Nano-materials for Energy conversion and storage

NAC 2401: Lecture 4

Energy: types

Ahmad Alakraa

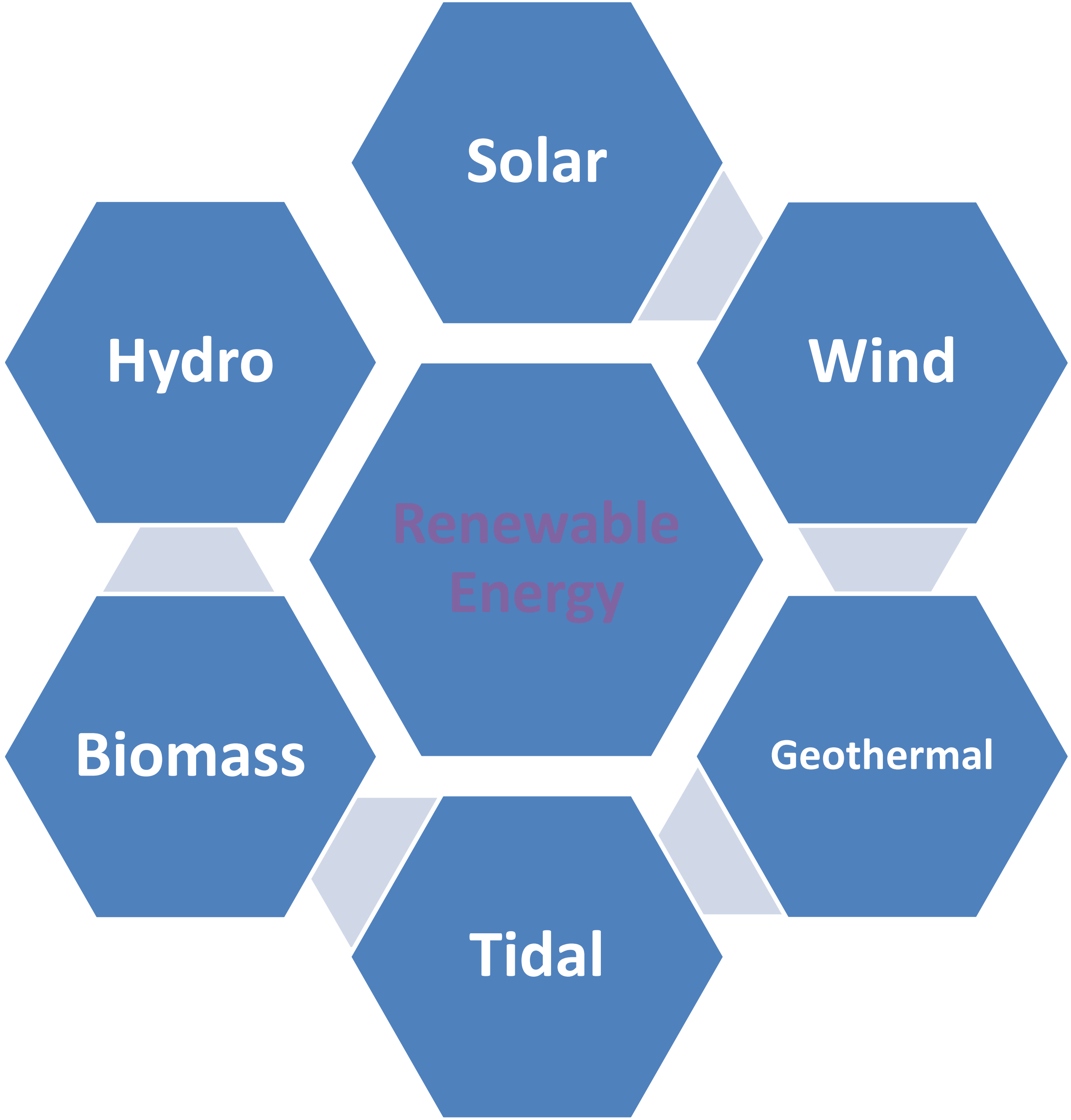
Renewable Energy

Hydroelectric Solar energy Ocean

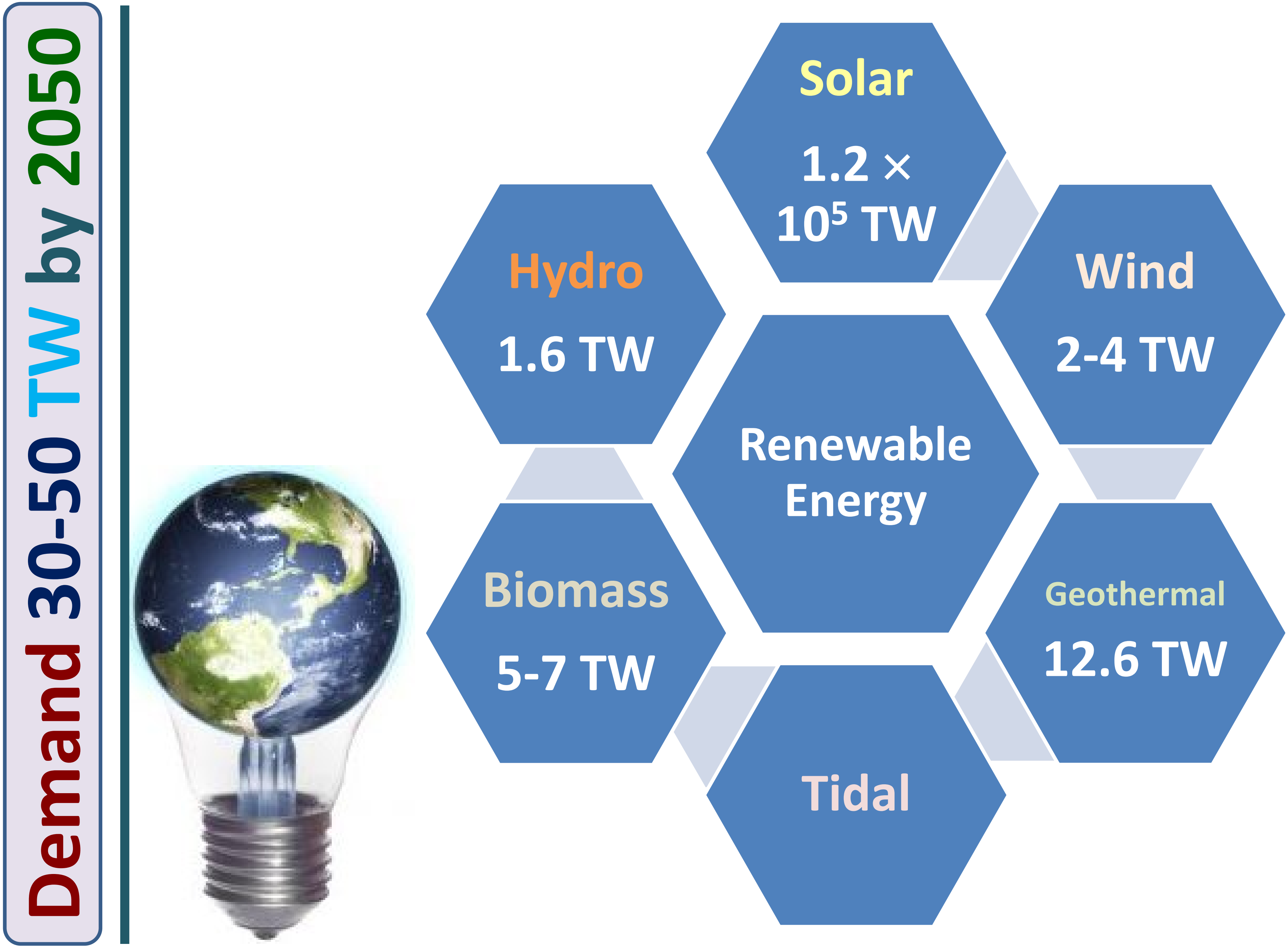
Wind Biomass Geothermal heat

naturally, replenished resources

Renewable Energy

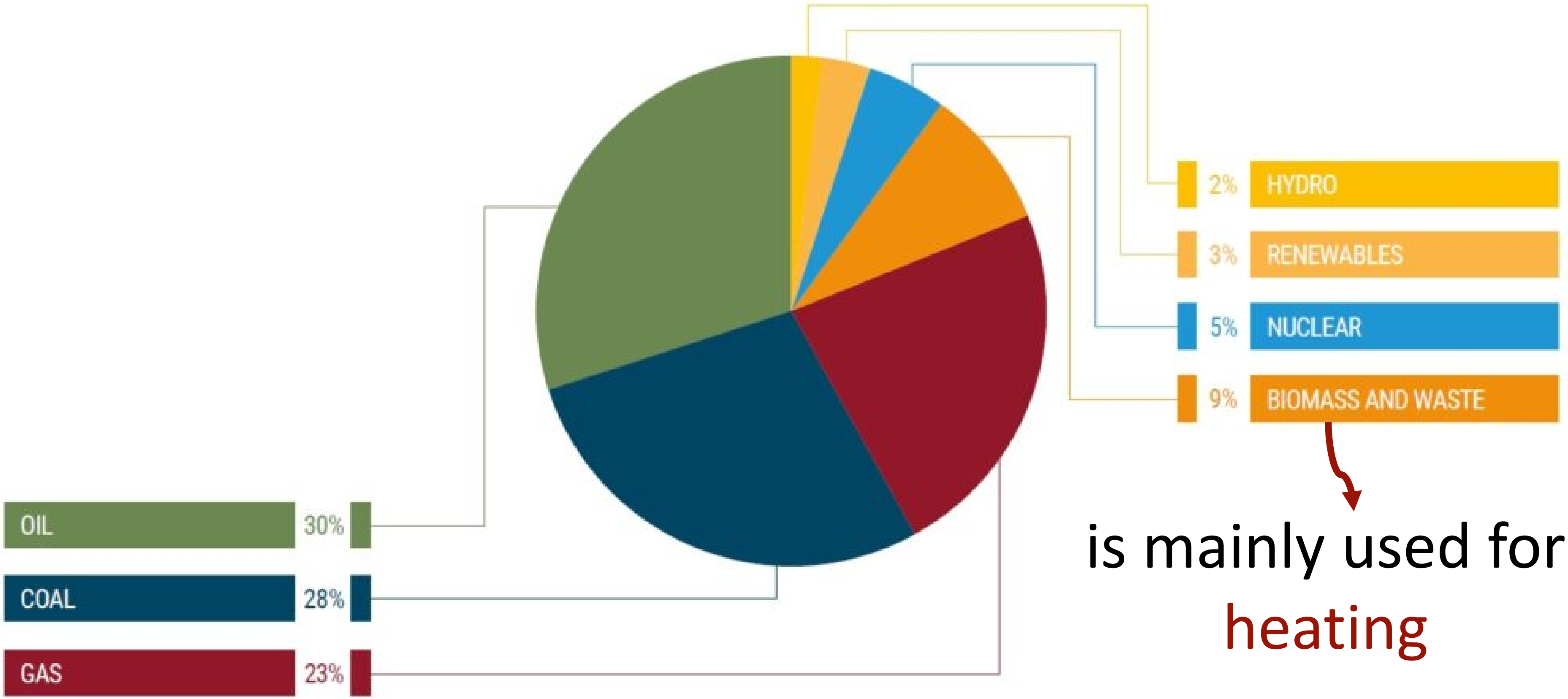


Solar power is greener, more convenient, more efficient and most abundant, more durable, less exhaustible, less noisy, of better moving flexibility, of less initial installation cost


Demand 30-50 TW by 2050
Solar
1.2 × 10^5 TW
Hydro
1.6 TW
Wind
2-4 TW
Renewable Energy
Biomass
5-7 TW
Geothermal
12.6 TW
Tidal

Renewable Energy, RE

- In its various forms, **RE** comes directly from the sun, or from heat generated deep within the earth.



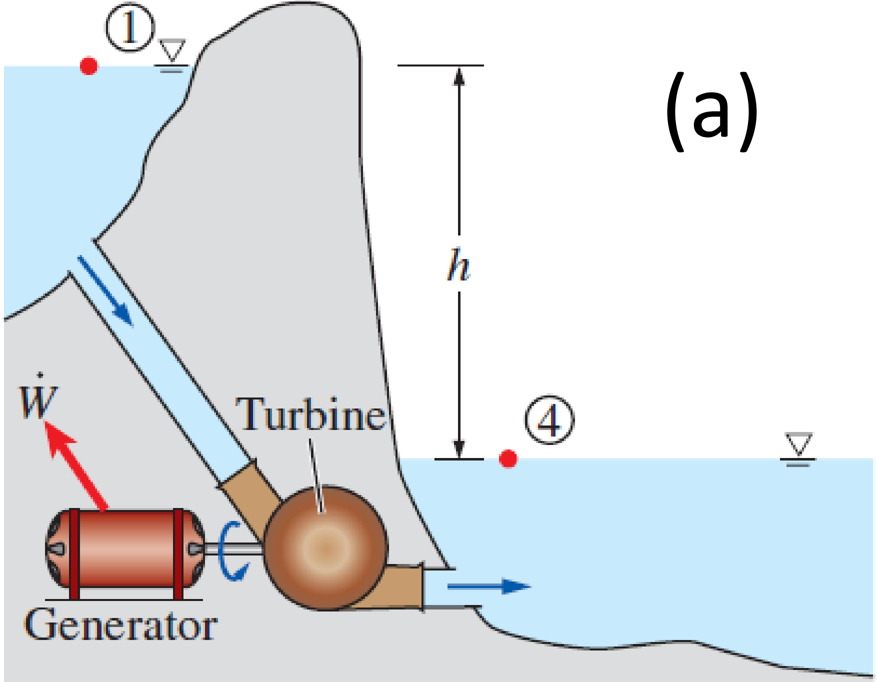
is mainly used for heating

2023 Global Energy Demand

Hydroenergy

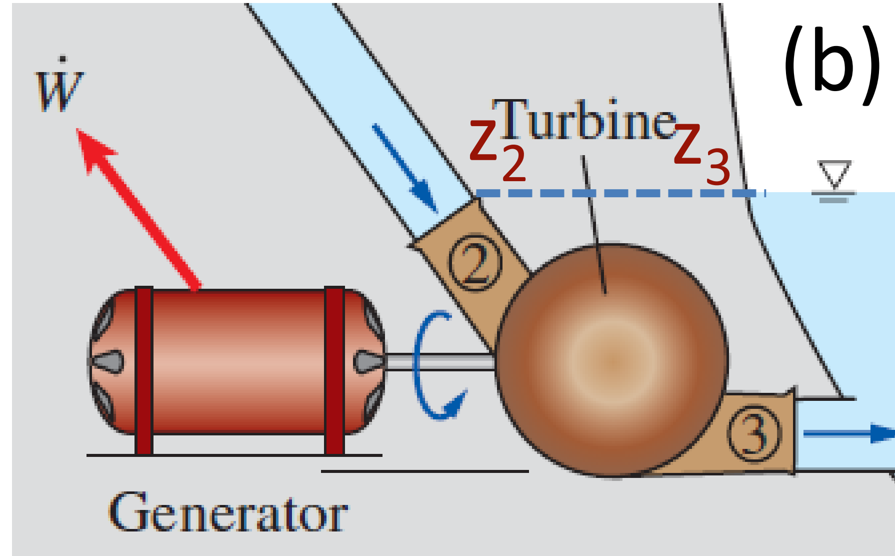
Hydroelectric energy, HEE

- is derived from the force or energy of **moving water**.
- Most **HEE** comes from the potential energy, PE of dammed water driving a water turbine and generator.
- The power extracted from the water depends on the **volume** and on the **difference in height** between the source and the water's outflow that called the **head**.
- The amount of PE in water is proportional to the **head**.
- To deliver water to a turbine while maintaining pressure arising from the head, a large pipe called a **penstock** may be used.



$$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}g(z_1 - z_4)$$

Since $P_1 \approx P_4 = P_{atm}$ and $V_1 = V_4 \approx 0$



$$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}\frac{P_2 - P_3}{\rho} = \dot{m}\frac{\Delta P}{\rho}$$

Since $V_2 \approx V_3$ and $z_2 = z_3$

An ideal hydraulic turbine coupled with an ideal generator. In the absence of irreversible losses (heat), the maximum produced power is proportional to (a) the change in water surface elevation from the upstream to the downstream reservoir or (b) (close-up view) the drop in water pressure from just upstream to just downstream of the turbine.

