EV20001: ENVIRONMENTAL SCIENCE

Lecture #6

Renewable Energy

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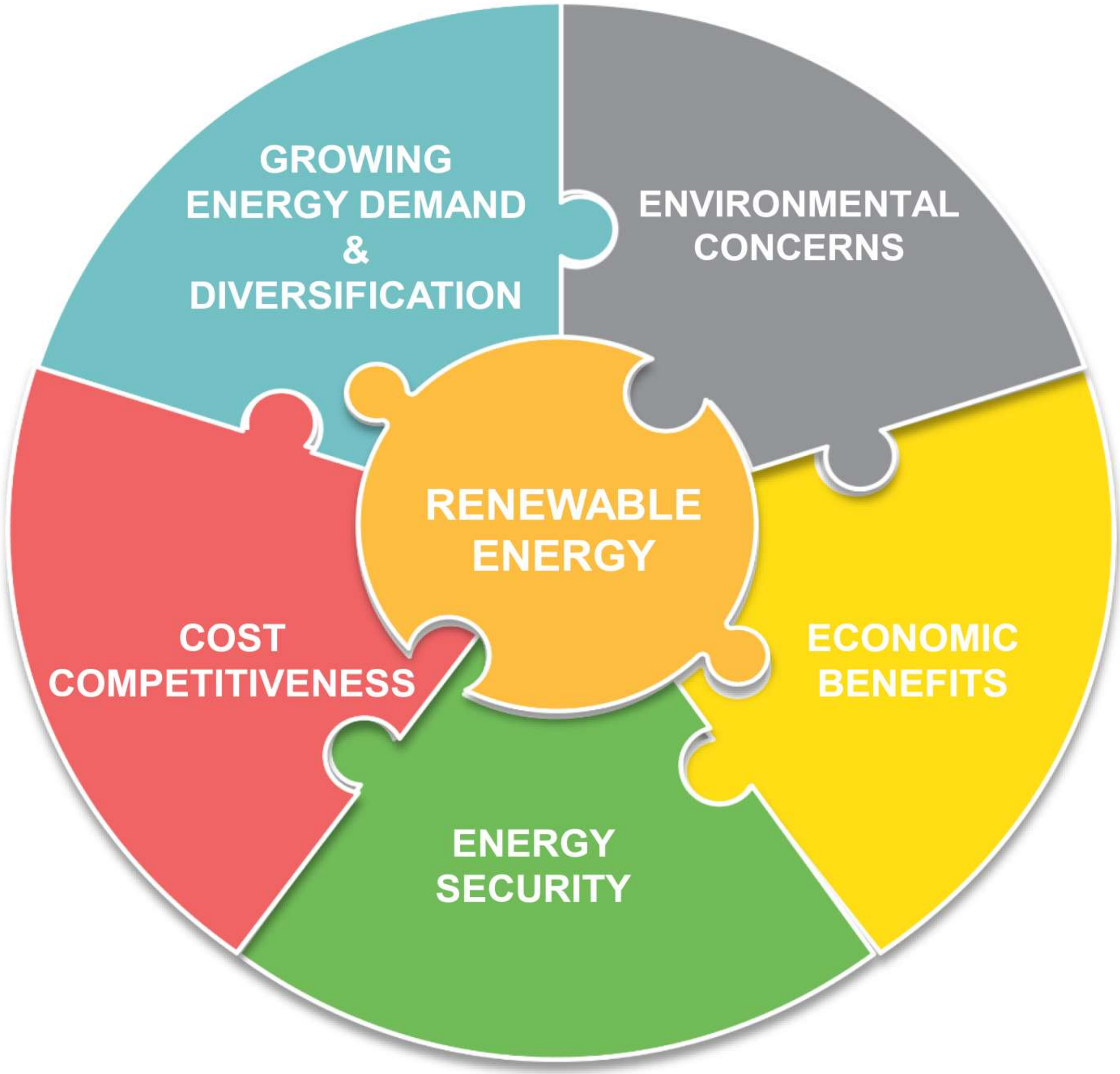
Renewable energy

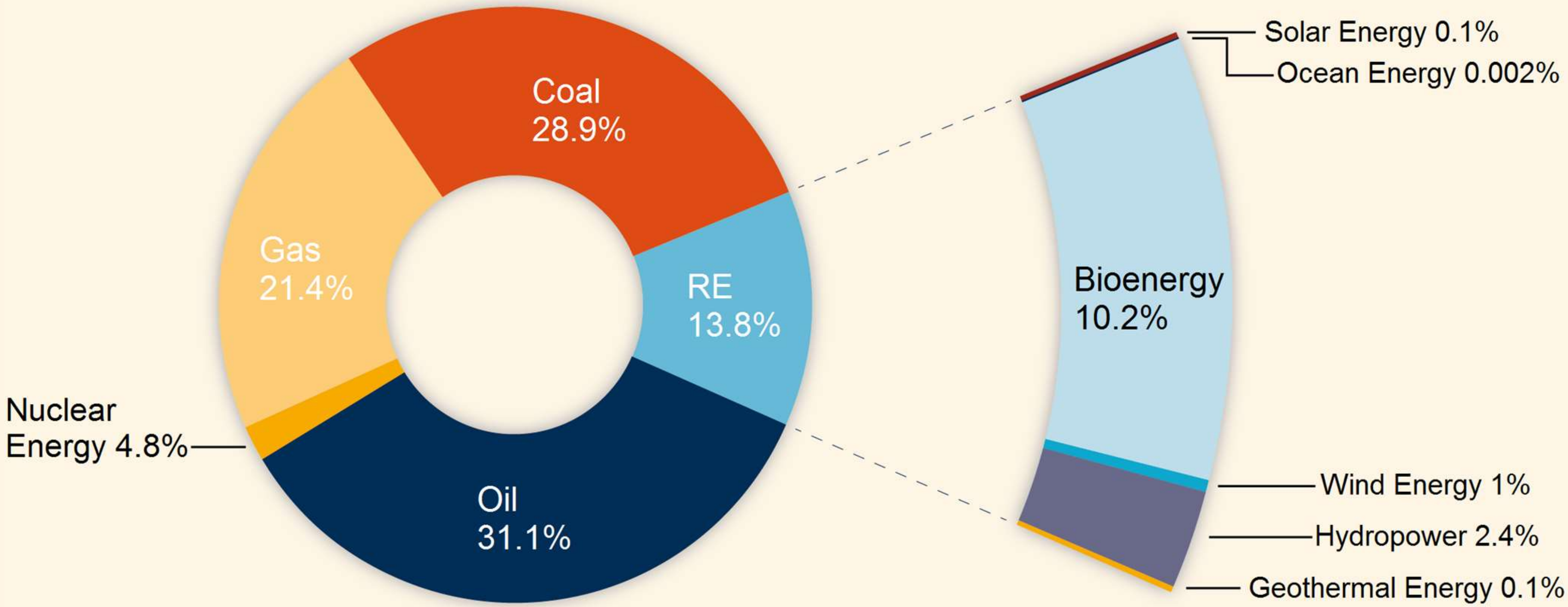
- Renewable energy (RE) is any form of energy that is **replenished by natural processes** at a rate that equals or exceeds its rate of use.
- RE is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes resources such as biomass, solar radiation, geothermal heat, hydropower, tides and waves, and wind.
- Unlike fossil fuels, RE sources do not directly emit CO_2 when producing electricity. In order to cut global CO_2 emissions by at least 80% by 2050 and slow the projected climate change, the world will need to transition to RE.
- Most RE technologies produce lower conventional air and water pollutants than fossil fuels, thereby greatly reducing the pollution of air, land and water.
- RE can also result in a more decentralized and efficient energy economy that would be less vulnerable to supply cutoffs from terrorist attacks and natural disasters, improve economic and national security for many countries by reducing their dependence on imported crude oil and natural gas, create large numbers of jobs and save consumers money.

Key drivers of renewable energy



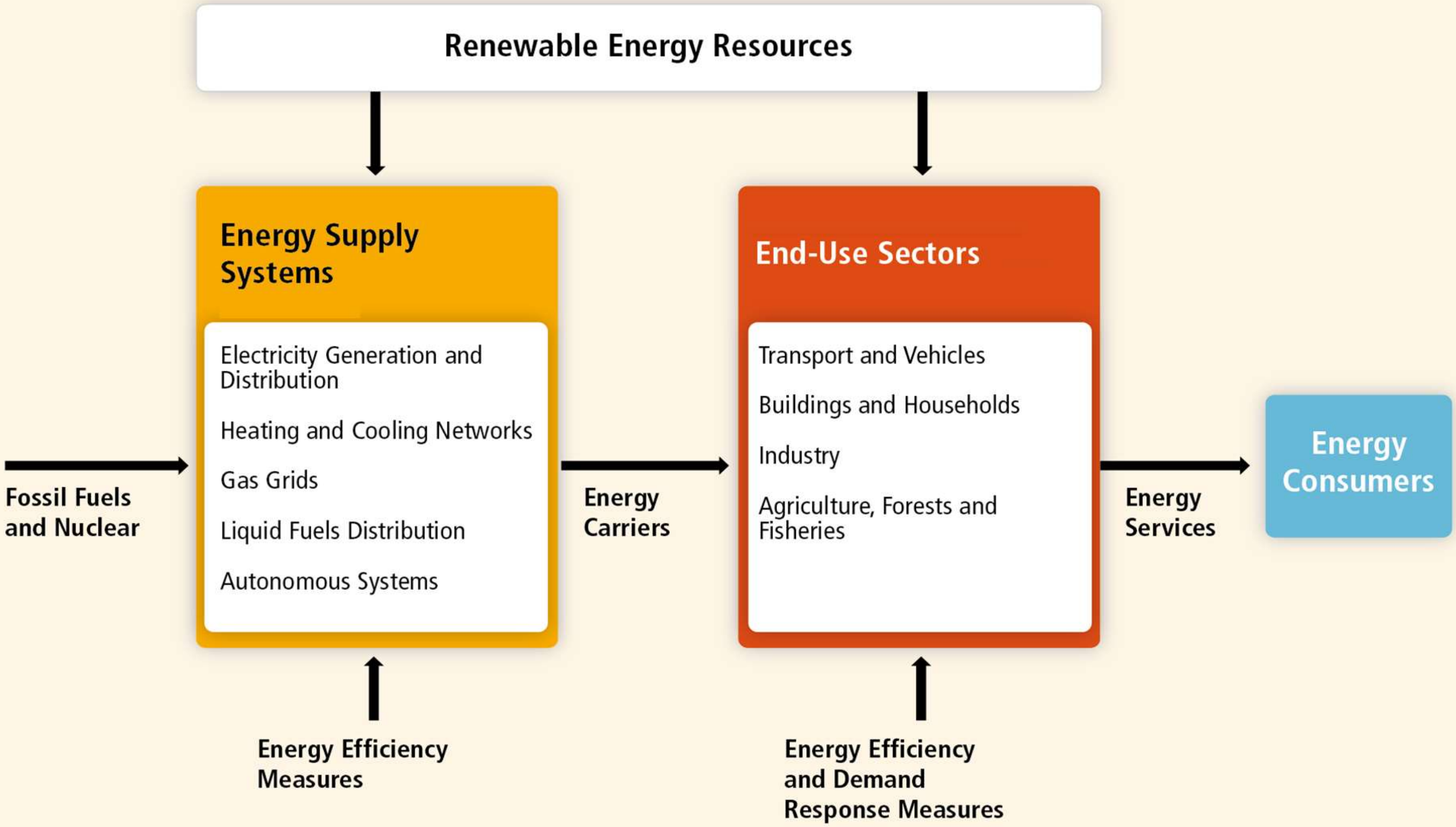
Types of renewable energy resources

- Deployment of RE has been increasing rapidly in recent years. On a global basis, it is estimated that RE accounted for 13.8% of the total primary energy supply in 2013. The largest RE contributor was biomass (10.2%), with the majority (roughly 60%) of the biomass fuel used in traditional cooking and heating applications in developing countries but with rapidly increasing use of modern biomass as well. Hydropower represented 2.4%, whereas other RE sources accounted for 1.2%.



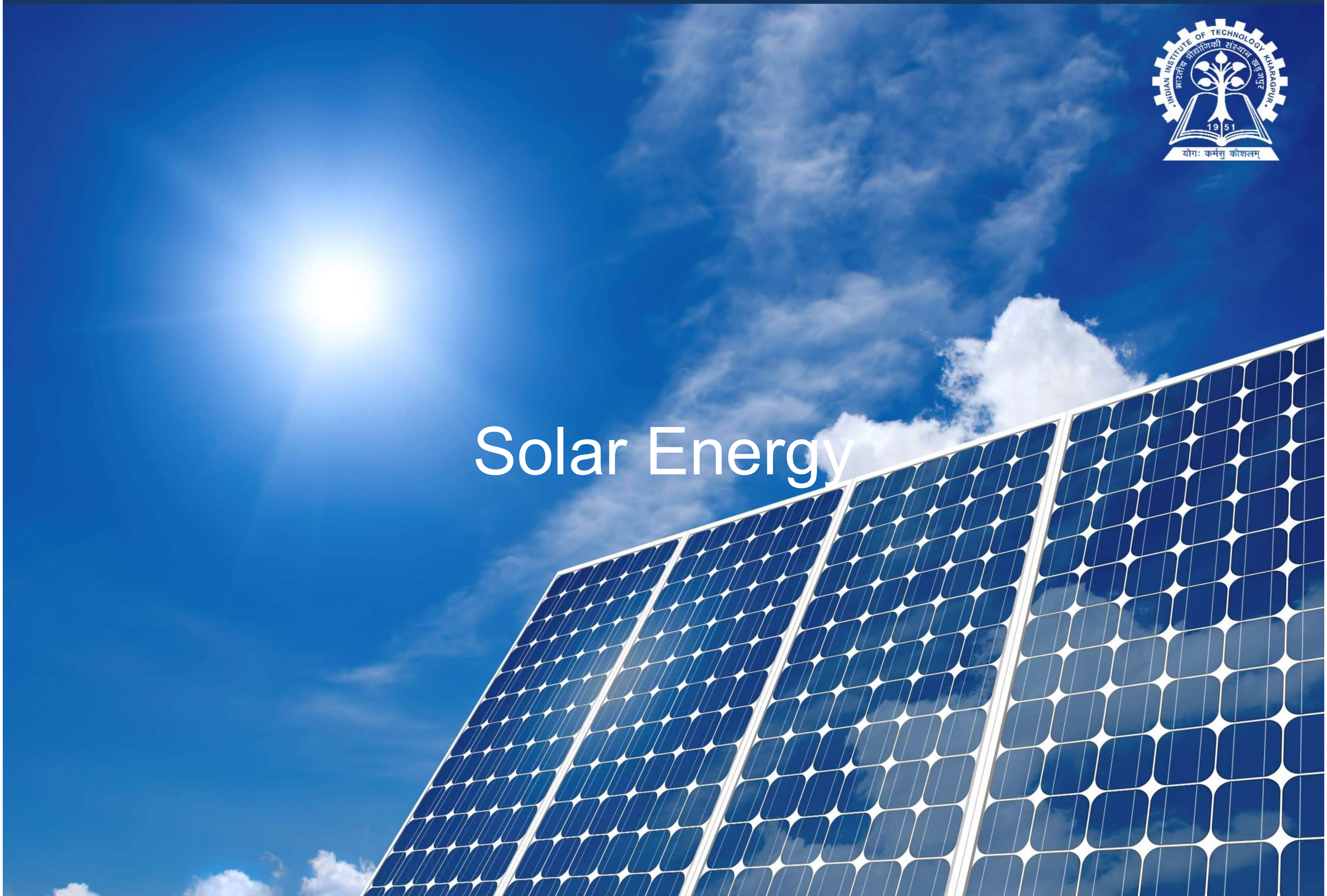
Shares of energy sources in total global total primary energy supply in 2013

- Various RE resources are already being successfully integrated into energy supply systems and into end-use sectors.



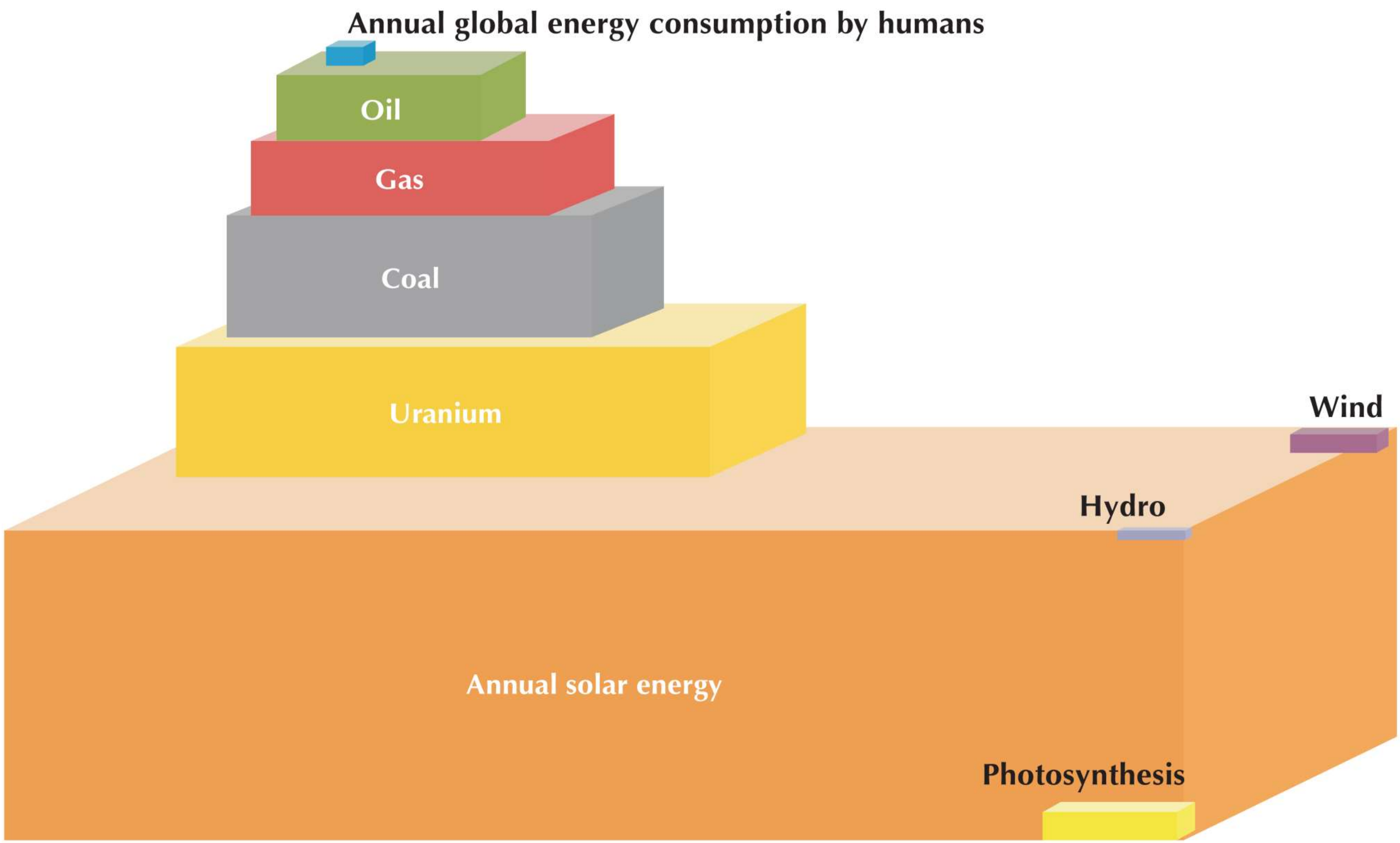
Pathways for RE integration to provide energy services, either into energy supply systems or on-site for use by the end-use sectors.

Solar Energy

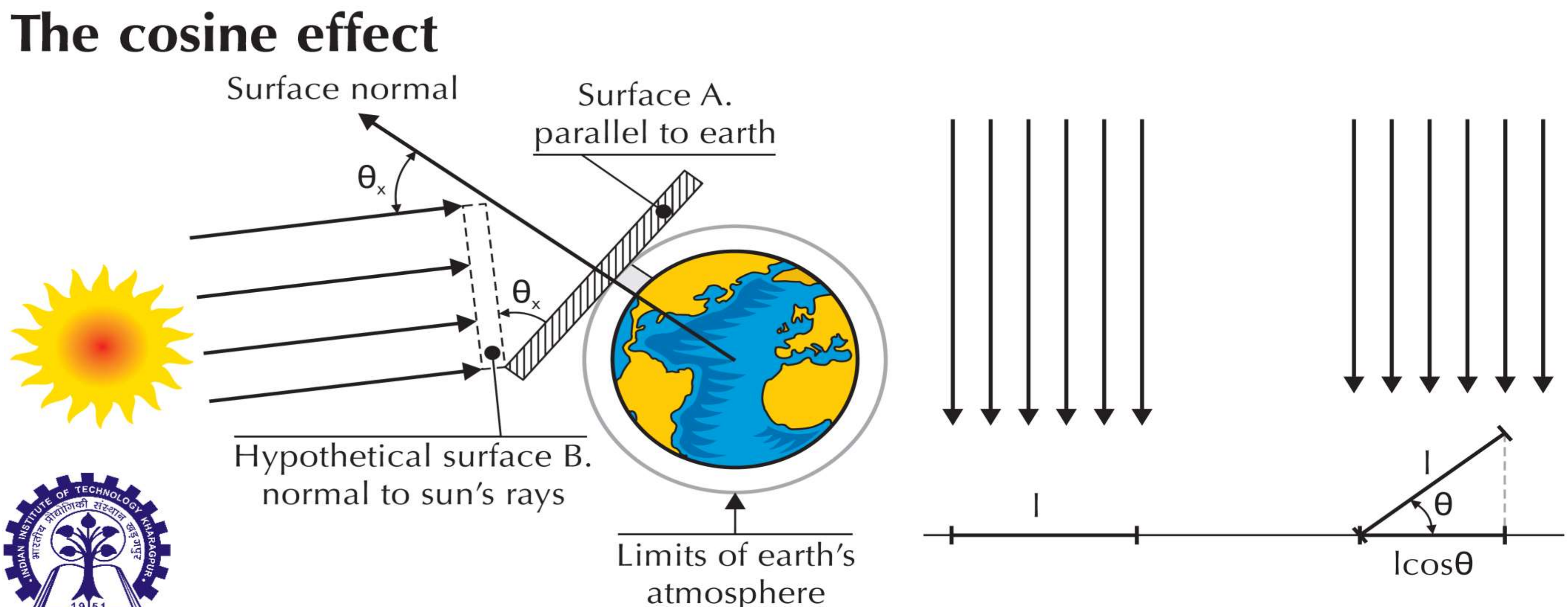


Direct solar energy

- Solar energy is the largest energy resource on Earth – and is inexhaustible.



- Solar irradiance is maximal when the sun is directly overhead. When the sun is lower in the sky, its energy is spread over a larger area, and is therefore weaker per surface area. This is called the **cosine effect**.
- More specifically, supposing no atmosphere, in any place on a horizontal surface the direction of the sun at its zenith forms an angle with the vertical. The irradiance received on that surface is equal to the irradiance on a surface perpendicular to the direction of the sun, multiplied by the cosine of this angle.



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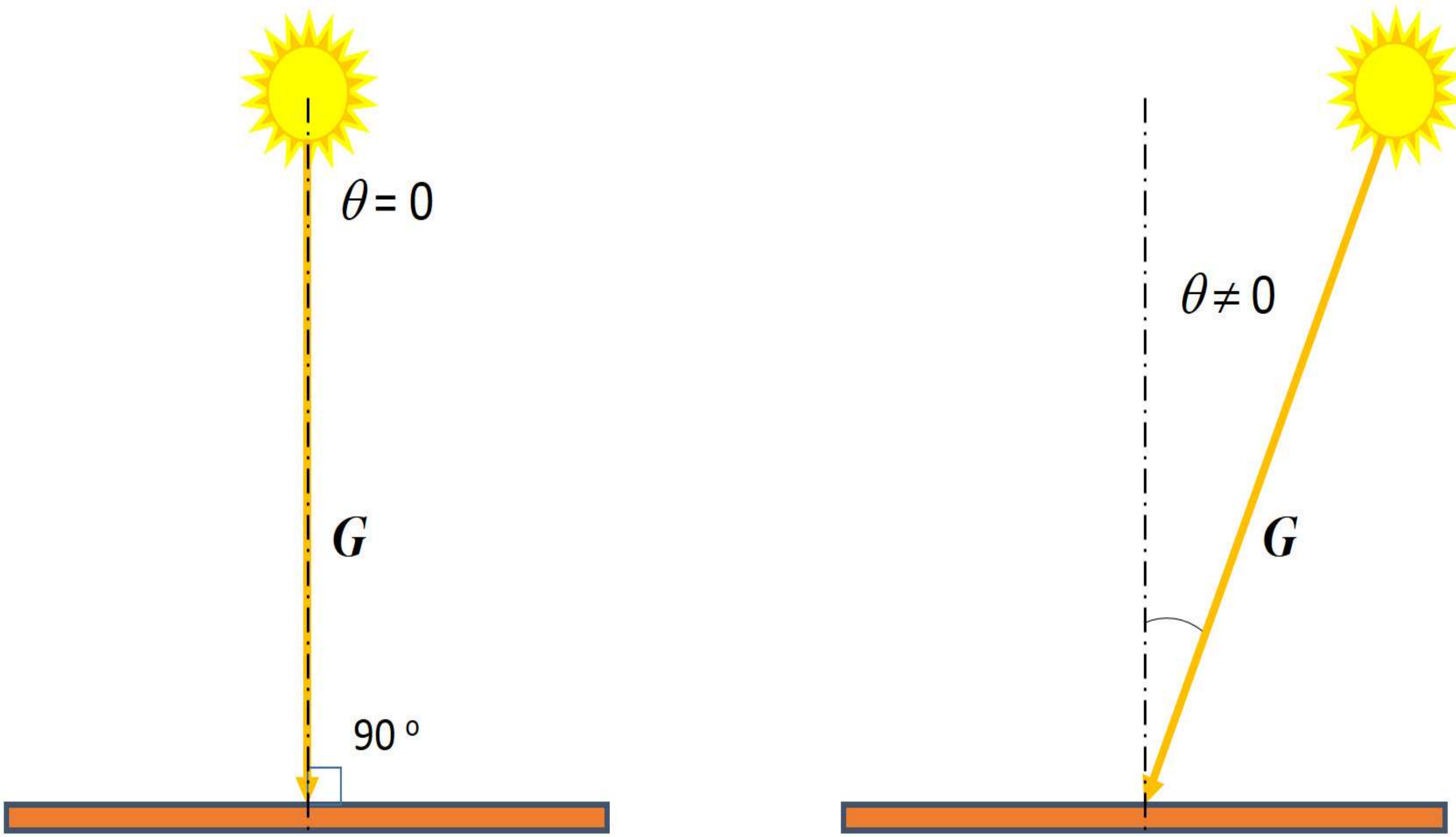

