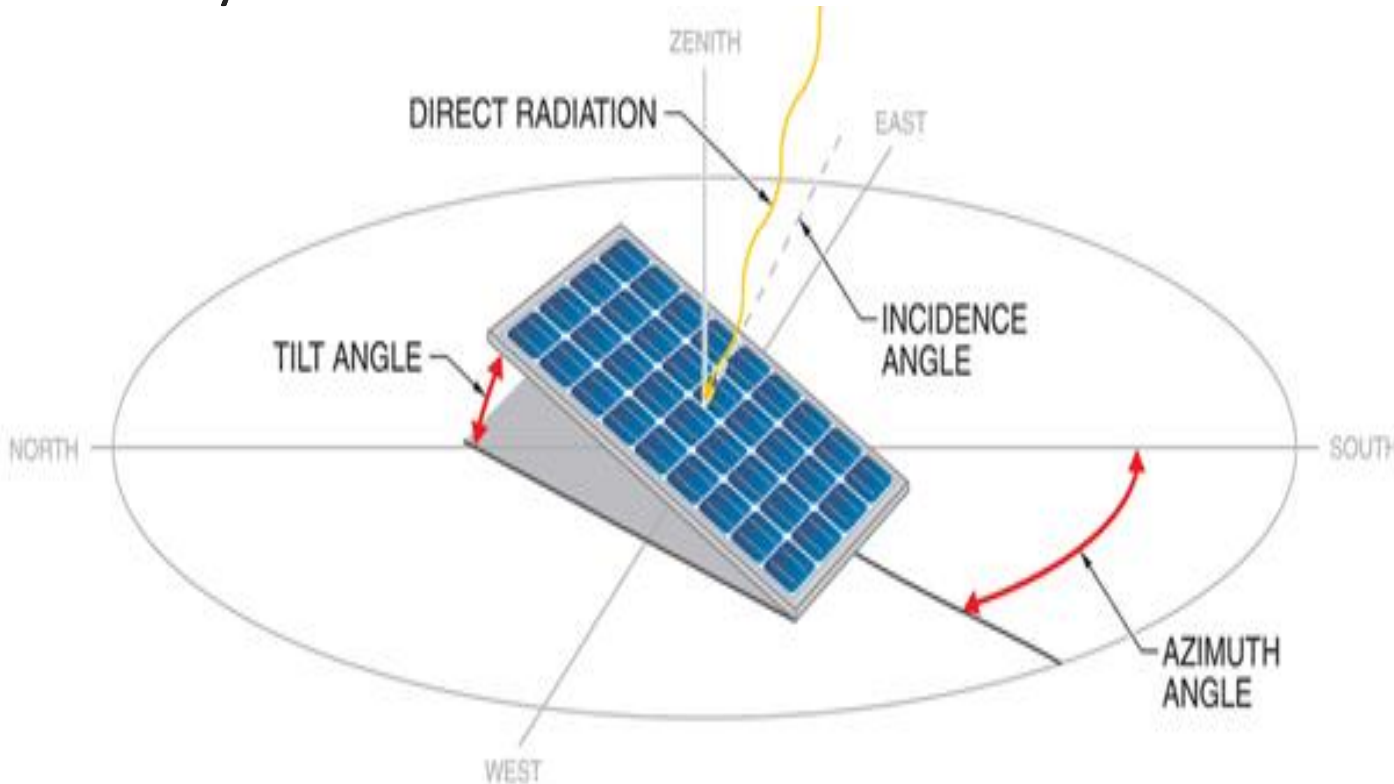
1. **Tilt angle** is the vertical angle between the horizontal and the array surface



B. Basic terminology

Asia-Pacific Economic Cooperation

2. Array Azimuth Angle is the horizontal angle between a reference direction - typically south - and the direction an array surface faces



B. Basic terminology

Measurement of solar radiation

Solar irradiation can be measured directly by using pyranometers and photovoltaic sensors or indirectly by satellite images. **Pyranometers** are high precision sensors using a thermocouple measuring the temperature difference beween an absorber surface and the environment.

C. Types of PV Systems

- Photovoltaic (PV) systems convert light energy directly into electricity.
- Commonly known as "solar cells."
- The simplest systems power the small calculators we use every day.
- PV represents one of the most promising means of maintaining our energy intensive standard of living while not contributing to global warming and pollution.

C. Types of PV Systems

How Does it Work?

