EV20001: ENVIRONMENTAL SCIENCE

Lecture #4

Climate Change: Scientific Basis, Mitigation & Adaption

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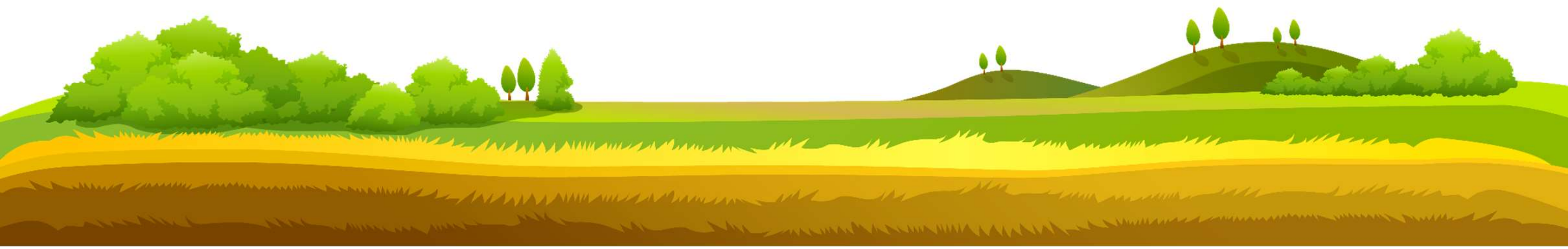
Climate Change: A Primer

- Climate is the statistical description of weather conditions and their variations, including both averages and extremes.
- Climate change is the alteration in the average weather pattern over a long period of time.
- Greenhouse gases (GHGs) play an important role in determining climate and causing climate change.
- These gases act like an insulating blanket, keeping the Earth's surface warmer than it would be if they were not present in the atmosphere, a phenomenon known as greenhouse effect.
- GHGs include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and some industrial gases such as chlorofluorocarbons (CFCs).



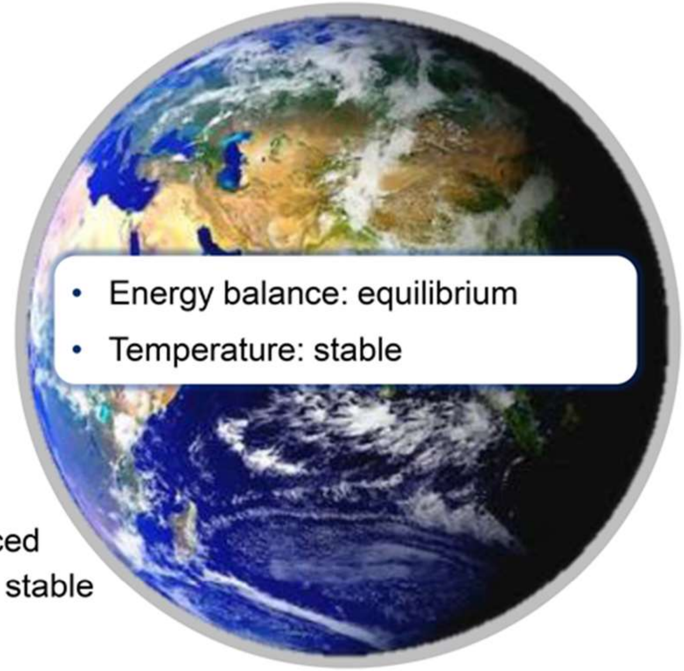
Science of Climate Change

The Greenhouse Effect

EARTH'S ENERGY BUDGET VIEWED FROM THE TOP OF THE ATMOSPHERE

Greenhouse gases

Incoming solar radiation

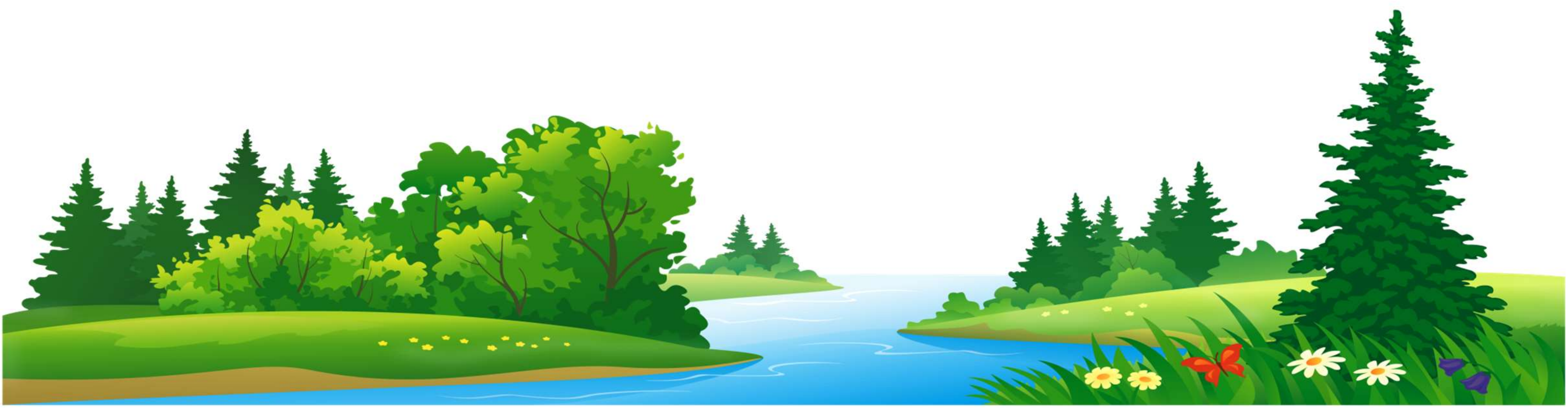


Emitted heat radiation
= Incoming radiation

❶ Initial equilibrium state

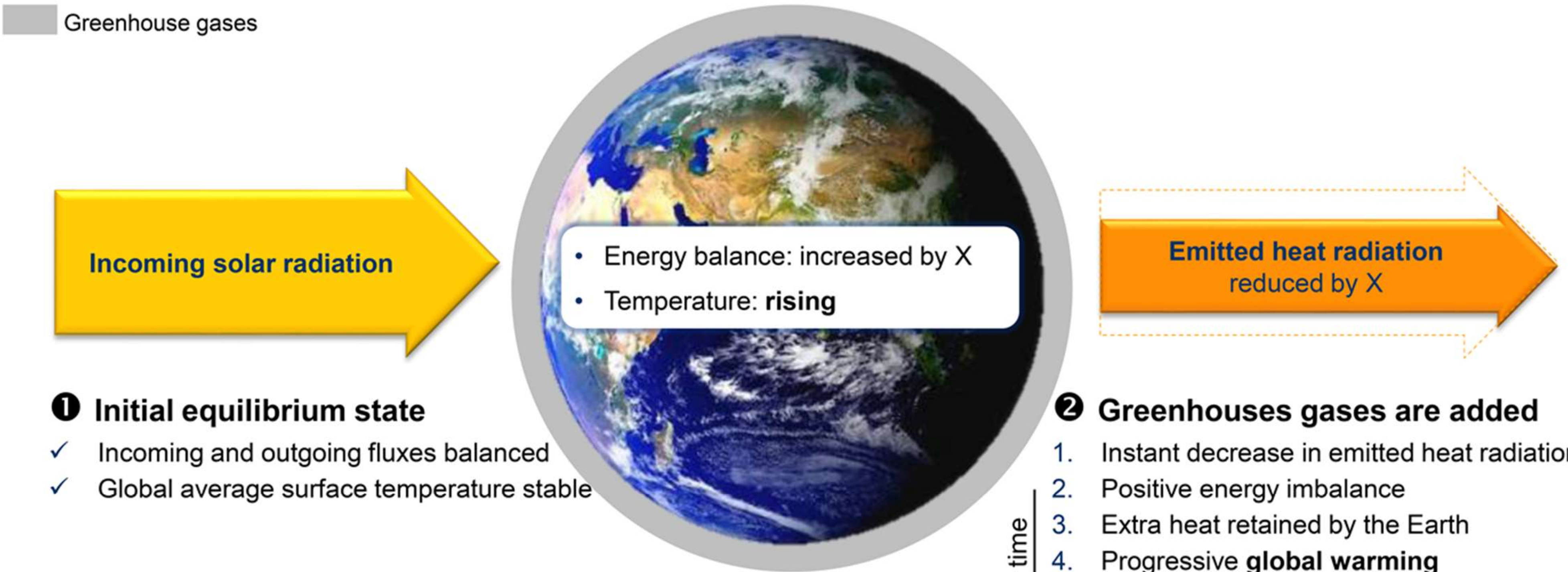
✓ Incoming and outgoing fluxes balanced

✓ Global average surface temperature stable



The Greenhouse Effect

EARTH'S ENERGY BUDGET VIEWED FROM THE TOP OF THE ATMOSPHERE



❶ Initial equilibrium state

- ✓ Incoming and outgoing fluxes balanced
- ✓ Global average surface temperature stable

❷ Greenhouses gases are added

time

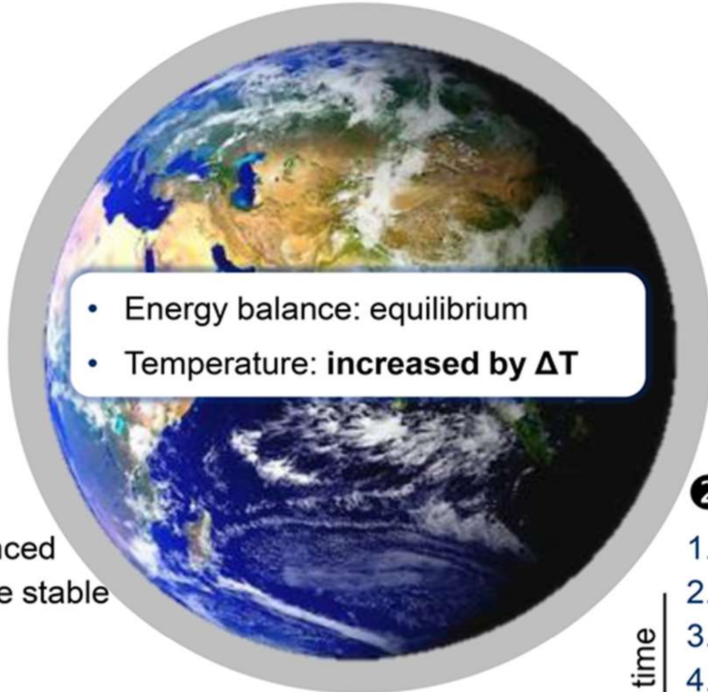
1. Instant decrease in emitted heat radiation
2. Positive energy imbalance
3. Extra heat retained by the Earth
4. Progressive **global warming**
5. Gradual increase in emitted heat radiation

The Greenhouse Effect

EARTH'S ENERGY BUDGET VIEWED FROM THE TOP OF THE ATMOSPHERE

Greenhouse gases

Incoming solar radiation
(~340 W/m²)



Emitted heat radiation
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❶ Initial equilibrium state

- ✓ Incoming and outgoing fluxes balanced
- ✓ Global average surface temperature stable

❷ Greenhouses gases are added

time ↓

1. Instant decrease in emitted heat radiation
2. Positive energy imbalance
3. Extra heat retained by the Earth
4. Progressive global warming
5. Gradual increase in emitted heat radiation

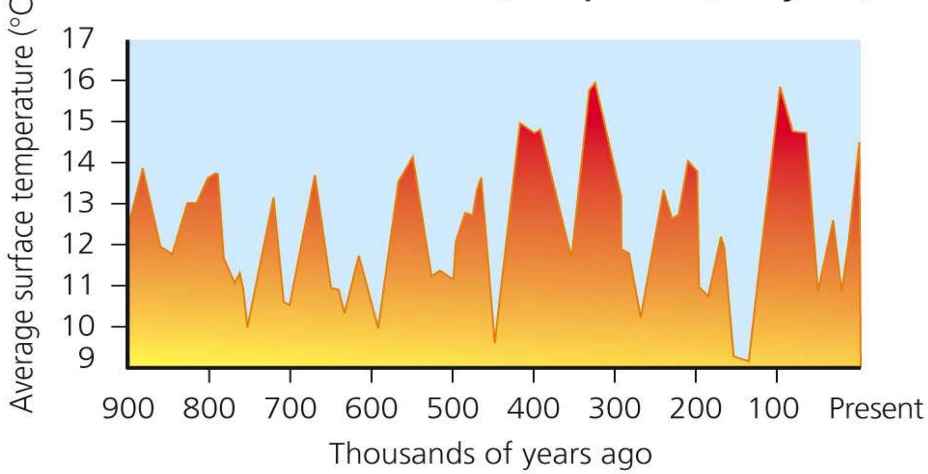
❸ New equilibrium reached

- ✓ Stabilization takes several centuries (**climate lag**)
- ✓ Energy balance back to equilibrium
- ✓ New average temperature (increased by ΔT)
- ✓ Induced **climate change**[1]

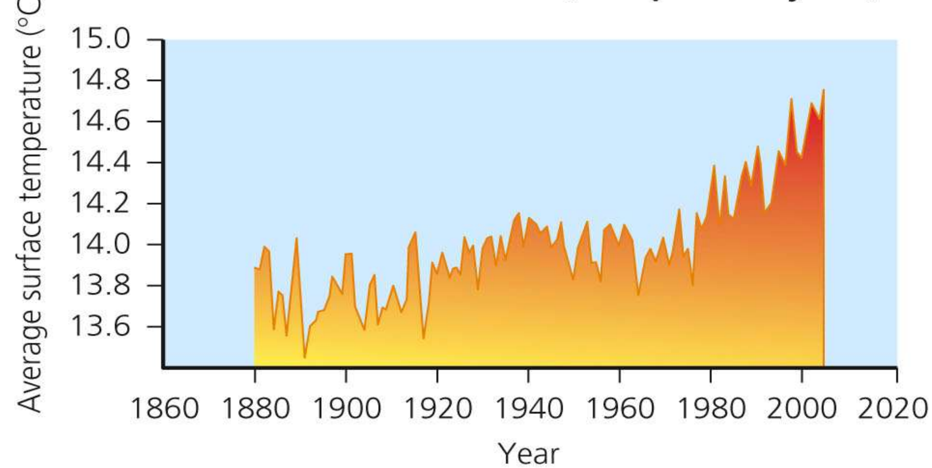
The Earth's Climate in the Past

- During the past million years, the average temperature of the Earth's surface has risen and fallen by about 5 ^{o}C. The millennium before the industrial revolution have been relatively stable.

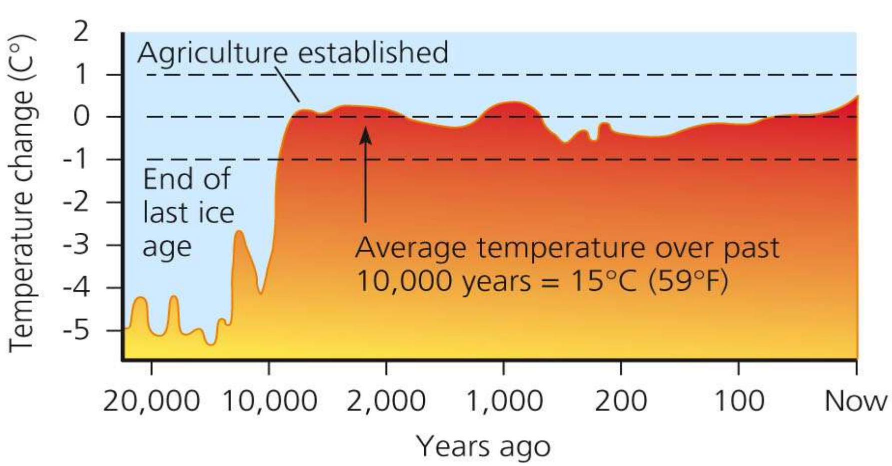
AVERAGE TEMPERATURE (over past 900,000 years)



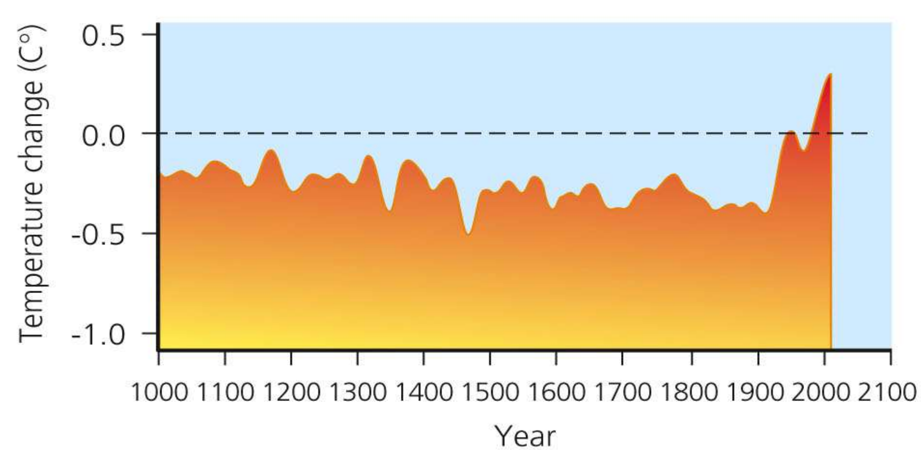
AVERAGE TEMPERATURE (over past 130 years)



TEMPERATURE CHANGE (over past 22,000 years)



TEMPERATURE CHANGE (over past 1,000 years)

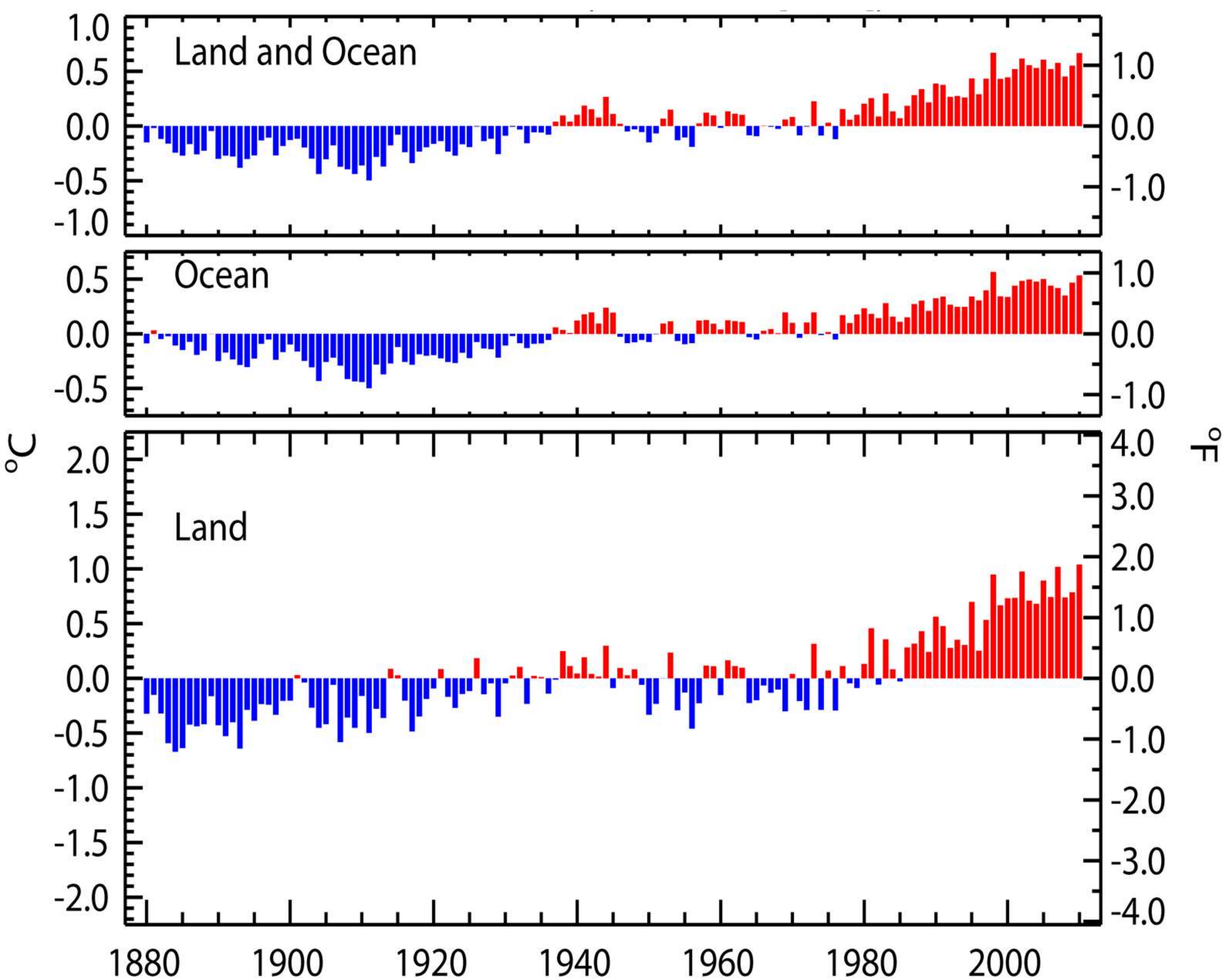


Estimating Past Temperatures

- Past temperature changes are estimated by analysis of radioisotopes in rocks and fossils, plankton and radioisotopes in ocean sediments, tiny bubbles of ancient air found in ice cores from glaciers, pollen from bottoms of lakes, tree rings, and historical records.

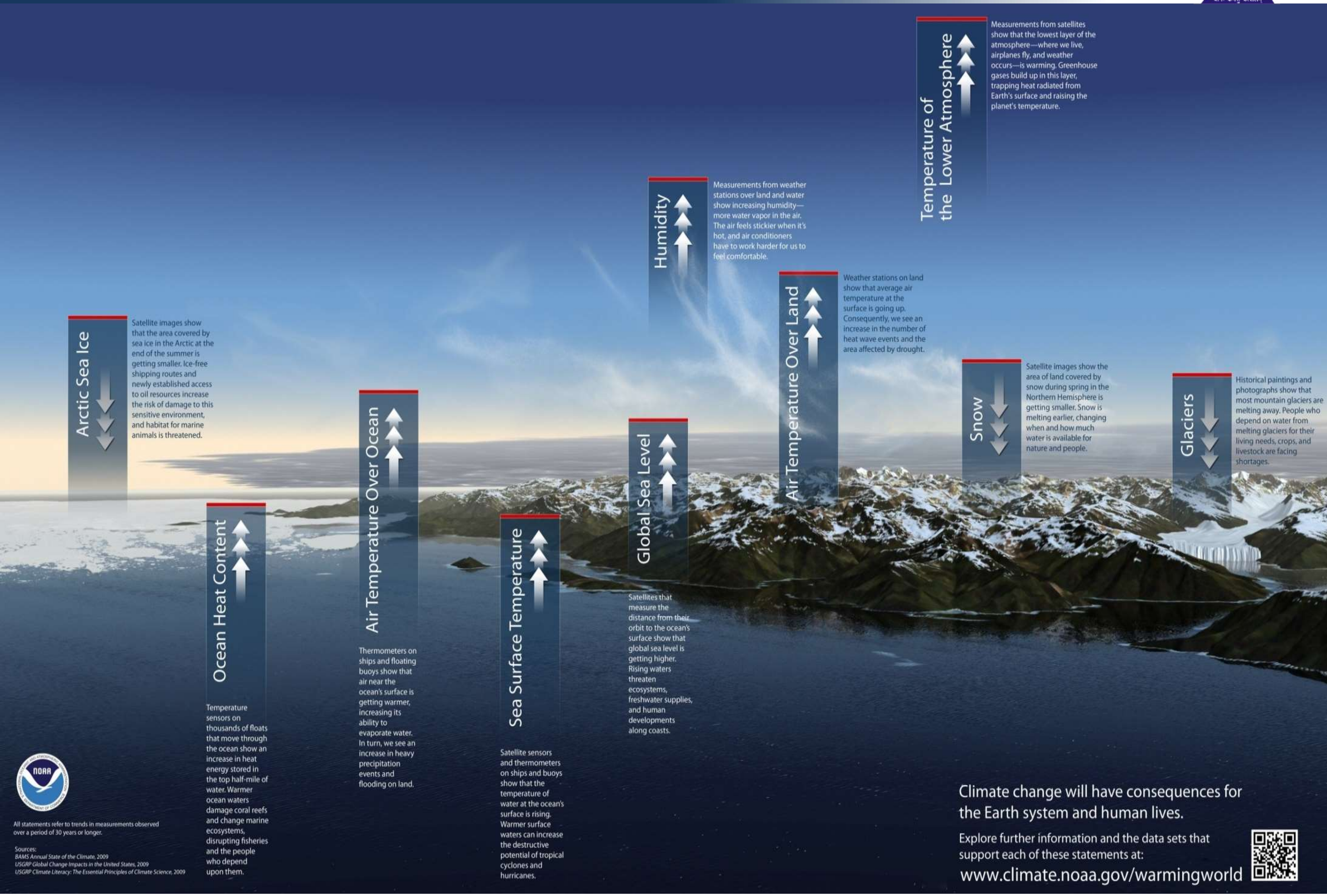
The Earth's Climate in the Recent Past

- The upward trend since the early 1960s indicates global warming.

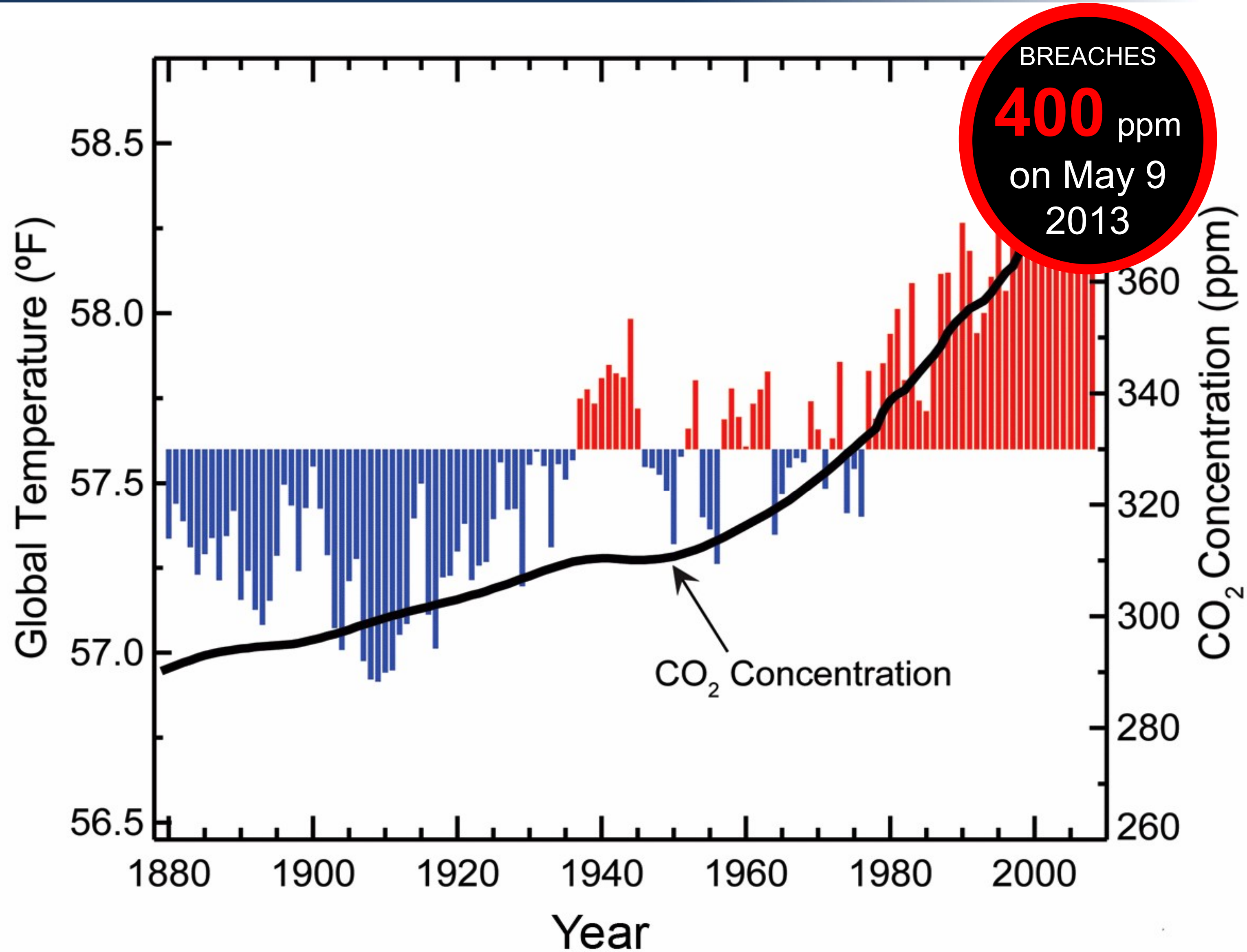


Global surface mean temperature anomalies.

Climate Change: Vital Signs of the Planet



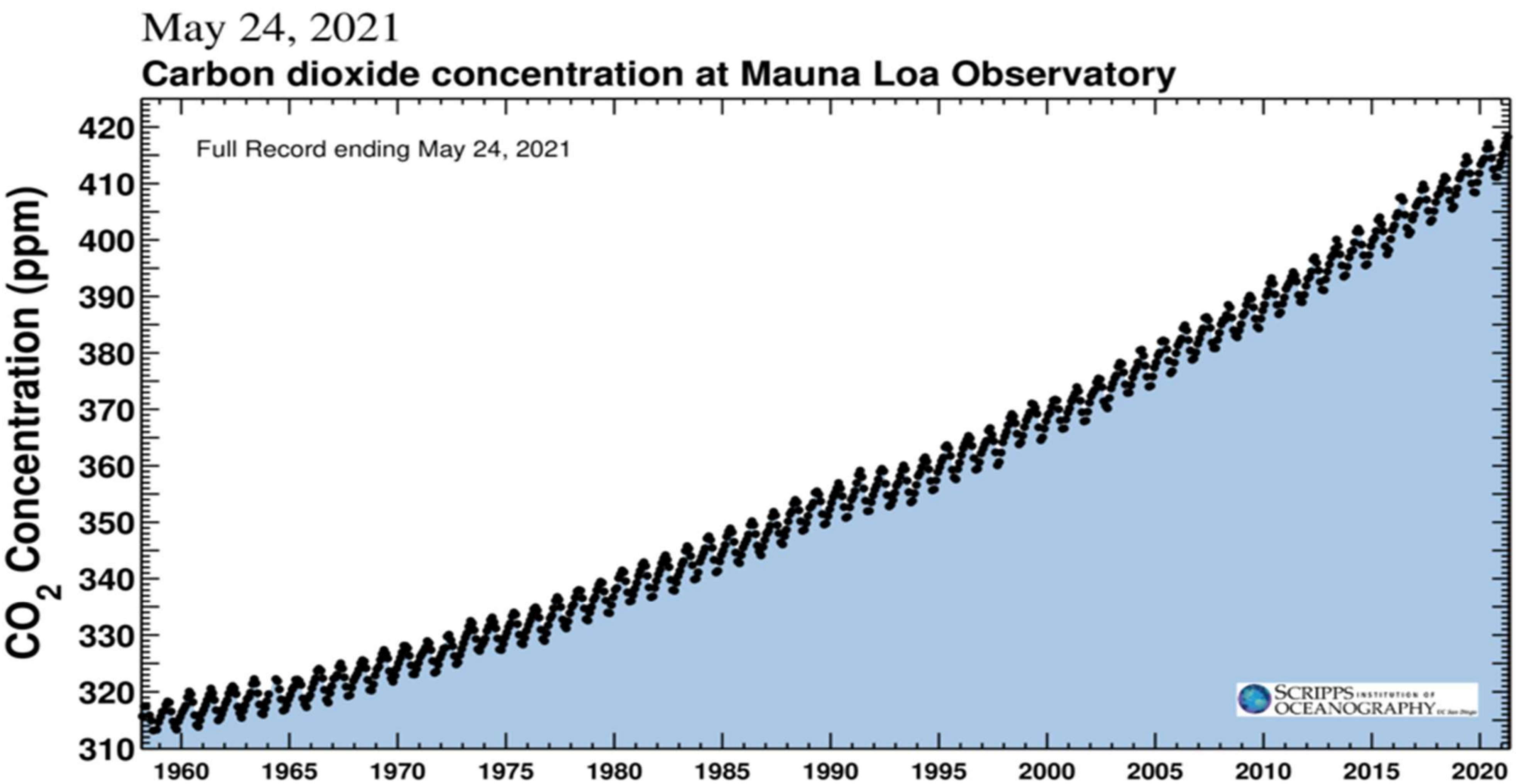
CO_2 is the Major Cause of Global Warming



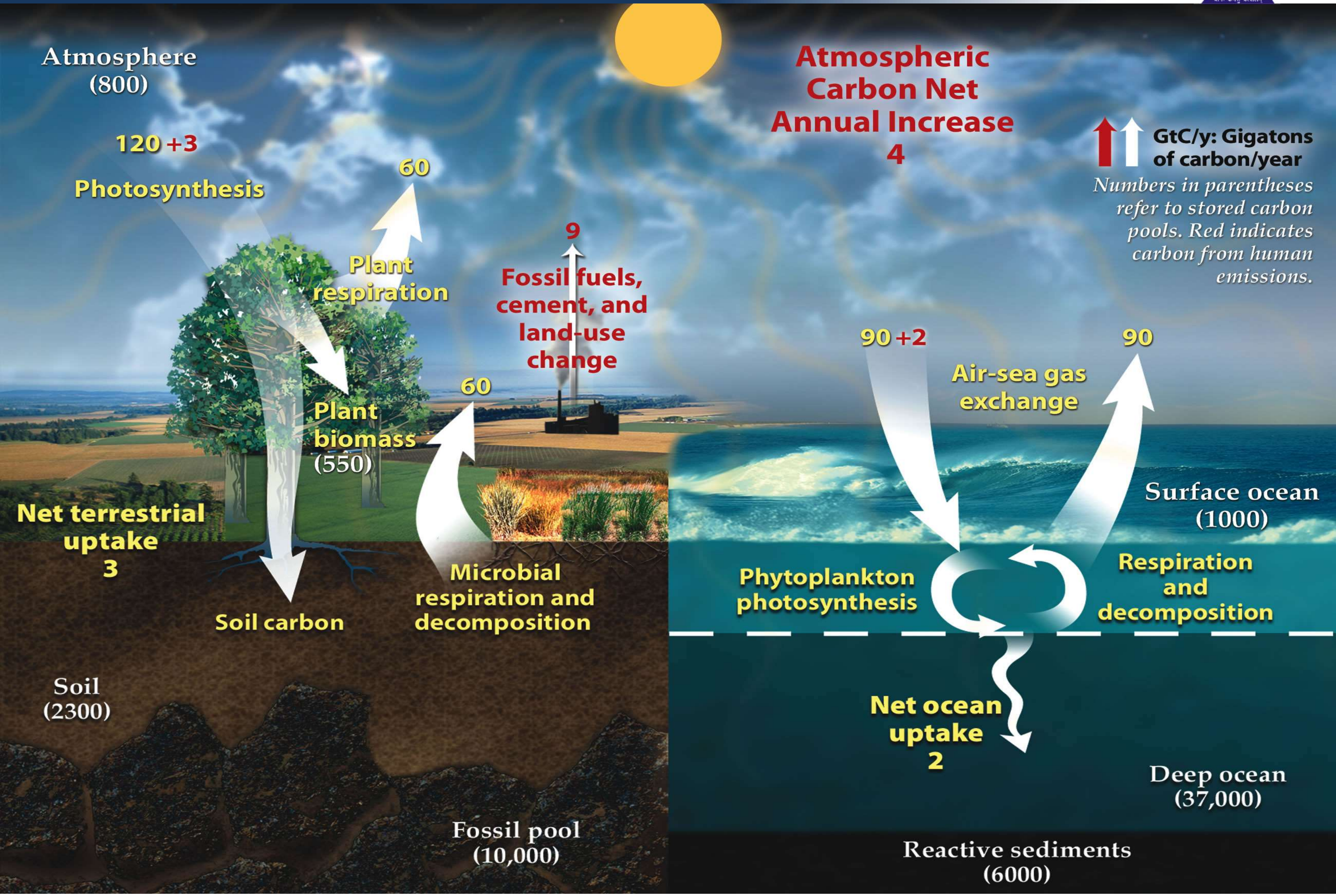
Atmospheric CO_2 concentrations and global annual average temperatures (as measured over both land and oceans) over the years 1880 to 2010. Red bars indicate temperatures above and blue bars indicate temperatures below the average temperature. The black line shows atmospheric CO_2 concentrations in parts per million (ppm).

Keeling Curve

- The Keeling Curve, devised by Dr. Charles David Keeling of the Scripps Institution of Oceanography, represents the concentration of CO_2 in the Earth's atmosphere since 1958, as recorded at the Mauna Loa Observatory in Hawaii.



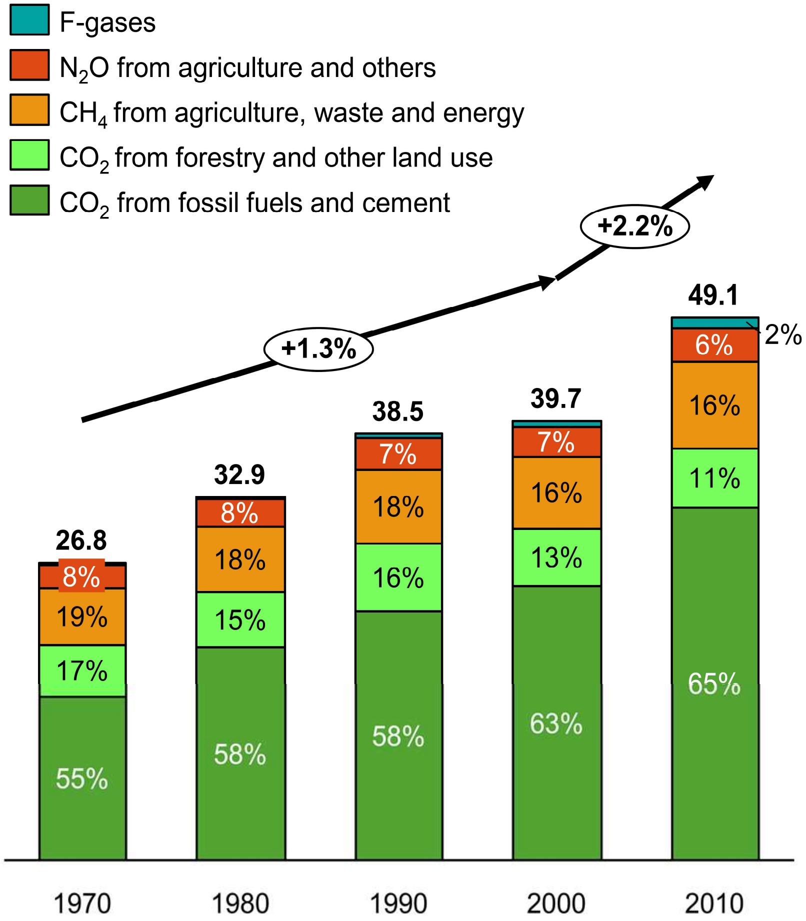
Why Are CO_2 Emissions So Significant?



Where Humanity's GHGs Come From?

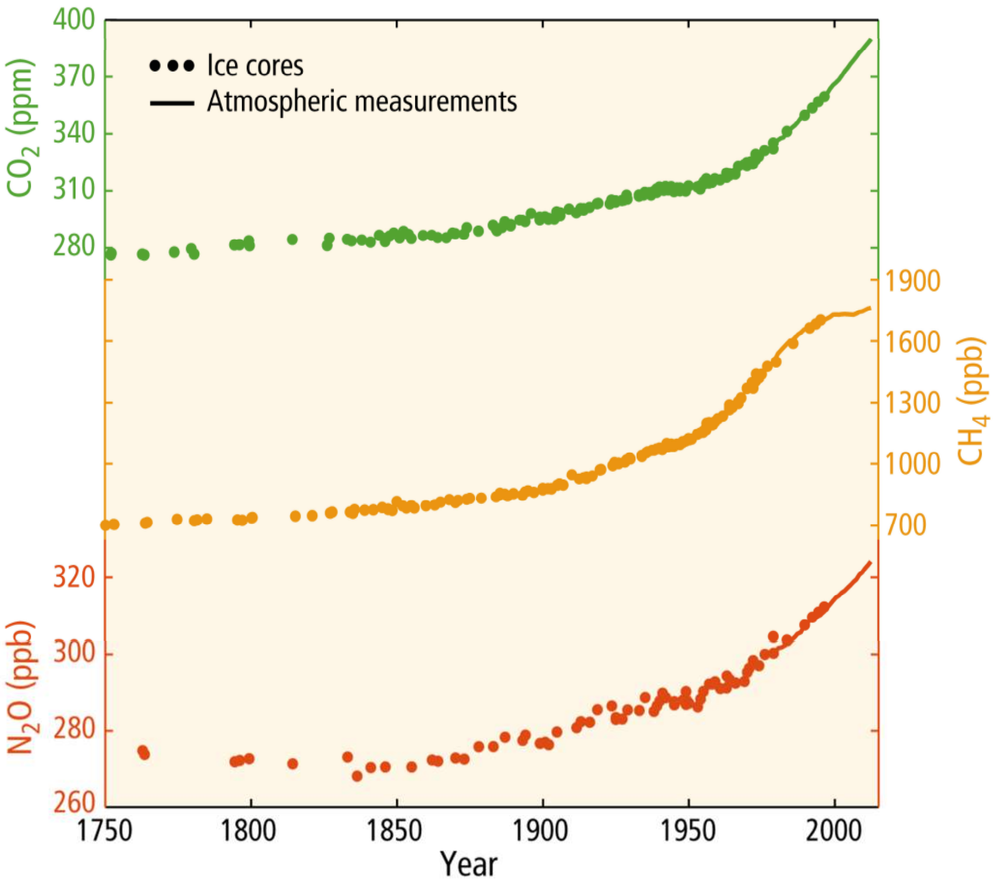
HUMAN GHG EMISSIONS BY ACTIVITY[1]

Gigatonne of CO_2-e per year, and % of total emissions



ATMOSPHERIC CONCENTRATION OF GHGS

Parts per billion (ppb), parts per million (ppm)



Global Warming Potential

- Global warming potential (GWP) and CO_2-equivalence are used to compare the potential warming influence of emissions of the same mass of different GHGs.
- GWP compares the warming effect of a given mass of GHG to the same mass of CO_2 over a specified time. As GHGs do not have the same life time in the atmosphere, the GWP depends on the time-horizon chosen.

