Renewable Power Systems and Energy Conservation

Power Plants Eng. Branch
Fourth Year: First Semester

Dr. Ing. Amar Sadun

- **Introduction**

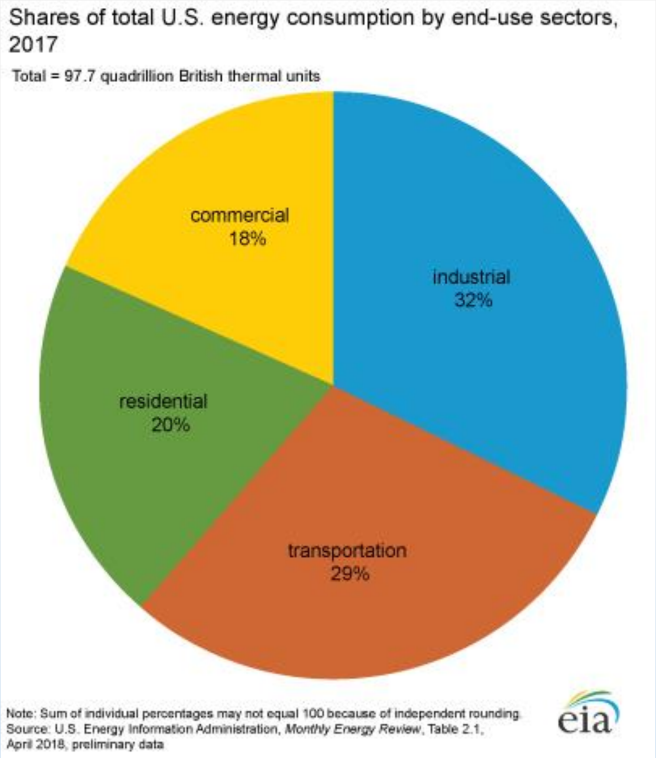
  - World energy consumption & Demand.

  - Renewable vs fossil energy sources.

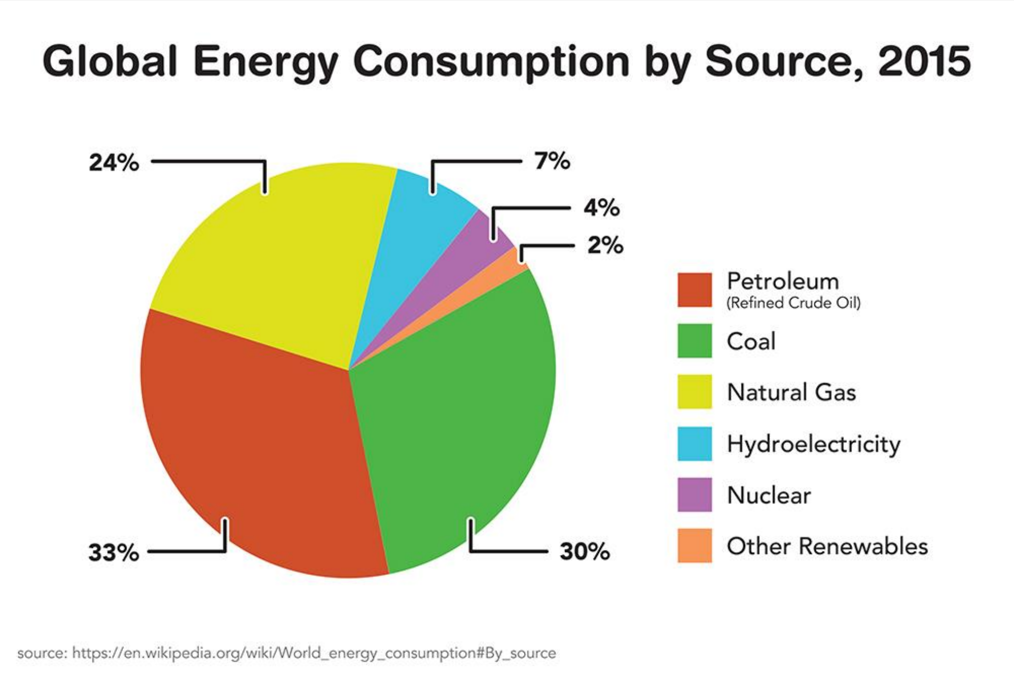
  - Renewable energy sources.

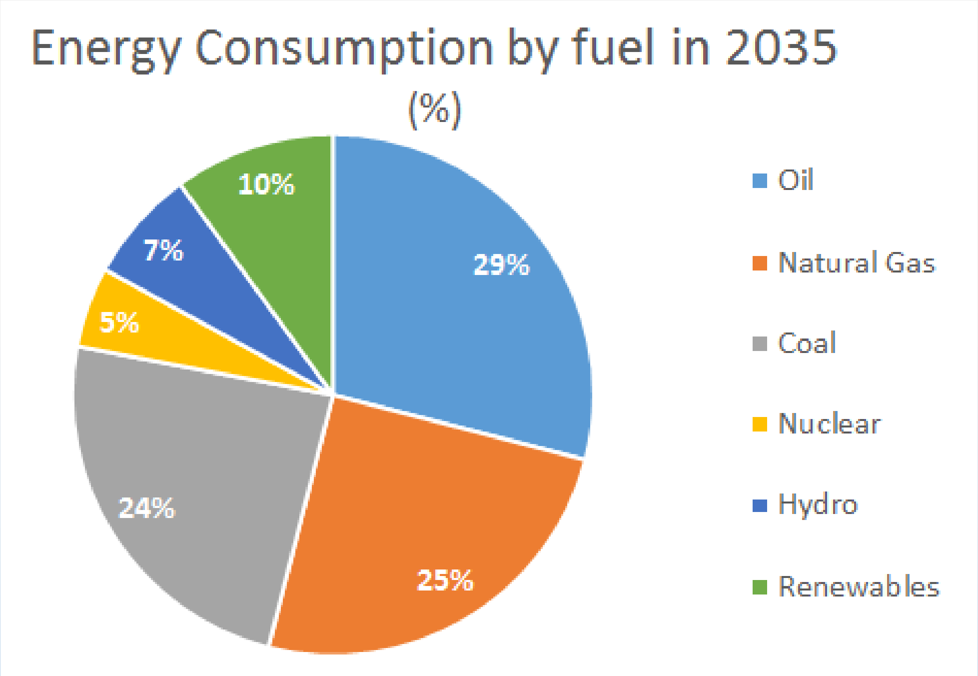
  - Advantages and benefits.