Sunlight is composed of photons, or bundles of radiant energy. When photons strike a PV cell, they may be reflected or absorbed (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.

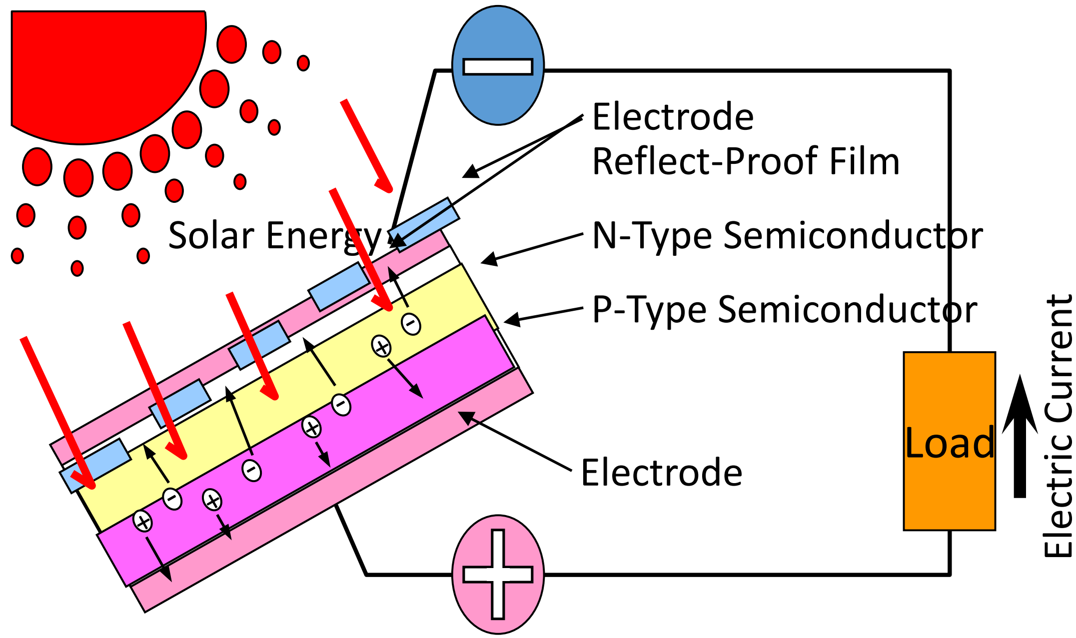
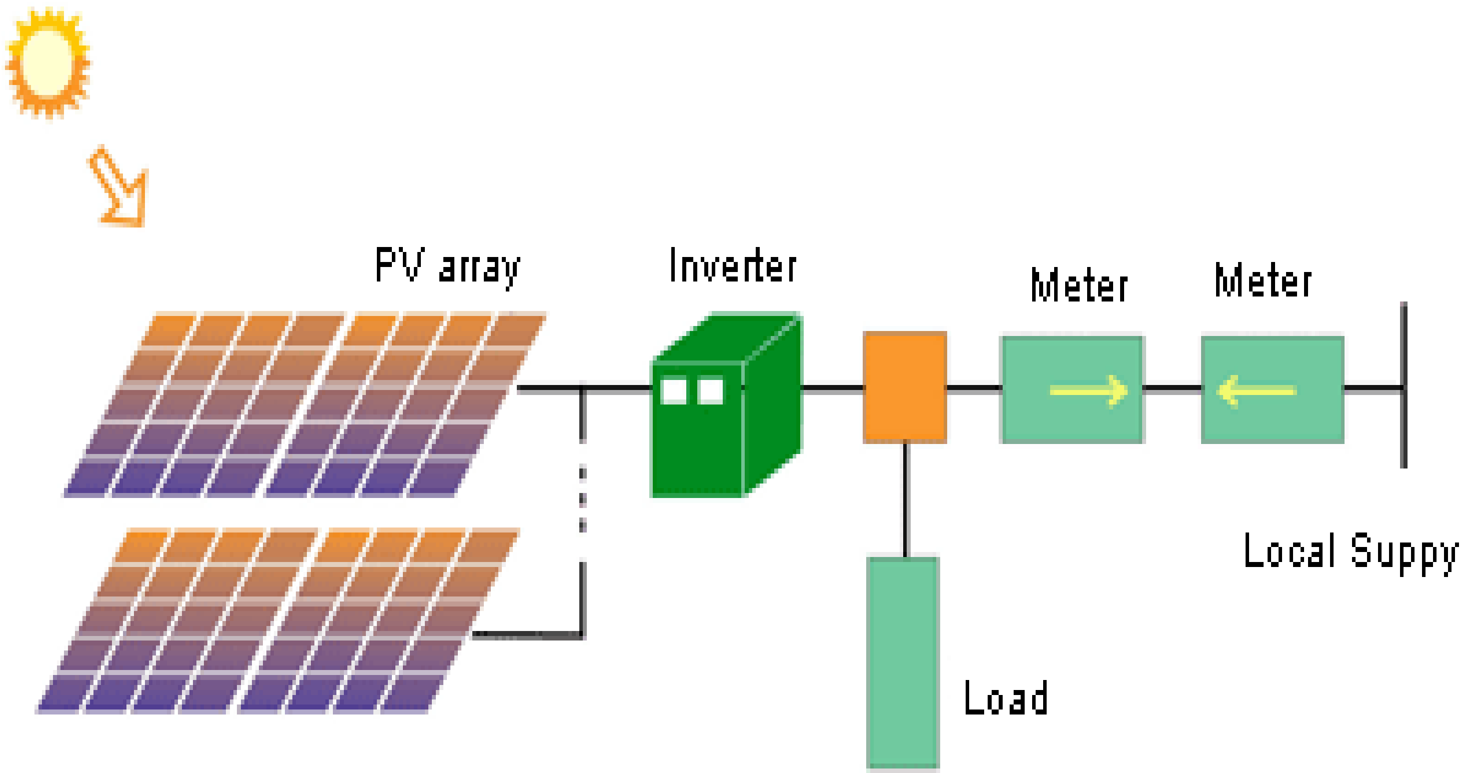