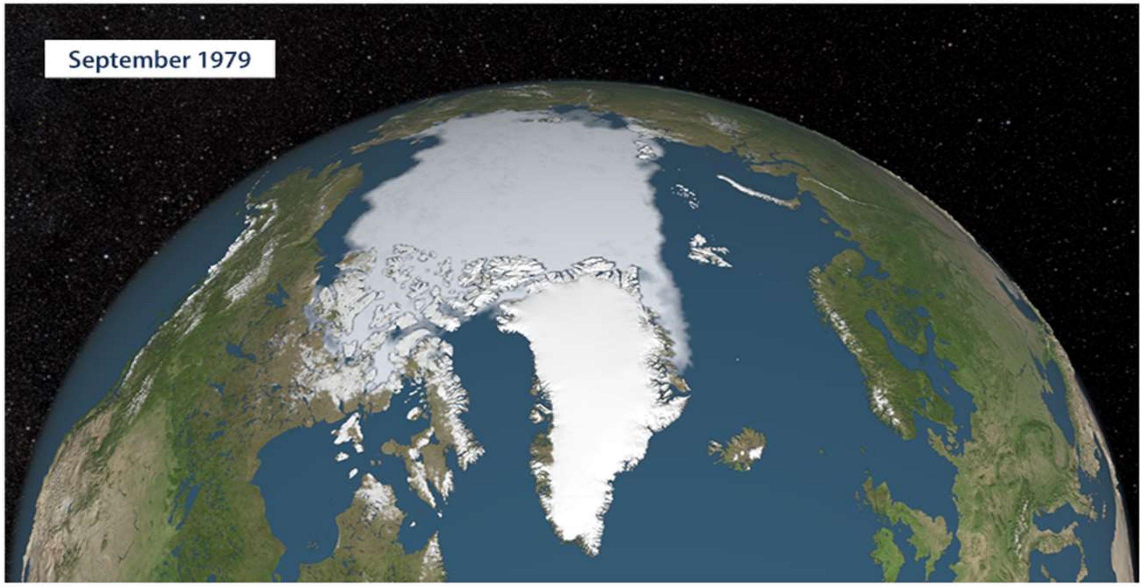
Gas name	Chemical formula	Half-life[1] (years)	Global warming potential (GWP) for given time horizon	
			20-yr	100-yr
Carbon dioxide	CO_2	100-1,000 years[2]	**1 (by definition)**	**1 (by definition)**
Methane	CH_4	12.4	~80	~30
Nitrous oxide	N_2O	121	~270	~300
Tetrafluoro-methane	CF_4	50,000	~5,000	~7,000

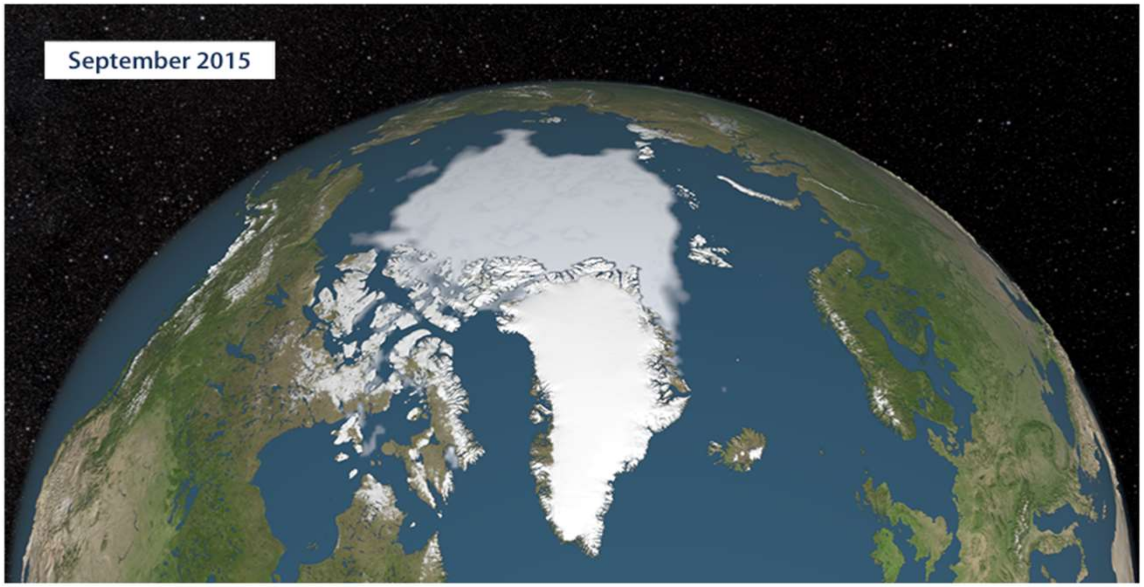
Impacts of Climate Change

Melting of More Ice and Snow

- Over the past 30 years, more than 20% of the polar ice cap has melted away, and the melting trend is accelerating.
- September 2012 had the lowest sea ice extent ever recorded: 44% below the 1981–2010 average for that month.
- The September 2015 sea ice extent was more than 700,000 square miles less than the historical 1981–2010 average for that month.

Dwindling Arctic Sea Ice



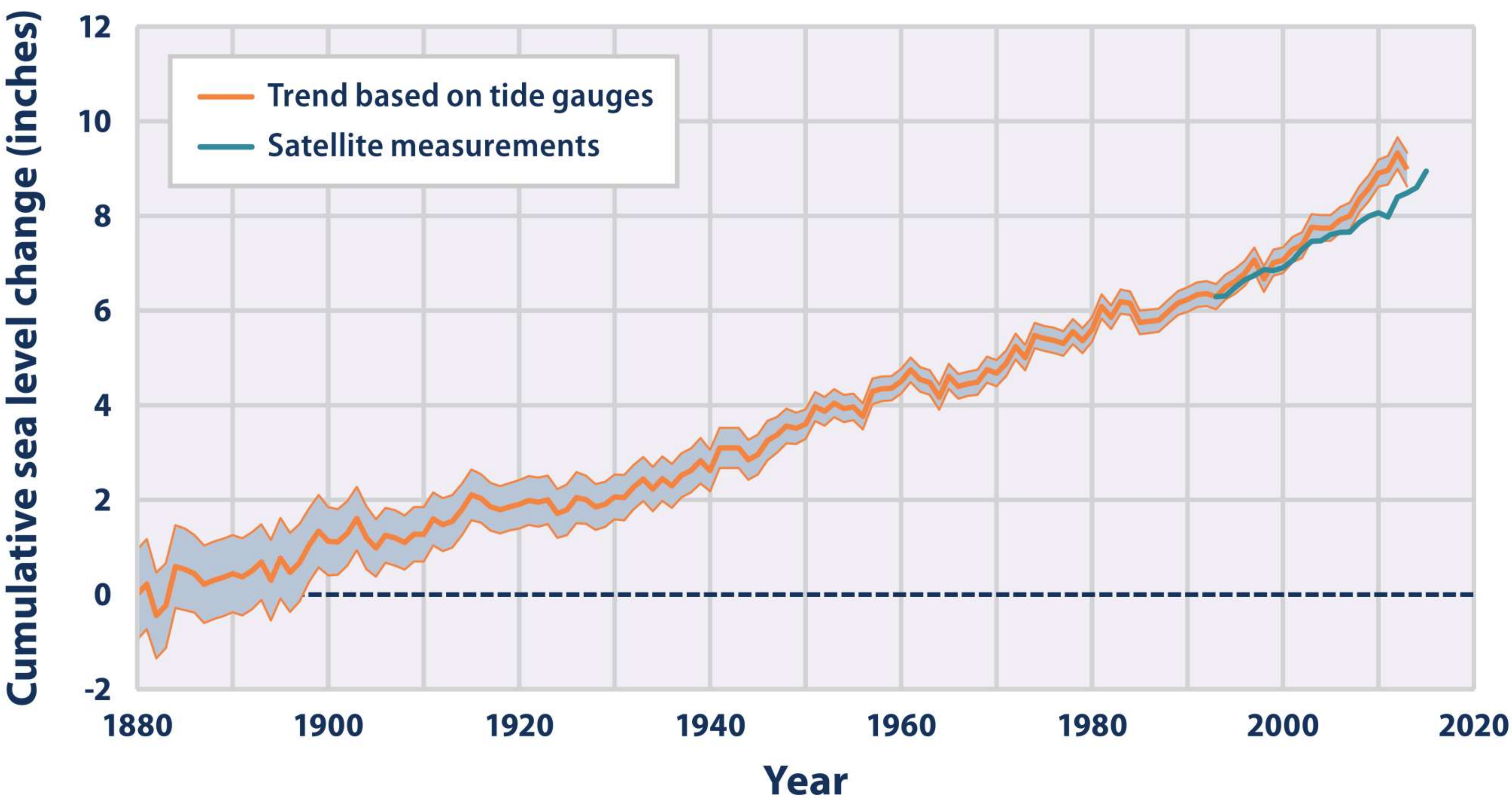


Source: NASA (National Aeronautics and Space Administration). 2016. NASA's Goddard Space Flight Center Scientific Visualization Studio. http://svs.gsfc.nasa.gov.

Sea Level Rise

- Many low-lying coastal land areas are expected to be gradually submerged by rising sea levels.

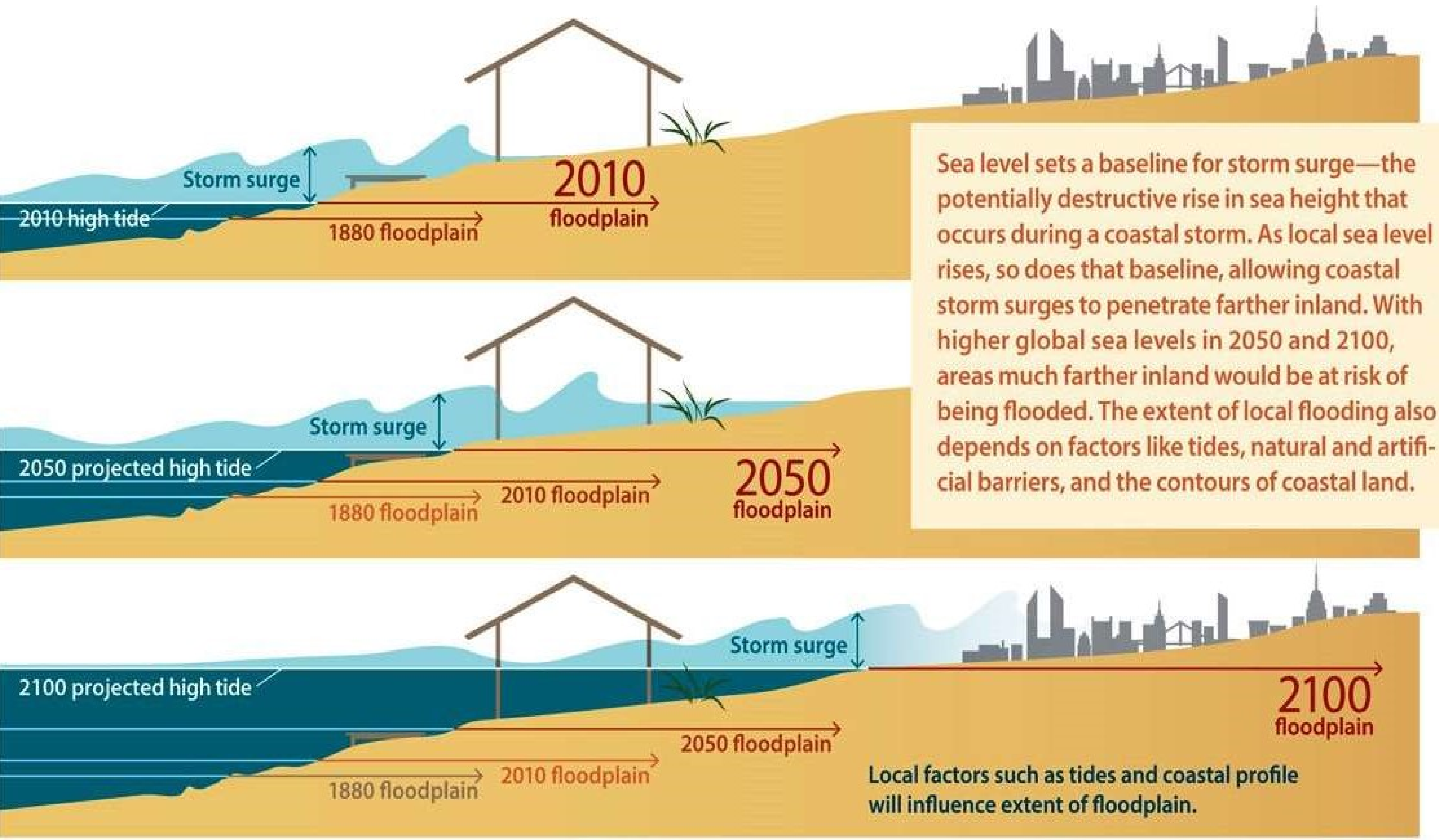
Global Average Absolute Sea Level Change, 1880–2015



- For a low-lying island nation like the Maldives in the Indian Ocean, even a small rise in sea level could spell disaster for most of its people. About 80% of the 1192 small islands making up this country lie less than 1 meter above sea level.

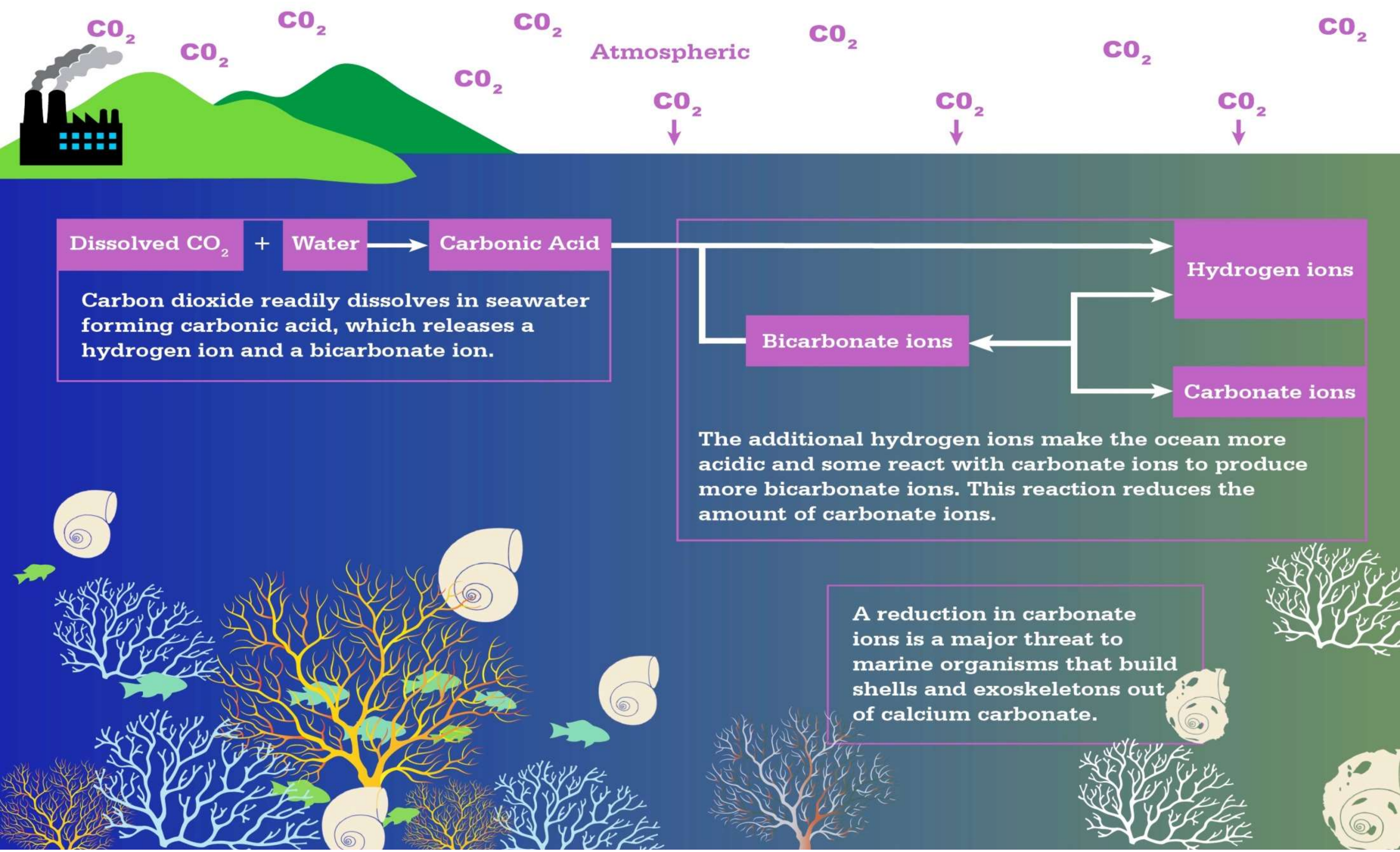
Coastal Flooding

- Sea level rise will magnify the adverse impact of storm surges and high waves on the coast.



Ocean Acidification

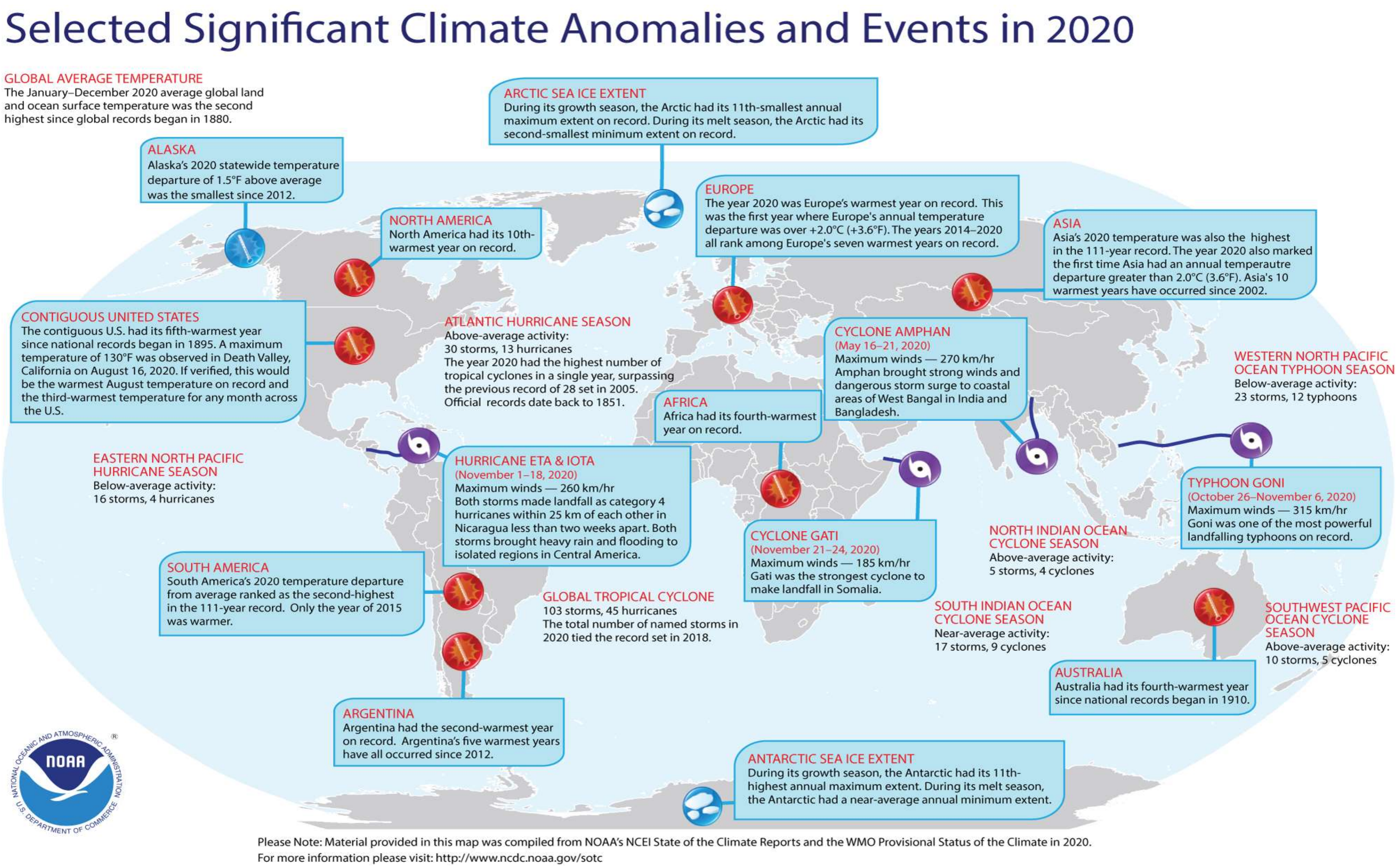
- ‘Acidification’ of ocean water can harm marine life.



- Declining pH levels in the world's oceans interferes with many species ability to form shells.

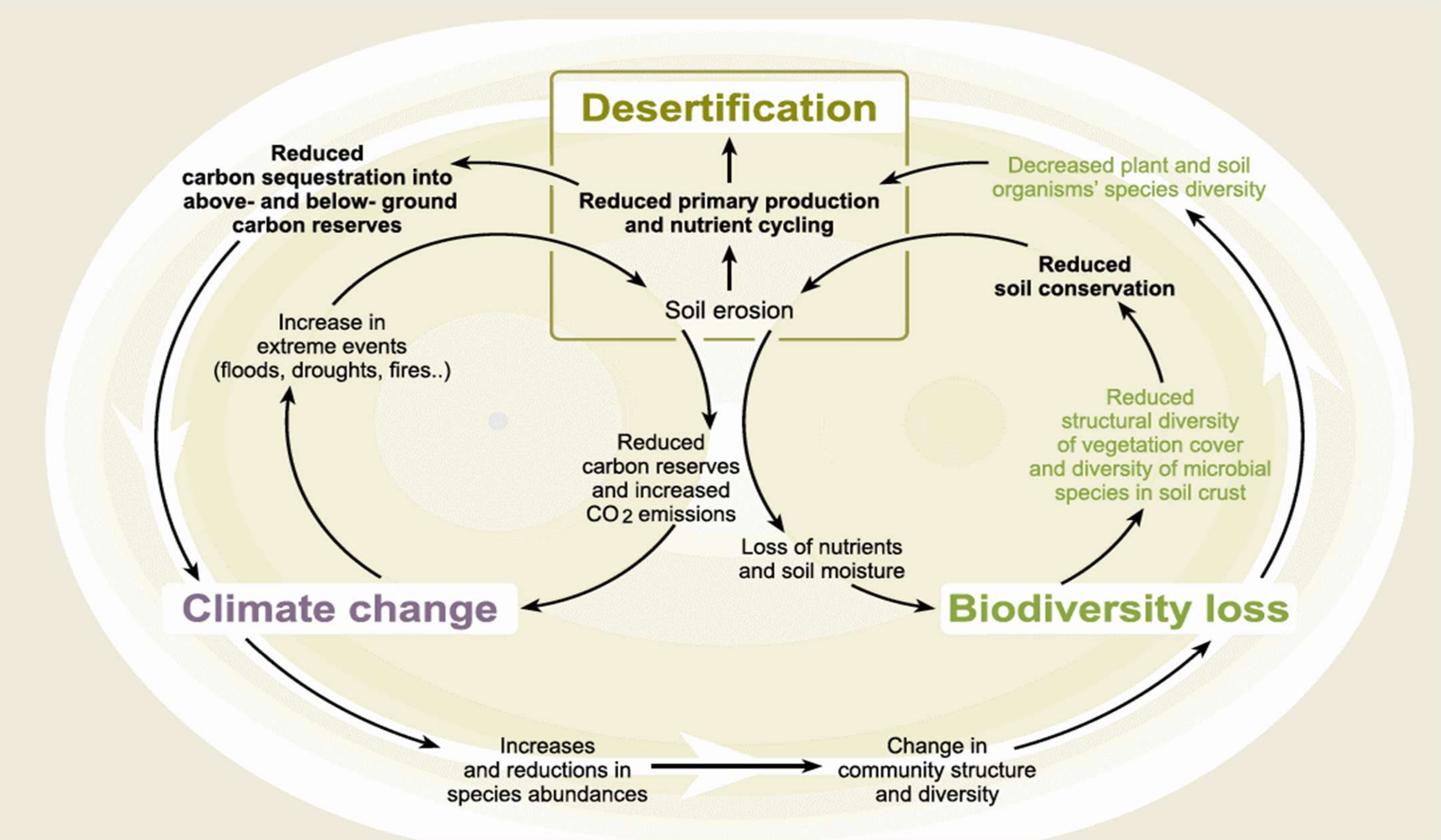
Extreme Weather Events

- As the climate has warmed, some types of extreme weather have become more frequent and severe in recent decades.



Biodiversity Loss

- Climate change alone is expected to threaten with extinction approximately one quarter or more of all species on land by the year 2050, surpassing even habitat loss as the biggest threat to life on land.

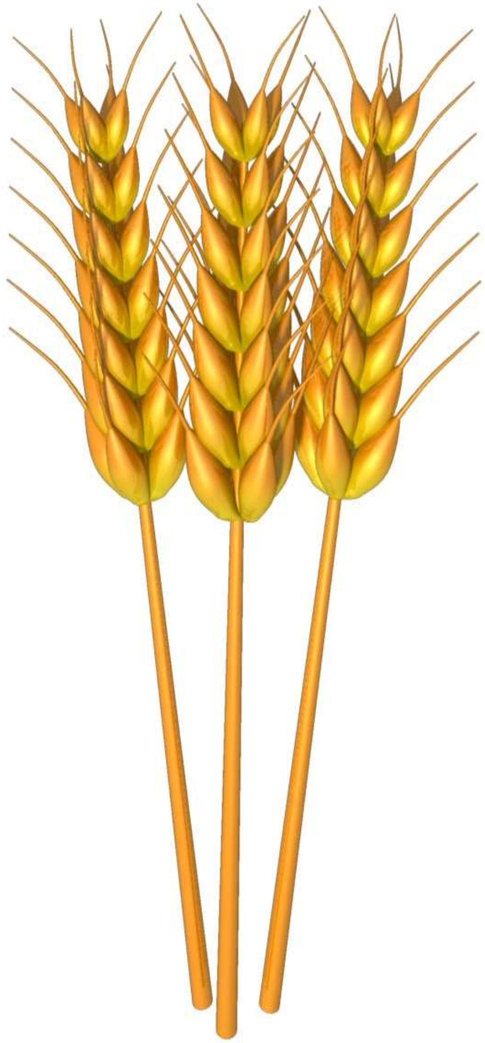


Impact on Food Production

POSTIVE IMPACTS

- Increased productivity from warmer temperatures
- Possibility of growing new crops
- Longer growing seasons
- Increased productivity from enhanced CO_2*
- Accelerated maturation rates
- Decreased moisture stress (for some crops)

*CO_2 fertilization only applies to some crops and will at best be a small temporary benefit for higher altitudes.

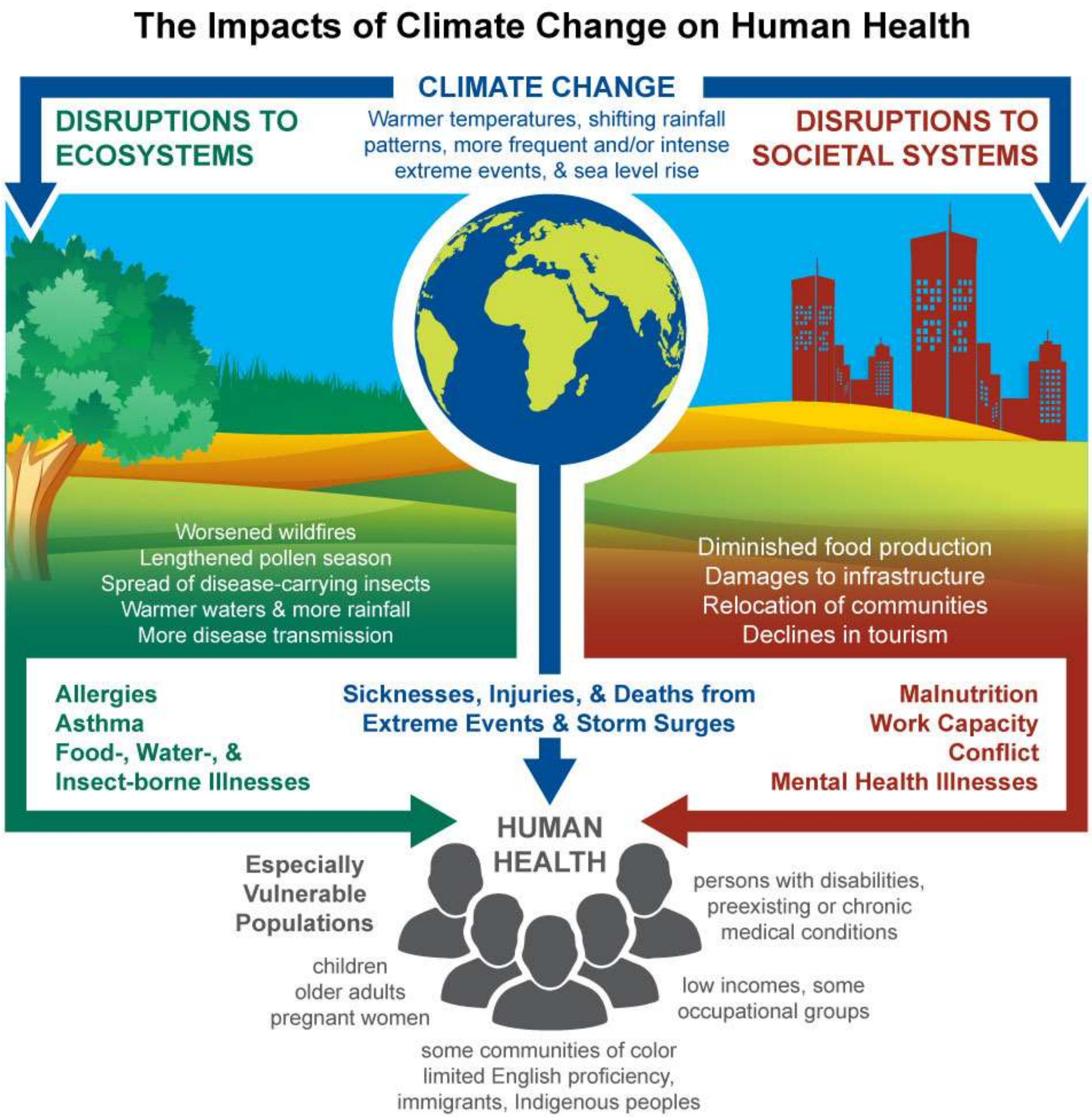


NEGATIVE IMPACTS

- Increased insect infestations
- Crop damage from extreme heat
- Planning problems due to less reliable forecasts
- Increased soil erosion
- Increased weed growth
- More plant disease
- Decreased herbicide and pesticide efficiency
- Increased moisture stress (for most crops)

Threat to Human Health

- Climate crisis can have serious consequences for human health and well-being.



Mitigating Climate Change

Climate solutions are within reach

Solutions

Slowing Climate Change

Prevention

Cut fossil fuel use (especially coal)

Shift from coal to natural gas

Improve energy efficiency

Shift to renewable energy resources

Transfer energy efficiency and renewable energy technologies to developing countries

Reduce deforestation

Use more sustainable agriculture and forestry

Limit urban sprawl

Reduce poverty

Slow population growth

Cleanup

Remove CO_2 from smokestack and vehicle emissions

Store (sequester) CO_2 by planting trees

Sequester CO_2 in soil by using no-till cultivation and taking cropland out of production

Sequester CO_2 deep underground (with no leaks allowed)

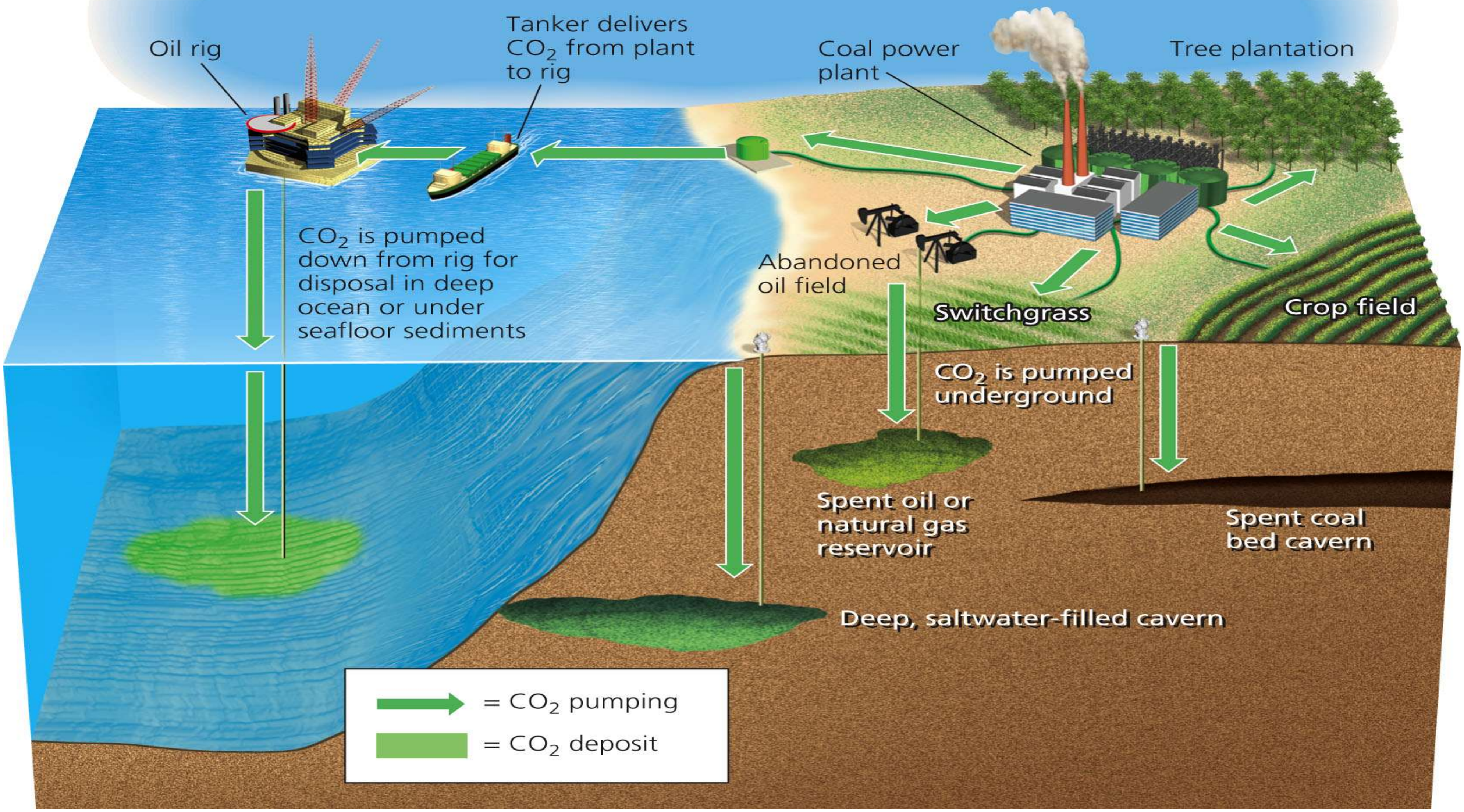
Sequester CO_2 in the deep ocean (with no leaks allowed)

Repair leaky natural gas pipelines and facilities

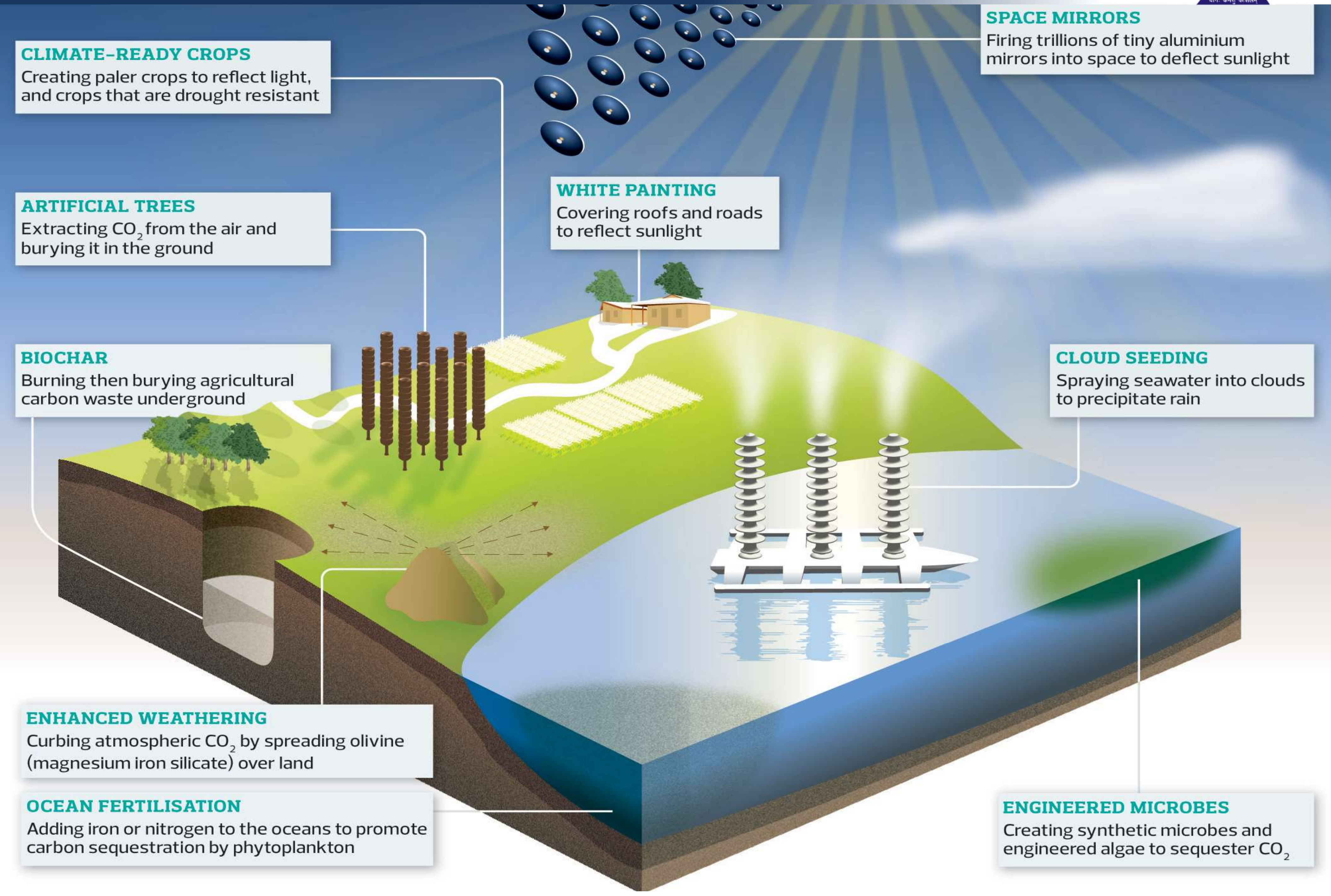
Use animal feeds that reduce CH_4 emissions from cows (belching)

Climate solutions are within reach

- Output strategies for dealing with CO_2 would allows us to keep burning fossil fuels. However, they would require us to capture and store as much CO_2 as possible in soil, in vegetation, underground, and in the deep ocean, and to hope that it would never leak out.

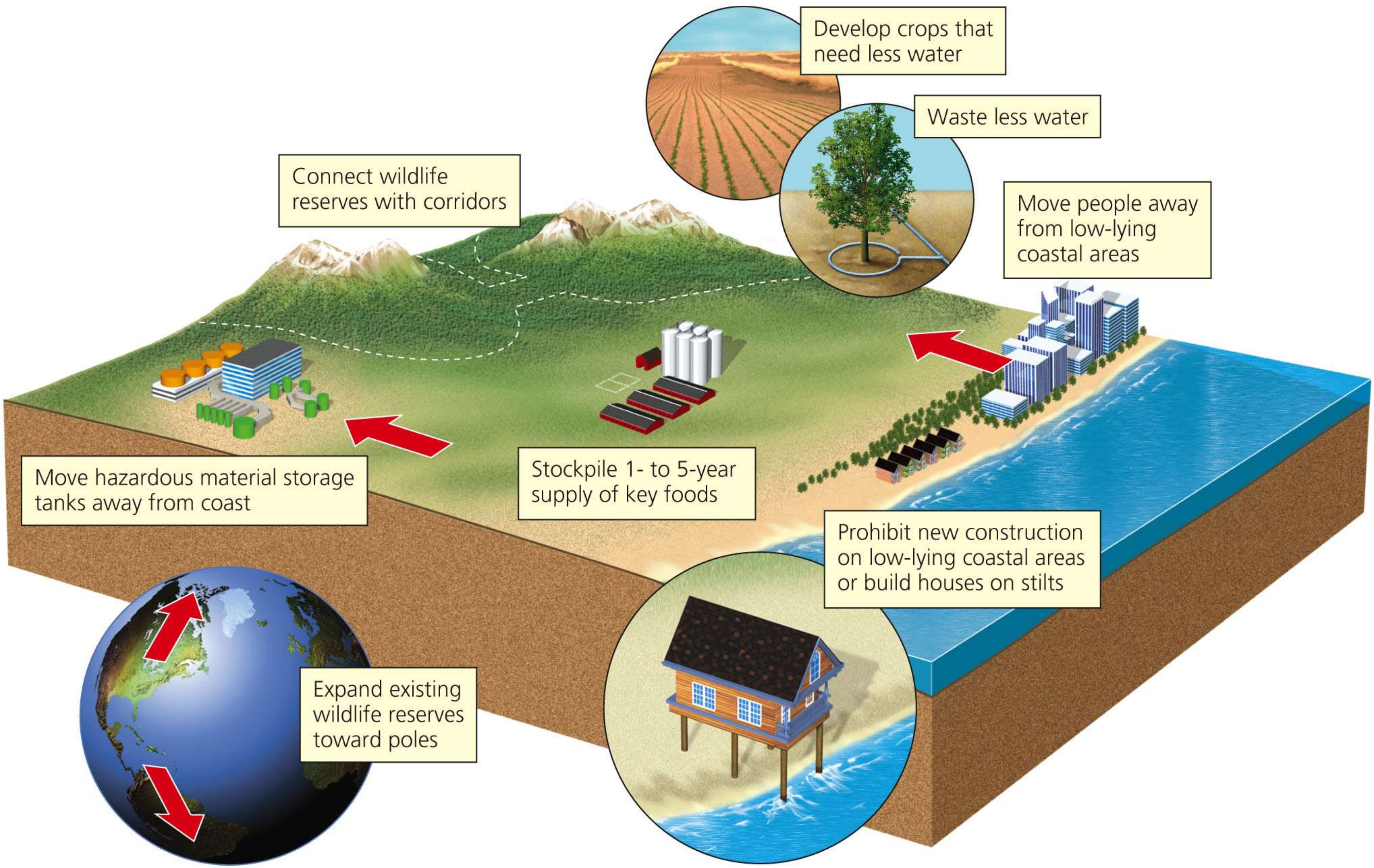


Geoengineering



Adapting to Climate Change

We can prepare for climate disruption



Governments can play a critical role

- Governments can adopt the following strategies to reduce the threat of climate disruption:

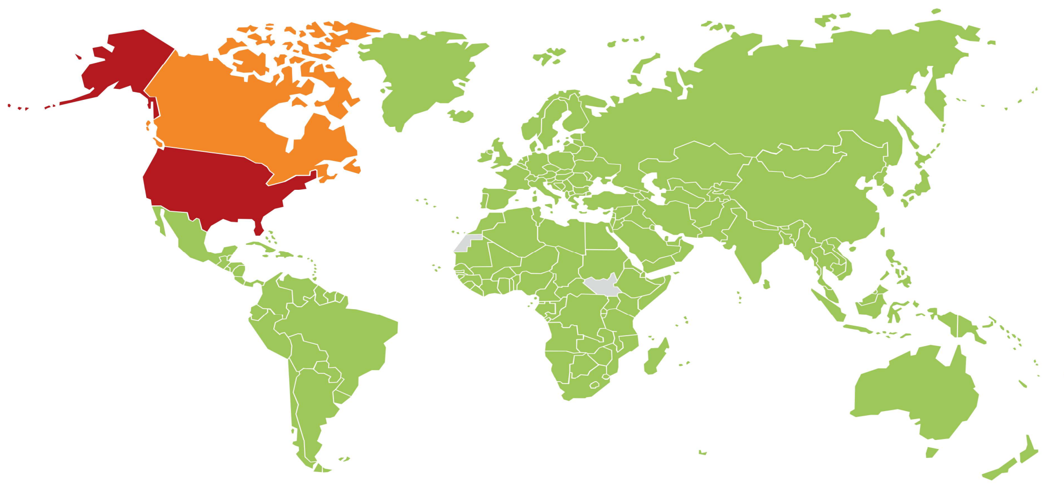
  - strictly regulate CO_2 and CH_4 as climate changing pollutants.
  - phase out the most inefficient polluting coal-burning power plants and replace them with more efficient and cleaner natural gas and renewable energy alternatives.
  - put a price on carbon emissions by phasing in taxes on each unit of CO_2 or CH_4 emitted, or phasing in energy taxes on each unit of any fossil fuel burned.
  - use a cap-and-trade system which uses the marketplace to help reduce emissions of CO_2 and CH_4.