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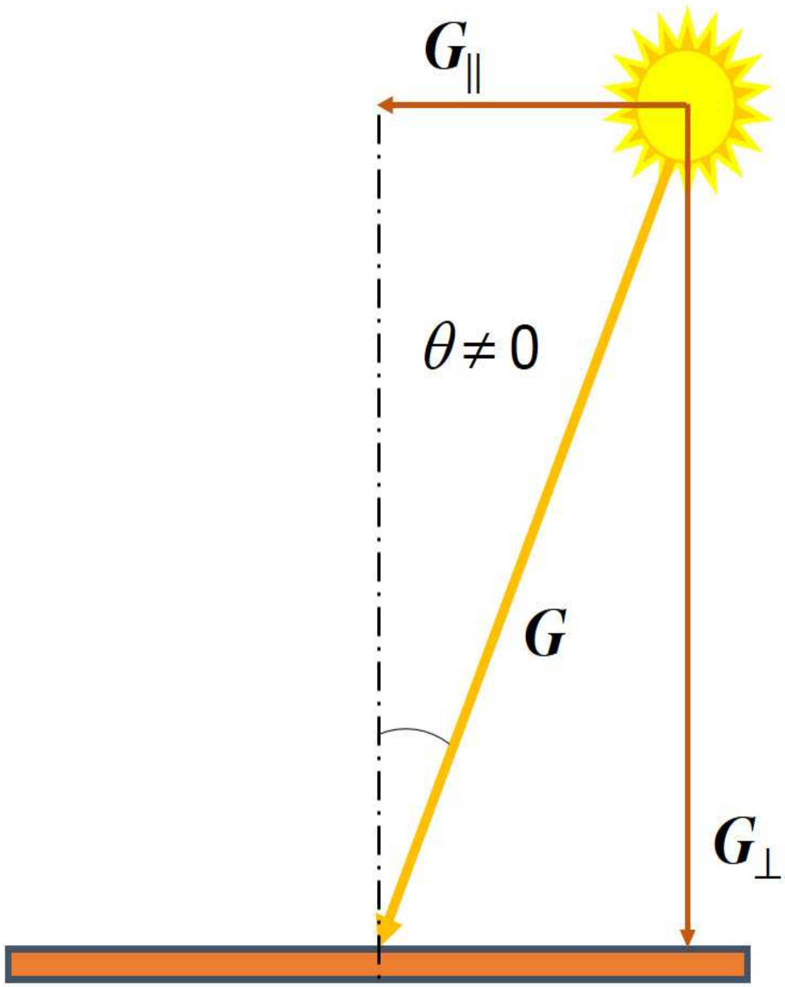

$$G_{\perp} = G\cos(\theta)$$

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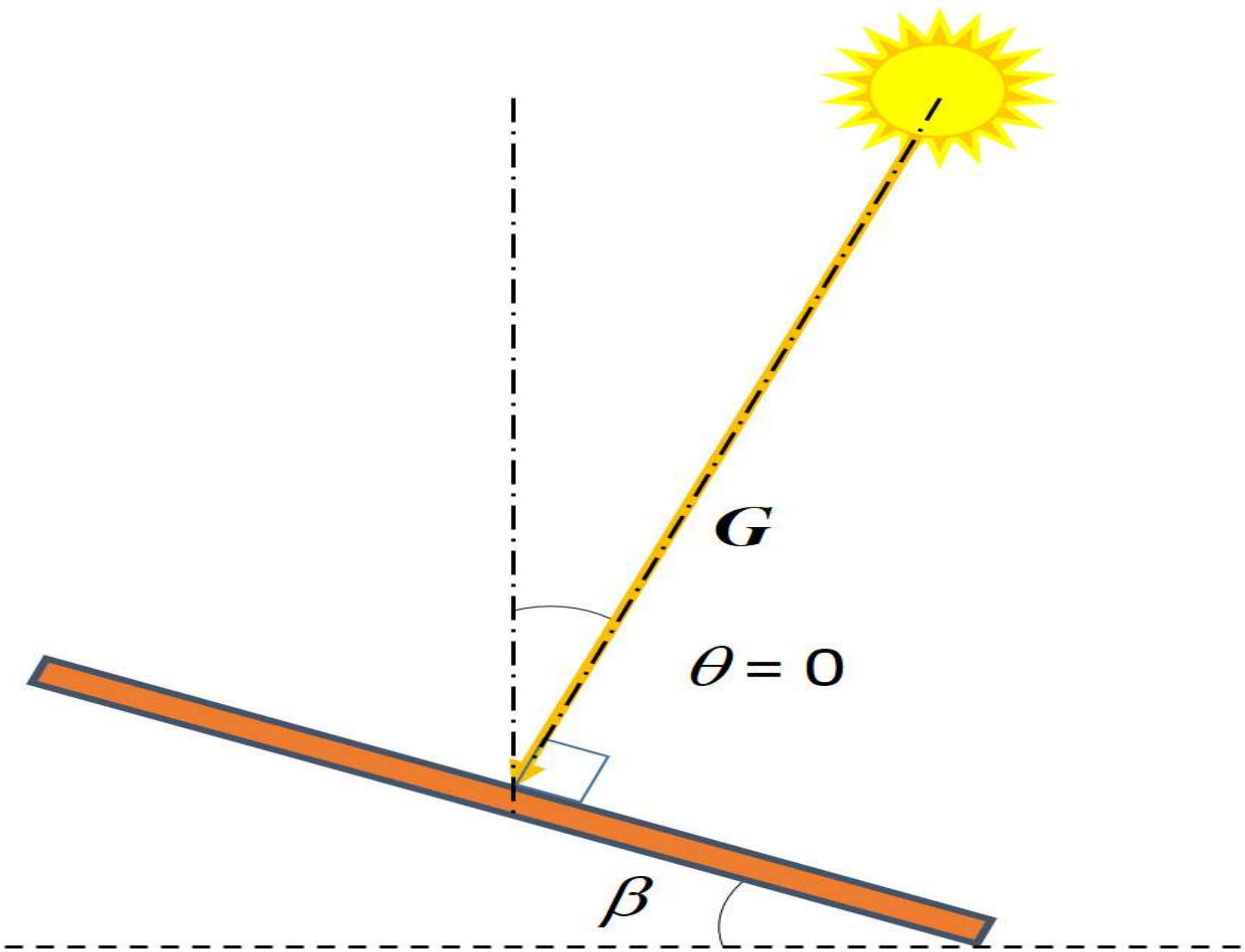
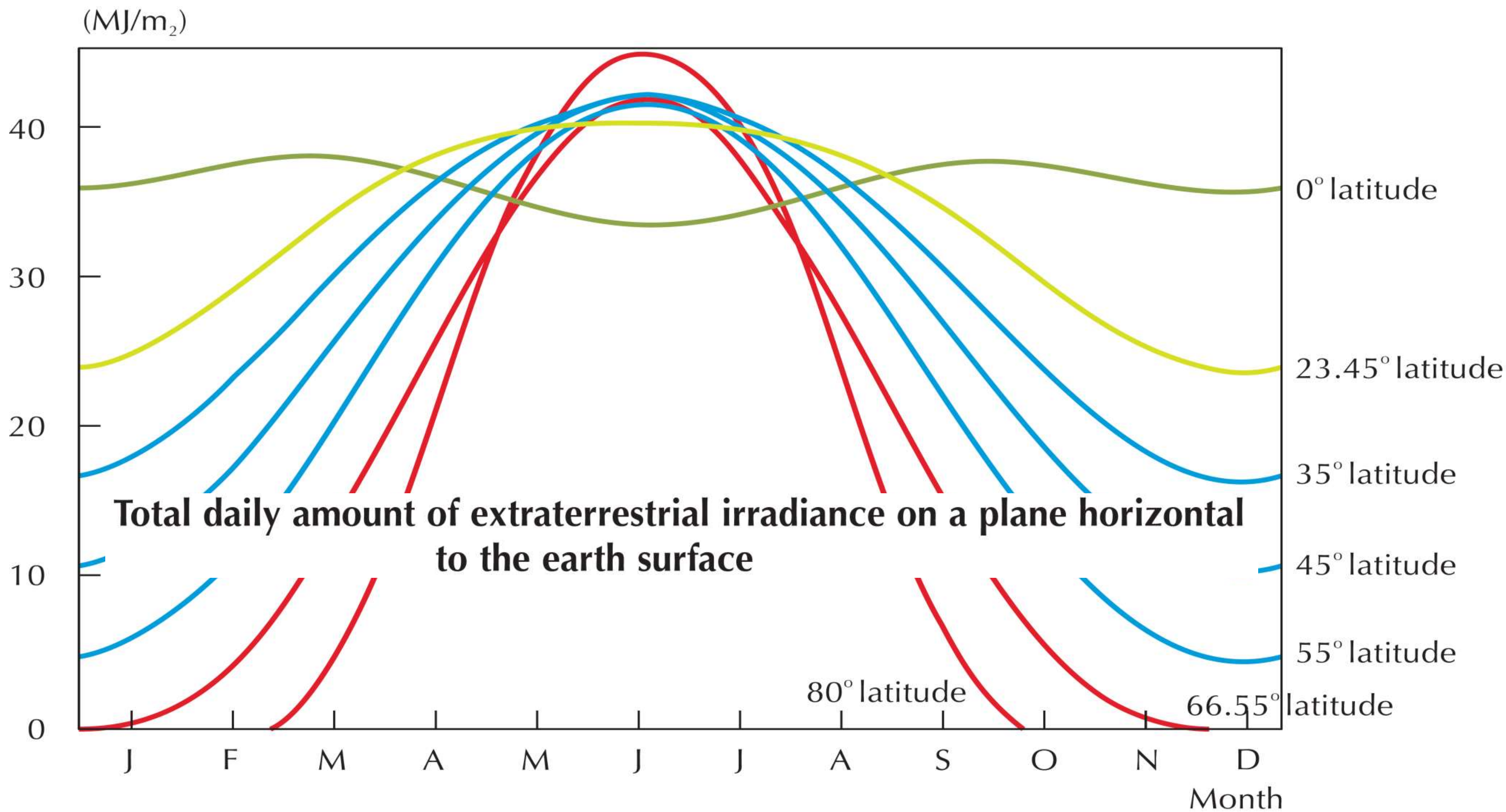
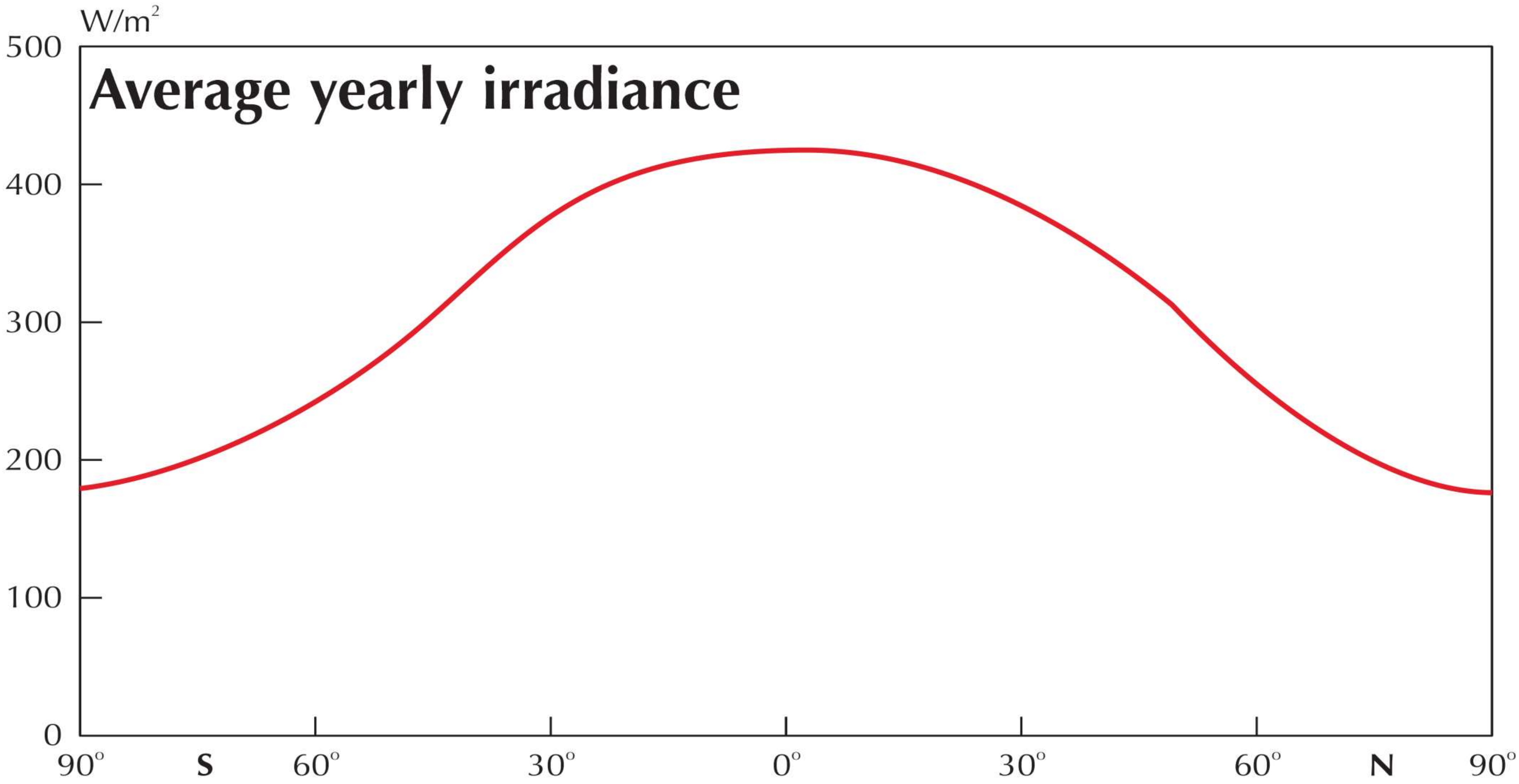


- Solar irradiance varies over the year at diverse latitudes – very much at high latitudes, especially beyond the polar circles, and very little in the tropics.



- Solar irradiance is of fundamental importance for harvesting high quality solar energy and is deemed good to excellent between 10º and 40º, South or North.

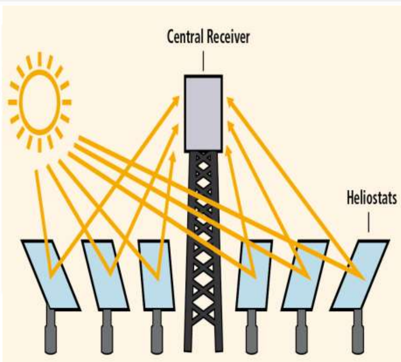


Capturing solar energy

- There are two main methods of capturing energy from the sun:
  - **Heat:** irradiative solar energy is easily transformed into heat through absorption by gases, liquids or solid materials
  - **Photoreaction:** solar radiation can be viewed as a flux of elementary particles that can promote photoreactions and generate a flow of electrons.

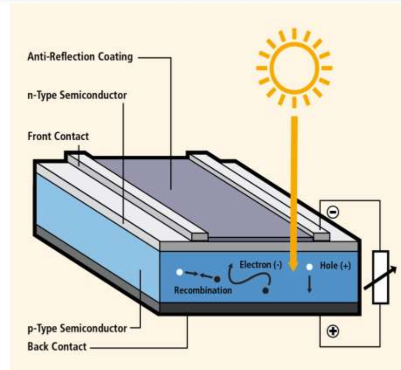
- Depending on the capturing mechanism, there are four major direct solar energy technologies.

Concentrating Solar Power (CSP)



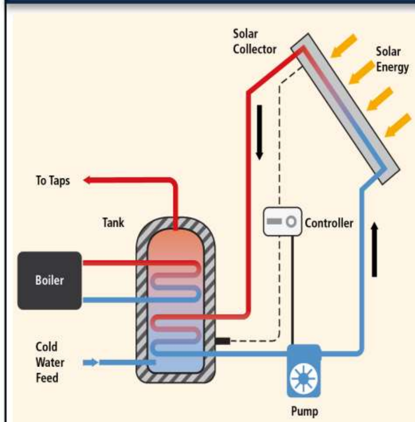
Electricity is generated by the **optical concentration** of solar energy, producing high-temperature fluids or materials to drive heat engines and electrical generators.

Solar Photovoltaic (PV)



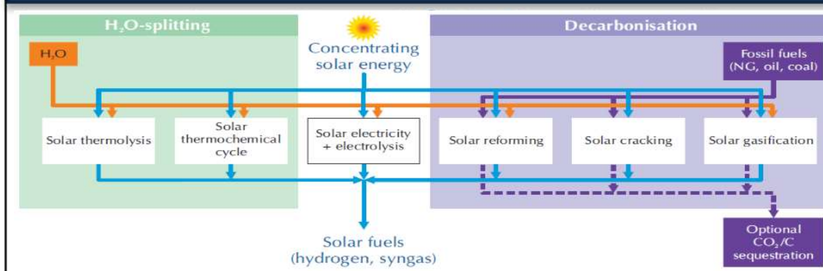
Electricity generation via direct conversion of sunlight to electricity by **photovoltaic cells** (conduction of electrons in semiconductors).

Solar Thermal



Solar panels made up of evacuated tubes or flat-plate collectors **heat up water stored in a tank**. The energy is used for hot-water supply and, occasionally, space heating.

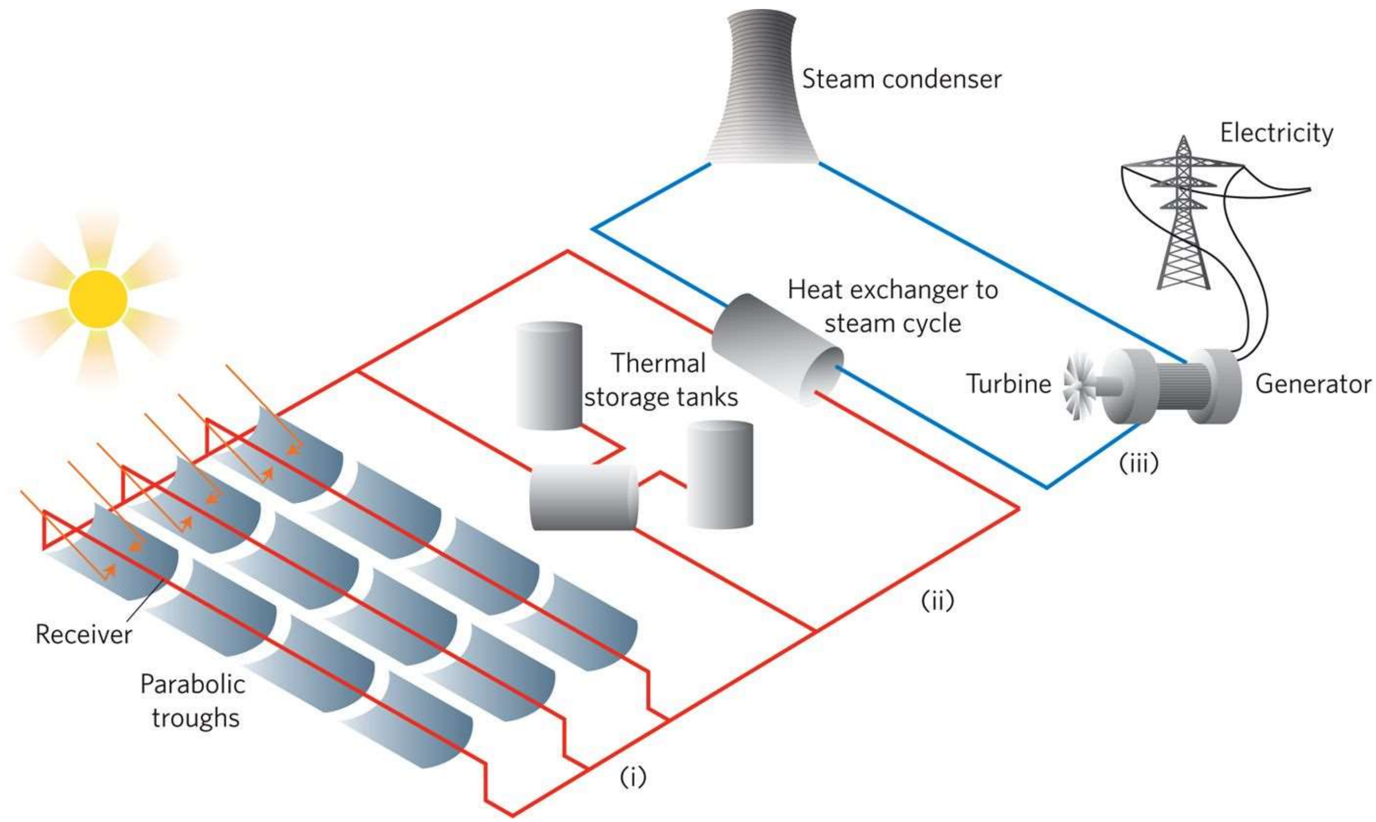
Solar fuels



Solar Fuels processes are being designed to transform the radiative energy of the sun into chemical energy carriers such as hydrogen or synthetic hydrocarbons fuels (*e.g.* electrolysis, thermolysis, photolysis).

Concentrating solar power

- Concentrating solar power (CSP) technologies use different mirror configurations to concentrate solar energy onto a receiver and convert it into heat. The heat can then be used to create steam to drive a turbine to produce electrical power or used as industrial process heat.



CSP plants consist of (i) a solar collector field, (ii) a heat transfer circuit that may include thermal storage and (iii) a conventional power block that converts the high temperature heat to electricity.

- Four main categories of CSP technologies coexist, distinguished by the way they focus the sun’s rays and the technology used to receive the sun’s energy.

THE 4 CSP TECHNOLOGIES

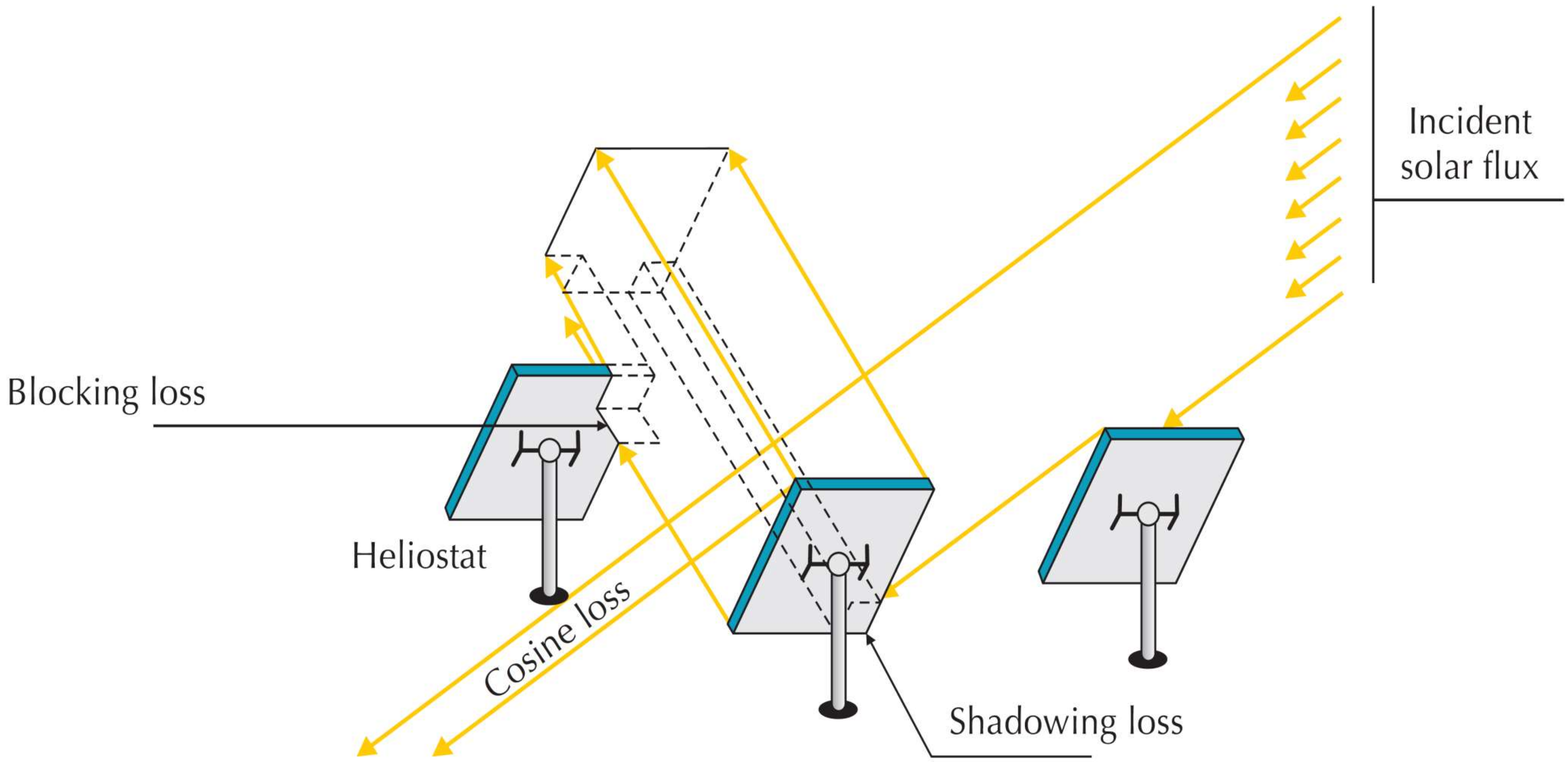
Receiver mobility	Line focus	Point focus
Fixed Receiver remains stationary and mechanically independent of the concentrating system, which is common for all the mirrors.	Linear Fresnel 	Solar Tower 
Tracking/aligned Receiver and concentrating system move together. Mobile receivers enable an optimal arrangement between concentrator and receiver, regardless of the position of the sun.	Parabolic Trough 	Parabolic Dish 

Increasing optical efficiency

Increasing optical efficiency

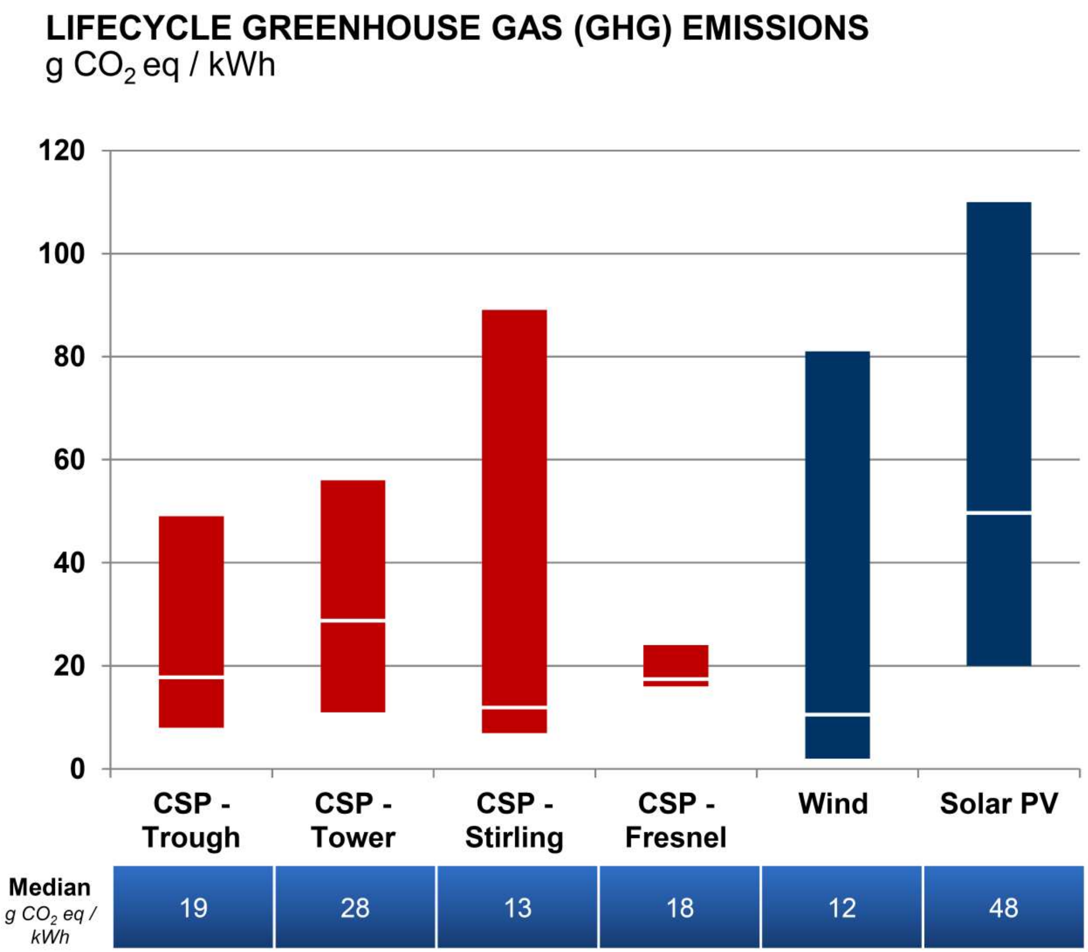
- The 392 MW *Ivanpah Solar Power Facility*, located in California's Mojave Desert, is the world's largest CSP project currently in operation. It deploys 173,500 heliostats, each with two mirrors, focusing solar energy on boilers located on three centralized solar power towers.