- World energy consumption & Demand

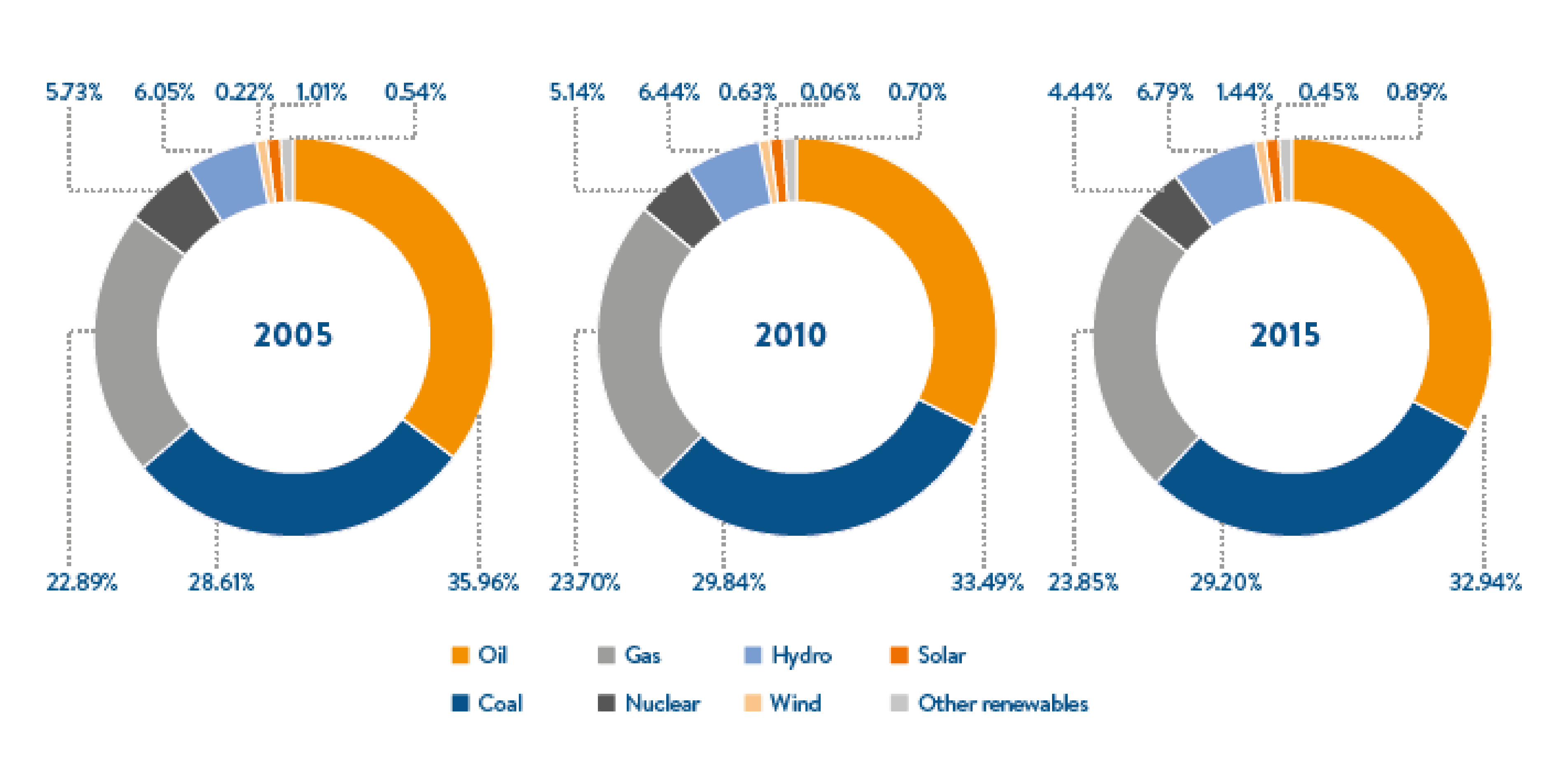


- World energy consumption & Demand





- Comparative Primary Energy Consumption Over The Past 15 Years.



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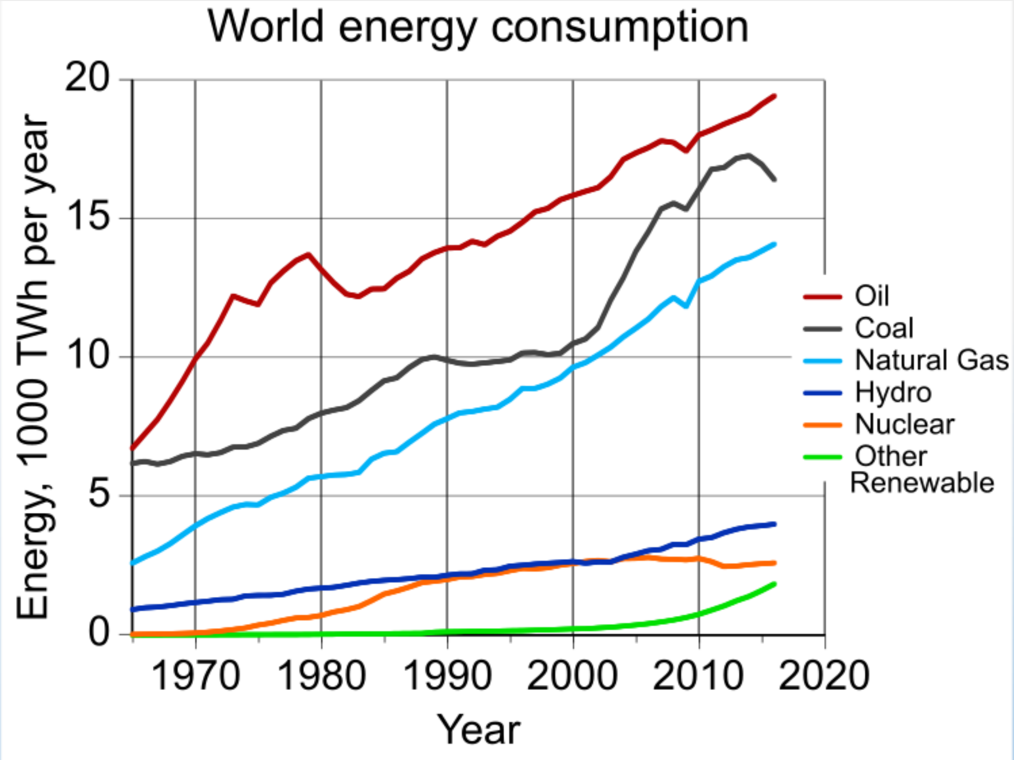
- World energy consumption & Demand

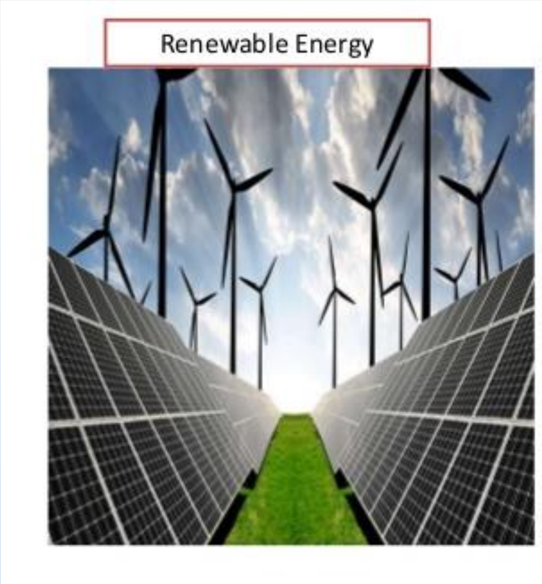


• Energy Options

• Nuclear energy

• Non-Renewable energy

• Renewable energy



What is Renewable Energy?