Governments can play a critical role

- phase out government subsidies and tax breaks for fossil fuels and industrialized food production.
- phase in government subsidies and tax breaks for energy efficiency technologies, low-carbon renewable energy sources, and more sustainable agriculture.
- focus research and development efforts on innovations that lower the cost of clean energy alternatives.
- work out agreements to finance and monitor efforts to reduce deforestation.
- encourage more-developed countries to help fund the transfer of the latest energy-efficiency and cleaner energy technologies to less-developed countries.

The Kyoto Protocol

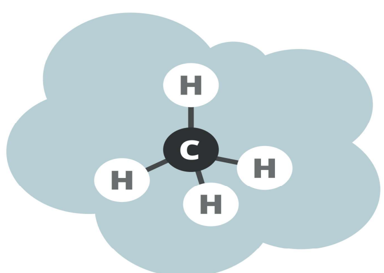
16TH FEBRUARY – THE KYOTO PROTOCOL (2005)



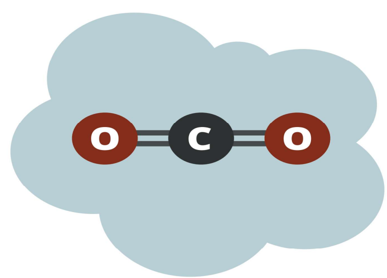
192 COUNTRIES

- signed and ratified
- ratified but withdrawn
- signed but not ratified

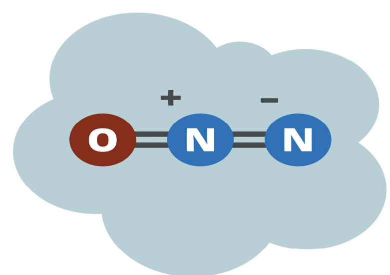
TARGET
↓ **5.2%**
by 2012 relative to 1990



METHANE



CARBON DIOXIDE



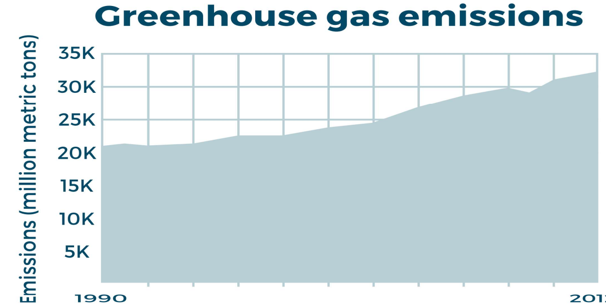
NITROUS OXIDE

GREENHOUSE GASES

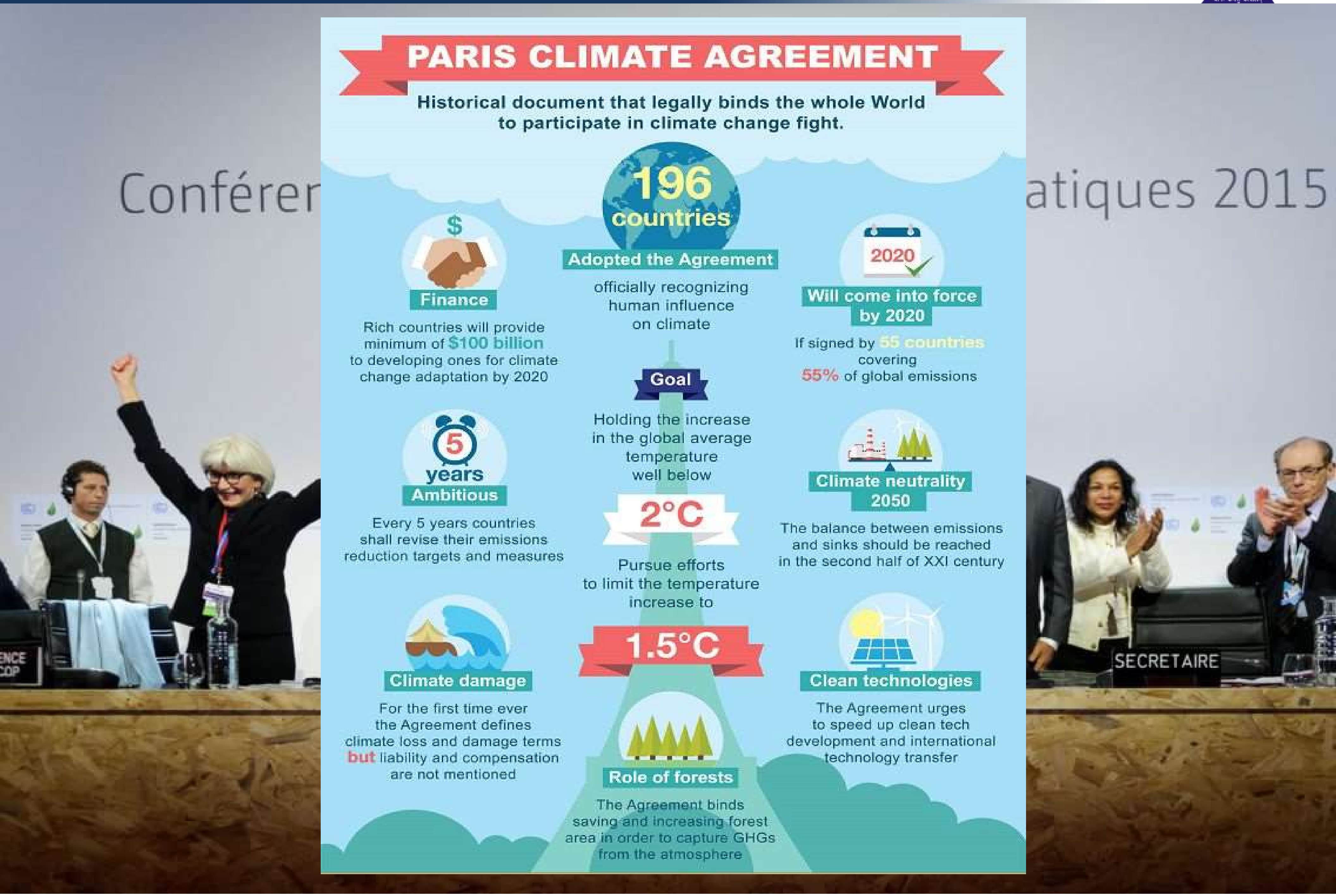
- HYDROFLUOROCARBONS
- PERFLUOROCARBONS
- SULFUR HEXAFLUORIDE

The Kyoto Protocol is an international treaty to reduce the emission of six greenhouse gases. 192 countries are party to the protocol, but only 38 had binding targets for the first period (2008–2012). These 38 countries met their target collectively – but an absence of binding targets for developing nations such as China and India meant that worldwide greenhouse gas emissions continued to rise.

Greenhouse gas emissions



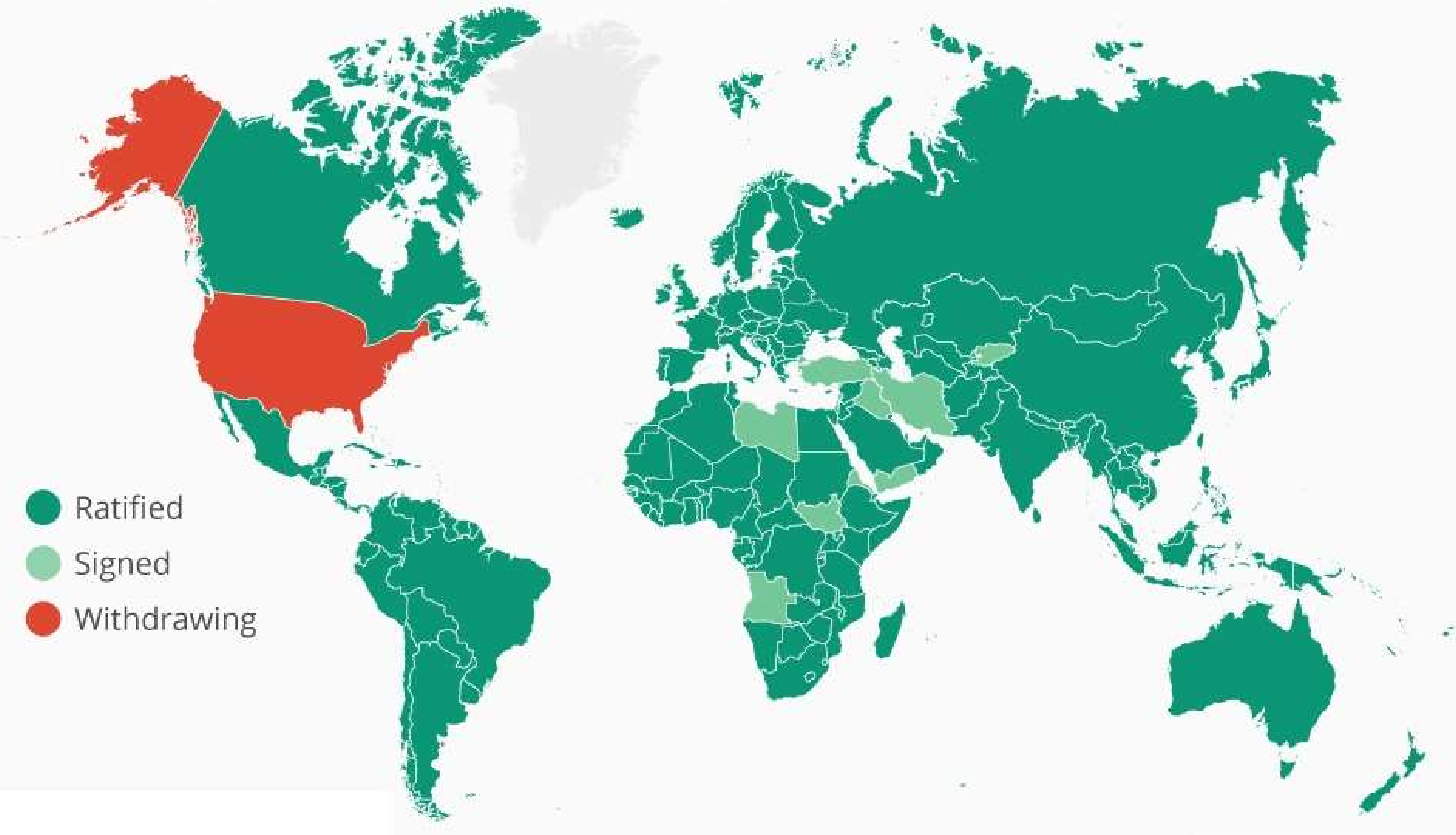
The Paris Agreement



The Paris Agreement

The State of the Paris Agreement

Countries by their participation in the Paris Agreement (as of Nov 5, 2019)



Intergovernmental Panel on Climate Change

- The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change.

- It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.

- In the same year, the UN General Assembly endorsed the action by WMO and UNEP in jointly establishing the IPCC.

- As an intergovernmental body, membership of the IPCC is open to all member countries of the UN and WMO.

Role of IPCC

- "… to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation."
- IPCC does not undertake new research, nor does it monitor climate-related data, instead, it conducts assessments of knowledge on the basis of published and peer reviewed scientific and technical literature.
- "IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies."

Structure of IPCC

UN Parent Organizations

WMO

UNEP

Intergovernmental Panel **(195 member states)**

IPCC Plenary

IPCC Bureau

Executive Committee

IPCC Secretariat

Working Group I

The Physical Science Basis

TSU

Working Group II

Impacts, Adaptation, and Vulnerability

TSU

Working Group III

Mitigation of Climate Change

TSU

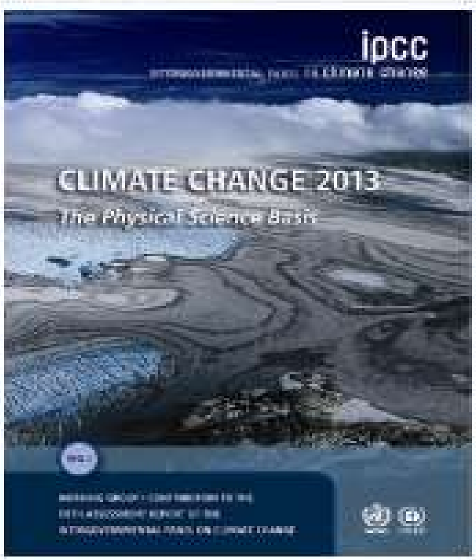
Task Force on National Greenhouse Gas Inventories

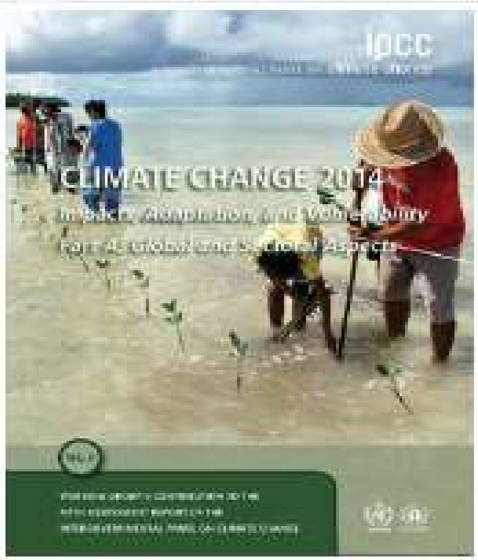
TSU

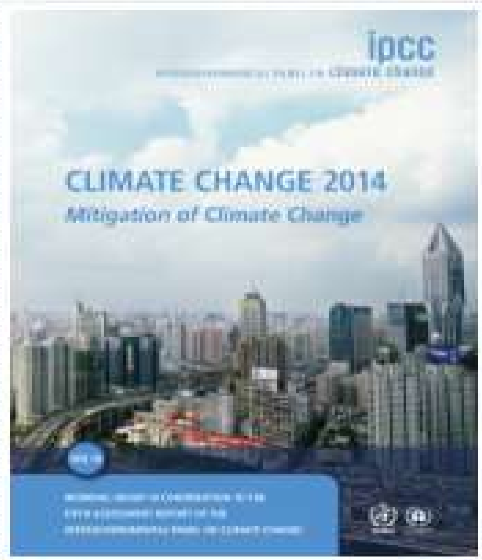
Authors, Contributors, Reviewers

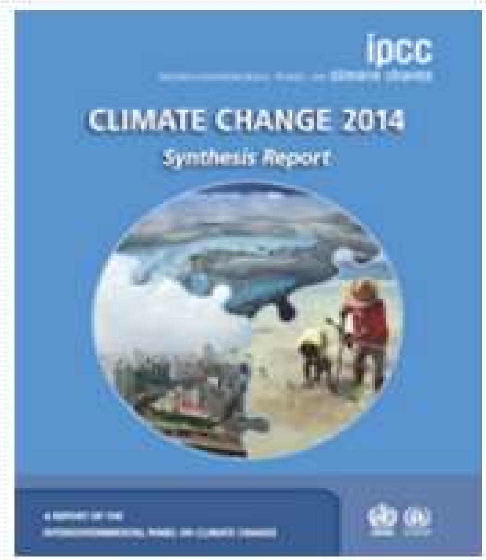
IPCC Reports

- Five assessment reports (1990, 1995, 2001, 2007, 2013-14)
- Nine special reports (1997, 1999, 2000, 2005, 2011, 2012): provide an authoritative scientific/technical assessment or guidance on any topic, which is not adequately covered in assessment reports.
- Guidelines for national GHG inventories, good practice guidance (1995, 2006, 2013)
- Technical papers and supporting material: TPs are produced from IPCC reports to provide tailored scientific/technical perspective on a particular topic; SM consists of published reports and proceedings from workshops and expert meetings within the scope of the IPCC work programme.









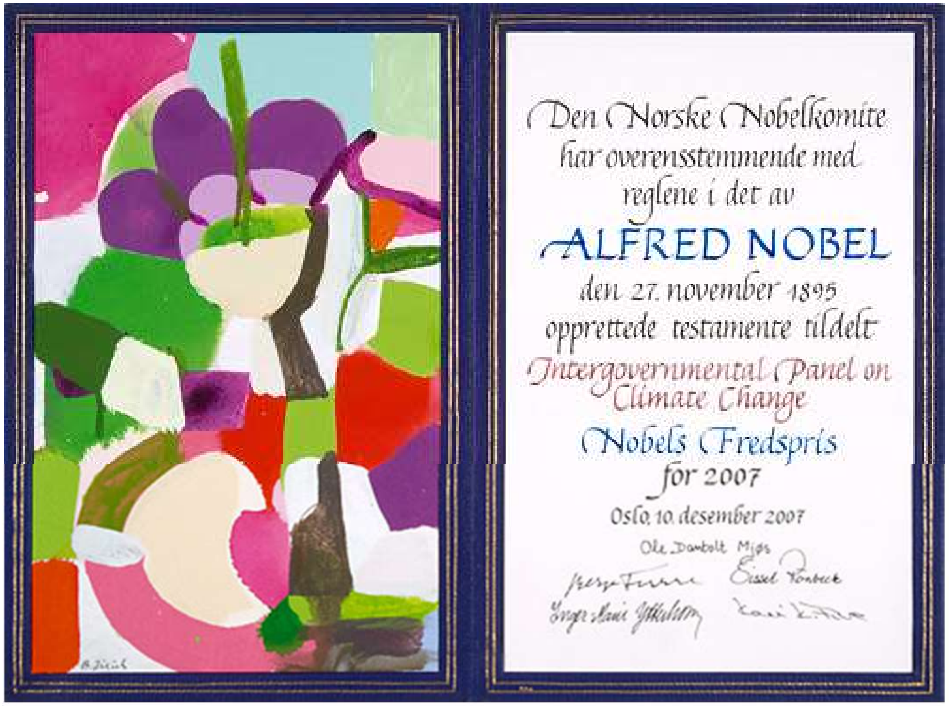
Significant Progress made in Understanding Climate Change since 1990 – WG I Reports

The reports are getting more comprehensive

Outcome of IPCC reports

- FAR (1990) – led to the United Nations Framework Convention on Climate Change (UNFCCC), an international environmental treaty adopted on 9 May 1992 to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"
- SAR (1995) – input for Kyoto Protocol which set targets for 37 industrialized countries to stabilize greenhouse gas emissions based on the principles of the UNFCCC.
- TAR (2001) – focused attention on impacts of climate change and need for adaptation
- AR4 (2007), AR5 (2013) – input for decision on 2 ºC limit; basis for post Kyoto Protocol agreement.

Nobel Peace Prize to IPCC



The Nobel Peace Prize 2007 was awarded jointly to Intergovernmental Panel on Climate Change (IPCC) and Albert Arnold (Al) Gore Jr. "*for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change*."

What is next for the IPCC?

IPCC Decision XLIII-5

"To take the outcomes of the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) into consideration when determining the IPCC programme of work and products for the sixth IPCC assessment cycle"

AR6 cycle Special Reports on

impacts of global warming of **1.5 ºC** above pre-industrial levels and related global greenhouse gas emission pathways ("Global Warming of 1.5ºC) -- by 2018

Climate change and **oceans** and the **cryosphere**

Climate change, **desertification**, **land degradation**, **sustainable land management**, **food security**, and **greenhouse gas fluxes in terrestrial ecosystems**

What is next for the IPCC?

AR6 Main Report

AR6

Expected to be released in **three working group contributions** in 2021 and a **Synthesis Report** in 2022

Methodology Report update

TFI

Methodology Report on National Greenhouse Gas Inventories by **2019** (2019 Refinement to the 2006 Guidelines)

Cities

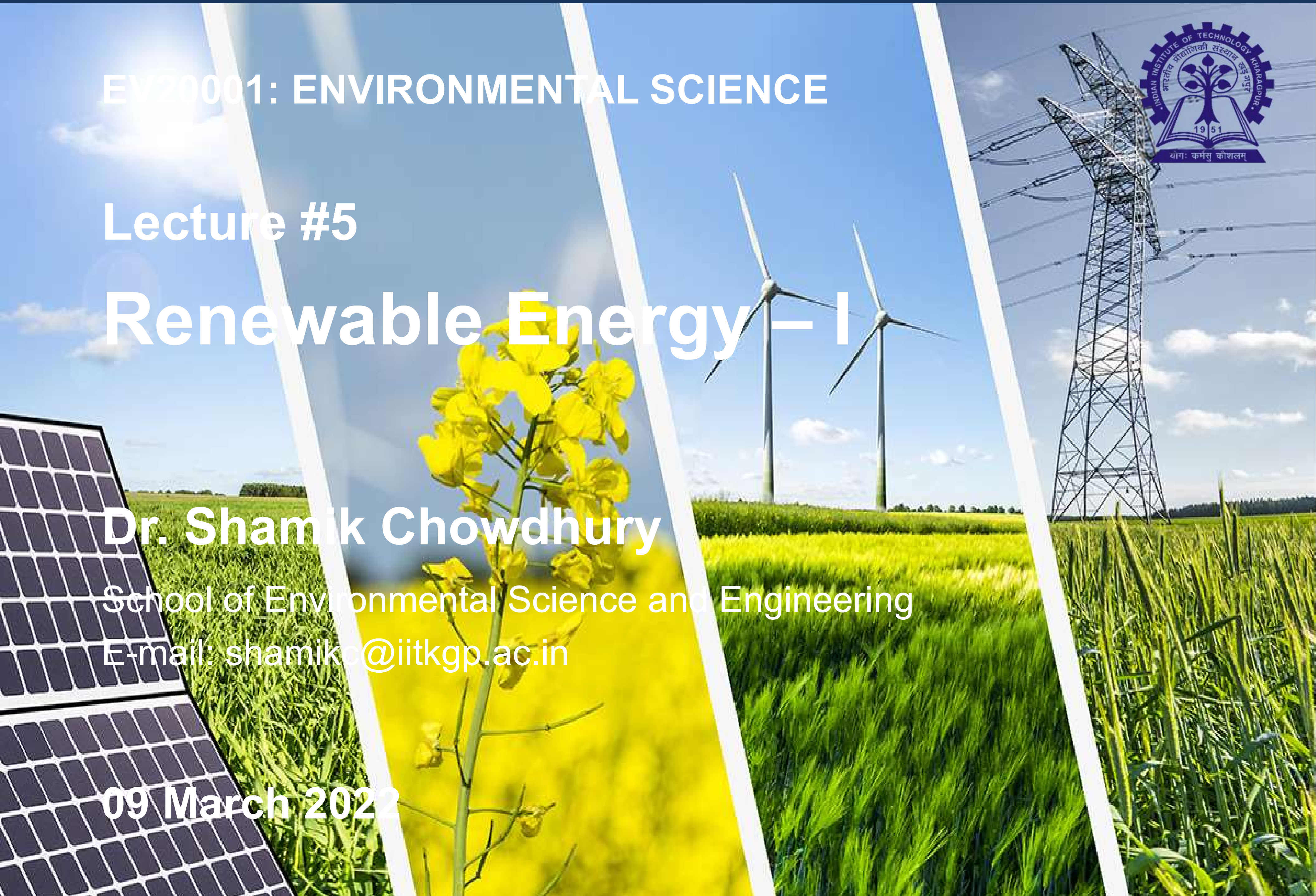
Attention on **cities** in AR6 including a conference and special report on cities in AR7

Individual choices make a difference

What Can You Do?

Reducing CO_2 Emissions

- Drive a fuel-efficient car, walk, bike, carpool, and use mass transit
- Use energy-efficient windows
- Use energy-efficient appliances and lights
- Heavily insulate your house and seal all air leaks
- Reduce garbage by recycling and reusing more items
- Insulate your hot water heater
- Use compact fluorescent lightbulbs
- Plant trees to shade your house during summer
- Set your water heater no higher than 49 °C (120 °F)
- Wash laundry in warm or cold water
- Use a low-flow showerhead
- Buy products from, or invest in, companies that are trying to reduce their impact on climate



EV20001: ENVIRONMENTAL SCIENCE

Lecture #5

Renewable Energy – I

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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.

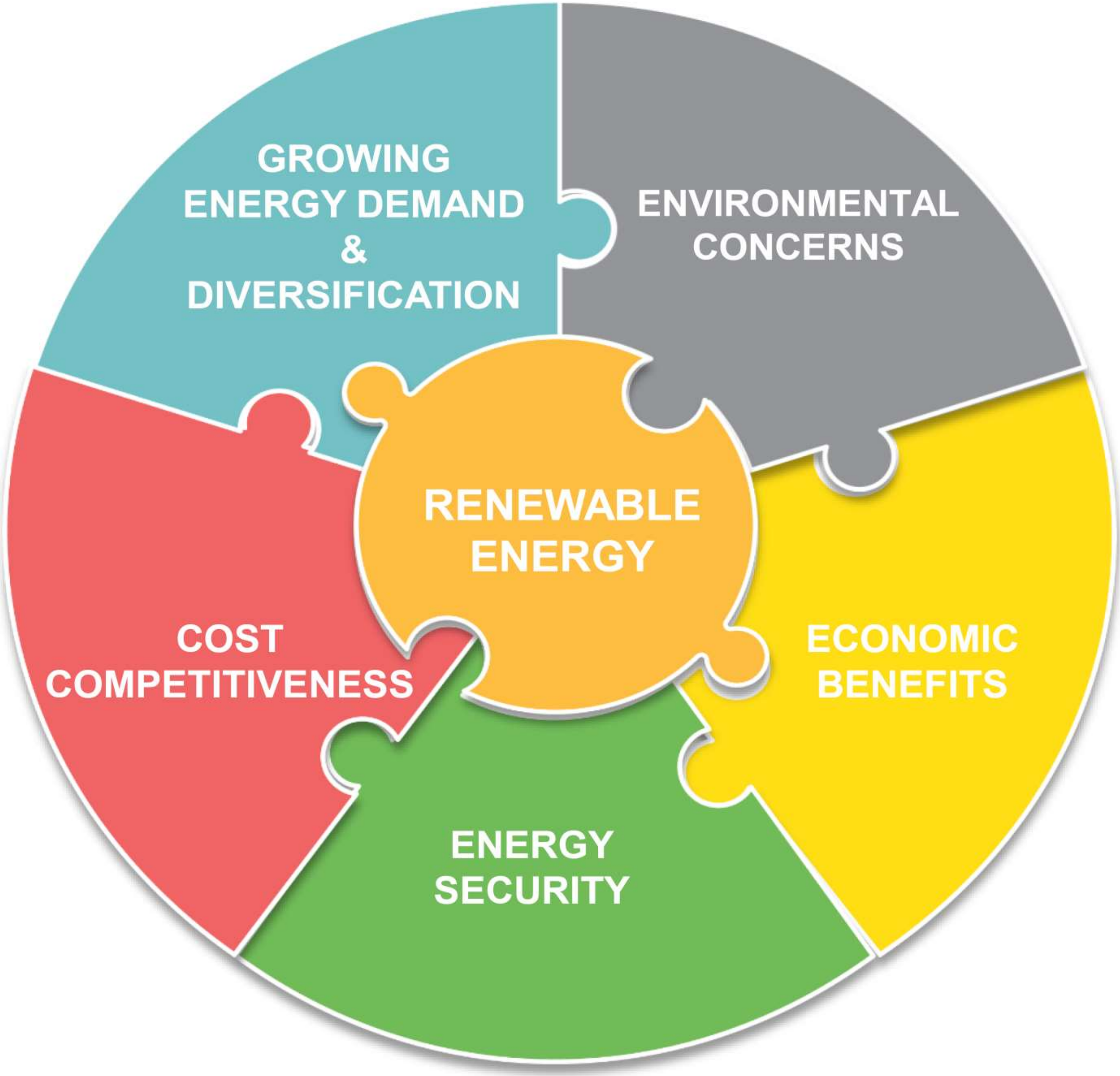
- RE is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes resources such as biomass, solar radiation, geothermal heat, hydropower, tides and waves, and wind.

- 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.

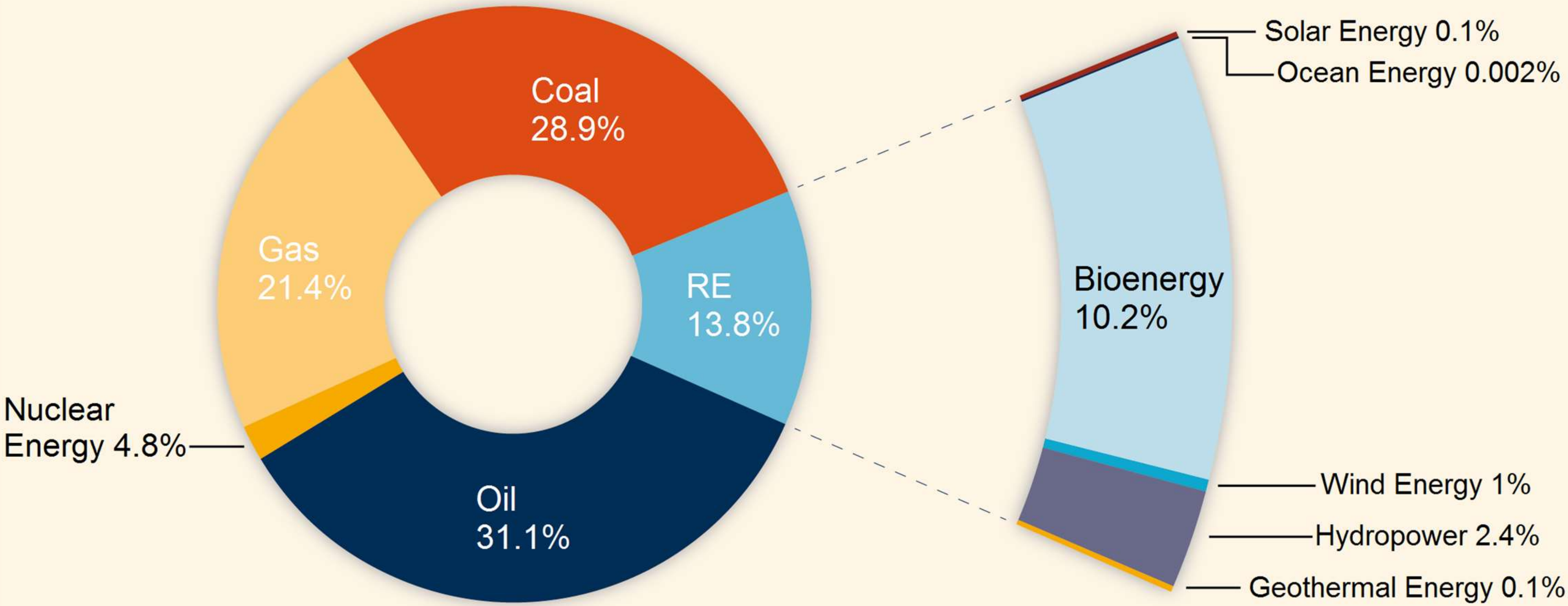
- RE can also result in a more decentralized and efficient energy economy that would be less vulnerable to supply cutoffs from terrorist attacks and natural disasters, improve economic and national security for many countries by reducing their dependence on imported crude oil and natural gas, create large numbers of jobs and save consumers money.

Key drivers of renewable energy



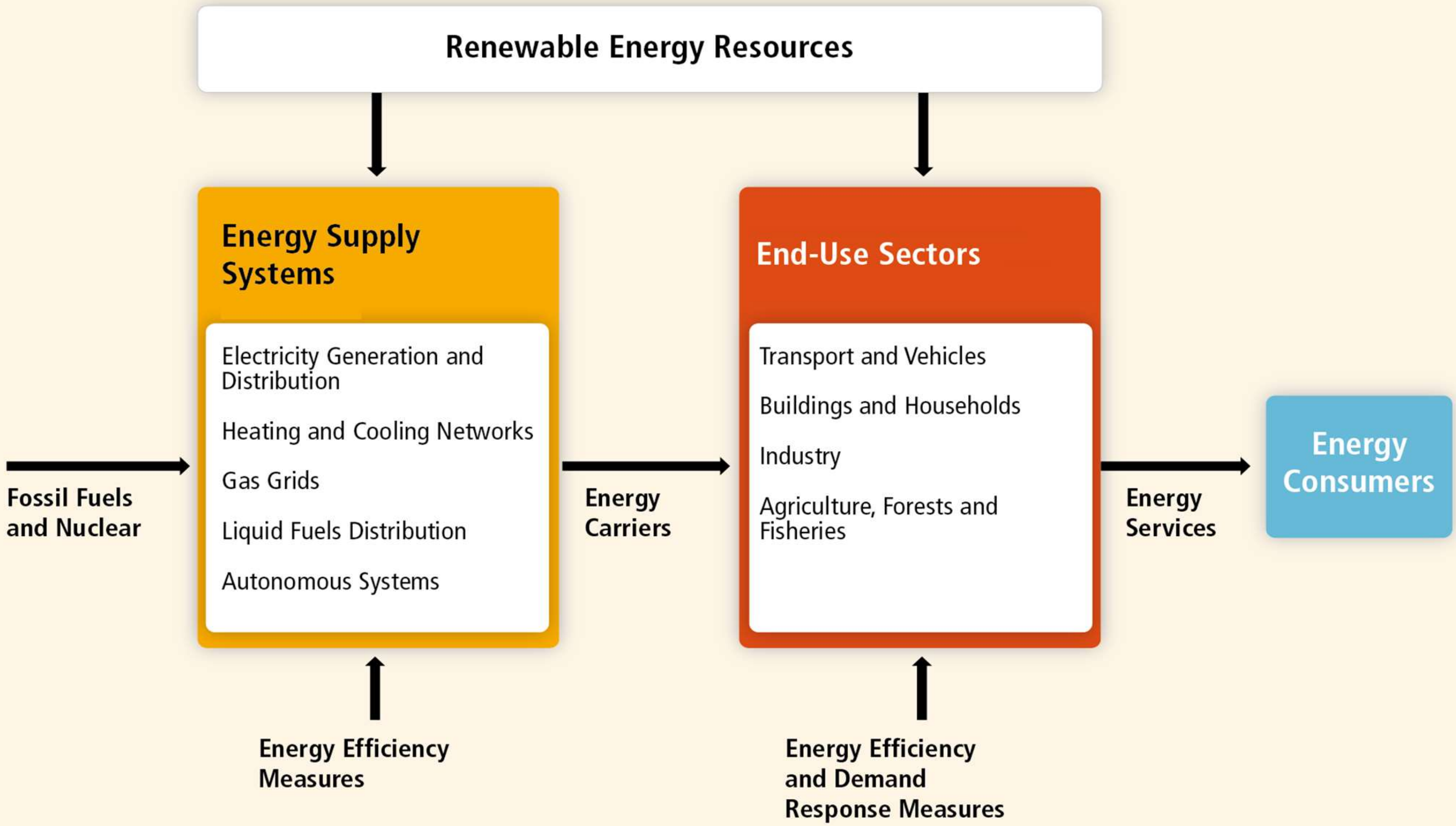
Types of renewable energy resources

- 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%.



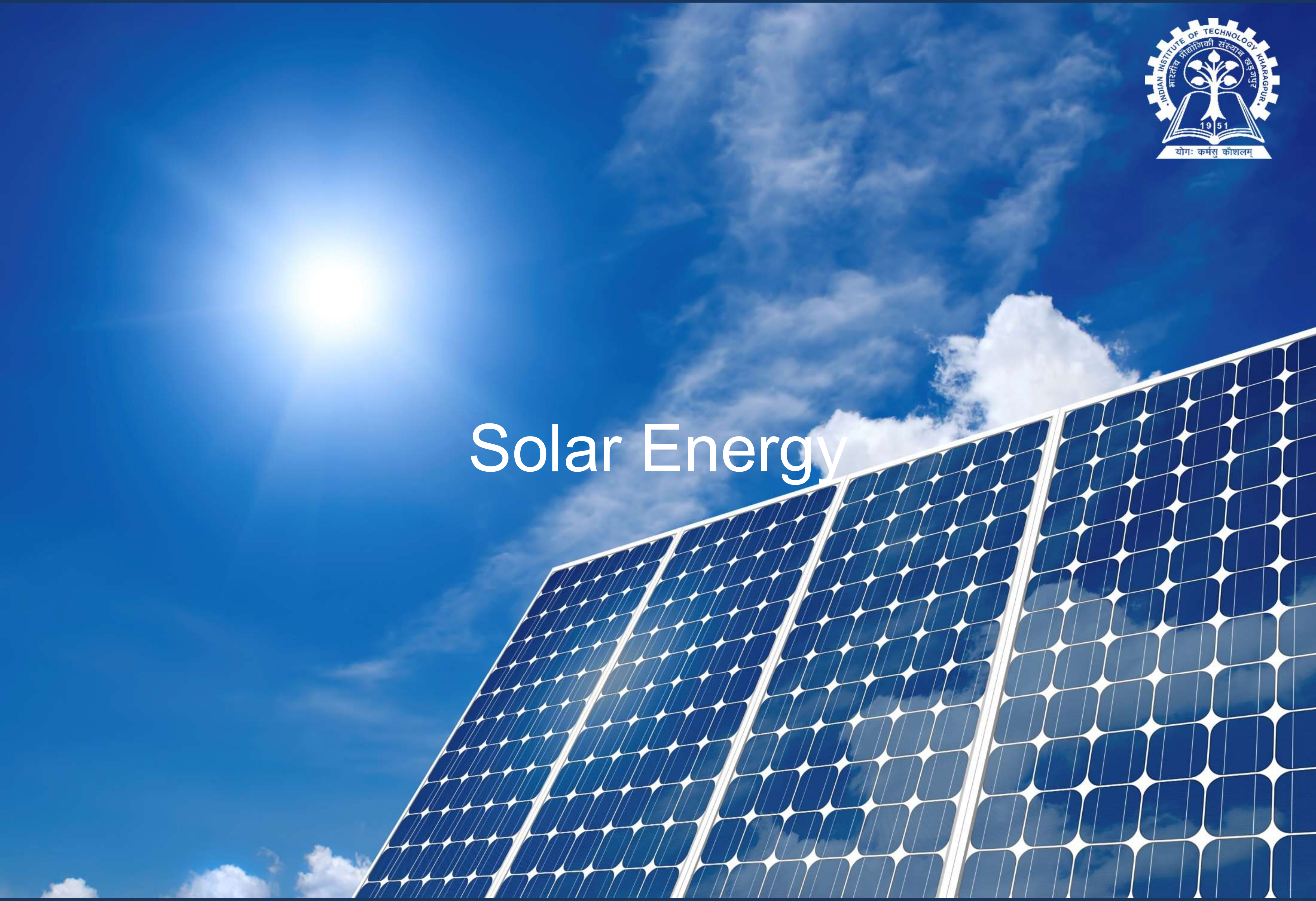
Shares of energy sources in total global total primary energy supply in 2013

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



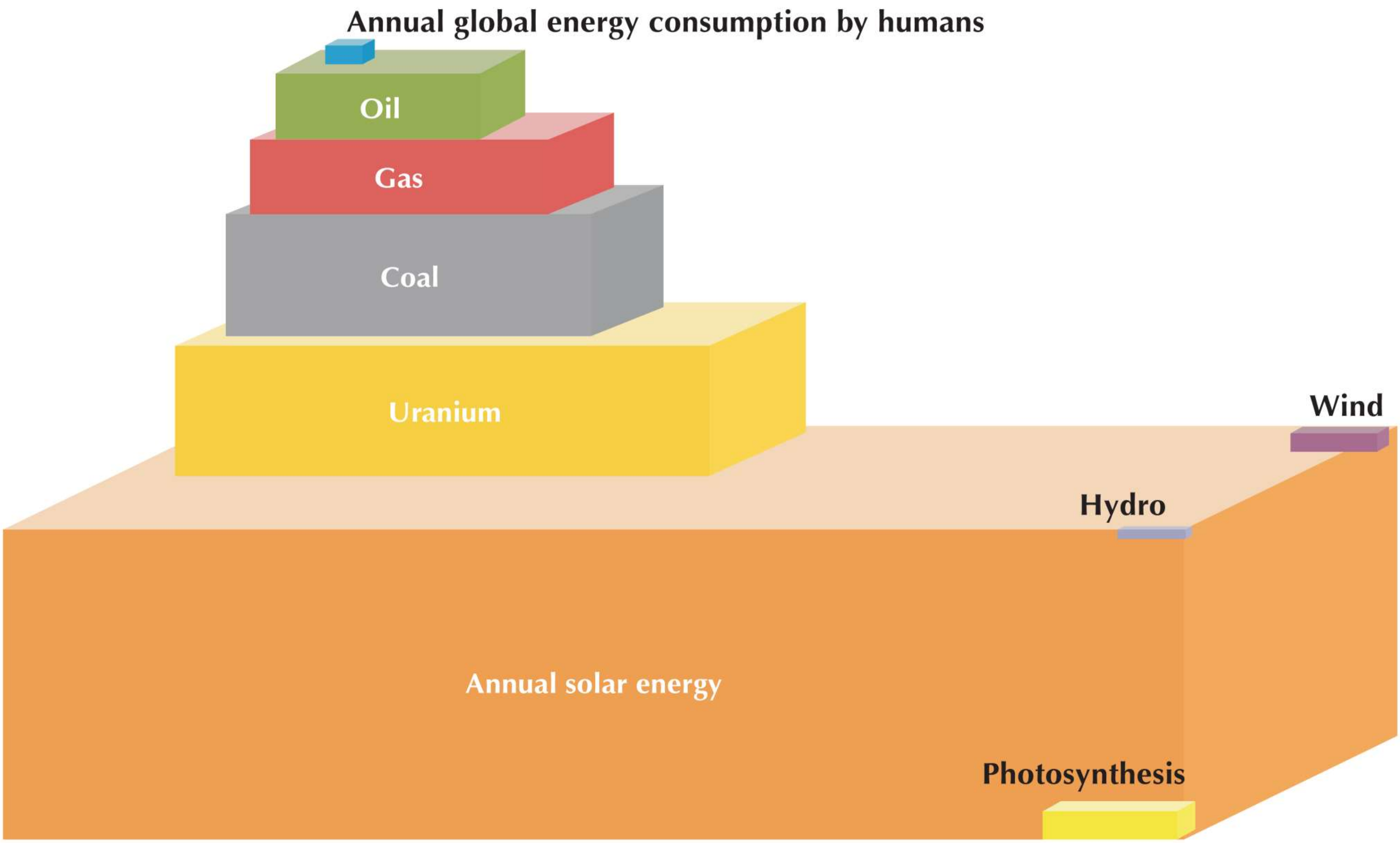
Pathways for RE integration to provide energy services, either into energy supply systems or on-site for use by the end-use sectors.

