



**EV 20001: ENVIRONMENTAL SCIENCE**



**Lecture #6**

# **Renewable Energy**

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# Wind Energy

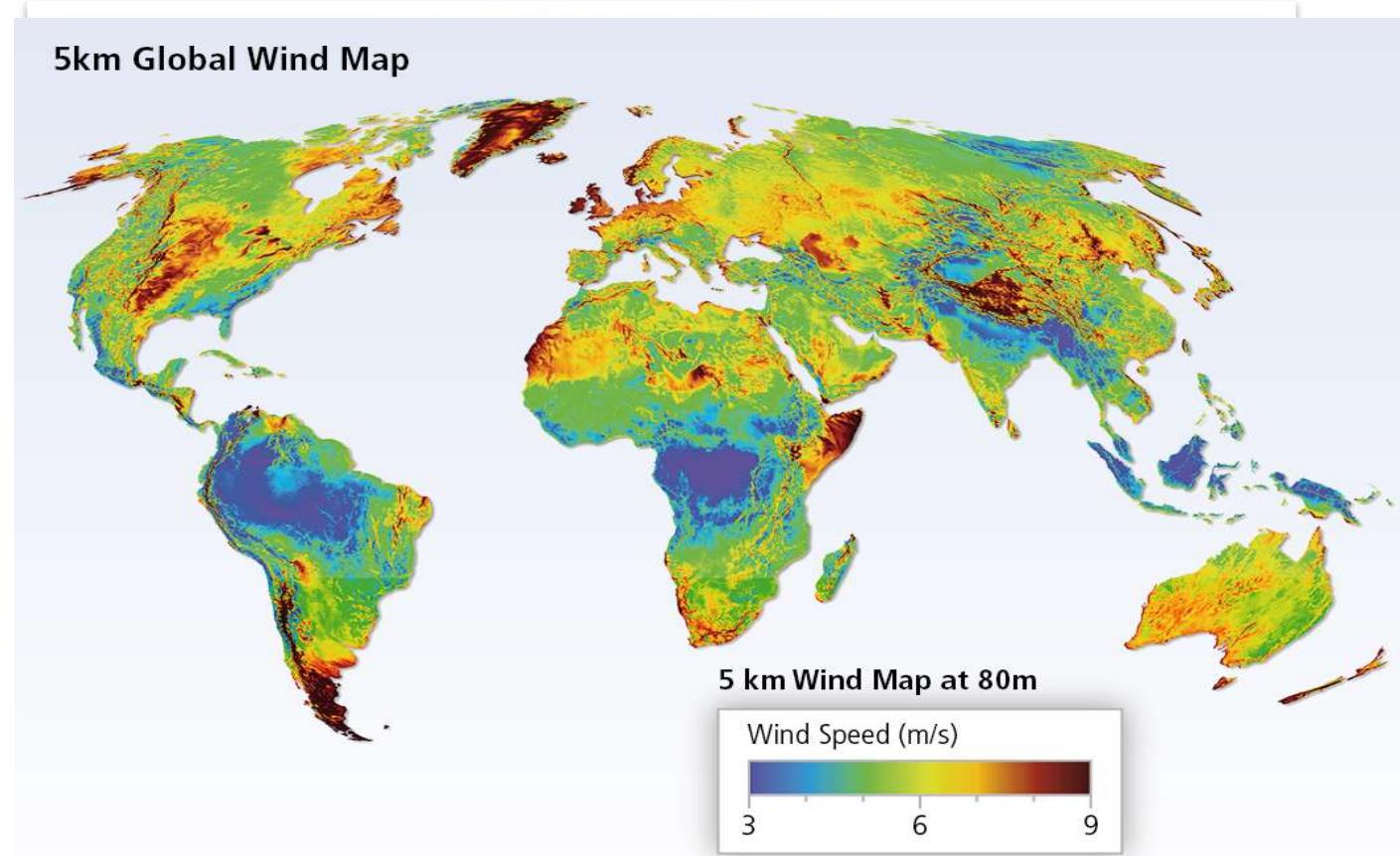


# Wind energy

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

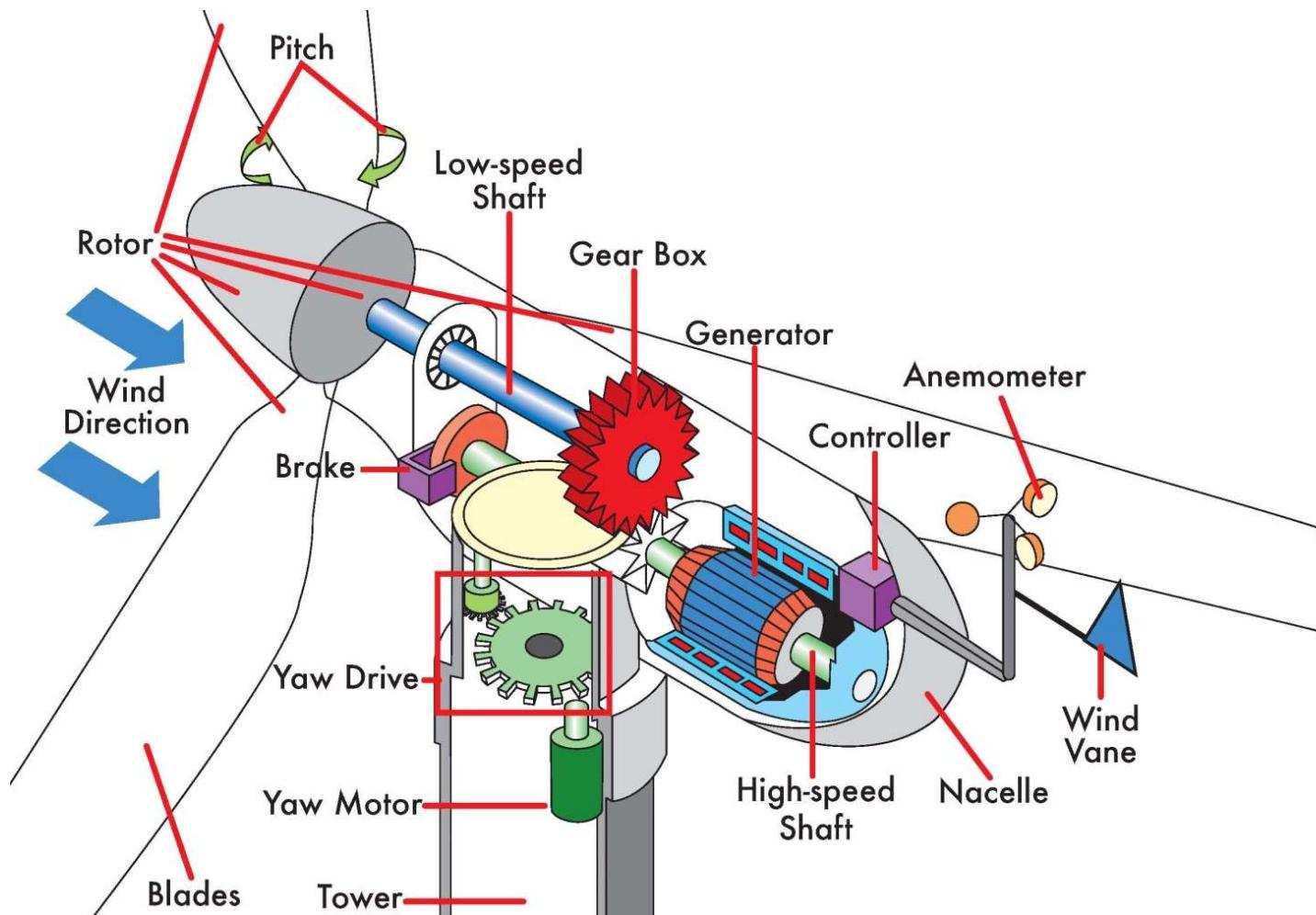
## GLOBAL WIND RESOURCE MAP

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.

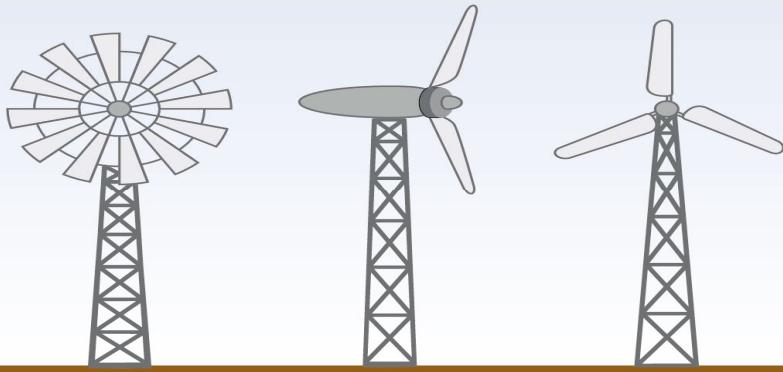
- Wind turbines use rotor blades and an electricity generator to convert kinetic energy of moving air into electrical energy. A typical wind turbine is composed of three blades attached to a hub, containing a gearbox, generator and control system.



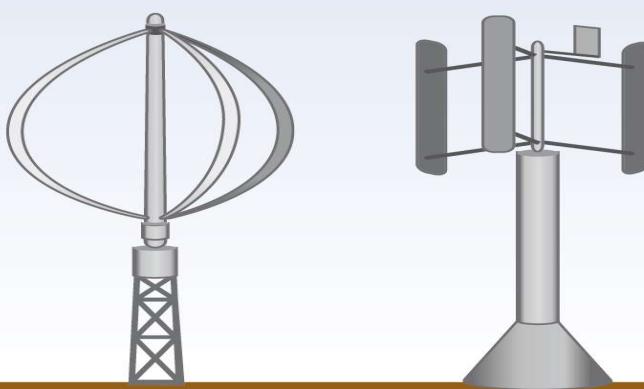
- Several designs have been investigated and have converged to horizontal three-bladed upwind rotors with variable speed operation.