Photo Voltaic cell

C. Types of PV Systems

Types of PV systems:

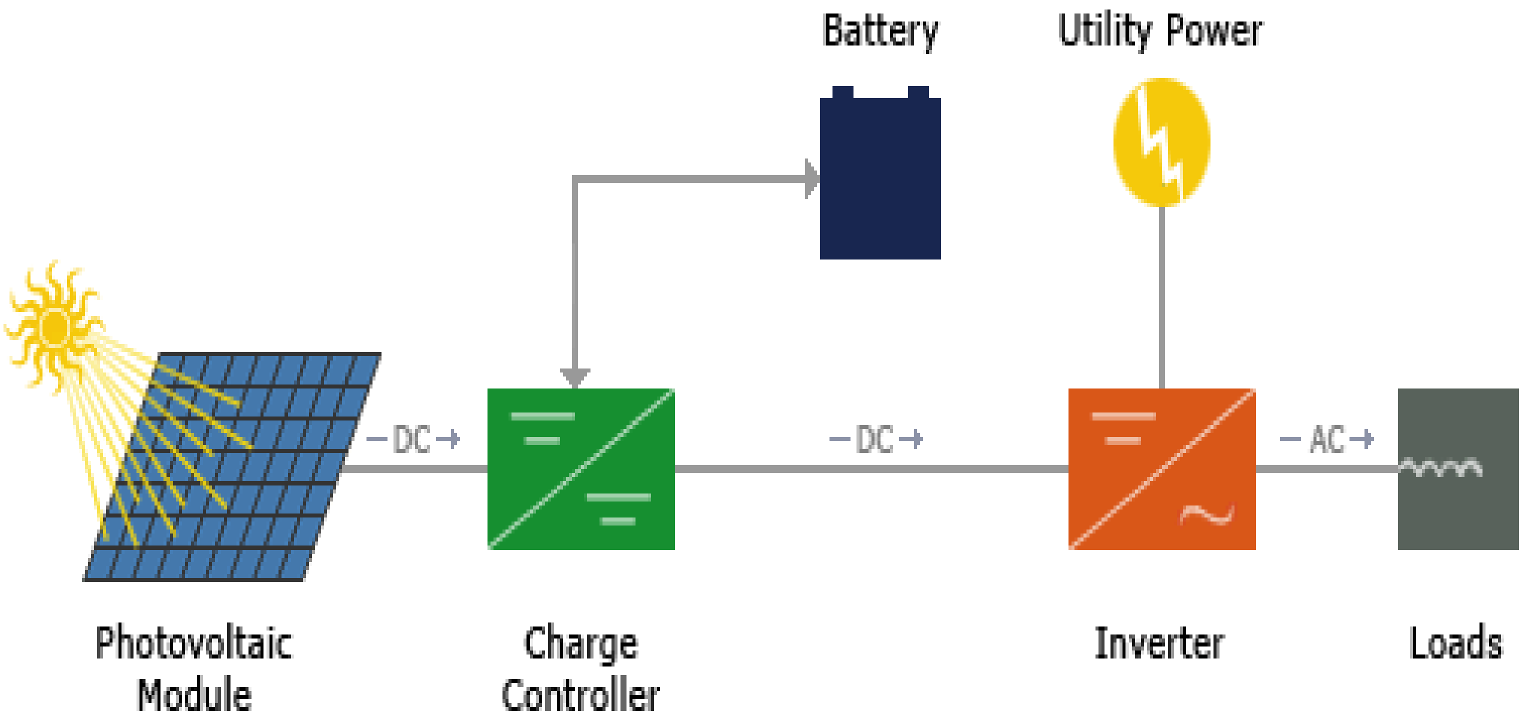
1. Grid-connected



C. Types of PV Systems

Asia-Pacific Economic Cooperation

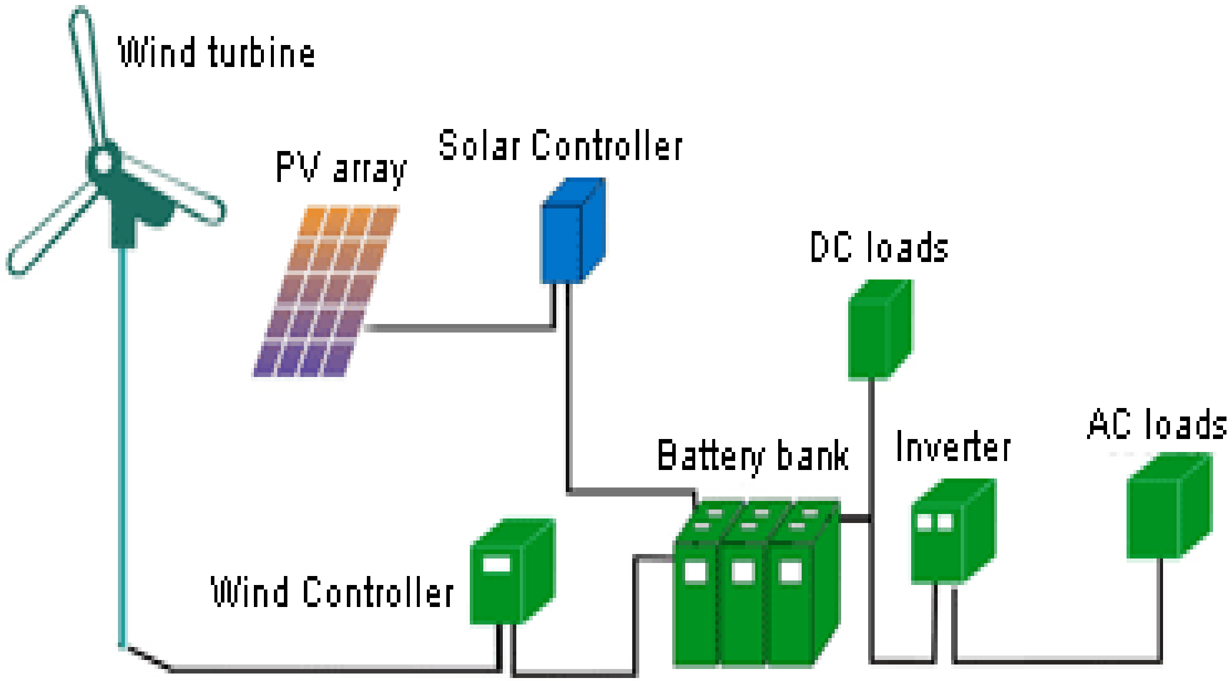
2. Off-Grid (local storage)



C. Types of PV Systems

Asia-Pacific Economic Cooperation

3. Hybrid



- In hybrid energy systems more than a single source of energy supplies the electricity.
- Wind and Solar compliment one another
- Solar PV and diesel generator is often a cost efficient solution

D. Energy Generation and Storage

Asia-Pacific Economic Cooperation

The solar cell is composed of a P-type semiconductor and an N-type semiconductor. Solar light hitting the cell produces two types of electrons, negatively and positively charged electrons in the semiconductors.