Solar Energy



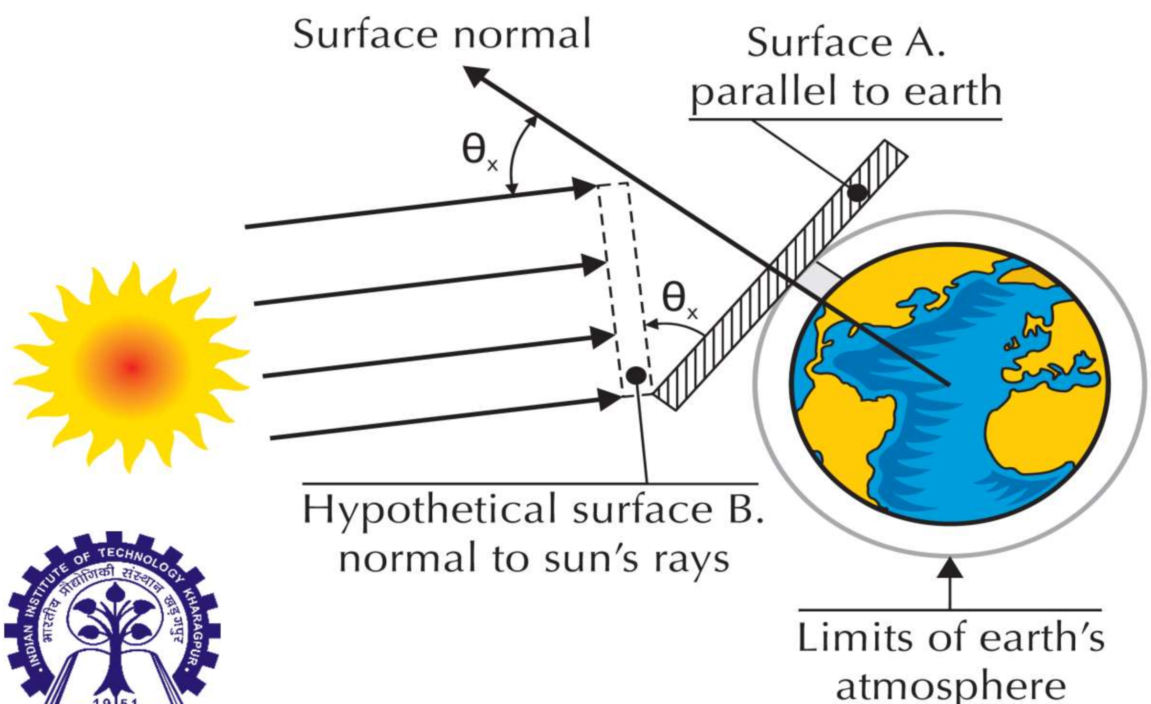
Direct solar energy

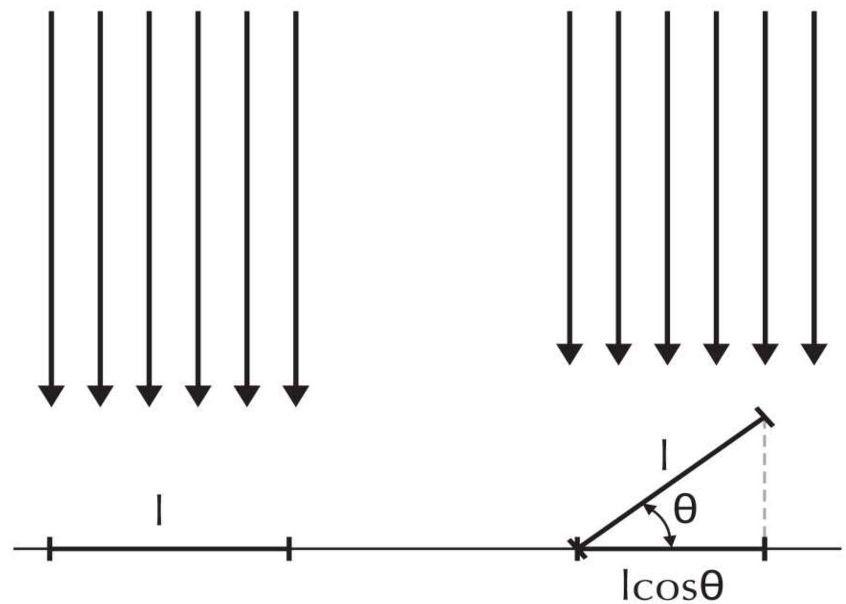
- Solar energy is the largest energy resource on Earth – and is inexhaustible.



- 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.

The cosine effect





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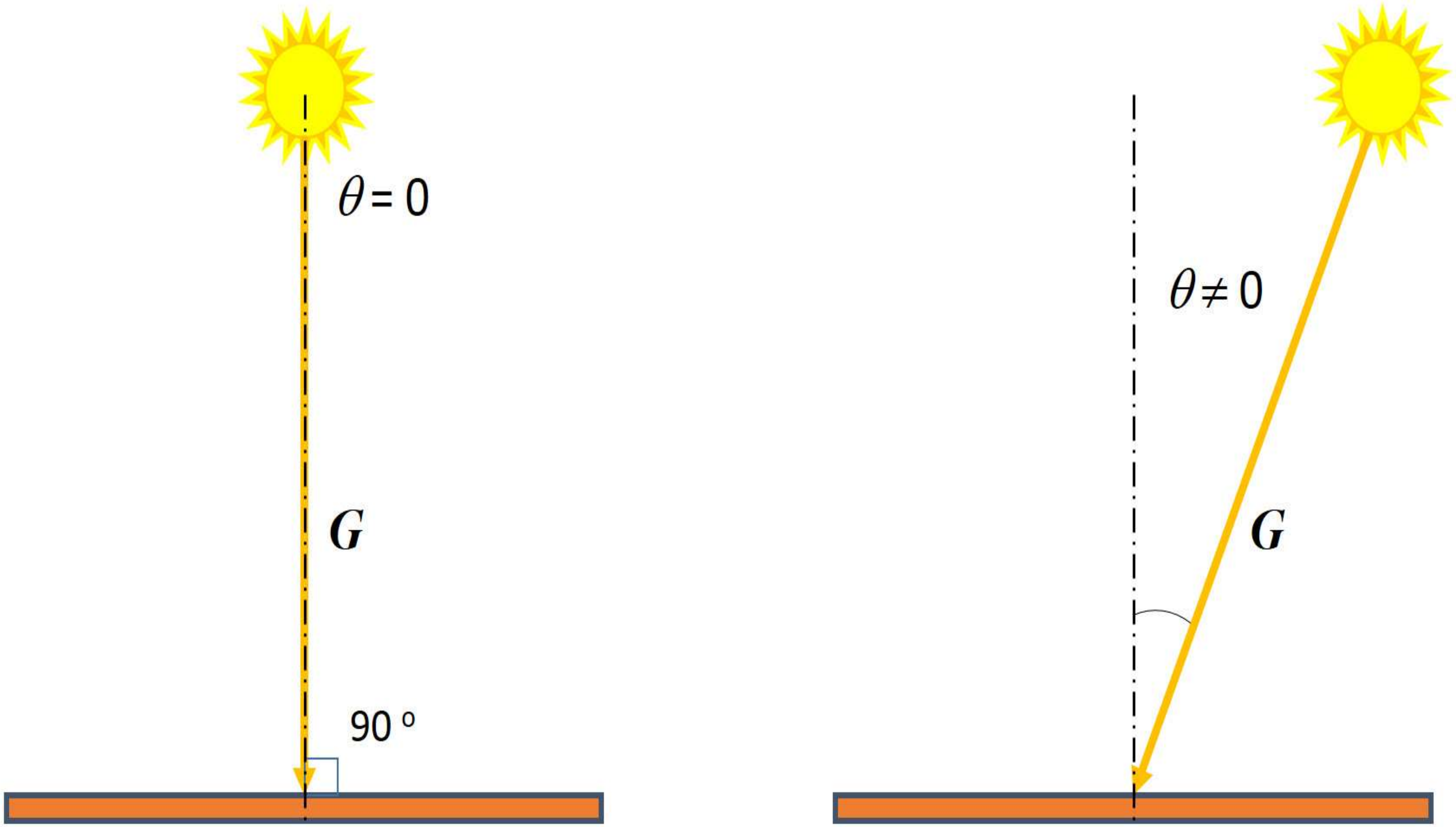

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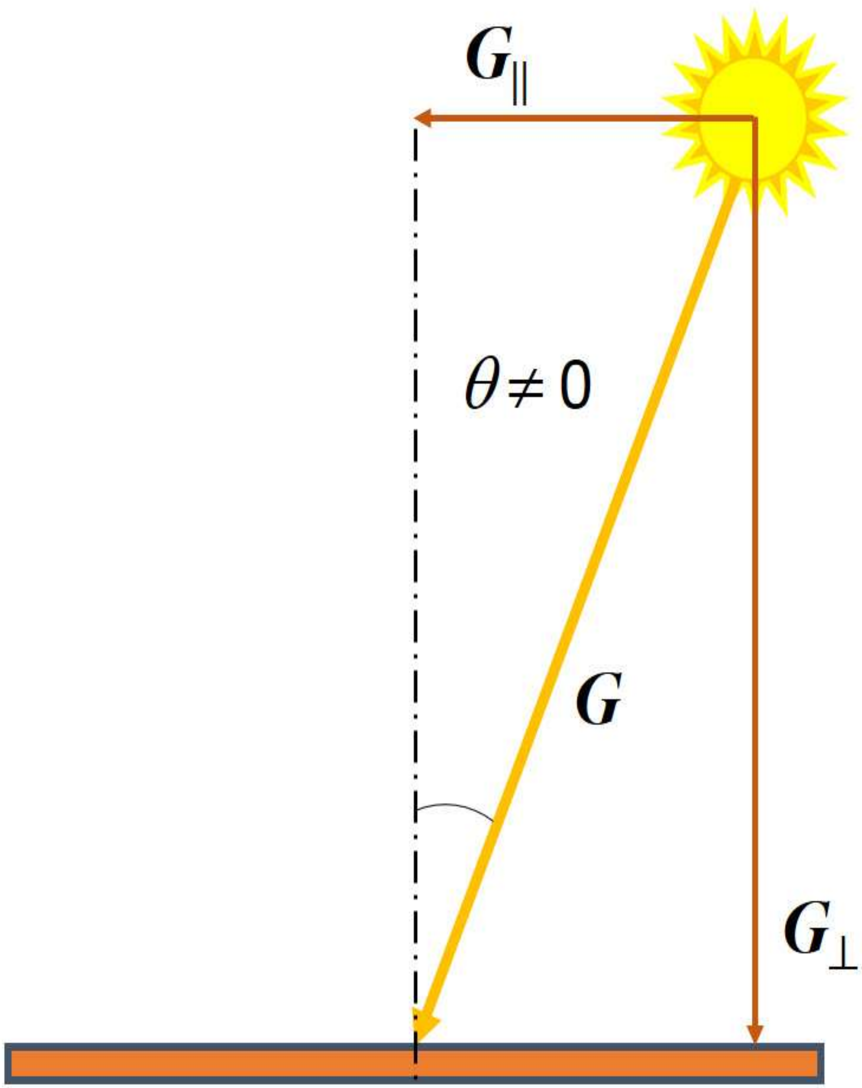

$$G_{\perp} = G\cos(\theta)$$

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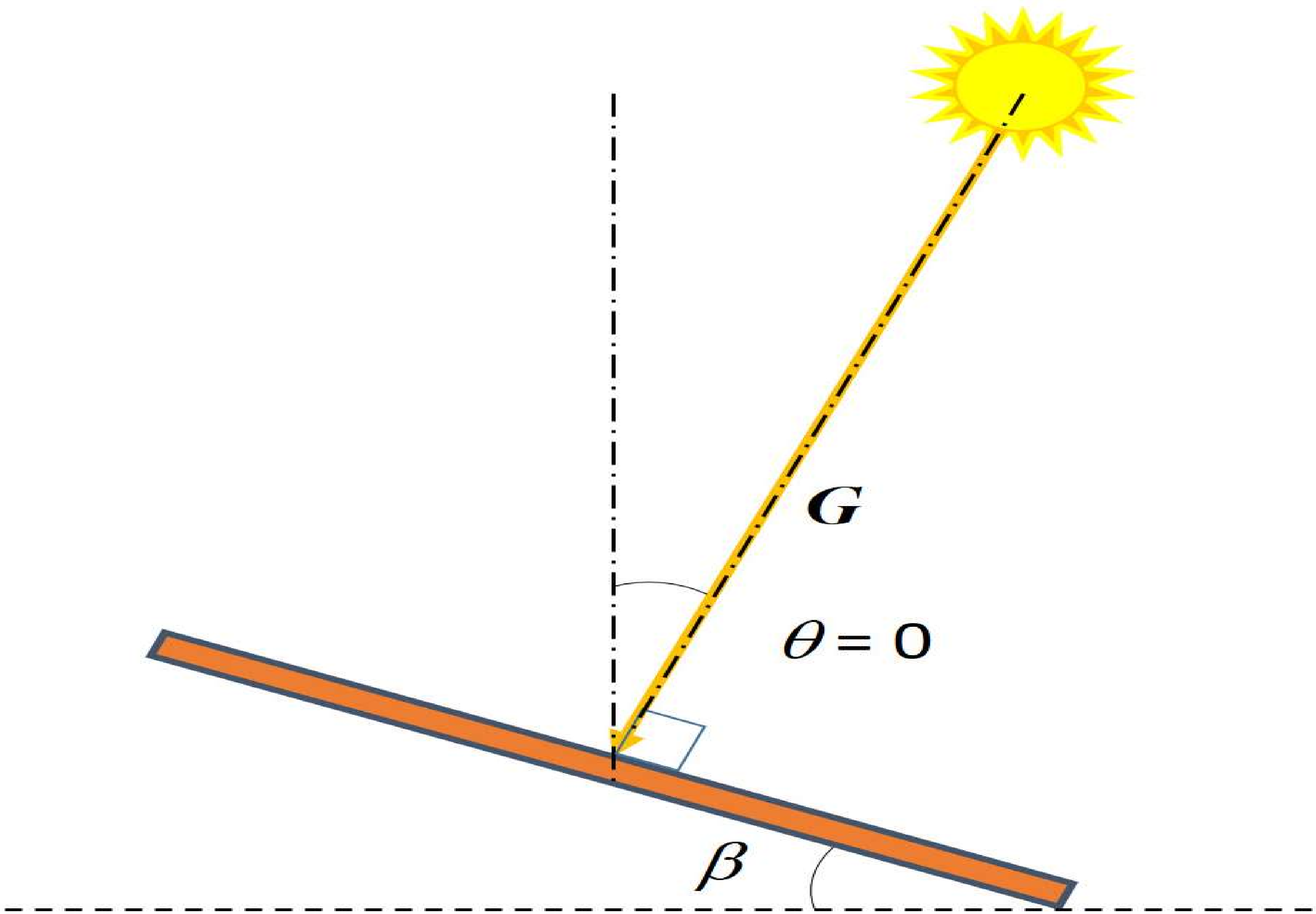
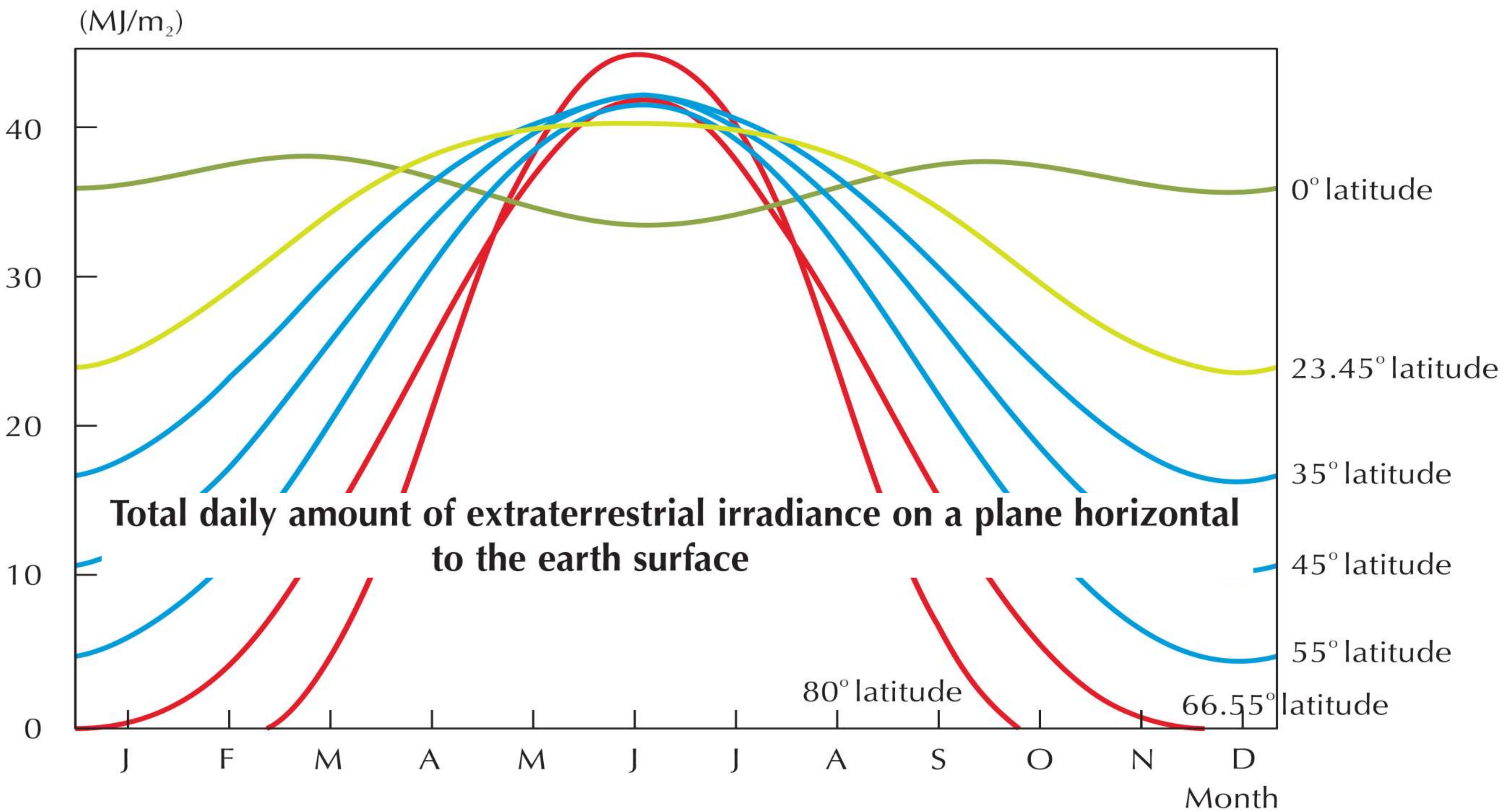
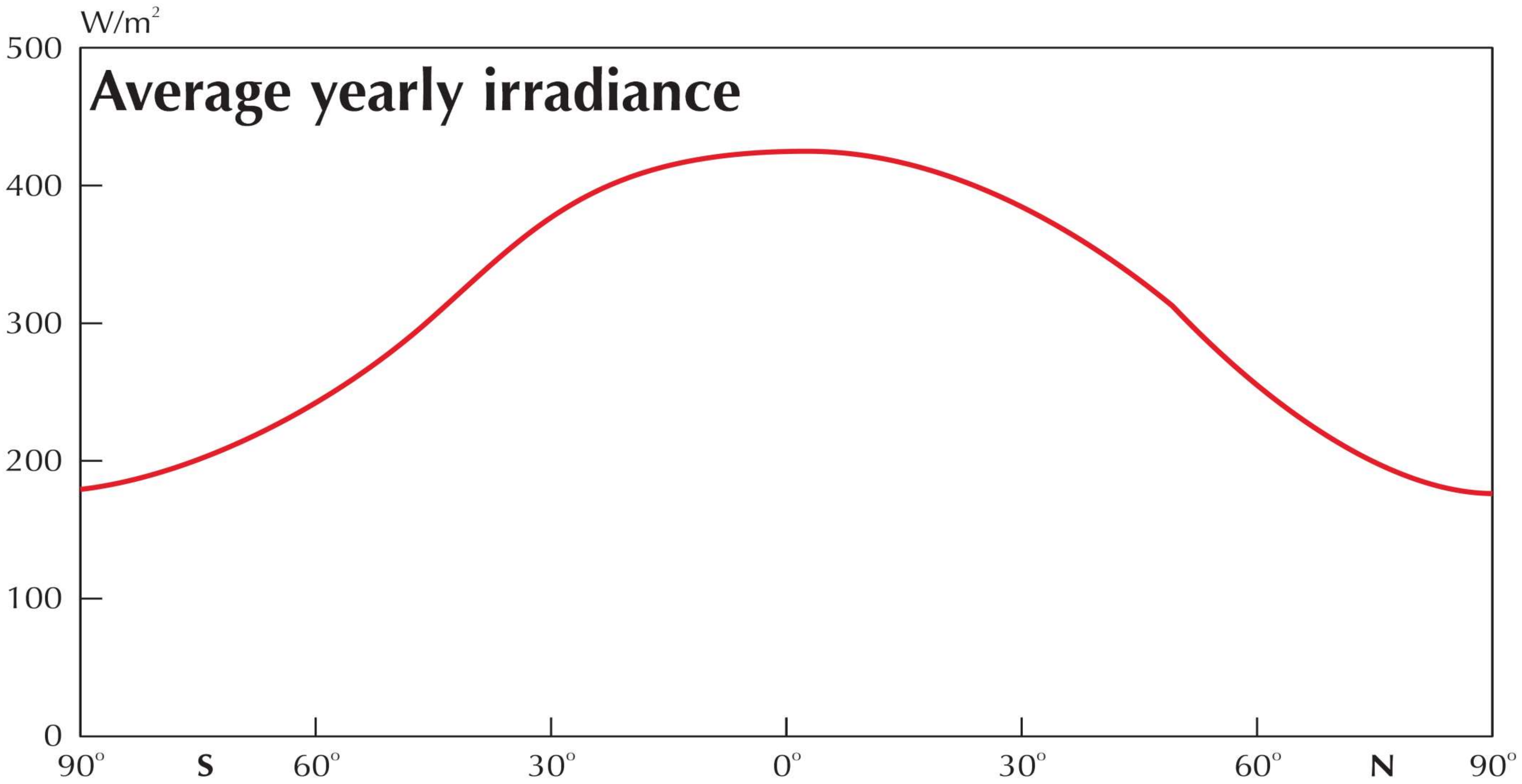


- Solar irradiance varies over the year at diverse latitudes – very much at high latitudes, especially beyond the polar circles, and very little in the tropics.



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

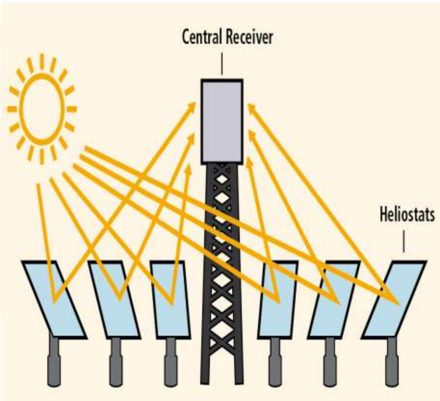


Capturing solar energy

- 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.

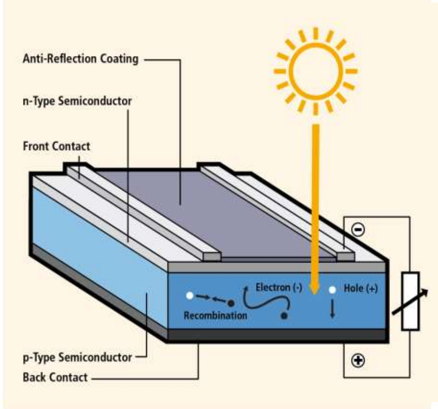
- Depending on the capturing mechanism, there are four major direct solar energy technologies.

Concentrating Solar Power (CSP)



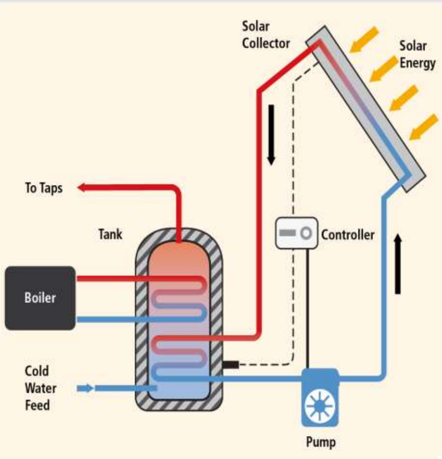
Electricity is generated by the **optical concentration** of solar energy, producing high-temperature fluids or materials to drive heat engines and electrical generators.

Solar Photovoltaic (PV)



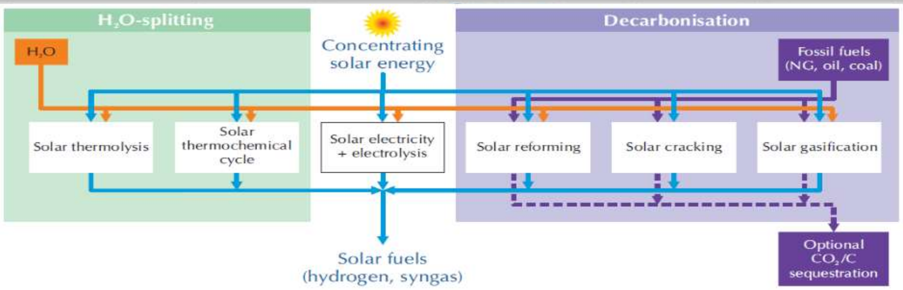
Electricity generation via direct conversion of sunlight to electricity by **photovoltaic cells** (conduction of electrons in semiconductors).

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.

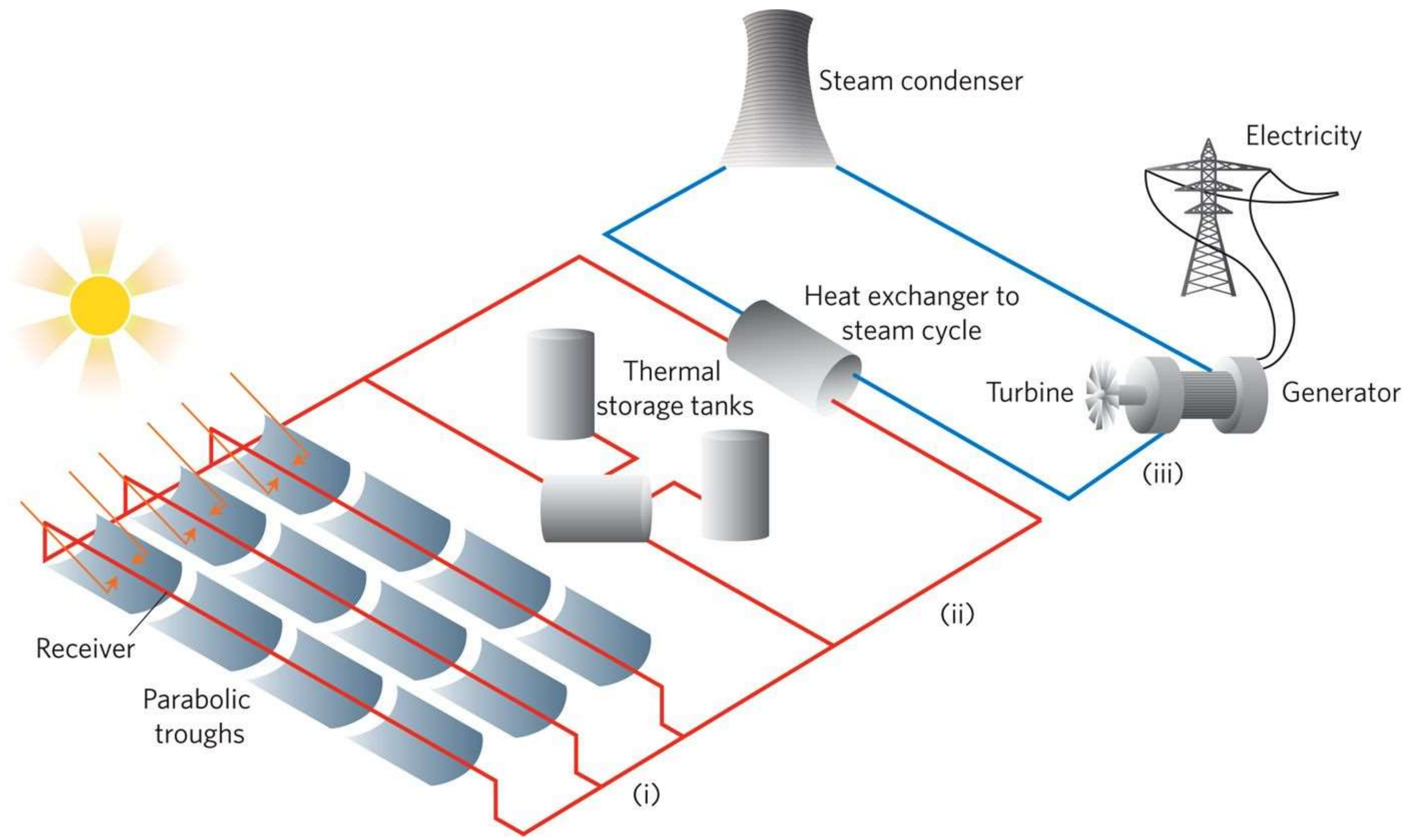
Solar fuels



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

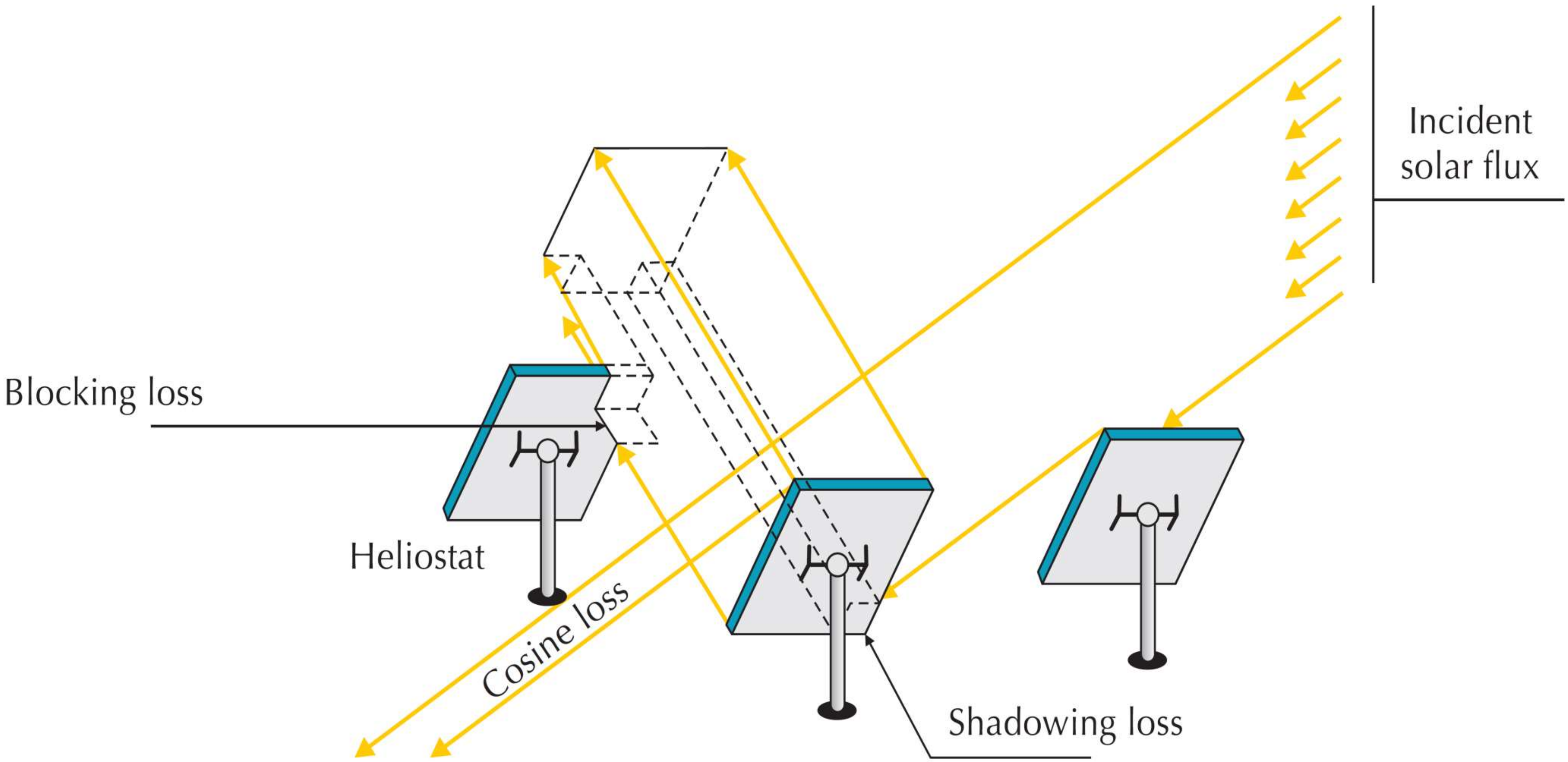
Receiver mobility	Line focus	Point focus
Fixed Receiver remains stationary and mechanically independent of the concentrating system, which is common for all the mirrors.	Linear Fresnel 	Solar Tower 
Tracking/aligned Receiver and concentrating system move together. Mobile receivers enable an optimal arrangement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

Increasing optical efficiency

Increasing optical efficiency

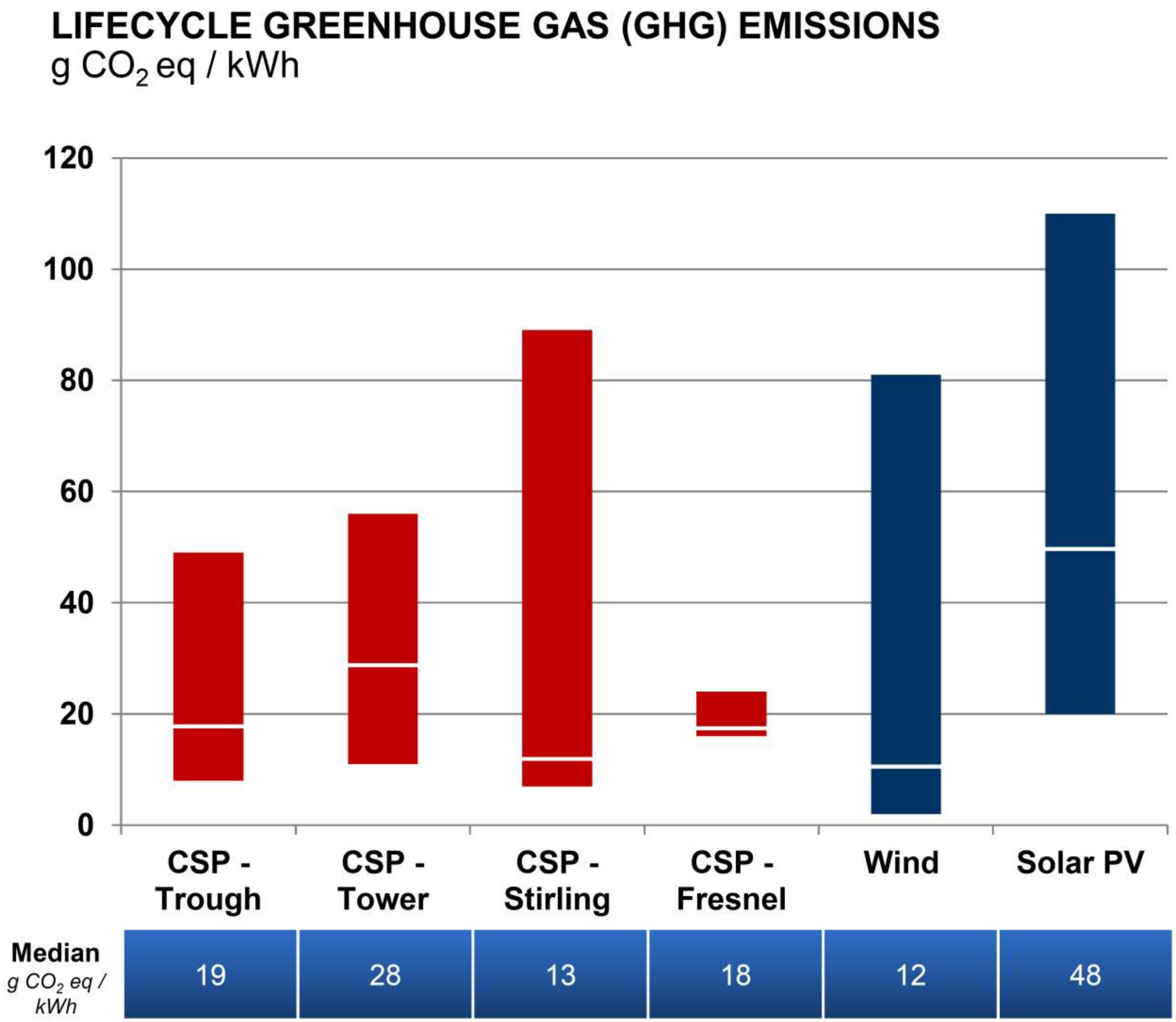
- The 392 MW *Ivanpah Solar Power Facility*, located in California's Mojave Desert, is the world's largest CSP project currently in operation. It deploys 173,500 heliostats, each with two mirrors, focusing solar energy on boilers located on three centralized solar power towers.

- 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

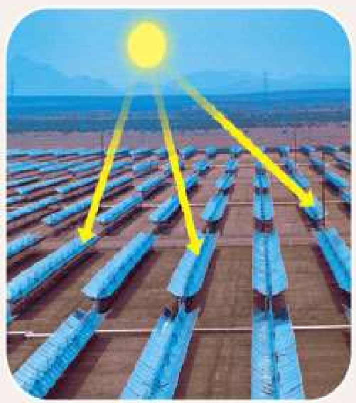
Advantages

Moderate environmental impact

No CO_2 emissions

Fast construction (1–2 years)

Costs reduced with natural gas turbine backup



Disadvantages

Low efficiency

Low net energy

High costs

Environmental costs not included in market price

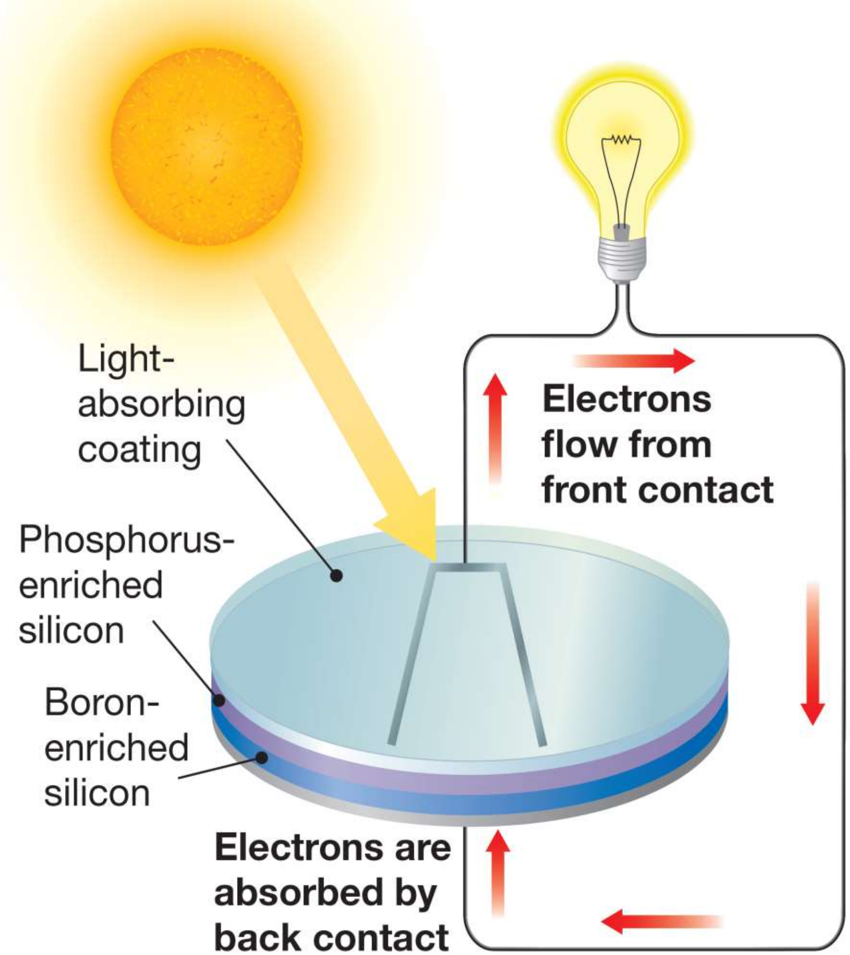
Needs backup or storage system

Needs access to sun most of the time

May disturb desert areas

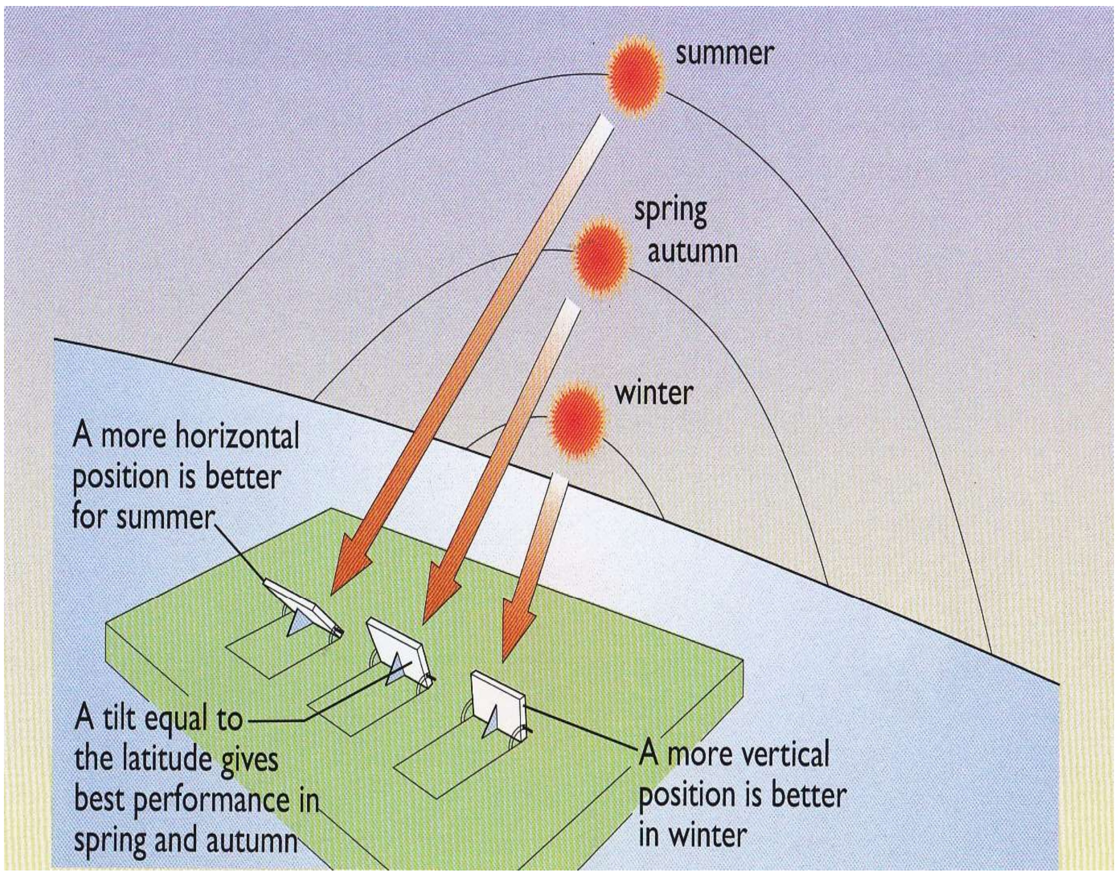
Solar photovoltaic

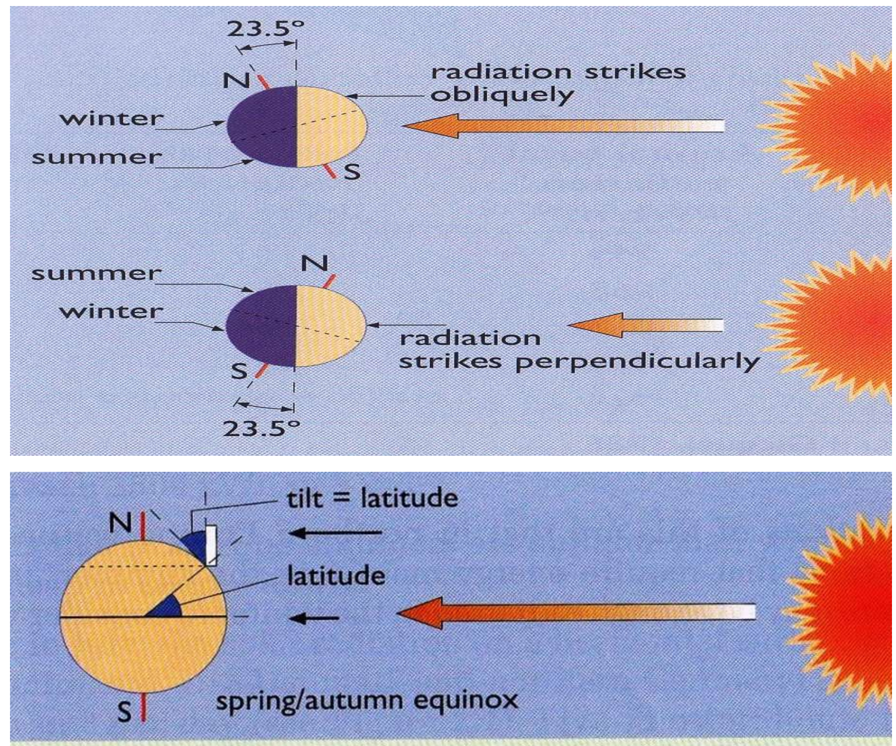
- Photovoltaic (PV) cells, also called solar cells, generate electricity by exploiting the photovoltaic effect.