- Renewable energy describes a collection of energy technologies derived from sources that are never-ending and can be replenished time after time.
- Renewable energy technologies include
- wind power,
- solar power,
- hydroelectricity,
- biomass energy, and biofuels,

• Goal of Using Renewable Energy

- The goal in using renewable energy sources is to **reduce the negative environmental effects** associated with non-renewable energy sources such as coal and natural gas.

• Advantages of Renewable Energy

1. Renewable energy is eco-friendly
2. It is a clean source of energy, meaning, it has low or zero carbon and greenhouse emission. The use of renewable energy dramatically reduces the dependence on fossil fuel as a source of energy.
3. It’s a renewable resource
4. Leads to job creation

6. Renewable energy has stabilized global energy prices.
7. Less maintenance of facilities
8. Boosts public health
9. Empowering of people in the countryside
10. Diversify our energy supply. “**Reducing our dependence on oil**”
11. Reduce global warming

12. Save money, Once the initial cost of construction and setup of a renewable power source is covered, it can quite quickly begin to pay for itself. Some sources allow you to save money quicker than others. Solar, for example, requires a large investment up front, so the payoff is delayed when compared to other sources.

• Disadvantages of Renewable Energy

1. Many forms of renewable energy are location-specific.
2. The electricity generation capacity is still not large enough. One disadvantage with renewable energy is that it is difficult to generate the quantities of electricity that are as large as those produced by traditional fossil fuel generators.
3. Renewable energy can be unreliable. Renewable energy technologies totally depend on the weather (for e.g.: sun and wind) to be able to harness any energy.

3. Low-efficiency levels
4. Requires a huge upfront capital outlay (investment cost)
5. Not every form of renewable energy is commercially viable.
6. Many forms of renewable energy require storage capabilities.
7. Some forms of renewable energy require a massive amount of space.

What is non-Renewable Energy?

- Fossil fuels are non-renewable forms of energy, meaning, they utilize limited resources that will ultimately deplete, hence, driving up overall energy costs.
- Most countries across the world heavily depend on fossil fuels (oil, coal and natural gas) as sources of energy to power their economies.

• Advantages of Non-Renewable Energy

- The main advantages of non-renewable energies is that they are **abundant and affordable**. For example, oil and diesel are still good choices for powering vehicles. Non-renewable energy is cost effective and easier to product and use.

• Disadvantages of Non-Renewable Energy

1. Fossil fuels emit high levels of greenhouse gas and carbon dioxide, which are greatly responsible for global warming, climate change, and degradation of air quality. Fossil fuels also contribute to sulfur emission to the atmosphere leading to acid rains. Acid rains can cause damage to buildings.

2. once sources of non-renewable energies are gone they can't be replaced or revitalized.
3. The prices of non-renewable energies such as oil has become a commodity where price fluctuation is always eminent.

• What is Nuclear energy?

- Nuclear energy is used to produce electricity. Heat generated from the splitting of uranium atoms in a process known as fission is used to produce steam. This steam in turn powers turbines, which are used to produce the electricity that supplies the surrounding community.

- **Advantages of Nuclear Energy**

1. Less uranium is needed to produce the same amount of energy as coal or oil, which lowers the cost of producing the same amount of energy. Uranium is also less expensive to procure and transport, which further lowers the cost.

2. **Reliability:** When a nuclear power plant is functioning properly, it can run uninterrupted for up to 540 days. This results in fewer brownouts or other power interruptions. The running of the plant is also not contingent of weather or foreign suppliers, which makes it more stable than other forms of energy.

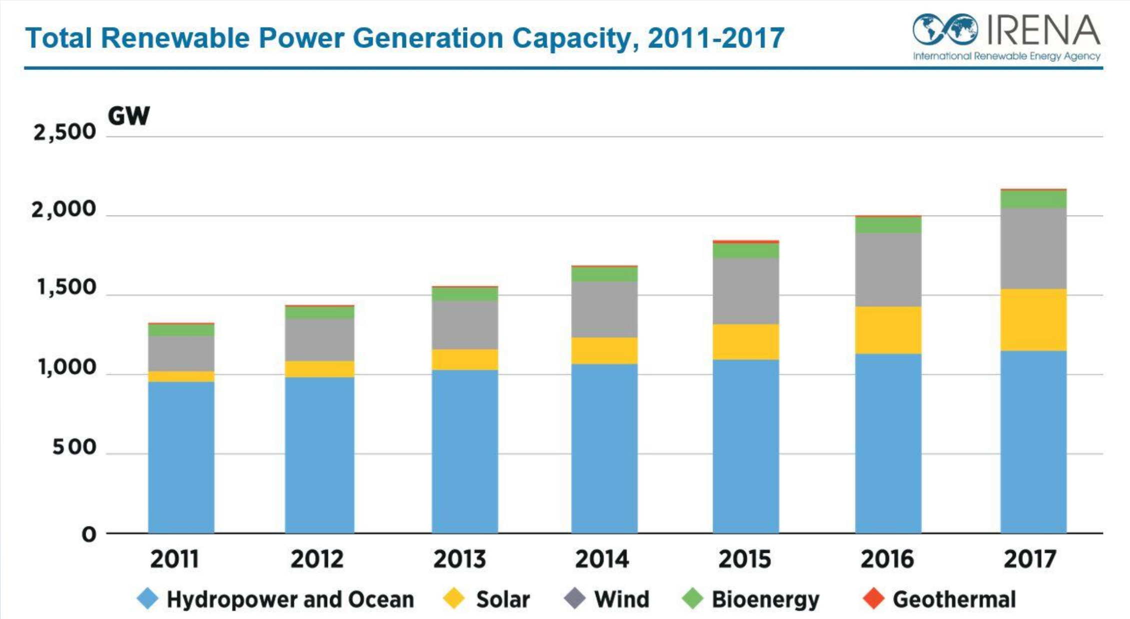
3. **No Greenhouse Gases:** While nuclear energy does have some emissions, the plant itself does not give off greenhouse gasses. Studies have shown that what life-cycle emissions that the plants do give off are on par with renewable energy sources such as wind power. This lack of greenhouse gases can be very attractive to some consumers.