## Horizontal-Axis Turbines

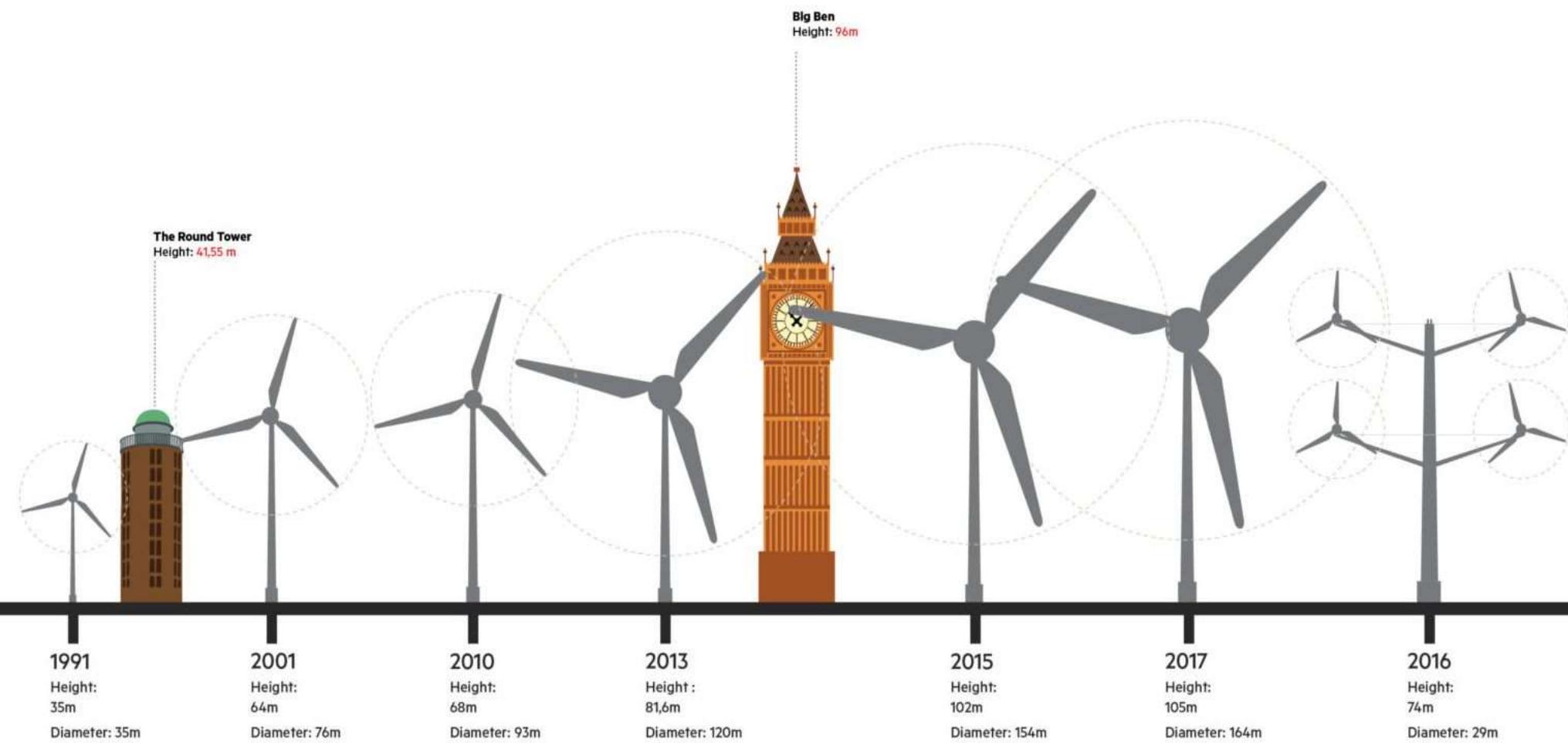


## Vertical-Axis Turbines



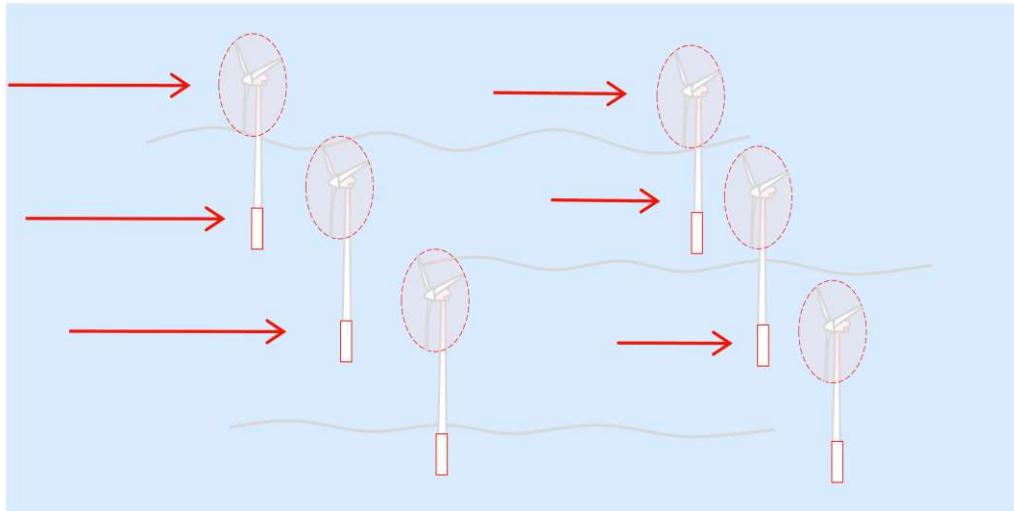
- **Several design options have been investigated:**
  - Horizontal vs vertical axis;
  - Upwind vs downwind;
  - Three blades vs two-blades;
  - Stall regulation vs pitch regulation;
  - Fixed vs variable speed machines.
- **A dominant design has emerged for large wind turbines:**
  - Horizontal axis;
  - 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!



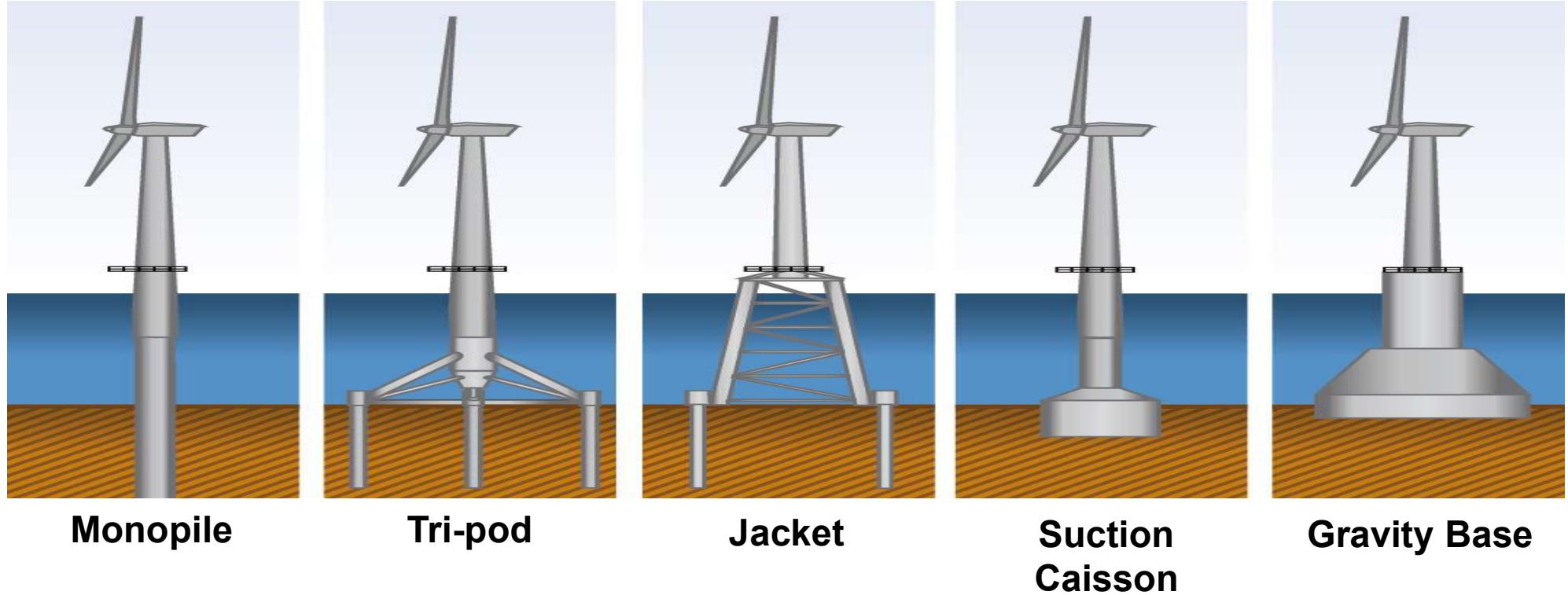
# Onshore and offshore wind energy

- 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.

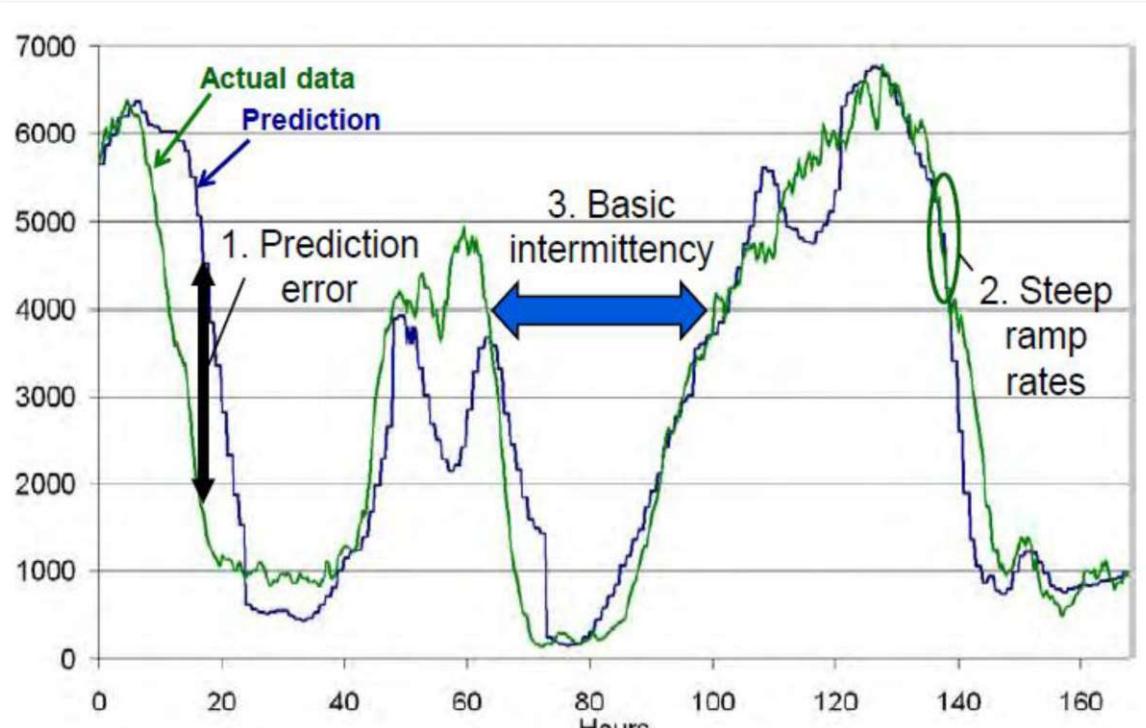


# Grid integration

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

## WIND INTERMITTENCY ILLUSTRATION

MW – Germany 2007



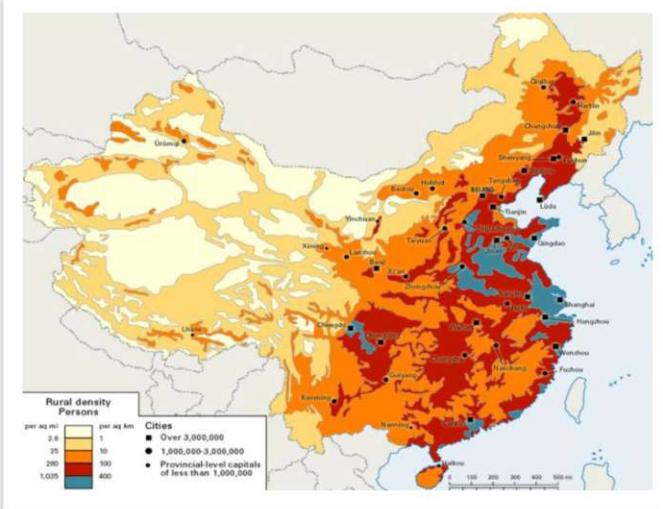
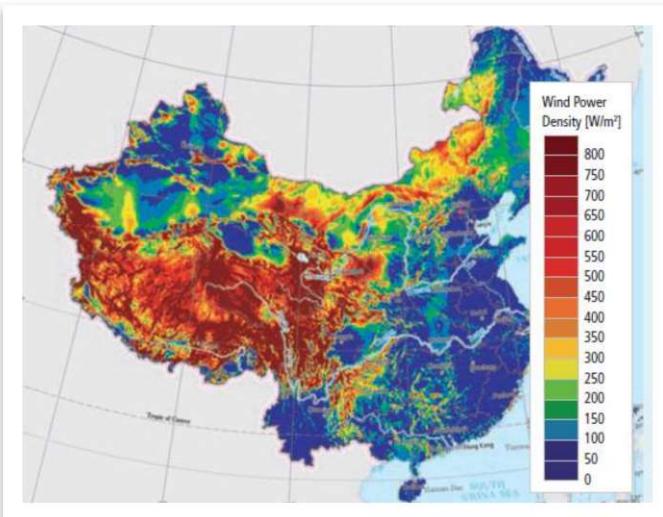
- Wind output is imperfectly predictable:
  - Lower level of predictability than fossil-fired power plants;
  - Forecast less accurate over longer time horizon (multiple hours to days).
- Wind output is subject to ramp events:
  - The output of a wind turbine can vary from zero to its rated capacity, 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



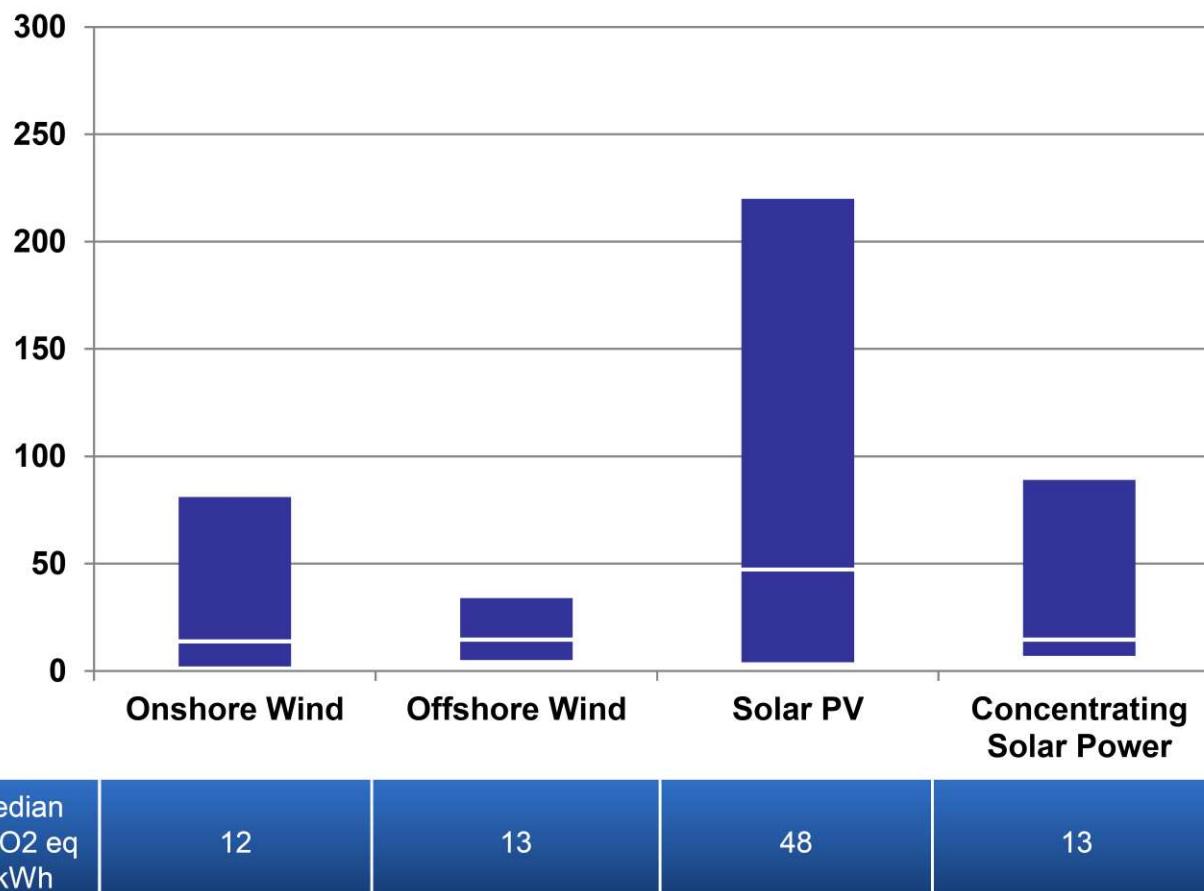
- Wind resource locations tend to be misaligned with large demand centers, requiring the construction of new long-distance transmission lines.
- Due to the impact of wind quality on economics, additional transmission infrastructure is sometimes economically justified.
- However additional long-distance 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<sub>2</sub> eq / kWh