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.

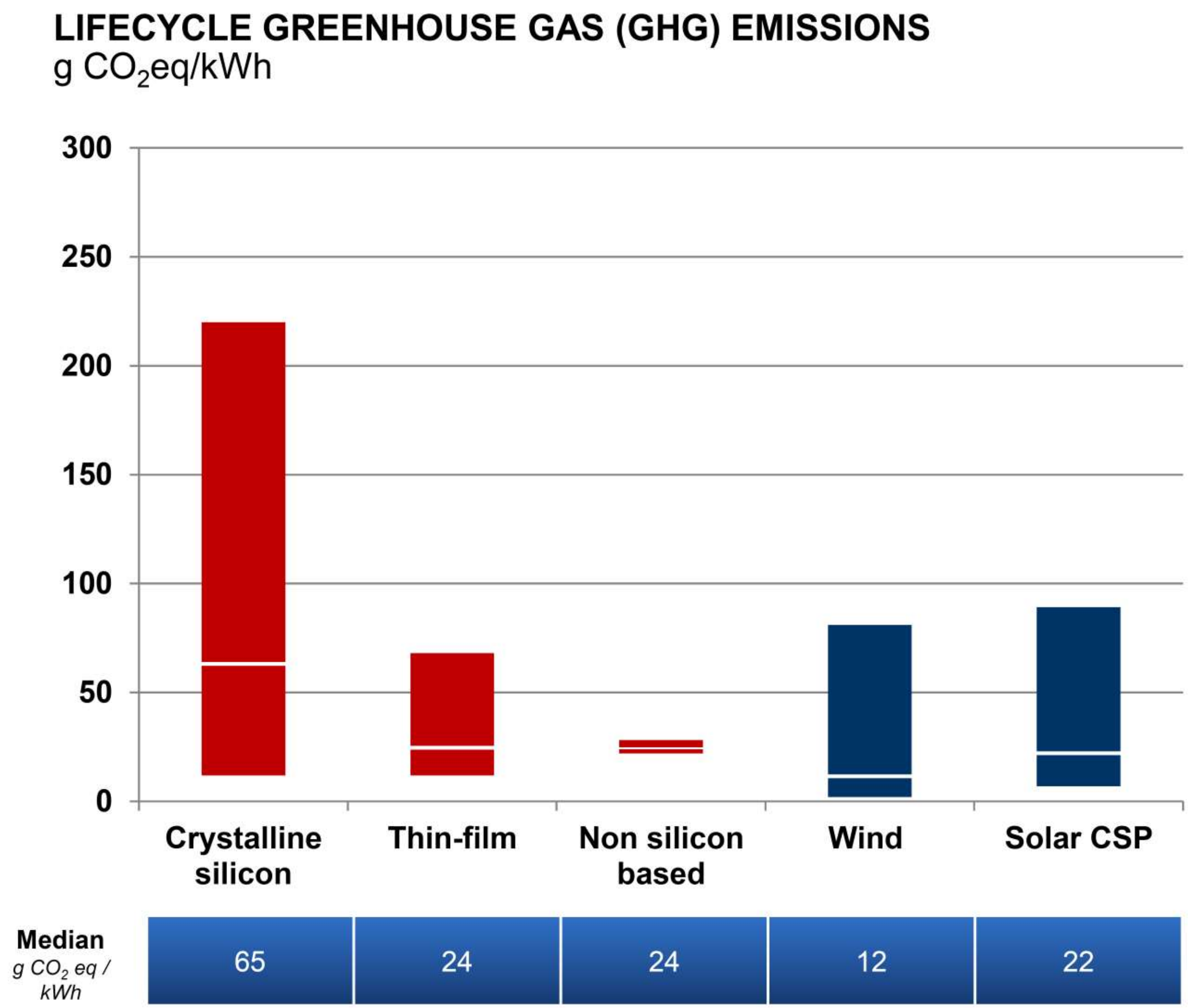
GRID CONNECTED

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

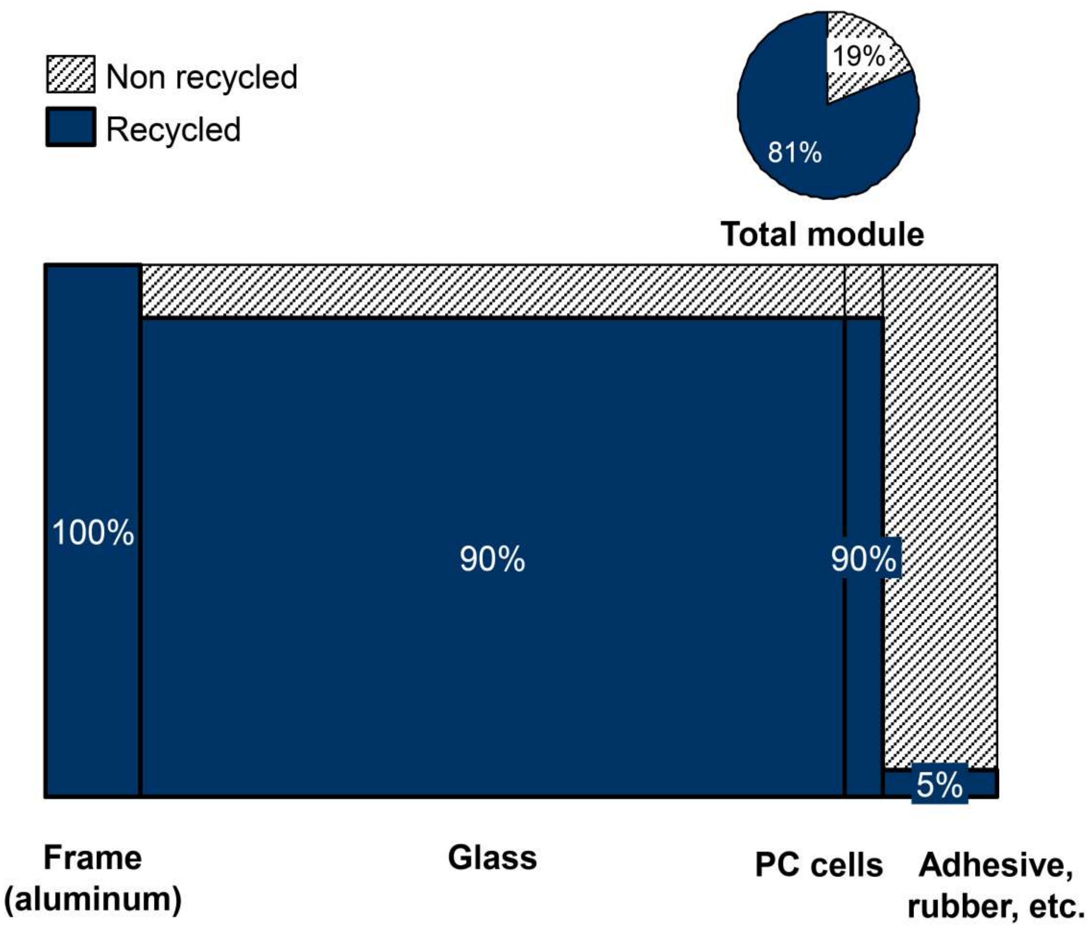
- Greenhouse gas (GHG) emissions from solar PV are low, but the technology's overall environmental impact depends on power-system integration.



- 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.

RECYCLABILITY OF A TYPICAL CRYSTALLINE PV MODULE
% of total mass



- 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

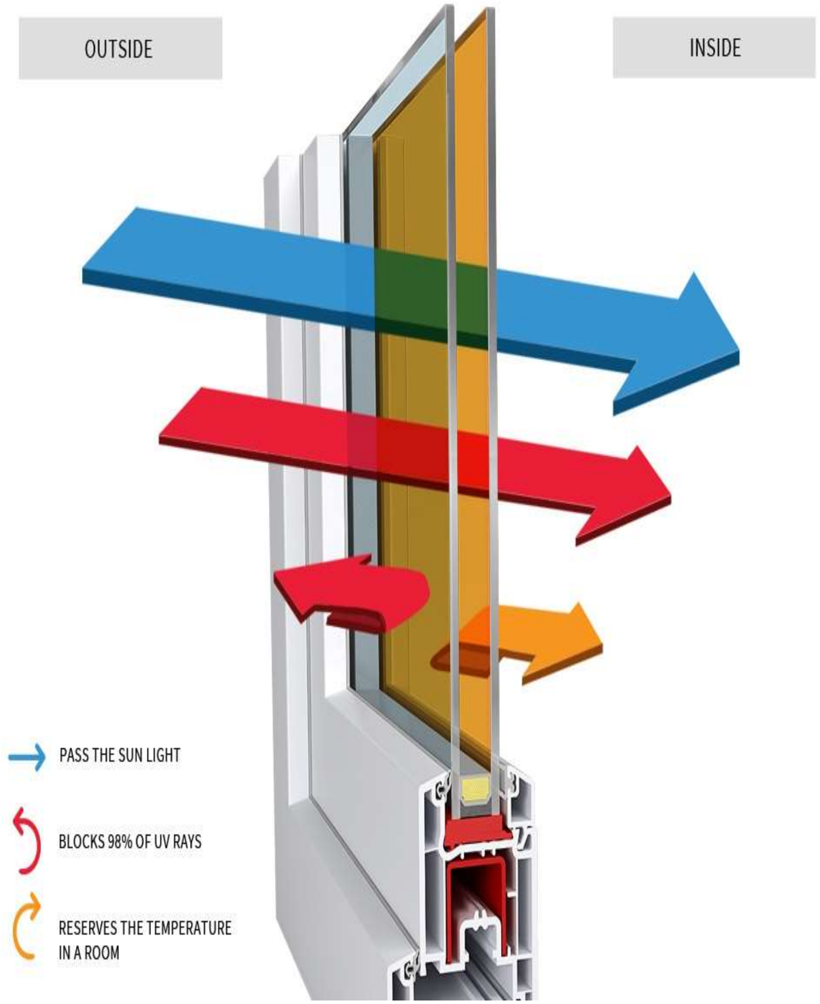
Disadvantages

- 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

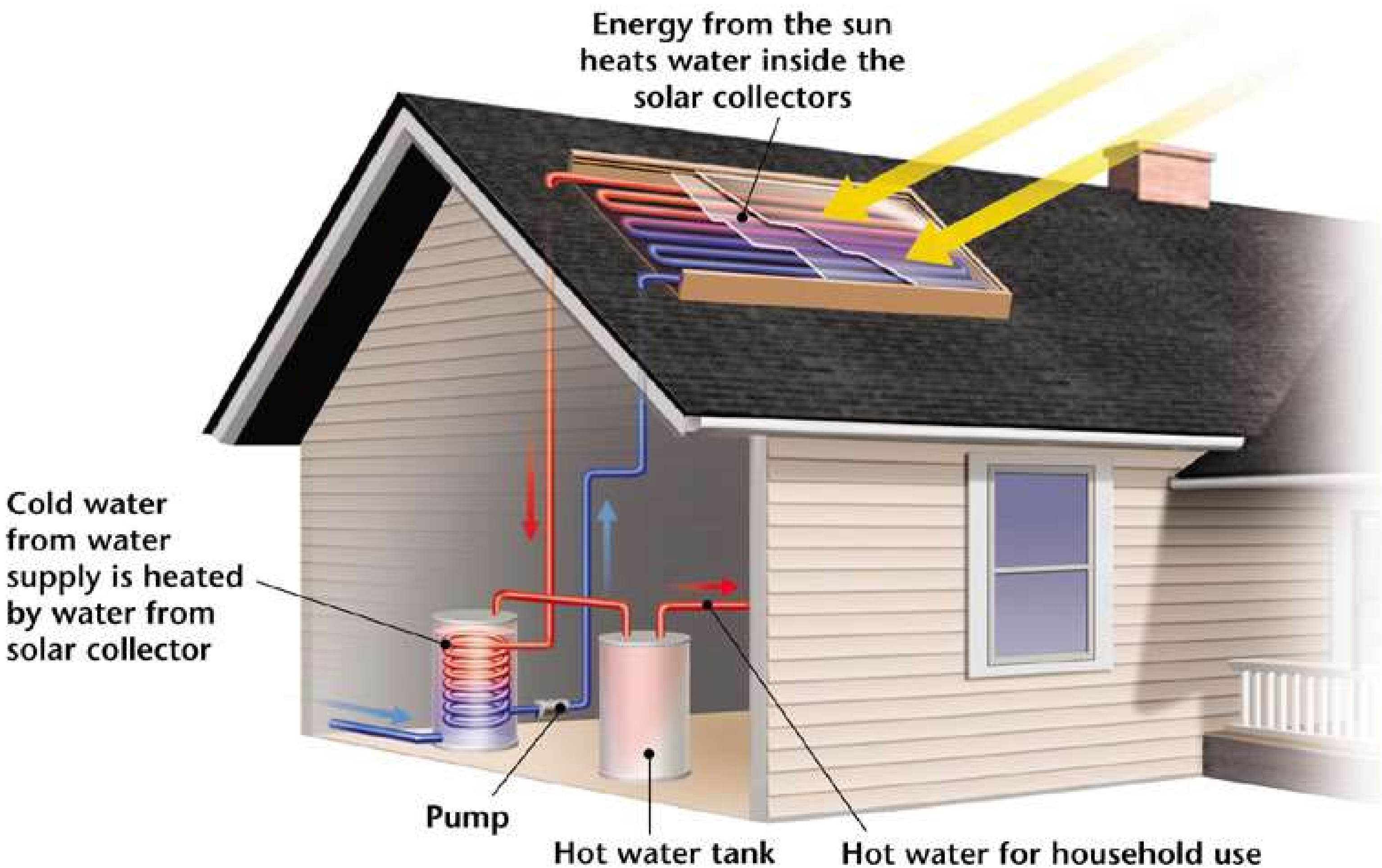
- Solar thermal energy is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in the residential and commercial sectors.

- 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/cooling
  - Solar daylighting



Active solar heating

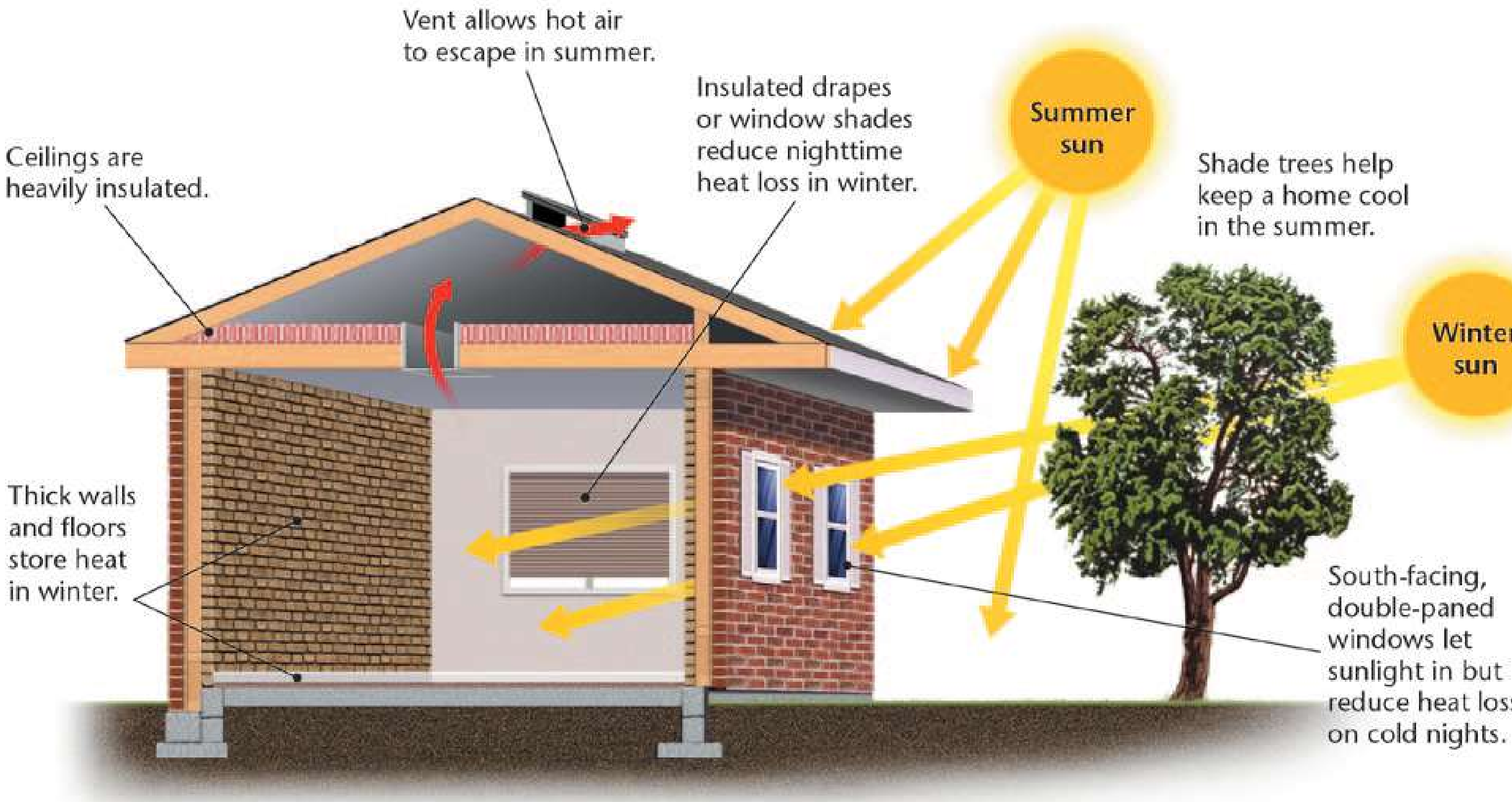
- In active solar heating systems, energy from the sun is gathered by collectors and used to heat water or to heat a building.



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.

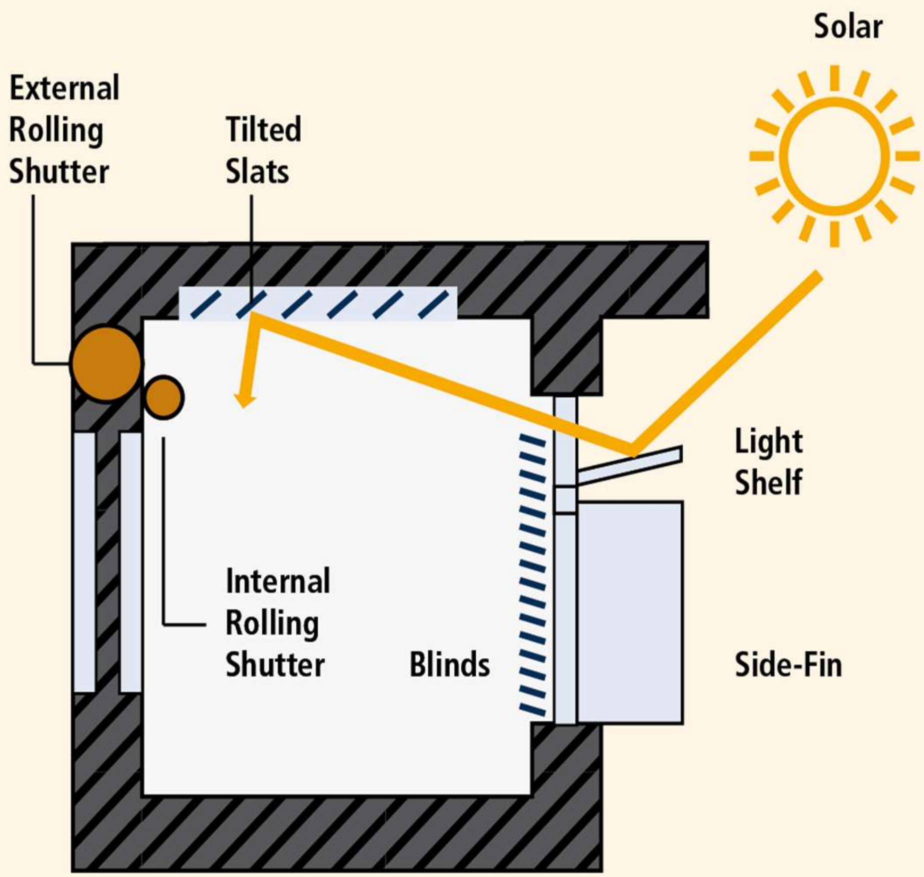
Passive solar heating

- 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

Energy is free

Net energy is moderate (active) to high (passive)

Quick installation

No CO_2 emissions

Very low air and water pollution

Very low land disturbance (built into roof or windows)

Moderate cost (passive)

Disadvantages

Need access to sun 60% of time

Sun can be blocked by trees and other structures

Environmental costs not included in market price

Need heat storage system

High cost (active)

Active system needs maintenance and repair

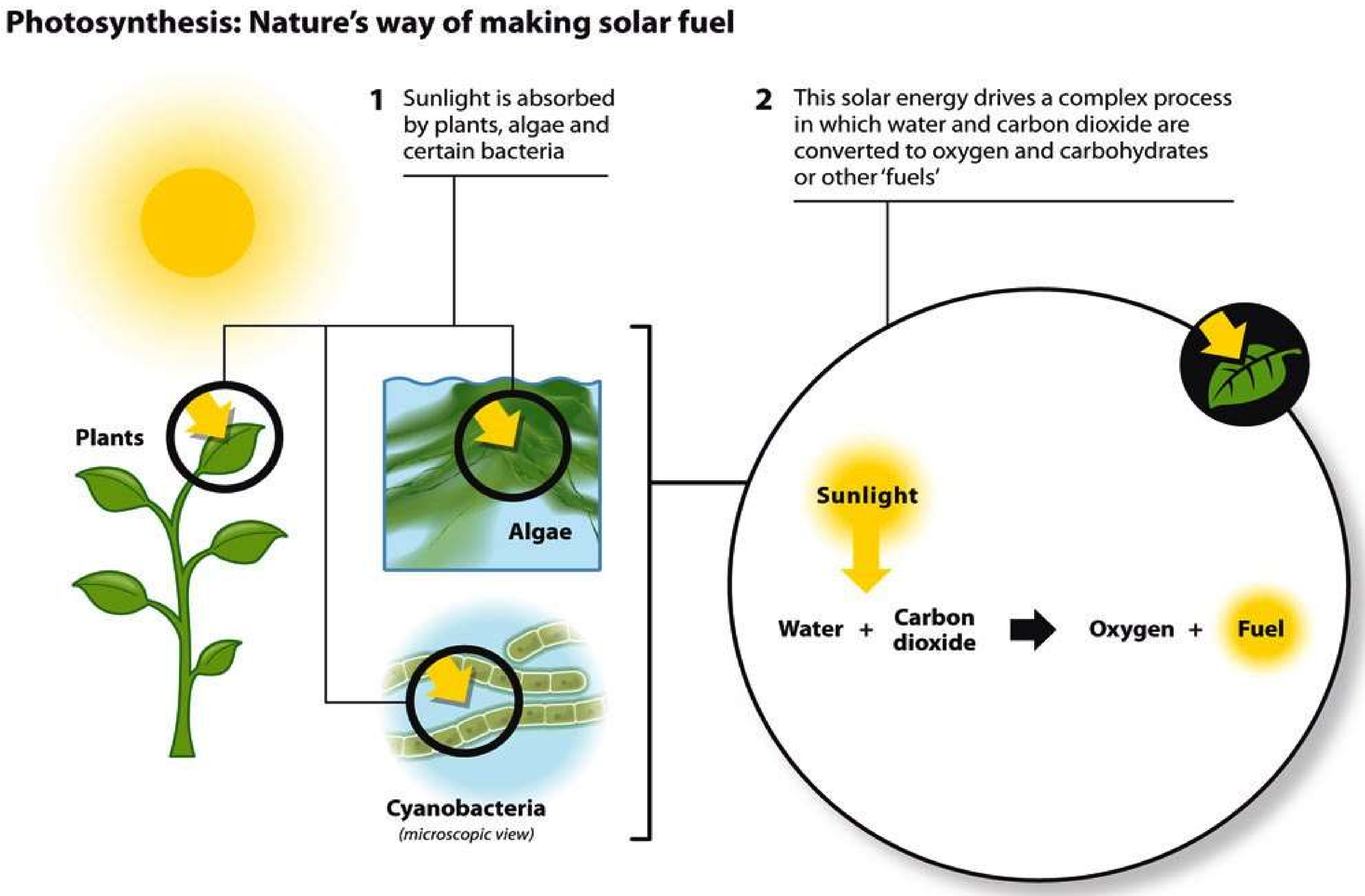
Active collectors unattractive

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.

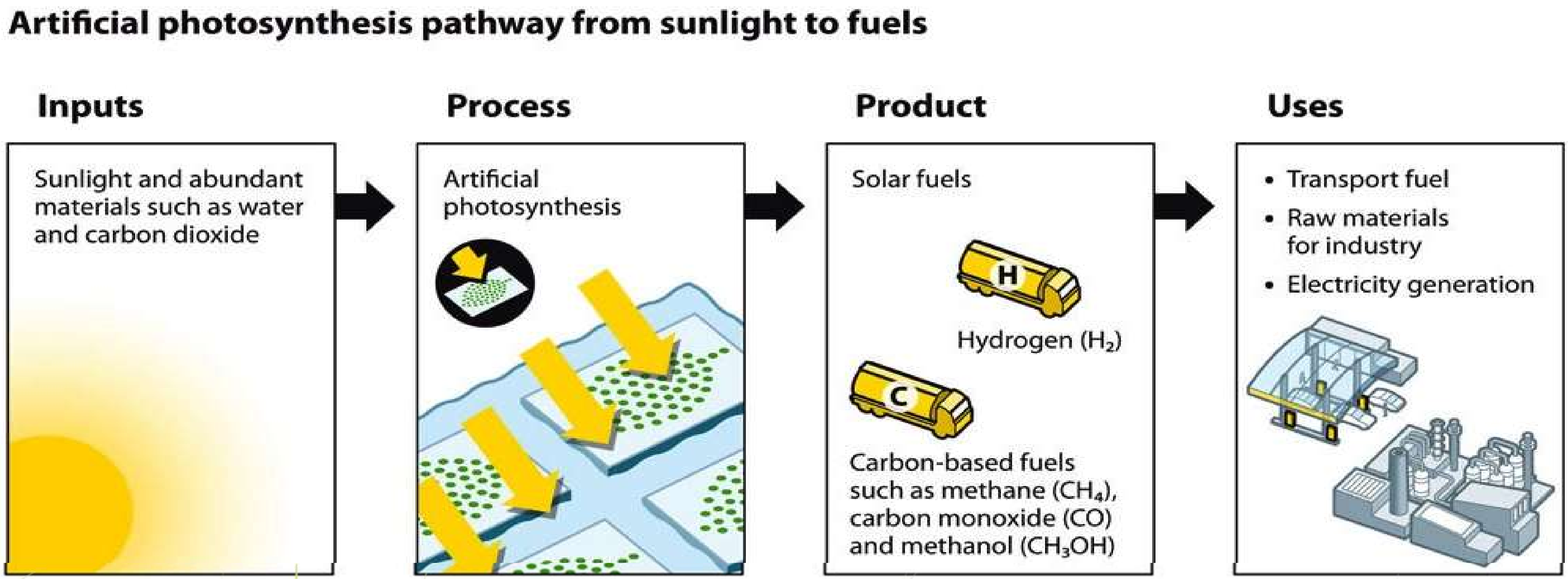
Photochemical/Photobiological method

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

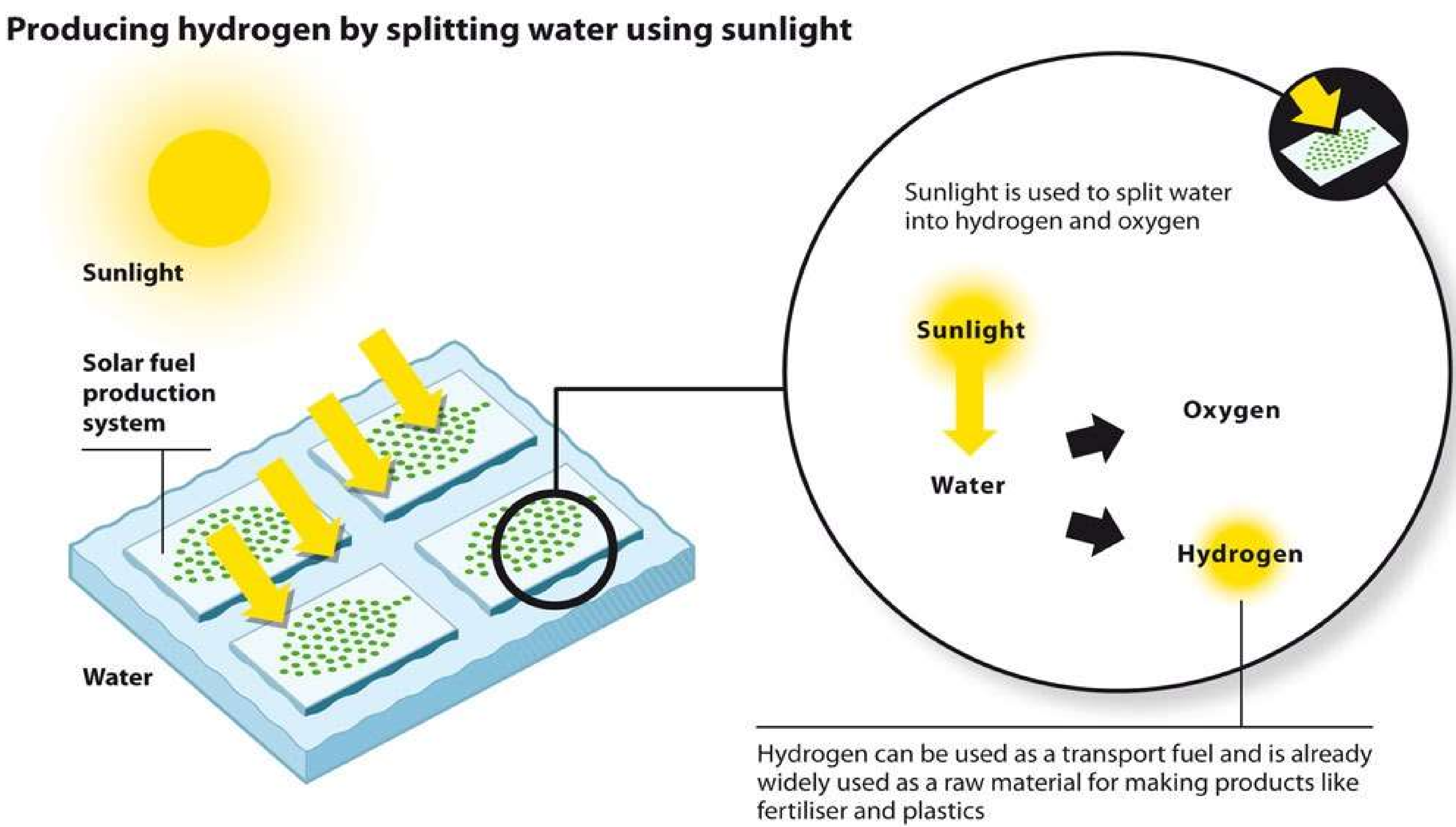


Artificial photosynthesis

- 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).

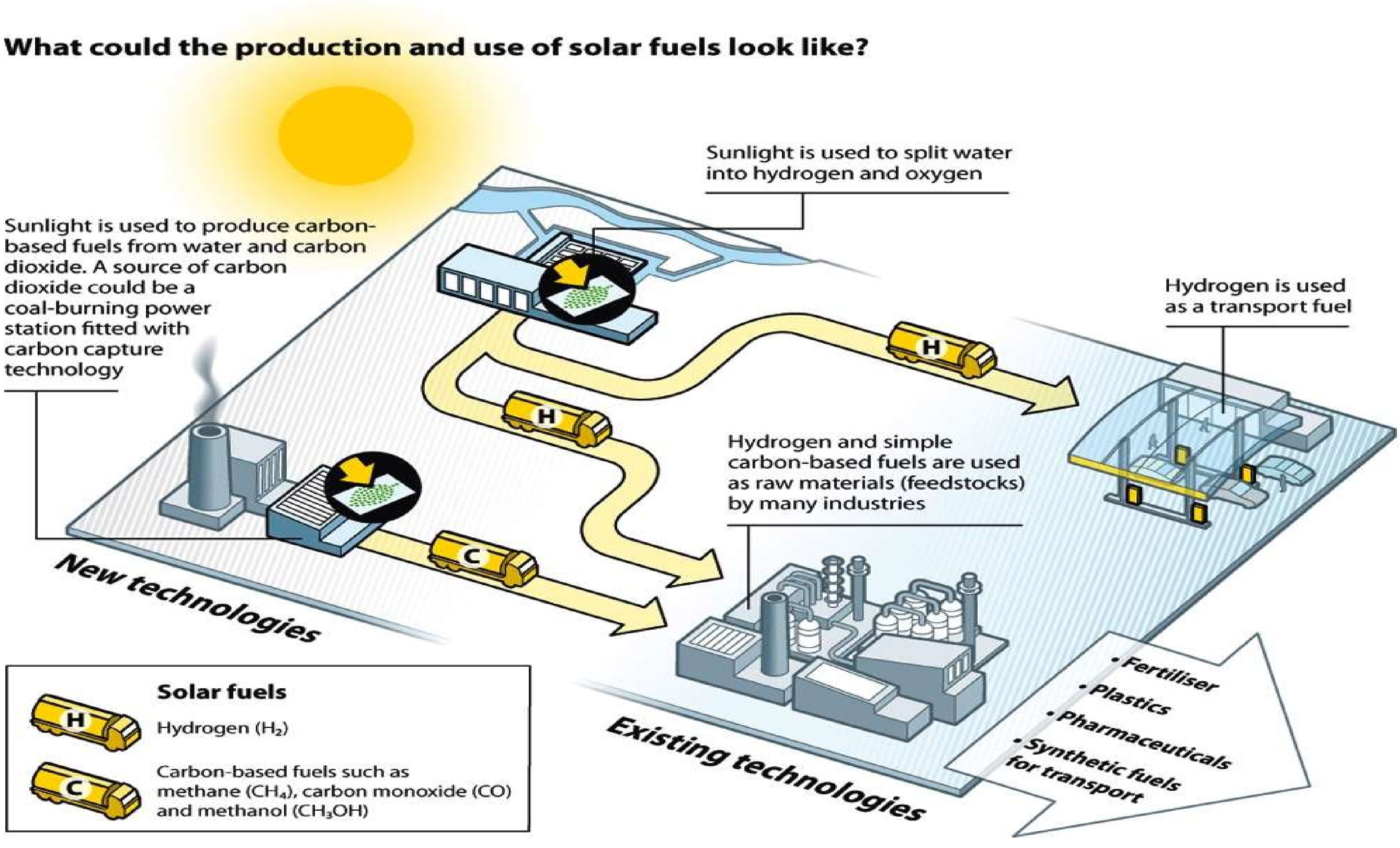


- Photocatalytic water splitting converts water into hydrogen ions and oxygen, and is an active research area in artificial photosynthesis.



Applications of solar fuels

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



EV20001: ENVIRONMENTAL SCIENCE

Lecture #6

Renewable Energy

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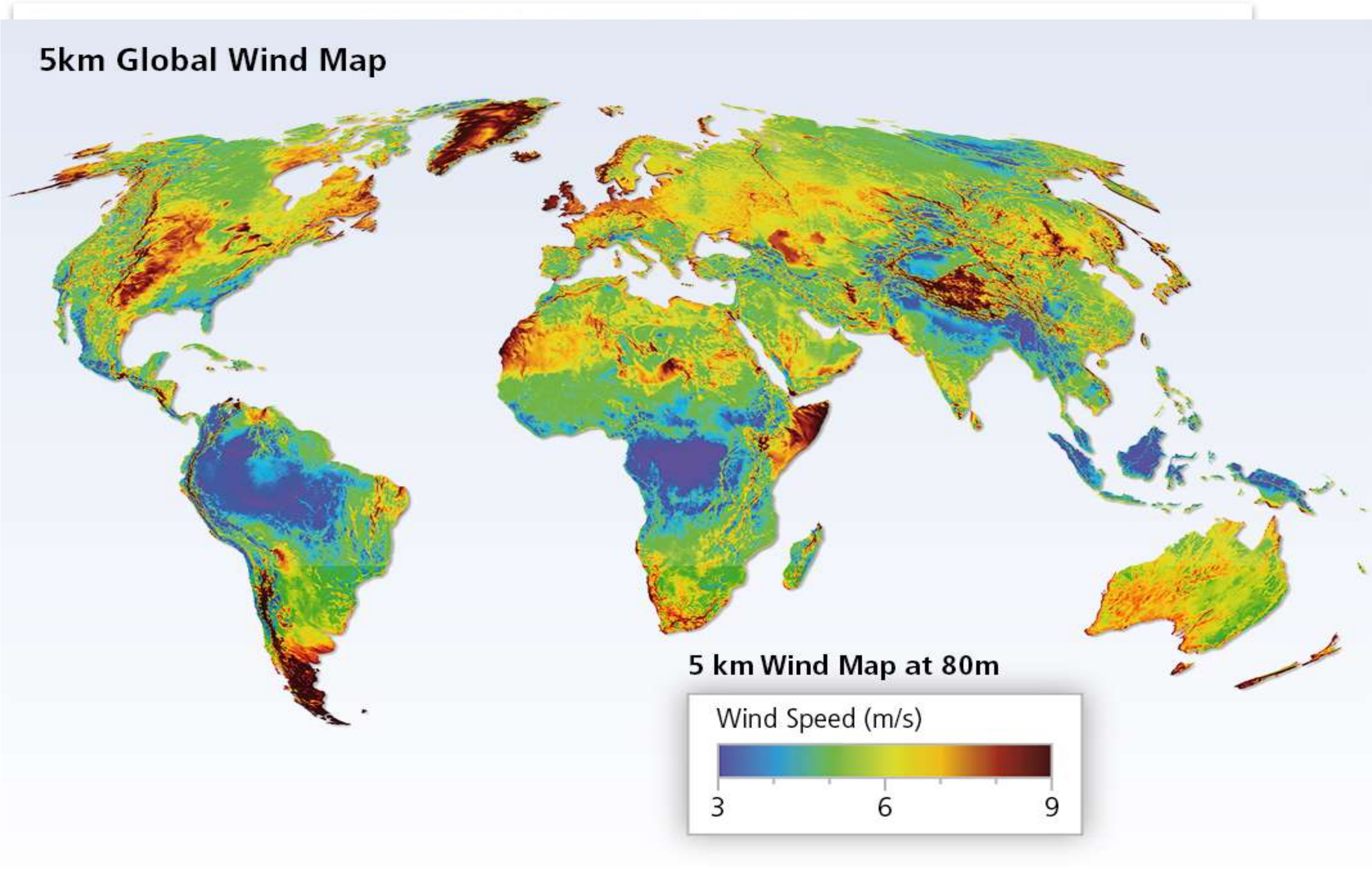
16 March 2022

Wind Energy

Wind energy

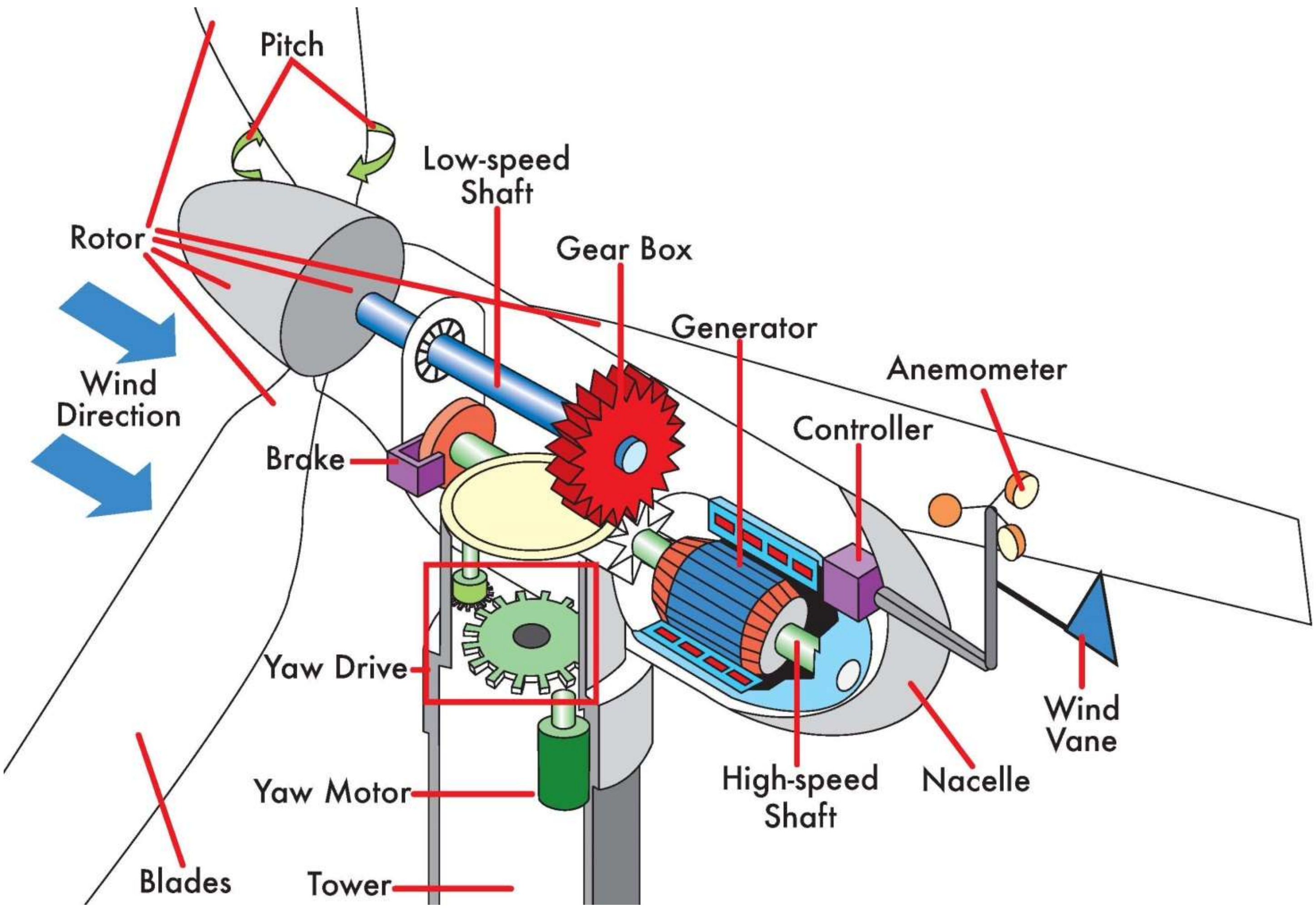
- The global technical potential for wind energy exceeds current global electricity production. Where on Earth doesn't the wind blow!