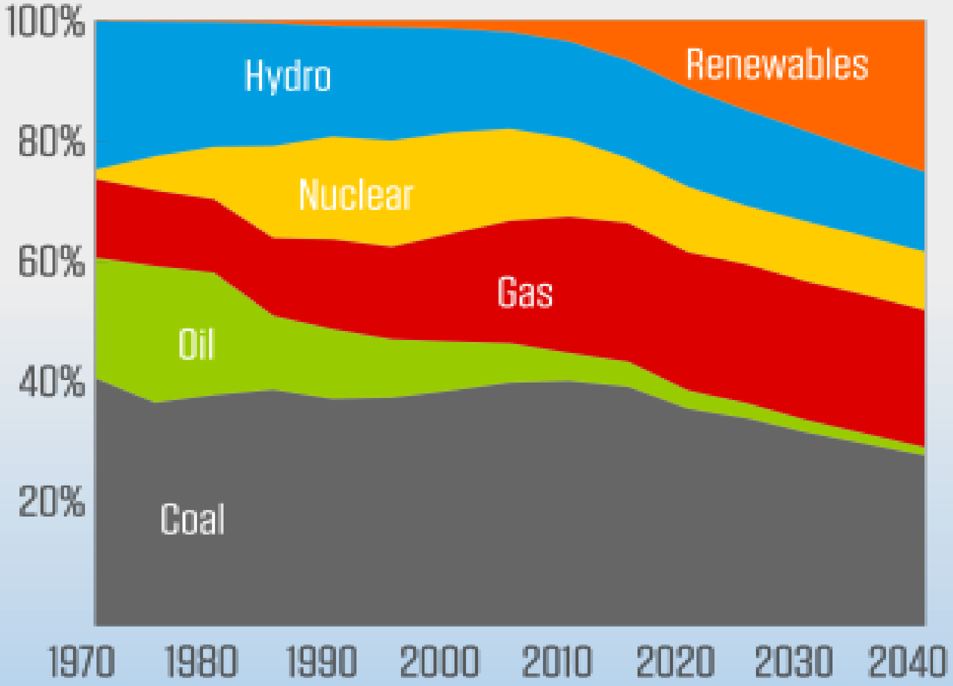
• Disadvantages of Nuclear Energy

1. **Raw Material:** Uranium is used in the process of fission because it's a naturally unstable element. This means that special precautions must be taken during the mining, transporting and storing of the uranium, as well as the storing of any waste product to prevent it from giving off harmful levels of radiation.

2. **Water Pollutant:** Nuclear fission chambers are cooled by water, in both the boiling water reactors (BWRs) and pressurized water reactors (PWRs). In PWRs, cold water enters through primary pipes and the secondary pipes remove the heated water away, so the coolant is not in contact with the reactor. In BWRs, water runs through the reactor core, so if there is any leakage of fuel, the water can get contaminated and is transported to the rest of system.

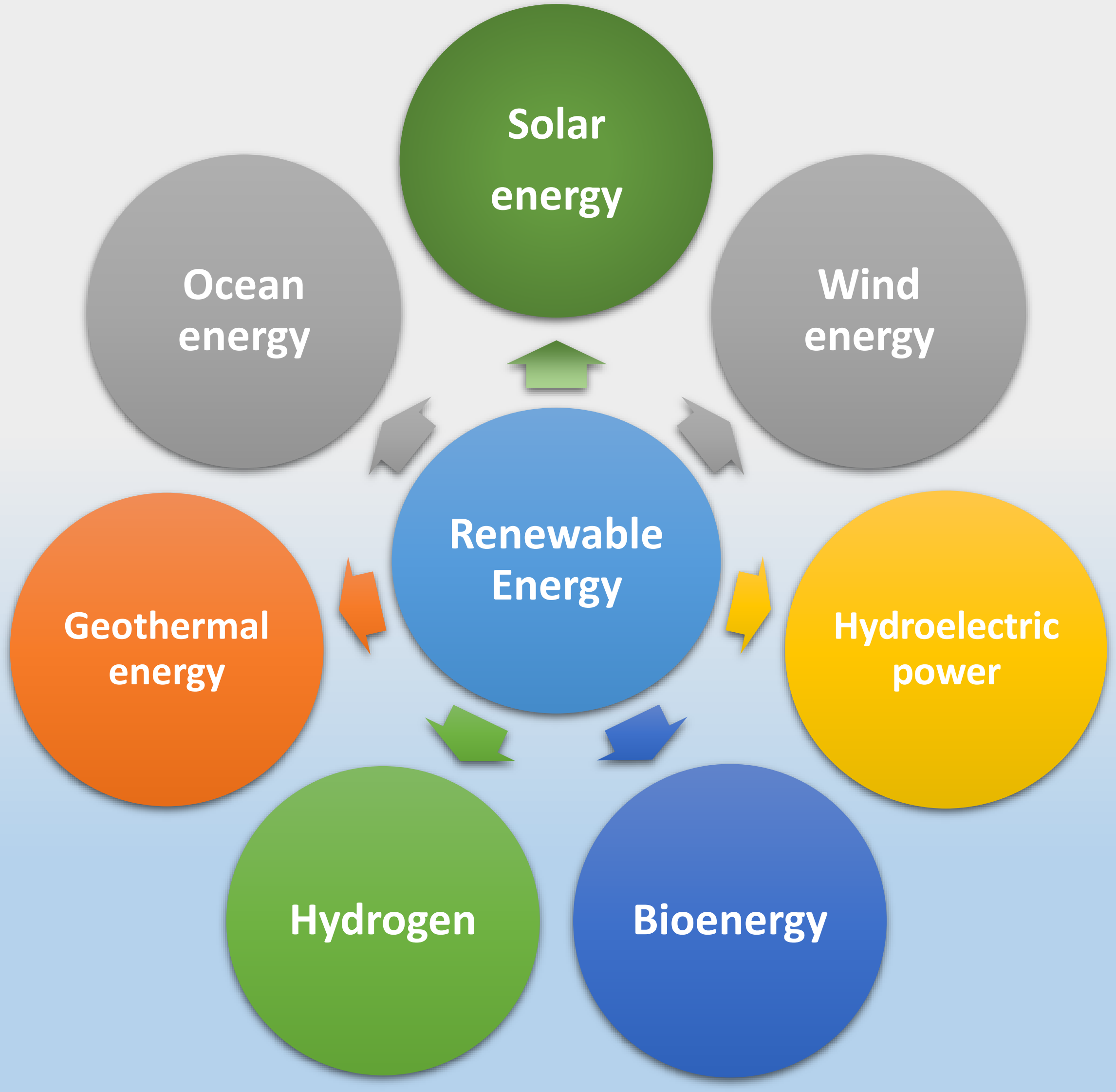
▪ Renewable vs fossil energy sources.





https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/demand-by-sector.html

- Renewable energy sources

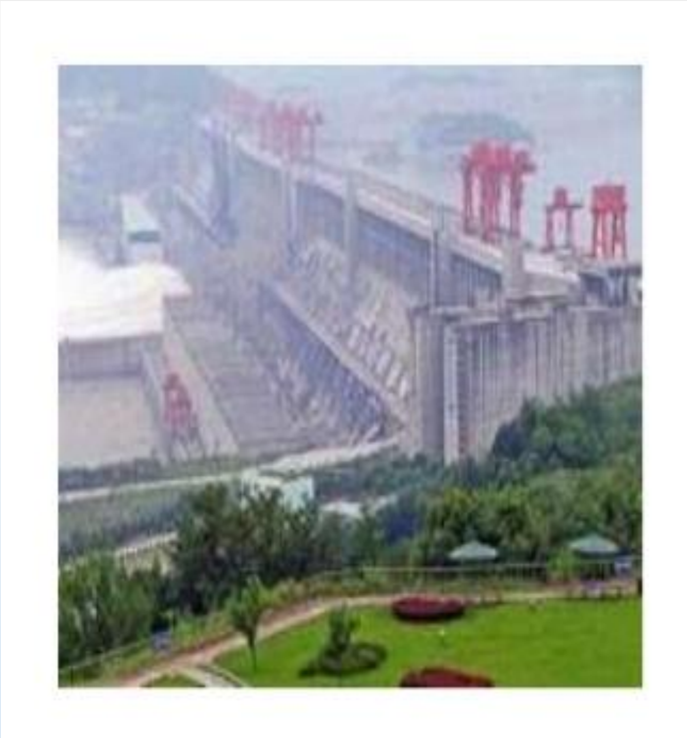


- The most widespread sources of energy include:

- **Wind:** This takes advantage of wind motion to generate electricity. Wind motion is brought about by the heat from the sun, and rotation of the earth, mainly by the Coriolis Effect.