- Wind does not directly emit GHGs or other pollutants.
- On average, wind emits 12g CO<sub>2</sub> 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<sub>2</sub> 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

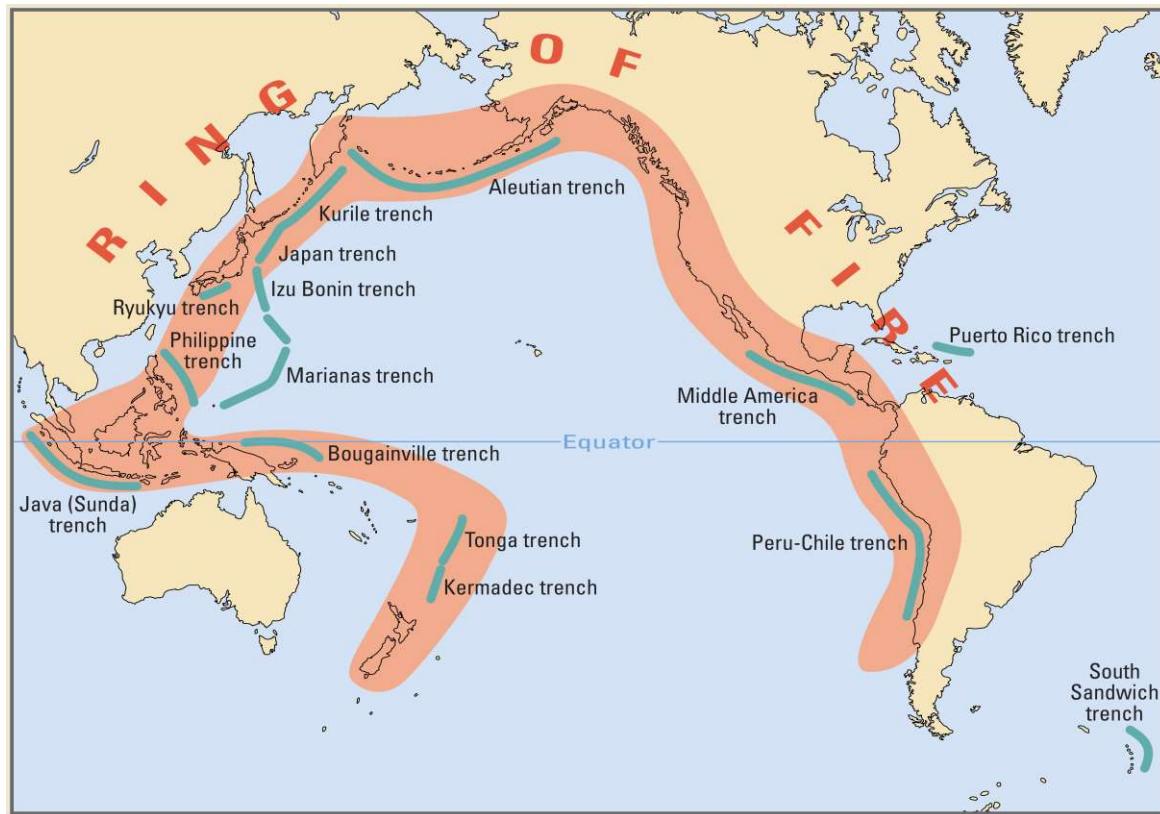


# Geothermal Energy

# 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



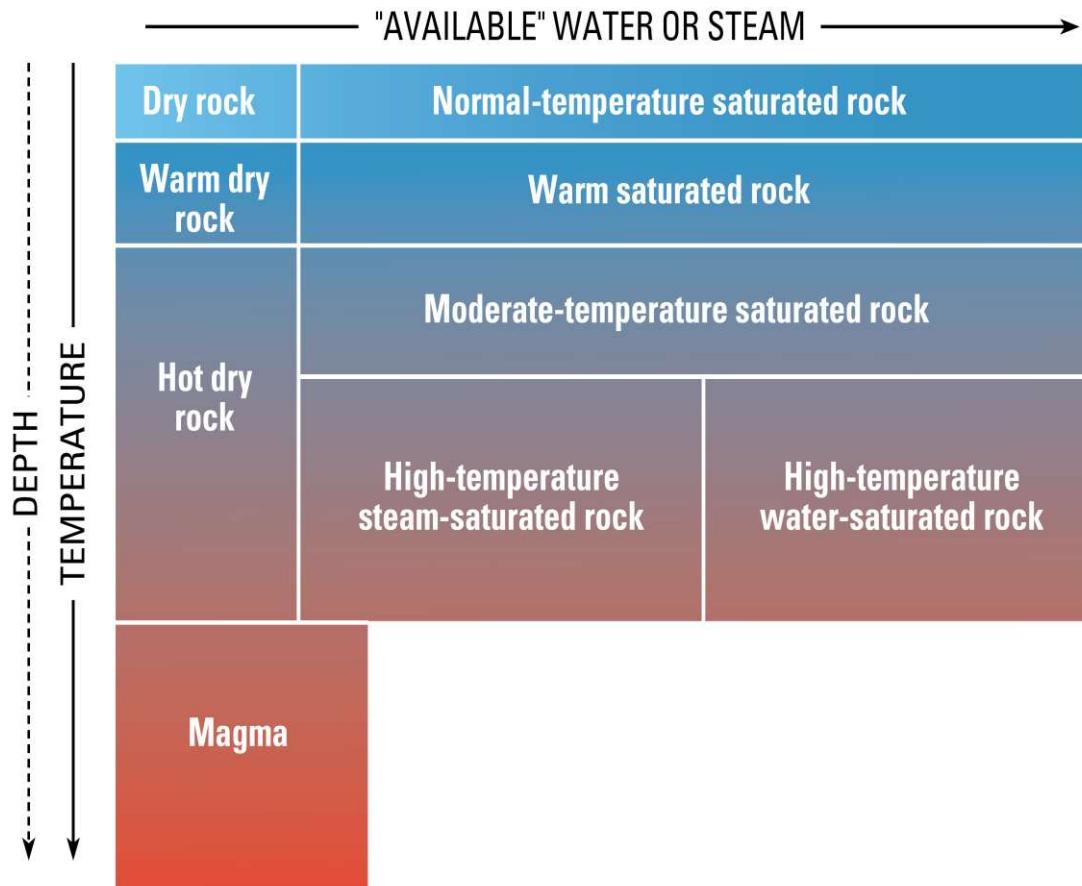
The volcanically active and earthquake-prone region rimming the Pacific Ocean is known as the "Ring of Fire." This region could also be called the Ring of Geothermal Energy, because it contains many high-temperature geothermal systems associated with active volcanoes.

- 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  $65 \text{ mW/m}^2$  on continents and  $101 \text{ mW/m}^2$  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  $12.6 \times 10^{12}$  EJ and that of the crust of the order of  $5.4 \times 10^9$  EJ to depths of up to 50 km.



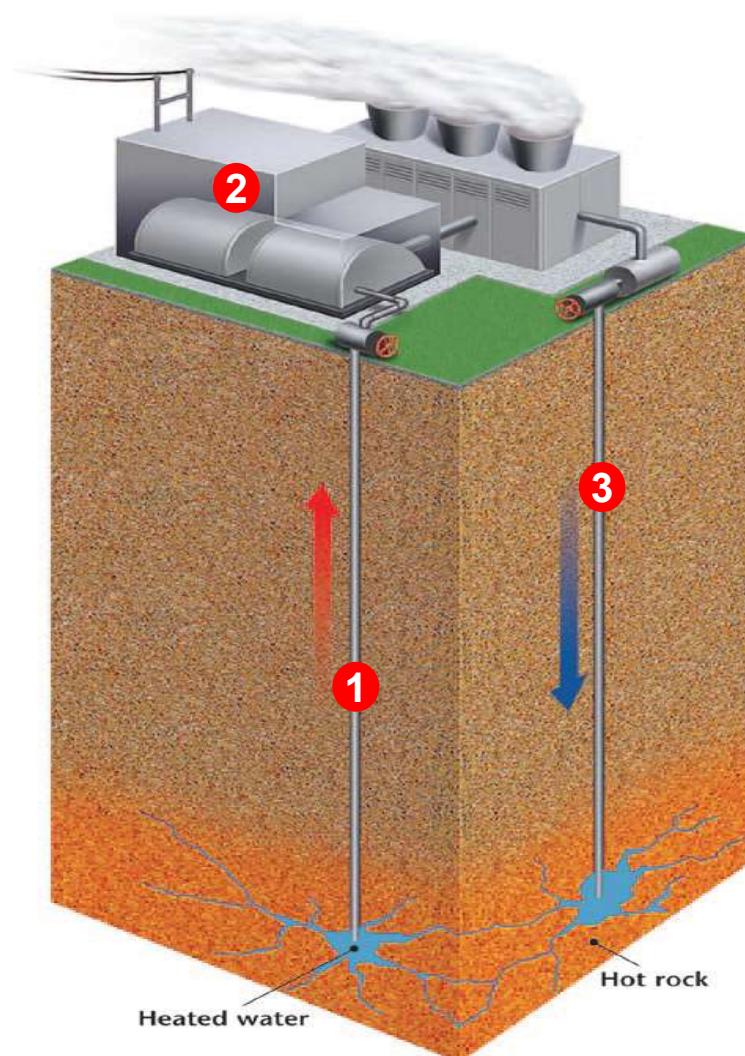
## DIFFERENT TYPES OF GEOTHERMAL ENVIRONMENT IN THE EARTH'S UPPER CRUST



- 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.



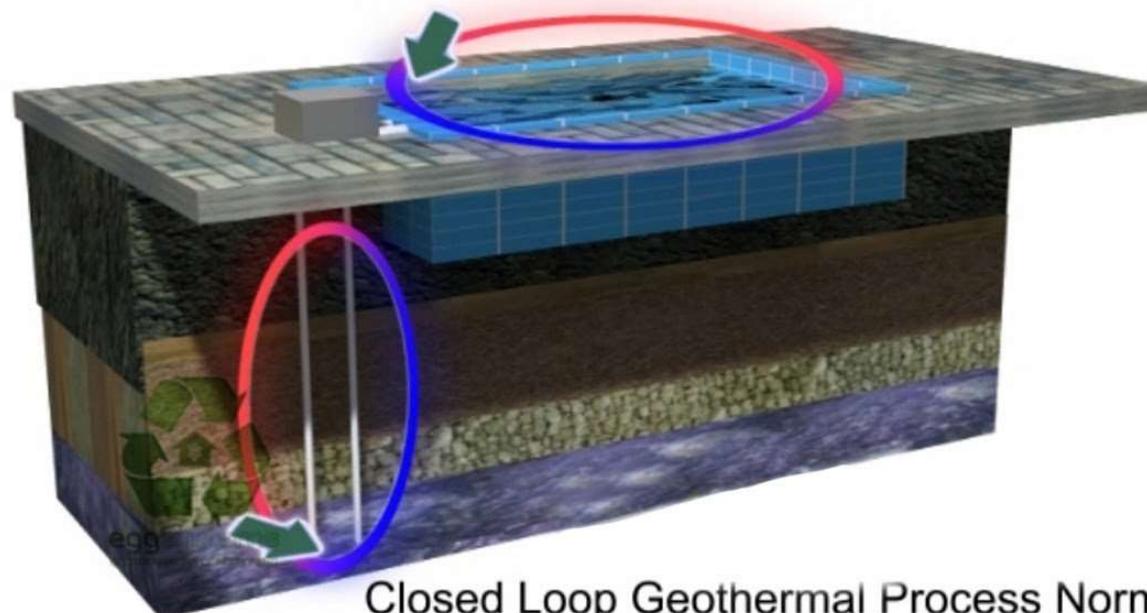
- The *Geysers Geothermal Complex* located about 121 km north of San Francisco, California, is comprised of 18 power plants making it the biggest geothermal installation in the world. The complex has an installed capacity of 1,517 MW and an active production capacity of 900 MW.



# 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.

Pool Water Through Closed Loop Heat Exchanger



Closed Loop Geothermal Process Normalizing  
Heat Exchanger Temperature

# Geothermal heat pump

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

The ground is warmer than the air in winter.



Heat is transferred from the ground to warm the house.

The ground is cooler than the air in summer.