- Heliostats must be distanced from each other to minimize blocking and shading.



Environmental and social impacts

- Greenhouse gas emissions from CSP are low and, when thermal storage is included, are not exacerbated by emissions from back-up plants.



- CSP does not directly emit GHGs or other pollutants when producing electricity.
- CSP emits fewer GHGs over its lifecycle than Solar Photovoltaic (PV) and Wind. If thermal storage is included, CSP also has the advantage of not incurring emissions from the back-up plants that would otherwise be needed to balance intermittency.
- The manufacturing and disposal processes associated with CSP generate pollutants. CSP makes much more intense use of materials than other technologies. However, the main materials used are commonplace commodities such as steel, glass and concrete, for which recycling rates are high.
- Few toxic substances are used in CSP plants. The synthetic organic heat transfer fluids used in parabolic troughs present the greatest risks. They can catch fire and contaminate soils. One goal of research is to replace toxic heat transfer fluids with water or molten salts.
- Finally, CSP's land requirement averages 50 MW per km², which is intermediate between solar PV and Wind. Visual impact should be limited if CSP plants are to be built in arid, uninhabited areas.

The good and bad of CSP

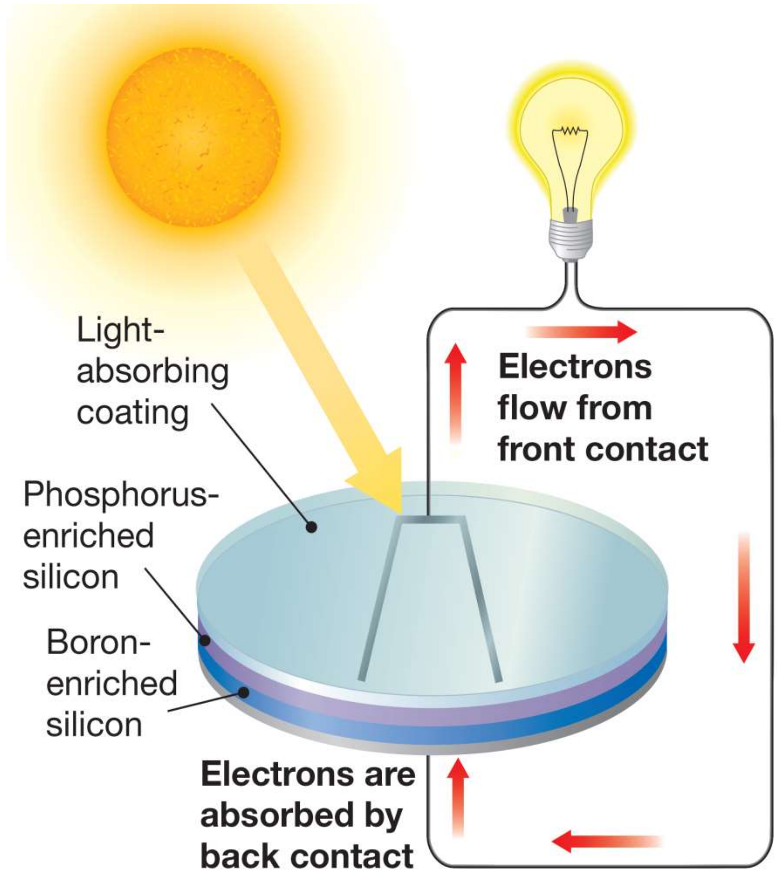
Trade-Offs

Solar Energy for High-Temperature Heat and Electricity

Advantages	Disadvantages
Moderate environmental impact	Low efficiency
No CO_2 emissions	Low net energy
Fast construction (1–2 years)	High costs
Costs reduced with natural gas turbine backup	Environmental costs not included in market price
	Needs backup or storage system
	Needs access to sun most of the time
	May disturb desert areas

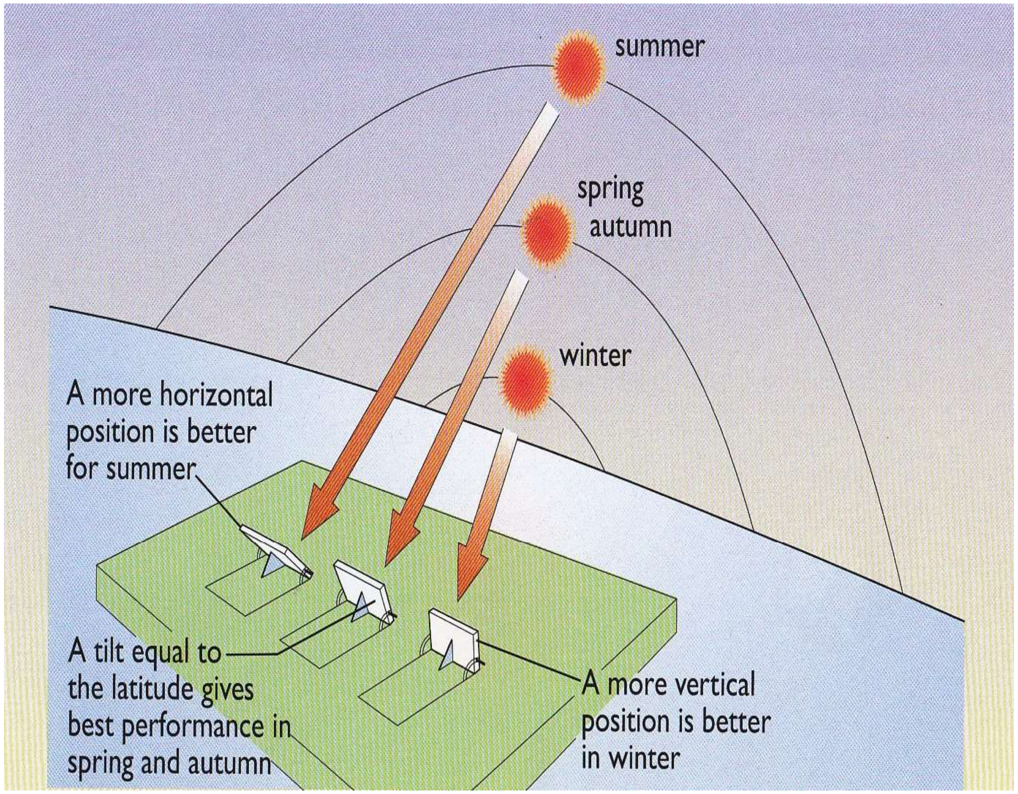
Solar photovoltaic

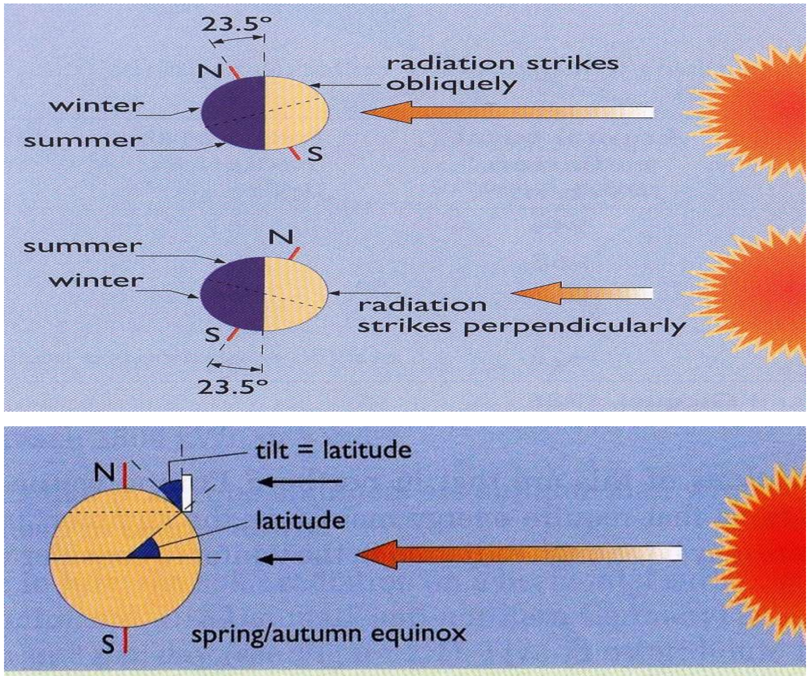
- Photovoltaic (PV) cells, also called solar cells, generate electricity by exploiting the photovoltaic effect.



In a **solar cell**, sunlight falls on a semiconductor, causing it to release electrons. The electrons flow through a circuit that is completed when another semiconductor in the solar cell absorbs electrons and passes them on to the first semiconductor.

- To collect as much radiation as possible, a PV module should face the equator and must be tilted toward the sun. During summer (when the amount and intensity of solar radiation is more), the tilt angle should be less than the latitude to maximize solar collection. For maximum solar collection in winter (when more solar radiation may be needed), the tilt angle should be greater than the latitude angle.





A surface tilted at the latitude angle will be perpendicular to the Sun's rays at mid-day on the spring or autumn equinox

Solar PV applications

- PV has four end-use sectors with varying costs and performance requirements.

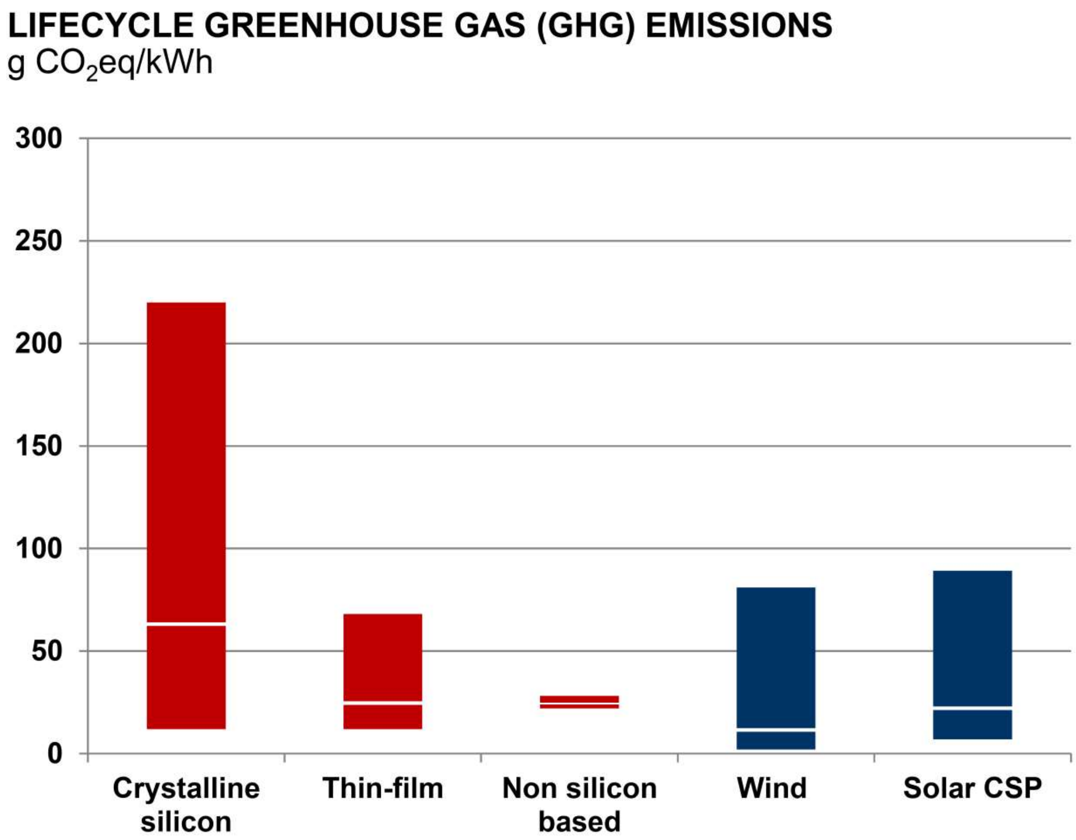
GRID CONNECTED

Residential	Commercial / industrial	Utility	Off-grid
Up to 20 kW	Up to 1 MW	1 MW upwards	Varying sizes
			
▪ Individual buildings / houses	▪ Commercial office buildings, schools, hospitals and retail	▪ Starting at 1 MW ▪ Mounted on buildings or directly on the ground	▪ Telecommunication units, remote communities and rural electricity supply

- The *Topaz Solar Farm* in San Luis Obispo County, California is the world's largest photovoltaic (PV) power plant. This facility has the capacity to generate 550 MW of solar electricity, which is enough to power 160,000 homes and displace 377,000 tons of CO_2 every year.

Environmental and social impacts

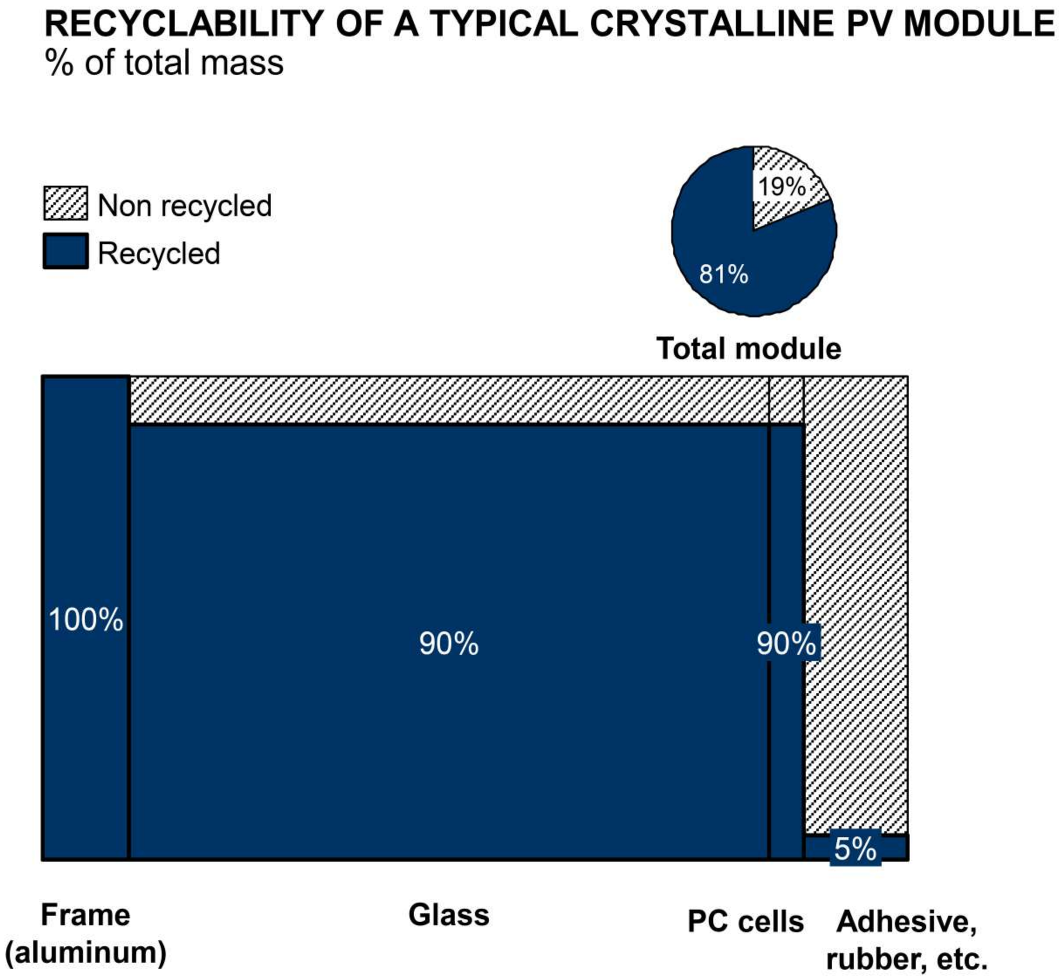
- Greenhouse gas (GHG) emissions from solar PV are low, but the technology's overall environmental impact depends on power-system integration.



Median g CO_2 eq / kWh	65	24	24	12	22

- Solar photovoltaic (PV) does not directly emit GHGs or other pollutants. However, median solar PV emissions range between 24 and 65 g CO_2 equivalent per kWh over the entire lifecycle, depending upon the material used for the cells. This range is close to concentrating solar power and wind, and significantly lower than natural gas and coal-fired power plants that range from 500 to 1,000 gCO_2eq/kWh, respectively, for conventional combustion turbines in the US.
- Lifecycle emissions depend on control and recycling measures during the manufacturing process, as well as installation, Operation & Maintenance, and disposal procedures.
- Crystalline silicon production is electricity intensive, so lifecycle emissions depend on the carbon content of the electricity used.
- Replacing fossil-fuel power capacity with solar PV may result in an increase in the use of flexible back-up plants. This could lead to a rise in GHG emissions, although the impact would be highly system specific. In general, however, greater use of solar PV should reduce significantly pollutants and GHG emissions.

Recycling is crucial in ensuring the PV industry is sustainable.



- Production of crystalline silicon modules generates a large amount of electronic waste, as in the semi-conductor industry.
- Recycling and disposal processes are therefore essential and will be even more crucial for thin films because of the use of rare metals.
- Recycling is already a core part of the PV industry as:
  - It is economically viable for large-scale applications. It is predicted that 80%-96% of glass, ethylene vinyl acetate and metals will be recycled;
  - Modules are being designed to aid recycling;
  - Solar PV manufacturers are increasingly being held responsible for the lifecycle impact of their products.

The good and bad of solar PV

Trade-Offs

Solar Cells

Advantages

- Fairly high net energy yield
- Work on cloudy days
- Quick installation
- Easily expanded or moved
- No CO_2 emissions
- Low environmental impact
- Last 20–40 years
- Low land use (if on roof or built into walls or windows)
- Reduces dependence on fossil fuels

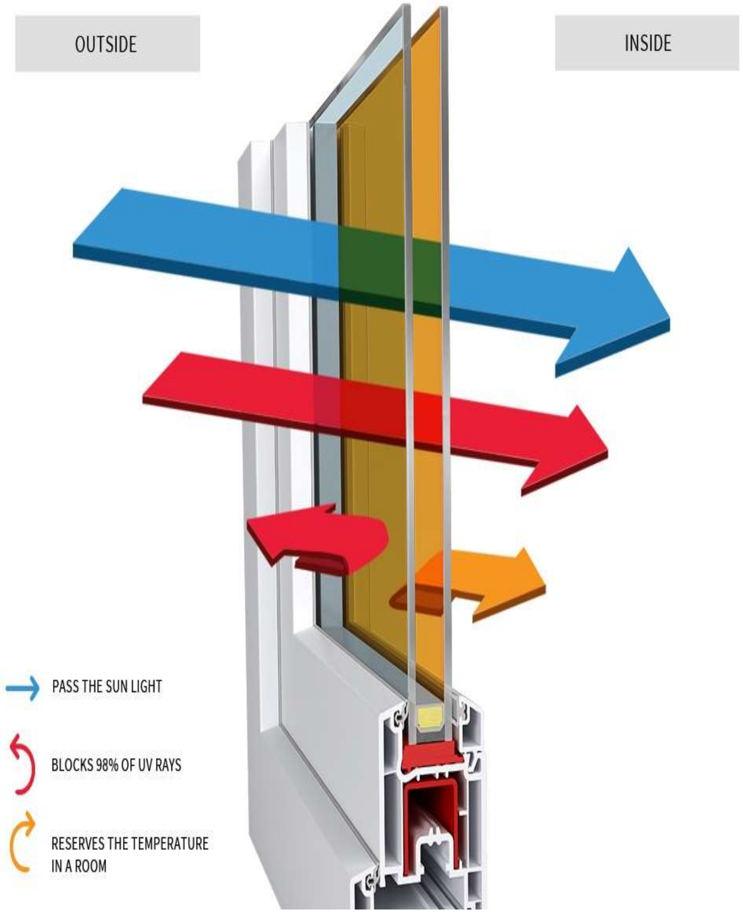
Disadvantages

- Need access to sun
- Low efficiency
- Need electricity storage system or backup
- Environmental costs not included in market price
- High costs (but should be competitive in 5–15 years)
- High land use (solar-cell power plants) could disrupt desert areas
- DC current must be converted to AC

Solar thermal energy

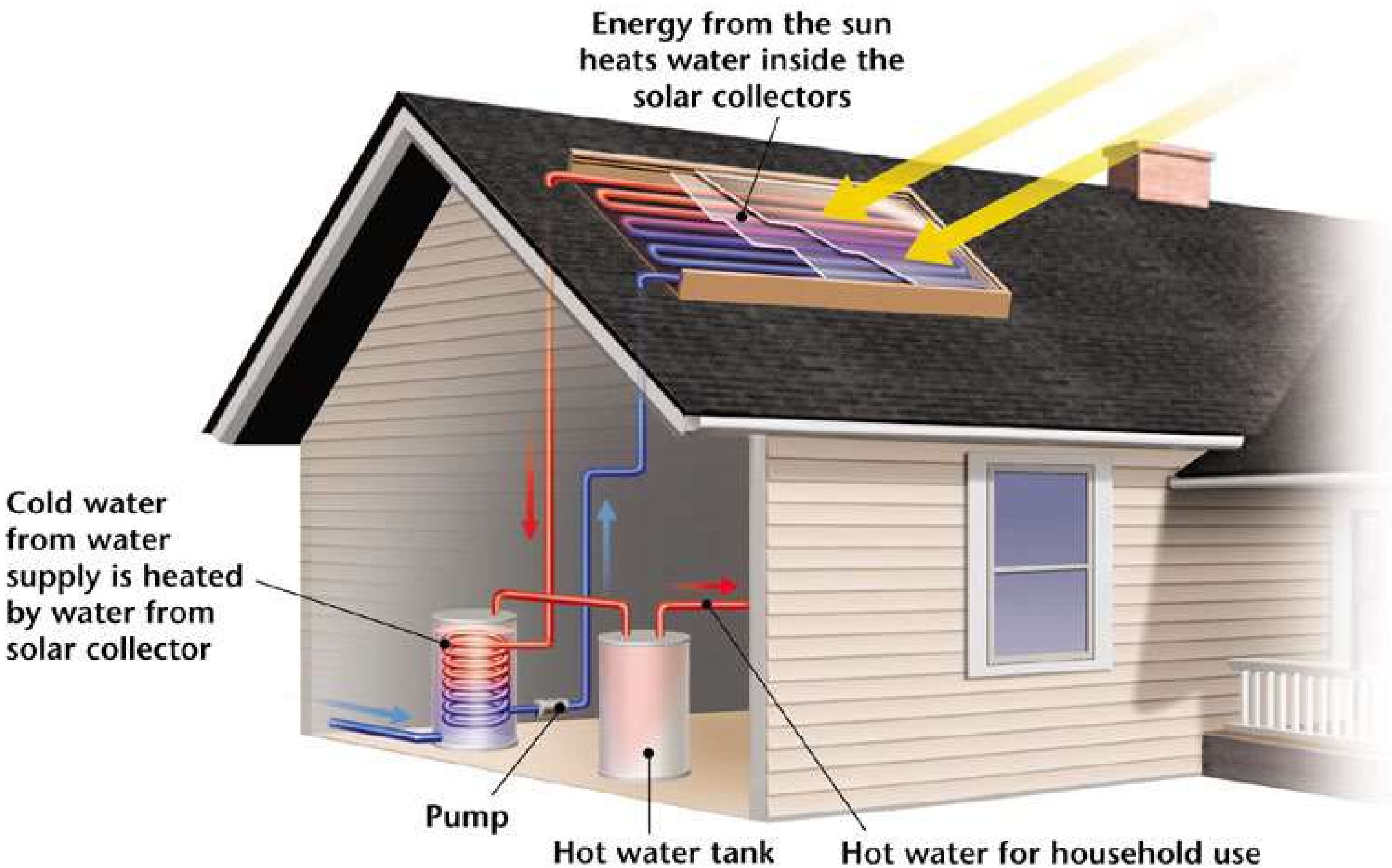
- Solar thermal energy is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in the residential and commercial sectors.

- Solar thermal collection methods are many and varied, but depend mostly on the principle of glazing, in particular its ability to transmit visible light but block infrared radiation. These include:
  - Active solar heating/cooling
  - Passive solar heating
  - Solar daylighting



Active solar heating

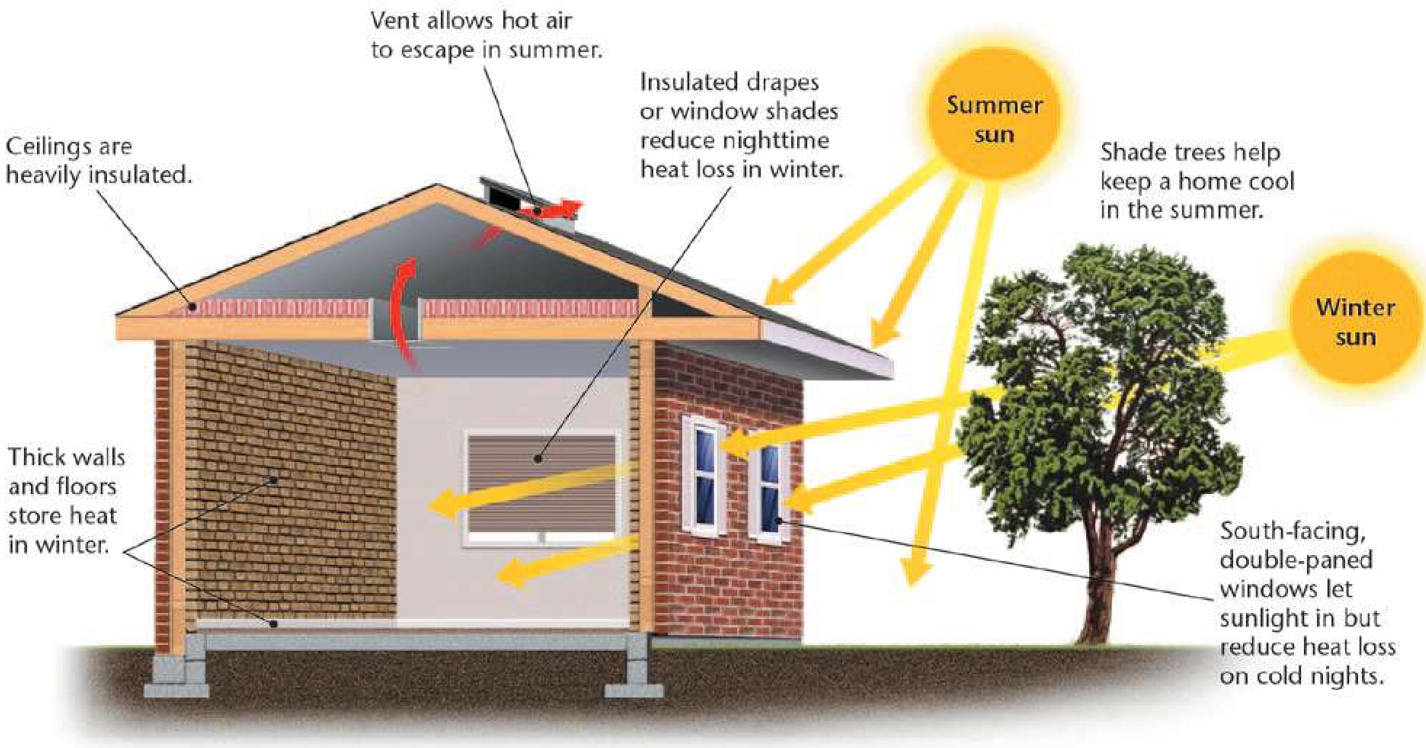
- In active solar heating systems, energy from the sun is gathered by collectors and used to heat water or to heat a building.