Hydroelectric Power Plant

Major Advantages of HEE

- elimination of fuel, i.e., little air pollution in comparison with fossil fuel plants and limited thermal pollution compared with nuclear plants.
- **HEE** plants also tend to have longer economic lives than fuel-fired power generation, with some plants now in service which were built 50–100 years ago.
- Operating labor cost is also usually **low**, as plants are automated and need **few personnel** on site during normal operation.
- The sale of electricity from the station may cover the construction costs after 5–8 years of full operation.

- **HEE** usually refers to large-scale hydroelectric dams.

- **Micro hydro systems** typically produce up to 100 kW of power.

- Hydro systems without dam derive **kinetic energy** from rivers and oceans.

- **Ocean** energy includes marine current power, ocean thermal energy conversion, and tidal المد والجزر (PE & KE) power.

Ocean energy

- employs changes in **salinity**, **thermal gradients** between the sea surface and deepwater, **tidal currents** or **ocean waves** to generate electricity, and provide reliable, sustainable and cost-competitive energy.

- At the mouth of **rivers** where freshwater mixes with salt water, energy associated with the salinity gradient can be harnessed using pressure-retarded reverse osmosis process and associated conversion technologies.

https://www.ocean-energy-systems.org/ocean-energy/what-is-ocean-energy/

Solar energy

Renewable Solar Power

- Solar radiation feeds the earth's surface with around **3×10^{24} J/year** at a power level of **120,000 TW** and a maximum flux density (irradiance) of about **1 kW/m^2** in a wavelength band between 0.3 and **14 μm**.

- This flux exceeds human energy needs (at least three orders of magnitude) the global energy production (**5.8×10^{20} J**) and consumption (**5.6×10^{20} J**) in 2015.

- Solar-powered electricity still accounts for ~ **1%** or a little bit more of the world electricity production.