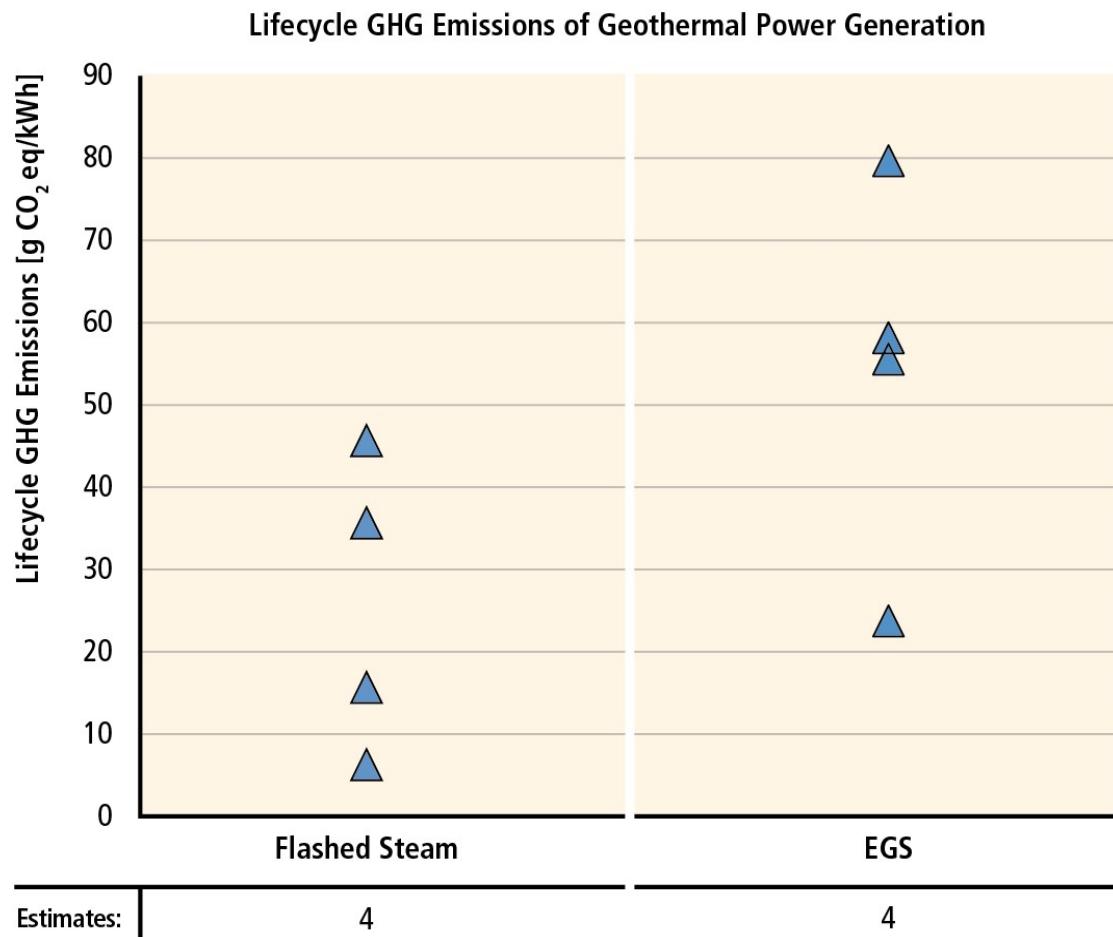


Heat is transferred from the house to the ground to cool the house.

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<sub>2</sub>, with the only direct emissions coming from the underground fluids in the reservoir.



- The full lifecycle CO<sub>2</sub>-equivalent emissions for geothermal energy technologies are less than 50 g CO<sub>2</sub> eq/kWh for flash steam geothermal power plants and less than 80 g CO<sub>2</sub> eq/kWh for EGS power plants.
- In closed-loop binary cycle power plants, the operational CO<sub>2</sub> emission is near zero.
- In direct heating applications, emissions of CO<sub>2</sub> 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

Very high efficiency

Moderate net energy at accessible sites

Lower CO<sub>2</sub> emissions than fossil fuels

Low cost at favorable sites

Low land use and disturbance

Moderate environmental impact



#### Disadvantages

Scarcity of suitable sites

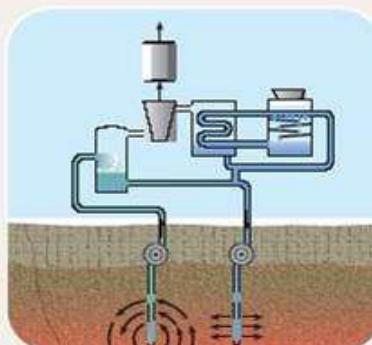
Can be depleted if used too rapidly

Environmental costs not included in market price

Moderate to high local air pollution

Noise and odor (H<sub>2</sub>S)

High cost except at the most concentrated and accessible sources





# Ocean Energy





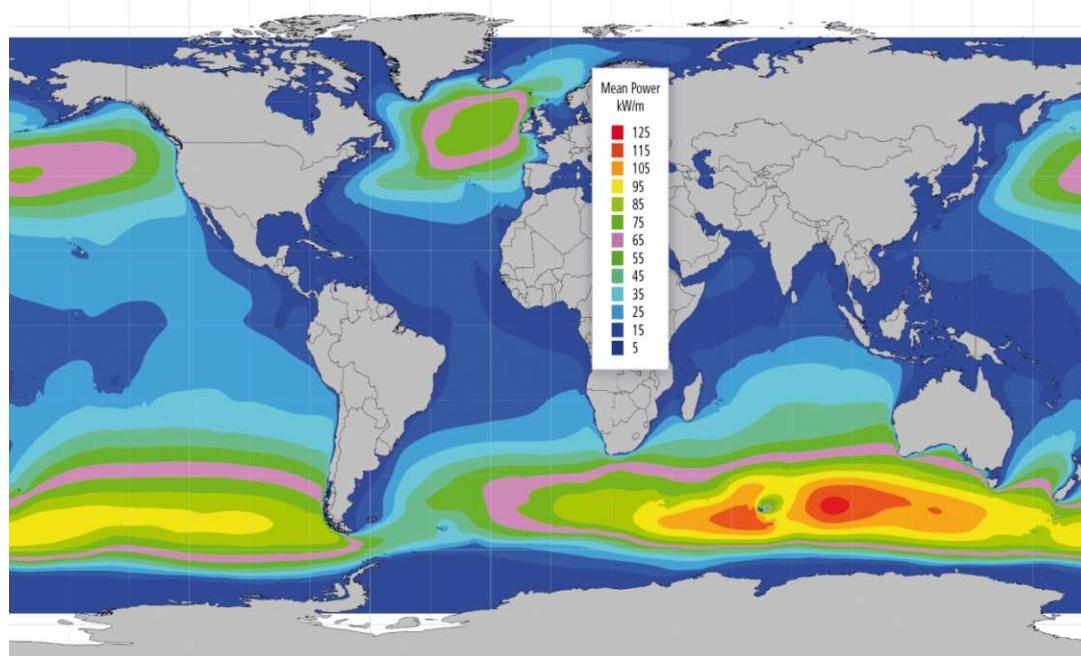
# Ocean energy

- 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.

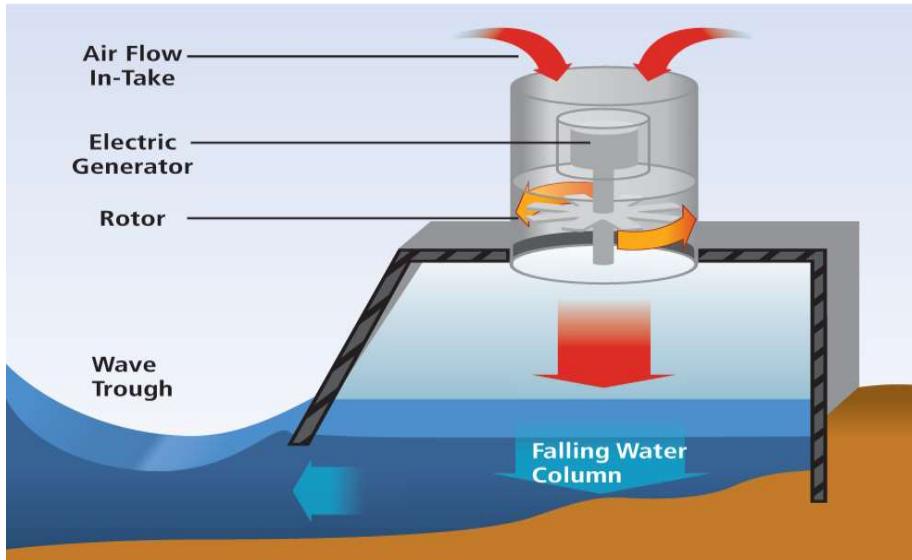
## GLOBAL OFFSHORE AVERAGE ANNUAL WAVE POWER DISTRIBUTION



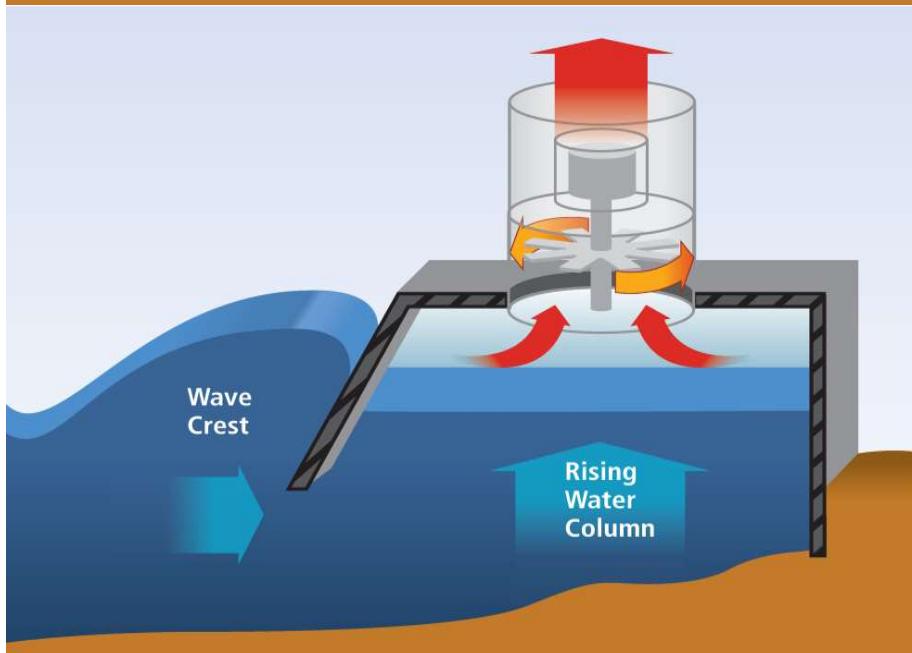
- Ocean wave energy is energy that has been transferred from the wind to the ocean. As the wind blows over the ocean, air-sea interaction transfers some of the wind energy to the water, forming waves, which store this energy as potential energy (in the mass of water displaced from the mean sea level)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

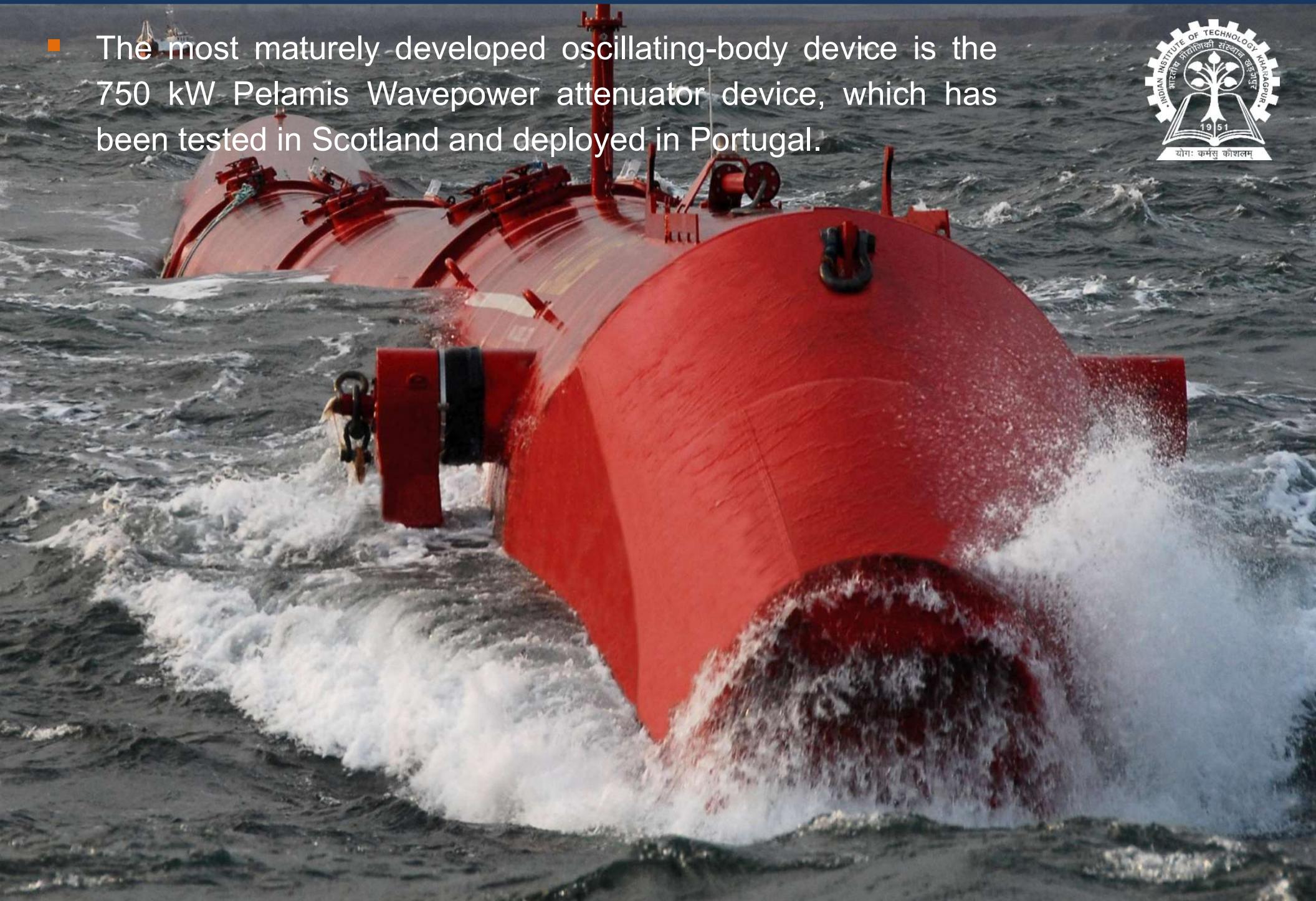


- As a wave rises, high-velocity air exhausts through an air turbine coupled to an electrical generator, which converts the kinetic energy into electricity.