In an **active solar water heating system**, a liquid is pumped through solar collectors. The heated liquid flows through a heat exchanger that transfers the energy to water, which is used in a household.

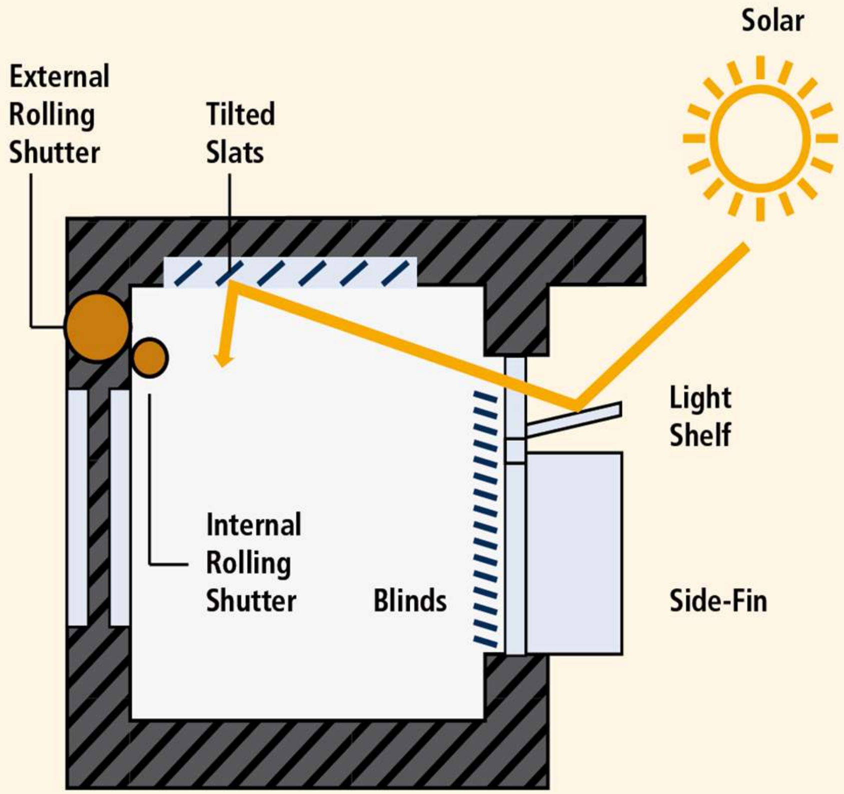
Passive solar heating

- Passive solar energy technologies absorb solar energy, store and distribute it in a natural manner (e.g., natural ventilation), without using mechanical devices (such as fans, blowers, or pumps).



A **passive solar house** is designed to reduce heating and cooling expenses and is oriented according to the yearly movement of the sun. In summer, the sun's path is high in the sky and the overhang of the roof shades the building and keeps it cool. In winter, the sun's path is lower in the sky, so sunlight shines into the house and warms it.

Solar daylighting



Schematic of several daylighting concepts designed to redistribute daylight into the office interior space.

- **Daylighting** is a combination of energy conservation and passive solar design.
- It aims to make the most of the natural daylight that is available.
- Traditional techniques include: shallow-plan design, allowing daylight to penetrate all rooms and corridors; light wells in the centre of buildings; roof lights; tall windows, which allow light to penetrate deep inside rooms; task lighting directly over the workplace, rather than lighting the whole building interior; and deep windows that reveal and light room surfaces to cut the risk of glare.

- In the solar settlement at Freiburg, Germany, the future of solar building and living in harmony with nature is already a reality. All roofs are covered with standard large area PV modules which are smartly integrated in a plane above the south facing roofs of the different buildings. It is the first housing community in the world in which all the homes produce a positive energy balance due to their passive solar design integrated with active solar heating and cooling.

The good and bad of solar thermal energy

Trade-Offs

Passive or Active Solar Heating

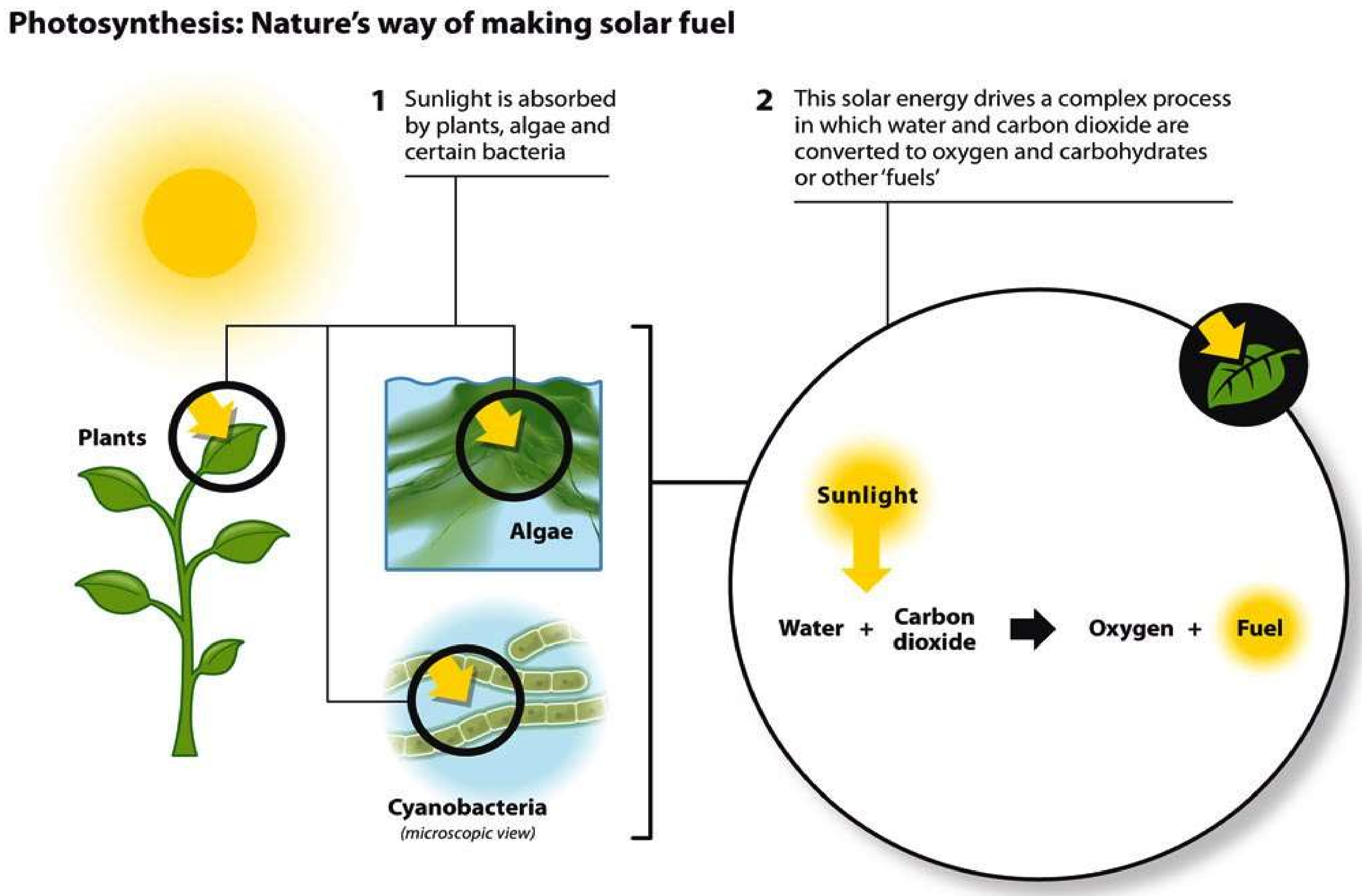
Advantages	Disadvantages
Energy is free	Need access to sun 60% of time
Net energy is moderate (active) to high (passive)	Sun can be blocked by trees and other structures
Quick installation	Environmental costs not included in market price
No CO_2 emissions	Need heat storage system
Very low air and water pollution	High cost (active)
Very low land disturbance (built into roof or windows)	Active system needs maintenance and repair
Moderate cost (passive)	Active collectors unattractive

Solar fuels

- Solar fuel technologies convert solar energy into chemical fuels, which can be a desirable method of storing and transporting solar energy.
- They can be used in a much wider variety of higher-efficiency applications than just electricity generation cycles.
- Solar fuels can be processed into liquid transportation fuels or used directly to generate electricity in fuel cells; they can be employed as fuels for high-efficiency gas-turbine cycles or internal combustion engines; and they can serve for upgrading fossil fuels, or for producing industrial or domestic heat.
- There are three basic routes, alone or in combination, for producing storable and transportable fuels from solar energy: (i) photochemical/photobiological; (ii) artificial photosynthesis; and (iii) thermochemical approaches.

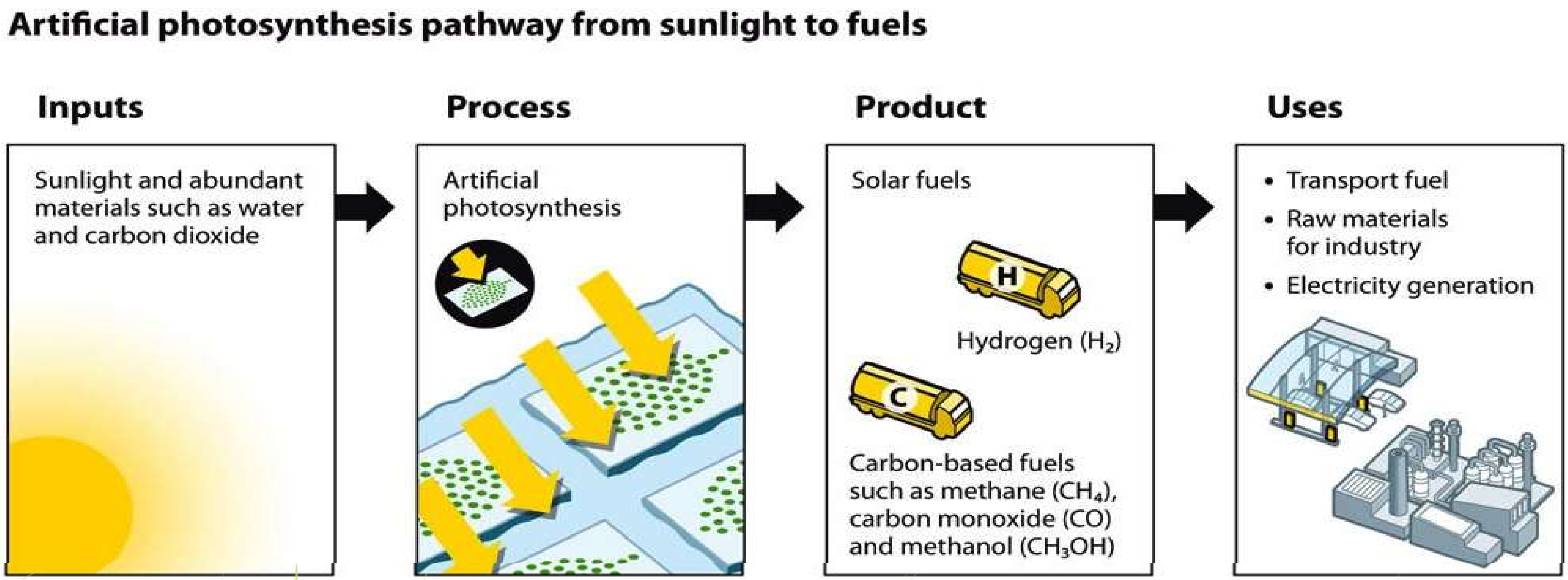
Photochemical/Photobiological method

- Photochemical/photobiological routes make direct use of solar photon energy for converting CO_2 into synthetic liquid fuel (natural photosynthesis).

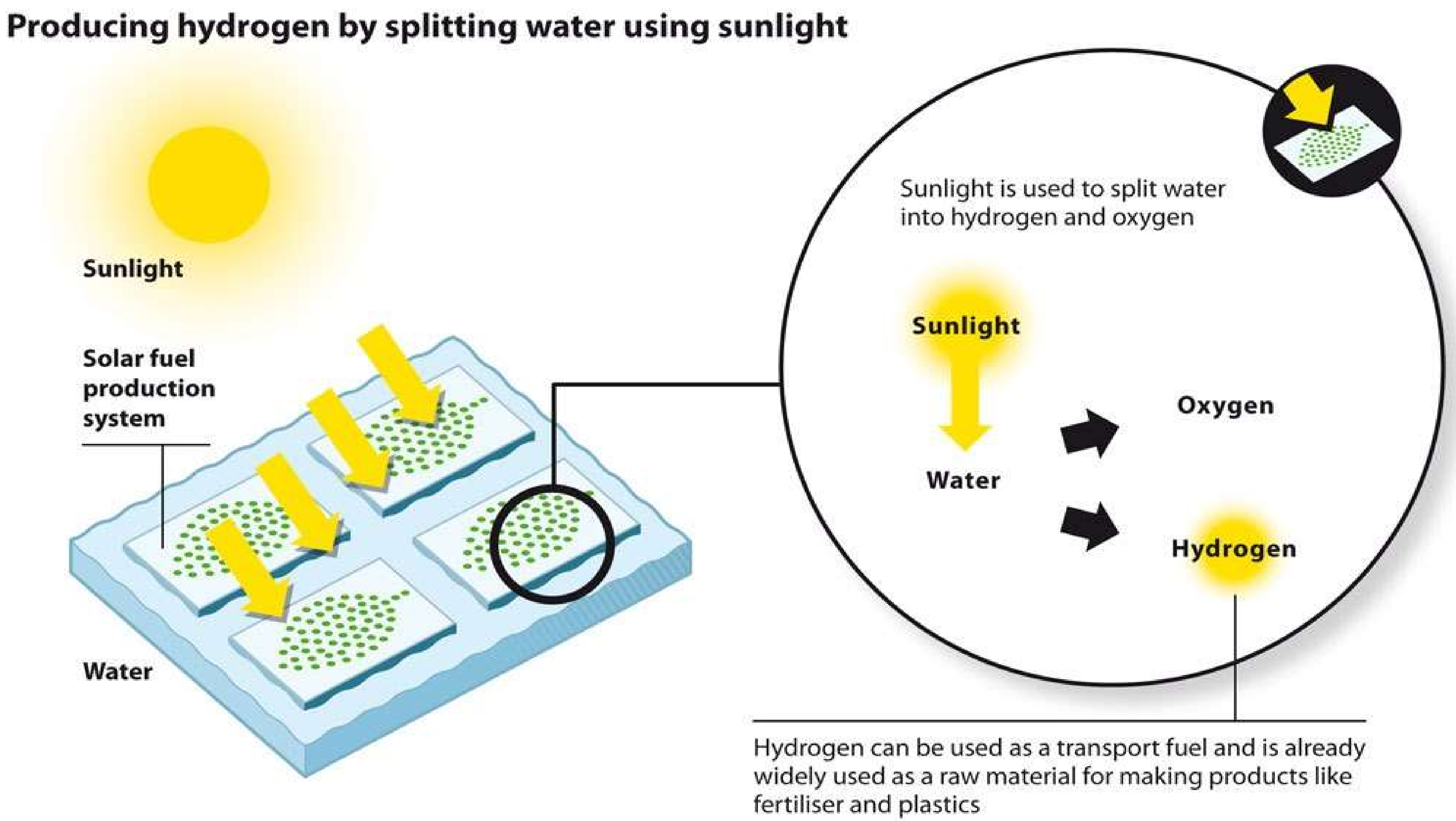


Artificial photosynthesis

- Artificial photosynthesis (also called artificial leaves) mimics the natural process of photosynthesis to convert raw materials like water and CO_2 into clean fuels and value-added chemicals (e.g., H_2, CO and hydrocarbons).

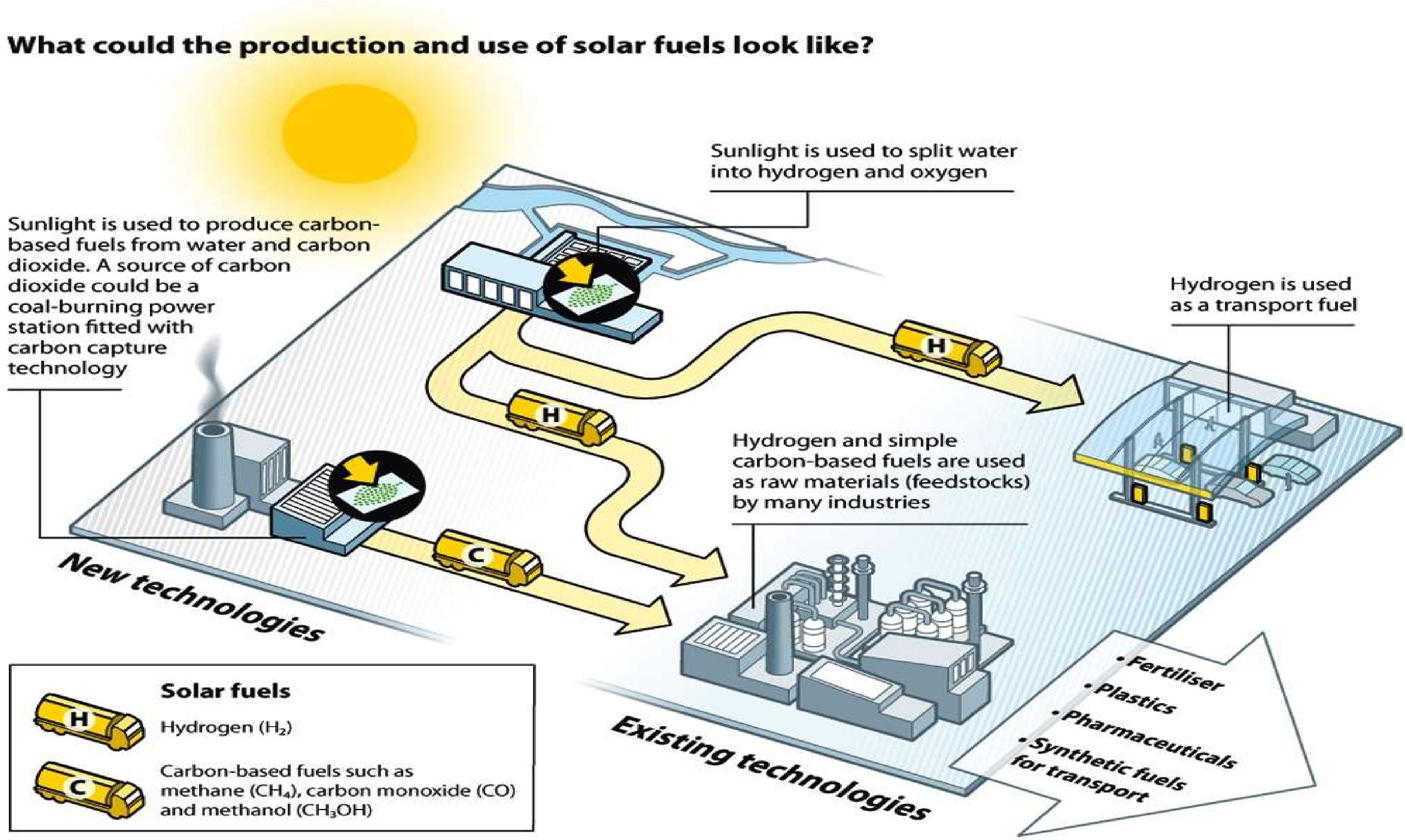


- Photocatalytic water splitting converts water into hydrogen ions and oxygen, and is an active research area in artificial photosynthesis.



Applications of solar fuels

- Solar fuels can not only be used for transport and electricity generation but also as feedstock in (the chemical) industry.

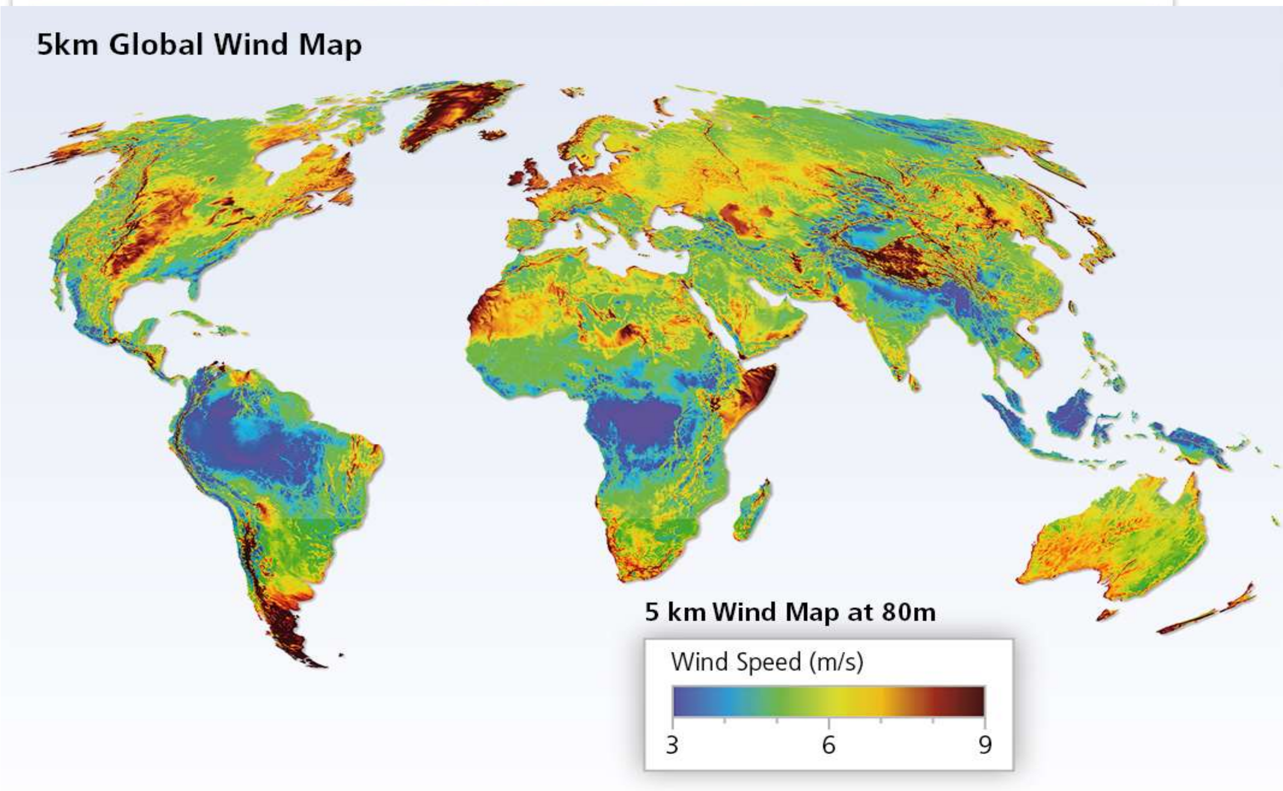


Wind Energy

Wind energy

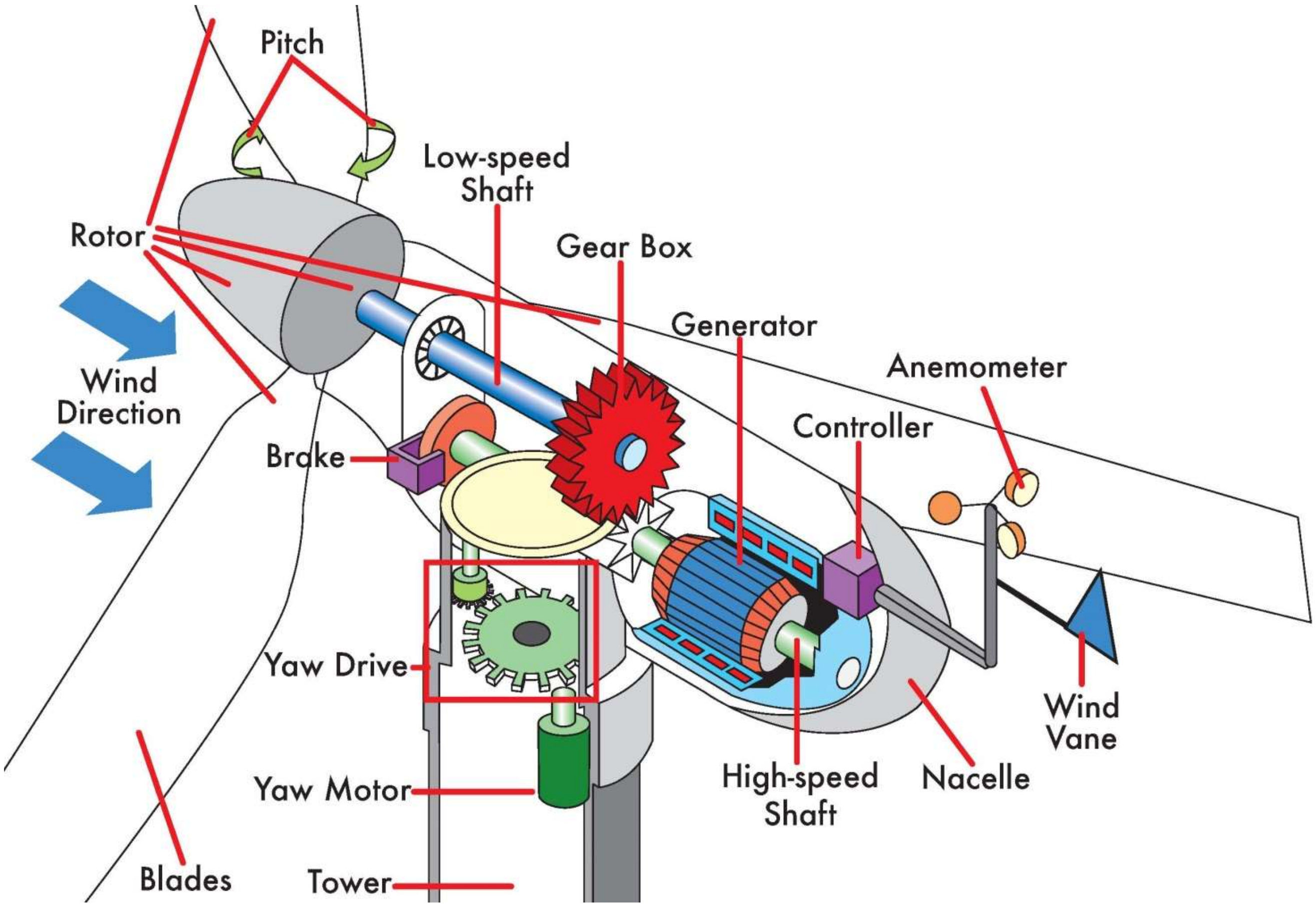
- The global technical potential for wind energy exceeds current global electricity production. Where on Earth doesn't the wind blow!