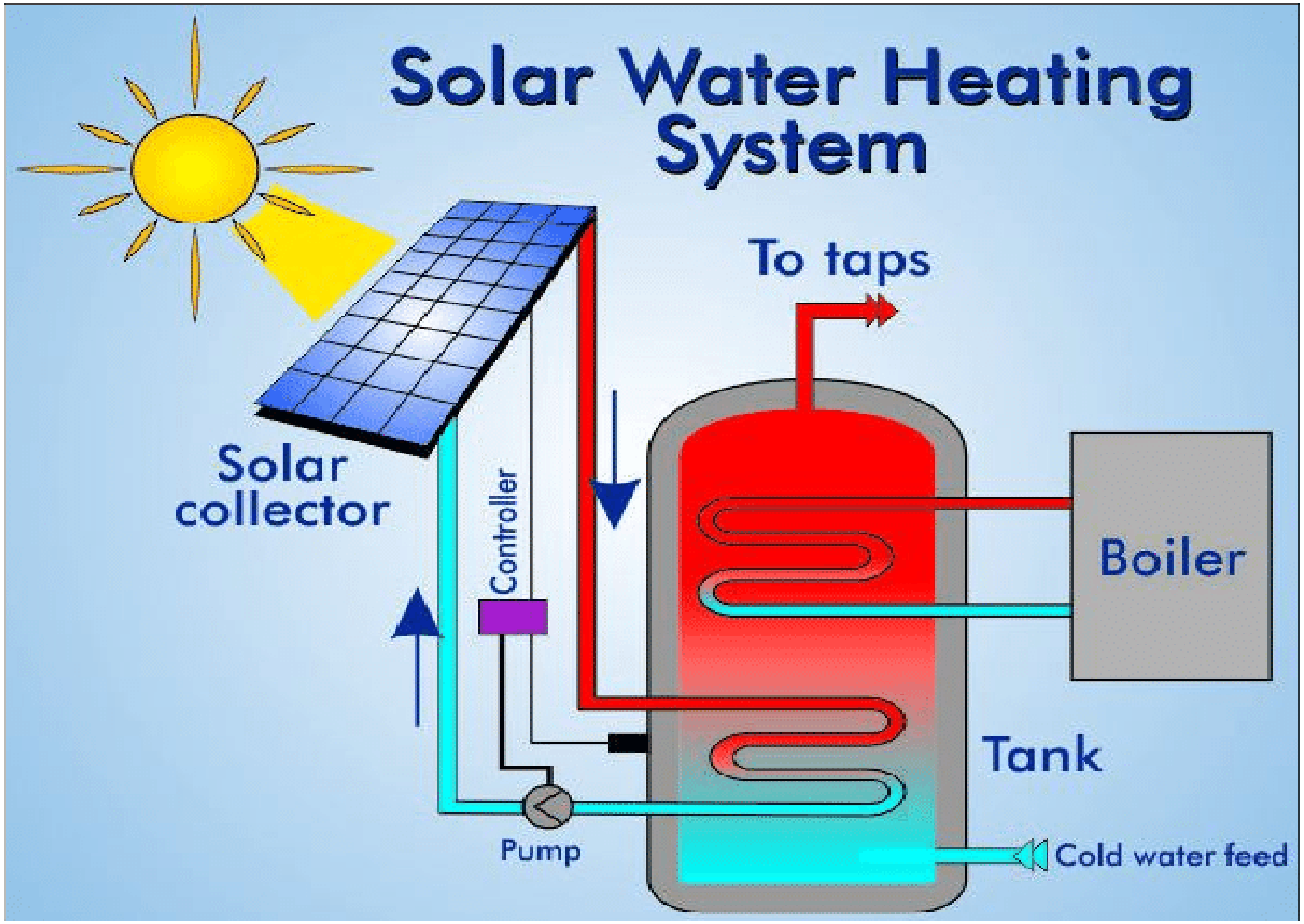
- This is forecasted to change dramatically by 2050 to generate more than **20%** of the world's electricity.

Solar energy

- Solar powered electrical generation relies on photovoltaics and heat engines.
- Other solar applications includes space **heating** and **cooling** through solar architecture, **daylighting**, **solar hot water**, **solar cooking**, and high temperature process **heat** for industrial purposes.
- Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy.

Active solar

- includes the use of solar thermal collectors to harness the energy for **heating** (buildings, space heating/cooling and water).
- A typical water heating system includes **solar collectors** that work along with a pump, heat exchanger, and one or more large heat storage tanks.
- The most common collector is called a ***flat-plate collector*** that is a thin, flat, rectangular box with a transparent cover that faces the sun.
- Small tubes run through the box and carry the heat transfer fluid (mainly water or air) to be heated.

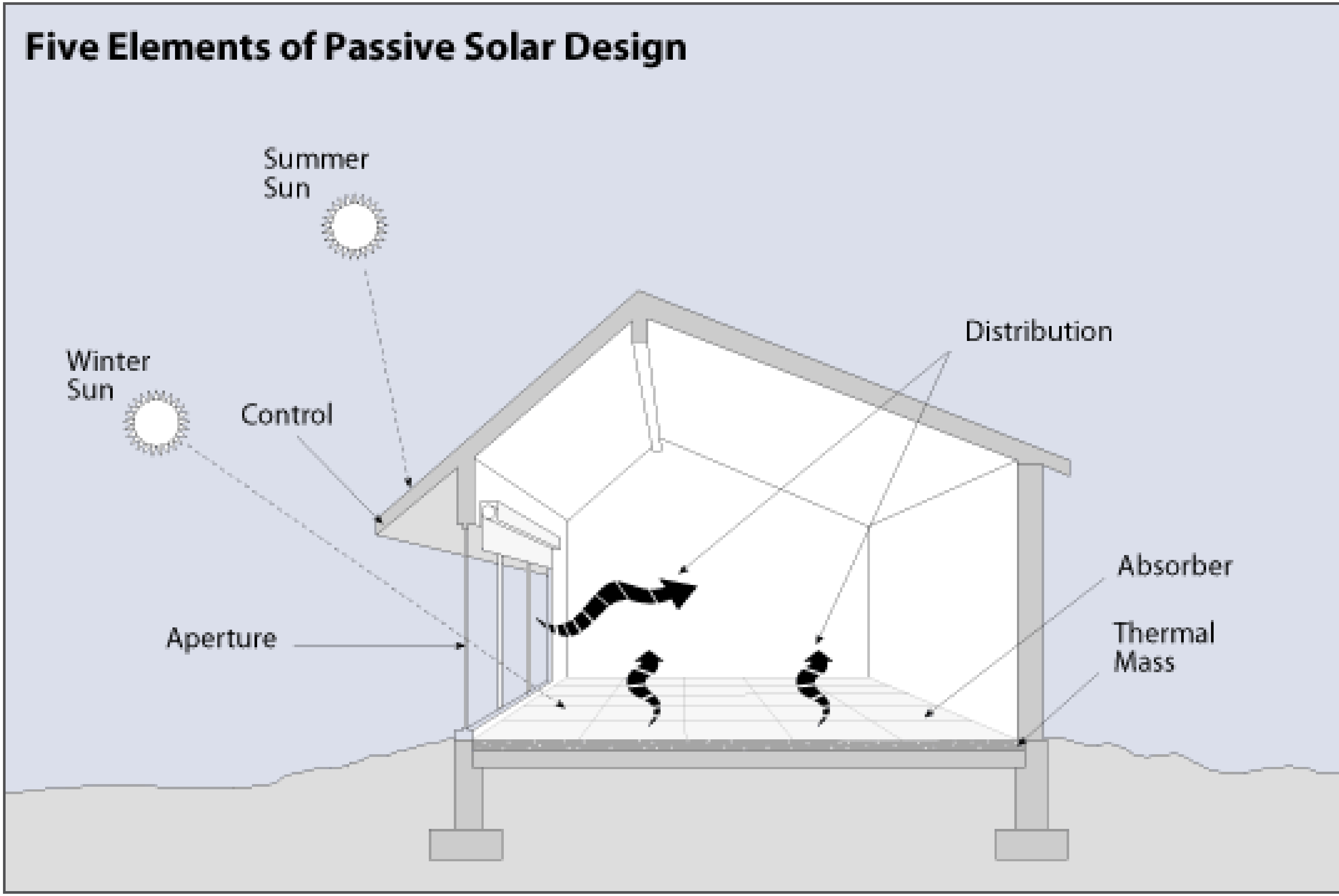


- The tubes attached to the absorber plate is painted black to absorb the heat.

https://www.researchgate.net/figure/Block-diagram-of-Solar-Water-Heating-System_fig6_325567967

Passive solar

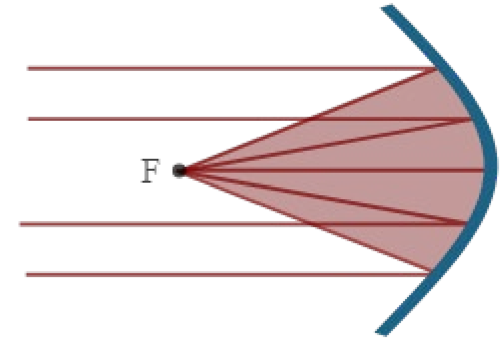
- captures sunlight **within** the building's materials and then release that heat during periods when the sun is absent, such as at **night**.
- South-facing glass and thermal mass to absorb, store, and distribute heat are necessary in the design
- relies on gravity and the tendency for water to naturally circulate as it is heated.
- orients buildings to the sun, selects materials with favorable thermal mass or light dispersing properties, and designs spaces that naturally circulate air.



https://sustainability.williams.edu/green-building-basics/passive-solar-design/

Solar Electric Generating Systems

- use parabolic trough collectors to collect the sun's energy to generate steam to drive a conventional steam turbine.