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

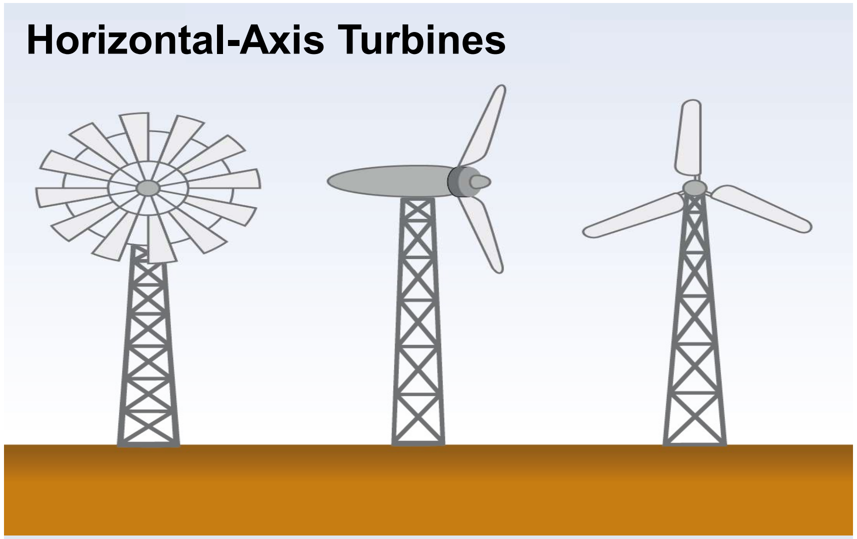


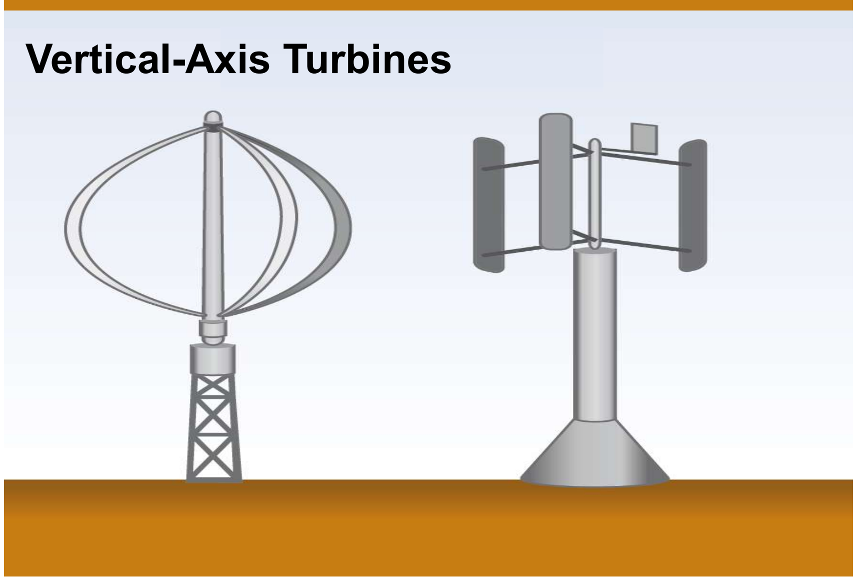
- **The technical potential of wind exceeds current global electricity production.** Estimates range from 70-450 EJ/year, while the global electricity production is of 60 EJ/year**.**
- **Wind is location and weather dependent.** Though wind speeds vary considerably by location, ample technical potential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

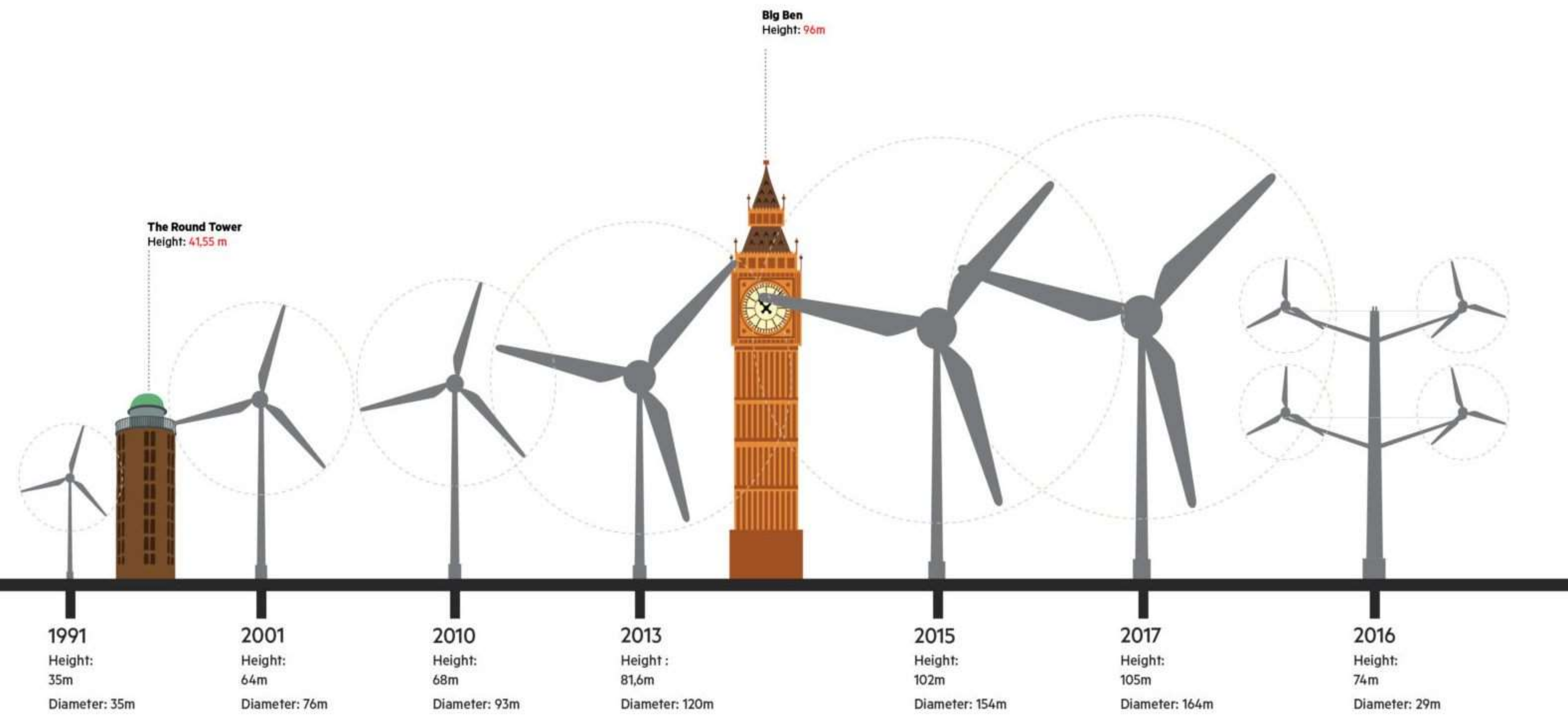




- **Several design options have been investigated**:
  - Horizontal *vs* vertical axis;
  - Upwind *vs* downwind;
  - Three blades *vs* two-blades;
  - Stall regulation *vs* pitch regulation;
  - Fixed *vs* variable speed machines.

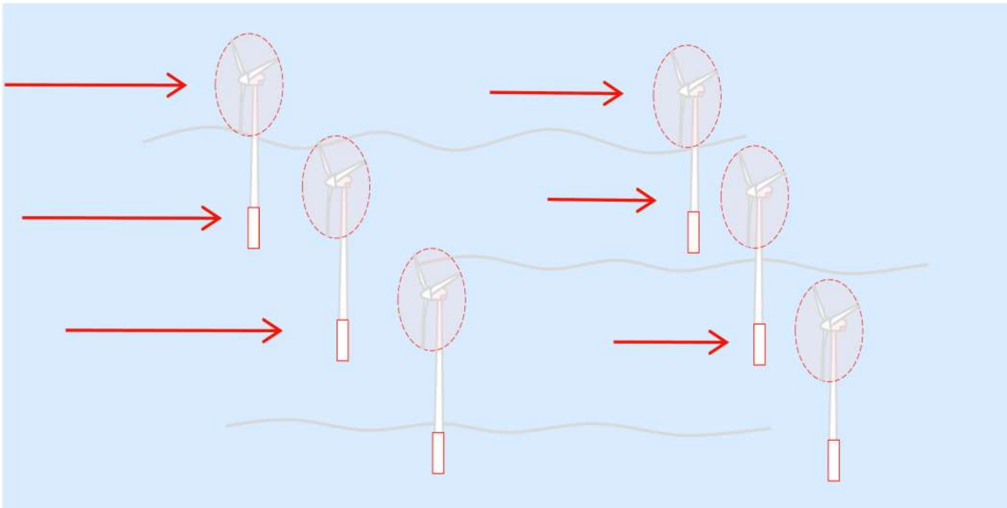
- **A dominant design has emerged for large wind turbines:**
  - Horizontal axis;
  - Upwind;
  - Three evenly spaced blades;
  - Pitch regulation (pitching the blade);
  - Variable speed.

- 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

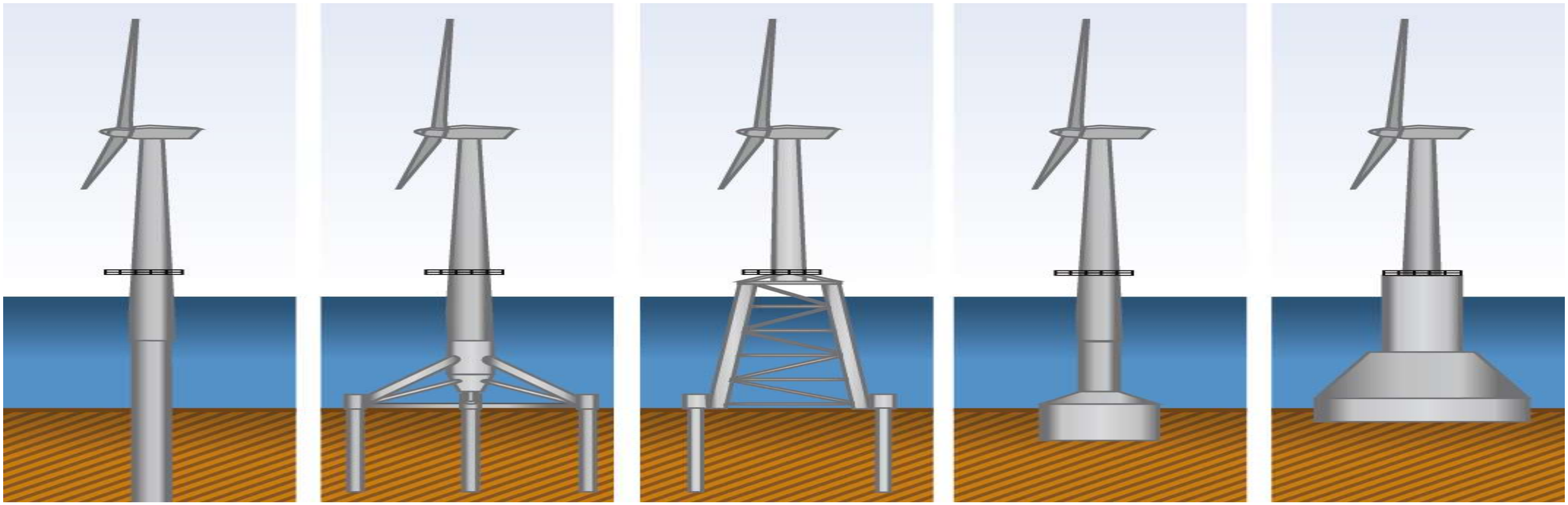
- Offshore wind is different from onshore wind.



- 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.



Monopile **Tri-pod** **Jacket** **Suction Caisson** **Gravity Base**

- 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%.

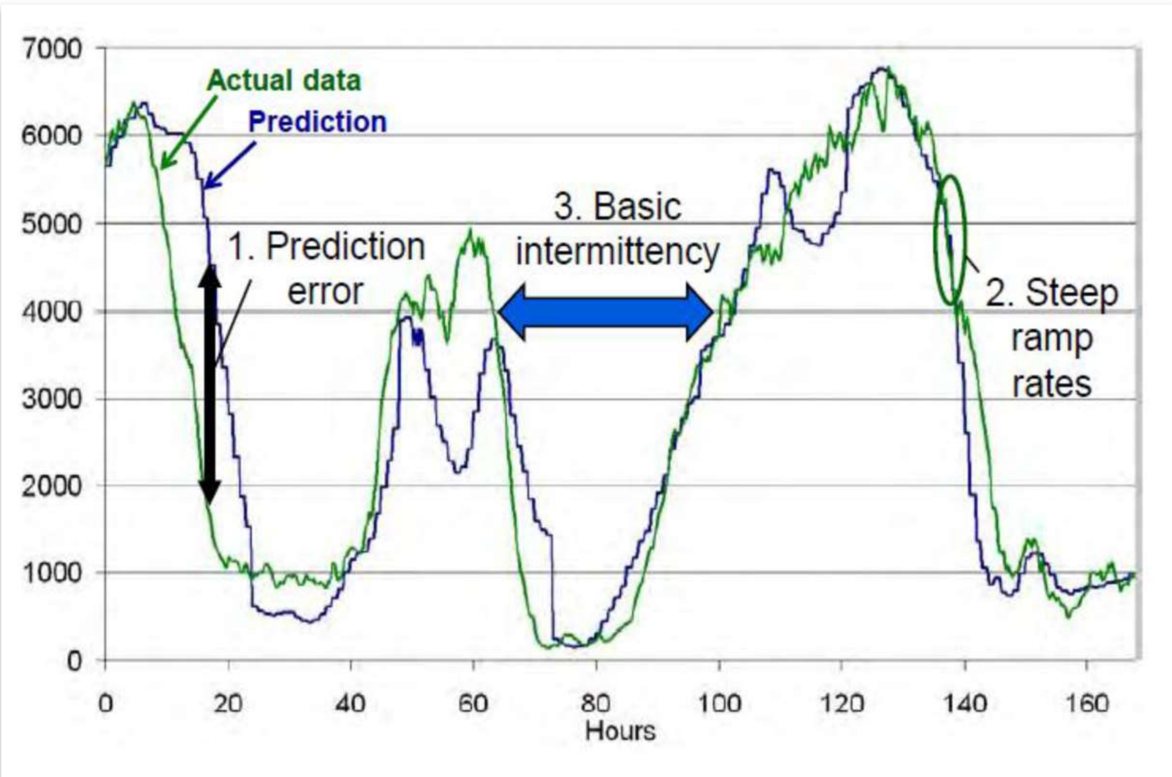
- The *Gansu Wind Farm* in China is the largest wind farm in the world. It has a capacity of over 6,000 MW of power as of 2012, with a goal of 20,000 MW by 2025.

- 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.

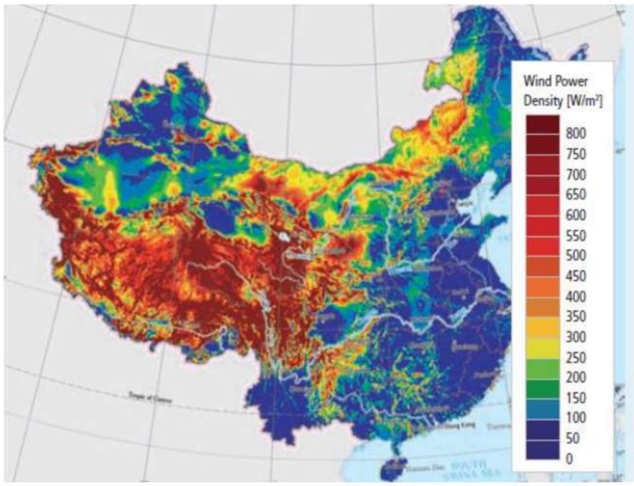
WIND INTERMITTENCY ILLUSTRATION
MW – Germany 2007



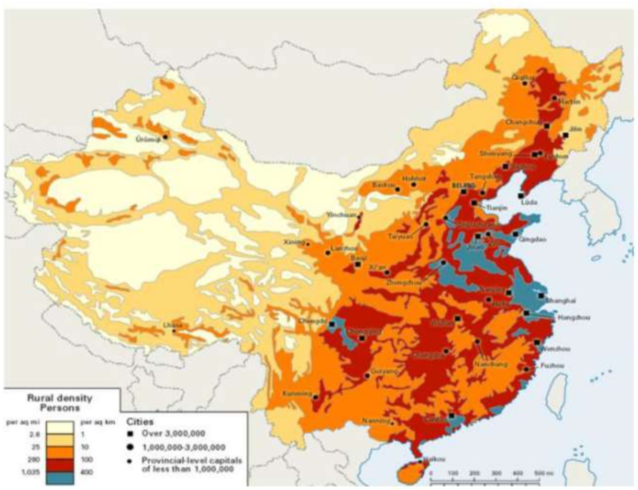
- Wind output is imperfectly predictable:
  - Lower level of predictability than fossil-fired power plants;
  - Forecast less accurate over longer time horizon (multiple hours to days).
- Wind output is subject to ramp events:
  - The output of a wind turbine can vary from zero to its rated capacity,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



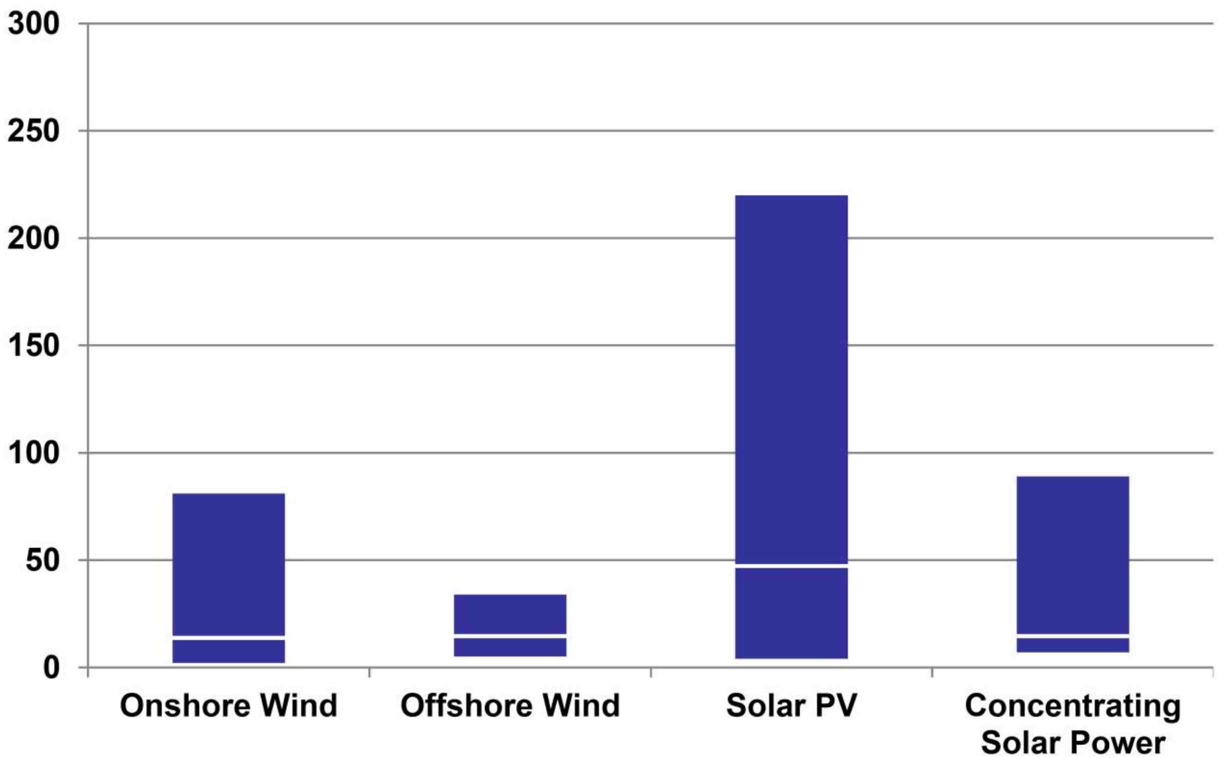
Population density
people / km²

- 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

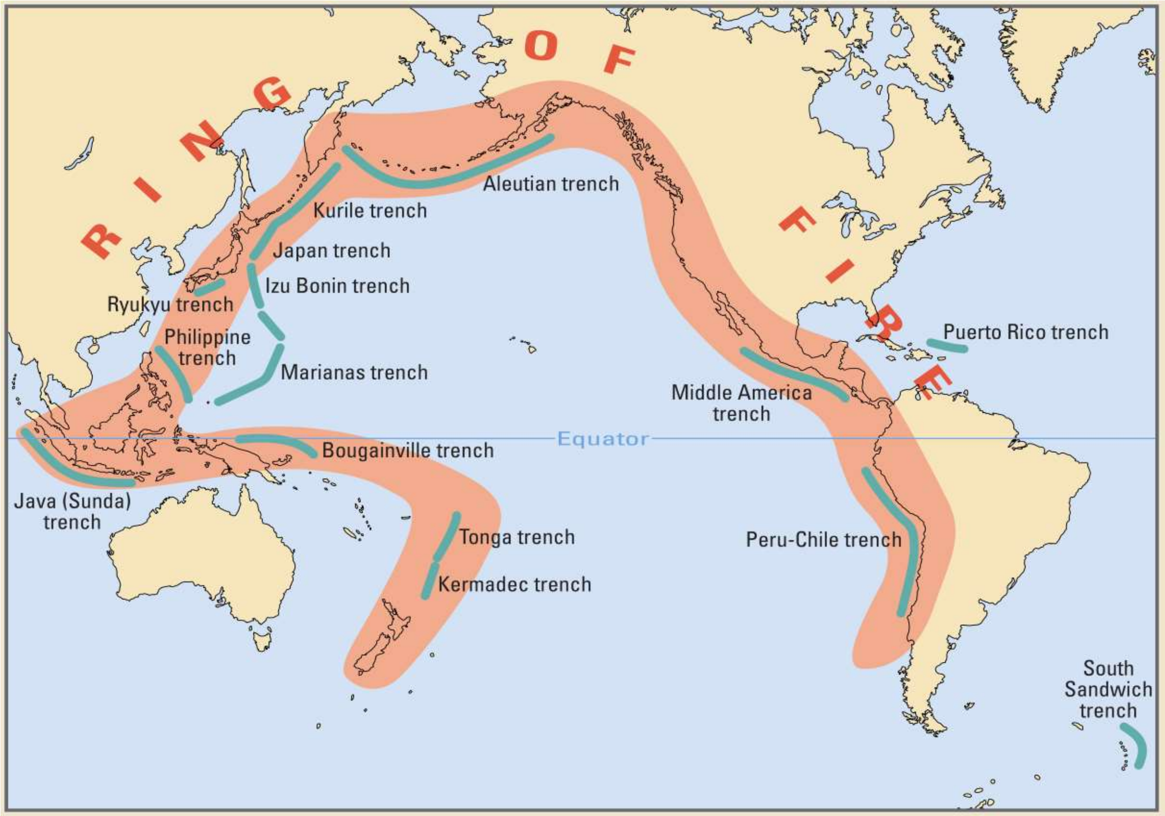
- Steady winds needed
- Backup systems needed when winds are low
- Plastic components produced from oil
- Environmental costs not included in market price
- High land use for wind farm
- Visual pollution
- Noise when located near populated areas
- Can kill birds and interfere with flights of migratory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

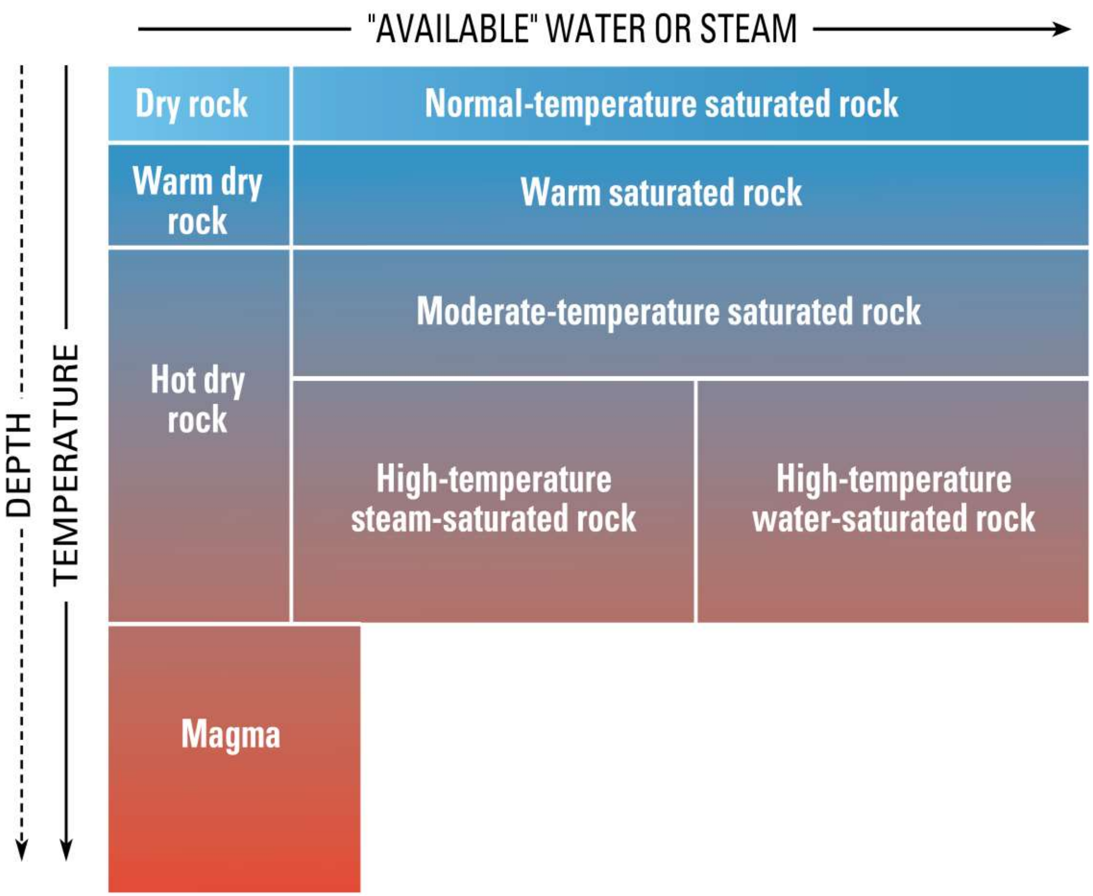


The volcanically active and earthquake-prone region rimming the Pacific Ocean is known as the "Ring of Fire." This region could also be called the Ring of Geothermal Energy, because it contains many high-temperature geothermal systems associated with active volcanoes.

- 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.

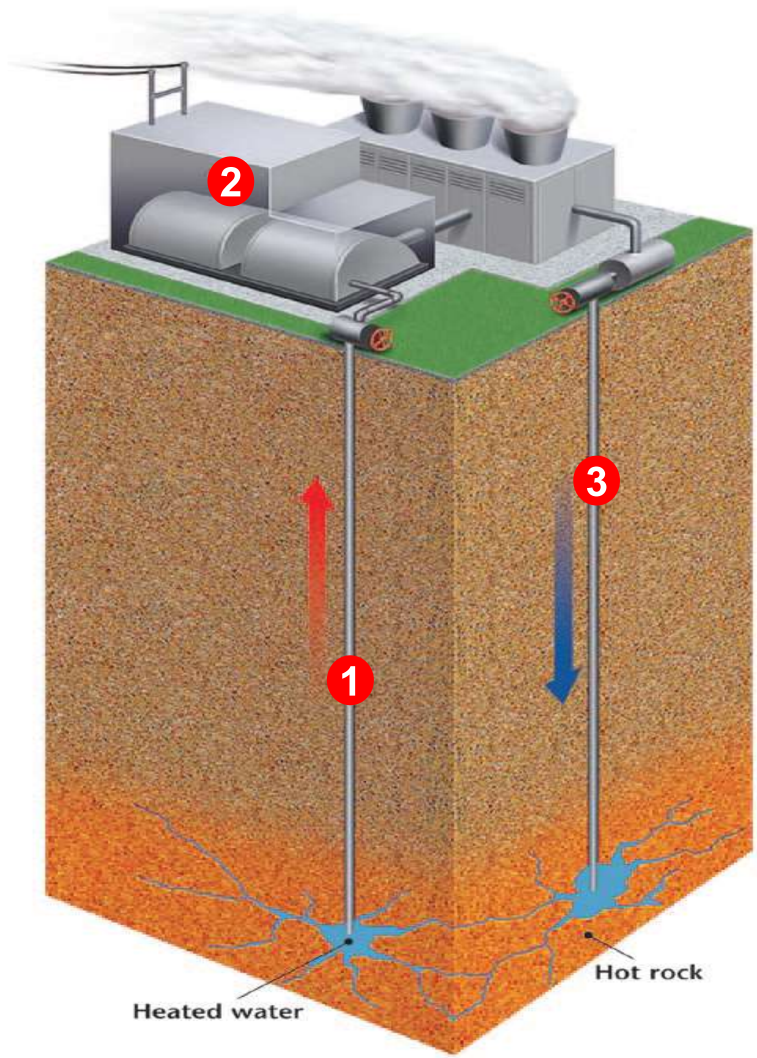
DIFFERENT TYPES OF GEOTHERMAL ENVIRONMENT IN THE EARTH'S UPPER CRUST



- 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

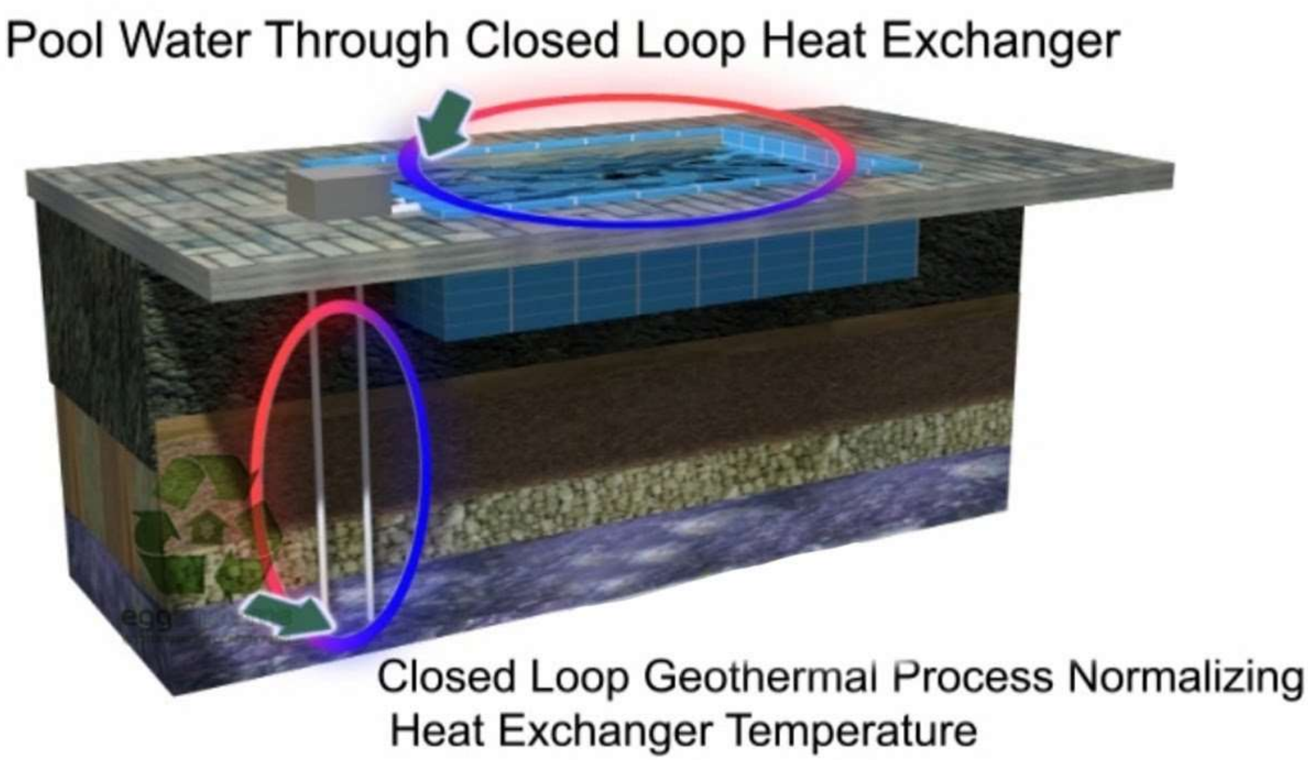
- Geothermal power plants generate electricity using the following steps: (1) steam rises through a well; (2) steam drives turbines, which generate electricity; (3) leftover liquid water is pumped back into the hot rock.



- 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.

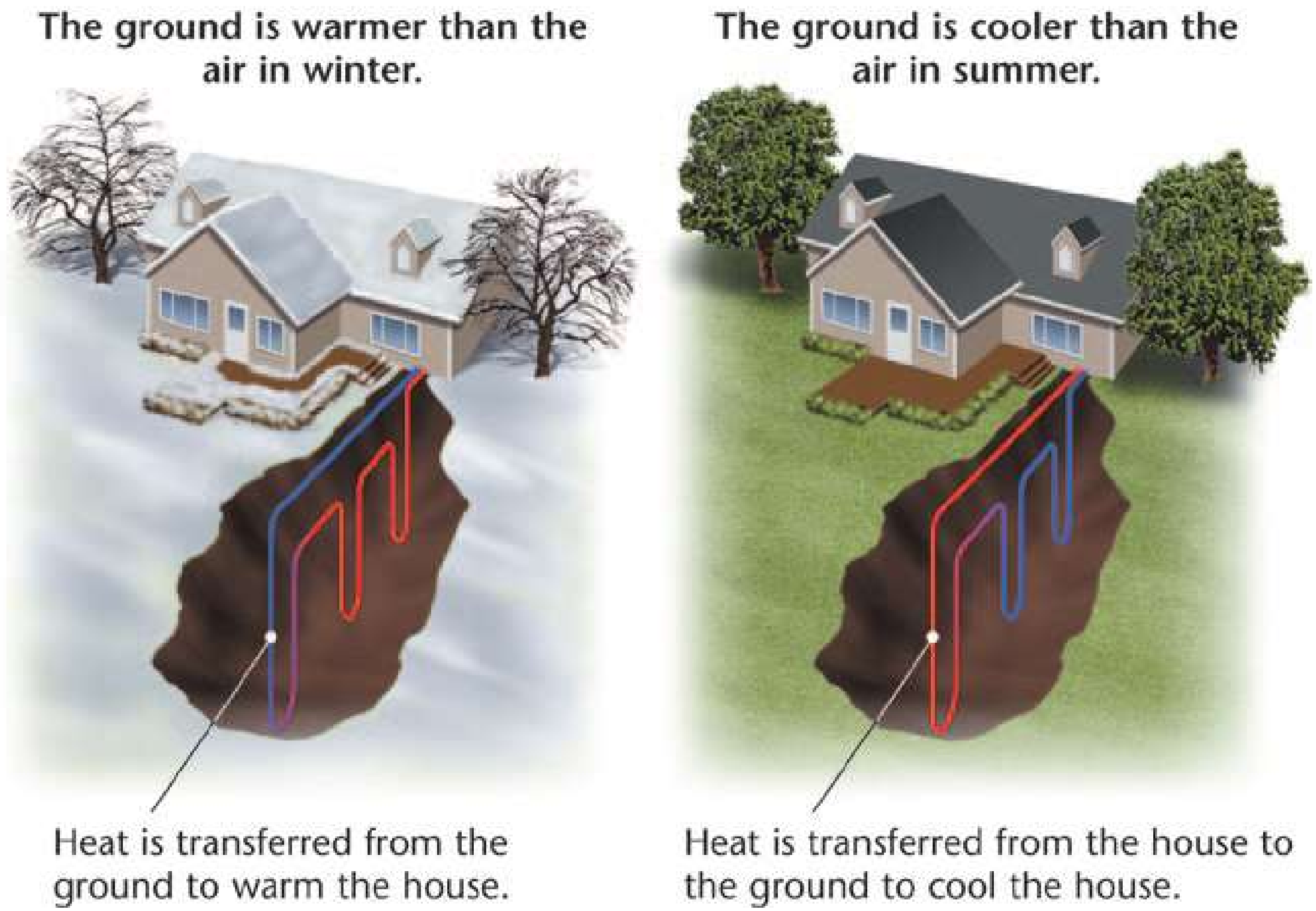
Uses of geothermal energy

- 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

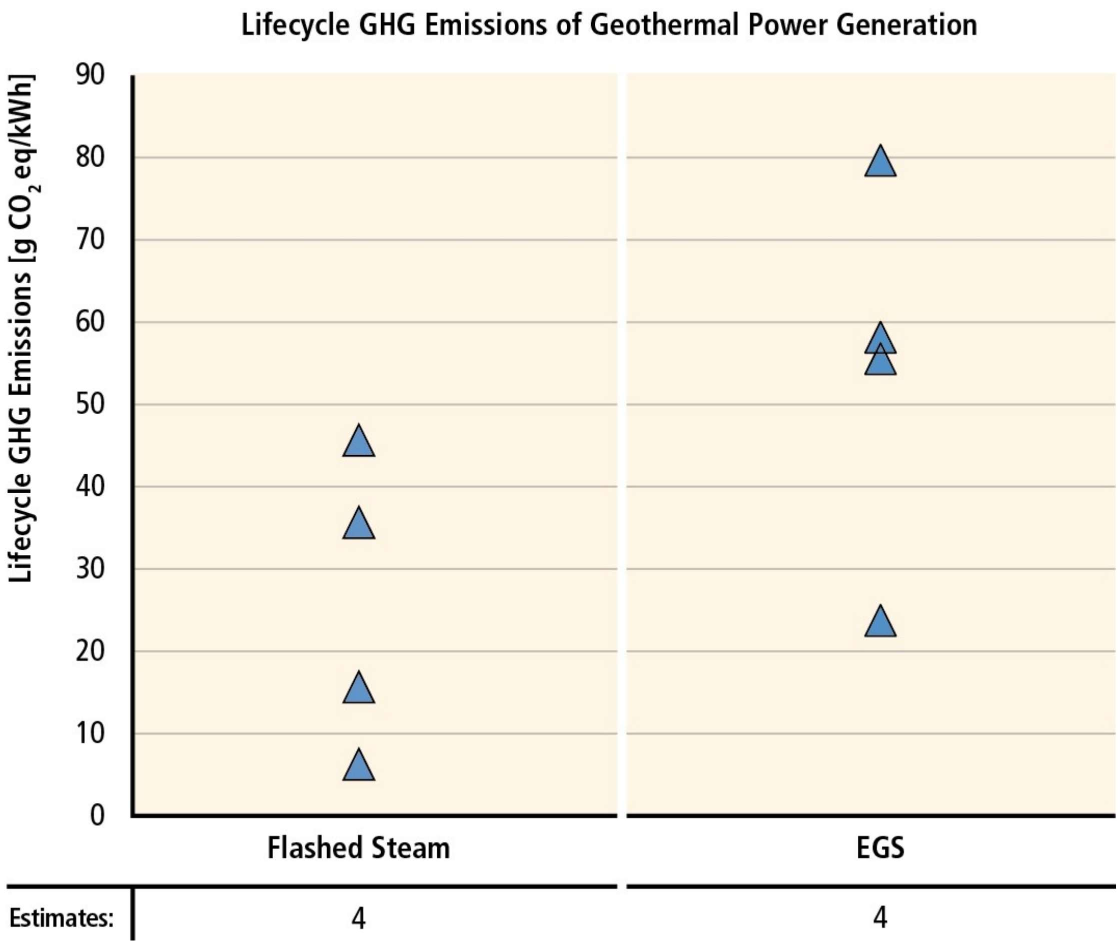
- A geothermal heat pump uses stable underground temperatures to warm and cool homes.