GLOBAL WIND RESOURCE MAP
2009, 5 km x 5 km resolution

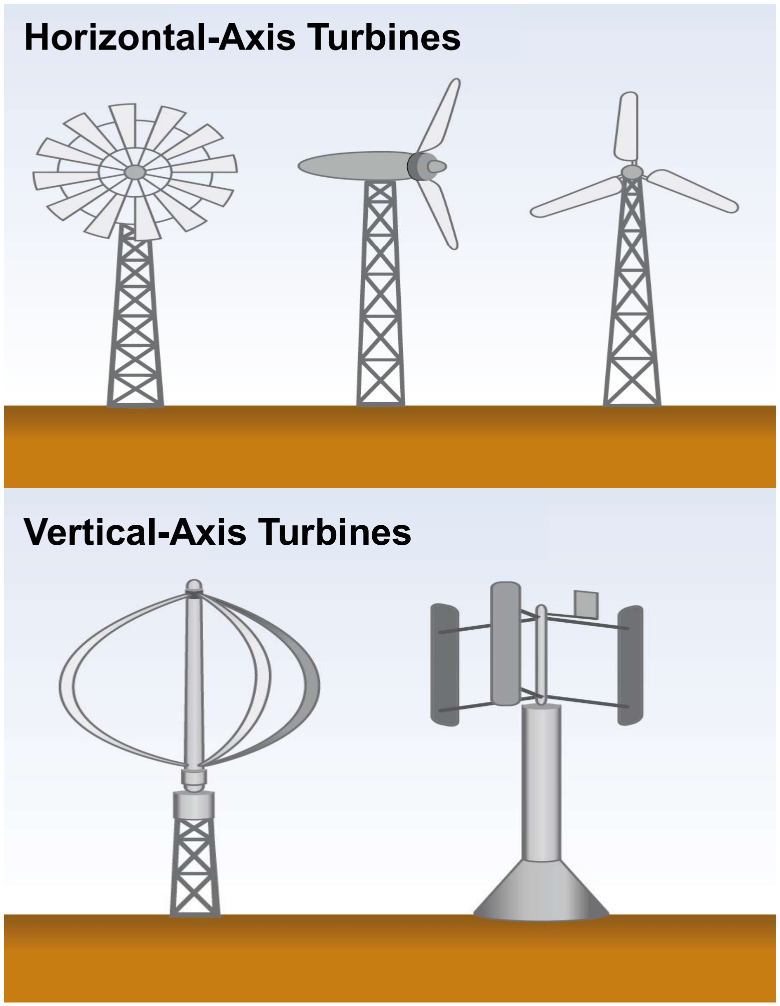


- **The technical potential of wind exceeds current global electricity production.** Estimates range from 70-450 EJ/year, while the global electricity production is of 60 EJ/year.
- **Wind is location and weather dependent.** Though wind speeds vary considerably by location, ample technical potential exists in most regions to enable significant wind energy deployment.

- Wind turbines use rotor blades and an electricity generator to convert kinetic energy of moving air into electrical energy. A typical wind turbine is composed of three blades attached to a hub, containing a gearbox, generator and control system.



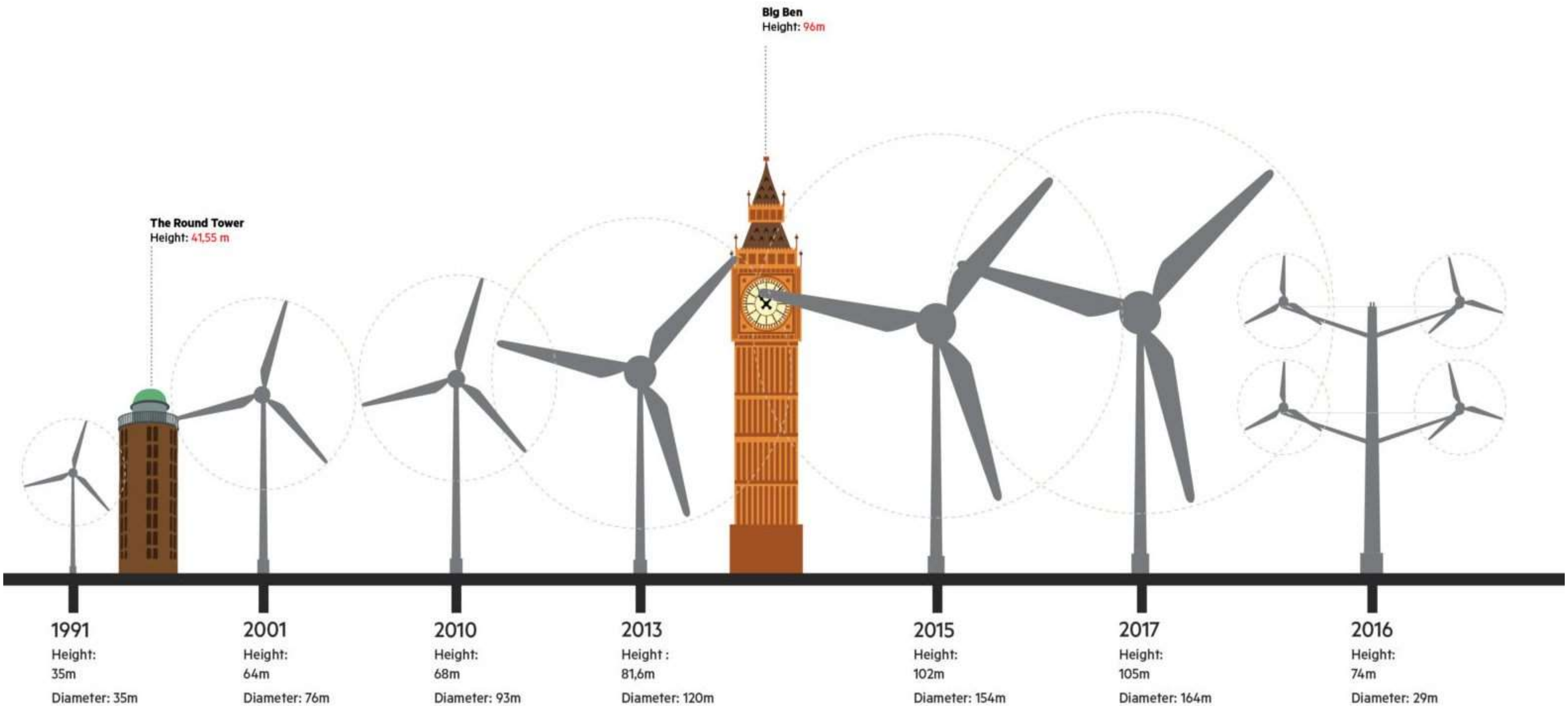
- Several designs have been investigated and have converged to horizontal three-bladed upwind rotors with variable speed operation.



- **Several design options have been investigated**:
  - Horizontal *vs* vertical axis;
  - Upwind *vs* downwind;
  - Three blades *vs* two-blades;
  - Stall regulation *vs* pitch regulation;
  - Fixed *vs* variable speed machines.

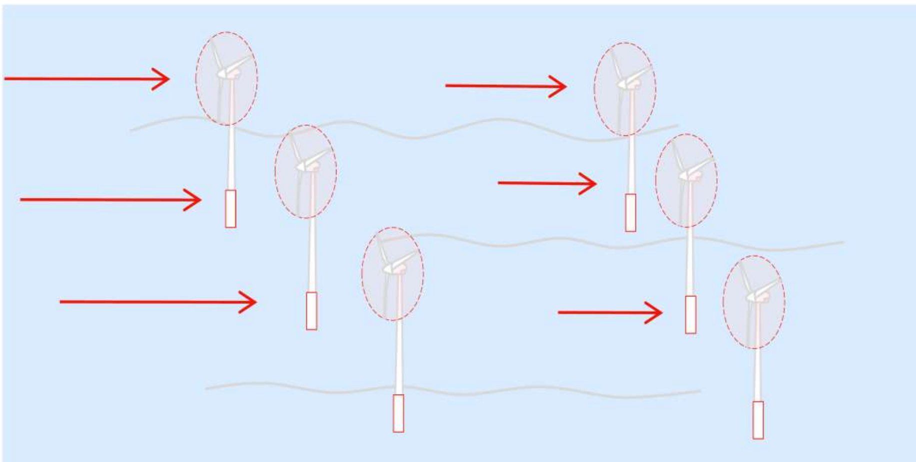
- **A dominant design has emerged for large wind turbines:**
  - Horizontal axis;
  - Upwind;
  - Three evenly spaced blades;
  - Pitch regulation (pitching the blade);
  - Variable speed.

- Since wind turbines can be as tall as 40-stories and have very long blades, they can tap into the stronger, more reliable, and less turbulent winds found at higher altitudes!



Onshore and offshore wind energy

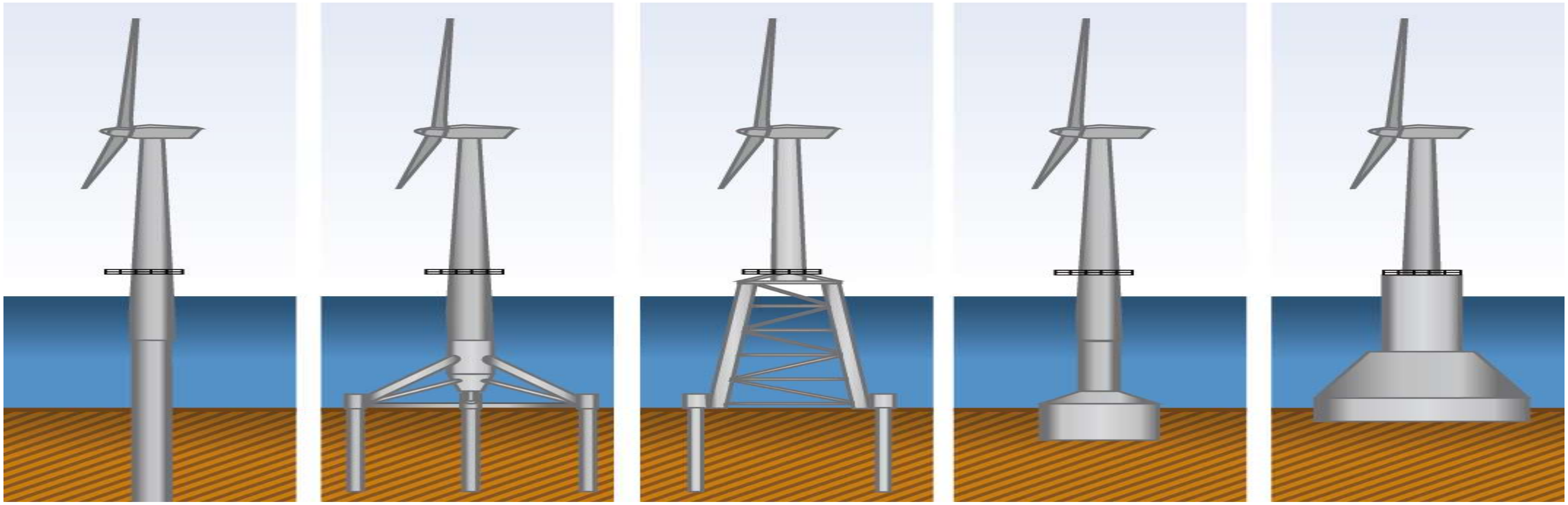
- Offshore wind is different from onshore wind.



- Wind conditions onshore and offshore differ essentially. While the landscape, trees and buildings distort the flow of onshore wind, offshore wind flow can develop without obstacles with higher wind speeds and a more even flow close to the surface which also allows lower tower heights.

- In order to use wind at its best, offshore wind farms are laid out in a specific way:
  - The wind farm layout depends on the main wind direction and the conditions of the seabed
  - To avoid turbulence from other wind turbines, wind farms are designed with a minimum distance between individual turbines of 5-8 times rotor diameter in main wind direction

- Apart from the wind conditions, the natural site conditions for offshore projects differ significantly, which requires different foundation types to cope with varying sea bed conditions, water depth, accessibility and ice formation.



- Water depth and consistency of the seabed determine the choice of foundation. So far, there is no universal foundation type suitable for all kinds of seabed conditions.

- With a share of 75% in 2011, monopile foundations were the most commonly used foundation type, followed by gravity foundations with a share of 21%.

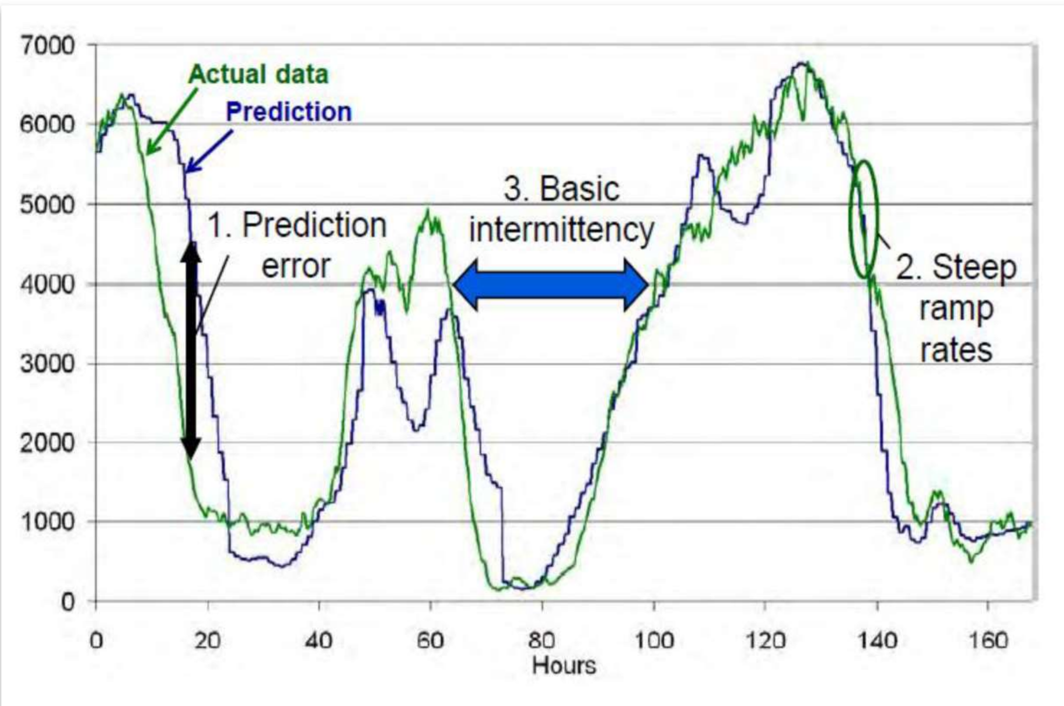
- The *Gansu Wind Farm* in China is the largest wind farm in the world. It has a capacity of over 6,000 MW of power as of 2012, with a goal of 20,000 MW by 2025.

- The *London Array* is the biggest offshore wind farm in the world. Located in the outer Thames Estuary of the United Kingdom (UK), the London Array consists of 175 Siemens 3.6 MW offshore wind turbines. Phase 1, now complete, is generating 630 MW of power for the UK. Phase 2 construction is currently underway for extra 240 MW of power with a total 275 turbines – enough to power 750,000 castles.

Grid integration

- Wind is weather-dependent and therefore variable, imperfectly predictable and subject to strong ramping effects.

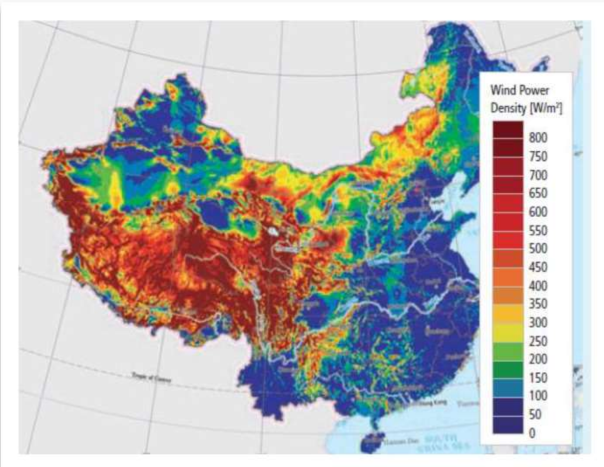
WIND INTERMITTENCY ILLUSTRATION
MW – Germany 2007



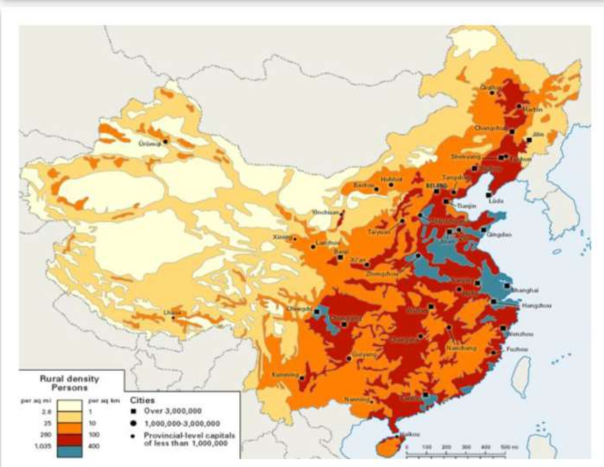
- Wind output is imperfectly predictable:
  - Lower level of predictability than fossil-fired power plants;
  - Forecast less accurate over longer time horizon (multiple hours to days).
- Wind output is subject to ramp events:
  - The output of a wind turbine can vary from zero to its rated capacity, sometimes changing very rapidly;
  - In particular, wind turbines can ramp down in case of high wind speeds.
- Wind output is variable and imperfectly controllable over several timescales:
  - Wind output depends on weather;
  - Variations can occur on multiple time scales, from sub-hourly to inter-annual.
- Intermittency is a crucial challenge for grid stability and to match demand & supply.

- The quality of wind resources is location specific, with the best locations often found far from the load centre.

WIND RESOURCES & POPULATION MISALIGNMENT
Illustration for China



Wind resources
W / km²



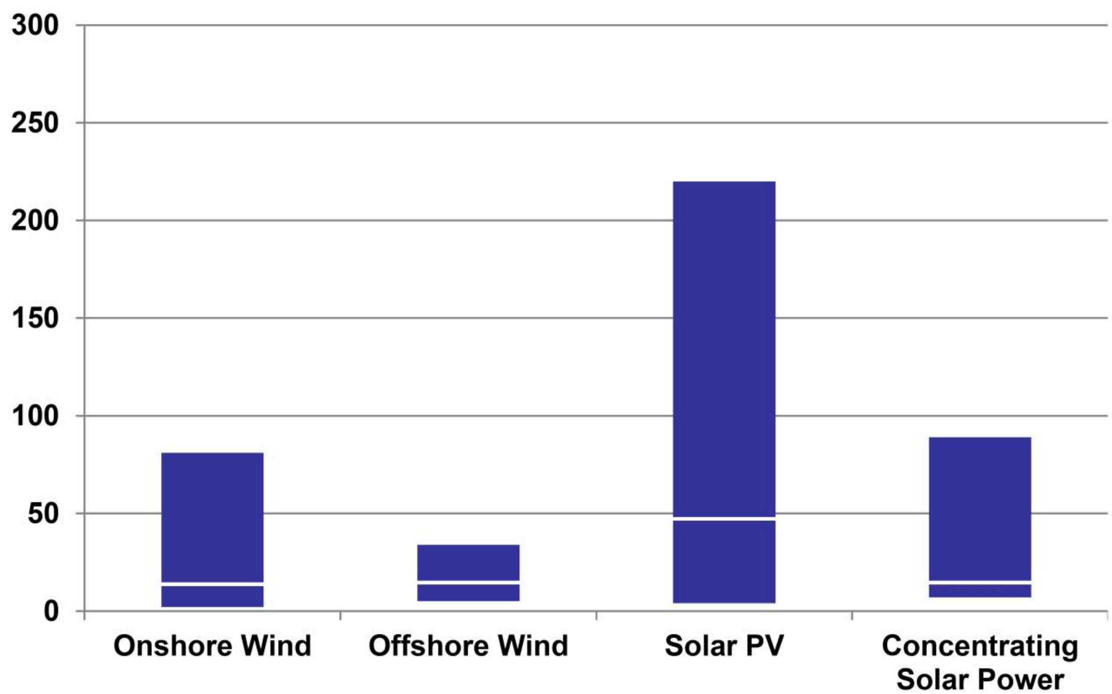
Population density
people / km²

- Wind resource locations tend to be misaligned with large demand centers, requiring the construction of new long-distance transmission lines.
- Due to the impact of wind quality on economics, additional transmission infrastructure is sometimes economically justified.
- However additional long-distance transmission lines face multiple challenges:
  - Technical challenges due to thermal, voltage and transient constraints on long lines;
  - Timescale challenges due to a longer development time than wind generation (8 to 15 years *vs* ~3 years respectively);
  - Economic challenges, as transmission and distribution (T&D) costs are supported by end-consumers and already account for a large proportion electricity prices.

Environmental and social impacts

- GHG emissions from wind are among the lowest of any renewable-energy technology, but its overall impact depends on power system integration.

LIFECYCLE GREENHOUSE GAS EMISSIONS
g CO_2 eq / kWh



Median g CO2 eq / kWh	12	13	48	13

- Wind does not directly emit GHGs or other pollutants.
- On average, wind emits 12g CO_2 equivalent per kWh over its full lifecycle:
  - ~ 22 for concentrating solar power;
  - ~ 48 for solar PV;
  - ~ 500 for natural gas power plants;
  - ~ 1000 for coal power plants.
- If wind displaces fossil-fuel power plants, it may result in greater use of flexible peak & intermediate plants emitting more GHGs.
- Impact is thus highly system specific, but nonetheless clear that it reduces air pollutants & GHG emissions.

- Wind incurs few social challenges except aesthetic and noise impacts.

MAIN SOCIAL IMPACTS OF WIND AND MEANS OF MITIGATING THEM

- Principal social issues for wind power are its aesthetic and noise impacts:
  - *Visual*: Not In My Backyard syndrome (NIMBY) raises major social acceptance challenge and may have negative impact in touristic areas;
  - *Noise*: generally restricted to 35 to 45 decibels at 300 meters and not of concern to humans after 800 meters.

- Wind projects may also have minor detrimental impacts on wildlife and land use:
  - *Wildlife*: wind may result in habitat destruction and involve collisions with bats and birds (even if wind is thought to represent only 0.003% of anthropogenic bird death);
  - *Marine ecosystems*: wind farms may disturb mammals, notably due to the noise during construction. The long-term impact is yet under debate, as it could also attract new species thanks to artificial reefs where marine species can thrive;
  - *Wealth:* Property value & recreational impact.

- Technology advances and siting wind farms offshore should largely avoid these impacts:
  - *Technology advances*: wind turbine manufacturers have worked on designs and aerodynamics that limit noise and the impact on wildlife;
  - *Offshore:* wind farms are being located further and further from shores, which should negate many of the public concerns relating to the visual and noise impact of turbines on coastal areas.

- Public acceptance: the more, the easier. Social impact studies indicate that public concern about wind energy is greatest directly after the announcement of a wind farm, while acceptance increases after construction, when the actual impacts can be assessed. People living closest to existing wind plants tend to be more accepting than those who live further away and are less familiar with the technology.

The good and bad of wind energy

Trade-Offs

Wind Power

Advantages

- Moderate to high net energy yield
- High efficiency
- Moderate capital cost
- Low electricity cost (and falling)
- Very low environmental impact
- No CO_2 emissions
- Quick construction
- Easily expanded
- Can be located at sea
- Land below turbines can be used to grow crops or graze livestock

Disadvantages

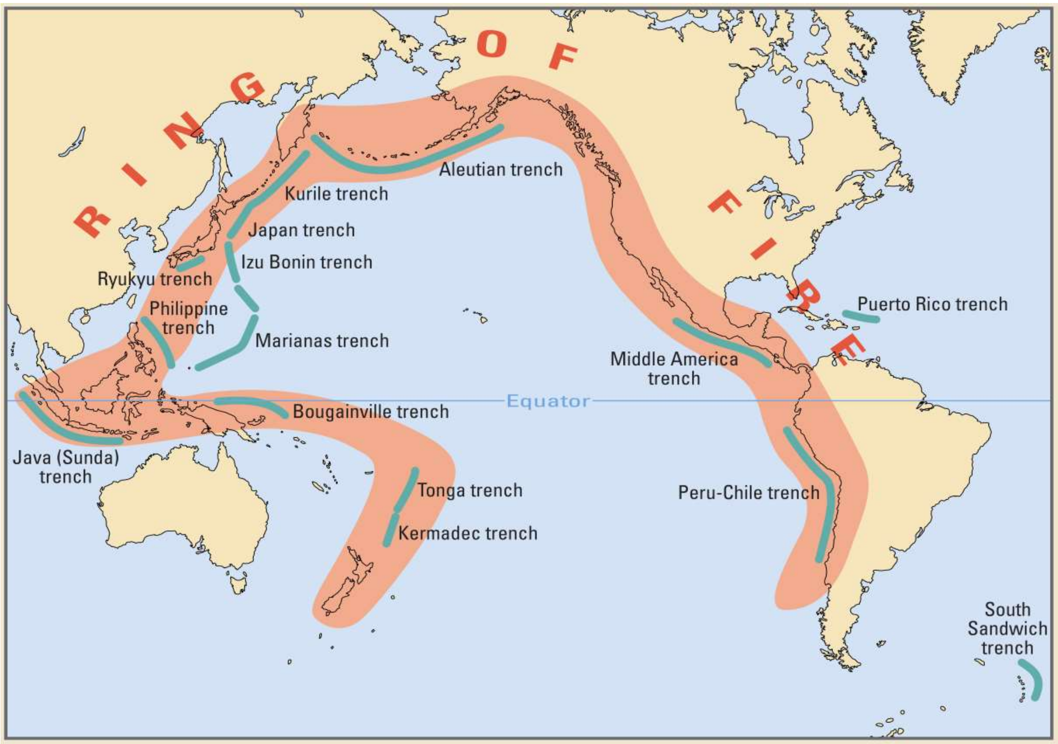
- Steady winds needed
- Backup systems needed when winds are low
- Plastic components produced from oil
- Environmental costs not included in market price
- High land use for wind farm
- Visual pollution
- Noise when located near populated areas
- Can kill birds and interfere with flights of migratory birds if not sited properly

Geothermal Energy

Geothermal energy

- Geothermal energy refers to the thermal energy from the Earth's interior stored in both rock and trapped steam or liquid water.