- The parabolic mirrors automatically track the sun throughout the day.
- The sun light is directed to central tube carrying synthetic oil, which heats around 400°C.
- The heat is used to convert water to steam to drive a steam turbine and produce electricity.
- The largest solar thermal power station is in the Mojave Desert in the US with a power output of 354 MW

Solar Photovoltaic, SPV

- converts light into electricity using semiconductors, as crystalline silicon (E_g ~ 1.12 eV, absorb **1160 nm**, infrared) .
- **SPV** cell is a solar cell or is a solid-state electrical device converting the energy of light **directly** into **electricity**.
- Assembles of cells are known as **solar modules** (jointly connected 60–72 cells) or **solar panels**.
- **SPV** systems produce **direct current**, which must be converted to **AC** via an inverter if the output from the system is to be used in the grid.

https://www.youtube.com/watch?v=HCCm0lFwqNw&ab_channel=KhanAcademy

Biomass & Bioenergy

- **Biomass** is organic material made from plants including microorganisms and animals.
- Plants absorb the sun's energy in photosynthesis and store the energy as biomass.
- **Biomass** is a renewable energy source based on the carbon cycle.
- Some examples of **biomass** fuels include wood, crops, and algae.
- When **burned**, the chemical energy in biomass is released as heat.

Biomass & Bioenergy

- **Biomass** can be converted to other biofuels, such as ethanol and biodiesel.
- **Biomass** grown for biofuel includes corn الذرة, soybeans فول الصويا, willow switch grass عشب الصفصاف, rapeseed بذور اللفت, sugar beet بنجر السكر, palm oil زيت النخيل, and sorghum الذرة الرفيعة.
- Cellulosic **biomass**, such as corn stover حطب الذرة, straw القش, timber الأخشاب, rice husks قشور الأرز can also be used for biofuel production.

Biomass & Bioenergy

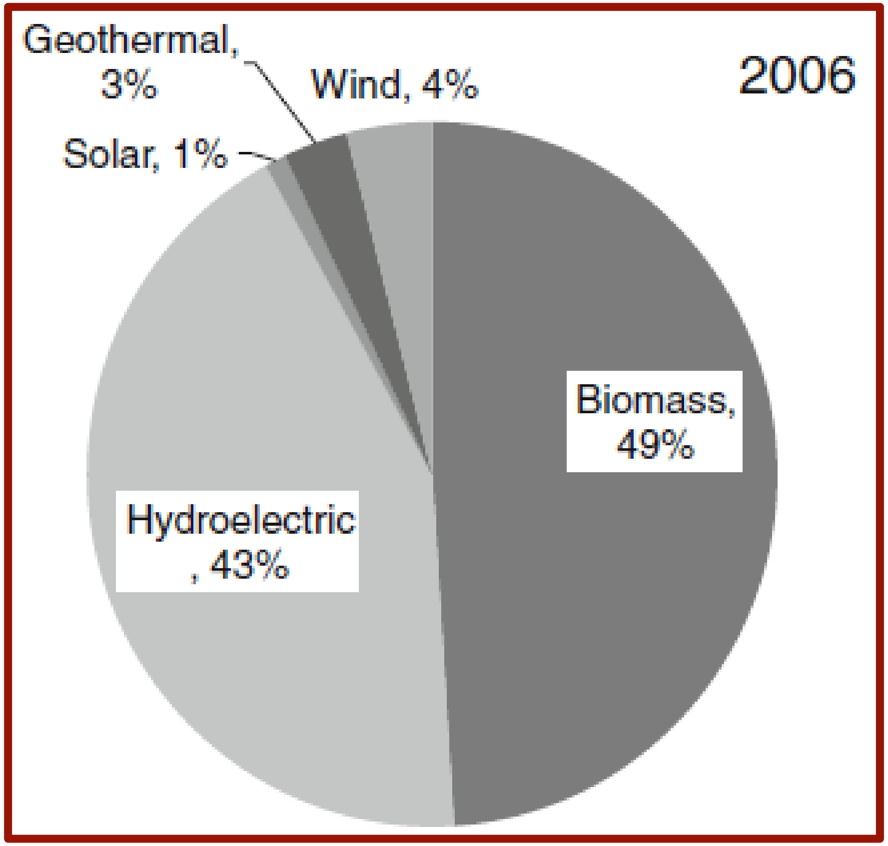
- Anaerobic digestion of biomass produces **biogas** (mixture of CH_4 + CO_2 + H_2S + Siloxanes), while gasification produces **syngas** ($CO + H_2$) that can be converted to liquid fuels.

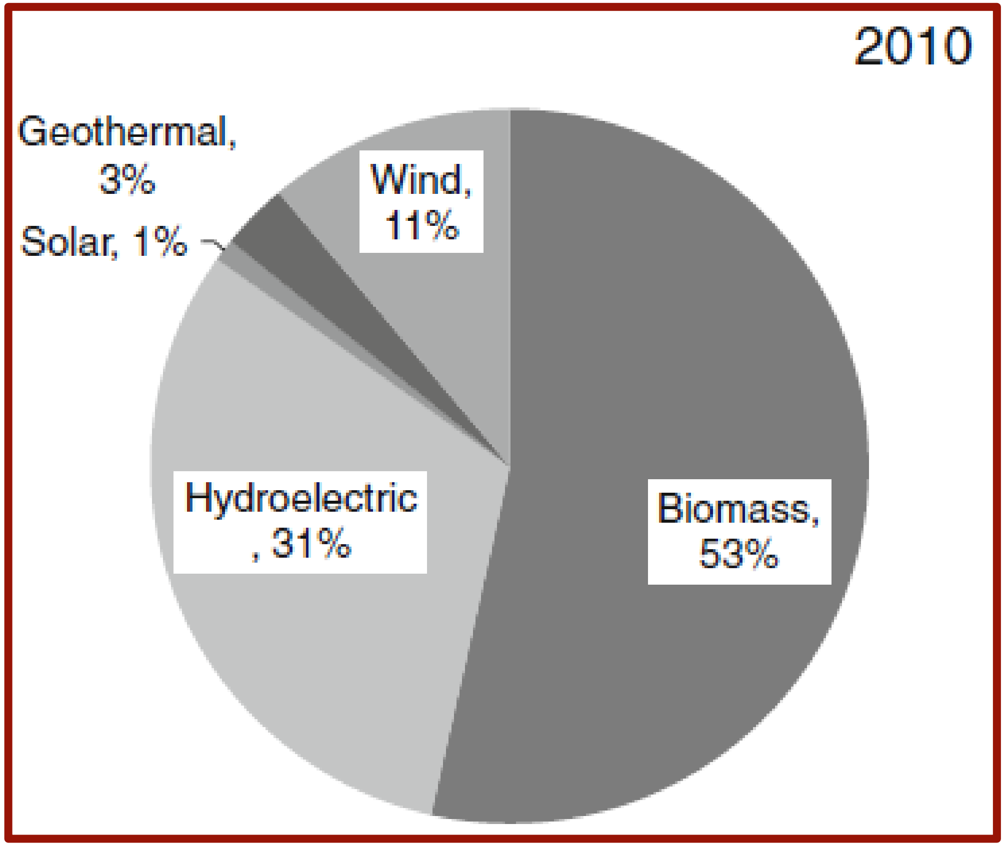
- **Cellulosic ethanol** can also be created by a thermo-chemical process, which uses various combinations of temperature, pressure, water, oxygen or air, and catalysts to convert biomass to cellulosic ethanol.