Negatively charged (-) electrons gather around the N-type semiconductor while positively charged (+) electrons gather around the P-type semiconductor.

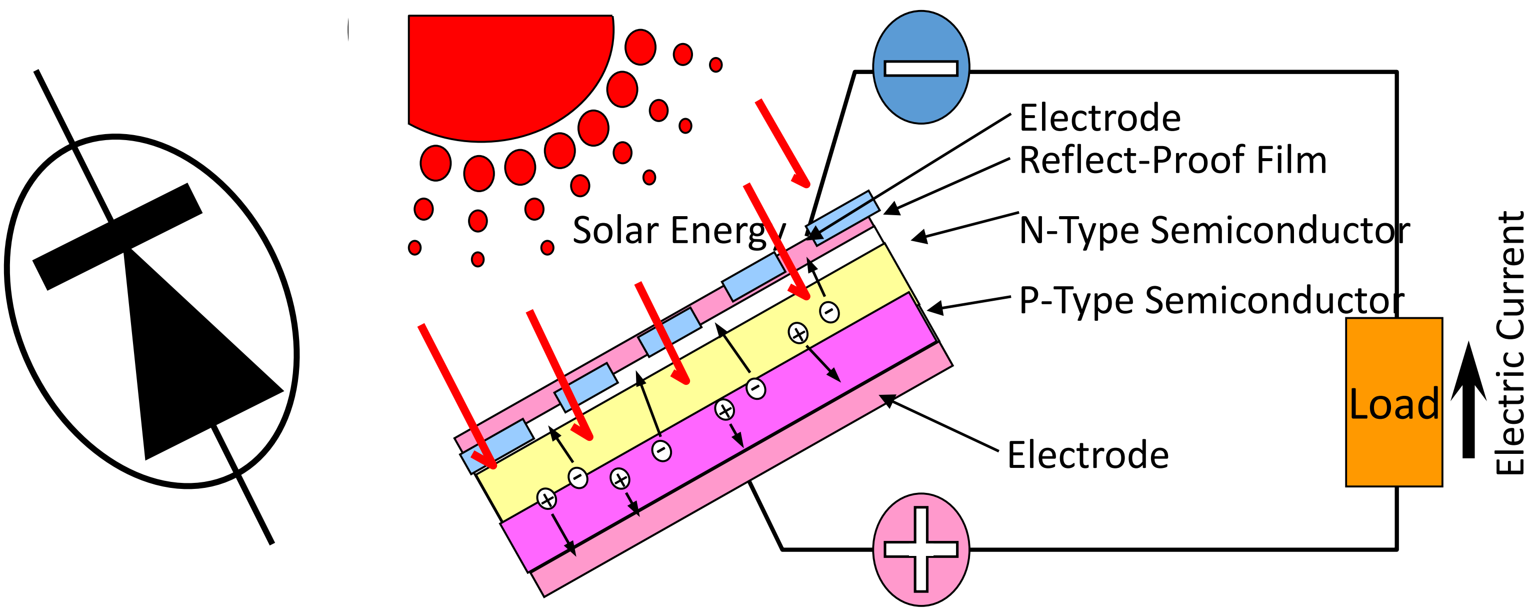
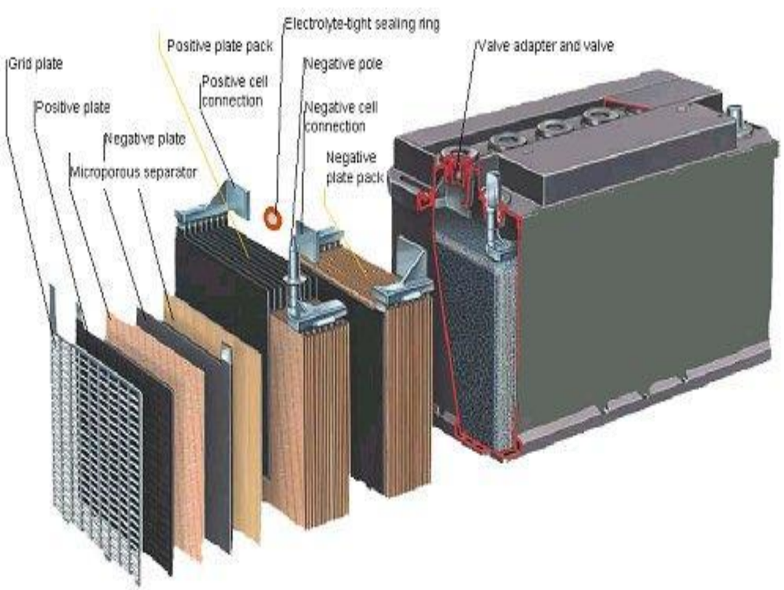
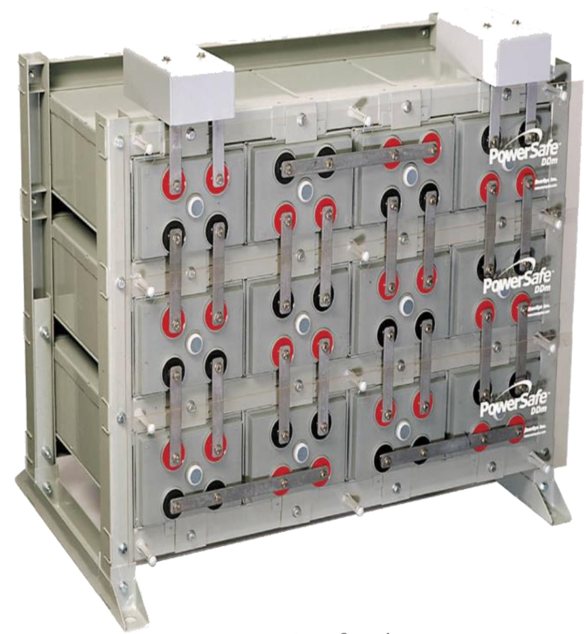