RING OF GEOTHERMAL ENERGY

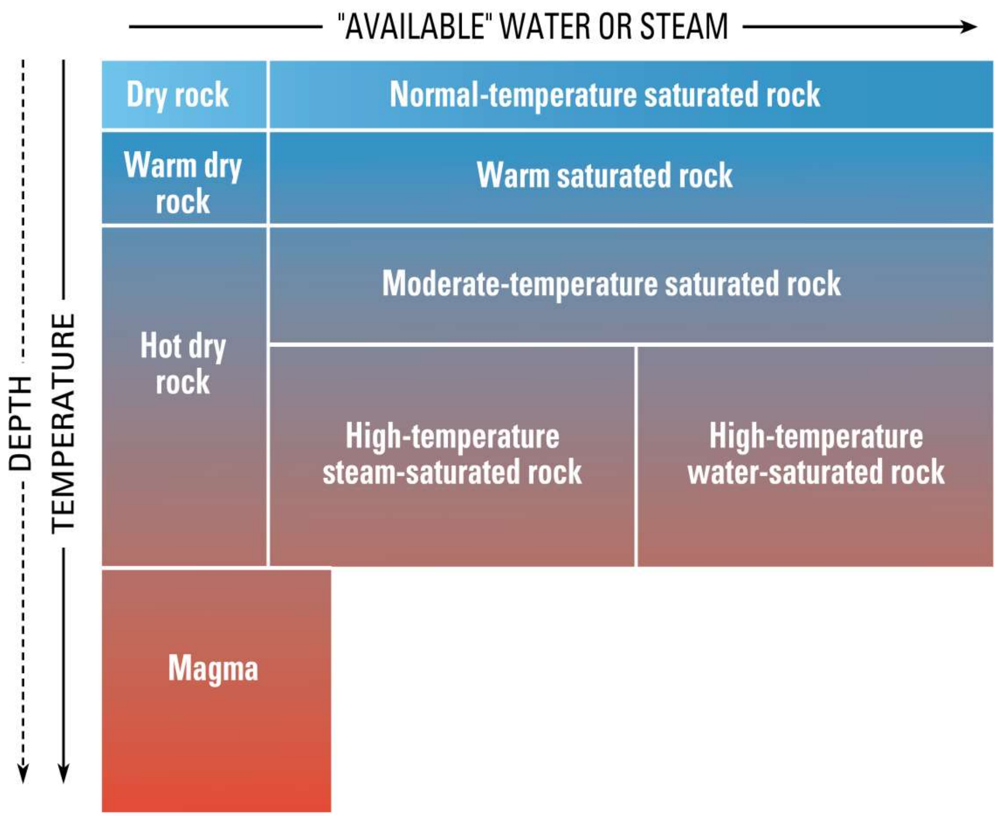


The volcanically active and earthquake-prone region rimming the Pacific Ocean is known as the "Ring of Fire." This region could also be called the Ring of Geothermal Energy, because it contains many high-temperature geothermal systems associated with active volcanoes.

- The main sources of this energy are due to the heat flow from the Earth's core and mantle, and that generated by the continuous decay of radioactive isotopes in the crust itself.
- Heat is transferred from the interior towards the surface, mostly by conduction, at an average of 65 mW/m^2 on continents and 101 mW/m^2 through the ocean floor.
- Geothermal energy is classified as a renewable resource because any projected heat extraction is small compared to the Earth's heat content.

- The total thermal energy contained in the Earth is of the order of 12.6×10^{12} EJ and that of the crust of the order of 5.4×10^{9} EJ to depths of up to 50 km.

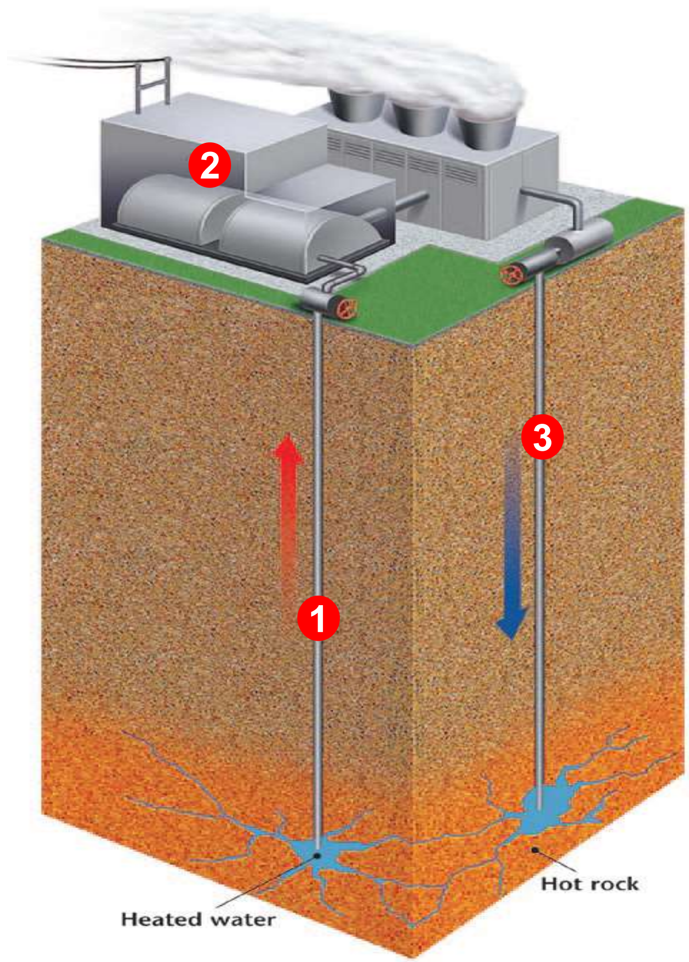
DIFFERENT TYPES OF GEOTHERMAL ENVIRONMENT IN THE EARTH'S UPPER CRUST



- Thermal energy is contained in a broad range of geothermal environments, and these are commonly **classified by temperature and amount of fluid** – water and (or) steam – available for carrying the energy to the Earth's surface.
- **High- and moderate-temperature rocks with considerable available water and (or) steam** are the only geothermal environments that can currently be developed to generate electricity.

Geothermal power plants

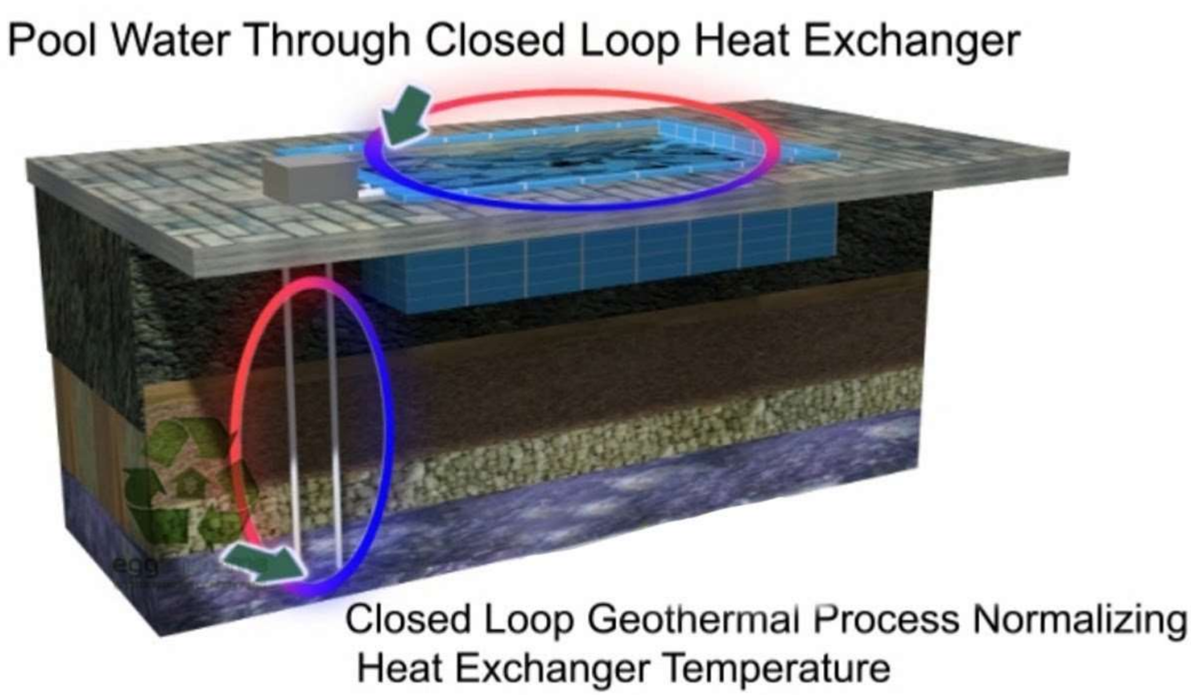
- Geothermal power plants generate electricity using the following steps: (1) steam rises through a well; (2) steam drives turbines, which generate electricity; (3) leftover liquid water is pumped back into the hot rock.



- The *Geysers Geothermal Complex* located about 121 km north of San Francisco, California, is comprised of 18 power plants making it the biggest geothermal installation in the world. The complex has an installed capacity of 1,517 MW and an active production capacity of 900 MW.

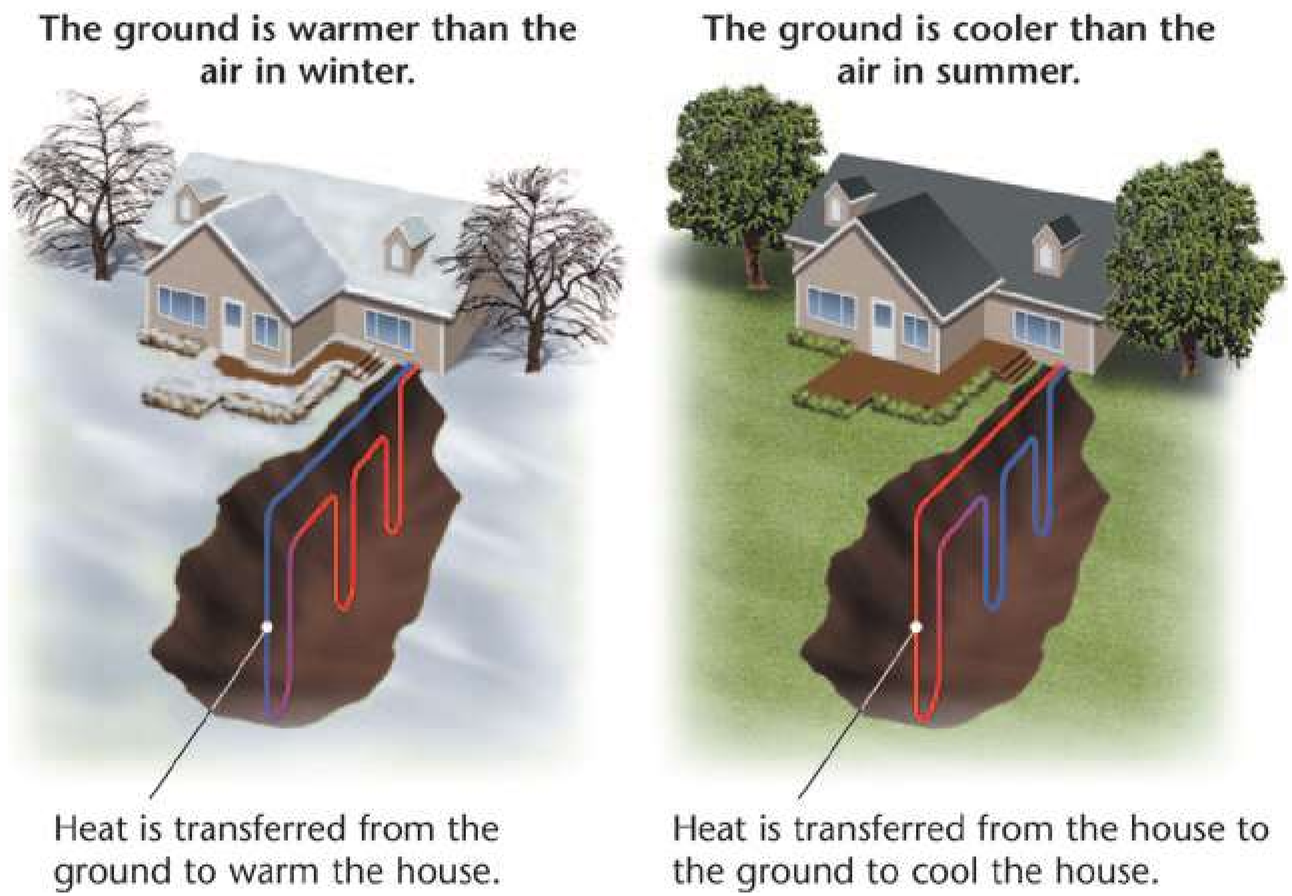
Uses of geothermal energy

- Direct use of geothermal energy involves heating and cooling for buildings, including space and water heating, greenhouses, bathing, wellness and swimming pools, water purification/desalination, and industrial and process heat for agricultural products and mineral extraction and drying.



Geothermal heat pump

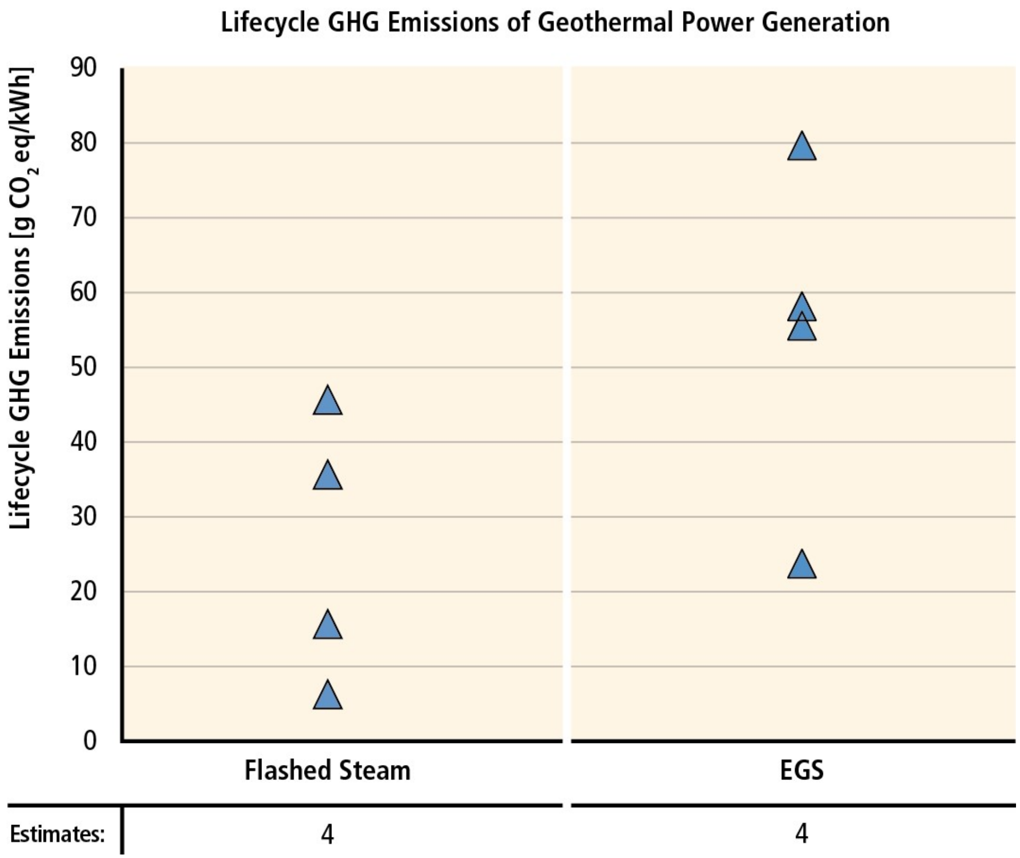
- A geothermal heat pump uses stable underground temperatures to warm and cool homes.



In winter (left), the ground is warmer than the air. A fluid is circulated underground to warm a house. In summer (right), the ground is cooler than the air, and the fluid is used to cool a house.

Environmental and social impacts

- Geothermal technologies are environmentally advantageous because there is no combustion process emitting CO_2, with the only direct emissions coming from the underground fluids in the reservoir.



- The full lifecycle CO_2-equivalent emissions for geothermal energy technologies are less than 50 g CO_2 eq/kWh for flash steam geothermal power plants and less than 80 g CO_2 eq/kWh for EGS power plants.
- In closed-loop binary cycle power plants, the operational CO_2 emission is near zero.
- In direct heating applications, emissions of CO_2 are also typically negligible.

- The successful realization of geothermal projects often depends on the level of acceptance by local people.

MAJOR SOCIAL IMPACTS OF GEOTHERMAL PROJECTS AND MEANS OF MITIGATING THEM

- Prevention or minimization of detrimental impacts on the environment, and on land occupiers, as well as the creation of benefits for local communities, is indispensable to obtain social acceptance. Public education and awareness of the probability and severity of detrimental impacts are also important.

- The necessary prerequisites to secure agreement of local people are:
  - prevention of adverse effects on people's health.
  - minimization of environmental impacts.
  - creation of direct and ongoing benefits for the resident communities.

- Geothermal development creates local job opportunities during the exploration, drilling and construction period.

- It also creates permanent and full-time jobs when the power plant starts to operate since the geothermal field from which the fluids are extracted must be operated locally. This can alleviate rural poverty in developing countries, particularly in Asia, Central and South America, and Africa, where geothermal resources are often located in remote mountainous areas.

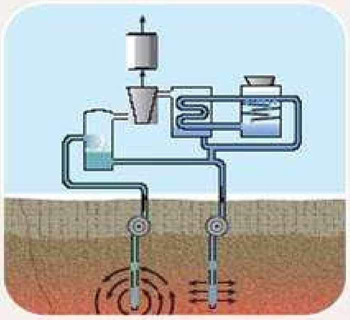
- Some geothermal companies and government agencies have approached social issues by improving local security, building roads, schools, medical facilities and other community assets, which may be funded by contributions from profits obtained from operating the power plant.

The good and bad of geothermal energy

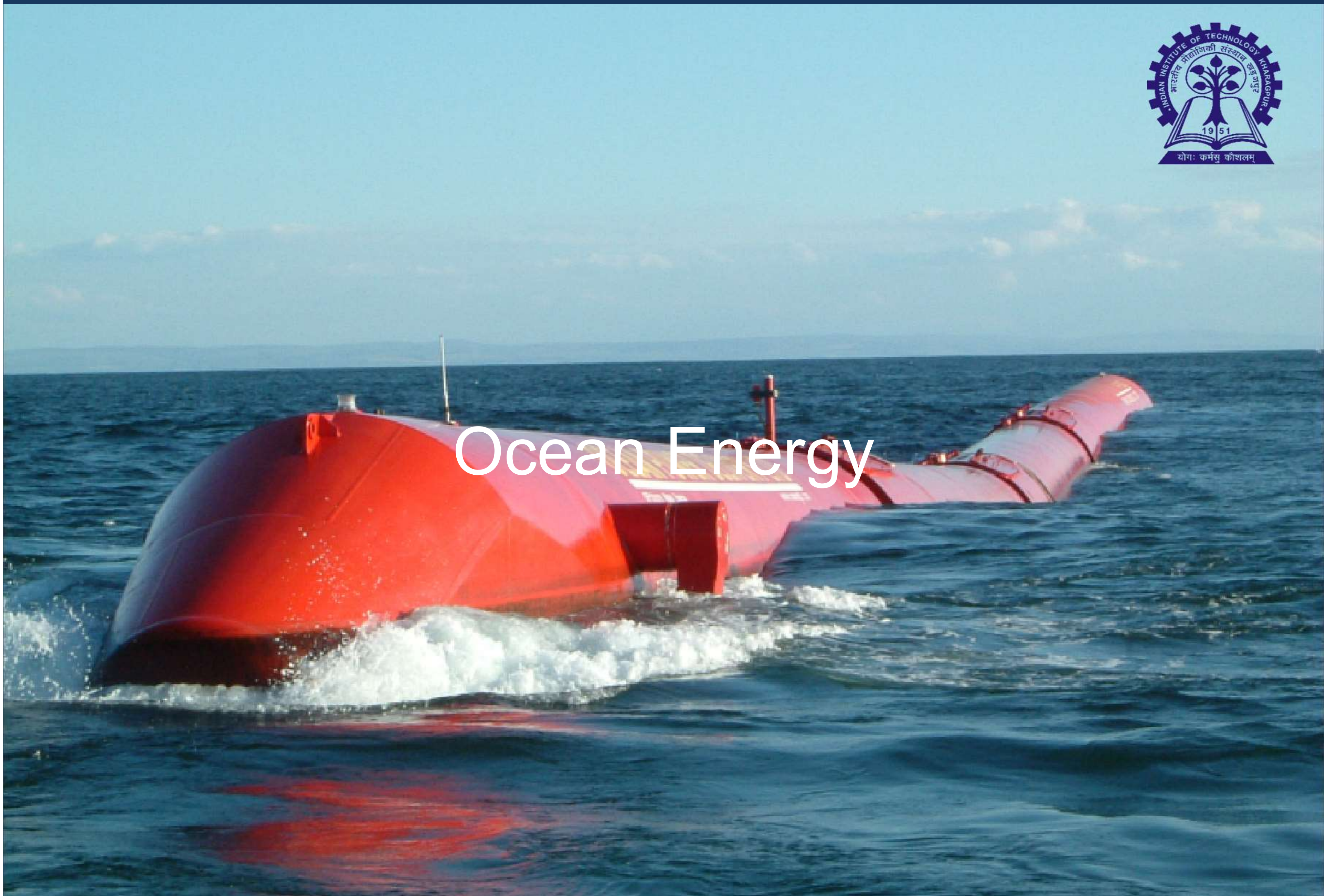
Trade-Offs

Geothermal Energy

Advantages	Disadvantages
Very high efficiency	Scarcity of suitable sites
Moderate net energy at accessible sites	Can be depleted if used too rapidly
Lower CO_2 emissions than fossil fuels	Environmental costs not included in market price
Low cost at favorable sites	Moderate to high local air pollution
Low land use and disturbance	Noise and odor (H_2S)
Moderate environmental impact	High cost except at the most concentrated and accessible sources



Ocean Energy



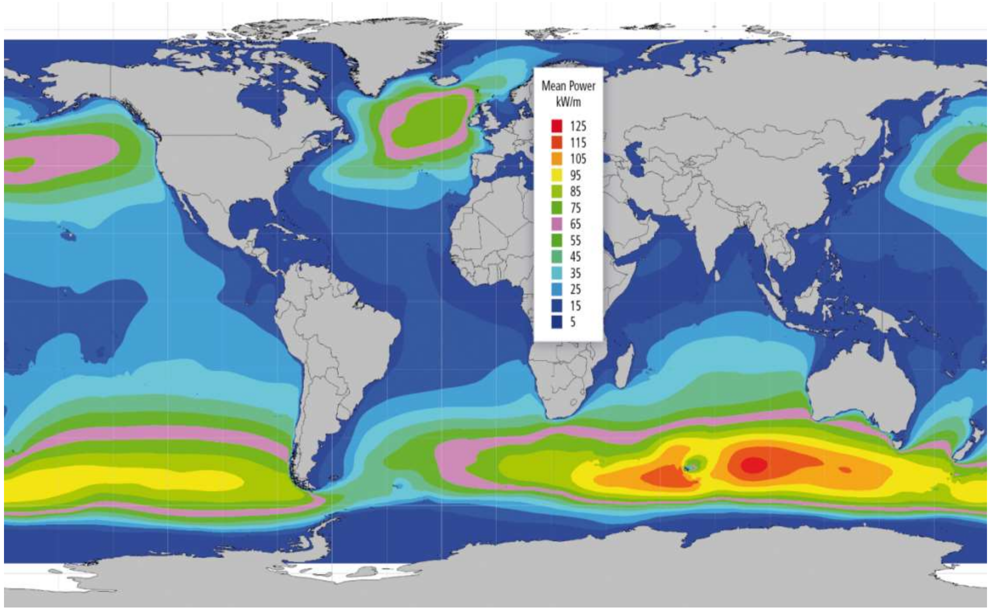
Ocean energy

- The RE resource in the ocean comes from six distinct sources, each with different origins and requiring different technologies for conversion.
- These sources are:
  - **Waves**, derived from the transfer of the kinetic energy of the wind to the upper surface of the ocean;
  - **Tidal range (tidal rise and fall)**, derived from the gravitational forces of the Earth-Moon-Sun system;
  - **Tidal currents**, water flow resulting from the filling and emptying of coastal regions as a result of the tidal rise and fall;
  - **Ocean currents**, derived from wind-driven and thermohaline ocean circulation;
  - **Ocean thermal energy**, derived from temperature differences between solar energy stored as heat in upper ocean layers and colder seawater, generally below 1,000 m;
  - **Salinity gradients (osmotic power)**, derived from salinity differences between fresh and ocean water at river mouths.

Wave energy

- The total theoretical wave energy potential is estimated to be 115 EJ/yr, roughly twice the current global electricity supply.

GLOBAL OFFSHORE AVERAGE ANNUAL WAVE POWER DISTRIBUTION



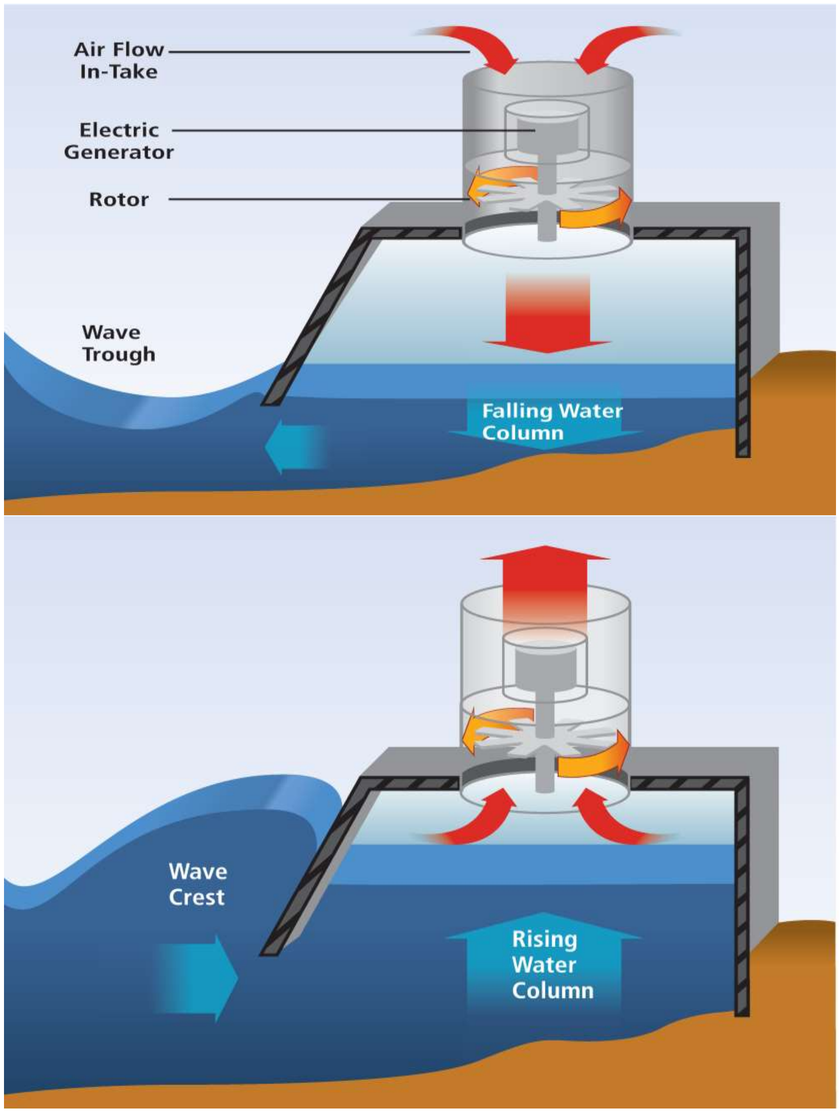
- Ocean wave energy is energy that has been transferred from the wind to the ocean. As the wind blows over the ocean, air-sea interaction transfers some of the wind energy to the water, forming waves, which store this energy as potential energy (in the mass of water displaced from the mean sea level) and kinetic energy (in the motion of water particles).

- The size and period of the resulting waves depend on the amount of transferred energy, which is a function of the wind speed, the length of time the wind blows (order of days) and the length of ocean over which the wind blows.

- Wave energy availability typically varies seasonally and over shorter time periods, with seasonal variation typically being greater in the northern hemisphere.