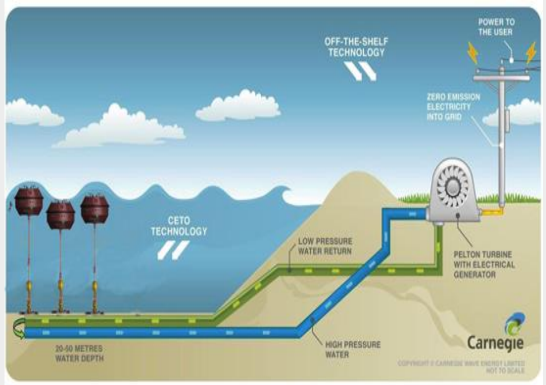
- **Solar:** Solar energy is one of the fastest growing and environmentally sustainable trends in renewable energy. Light and heat from the sun is converted into electricity using photovoltaic (PV) solar panels installed on the roof.

- **Hydropower:** Utilizes moving water to produce electricity. Moving water creates high energy that can be harnessed and turned into power.

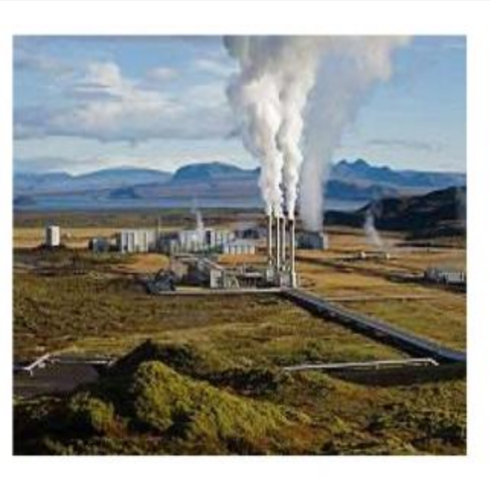


Biomass: Organic matter that constitutes plants is referred to as biomass, which can be utilized to generate electricity, chemicals or fuels to power vehicles. Examples include corn, soybeans, and agricultural wastes.

- **Ocean:** Takes advantage of rising and falling of tides to generate electricity



Geothermal: Leverages heat from underneath the earth to generate electricity.



- Future outlook

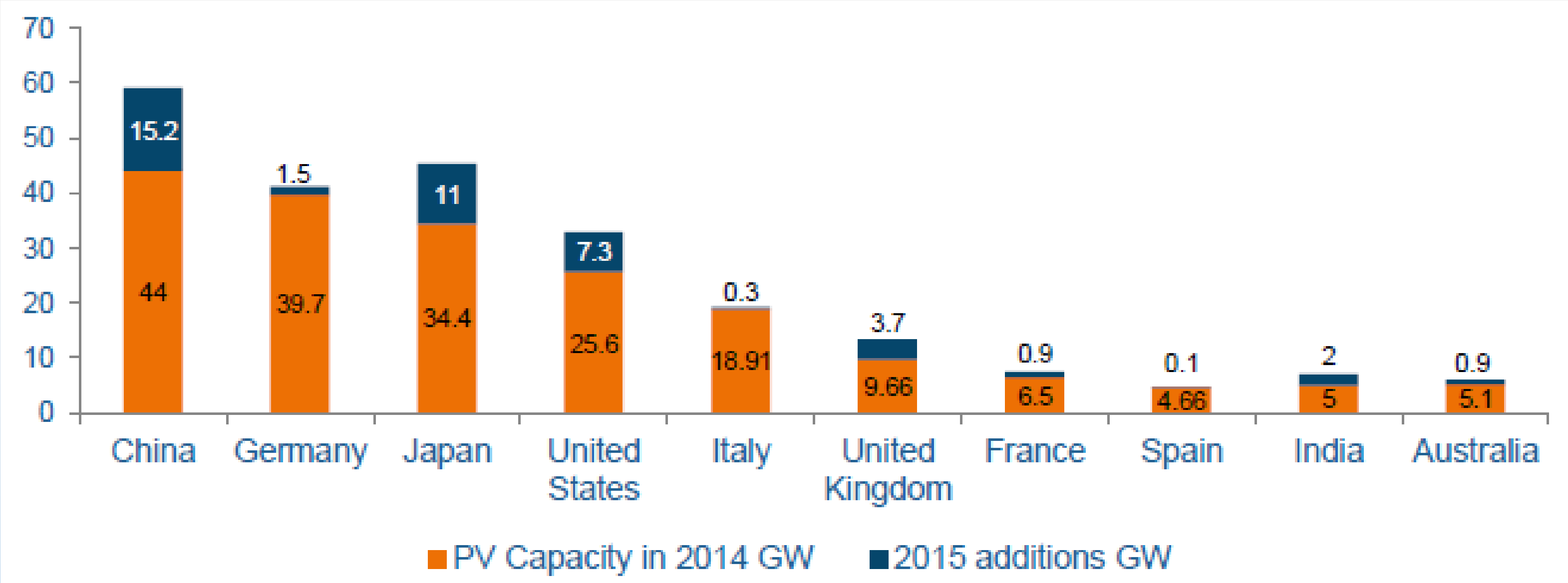
Solar

Global installed capacity for solar-powered electricity has seen an exponential growth, reaching around 227 GWe at the end of 2015, producing 1% of all electricity used globally.

The total capacity for solar heating and cooling in operation in 2015 was estimated at 406 GWth.

As solar PV module prices have declined around 80% since 2007 (from ~ US$4/W in 2007 to ~ US$1.8/W in 2015), the cost associated with balancing the system represents the next great challenge for the Solar PV industry.