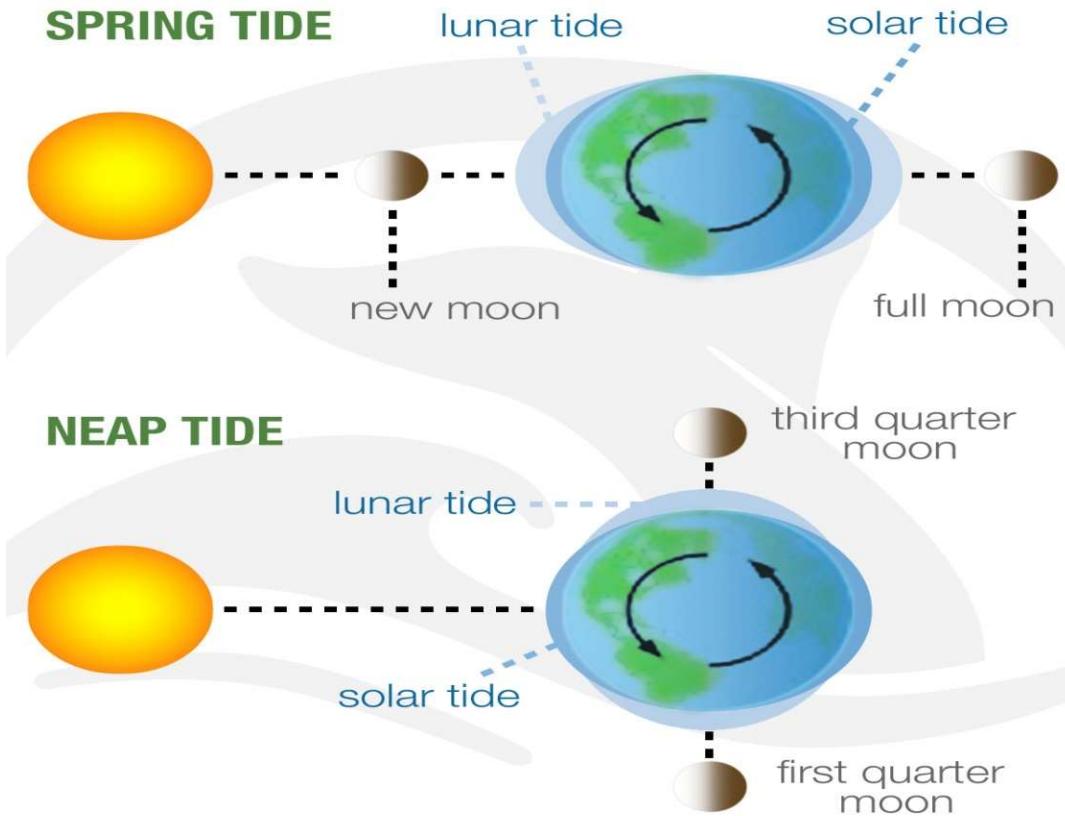
- When the wave falls, the airflow reverses and fills the chamber, generating another pulse of energy (bottom).

- 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.



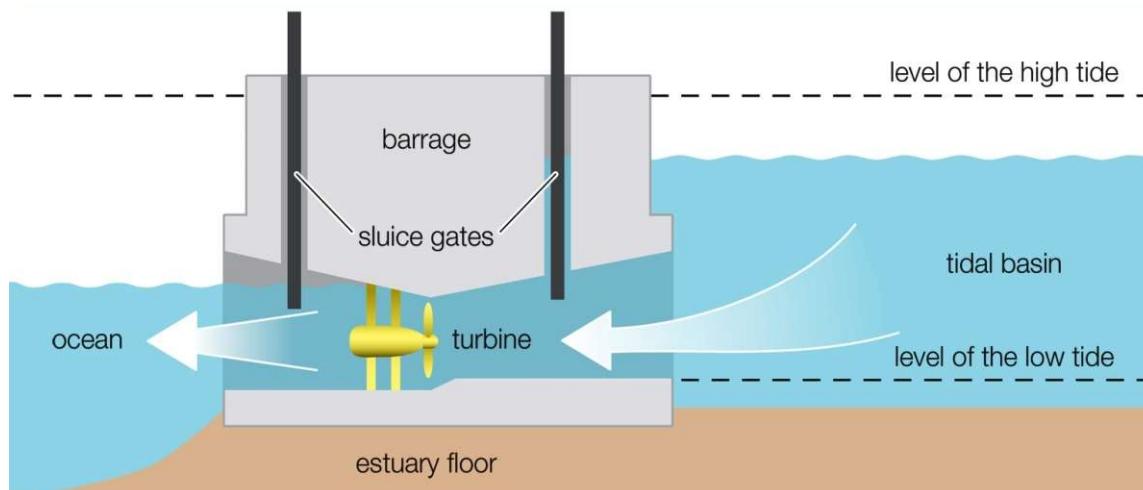
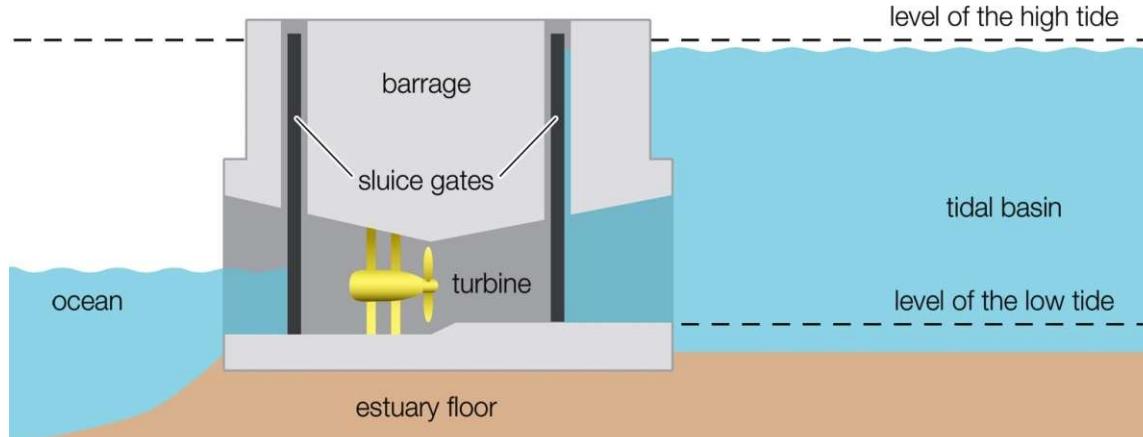
During the year, the amplitude of the tides varies depending on the respective positions of the Earth, the Moon and the Sun. **Spring tides** (maximum tidal range) occur when the Sun, Moon and Earth are aligned (at full moon and at new moon). **Neap tides** (minimum tidal range) occur when the gravitational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

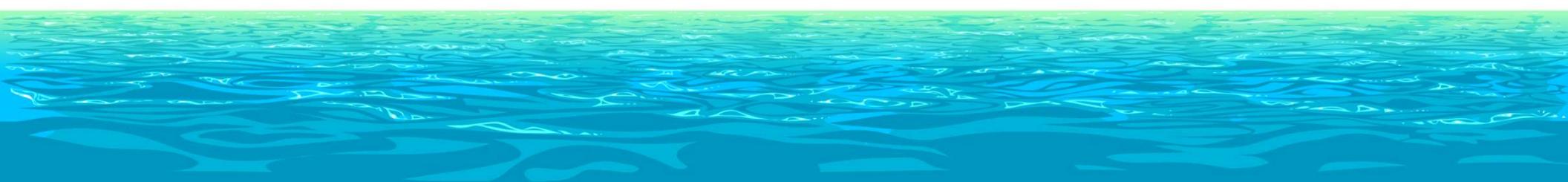


- The basin is filled with water until high tide, when the sluice gates are shut.
- During low tide, the sluice gates are opened, allowing water to flow from the tidal basin, and through the turbine inside the barrage (after several hours, the gates close to begin the process again).
- The water flows 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.