LHV for selected biomass

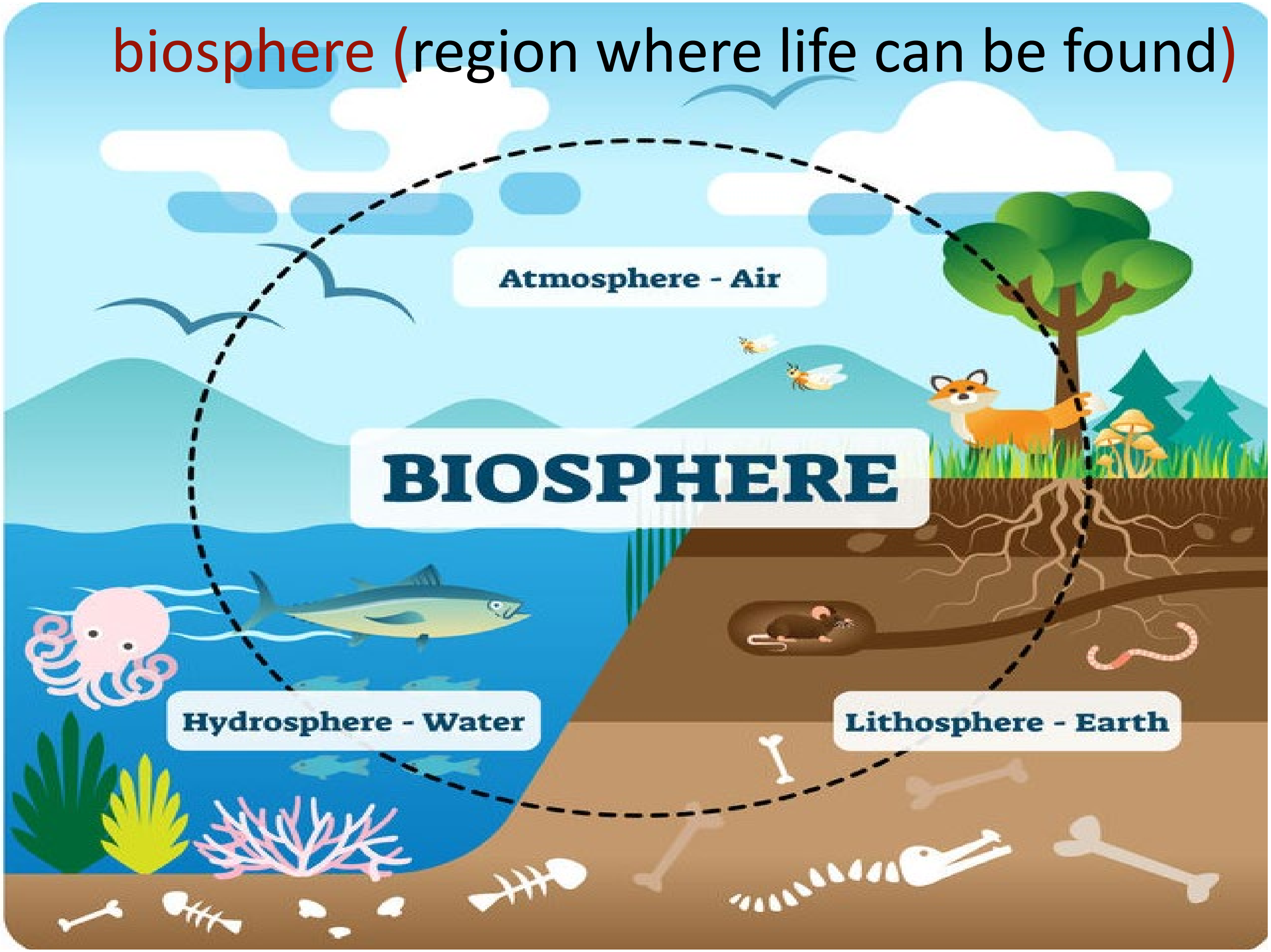
Product	Moisture (%)	Ash content[a] (%)	LHV (MJ/kg)
Bagasse sugarcane	18	4	17–18
Coconut husks	5–10	6	16,7
Coffee husks	13	8–10	16,7
Corn stover	5–6	8	17–19
Corncobs	15	1–2	19,3
Cotton husks	5–10	3	16,7
Oil-palm fibers	55	10	7–8
Oil-palm husks	55	5	7–8
Poplar wood	5–15	1.2	17–19
Rice hulls	9–11	15–20	13–15
Rice straw and husk	15–30	15–20	17–18
Switchgrass	8–15	6	18–20
Wheat straw and husk	7–15	8–9	17–19
Willow wood	12	1–5	17–19

US shares of RE





Carbon Cycle



https://www.australianenvironmentaleducation.com.au/

Carbon Cycle

- Carbon in various forms is transported in a dynamic equilibrium between the various components of the Earth's biosphere, between the atmosphere (air), hydrosphere (water: seas and oceans), lithosphere (rocks, soils and mineral deposits, including fossil fuels) and biological material including plants and animals.
- Other forms, most notably fossil fuels, can potentially store carbon indefinitely, however if they are burned the carbon is released and makes a net addition to the carbon cycle and raising the total free carbon.
- If biomass is used without replacement (as in forest clearance), a net addition is made to the carbon cycle.

Estimated HHV of biomass

Ultimate analysis

$$HHV\left(\frac{kJ}{g}\right) = 0.3491\,C + 1.1783\,H - 0.1034\,O - 0.0211\,A + 0.1005\,S - 0.0151\,N$$

where C is the **mass percent** of carbon, H of hydrogen, O of oxygen, A of ash, S of sulfur, and N of nitrogen appearing in the ultimate analysis.

Based on main constituents, in mass%

$$HHV\left(\frac{MJ}{kg}\right) = 0.3137\,C + 0.7009\,H - 0.0318\,O - 1.3675$$

Based on fixed carbon content

$$HHV\left(\frac{MJ}{kg}\right) = 0.196\ \mathrm{FC} + 14.119$$

Fixed carbon (FC, **mass %**): solid combustible residue remaining after heating biomass and expelling the volatile matter.

$$\mathrm{FC} = 100 - (\%\ \mathrm{water} + \%\ \mathrm{volatile\ matter} + \%\ \mathrm{ash})$$

Based on Ash content, in mass%

$$HHV\left(\frac{MJ}{kg}\right) = 19.914 - 0.232\ Ash$$

Exercise

- Using the following data, estimate the gross heating values in kJ/kg for the biomass redwood from: (a) ultimate analysis, (b) fixed carbon, (c) dry ash content, and (d) carbon (C), hydrogen (H), and oxygen (O) compositions.

Name	Fixed Carbon	Volatiles (%)	Ash (%)	C (%)	H (%)	O (%)	N (%)	S (%)	HHV_m (kJ/g)	HHV_{est} (kJ/g)
Redwood	16.10	83.50	0.40	53.50	5.90	40.30	0.10	0.00	21.03	21.45

Solution

$$HHV\ (kJ/g) = 0.3491\,C + 1.1783\,H - 0.1034\,O - 0.0211\,A + 0.1005\,S - 0.0151\,N$$

$$= (0.3491 \times 53.5) + (1.1783 \times 5.9) - (0.1034 \times 40.3) - (0.0211 \times 0.4) + (0.1005 \times 0.0) - (0.0151 \times 0.1)$$

Ultimate analysis

$$= 21.452\ kJ/g = 21{,}452\ kJ/kg$$

Based on FC

$$HHV\left(\frac{MJ}{kg}\right) = 0.196\ \mathrm{FC} + 14.119$$

$$HHV\left(\frac{MJ}{kg}\right) = (0.196 \times 16.10) + 14.119 = 17.274$$

$$= 17{,}274\ kJ/kg$$

Based on Ash content, in mass%

$$HHV\left(\frac{MJ}{kg}\right) = 19.914 - 0.232\ Ash$$

$$HHV\left(\frac{MJ}{kg}\right) = 19.914 - (0.232\ \times\ 0.4) = 19.821$$

$$= 19{,}821\ \mathrm{kJ/kg}$$

Based on main constituents, in mass%

$$HHV\left(\frac{MJ}{kg}\right) = 0.3137\,\mathrm{C} + 0.7009\,\mathrm{H} - 0.0318\,\mathrm{O} - 1.3675$$

$$HHV\left(\frac{MJ}{kg}\right) = (0.3137 \times 53.5) + (0.7009 \times 5.9) - (0.0318 \times 40.3) - 1.3675 = 18.269 = 18{,}269\ kJ/kg$$

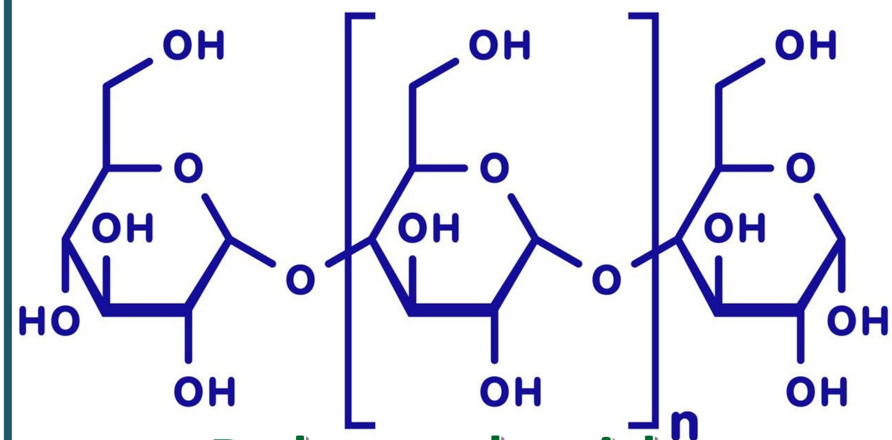
Bioenergy, or Biofuels

Natural biofuels (produced from photosynthesis)

1- Carbohydrates: 4 kcal/g or 17 kJ/g

- mixtures of mono-, di- and poly-saccharides containing aldehydes or ketones groups with many hydroxyl groups.

- Carbohydrates as starch are the most abundant biological molecules, and play numerous roles, such as the storage and transport of energy, and structural components such as cellulose in plants.