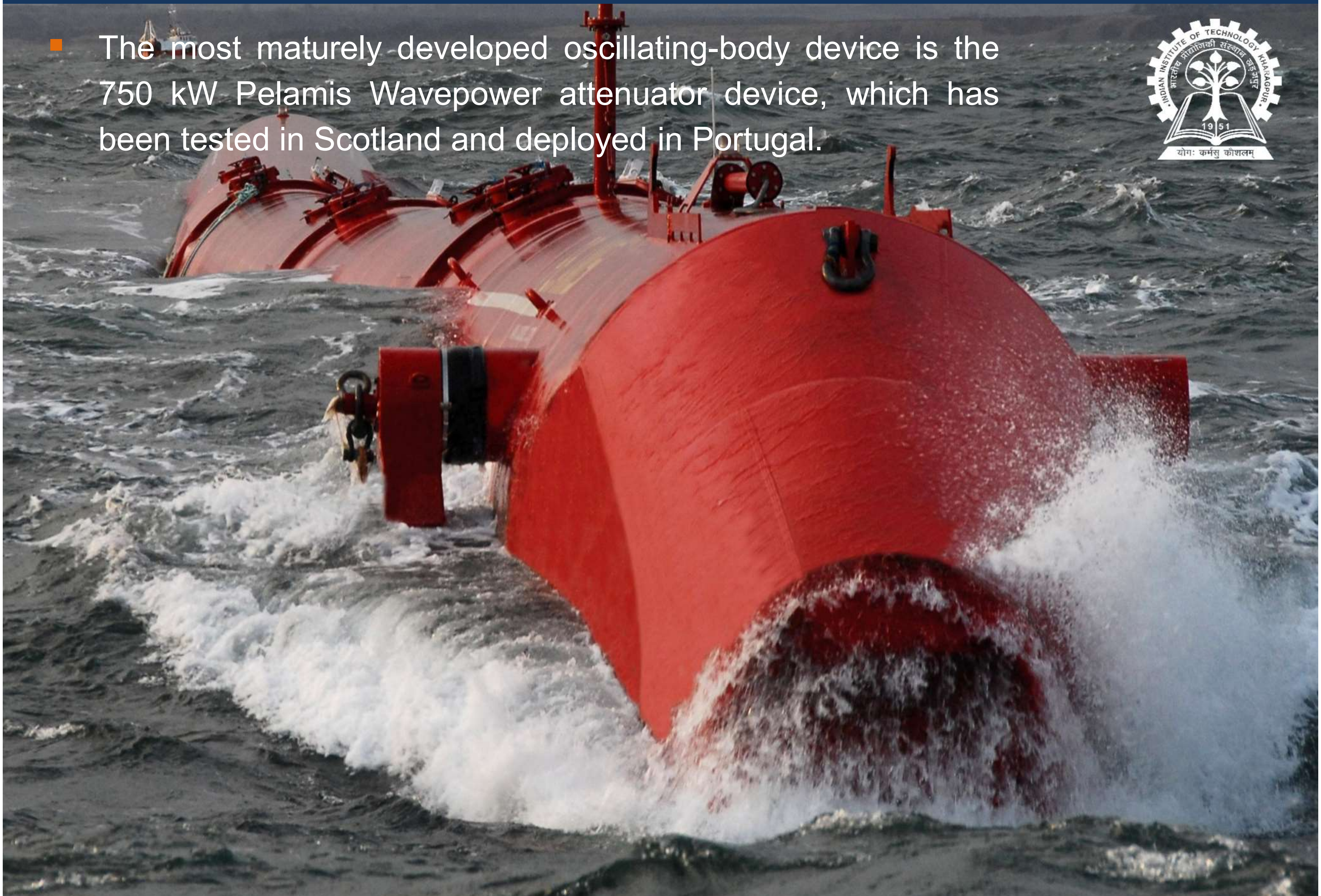
Wave energy converter

- Wave energy hitting the shore is converted into electricity using **oscillating water column**.



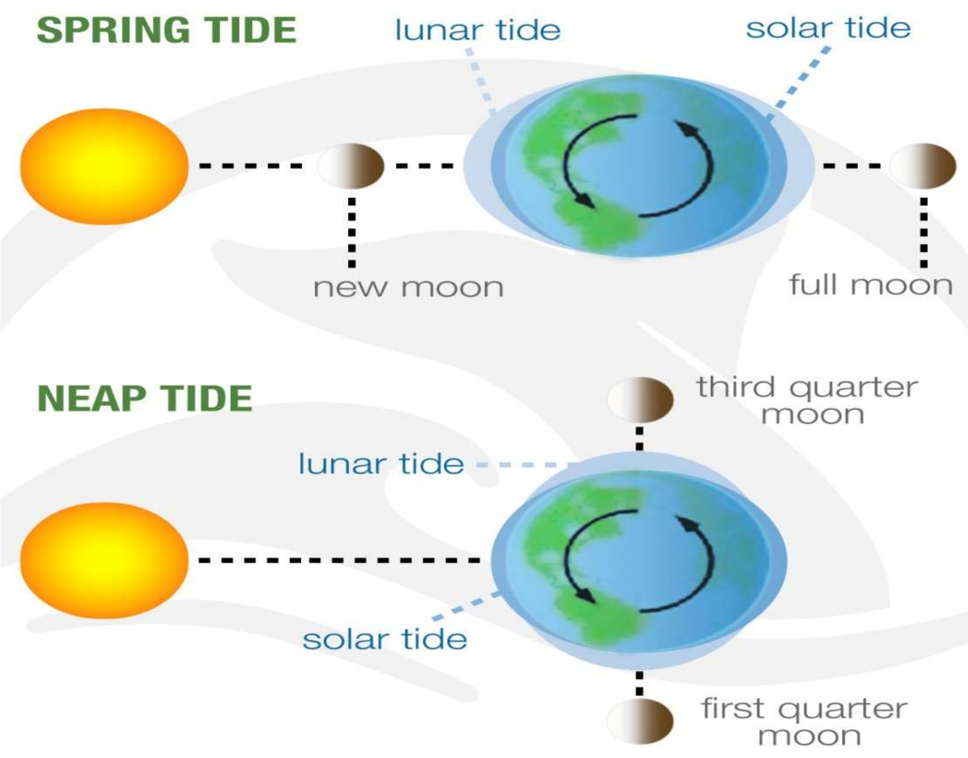
- As a wave rises, high-velocity air exhausts through an air turbine coupled to an electrical generator, which converts the kinetic energy into electricity.
- When the wave falls, the airflow reverses and fills the chamber, generating another pulse of energy (bottom).

- The most maturely developed oscillating-body device is the 750 kW Pelamis Wavepower attenuator device, which has been tested in Scotland and deployed in Portugal.



Tidal energy

- The world's theoretical tidal power potential is in the range of 3 TW/yr, with 1 TW located in relatively shallow waters.

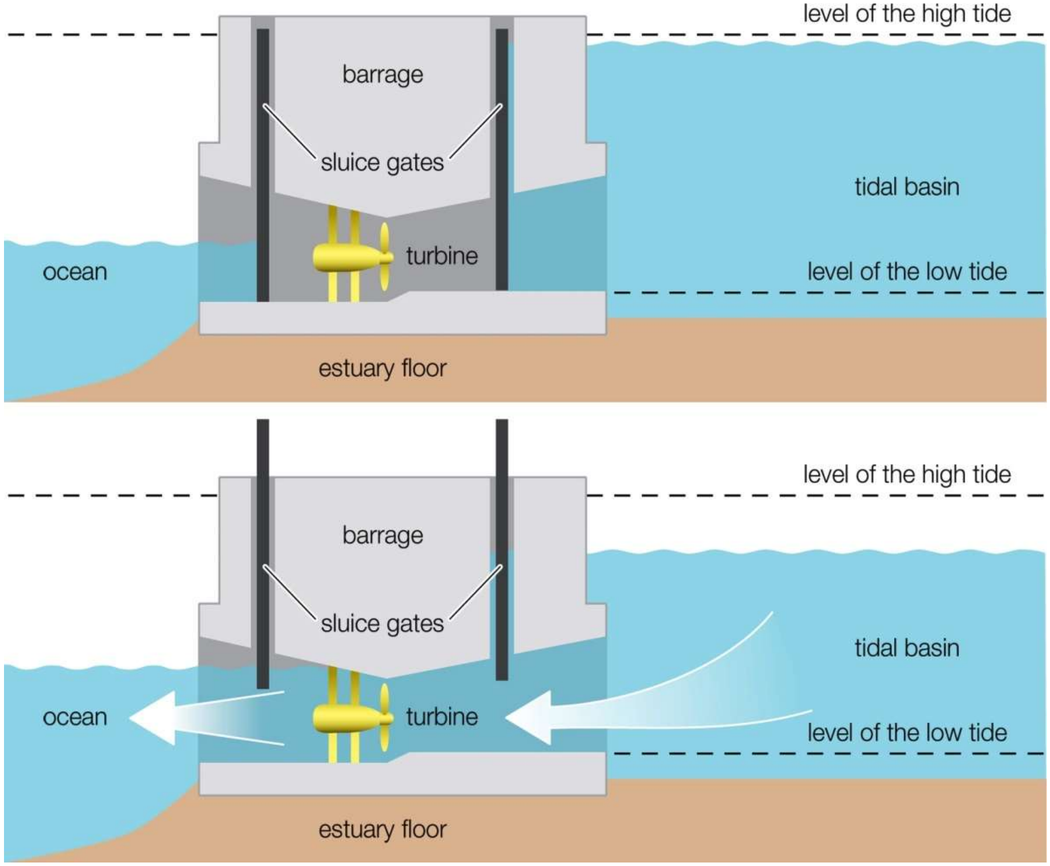


During the year, the amplitude of the tides varies depending on the respective positions of the Earth, the Moon and the Sun. **Spring tides** (maximum tidal range) occur when the Sun, Moon and Earth are aligned (at full moon and at new moon). **Neap tides** (minimum tidal range) occur when the gravitational forces of the Earth-Moon axis are at 90 degrees to the Earth-Sun axis.

- Tides are the regular and predictable change in the height of the ocean, driven by gravitational and rotational forces between the Earth, Moon and Sun, combined with centrifugal and inertial forces.
- Many coastal areas experience roughly two high tides and two low tides per day (called **semi-diurnal**); in some locations there is only one tide per day (called **diurnal**).
- The timing and magnitude of the tide varies depending on global position and also on the shape of the ocean bed, the shoreline geometry and Coriolis acceleration.
- Tidal range can be forecast with a high level of accuracy, even centuries in advance: while the resultant power is variable, there is no resource risk due to climate change.

- The development of tidal range hydropower has usually been based on estuarine developments, where a barrage encloses an estuary, which creates a single reservoir (basin) behind it and incorporates conventional low-head hydro turbines.

TIDAL BARRAGE



- The basin is filled with water until high tide, when the sluice gates are shut.
- During low tide, the sluice gates are opened, allowing water to flow from the tidal basin, and through the turbine inside the barrage (after several hours, the gates close to begin the process again).
- The water flows from the tidal basin, through the turbine and into the ocean. The movement of water generates the rotary motion of the turbine, which is then converted into electricity.
- An alternative method is a two-way generation scheme which generates power during both incoming and outgoing tides.

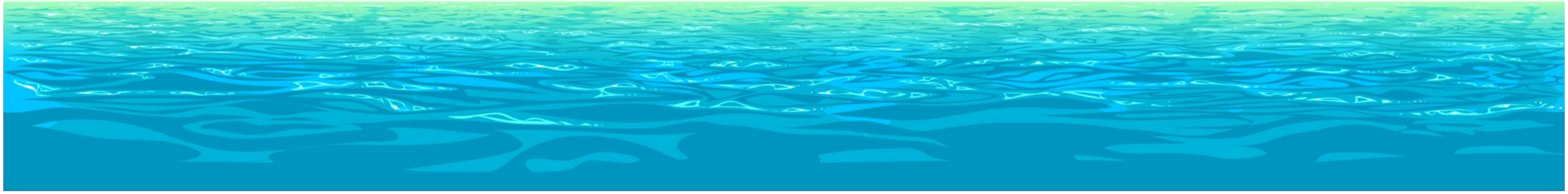
Environmental and social impacts

- Ocean energy technologies do not generate GHGs in operation and have low lifecycle GHG emissions, providing the potential to significantly contribute to emissions reductions and help mitigate long-term climate change.

- Utility-scale deployments with transmission grid connections can be used to displace carbon-emitting energy supplies, while smaller-scale developments may supply electricity and/or drinking water to remote communities.

- The local social and environmental impacts of ocean energy projects are being evaluated as actual deployments multiply, but can be estimated based on the experience of other maritime and offshore industries.

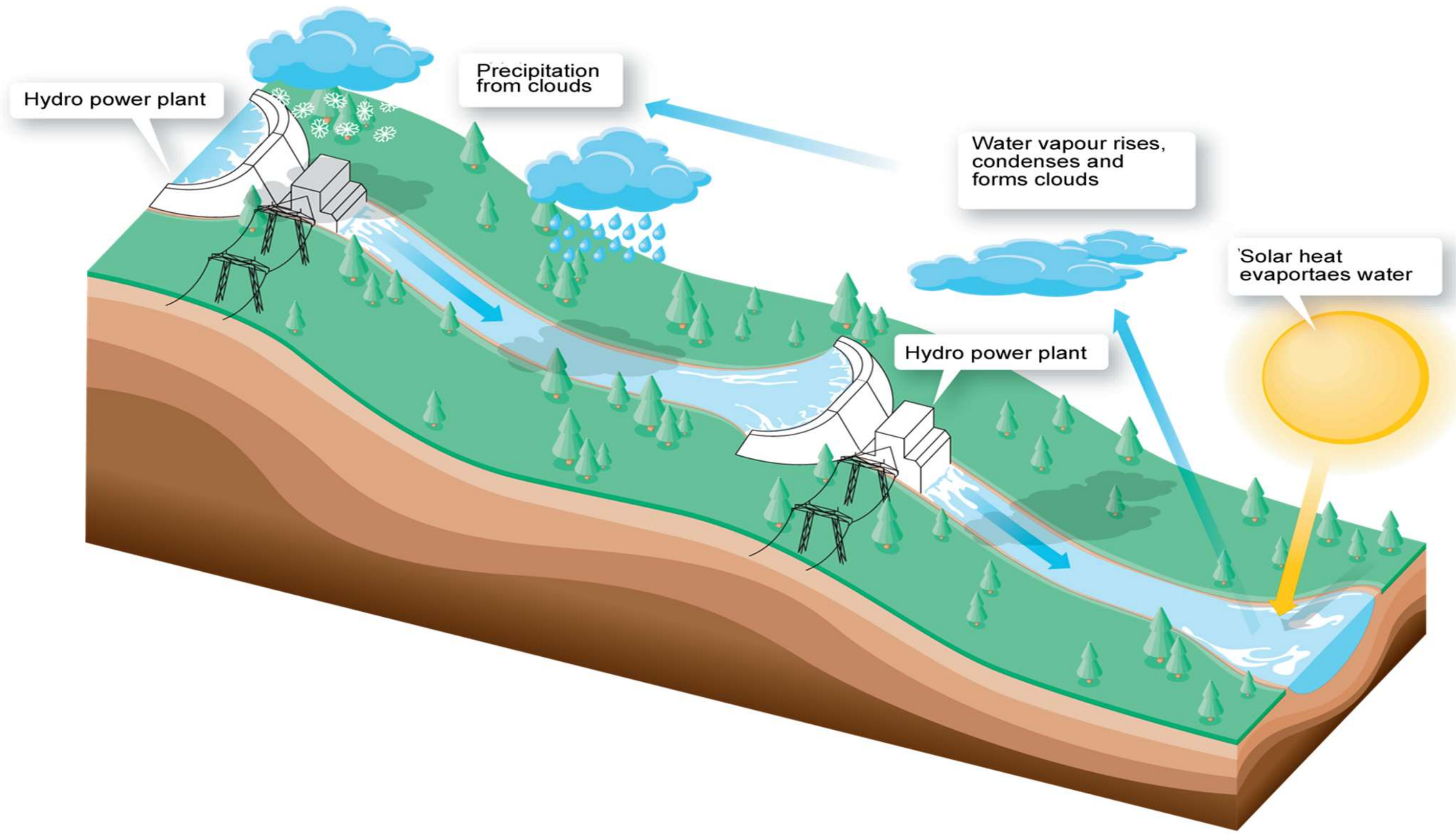
- Environmental risks from ocean energy technologies appear to be relatively low, but the early stage of ocean energy deployment creates uncertainty on the degree to which social and environmental concerns might eventually constrain development.



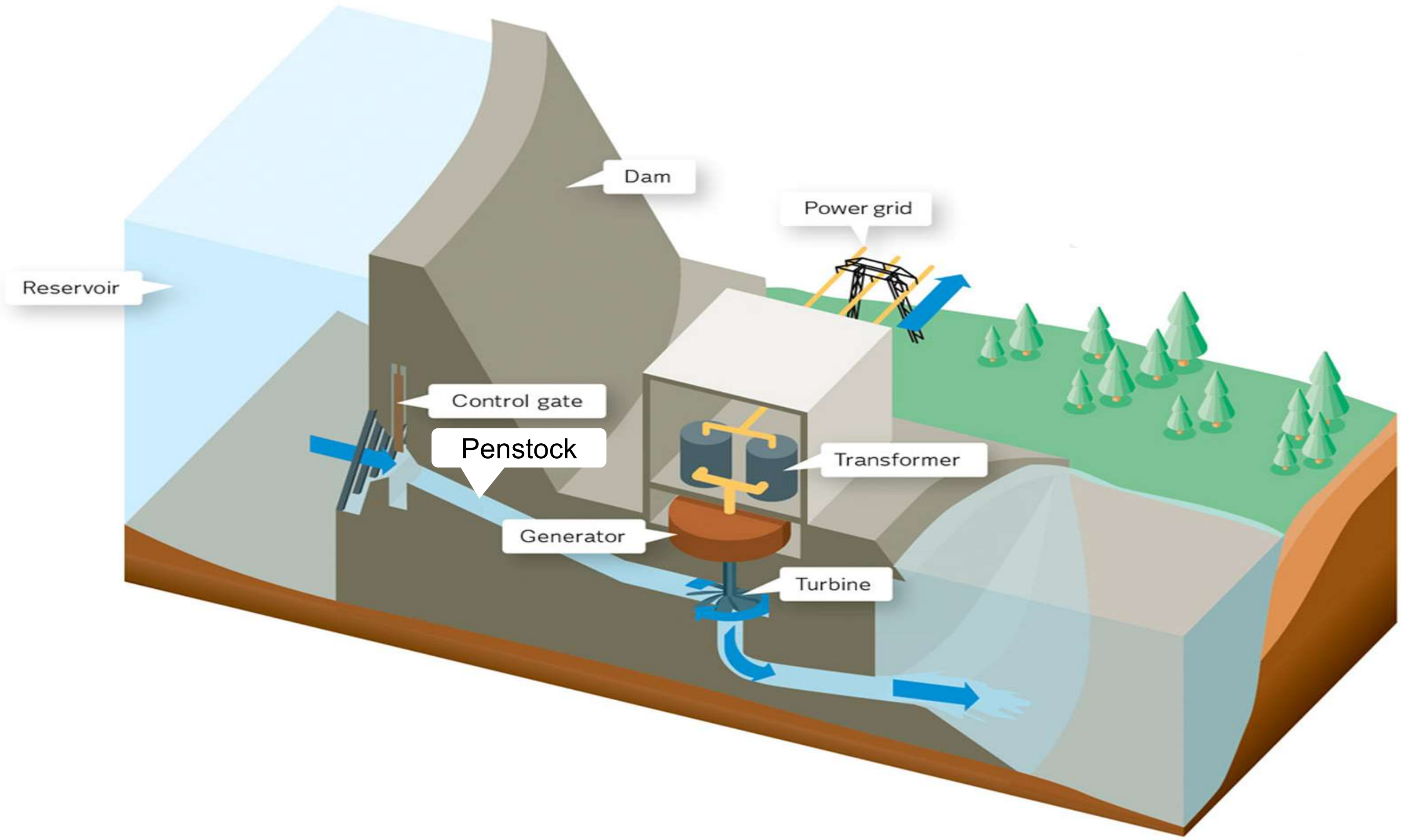
Hydroelectricity

Hydroelectricity

- Hydroelectricity is generated from water moving (kinetic energy) in the hydrological cycle, which in turn is driven by solar radiation.

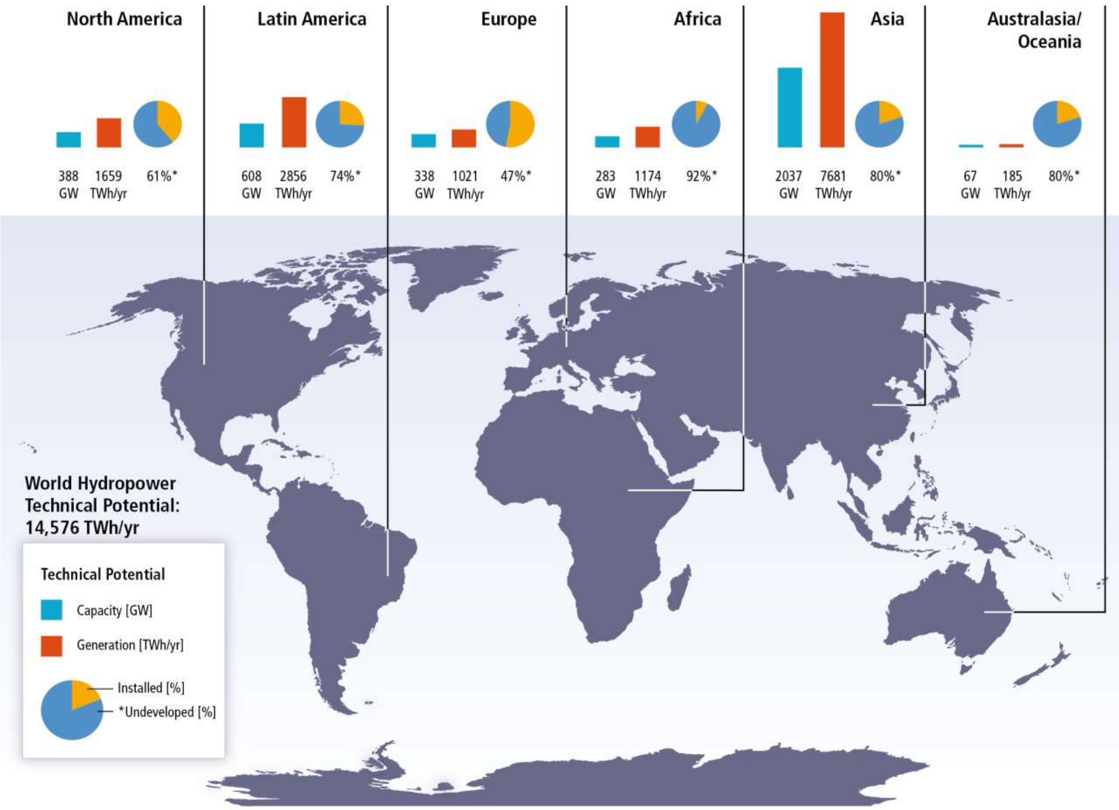


- The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Water released at a height from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity.



- Since most precipitation usually falls in mountainous areas, where elevation differences (head) are the highest, the largest potential for hydropower development is in mountainous regions, or in rivers coming from such regions.

REGIONAL HYDROPOWER TECHNICAL POTENTIAL



- The total global annual runoff has been estimated as 47,000 km^3, out of which 28,000 km^3 is surface runoff, yielding a theoretical potential for hydropower generation of 41,784 TWh/yr (147 EJ/yr).
- The total worldwide technical potential for hydropower is estimated at 14,576 TWh/yr (52.47 EJ/yr), over four times the current worldwide annual generation.

- Hydroelectric plants do not consume the water that drives the turbines. The water, after power generation, is available for various other essential uses. In fact, a significant proportion of hydroelectric projects are designed for multiple purposes.

- Most widely used renewable energy resource in the world today.
- Only about 13% of the world's potential for hydropower has been developed.
- The world's top five producers of hydropower are Canada, China, Brazil, the United States and Russia.
- The contribution of large scale hydropower plants is projected to fall shortly as many existing reservoir systems get fill with silt and become useless faster than new plants are built.

- Spanning across the Yangtze River near the town of Sandouping in China, the *Three Gorges Dam* is the world's largest hydropower station in terms of installed capacity (22,500 MW). In 2014 the dam generated 98.8 TWh of electricity, setting a new world record by 0.17 TWh previously held by the Itaipú Dam on the Brazil/Paraguay border in 2013 of 98.63 TWh.

Environmental and social impacts

- After more than a century of experience, hydropower's strengths and weakness are equally well understood. Although not all negative impacts can be eliminated, but much can be done to mitigate them.