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

Very high efficiency

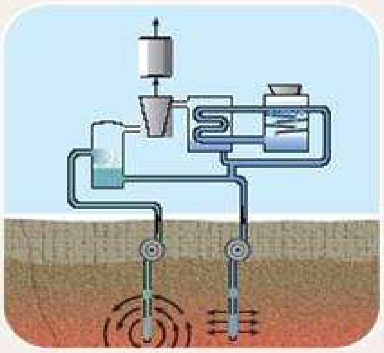
Moderate net energy at accessible sites

Lower CO_2 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_2S)

High cost except at the most concentrated and accessible sources

Ocean Energy

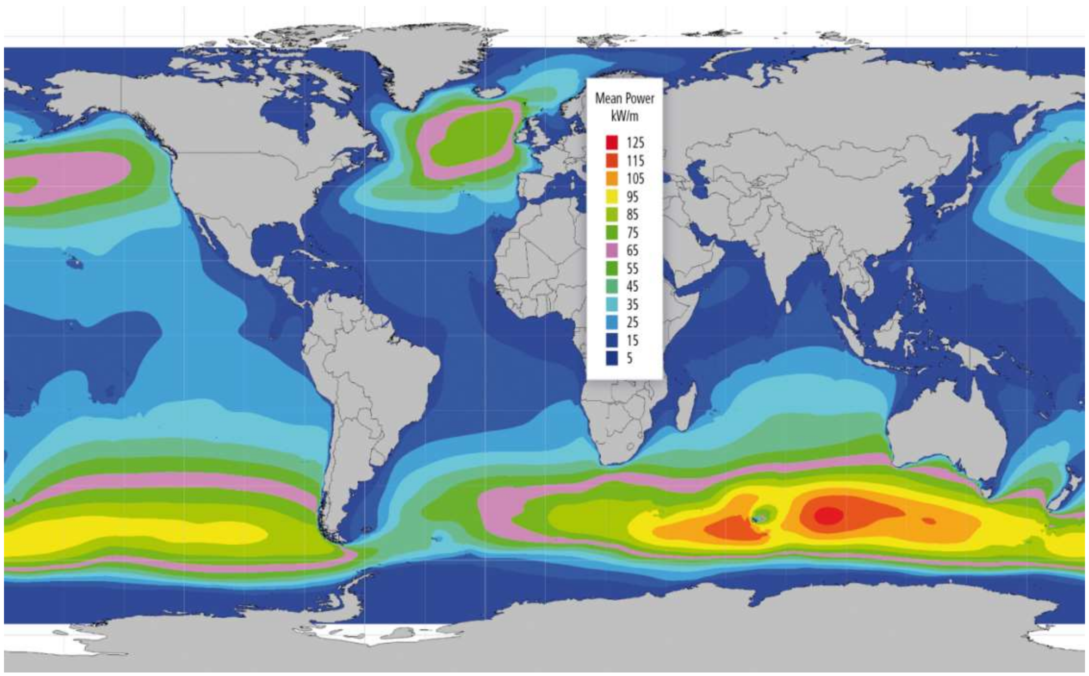
Ocean energy

- 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



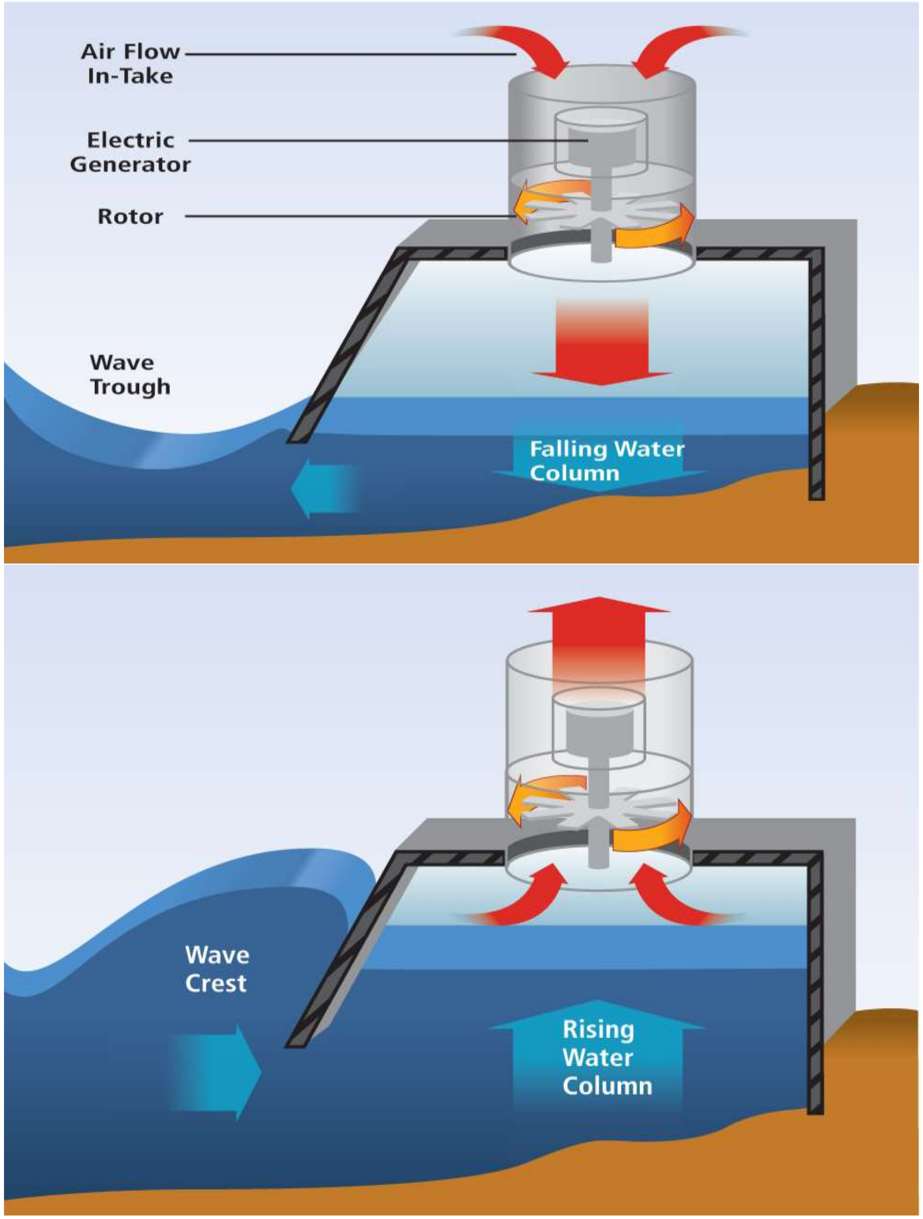
- Ocean wave energy is energy that has been transferred from the wind to the ocean. As the wind blows over the ocean, air-sea interaction transfers some of the wind energy to the water, forming waves, which store this energy as potential energy (in the mass of water displaced from the mean sea level)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

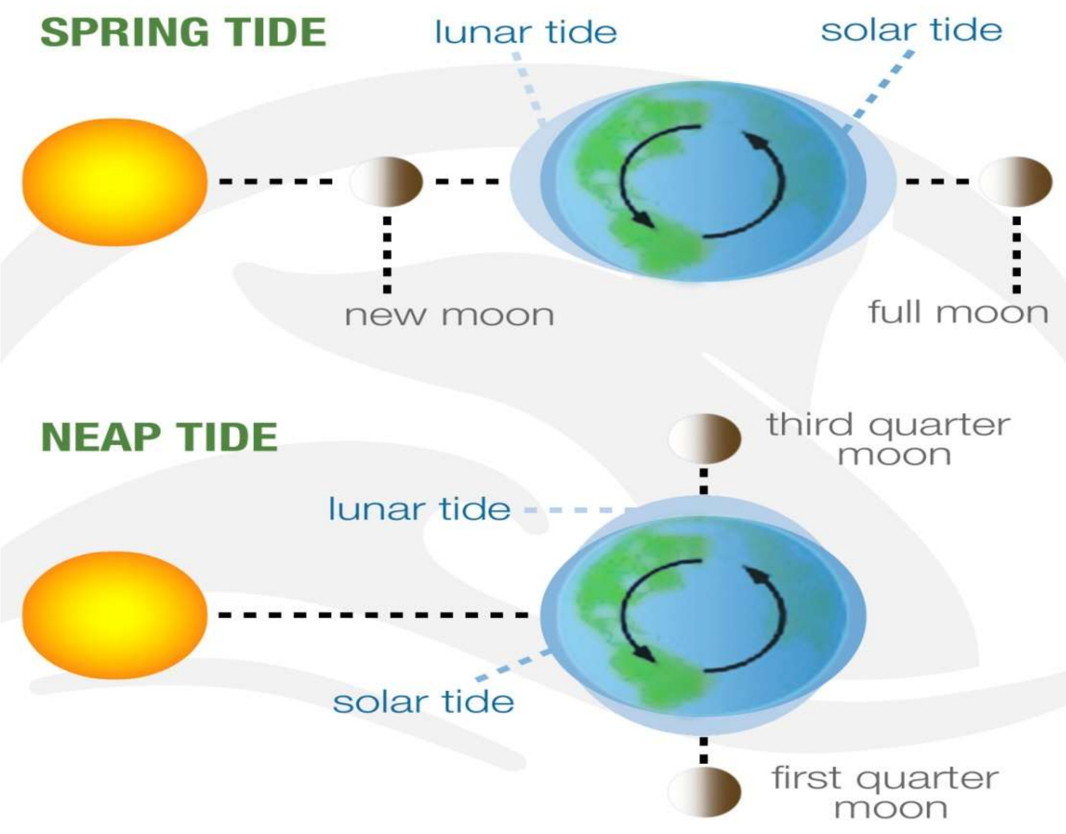


- As a wave rises, high-velocity air exhausts through an air turbine coupled to an electrical generator, which converts the kinetic energy into electricity.
- When the wave falls, the airflow reverses and fills the chamber, generating another pulse of energy (bottom).

- 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.

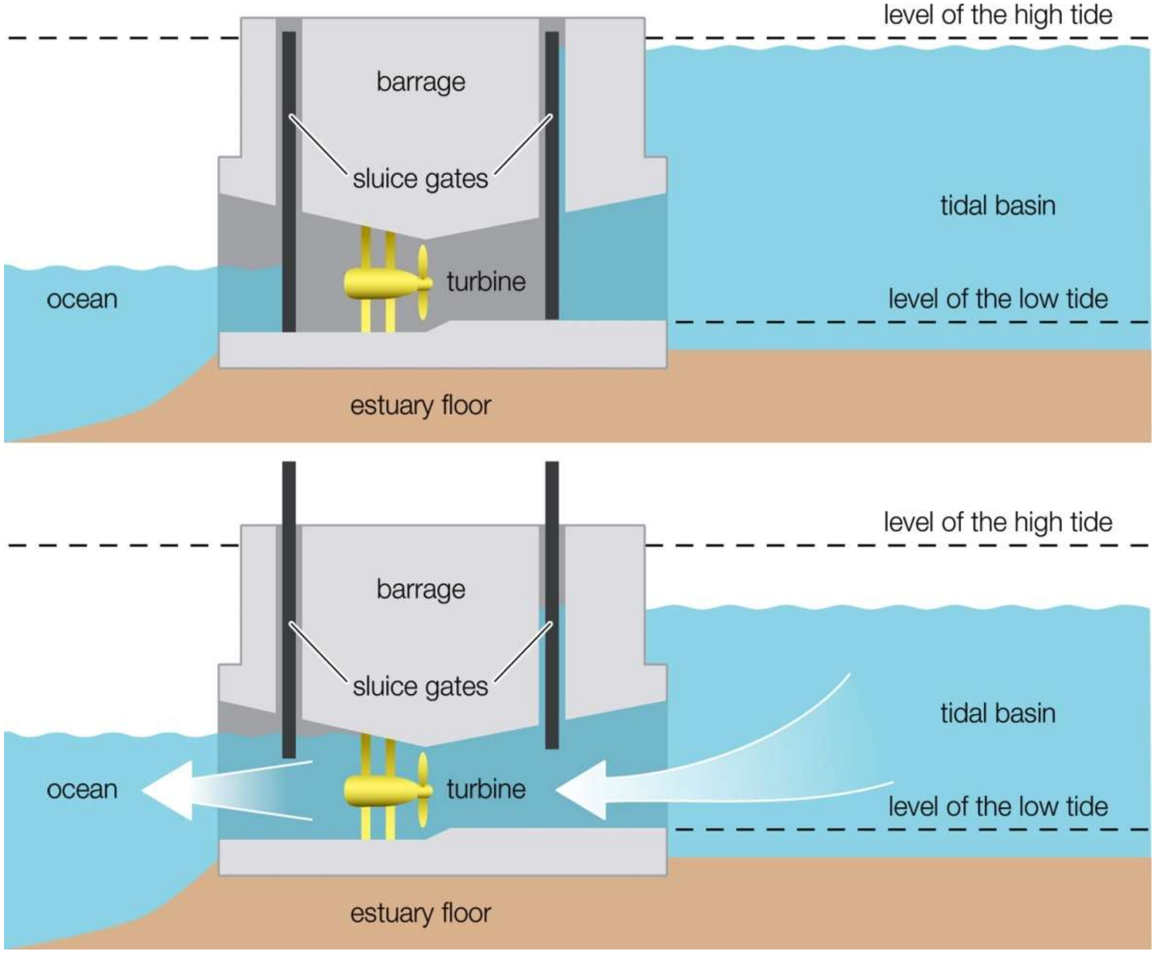
- Many coastal areas experience roughly two high tides and two low tides per day (called **semi-diurnal**); in some locations there is only one tide per day (called **diurnal**).

- 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.

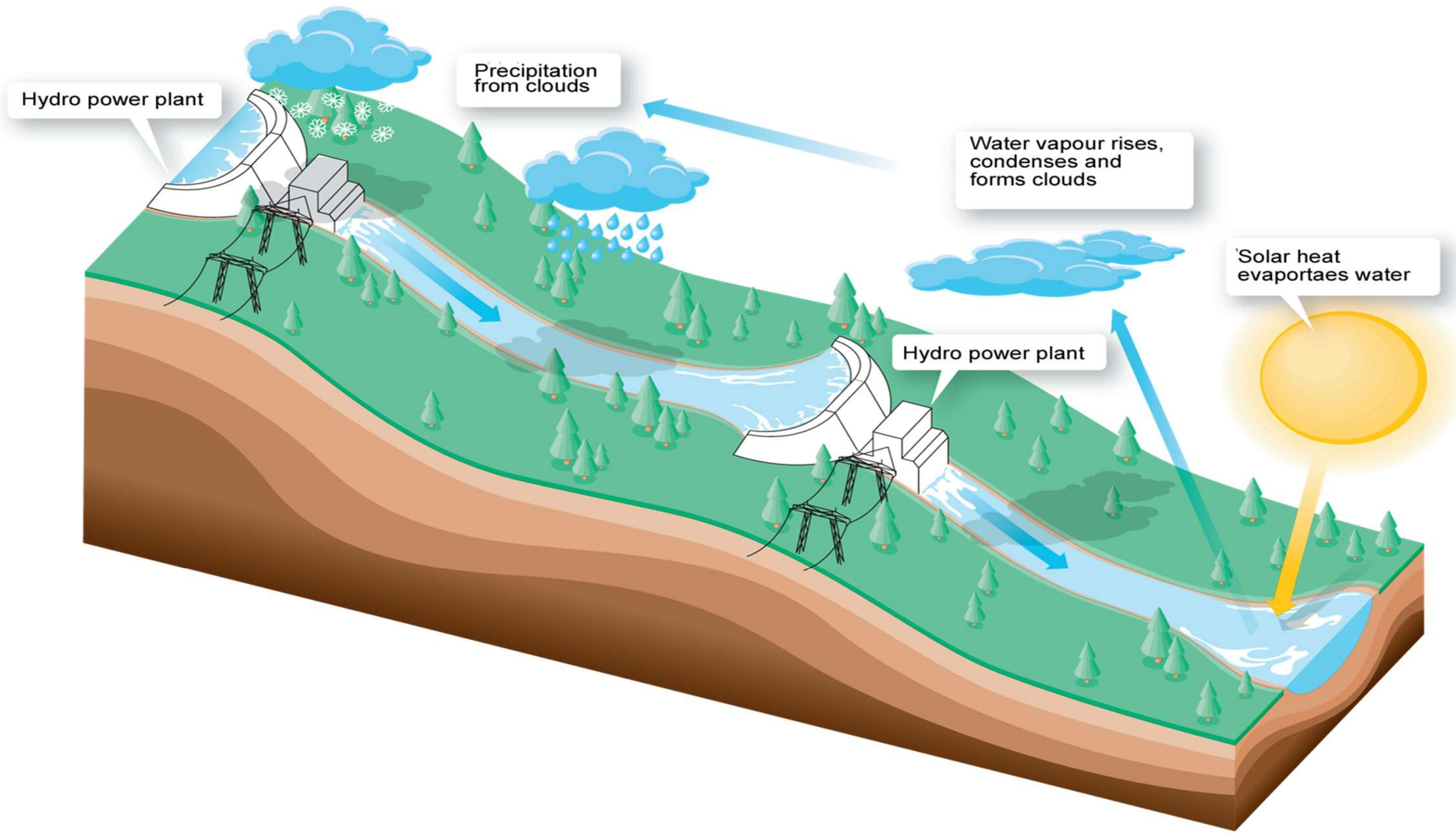
- The local social and environmental impacts of ocean energy projects are being evaluated as actual deployments multiply, but can be estimated based on the experience of other maritime and offshore industries.

- 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.

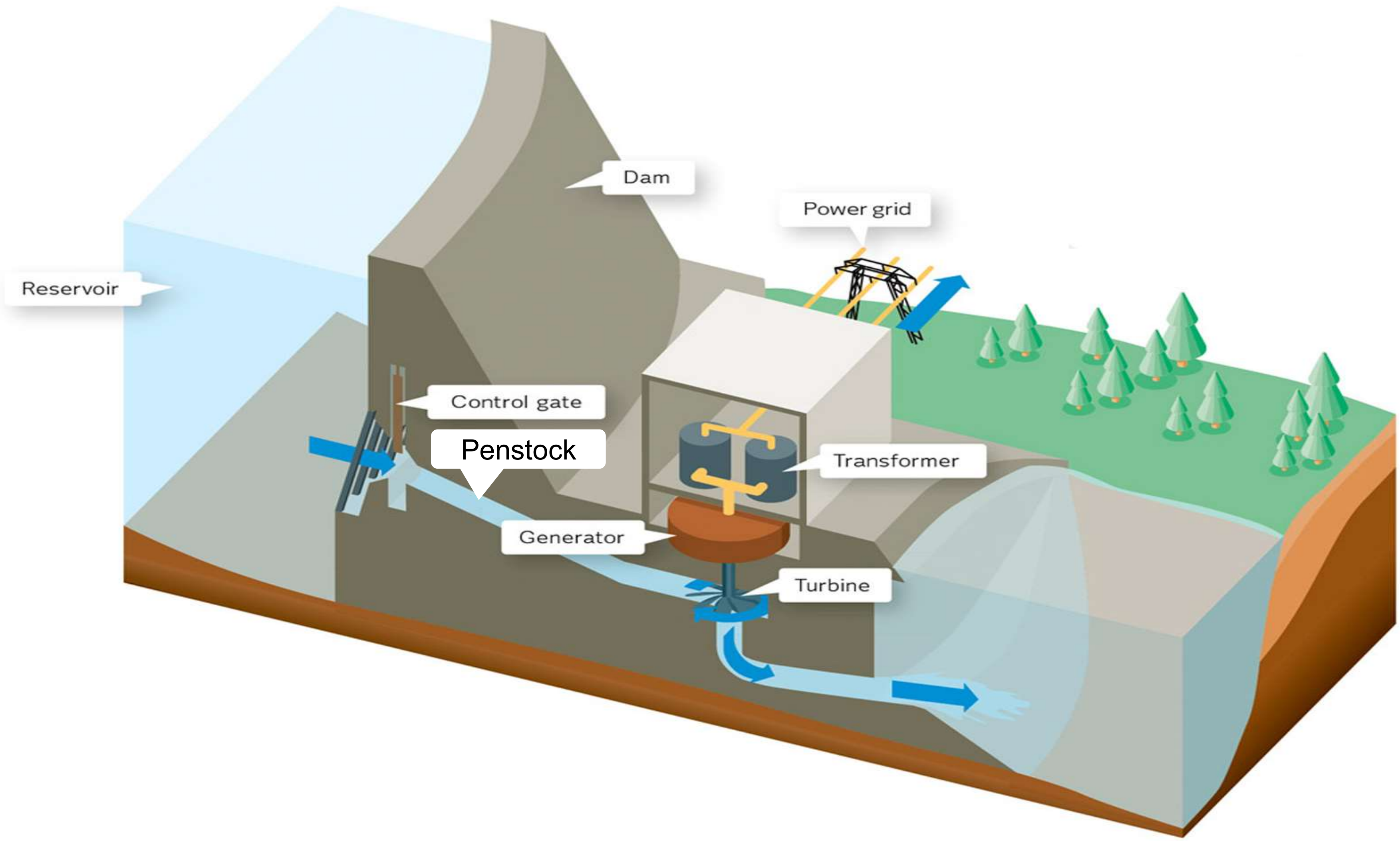
Hydroelectricity

Hydroelectricity

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

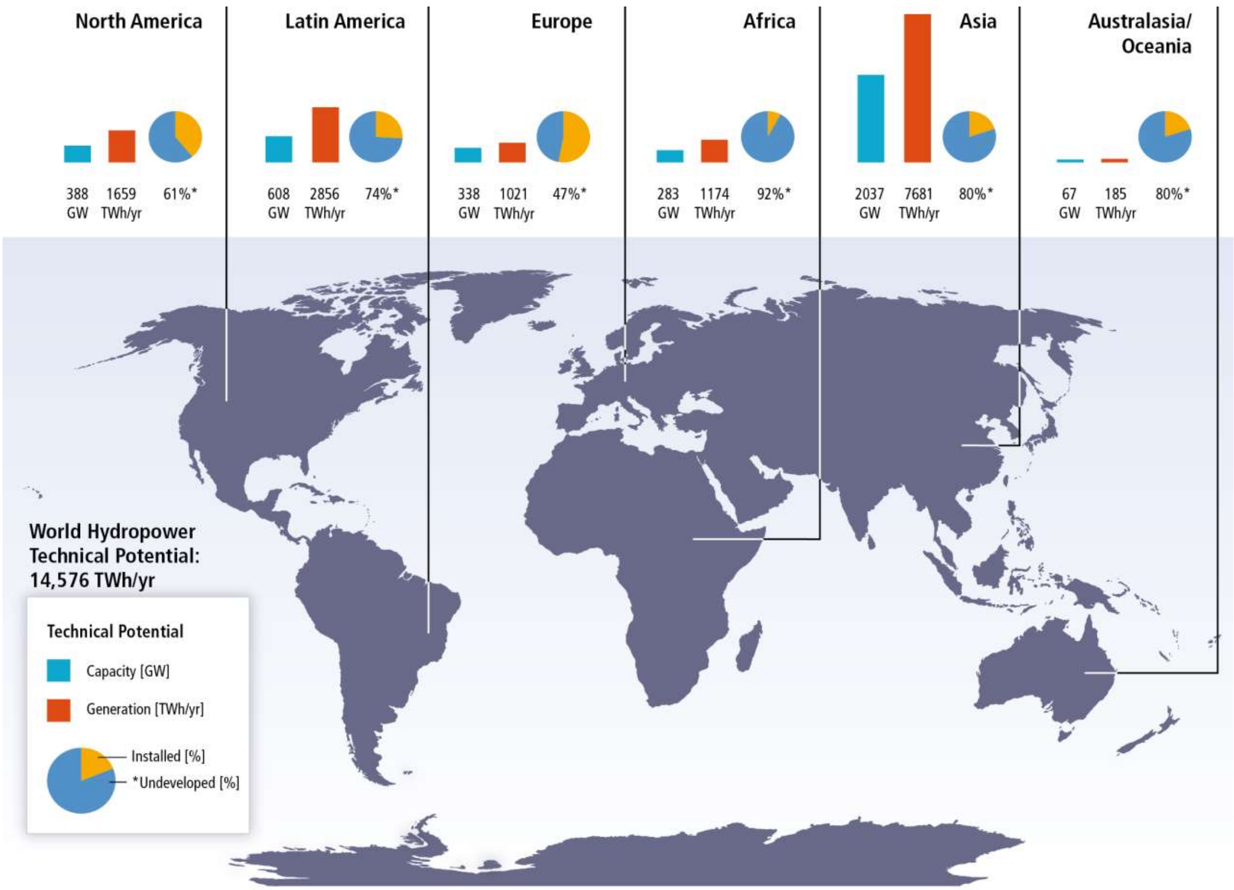


- The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Water released at a height from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity.



- 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.

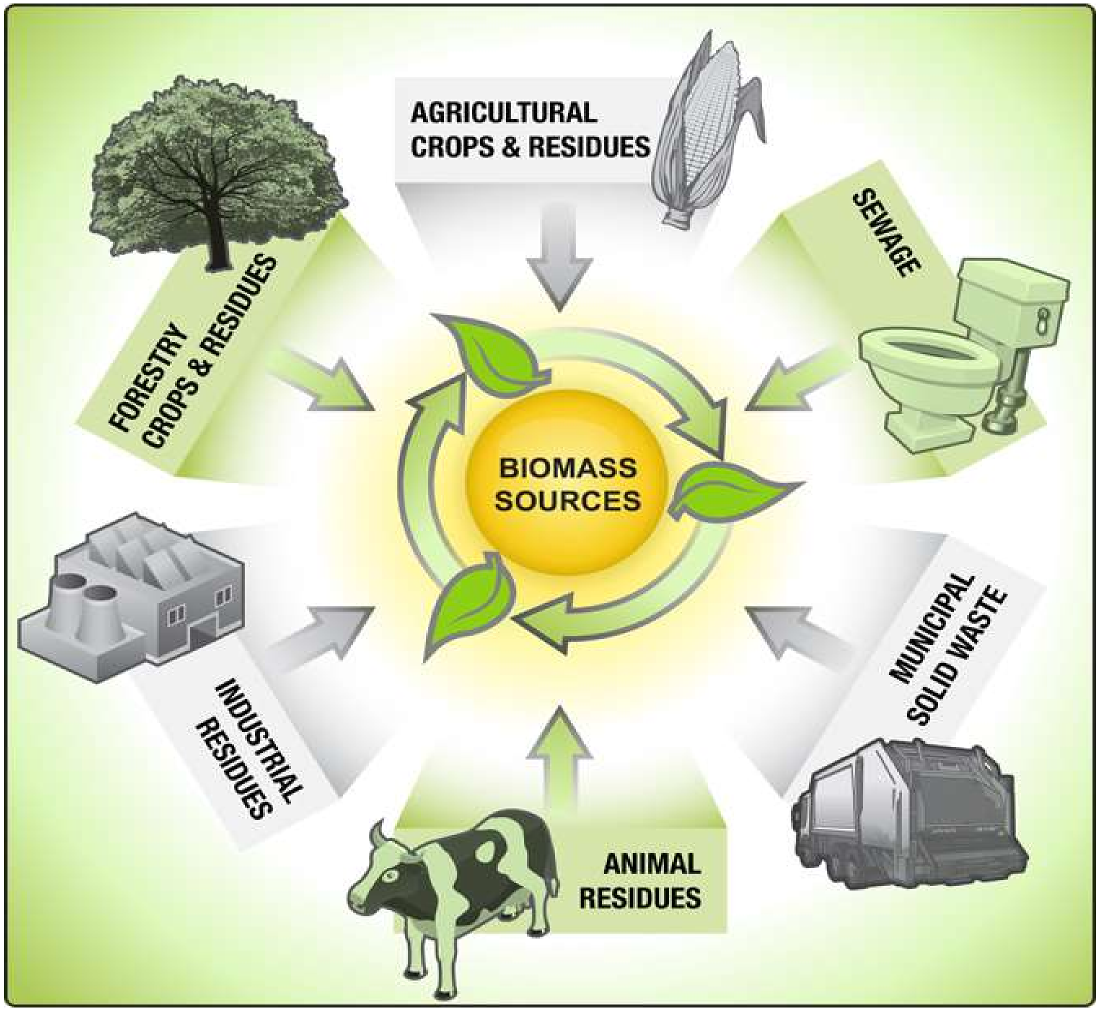
Environmental aspects	
Advantages	**Disadvantages**
Produces no atmospheric pollutants	Inundation of terrestrial habitat
Neither consumes nor pollutes the water it uses for electricity generation purposes	Modification of hydrological regimes
Produces no waste	Modification of aquatic habitats
Avoids depleting 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)	

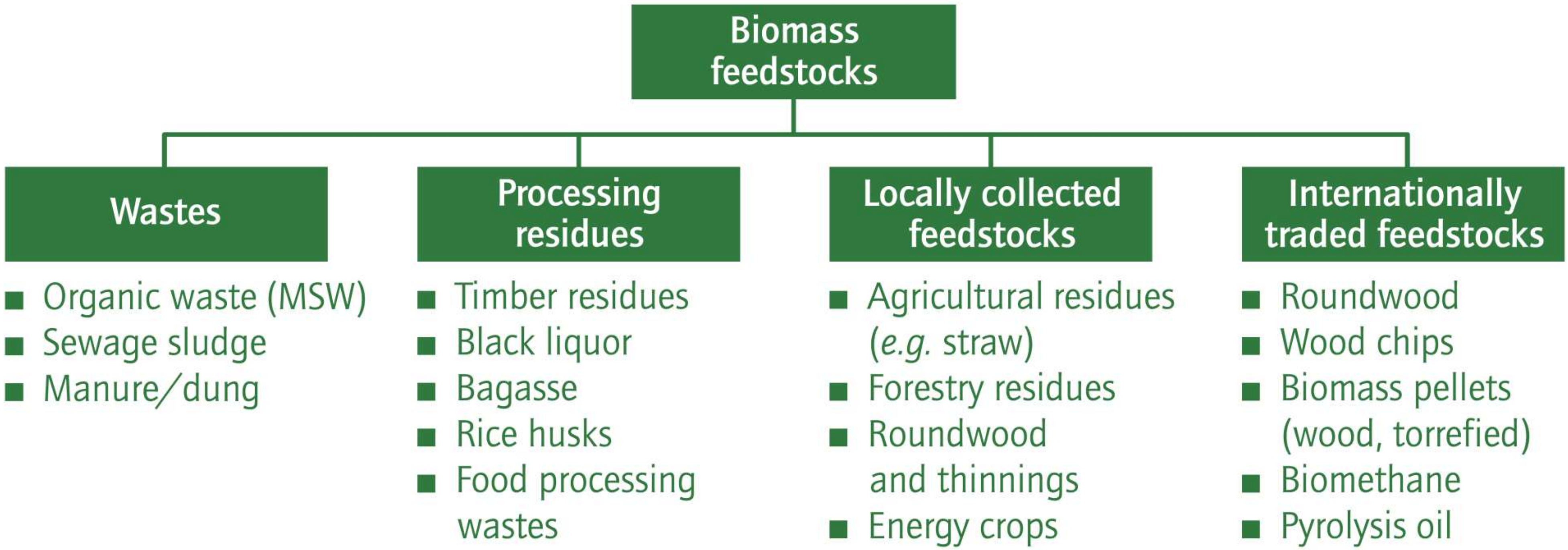
Bioenergy

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.

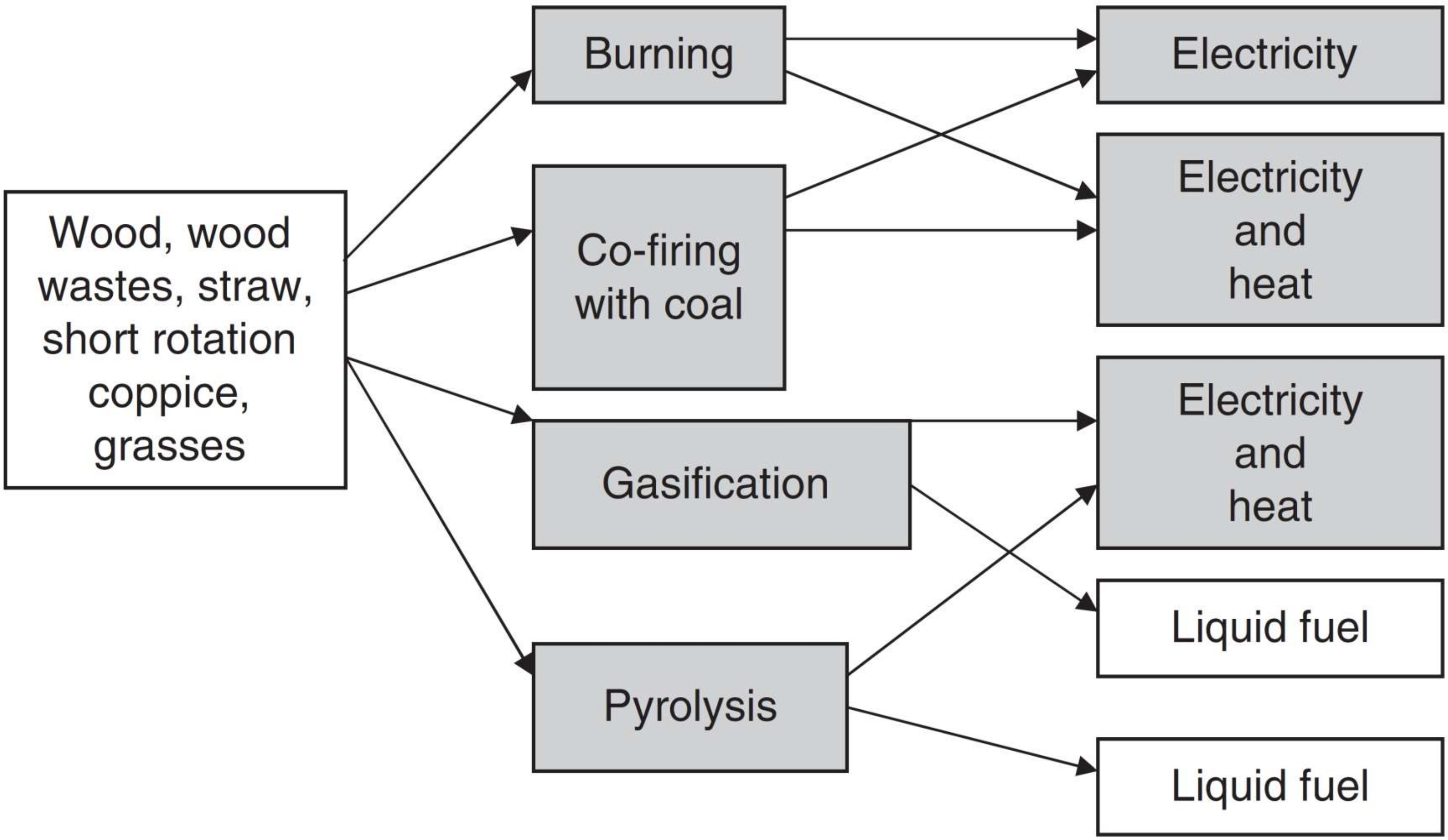


- As a feedstock for producing electricity or heat, biomass has a number of advantages over fossil fuels.
  - It is widely distributed, relatively easy to collect and use, and can produce less net CO_2 emissions than fossil fuels per unit of useful energy delivered, if sourced sustainably.
  - In addition,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



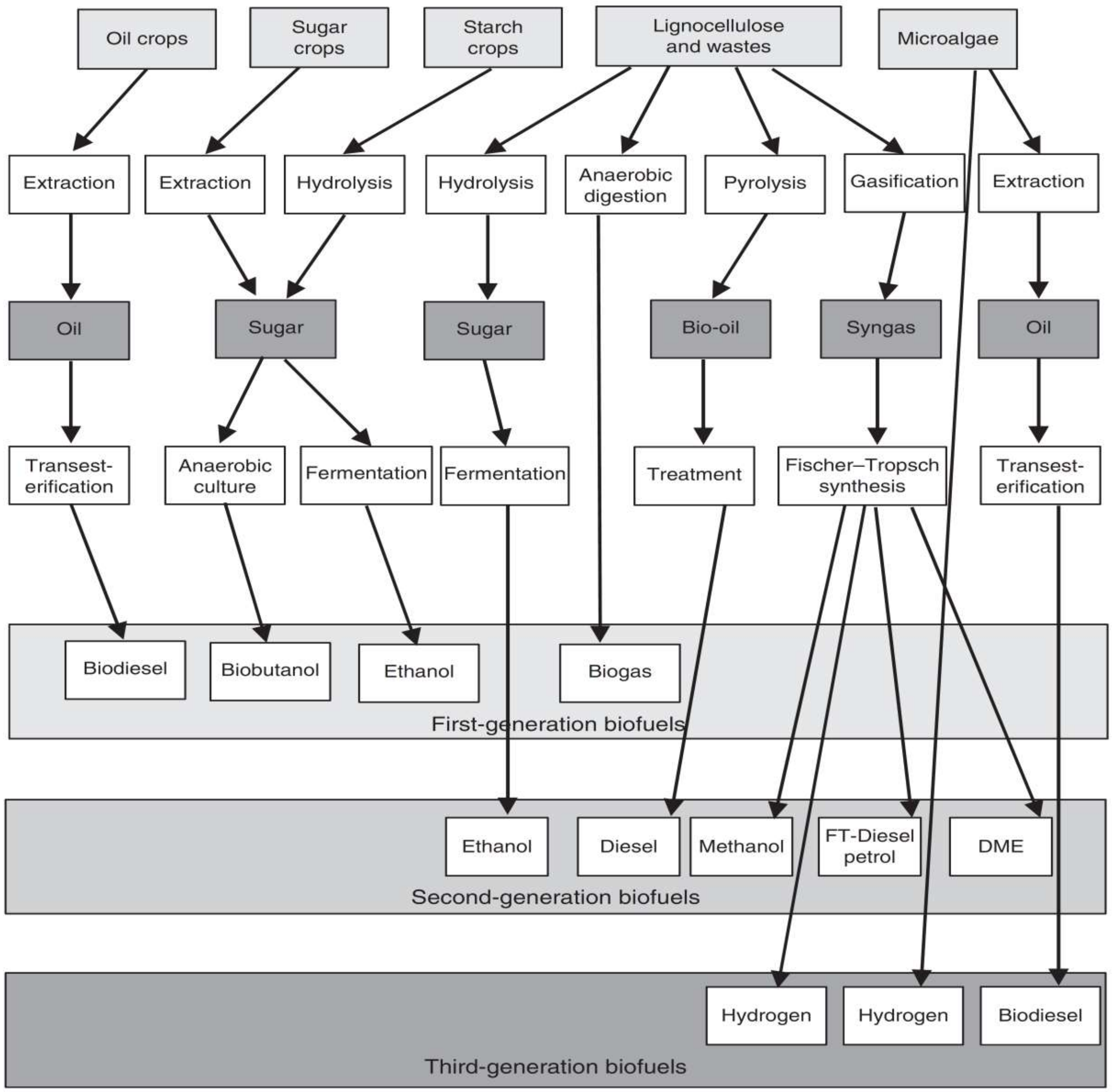
Biomass for heat and electricity

- 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.