Photo Voltaic cell

D. Energy Generation and Storage

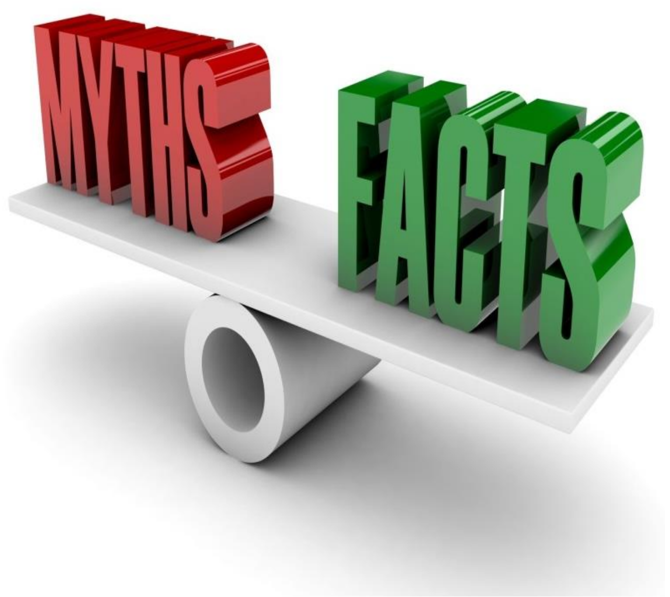
- **Batteries** consist of voltaic cells that are connected in series to provide a steady DC voltage at the output terminals.
- The voltage is produced by a chemical reaction inside the cell. Electrodes are immersed in an electrolyte, which forces the electric charge to separate in the form of ions and free electrons.





E. Solar PV myths

Solar PV systems are not perfect, they have their limitations. However, there are a lot of misconceptions and myths out there about the limitations of solar PV systems. The following are just a few examples of these myths that need to be debunked