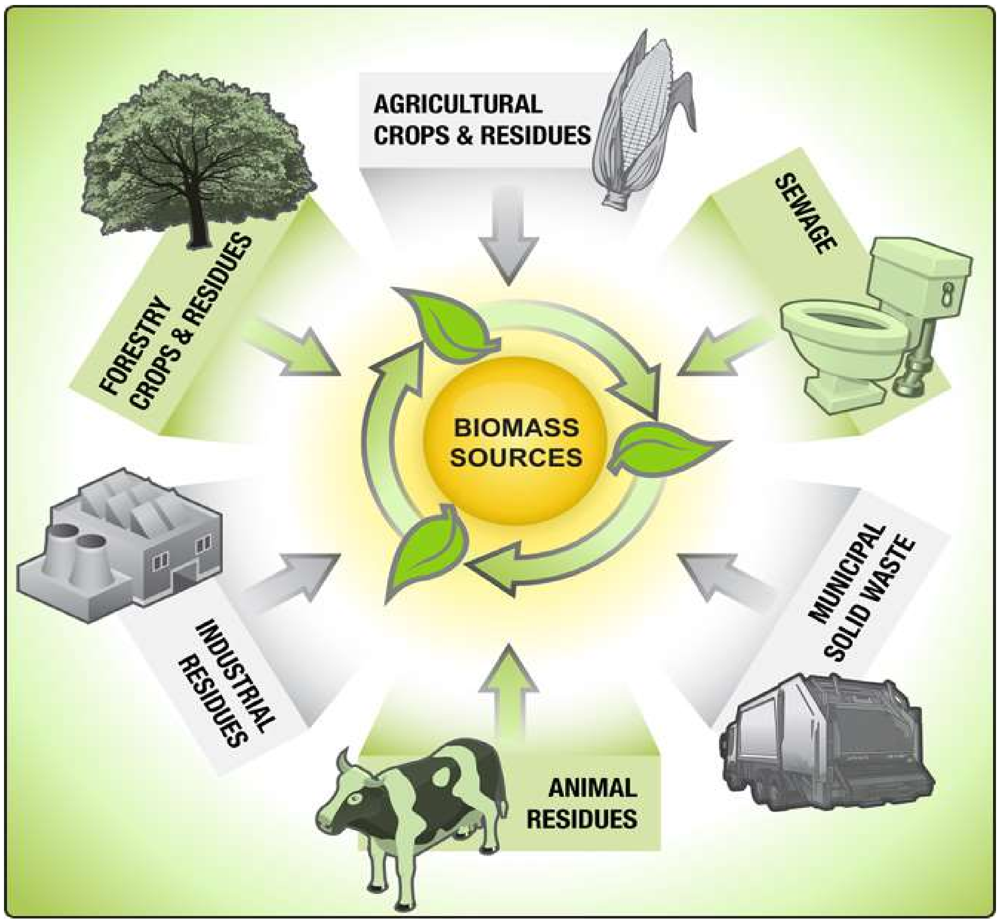
Environmental aspects	
Advantages	**Disadvantages**
Produces no atmospheric pollutants	Inundation of terrestrial habitat
Neither consumes nor pollutes the water it uses for electricity generation purposes	Modification of hydrological regimes
Produces no waste	Modification of aquatic habitats
Avoids depleting non-renewable fuel resources (i.e. coal, gas, oil)	Water quality needs to be monitored/managed
Very few greenhouse gas emissions relative to other large-scale energy options	Greenhouse gas emissions can arise under certain conditions in tropical reservoirs
Can create new freshwater ecosystems with increased productivity	Temporary introduction of methylmercury into the food chain needs to be monitored/managed
Enhances knowledge and improves management of valued species due to study results	Species activities and populations need to be monitored/managed
Can result in increased attention to existing environmental issues in the affected area	Barriers for fish migrations, fish entrainment
	Sediment composition and transport may need to be monitored/managed
	Introduction of pest species needs to be monitored/managed

Social aspects	
Advantages	**Disadvantages**
Leaves water available for other uses	May involve resettlement
Often provides flood protection	May restrict navigation
May enhance navigation conditions	Local land use patterns will be modified
Often enhances recreational facilities	Waterborne disease vectors may occur
Enhances accessibility of the territory and its resources (access roads and ramps, bridges)	Requires management of competing water uses
Provides opportunities for construction and operation with a high percentage of local manpower	Effects on impacted peoples' livelihoods need to be addressed, with particular attention to vulnerable social groups
Improves living conditions	Effects on cultural heritage may need to be addressed
Sustains livelihoods (fresh water, food supply)	

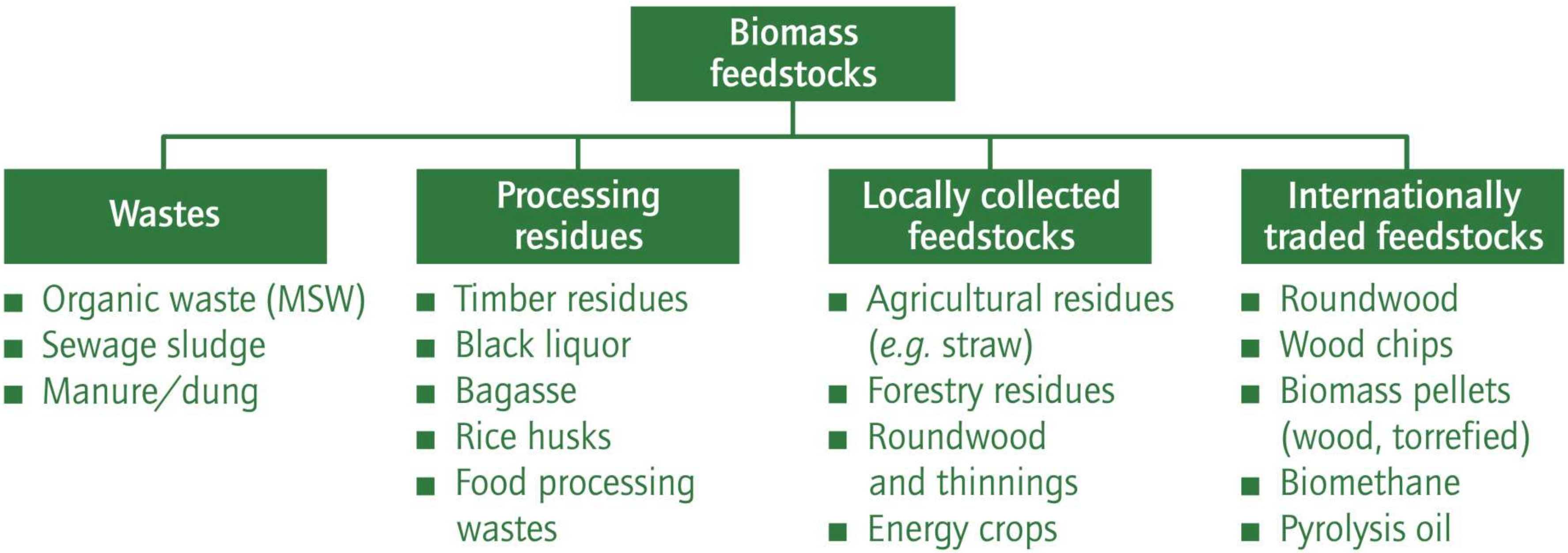
Bioenergy

Bioenergy

- Bioenergy is embedded in complex ways in global biomass systems for food, fodder and fibre production and for forest products; in wastes and residue management; and in the everyday living of the developing countries' poor.

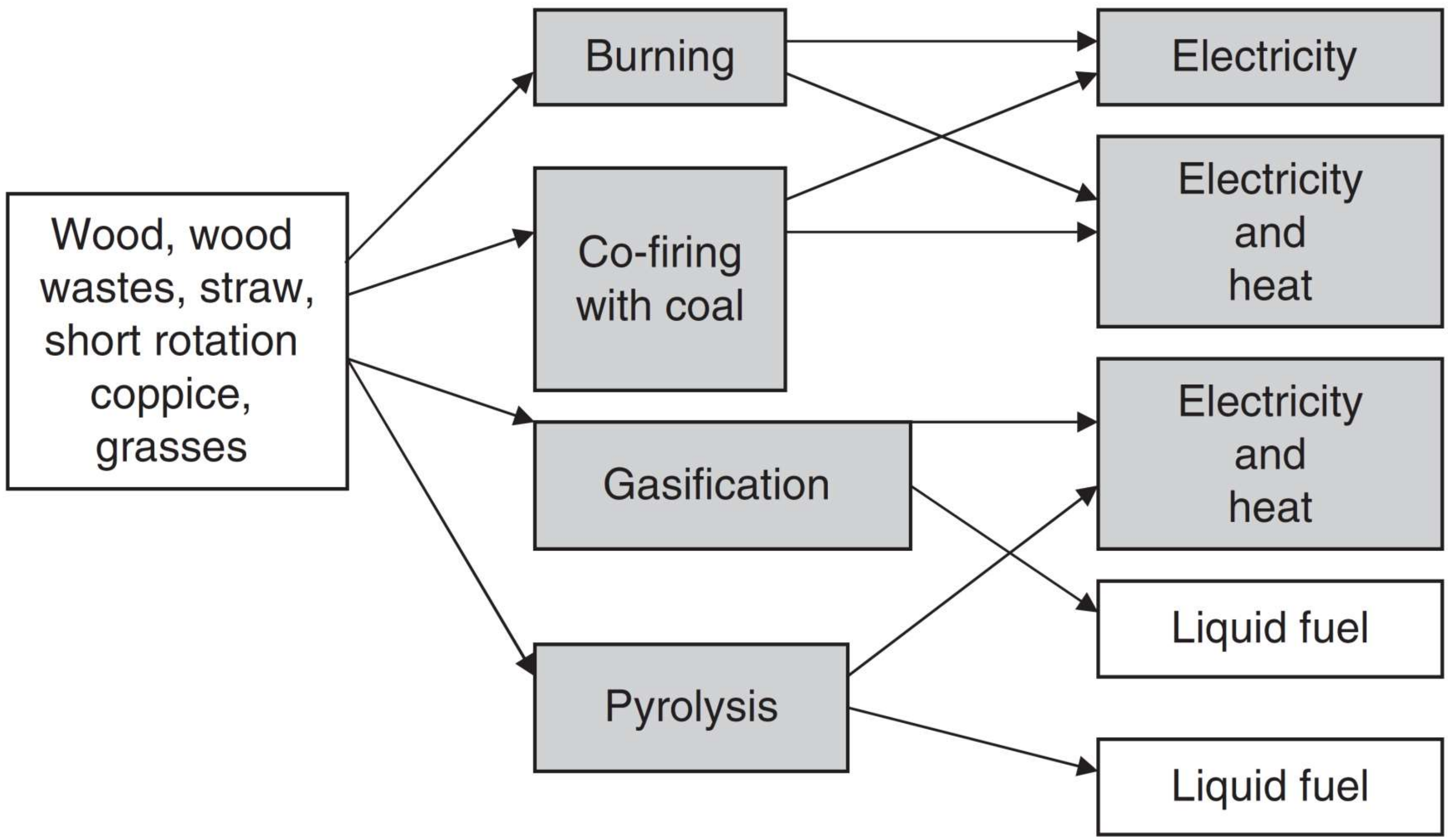


- As a feedstock for producing electricity or heat, biomass has a number of advantages over fossil fuels.
    - It is widely distributed, relatively easy to collect and use, and can produce less net CO_2 emissions than fossil fuels per unit of useful energy delivered, if sourced sustainably.
    - In addition, biomass usually contains less sulphur than coal or oil.



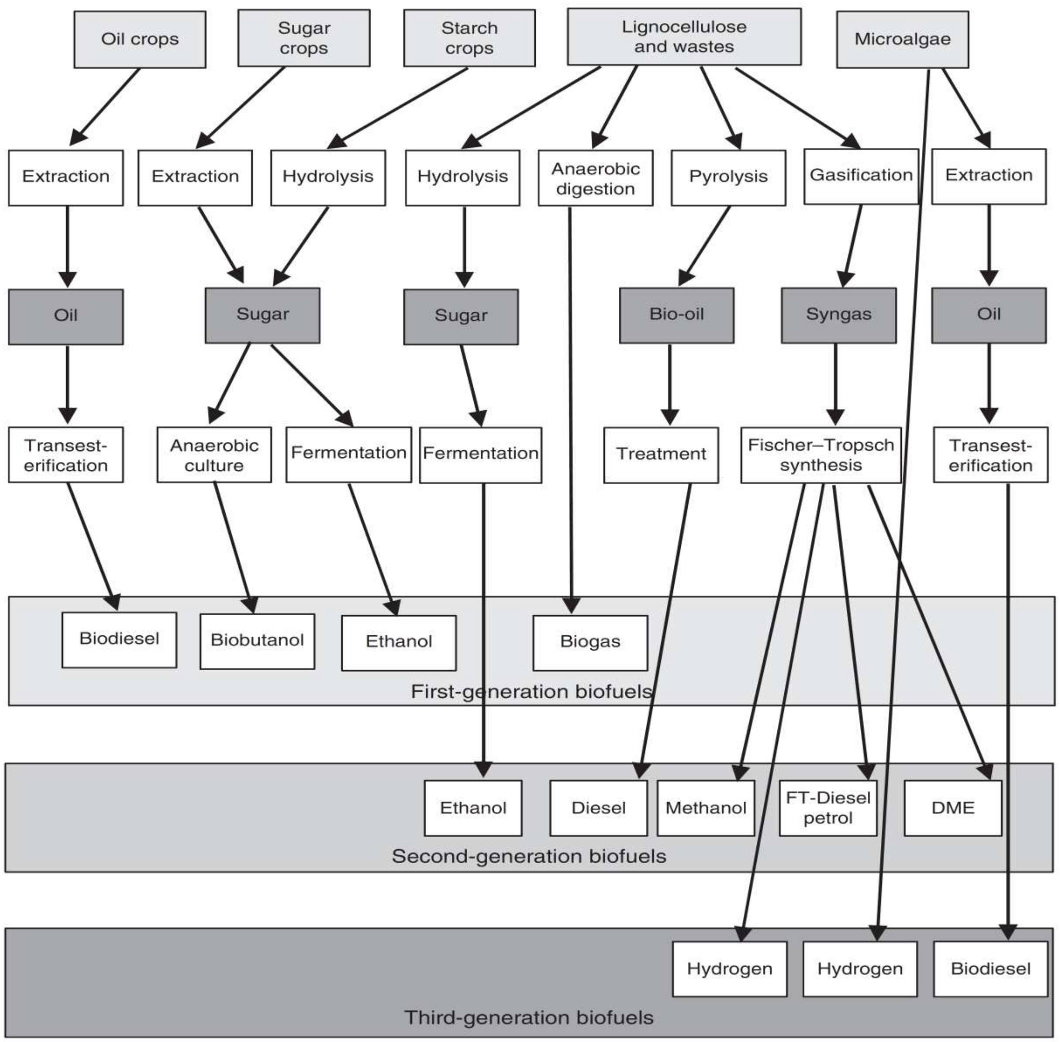
Biomass for heat and electricity

- There are four processes whereby biomass can be used to generate electricity and/or produce heat. These include direct combustion, co-firing, gasification and pyrolysis.



Biomass for fuels (biofuels)

- Biomass-based fuels can be liquid or gas and are divided into first-, second- and third-generation biofuels.

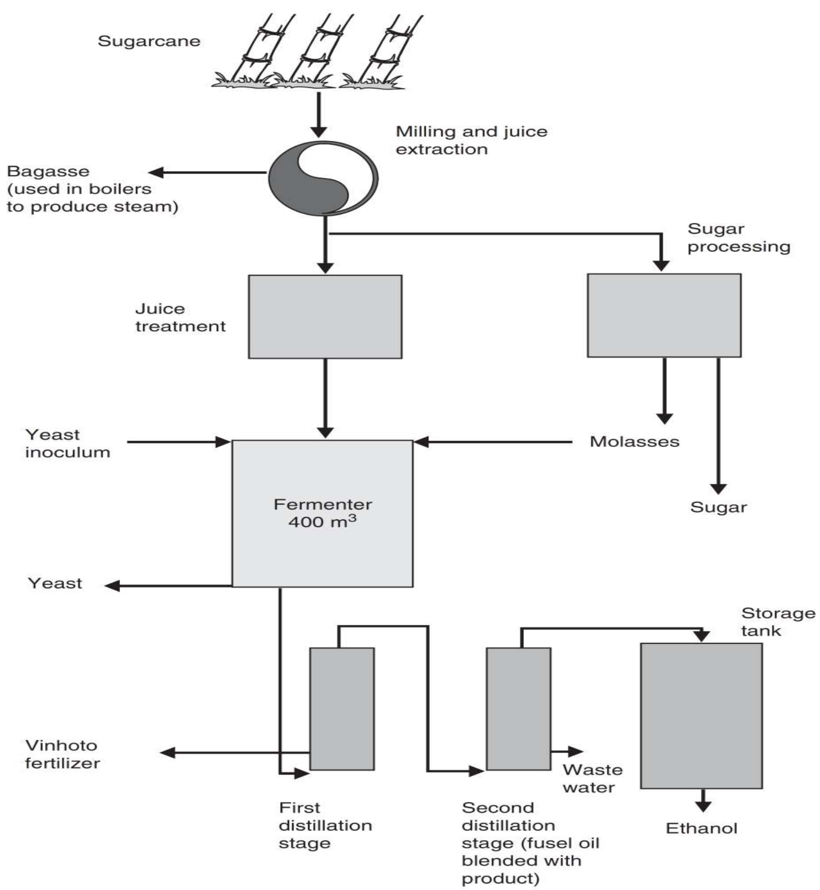


- Biofuels can not only be used for both electricity generation and heating, but also most importantly as a transport fuel.
- Those biofuels currently used and produced in large quantities are the **first- generation** biofuels.
- The biofuels that have been produced but technical difficulties and high costs have delayed their application on a large scale are the **second generation**.
- The **third-generation** biofuels are those which are still at the research and development stage.

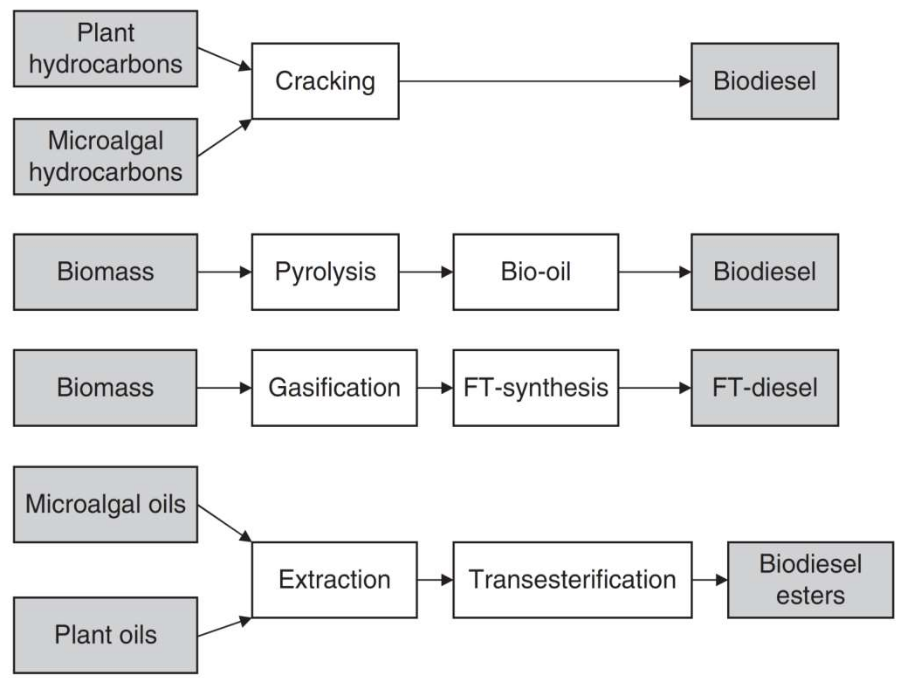
Liquid biofuels

- Liquid biofuels which can supplement or replace conventional liquid fuels (petrol and biodiesel) mainly include methanol, bioethanol and biodiesel.

PRODUCTION OF BIOETHANOL



ROUTES TO THE PRODUCTION OF BIODIESEL



The good & bad of bioethanol

Trade-Offs

Ethanol Fuel

Advantages

- High octane
- Some reduction in CO_2 emissions (sugarcane bagasse)
- High net energy yield (bagasse and switchgrass)
- Can be sold as a mixture of gasoline and ethanol or as pure ethanol
- Potentially renewable

Disadvantages

- Lower driving range
- Low net energy yield (corn)
- Higher CO_2 emissions (corn)
- Much higher cost
- Environmental costs not included in market price
- May compete with growing food and raise food prices
- Higher NO_x emissions and more smog
- Corrosive
- Can make engines hard to start in cold weather

The good & bad of biodiesel

Trade-Offs

Biodiesel

Advantages

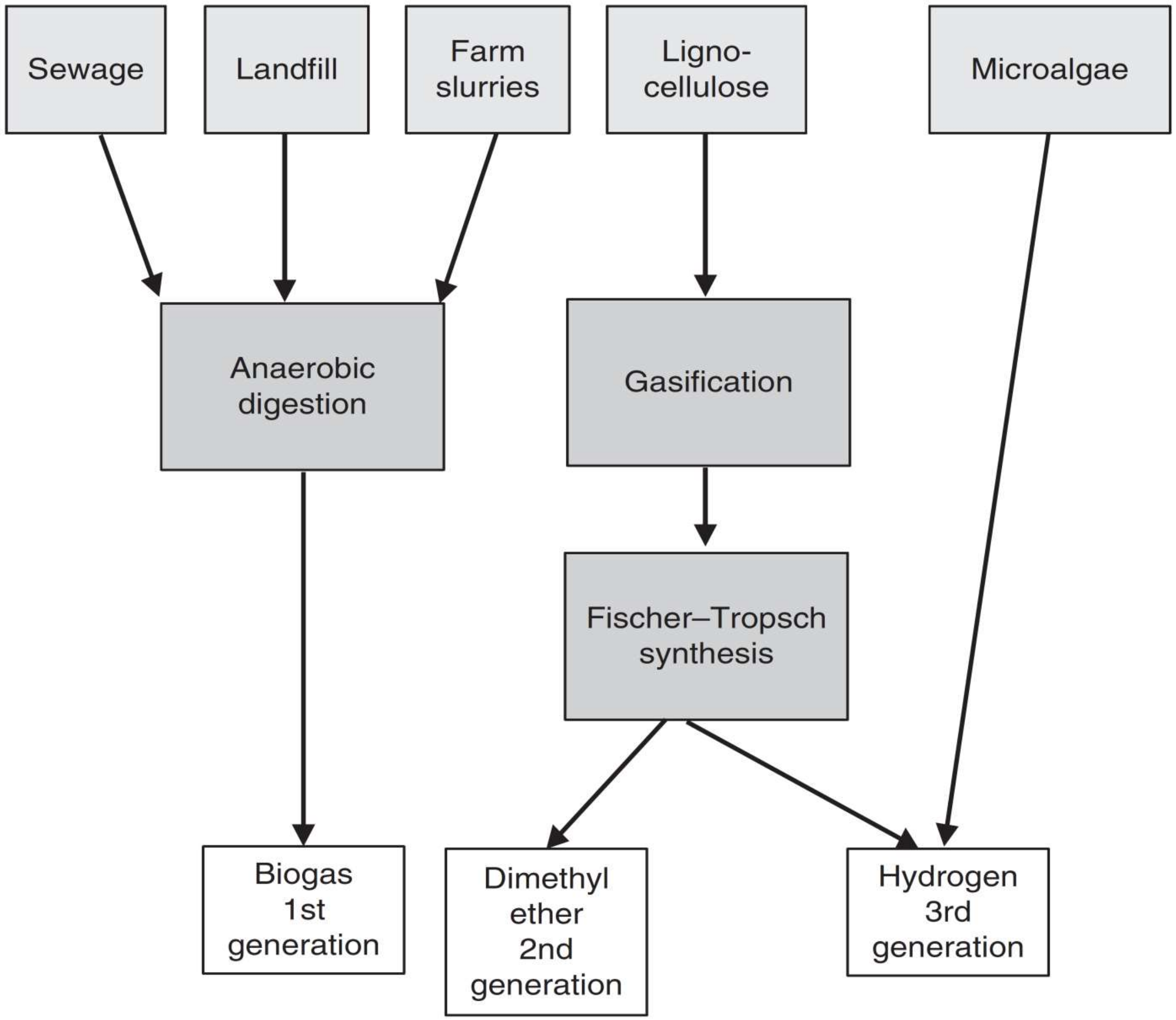
- Reduced CO emissions
- Reduced CO_2 emissions (78%)
- High net energy yield for oil palm crops
- Moderate net energy yield for rapeseed crops
- Reduced hydrocarbon emissions
- Better gas mileage (40%)
- Potentially renewable

Disadvantages

- Increased NO_x emissions and more smog
- Higher cost than regular diesel
- Environmental costs not included in market price
- Low net energy yield for soybean crops
- May compete with growing food on cropland and raise food prices
- Loss and degradation of biodiversity from crop plantations
- Can make engines hard to start in cold weather

Gaseous biofuels

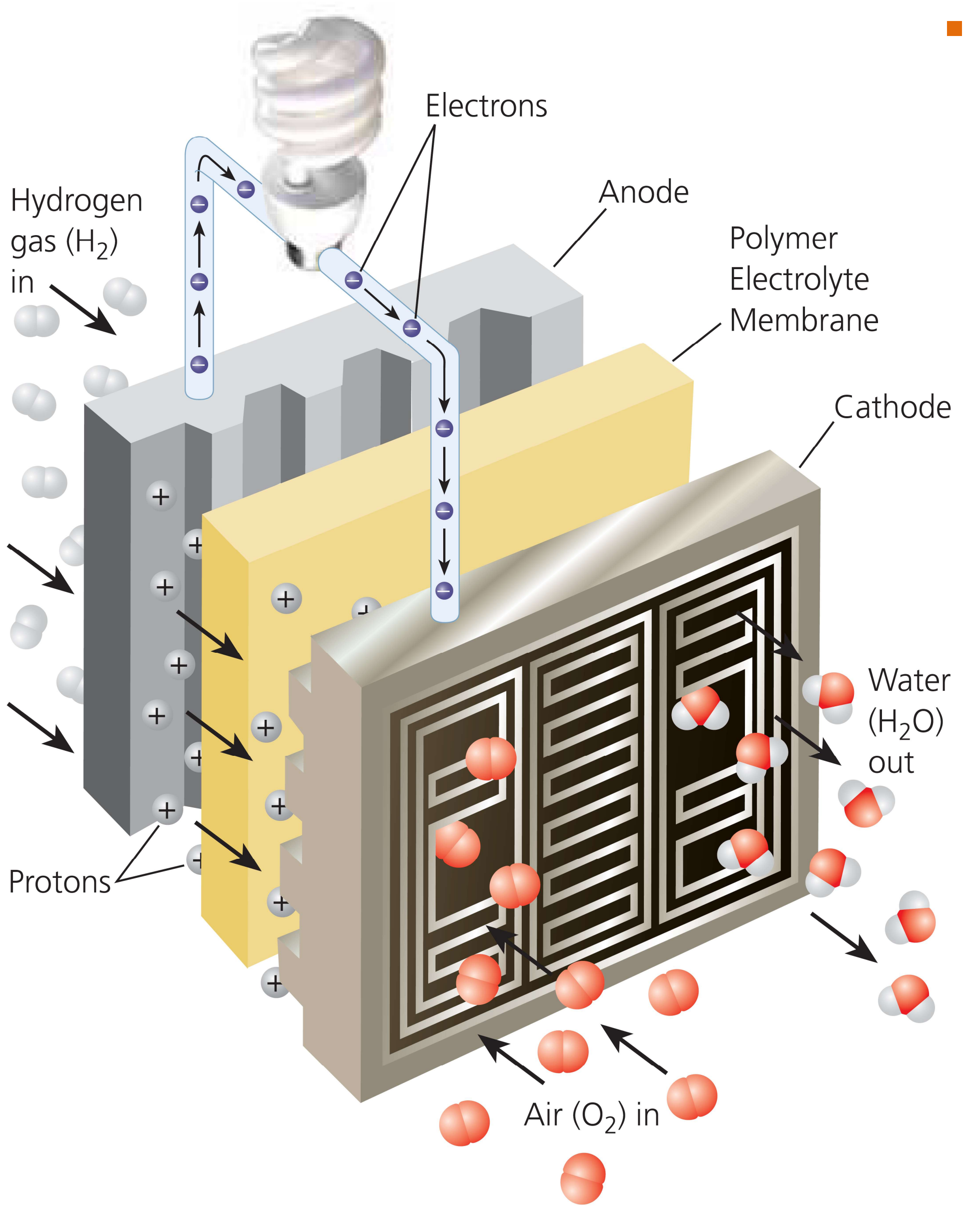
- Gaseous biofuels include methane (biogas), hydrogen and dimethyl ether (DME).



Hydrogen energy

- Considered as the fuel of the future.
- Widespread use of hydrogen as a fuel would eliminate most of the urban outdoor air pollution problems.
- Can greatly reduce the threat of projected climate change because it emits no CO_2.
- Provides more energy per gram than does any other fuel, making it the ideal aviation fuel by allowing planes to greatly decrease fuel weight.
- Various schemes for producing and storing hydrogen as fuel has been proposed.
- Hydrogen is not an energy source like coal or oil. It is a fuel produced by using energy, and thus its net energy yield will always be negative.

Fuel cells



- Like a battery, a fuel cell produces electricity chemically, by combining hydrogen fuel with oxygen from the air. When hydrogen and oxygen are combined, electrical energy is produced and water is the only byproduct.

The good & bad of hydrogen

Trade-Offs

Hydrogen

Advantages

Can be produced from plentiful water

Low environmental impact

Renewable if produced from renewable energy resources

No CO_2 emissions if produced from water

Good substitute for oil

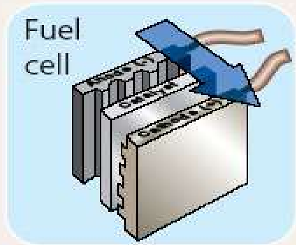
Competitive price if environmental and social costs are included in cost comparisons

Easier to store than electricity

Safer than gasoline and natural gas

Nontoxic

High efficiency (45–65%) in fuel cells



Disadvantages

Not found as H_2 in nature

Energy is needed to produce fuel

Negative net energy

CO_2 emissions if produced from carbon-containing compounds

Environmental costs not included in market price

Nonrenewable if generated by fossil fuels or nuclear power

High costs (that may eventually come down)

Will take 25 to 50 years to phase in

Short driving range for current fuel-cell cars

No fuel distribution system in place

Excessive H_2 leaks may deplete ozone in the atmosphere