- Top Solar PV capacity in 2014 and additions in 2015



Source: REN21 (2016)

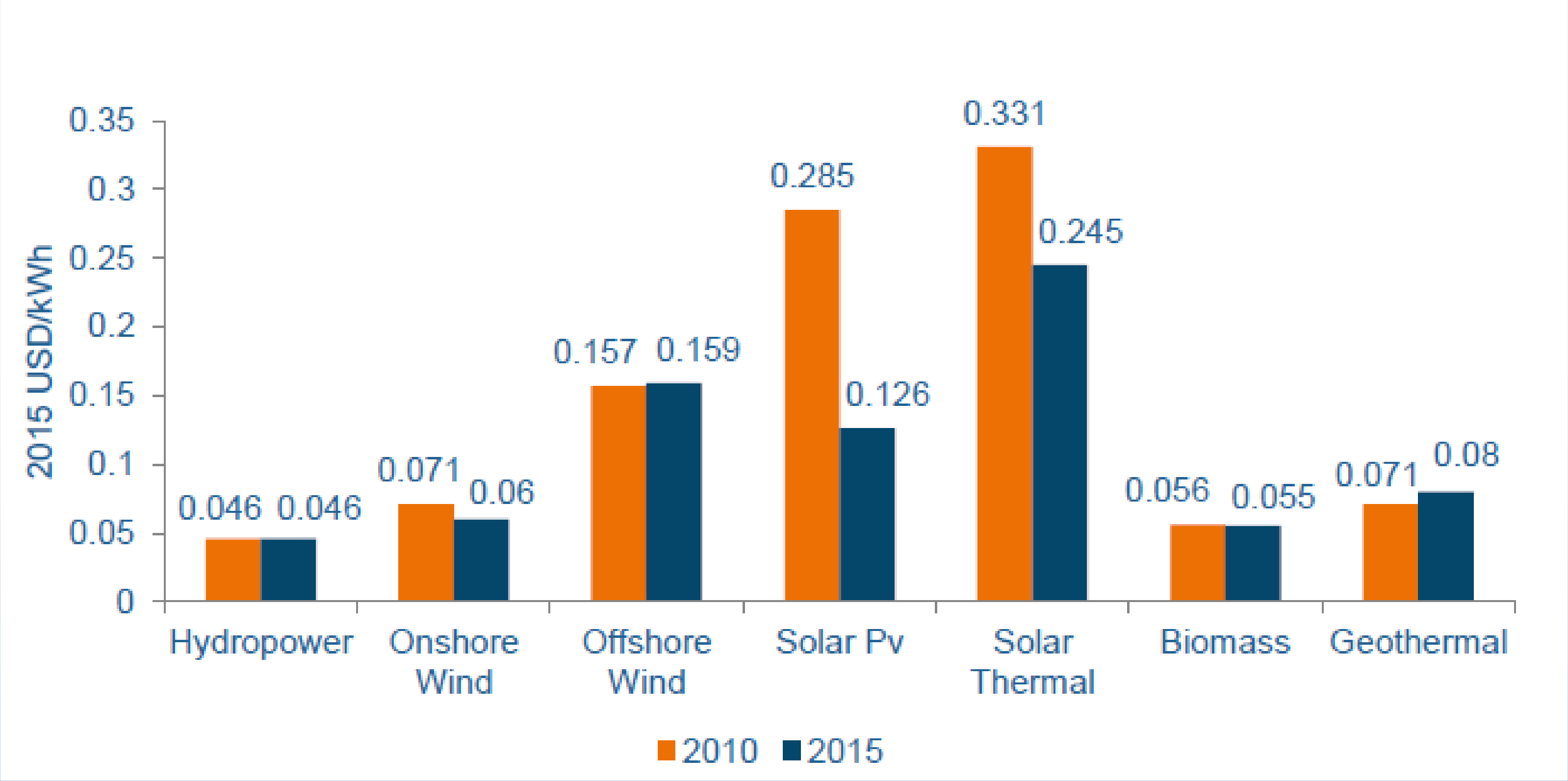
- **Hydropower**
- Hydropower is the leading renewable source for electricity generation globally, supplying 71% of all renewable electricity at the end of 2015. Undeveloped potential is approximately 10 000 TWh/y worldwide.
- The global hydropower capacity increased by more than 30% between 2007 and 2015

Wind

Global wind power generation reached 432 GW in 2015, around 7% of total global power generation capacity (420 GW onshore, 12 GW offshore). A record of 63 GW was added in 2015.

- **Geothermal**
- Geothermal global output is estimated to be 75 TWh for heat and 75 TWh for power, but is concentrated on geologic plate boundaries.
- **Bioenergy**
- Bioenergy is the largest renewable energy source with 14% out of 18% renewables in the energy mix and supplies 10% of global energy supply.

Energy prices



Source: IRENA (2016)

• Oil

- Oil remained the world’s leading fuel, accounting for 32.9% of global energy consumption. Roughly 63% of oil consumption is from the transport sector. Oil substitution is not yet imminent and is not expected to reach more than 5% for the next five years.

- **Natural Gas**
- Natural gas is the second largest energy source in power generation, representing 22% of generated power globally and the only fossil fuel whose share of primary energy consumption is projected to grow.