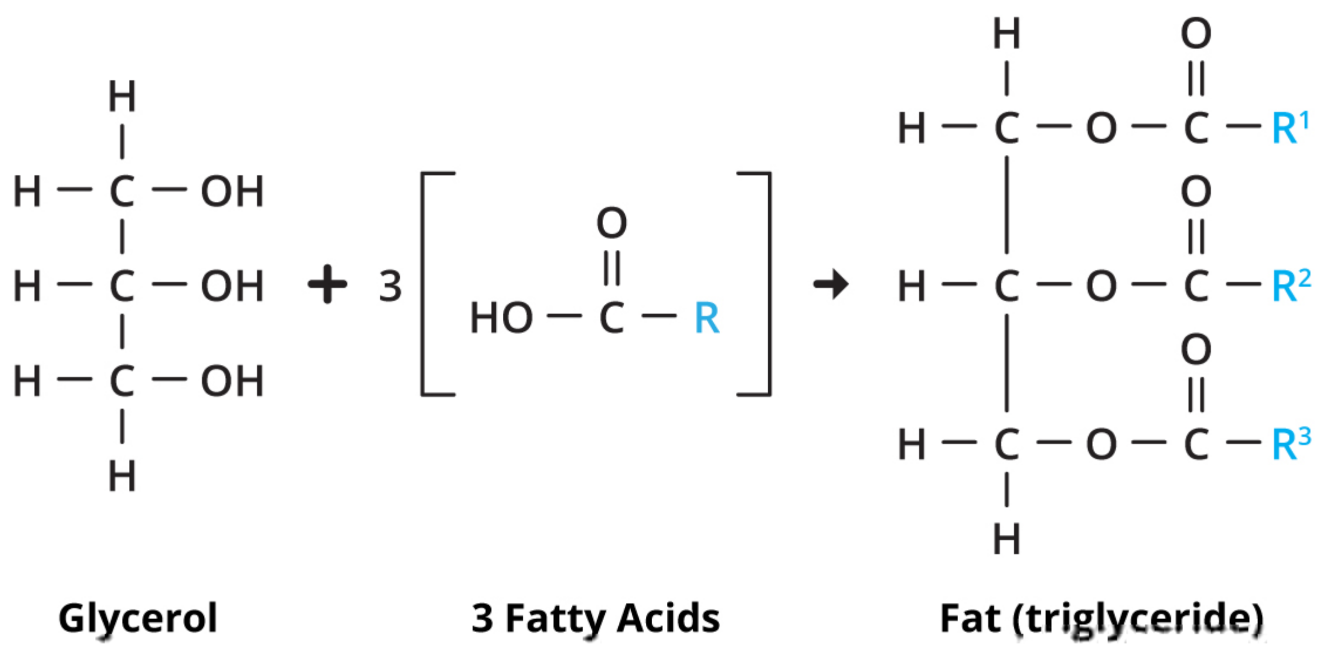
Polysaccharide

https://www.thoughtco.com/polysaccharide-definition-and-functions-4780155

2- Fats, unsaturated and saturated fatty acids:

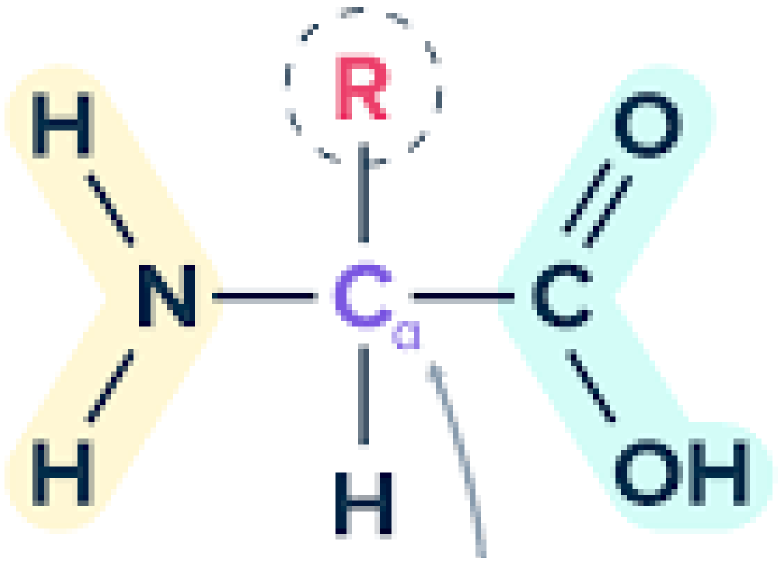
9 kcal/g or 39 kJ/g

- (triacylglycerol or triglyceride)
- contain long, linear **aliphatic** hydrocarbon chains, which are partially unsaturated and have a carbon number range.



3- Proteins   4 kcal/g or 17 kJ/g

- chains of amino acids, which fold into unique three-dimensional shapes.
- Carbohydrates and fats can be completely oxidized while proteins can only be **partially** oxidized and hence has lower fuel values.



Amino acid

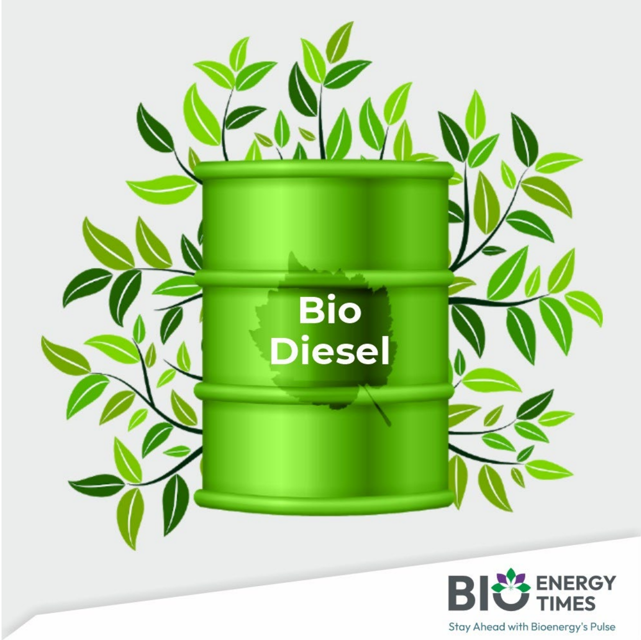
Synthetic biofuels

1- Bioethanol:

- In US, corn-based **ethanol** (*prepared by dry or wet milling*) is the largest source of biofuel and is a gasoline substitute or additive.
- Gasoline is mixed with 10% ethanol, a mix known as E10 (or gasohol).
- E85 is an alternative fuel that contains up to 85% ethanol.