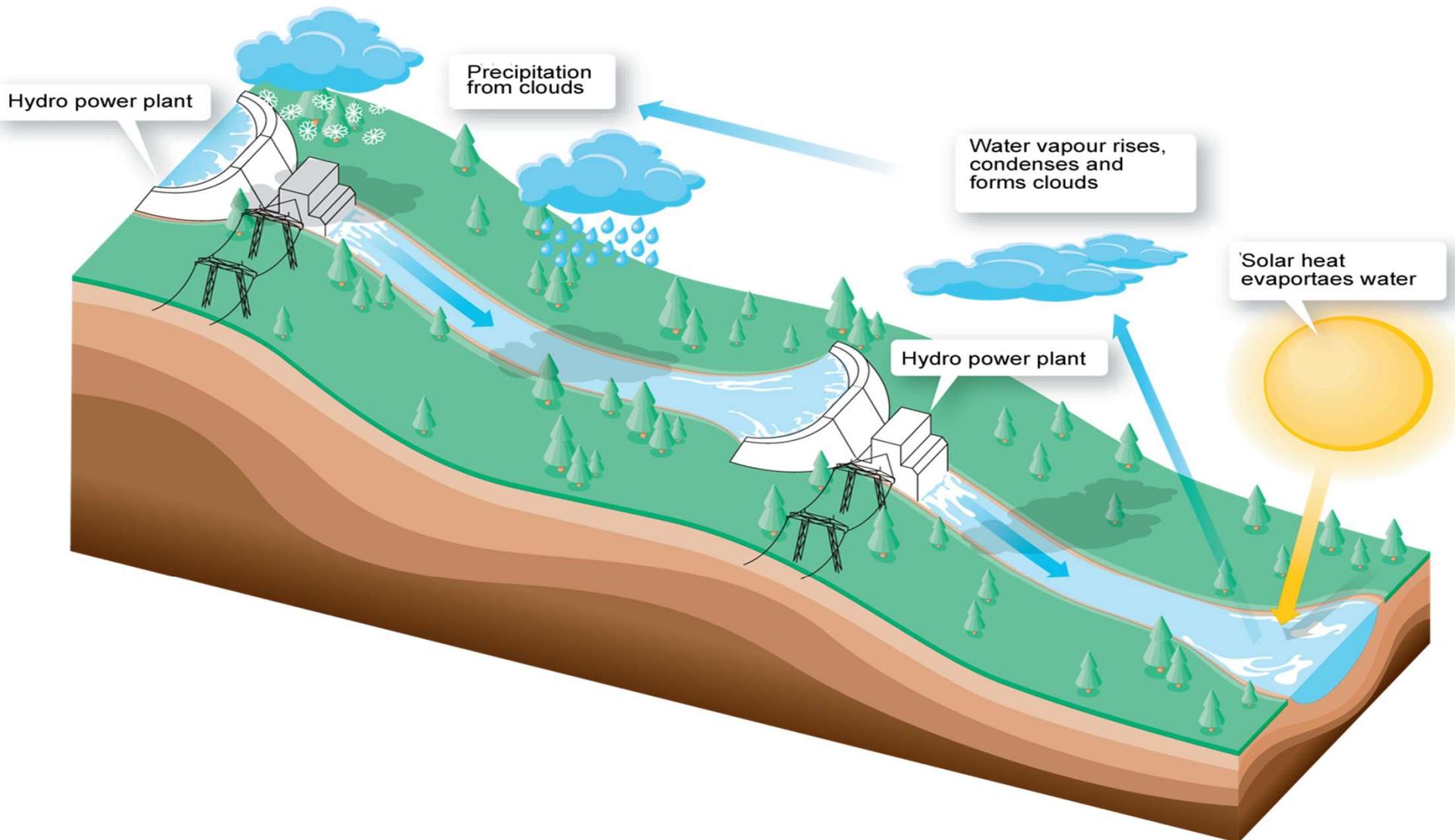




# Hydroelectricity

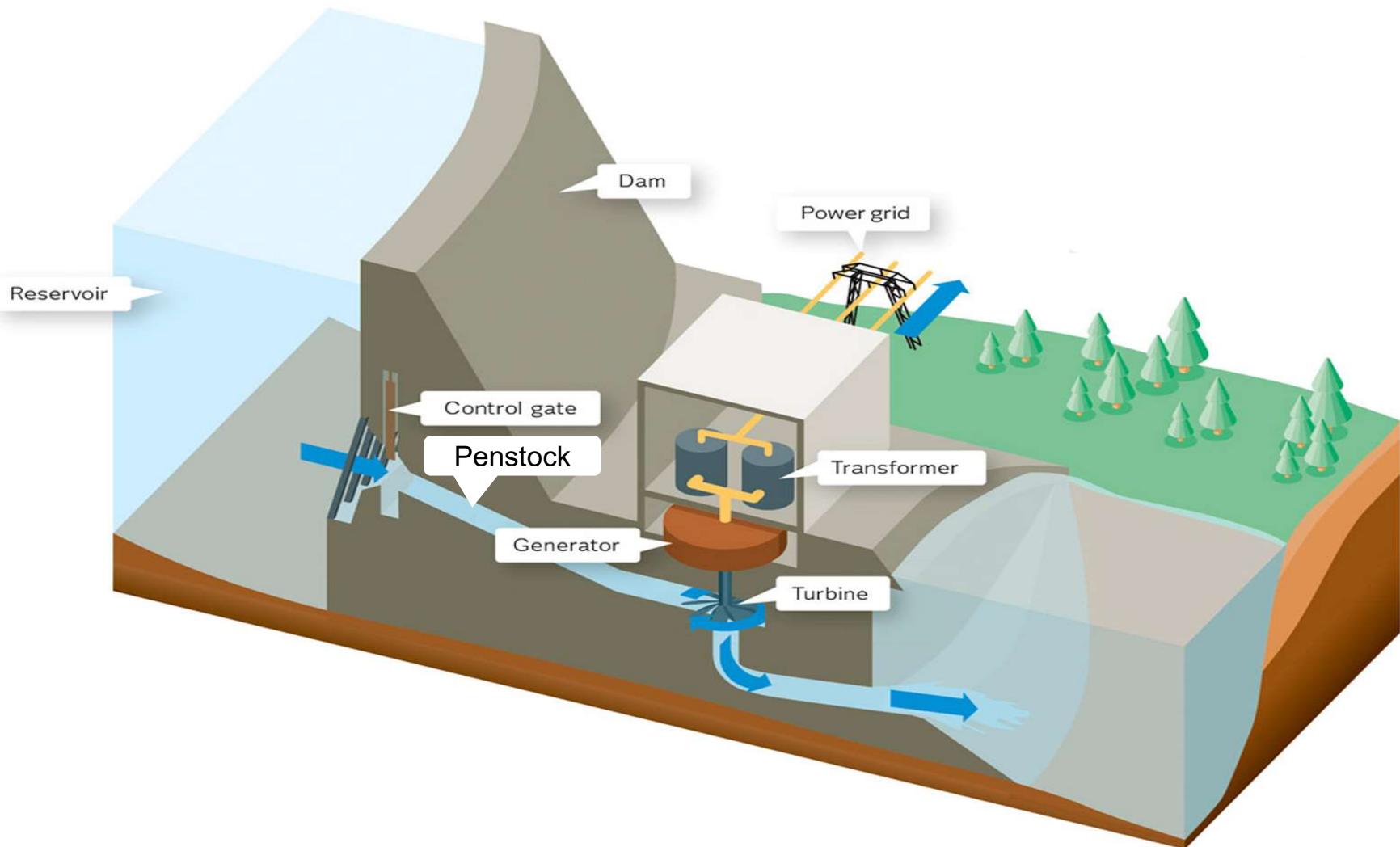
# Hydroelectricity

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





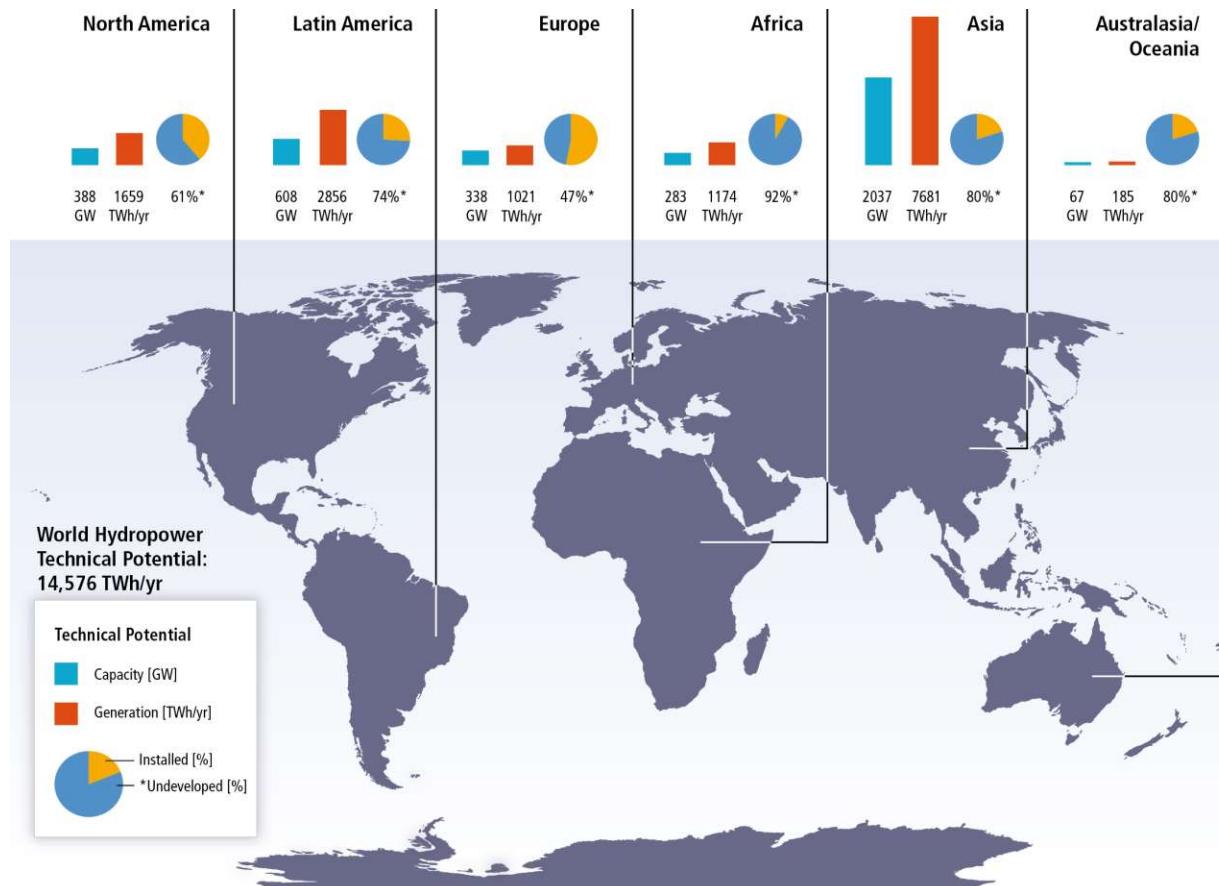
- The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Water released at a height from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity.



- 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<sup>3</sup>, out of which 28,000 km<sup>3</sup> 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.



Irrigation



Domestic & Industrial  
Water Supply



Recreation



- 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		Social aspects	
Advantages	Disadvantages	Advantages	Disadvantages
<p>Produces no atmospheric pollutants</p> <p>Neither consumes nor pollutes the water it uses for electricity generation purposes</p> <p>Produces no waste</p> <p>Avoids depleting non-renewable fuel resources (i.e. coal, gas, oil)</p> <p>Very few greenhouse gas emissions relative to other large-scale energy options</p> <p>Can create new freshwater ecosystems with increased productivity</p> <p>Enhances knowledge and improves management of valued species due to study results</p> <p>Can result in increased attention to existing environmental issues in the affected area</p>	<p>Inundation of terrestrial habitat</p> <p>Modification of hydrological regimes</p> <p>Modification of aquatic habitats</p> <p>Water quality needs to be monitored/managed</p> <p>Greenhouse gas emissions can arise under certain conditions in tropical reservoirs</p> <p>Temporary introduction of methylmercury into the food chain needs to be monitored/managed</p> <p>Species activities and populations need to be monitored/managed</p> <p>Barriers for fish migrations, fish entrainment</p> <p>Sediment composition and transport may need to be monitored/managed</p> <p>Introduction of pest species needs to be monitored/managed</p>	<p>Leaves water available for other uses</p> <p>Often provides flood protection</p> <p>May enhance navigation conditions</p> <p>Often enhances recreational facilities</p> <p>Enhances accessibility of the territory and its resources (access roads and ramps, bridges)</p> <p>Provides opportunities for construction and operation with a high percentage of local manpower</p> <p>Improves living conditions</p> <p>Sustains livelihoods (fresh water, food supply)</p>	<p>May involve resettlement</p> <p>May restrict navigation</p> <p>Local land use patterns will be modified</p> <p>Waterborne disease vectors may occur</p> <p>Requires management of competing water uses</p> <p>Effects on impacted peoples' livelihoods need to be addressed, with particular attention to vulnerable social groups</p> <p>Effects on cultural heritage may need to be addressed</p>

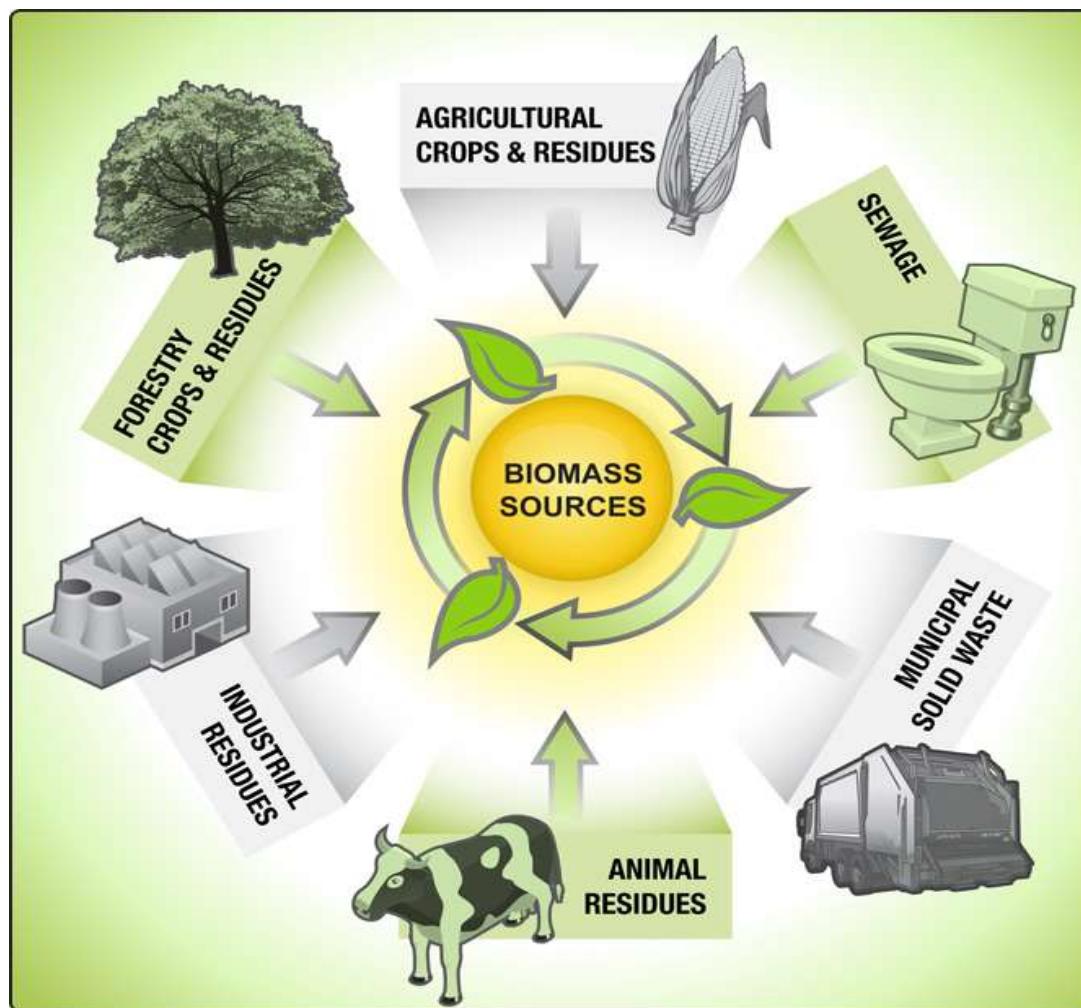


# Bioenergy



# Bioenergy

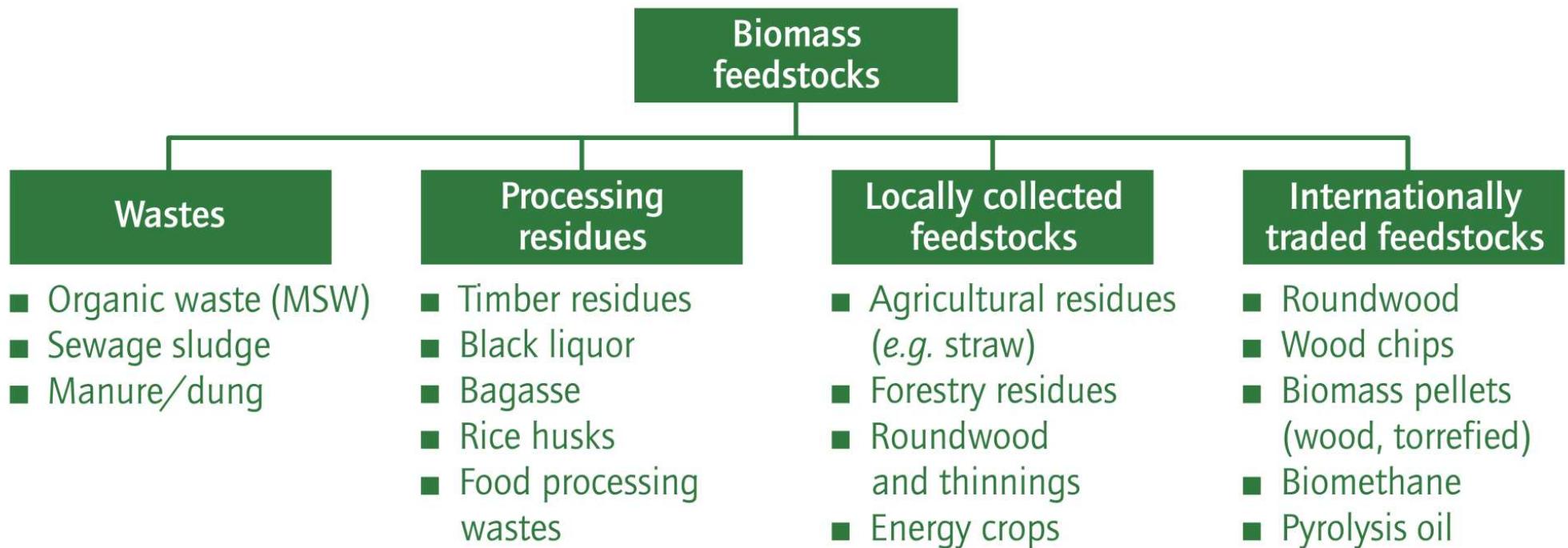
- Bioenergy is embedded in complex ways in global biomass systems for food, fodder and fibre production and for forest products; in wastes and residue management; and in the everyday living of the developing countries' poor.