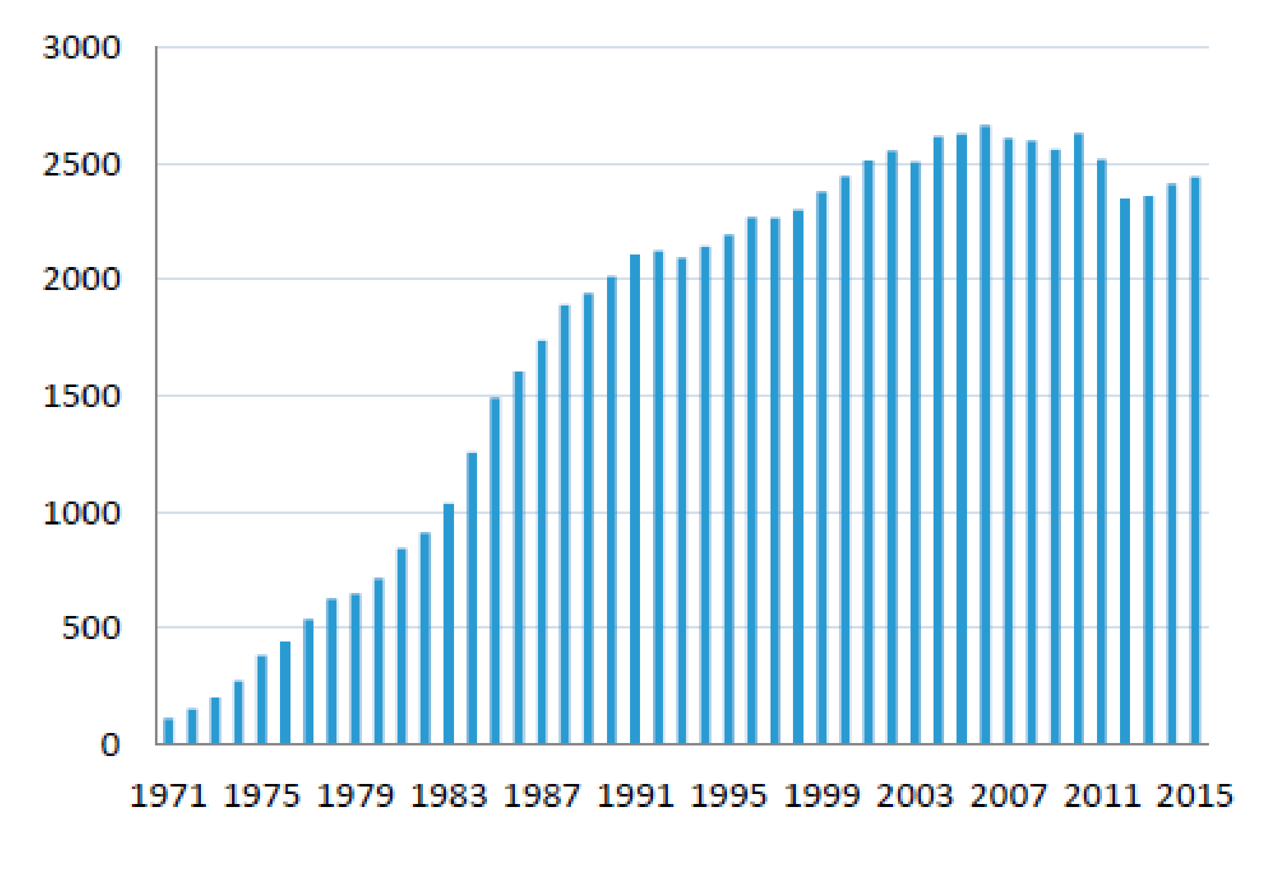
Coal

- Coal production decreased with 0.6% in 2014 and with a further 2.8% in 2015, the first decline in global coal production growth since the 1990s.
- Coal still provides around 40% of the world's electricity. However, climate change mitigation demands, transition to cleaner energy forms and increased competition from other resources are presenting challenges for the sector.
- Asia presents the biggest market for coal and currently accounts for 66% of global coal consumption.

• **Uranium and Nuclear**

- Global uranium production increased by 40% between 2004 and 2013.
- As of December 2015, 65 nuclear reactors were under construction with a total capacity of 64 GW. Two-thirds (44) of the units under construction are located in three countries: China, India and Russia.
- Currently there are more than 45 Small Modular Reactors designs under development and four reactors under construction.

- **WORLD NUCLEAR ELECTRICITY PRODUCTION, TWH**



Source: International Atomic Energy Agency, Power Reactor Information System

Renewable Power Systems and Energy Conservation

Power Plants Eng. Branch
Fourth Year: First Semester

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- **Solar power plant.**

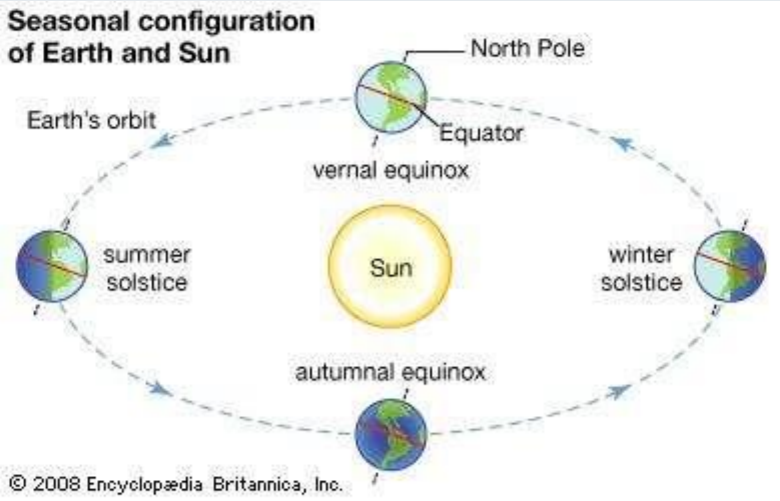
  - Solar radiation.
  - Angles of solar radiation.
  - Prediction of solar radiation and measurement.
  - Photovoltaic technology. P-n junctions.
  - Photovoltaic cells and Solar towers.

Solar radiation:

- **What is Solar Radiation ?**
- Solar radiation, often called the solar resource, is a general term for the electromagnetic radiation emitted by the sun.
- Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies.
- The technical feasibility and economical operation of these technologies at a specific location depends on the available solar resource.

• BASIC PRINCIPLES

- Every location on Earth receives sunlight at least part of the year.
- The amount of solar radiation that reaches any one spot on the Earth's surface varies according to:
- **Geographic location**
- **Time of day**
- **Season**
- **Local landscape**
- **Local weather.**



- **SOLAR CONSTANT:**
  Solar Constant is the intensity of the solar radiation hitting one square meter of the Earth

- SC= $\sigma T^4 \left(\frac{R}{D}\right)^2$

Where

- $\sigma = 5.67 \cdot 10^{-8}$ W/m^2.K^4 is the Stefan-Boltzmann constant.
- R= $696 \cdot 10^6$ m is the Sun radiuses
- D=150 $\cdot 10^9$ m is the average distance between the Sun and the earth
- T = 5785^{o}K is temperature of spherical black body

DIFFUSE AND DIRECT SOLAR RADIATION

- As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by:
- **Air molecules**
- **Water vapor**
- **Clouds**
- **Dust**
- **Pollutants**
- **Forest fires**
- **Volcanoes.**

- **Diffuse sky radiation** is solar radiation reaching the Earth's surface after having been scattered from the direct solar beam by molecules or particulates in the atmosphere. Also called sky radiation, diffuse skylight, or just skylight.
- The solar radiation that reaches the Earth's surface without being diffused is called **direct beam solar radiation**.
- The sum of the diffuse and direct solar radiation is called **global solar radiation**. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.

Measurement

- Direct estimates of solar energy may be expressed as watts per square meter (W/m^2).
- Solar radiation is measured by some types of **radiometer.** Meteorologists and climatologists use various types of radiometers **depending upon the type of solar radiation they intend to measure**.

Device Types

- **Pyranometers** measure hemispherical solar irradiance, or broadband solar radiation within a 180-degree field of view; this may be considered the global solar radiation of a given hemisphere.

A typical **analog pyranometer** does not require power to operate and consists of a thermopile sensor beneath a glass dome. The thermopile absorbs all the solar radiation which encounters it and generates a small, proportional output voltage. Pyranometers are typically used on or near solar panels to facilitate optimum panel positioning.

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- **Angles of solar radiation.**

1. Solar Declination

- Solar declination (δ) is the angle between the earth-sun line and the equatorial plane. Solar declination varies throughout the year.

- $\delta = \sin 23.45 \sin 360 \frac{284+d}{365.25}$
- The Declination varies between $-23.45° \leq \delta \leq 23.45°$

- It is positive during summer and negative during winter

2. Hour Angle

- Hour angle (H) is the angle on a horizontal plane between the local solar noon and the horizontal projection of the sun's rays. The hour angle is given by:

$$H = 15^{\circ}\,(\text{Solar Time} - 12)$$

$-180° \leq H \leq 180°$, negative before Solar Noon

Solar Time = standard time + 4 ($long_{st}$ - $Long_{loc}$) + EOT

$$\mathrm{EOT} = 229.2\ (0.000075 + 0.001868 \cos \mathrm{B} - 0.032077\ \sin\mathrm{B} - 0.014615 \cos 2\mathrm{B} - 0.04089 \sin 2\mathrm{B})$$

$$B = \frac{(n-1)360}{365}$$

Where:

EOT is Equation of Time

3. Latitude Angle φ

- latitude is used to state how far north or south you are, relative to the equator.
- If you are on the equator your latitude is zero.
- If you are near the north pole or the south pole your latitude is nearly 90 degrees.