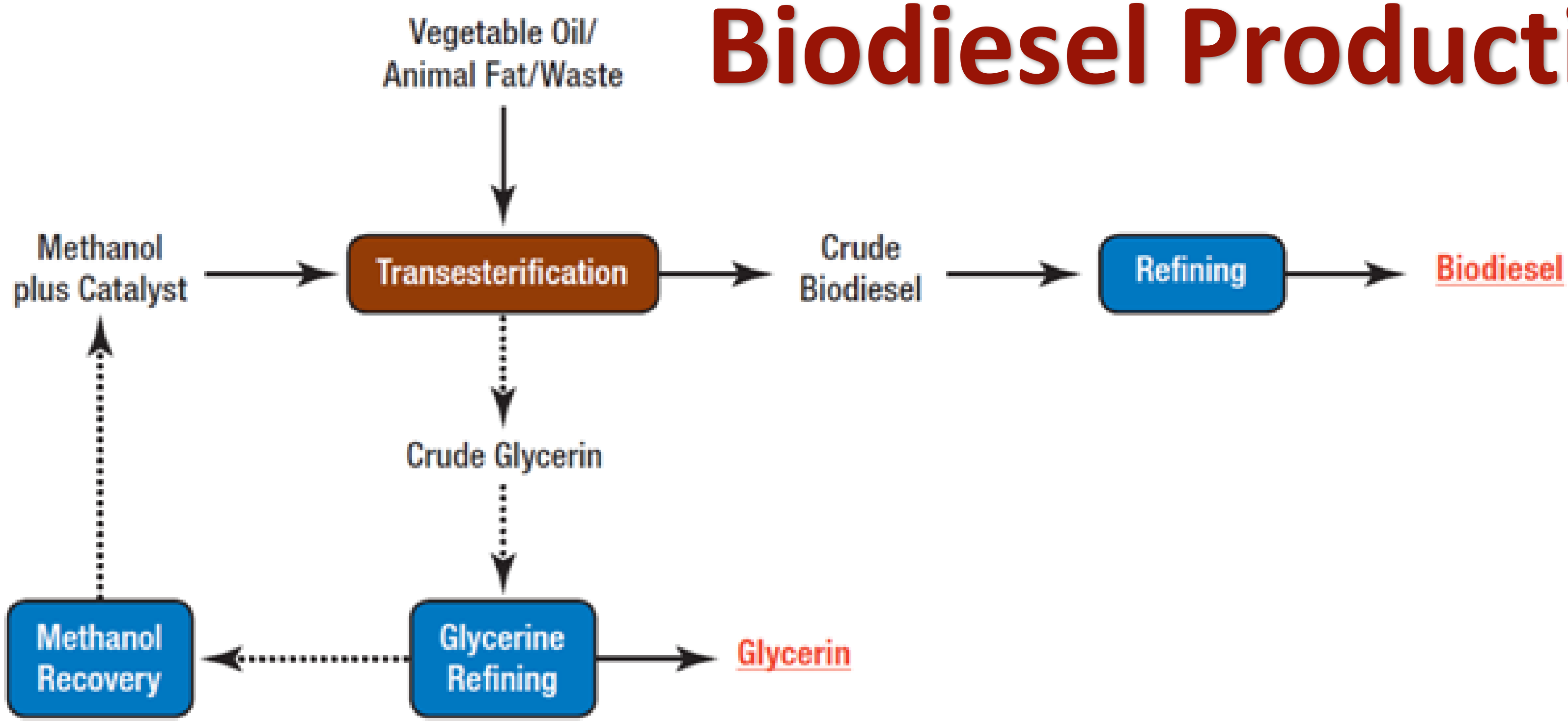
Synthetic biofuels

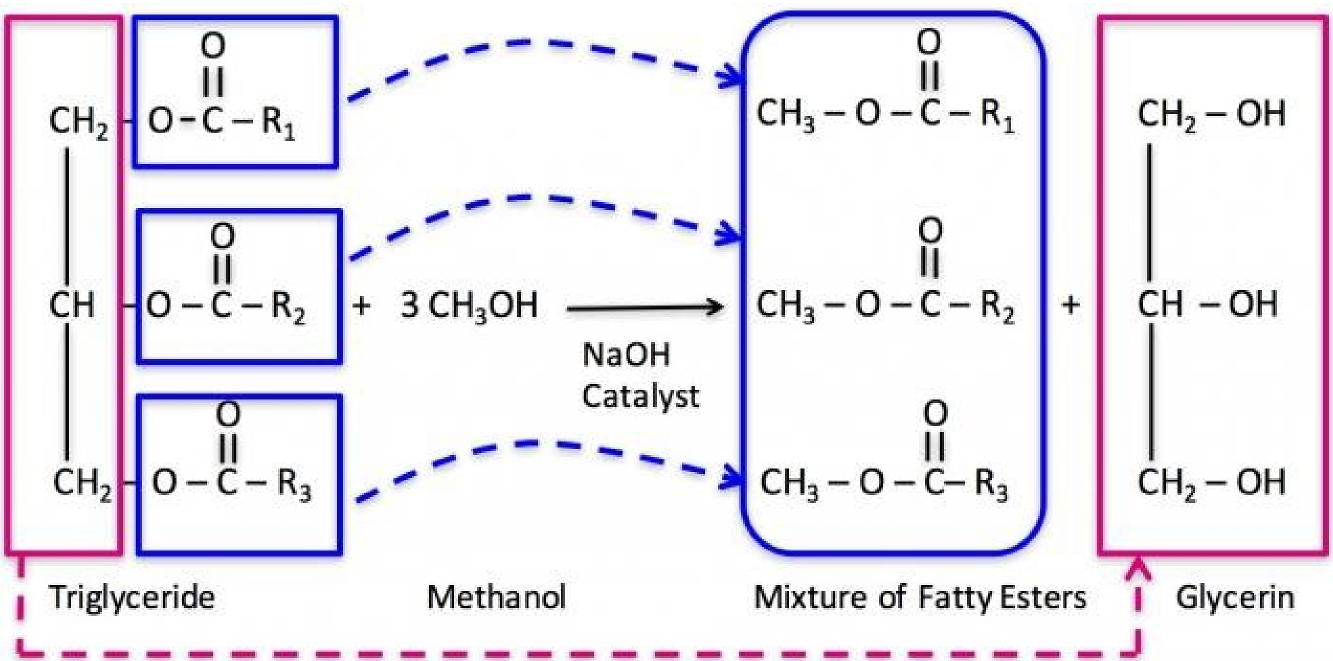
2- Biodiesel:



- is a renewable, **biodegradable** fuel manufactured domestically from vegetable oils, animal fats, or recycled restaurant grease.
- is used in regular diesel vehicles without making any changes to the engines.
- is most often blended with petroleum diesel in ratios of 2% (B2), 5% (B5), or 20% (B20). It can also be used as pure biodiesel (B100).

Biodiesel Production





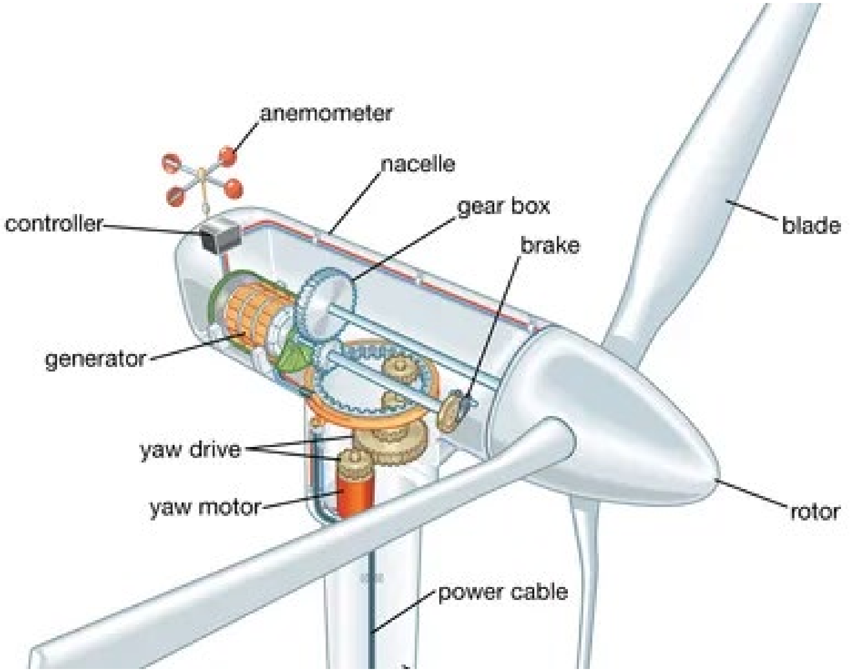
Synthetic biofuels

3- Green diesel:

- is produced by removing **oxygen** by catalytic reaction with hydrogen from renewable feedstock containing triglycerides and fatty acids, producing a paraffin-rich product, water, and carbon oxides.
- has a heating value equal to conventional diesel.
- is fully compatible for blending with the standard mix of petroleum-derived diesel fuels.
- Biodiesel has around 11% oxygen, whereas petroleum-based diesel and green diesel have no oxygen.

Wind Energy

- most of the solar energy is stored in wind movements that reaches to a speed of **160 km/h** at high altitudes.
- is totally renewable source with no greenhouse gas emissions.
- due to its unpredictability, it has problems integrating with national grids.



Geothermal Energy

- is the heat originating from the original formation of the planet, from radioactive decay of minerals, from volcanic activity, and from solar energy absorbed at the surface.
- The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface.
- is cost effective, reliable, sustainable, and environmentally friendly.

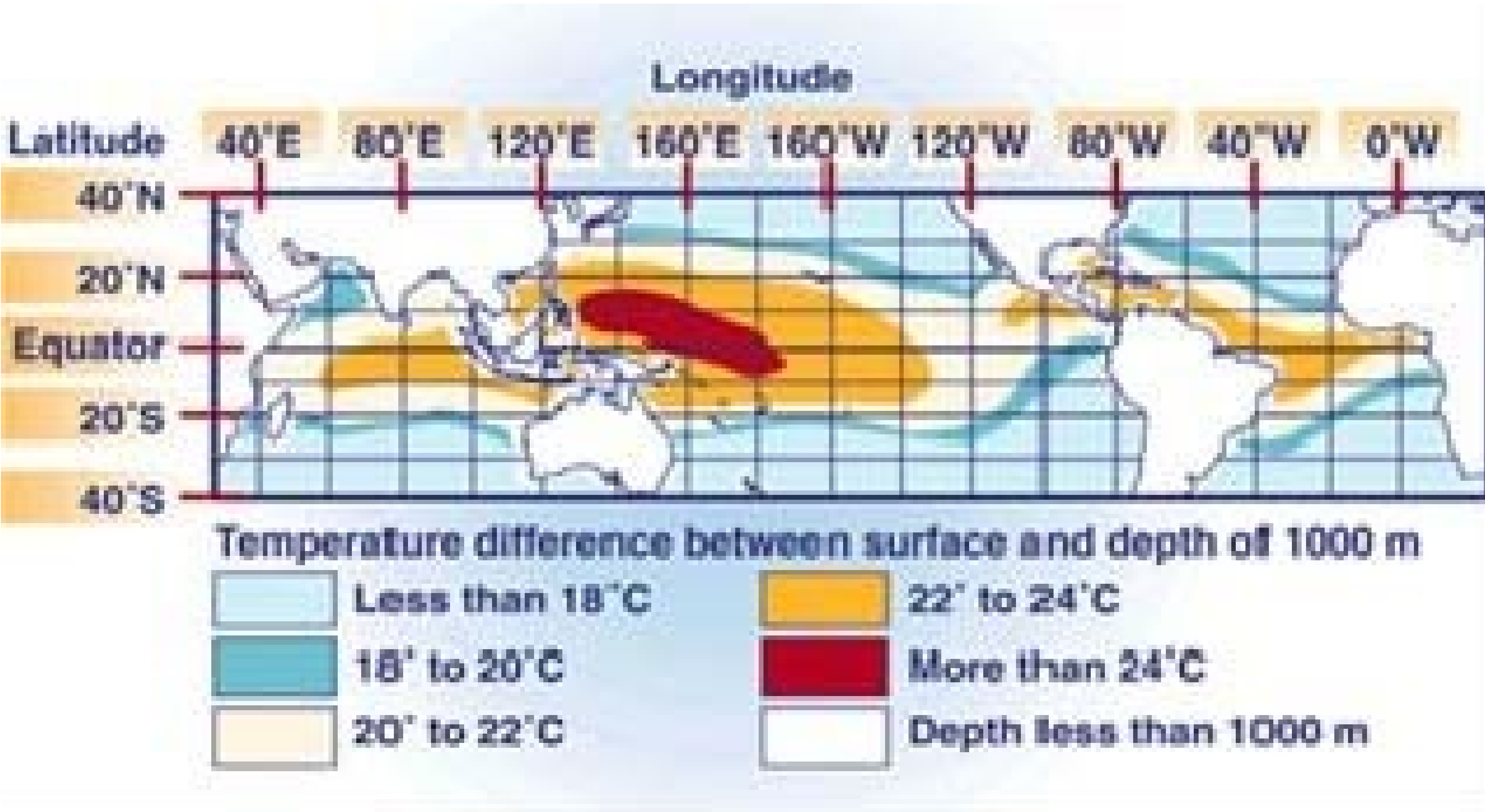
Geothermal Energy

- Hot water or steam reservoirs deep in the earth are accessed by drilling.
- Geothermal reservoirs located near the earth's surface maintain a relatively constant temperature of 50–60°F.
- The hot water and steam from reservoirs can be used to drive generators and produce electricity or in heating buildings and industrial plants.
- a geothermal plant runs 24 hours per day, 7 days per week and can provide base load power, thus competing against coal plants.