- As a feedstock for producing electricity or heat, biomass has a number of advantages over fossil fuels.

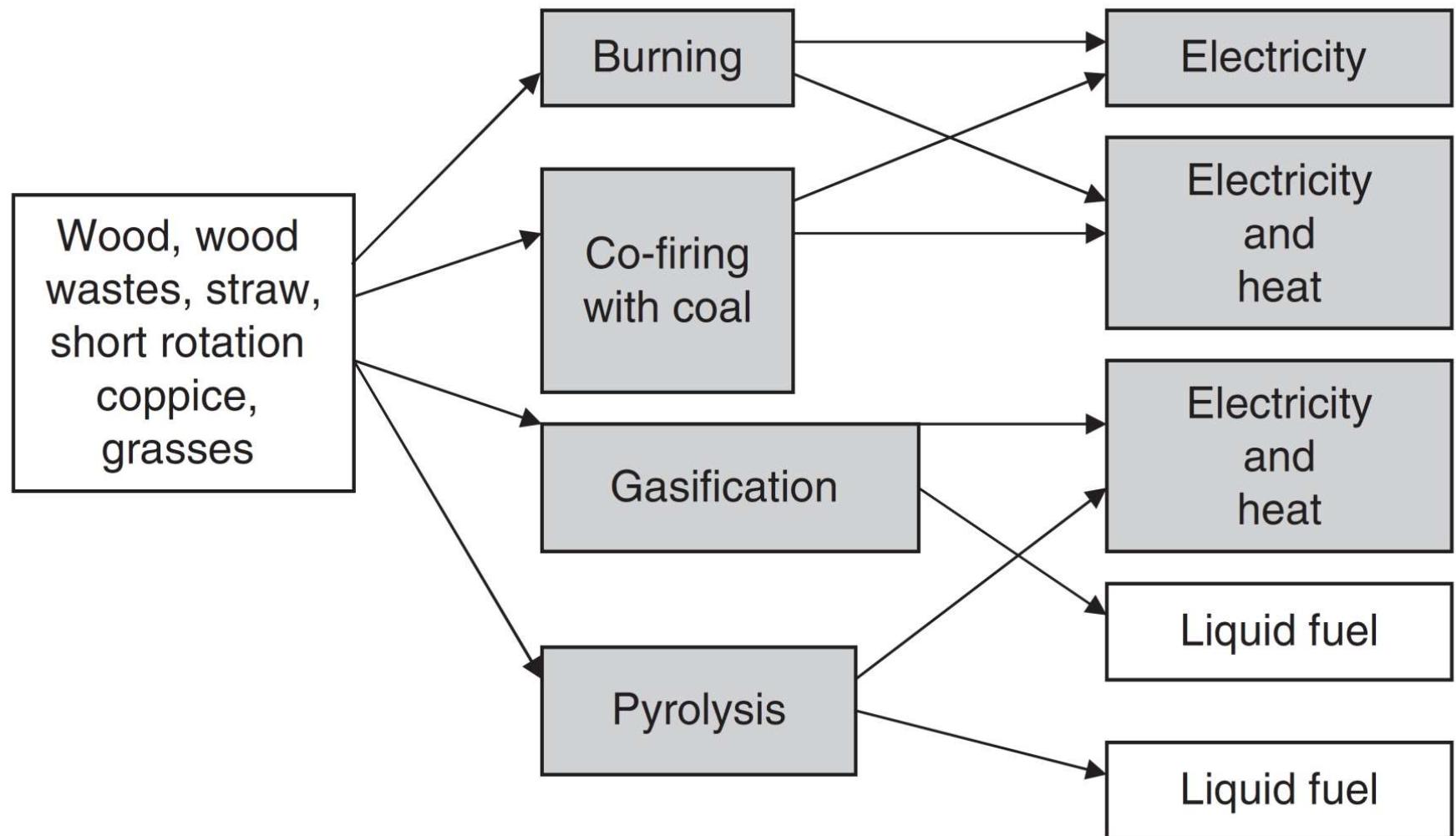


- It is widely distributed, relatively easy to collect and use, and can produce less net CO<sub>2</sub> emissions than fossil fuels per unit of useful energy delivered, if sourced sustainably.
- In addition, biomass usually contains less sulphur than coal or oil.



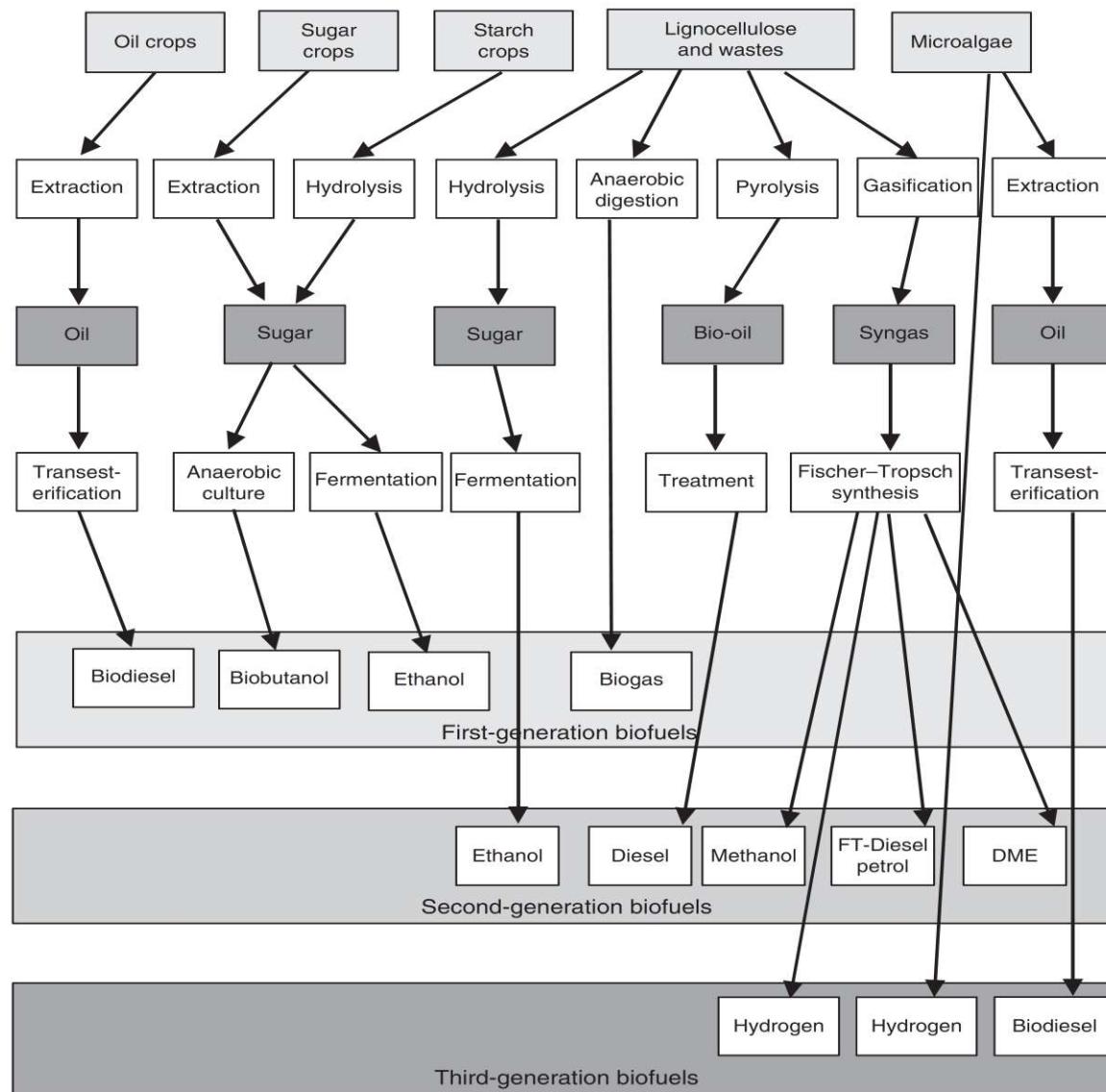
# Biomass for heat and electricity

- 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.

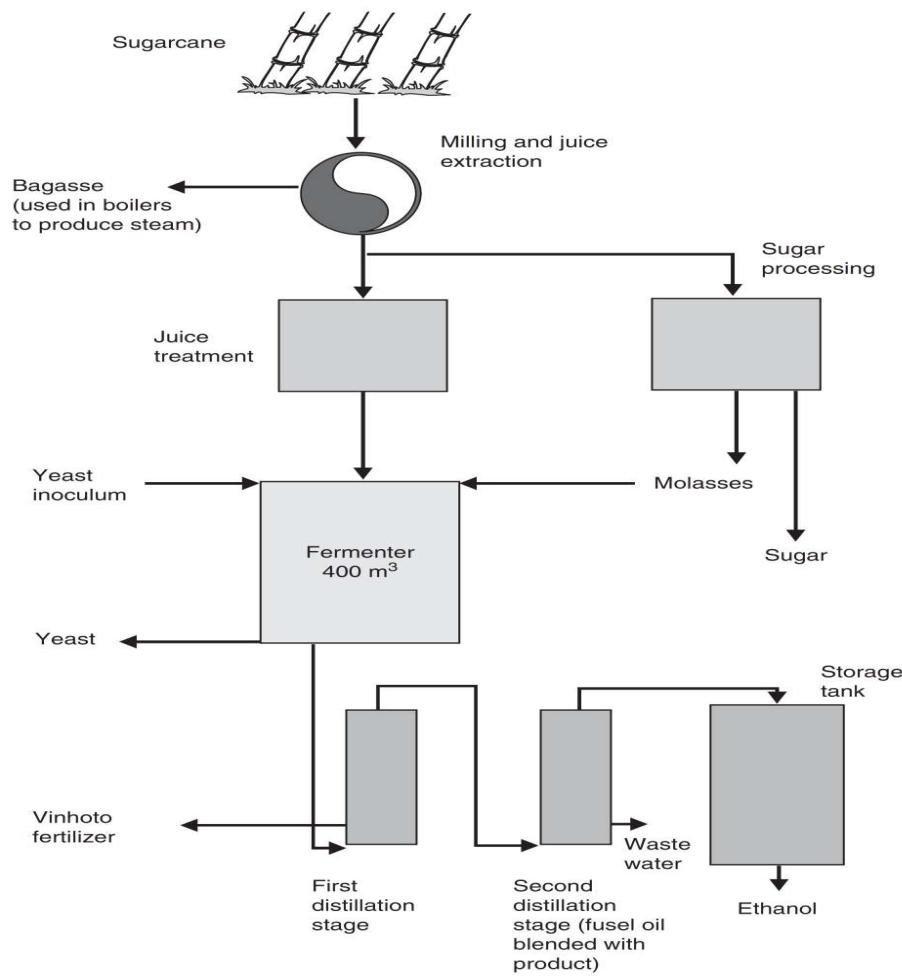


- Biofuels can not only be used for both electricity generation and heating, but also most importantly as a transport fuel.
- Those biofuels currently used and produced in large quantities are the **first- generation** biofuels.
- The biofuels that have been produced but technical difficulties and high 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.