4. Longitude

- Longitude shows your location in an east or west direction, relative to the Greenwich meridian.
- Places to the east of Greenwich have longitude angles up to 180 degrees east.
- Places to the west of Greenwich have negative angles up to
- 180 deg west.

- Longitude is the angle at center of the Earth, between where you are and Greenwich. It can be measured either east or west and varies from 0° to 180°.

Iraq latitude and longitude

33.2232° N, 43.6793° E

- Solar Angles

5. Solar Altitude β

- Solar altitude (β) is the angle ROQ on a vertical plane between the sun's rays and the horizontal plane on the earth's surface.

- $\beta = \ sin^{-1}[\cos\varphi\cos\delta\cos H + \sin\varphi\sin\delta]$

Solar declination (δ)
Hour angle (H)
Latitude Angle φ

6. Solar Azimuth

Solar azimuth (Φ) is the angle SOQ on a horizontal plane between the due-south direction line and the horizontal projection of the sun's rays.

$$\tan A = sinD^{`} sin \frac{H}{sinD^{`} \cos L^{`} cosH - cosD^{`} \sin L^{`}}$$

$D^{`}$ is Codeclination
H is hour angle
$L^{`}$ is Colatitude

- The power incident on a solar system depends not only on the power contained in the sunlight, but also on the angle between the module and the sun.
- When the absorbing surface and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight (in other words, the power density will always be at its maximum when the solar system is perpendicular to the sun).

• Locate the sun through the observer in the earth's center

- $cos\ D^{`}$ = sin 23.5 sin $\frac{360 * n}{365.25}$
- H = $\frac{360}{24}$ t
- Where:
- $D^{`}$ is Codeclination
- H is hour angle
- n number of days after vernal Equinox
- t number of hours in the day

• Locate the sun through the observer on the earth's surface

- $cos\,Z = cosD^{`}\cos L^{`} + sinD^{`}\sin L^{`}cosH$
- $\tan A = sinD^{`}sin\,\frac{H}{sinD^{`}\cos L^{`}cosH - cosD^{`}\sin L^{`}}$
- Where
- Z is Zeinth angle
- A azimnth angle
- $L^{`}$ is Colatitude

- The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the **module surface**.
- The following figure shows how to calculate the radiation incident on a titled surface (S_{module}) given either the solar radiation measured on horizontal surface (S_{horiz}) or the solar radiation measured perpendicular to the sun ($S_{incident}$).

Tilting the module to the incoming light reduces the module output.

$$S_{horizontal} = S_{incident} \sin\alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

where
α is the elevation angle; and
β is the tilt angle of the module measured from the horizontal.
The elevation angle has been previously given as:

$$\alpha = 90 - \phi + \delta$$

where Φ is the latitude; and
δ is the declination angle previously given as:

$$\delta = 23.5 \sin \frac{360}{365.25}(284 + d)$$

where d is the day of the year.

From these equations a relationship between S_{module} and S_{horiz} can be determined as:

$$S_{module} = \frac{S_{horizontal} \sin(\alpha+\beta)}{\sin \alpha}$$

- The tilt angle has a major impact on the solar radiation incident on a surface. For a fixed tilt angle,
- The maximum power over the course of a year is obtained when the **tilt angle is equal to the latitude of the location**. However, steeper tilt angles are optimized for **large winter loads**, while lower title angles use a greater fraction of light in **the summer**.

• Prediction of solar

- Solar radiation data plays an important role in solar energy research. Long-standing records of global solar radiation data are not available in many places because of the cost and maintenance of the measuring instruments. Therefore, the solar radiation has to be predicted accurately for these locations using various solar radiation estimation models.
- solar potential assessment is depend upon geographical location and meteorological parameters such as latitude, longitude, altitude, month, mean diffuse radiation, mean beam radiation, air temperature, relative humidity and sunshine duration, etc.

• Photovoltaic technology

- Solar radiation can be converted into electrical energy by using photovoltaic cells.
- Photovoltaic cells are made from **semiconductors** where they are usually made of **crystalline silicon chips**.
- The principle of photovoltaic cells depends on the absorption of photons in solar radiation and converts them into electrons.

- A solar cell is essential a PN junction with a large surface area. The N-type material is kept **thin to allow light to pass through** to the PN junction.
- Light travels in packets of energy called photons. The generation of electric current happens inside the depletion zone of the PN junction.
- When a photon of light is absorbed by one of these atoms in the N-Type silicon it will dislodge an electron, creating a free electron and a hole.

- The electron is attracted to the positive charge of the P-type material and travels through the external load (meter) creating a flow of electric current. The hole created by the dislodged electron is attracted to the negative charge of N-type material and migrates to the back electrical contact. As the electron enters the P-type silicon from the back electrical contact it combines with the hole restoring the electrical neutrality.

- The free electron and hole has sufficient energy to jump out of the depletion zone. If a wire is connected from the cathode (N-type silicon) to the anode (P-type silicon) electrons will flow through the wire.

• Types of photovoltaic cells

- Flat plate systems
- Concentrator systems
- Hybrid system between photovoltaic cells and solar complexes (Hybrid photovoltaic panels)

Types of materials used in the photovoltaic industry

1. Single Crystalline :

- a) Single crystalline silicon
- b) Polycrystalline silicon
- c) Amorphous silicon (non crystalline Silicon for higher light absorption)
- d) Gallium arsenide

2. Polycrystalline (thin films) :

- a) Cadmium telluride
- b) Copper indium diselenide

Solar towers

- Solar power tower convert sunshine into clean electricity. The technology uses many large, sun-tracking mirrors commonly referred to as heliostats to focus sunlight on a receiver at the top of a tower.
- A heat transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine-generator to produce electricity.
- The system uses hundreds to thousands of sun-tracking mirrors called heliostats to reflect the incident sunlight onto the receiver.

- In power tower systems, heliostats (A Heliostat is a device that tracks the movement of the sun which is used to orient a mirror of field of mirrors, throughout the day, to reflect sunlight onto a target-receiver) reflect and concentrate sunlight on to a central tower-mounted receiver where the energy is transferred to a HTF.

- To maintain constant steam parameters even at varying solar irradiation, two methods can be used:
  - Integration of a fossil back-up burner; or
  - Utilization of a thermal storage as a buffer

By the use of thermal storage, the heat can be stored for few hours to allow electricity production during periods of peak need, even if the solar radiation is not available.

- Major parts of solar tower are –
- 1)Heliostats
- 2)Central Receiver
- 3) heat-transfer fluid
- 4)Steam Generator

- Heliostats

Heliostats are reflective surfaces or mirrors which track the suns rays and reflect it onto the central receiver.

- Central Receiver:

Central receiver (or power tower) systems use a field of distributed mirrors – heliostats – that individually track the sun and focus the sunlight on the top of a tower.
By concentrating the sunlight 600–1000 times, they achieve temperatures from 800°C to well over 1000°C.

The central receiver is also called high-tech heat exchanger which sits atop a tower. The central receiver heats molten salt at around 250°C, pumped from a “cold” storage tank, to 565°C, where it flows to a “hot” tank for storage.