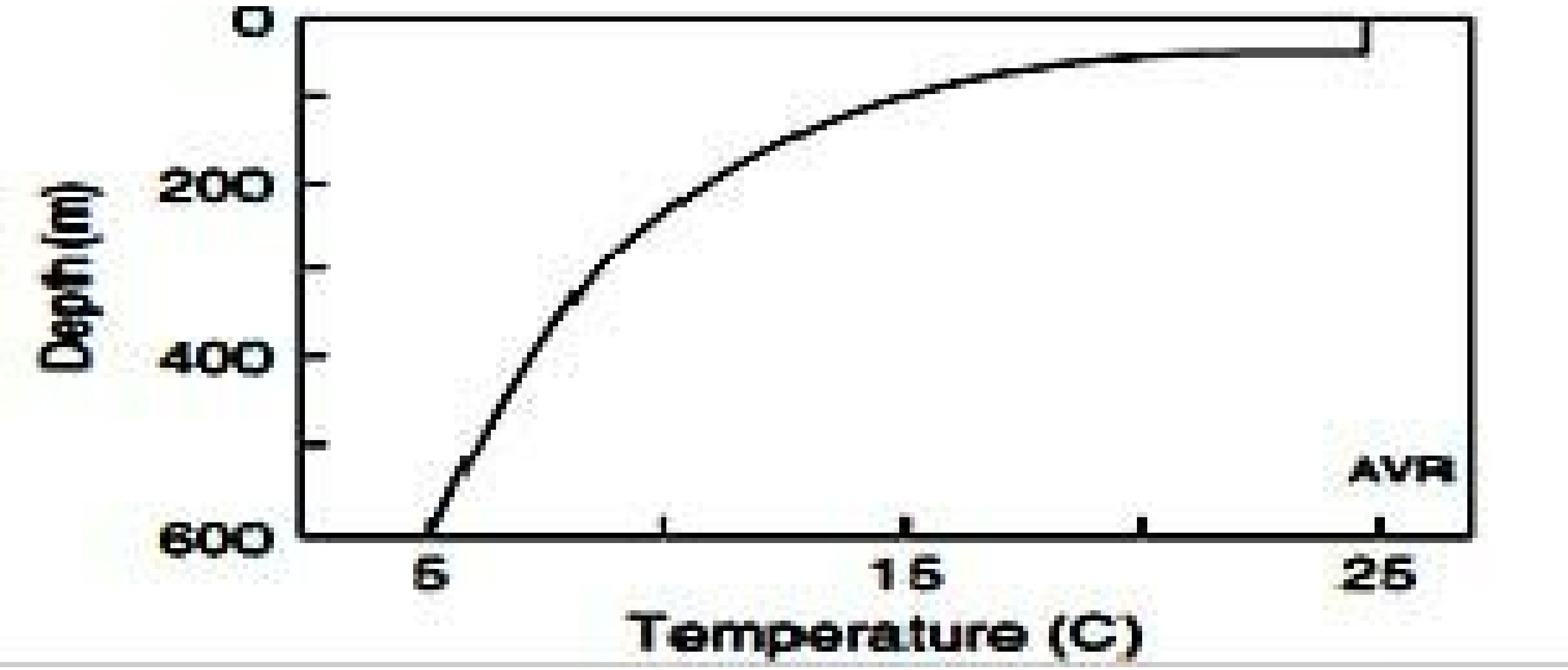
Ocean Energy

- Of the total solar radiation, oceans are the largest collectors, accumulating 250 billion barrels of oil equivalent that can be converted into **electricity** by a process known as Ocean Thermal Energy Conversion (**OTEC**).
- **OTEC** makes use of ΔT of warm surface water (22-27 °C) and very cold water at a depth of 1 km (4-7 °C).
- OTEC uses the heat stored in warm surface water to create steam to drive a turbine, while pumping cold, deep water to the surface to recondense the steam.
- It functions best when there is a temperature difference of at least 20°C.
- Ocean surface can vary in T from a warm 30°C in the tropics المناطق الاستوائية to a very cold –2°C near the poles.

Ocean Temperature Differences between Surface and 1,000 Meters Deep



Typical ocean temperature profile in the tropics



- turbines have minimal environmental impact, as they are almost entirely submerged, and the rotors pose no danger to wildlife as they turn quite slowly.

OTEC

- In **closed-cycle** **OTEC** plant, warm seawater heats a working fluid with a low boiling point, such as **ammonia**, and the ammonia vapor turns a turbine, which drives a generator. The vapor is then condensed by the cold water and cycled back through the system.

- In an **open-cycle** **OTEC** plant, warm seawater from the surface is pumped into a **vacuum** chamber where it is flash evaporated, and the resulting steam drives the turbine. Cold seawater is then brought to the surface to condense the steam into water, which is returned to the environment.

Hydrogen

- most abundant element in the universe, lightest element, transparent, odorless, colorless, and tasteless.
- as a fuel can be used for heating, electricity production, and as a motor fuel.
- its widespread use is limited due to high production and storage costs.
- In the sun's core, hydrogen atoms combine to form helium atoms (fusion) and gives off radiant energy that sustains life on earth; drives the **photosynthesis** in plants and other living systems, and is stored as chemical energy in fossil fuels.
- **H_2** does not exist on earth as a gas and is found only in compounds as H_2O and CH_4.

Hydrogen

- **H_2** is produced from resources as natural gas, coal, and biomass via steam reforming (least expensive) or water electrolysis (expensive).
- **H_2** has the highest energy content of any common fuel by mass (~ **3-times** *more than gasoline*), but the lowest energy content by volume.
- **H_2** transports energy (**carrier**) in a useable form from one place to another.
- **H_2** burns cleanly, producing H_2O.
- **renewable H_2** is produced using renewable energy, as wind or solar power.
- **Applications**: NH_3 synthesis, Hydrocracking, Fuel.

Electric Energy

- Electricity is the fastest growing form of end-use energy.
- The amount of electric energy, E_e, due to an electric current, I, is given by:

$$E_e = VIt = I^2Rt$$

- Alternating current (AC, homes), direction of e's flow of switches back and forth at regular intervals or cycles.
- Standard current in US is 60 cycles per second (60 Hz); in Europe, Egypt and most other world parts is 50 Hz.
- In Direct current (DC), electrical current flows consistently in one direction.
- AC is relatively cheap to change the voltage of the current and the loss of energy in carrying current for long distances is far smaller.

Global warming

- Burning of fossil fuels produces around 21.3 Gigatons CO_2 per year.
- Natural processes can only absorb about half of that amount, so there is a net increase of 10.65 billion tons of atmospheric CO_2 per year.
- CO_2 emission can be calculated as:

$$e_{CO_2}\left(\frac{kg\ CO_2}{kWh}\right) = \frac{C_f}{E_f} \times \frac{MW_{CO_2}}{MW_C}$$

where e_{CO_2} is the CO_2 emission in kg CO_2/kWh, C_f is the carbon content in the fuel (kg C/kg fuel) and E_f is the energy content of the fuel (kWh/ kg fuel).

- An average car traveling 10,000 miles per year and consuming an average 25 miles per gallon emits about 1.2 tons CO_2 per year.

Emission of carbon dioxide from the combustion of various fuels

Fuel	Specific carbon (kg_c/kg_{fuel})	Specific energy (kWh/kg_{fuel})	Specific CO_2 emission (kg_{CO_2}/kg_{fuel})	Specific CO_2 emission (kg_{CO_2}/kWh)
Coal (bituminous/anthracite)	0.75	7.5	2.3	0.37
Gasoline	0.9	12.5	3.3	0.27
Light oil	0.7	11.7	2.6	0.26
Diesel	0.86	11.8	3.2	0.24
LPG—liquid petroleum gas	0.82	12.3	3.0	0.24
Natural gas, methane	0.75	12	2.8	0.23
Crude oil				0.26
Kerosene				0.26
Wood[a]				0.39
Peat[a]				0.38
Lignite				0.36

Emission of carbon dioxide from the combustion of various fuels

Global warming

- various atmospheric gases (CO_2 is major), acting like the glass in a greenhouse, transmit incoming sunlight but absorb outgoing infrared radiation, thus, **raising** the average air temperature at the earth's surface.
- Increase in temperature can release CO_2 from the ground and seawater.
- **Consequences**: ice melts, sea level rises, and severe storms because of the additional energy in the atmosphere.
- The melt water flows like a river, causing rapid heat transfer and erosion.