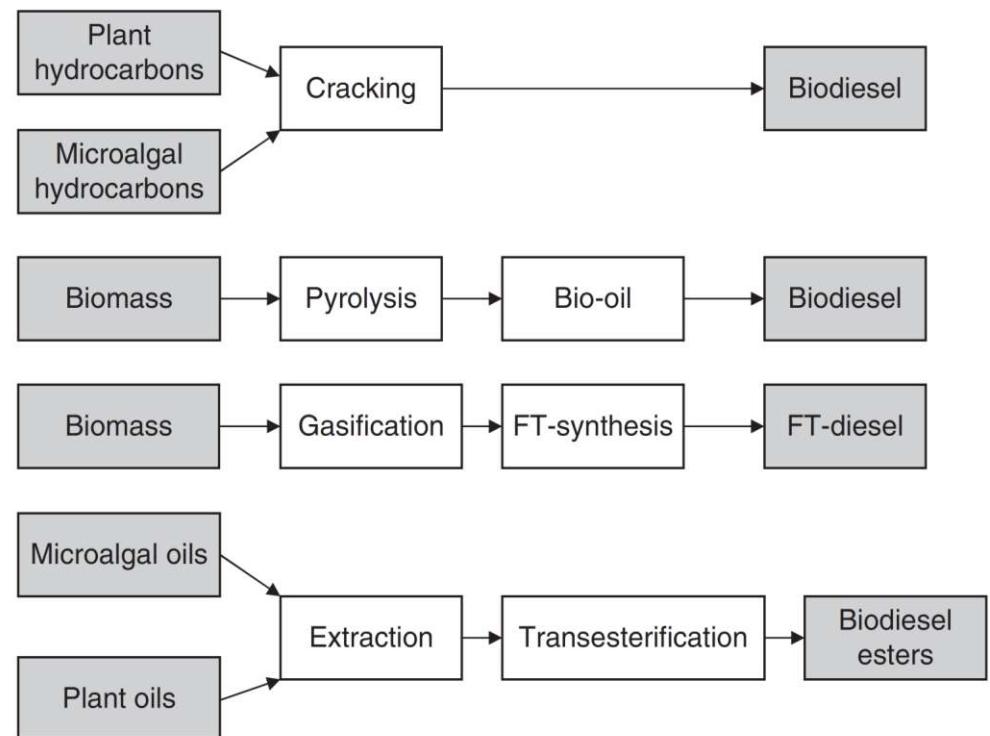
# Liquid biofuels

- 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<sub>2</sub> 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<sub>2</sub> emissions (corn)

Much higher cost

Environmental costs not included in market price

May compete with growing food and raise food prices

Higher NO<sub>x</sub> 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<sub>2</sub> emissions (78%)

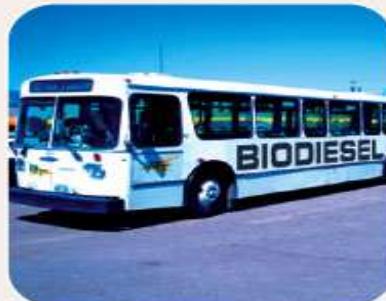
High net energy yield for oil palm crops

Moderate net energy yield for rapeseed crops

Reduced hydrocarbon emissions

Better gas mileage (40%)

Potentially renewable



#### Disadvantages

Increased NO<sub>x</sub> emissions and more smog

Higher cost than regular diesel

Environmental costs not included in market price

Low net energy yield for soybean crops

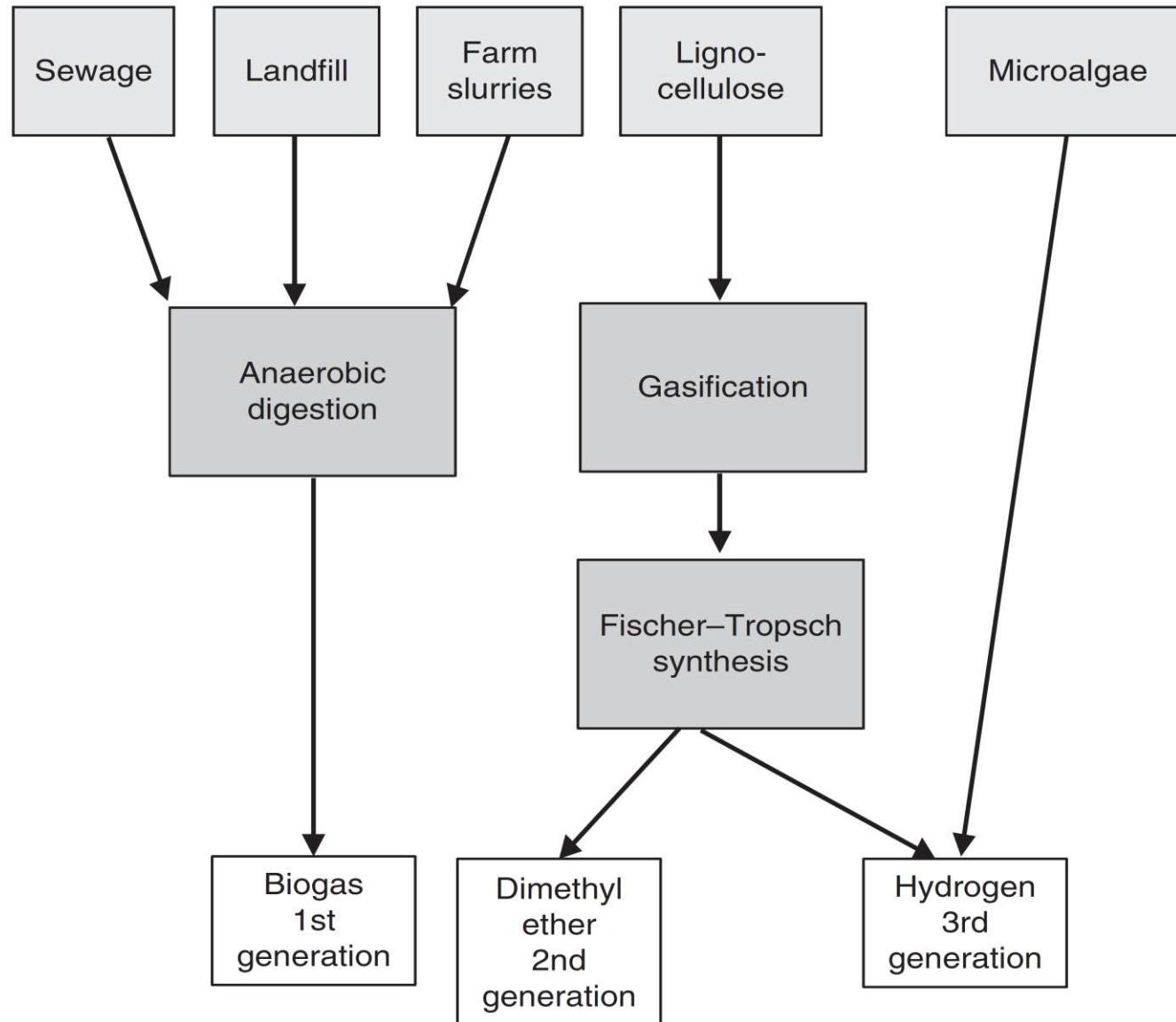
May compete with growing food on cropland and raise food prices

Loss and degradation of biodiversity from crop plantations

Can make engines hard to start in cold weather

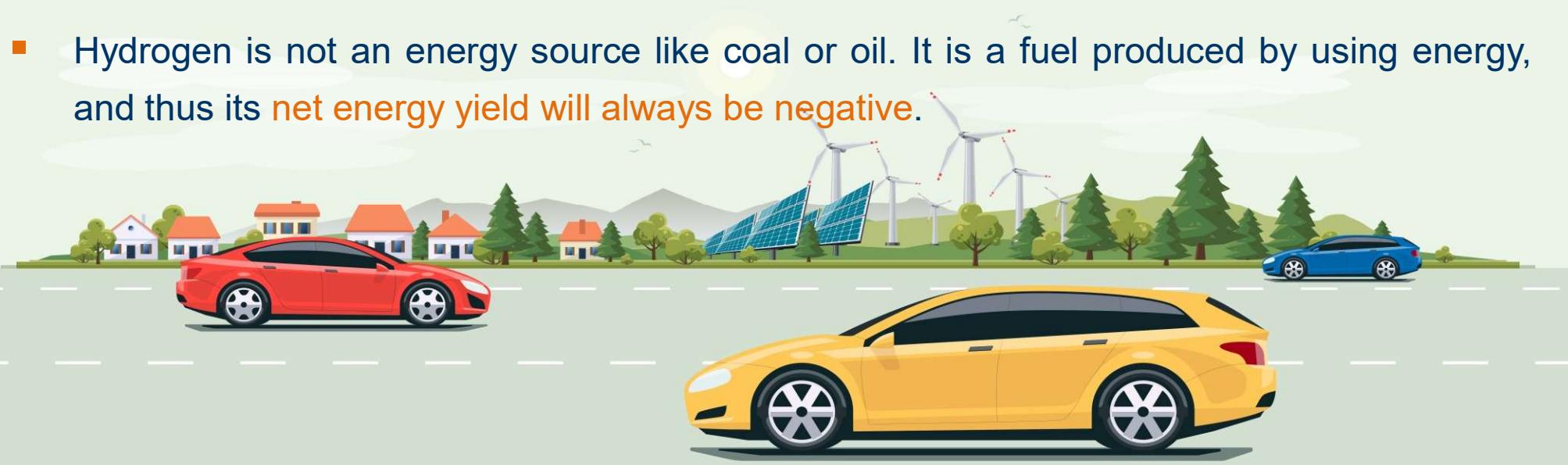
# Gaseous biofuels

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

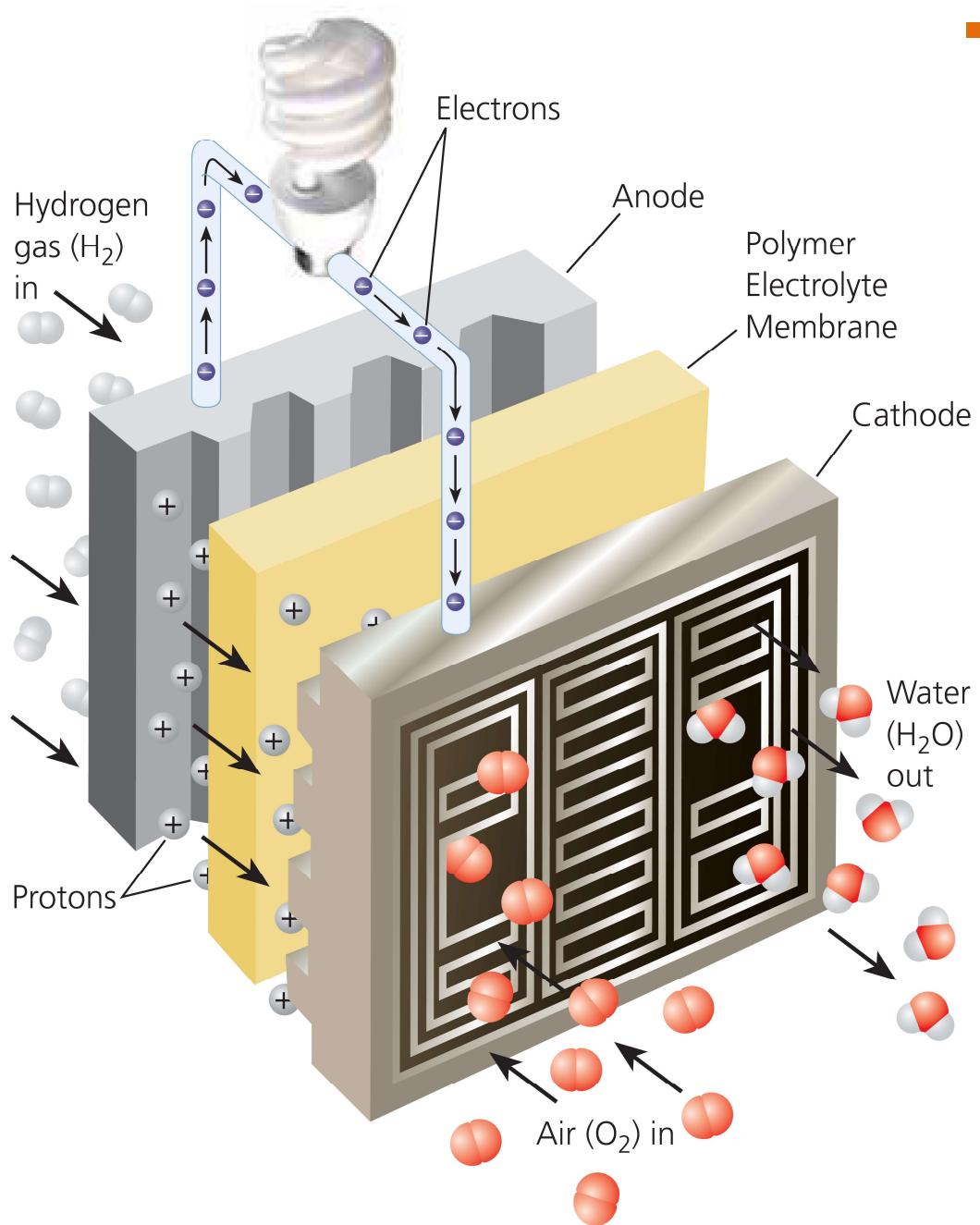


# Hydrogen energy

- 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<sub>2</sub>.
- 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.

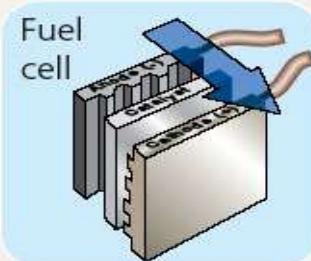
# The good & bad of hydrogen

## Trade-Offs

### Hydrogen

#### **Advantages**

- Can be produced from plentiful water
- Low environmental impact
- Renewable if produced from renewable energy resources
- No CO<sub>2</sub> 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<sub>2</sub> in nature
- Energy is needed to produce fuel
- Negative net energy
- CO<sub>2</sub> 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<sub>2</sub> leaks may deplete ozone in the atmosphere