E. Solar PV myths

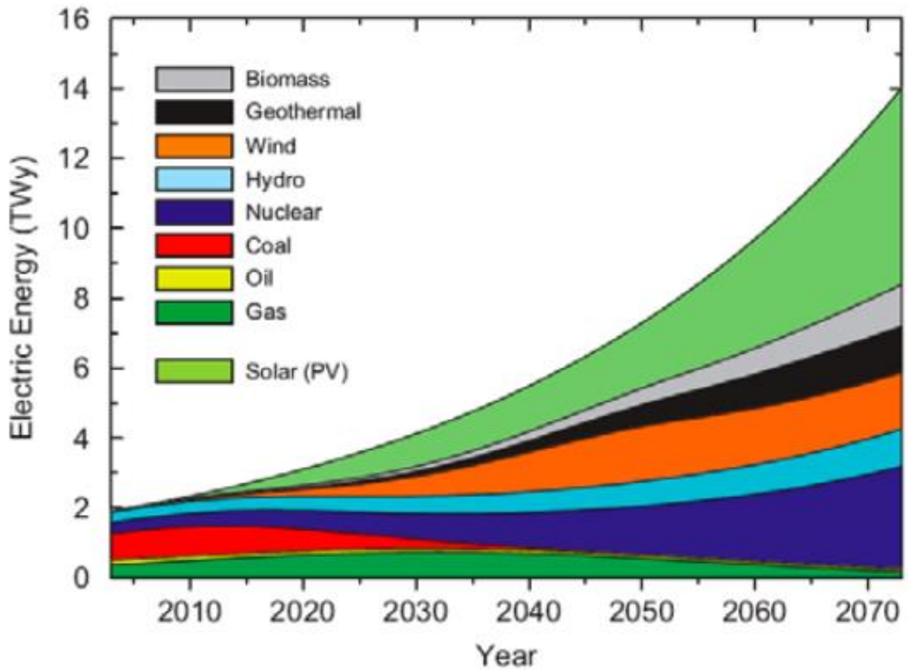
"Solar power takes up too much land"

Average solar PV systems take between 1.2 to 2 hectares per MW. Compare this with 1.6 to 2.5 hectares per MW for a nuclear power plant. Or 12 to 30 hectares per MW for a wind farm.

E. Solar PV myths

"Solar power is inefficient"

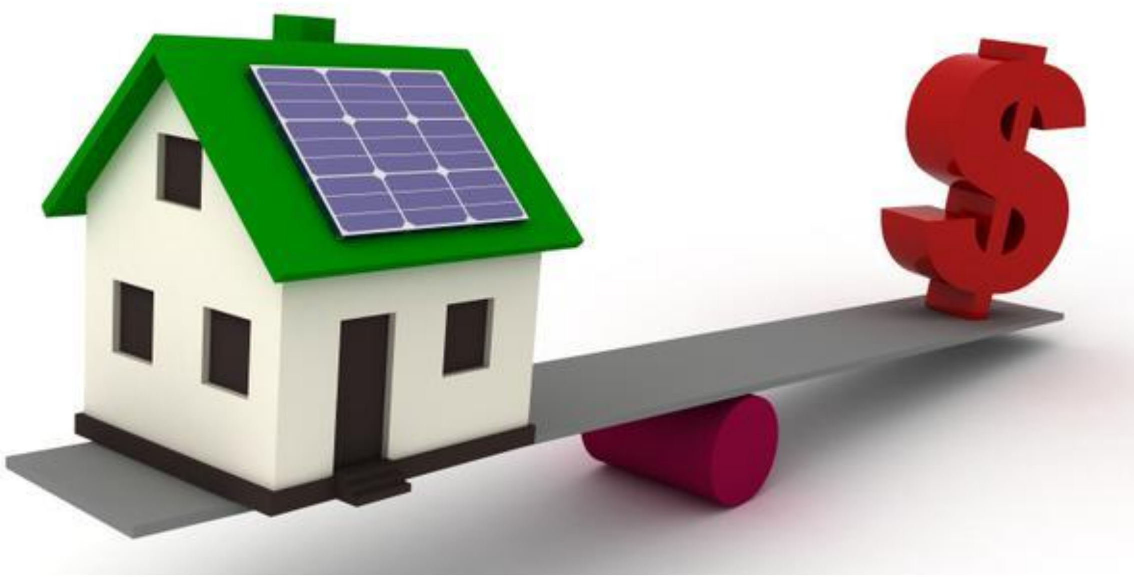
When we only look at the fact that the best solar panels have an efficiency numbers of around 15-20%, it may sound like it. But solar power has one of the best efficiency figures for area vs GWh of energy produced per year.



E. Solar PV myths

"Solar power is too expensive."

Solar energy cost has dramatically decreased. Some countries provide tax credits and other subsidies for solar PV installation projects. Levelized cost of energy for rooftop solar PV systems are as low as US 0.12/kWh in some regions



E. Solar PV myths

“Solar PV won’t work when cloudy”

Solar PV panels will produce electricity as long as there’s light. Cloudy days will still have enough light for solar PV panels to produce usable electricity.

Project Number : EWG 22/2013A

Produced By

Andre Susanto
Chitra Priambodo
Castlerock Consulting - http://www.castlerockasia.com/

For
Asia Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

APEC#215-RE-03.2