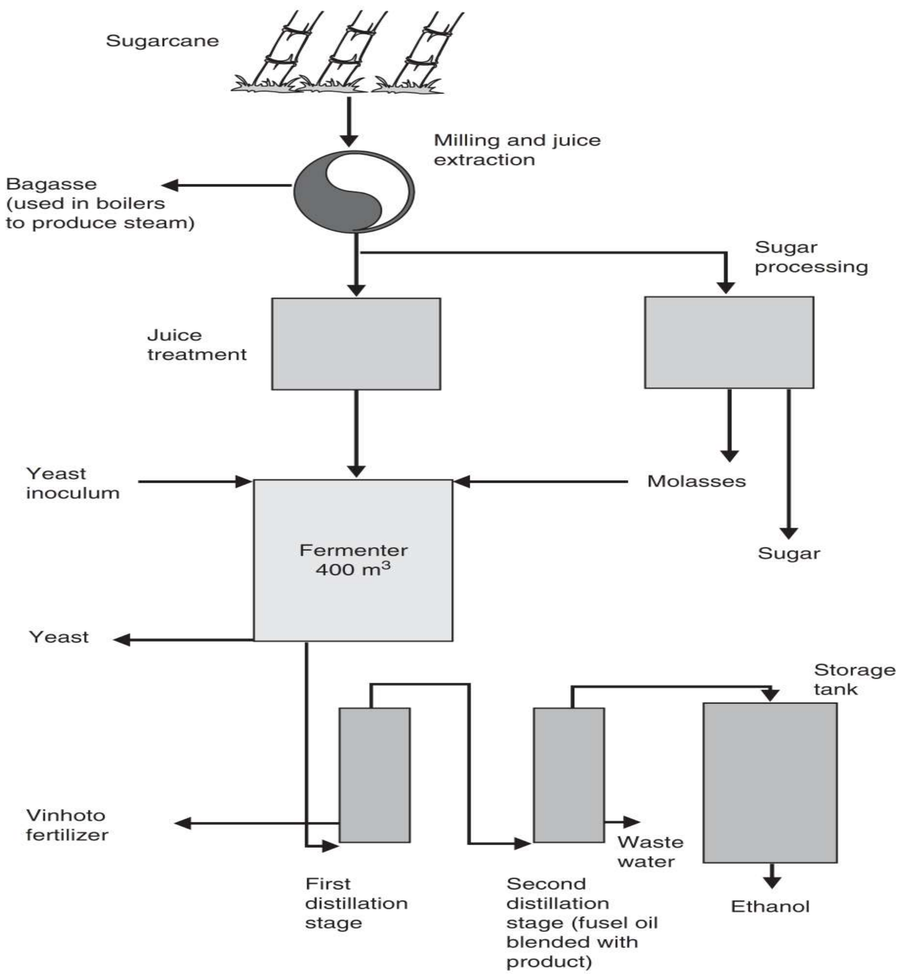


- Biofuels can not only be used for both electricity generation and heating, but also most importantly as a transport fuel.
- Those biofuels currently used and produced in large quantities are the **first- generation** biofuels.
- The biofuels that have been produced but technical difficulties and high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

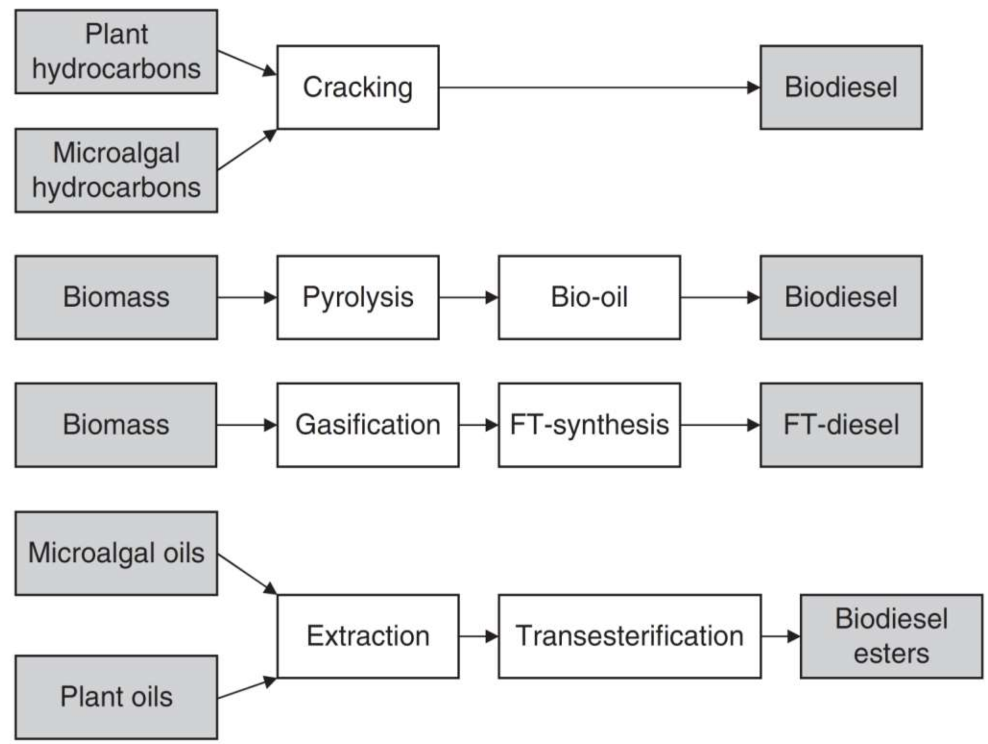
Liquid biofuels

- 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

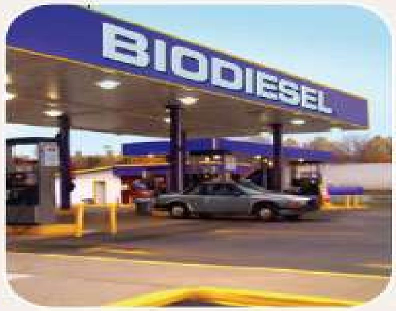
Can make engines hard to start in cold weather

The good & bad of biodiesel

Trade-Offs

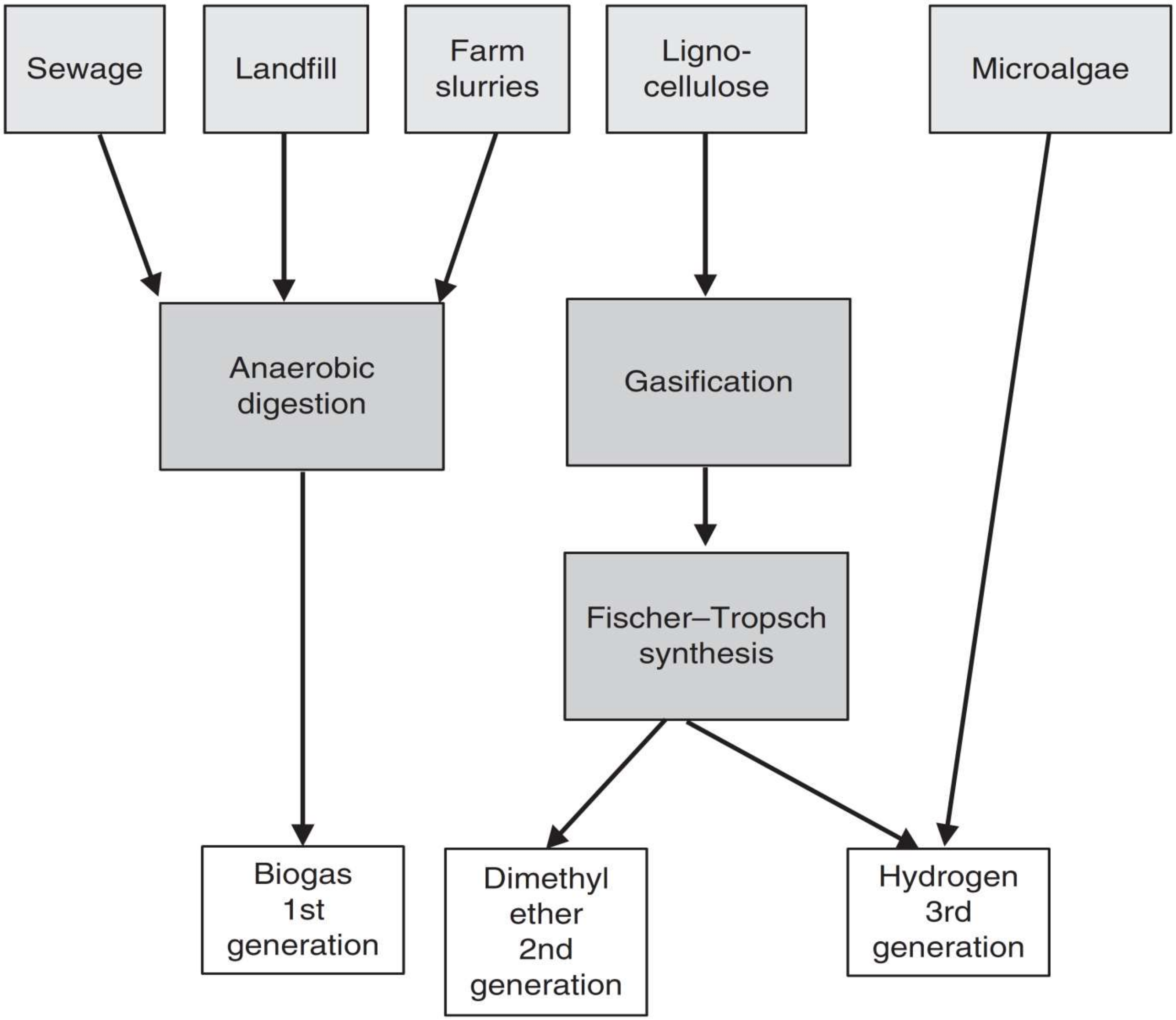
Biodiesel

Advantages	Disadvantages
Reduced CO emissions	Increased NO_x emissions and more smog
Reduced CO_2 emissions (78%)	Higher cost than regular diesel
High net energy yield for oil palm crops	Environmental costs not included in market price
Moderate net energy yield for rapeseed crops	Low net energy yield for soybean crops
Reduced hydrocarbon emissions	May compete with growing food on cropland and raise food prices
Better gas mileage (40%)	Loss and degradation of biodiversity from crop plantations
Potentially renewable	Can make engines hard to start in cold weather



Gaseous biofuels

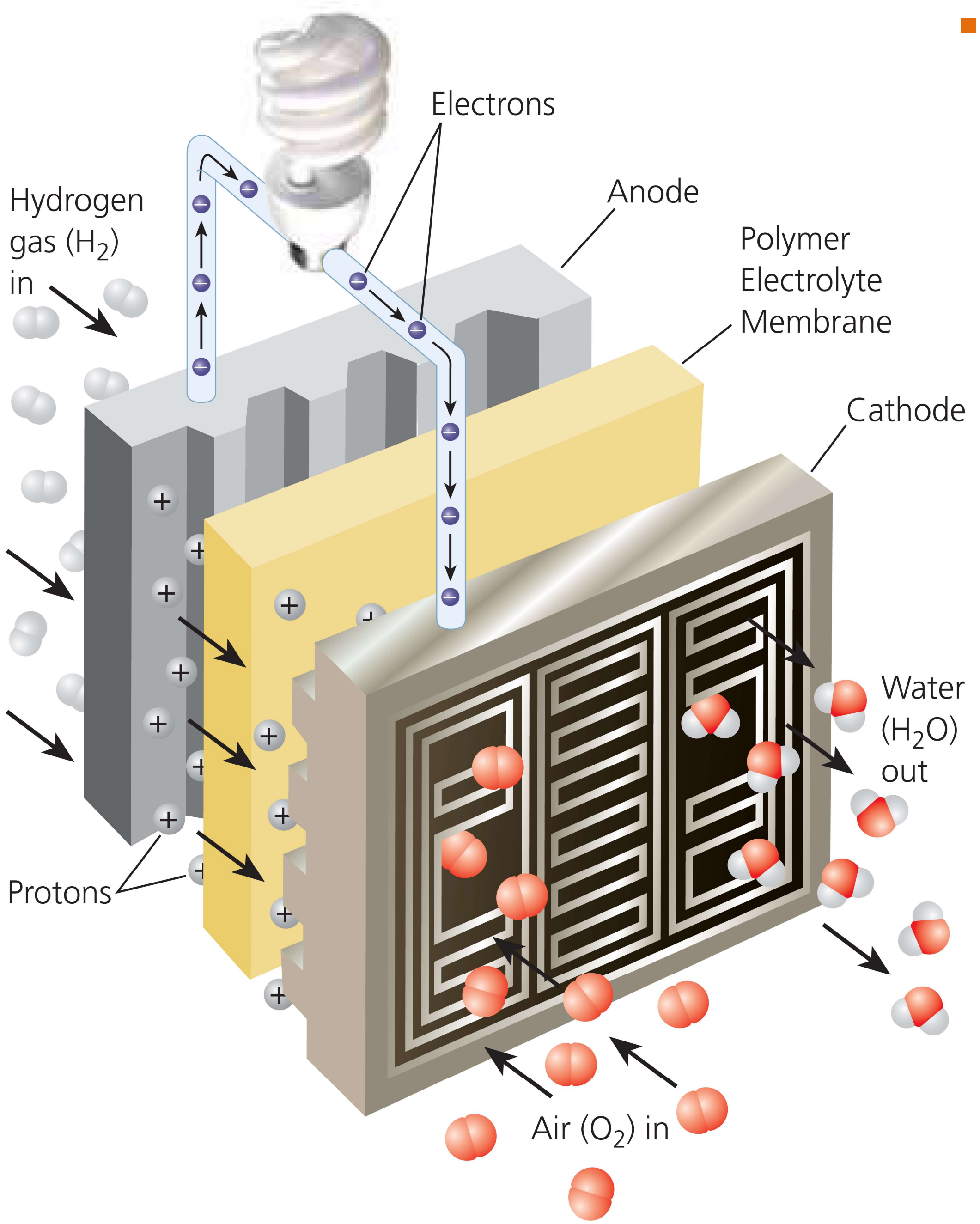
- Gaseous biofuels include methane (biogas), hydrogen and dimethyl ether (DME).



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

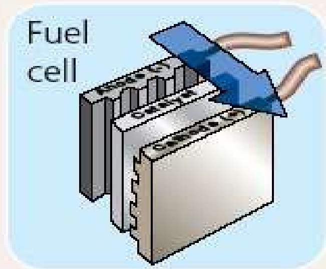
Competitive price if environmental and social costs are included in cost comparisons

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

EV20001: ENVIRONMENTAL SCIENCE

Lecture #7

Solid and Hazardous Waste Management

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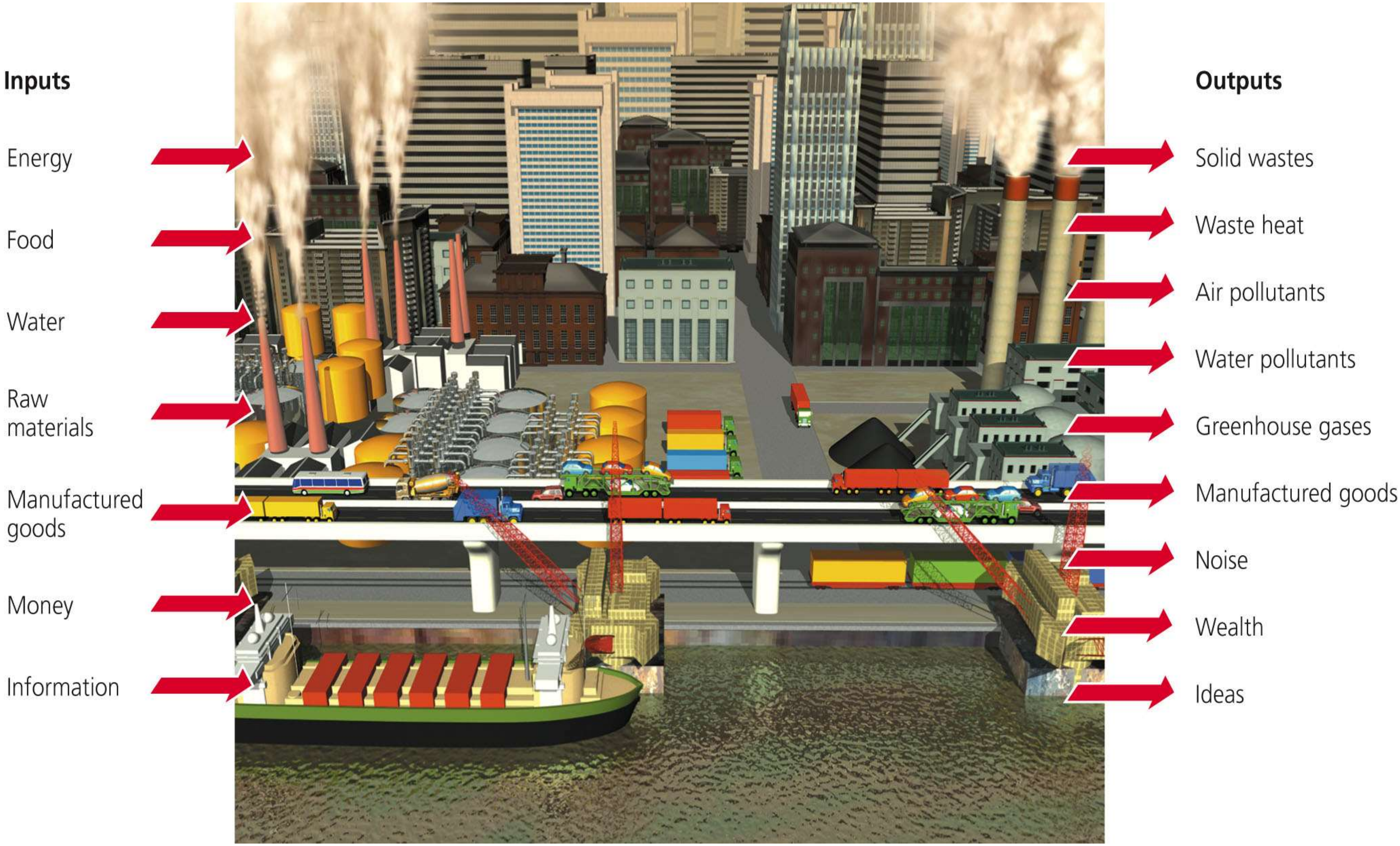
23 March 2022

We are living unsustainably

- Most urban areas are unsustainable systems.



Solid waste

- **Solid waste** refers to any unwanted or discarded material resulting from industrial, commercial, mining and agricultural operations, and from community activities.

- Two types of solid waste:

    - **Industrial solid waste** refers to waste produced by mines, agriculture and industries that supply people with goods and services (e.g., chemical solvents, paints, sandpaper, paper products, metals, and radioactive wastes).

    - **Municipal solid waste** comprises the combined solid waste produced by homes and workplaces (e.g., paper, cardboard, waste food, cans, bottles, wood, e-waste, etc.).

Hazardous waste

- **Hazardous waste** threatens human health or the environment because it is poisonous, dangerously chemically reactive, corrosive, or flammable.

- Examples include industrial solvents, medical waste, car batteries, dry-cell batteries, household pesticide products, ash from incinerators and coal-burning power plants.

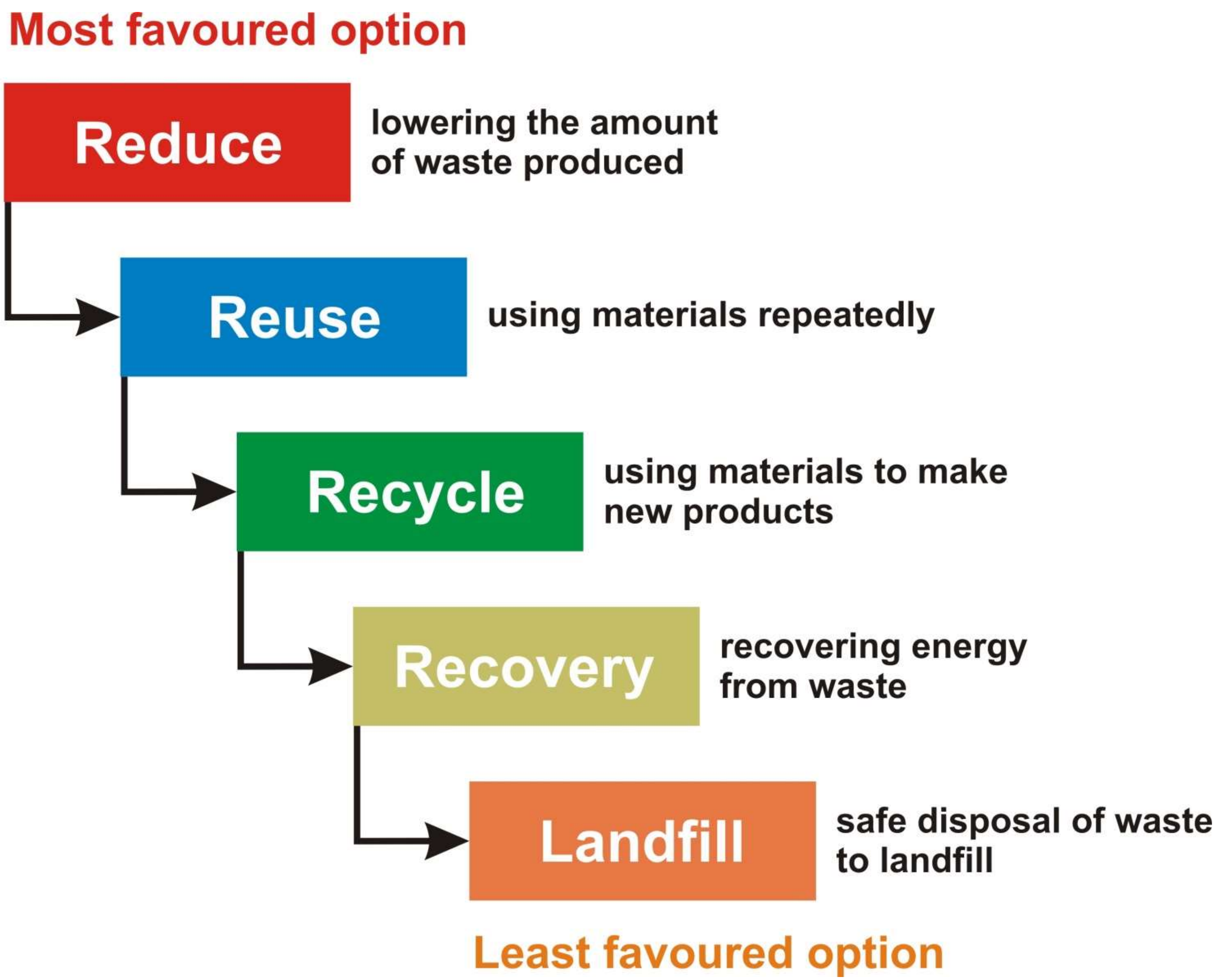
- Two types of hazardous waste:

    - **Organic compounds** (such as various solvents, pesticides, polychlorinated biphenyls (PCBs), and dioxins)

    - **Toxic heavy metals** (such as lead, mercury and arsenic)

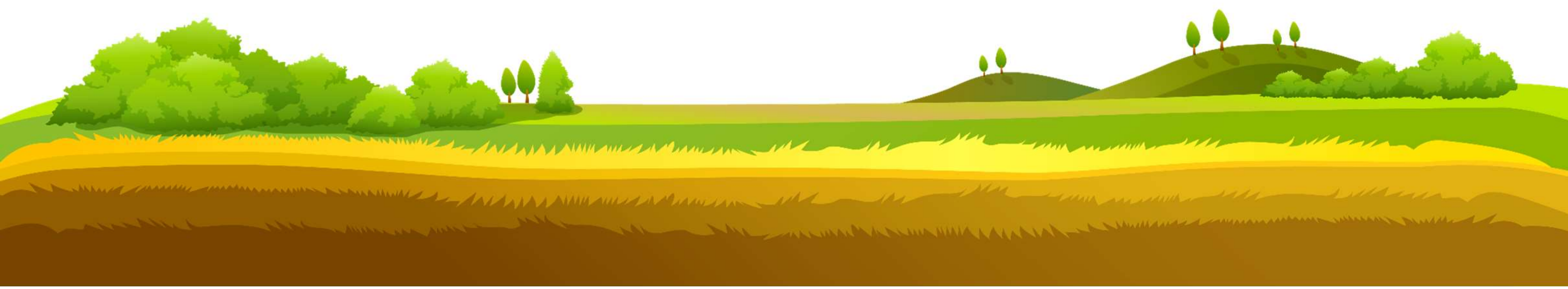
Managing solid waste

- The waste hierarchy sets out a set of priorities that are based on sustainability with an order of preference for actions to reduce and manage waste.



Dealing with solid waste

- **Waste management**
  - Attempt to manage wastes in ways that reduce their environmental harm
  - Involves mixing wastes together and then transferring them from one part of the environment to another
- **Waste reduction**
  - Involves producing much less waste and pollution
  - Wastes produced are considered to be potential resources that can be reused, recycled, or composted
- **Integrated waste management**
  - Involves a variety of strategies for both waste reduction and waste management

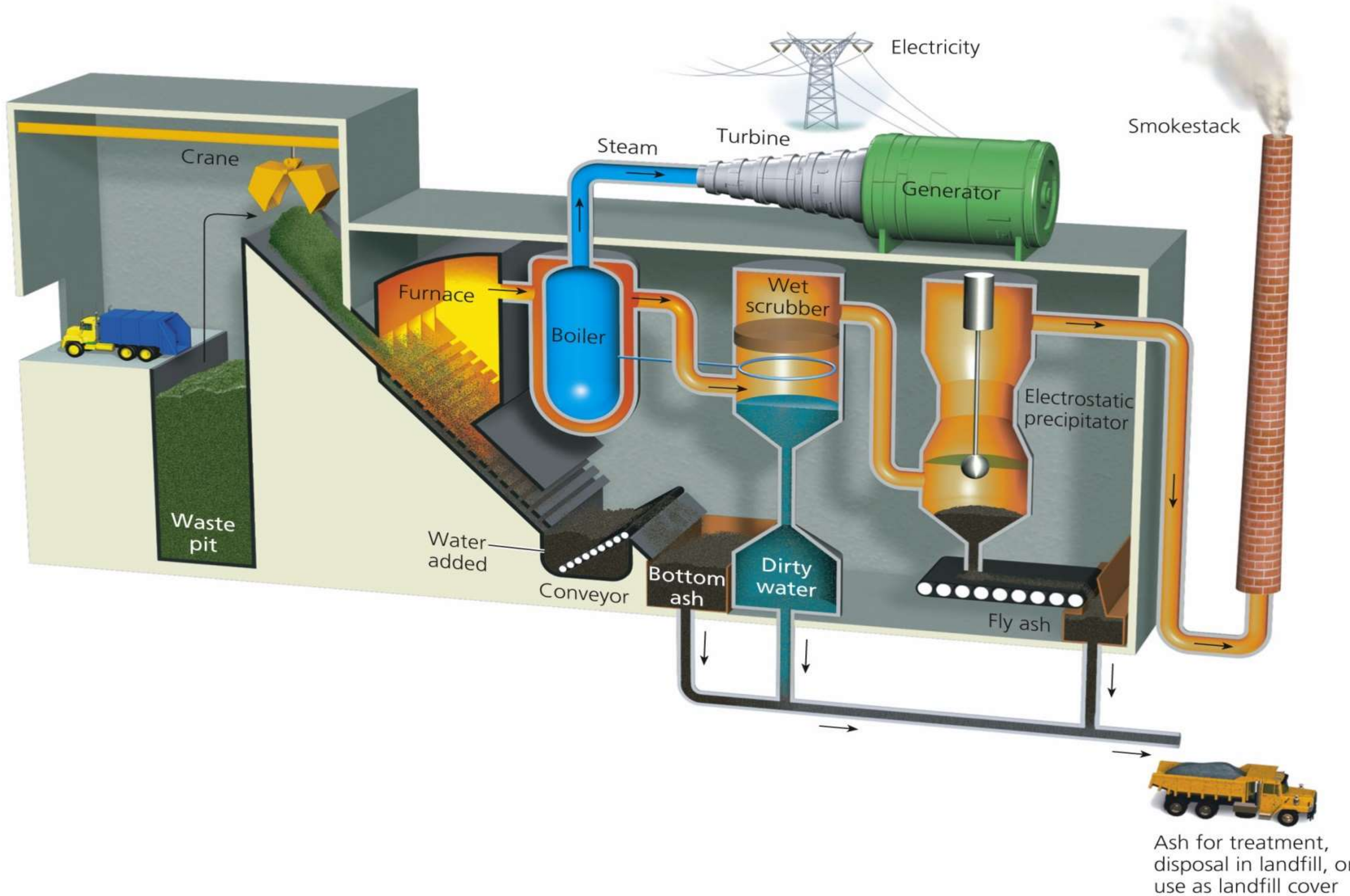


Waste management

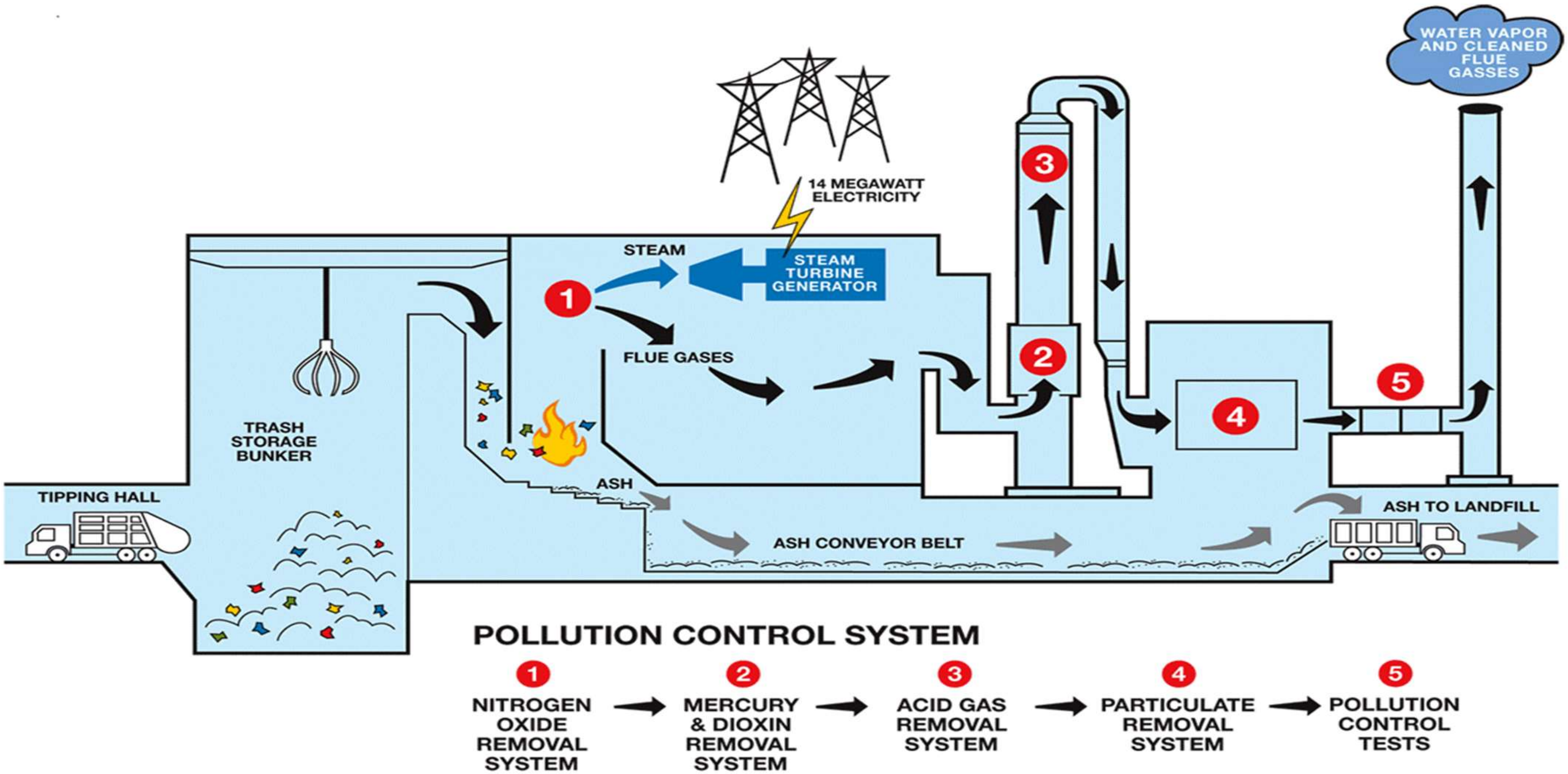
- Does not attempt to reduce the amount of waste produced.
- Involves transferring wastes from one part of the environment to another, usually by burying them, burning them, or shipping them to another location.
- Technologies for burning and burying solid wastes are well developed.
- Burning contributes to pollution and greenhouse gas emissions.
- Buried wastes can eventually contribute to air and water pollution and land degradation.
- Waste management practices are not uniform among countries (developed and developing nations), regions (urban and rural area), and sectors (residential and industrial).

Burning solid waste (incineration)

- A waste-to-energy incinerator with pollution controls that burns mixed solid wastes and recovers some of the energy to produce steam used for heating or producing electricity.



- Despite being an attractive technological option for energy production and waste management, direct combustion of solid waste has been largely criticized since it emits heavy metals, dioxins and furans. However, the concerns over the health effects of dioxin and furan emissions have been significantly lessened in recent years by advances in emission control designs and very stringent new governmental regulations that have resulted in large reductions in the amount of dioxins and furans emissions.



The good and bad of incineration

Trade-Offs

Incineration

Advantages

Reduces trash volume

Less need for landfills

Low water pollution

Concentrates hazardous substances into ash for burial

Sale of energy reduces cost

Modern controls reduce air pollution

Some facilities recover and sell metals

Disadvantages

Expensive to build

Costs more than short-distance hauling to landfills

Difficult to site because of citizen opposition

Some air pollution and CO_2 emissions

Older or poorly managed facilities can release large amounts of air pollution

Output approach that encourages waste production

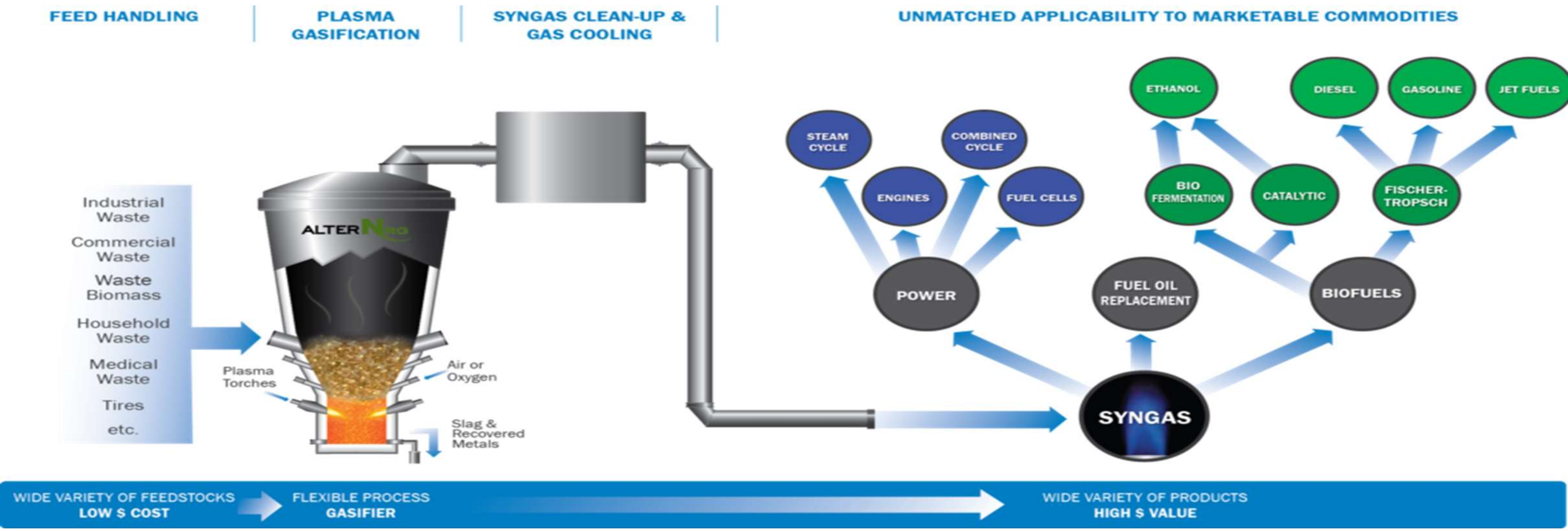
Can compete with recycling for burnable materials such as newspaper

Gasification of solid waste

- Gasification involves conversion of waste into syngas – a mixture of CO and H_2 – by reacting it with steam or by heating at 1300°C in an oxygen-limited atmosphere. The syngas is then reacted with steam to convert CO to CO_2 and H_2. Finally, CO_2 is separated from the CO_2/H_2 mixture, by contact with physical solvents in an absorption column, and the resulting H_2 is burnt to produce power, leaving H_2O as the main gaseous product emitted to the atmosphere.

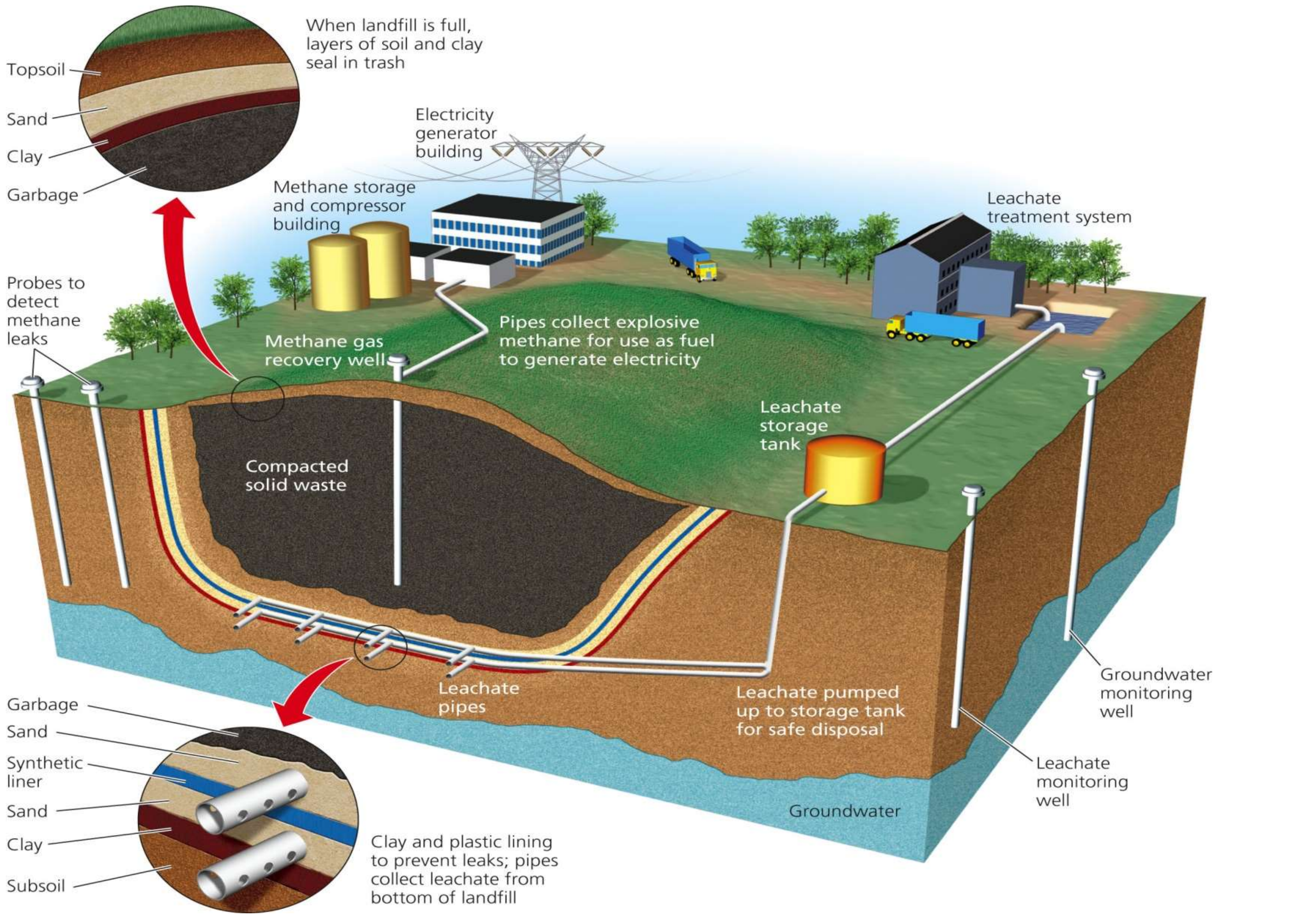
Plasma gasification

- Plasma gasification uses electrical energy to create high temperature (>2000ºC) plasma arc for waste gasification. The plasma arc effectively breaks down the waste material into elemental molecules and produces syngas and inert vitreous slag as outputs.
- The syngas, which contains dust (particulates) and other undesirable elements like mercury, undergoes a clean-up process to make it suitable for conversion into other forms of energy including power, heat and liquid fuels.
- The slag has the potential for use as rock wool, landfill cover, reclamation purposes, base material for construction, landscaping blocks, asphalt road and pavement aggregate among other possible applications.



Burying solid waste (sanitary landfills)

- Sanitary landfills are sites where waste is isolated from the environment until it is safe, i.e., when it has completely degraded biologically, chemically and physically.



The good and bad of sanitary landfills

Trade-Offs

Sanitary Landfills

Advantages

No open burning

Little odor

Low groundwater pollution if sited properly

Can be built quickly

Low operating costs

Can handle large amounts of waste

Filled land can be used for other purposes

No shortage of landfill space in many areas

Disadvantages

Noise and traffic

Dust

Air pollution from toxic gases and trucks

Releases greenhouse gases (methane and CO_2) unless they are collected

Slow decomposition of wastes

Output approach that encourages waste production

Eventually leaks and can contaminate groundwater

Waste reduction

- Waste reduction is based on three R's:
  - Reduce: consume less and live a simpler lifestyle
  - Reuse: rely more on items that can be used repeatedly instead on throwaway items, and buy necessary items secondhand or borrow or rent them
  - Recycle: separate and recycle paper, glass, cans, plastics, metal, and other items, and buy products made from recycled materials

Reusing solid waste

- Reuse involves cleaning and using materials over and over, thus increasing the typical life span of a product.
- Decreases the use of matter and energy resources, cuts pollution and waste, creates local jobs, and saves money.
- Reuse strategies include yard sales, flea market, secondhand stores, and online sites such as e-bay and craigslist.
- Current available technology allows reuse of many items.
- Encourage the use of refillable containers and reusable bags.

Reusing solid waste

What Can You Do?

Reuse

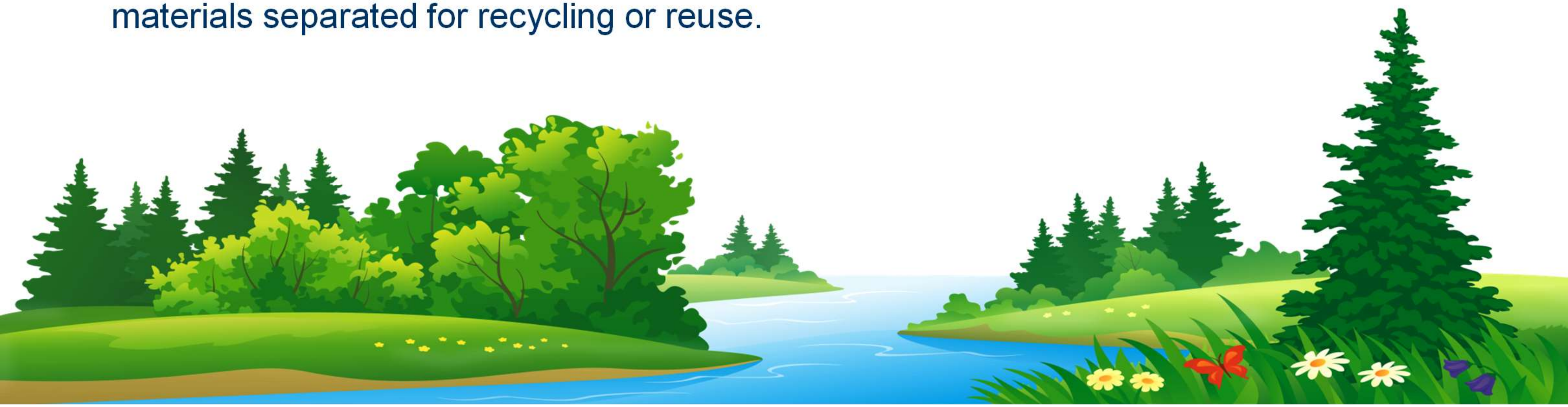
- Buy beverages in refillable glass containers instead of cans or throwaway bottles
- Use reusable plastic or metal lunchboxes
- Carry sandwiches and store food in the refrigerator in reusable containers instead of wrapping them in aluminum foil or plastic wrap
- Use rechargeable batteries and recycle them when their useful life is over
- Carry groceries and other items in a reusable basket, a canvas or string bag, or a small cart
- Buy used furniture, computers, cars, and other items instead of buying new
- Give away or sell items you no longer use

Recycling solid waste

- Recycling involves reprocessing discarded solid materials into new, useful products.
- Two types of wastes can be recycled:
  - Preconsumer / Internal waste: generated in a manufacturing process.
  - Postconsumer / External waste: generated by consumer use of products.
- Such materials can be reprocessed in two ways:
  - Primary / Closed-loop recycling: materials are recycled into new products of the same type. e.g., used aluminum cans can be turned into new aluminum cans.
  - Secondary recycling: waste materials are converted into different products. e.g., used tires can be shredded and turned into rubberized road surfacing.

Recycling household solid waste

- We can mix or separate household solid wastes for recycling.
- Materials recovery facilities (MRFs) involve machines or workers to separate the mixed wastes to recover valuable materials for sale to manufacturers as raw materials. The remaining wastes are either recycled or burned to produce steam or electricity.
- Source separation approach encourage households and businesses to separate their trash into recyclable categories such as glass, paper, metals, certain types of plastics, and compostable materials, thus saving more energy and reduces environmental pollution.
- Pay-as-you-throw (PAUT) or fee-per-bag waste collection system charges households and businesses for the amount of mixed waste picked up, but does not charge for pickup of materials separated for recycling or reuse.



Recycling biodegradable solid waste

- Composting is a form of recycling that mimics nature's recycling of nutrients.
- Composting involves using decomposer bacteria to recycle yard trimmings, food scraps, and other biodegradable organic waste.
- The resulting organic material can be added to soil to supply plant nutrients, slow soil erosion, retain water, and improve crop yields.
- Large-scale composting program must be located carefully and odors must be controlled, especially near residential areas.
- Composting programs must also exclude toxic materials that can contaminate the compost and make it unsafe for fertilizing crops and lawns.

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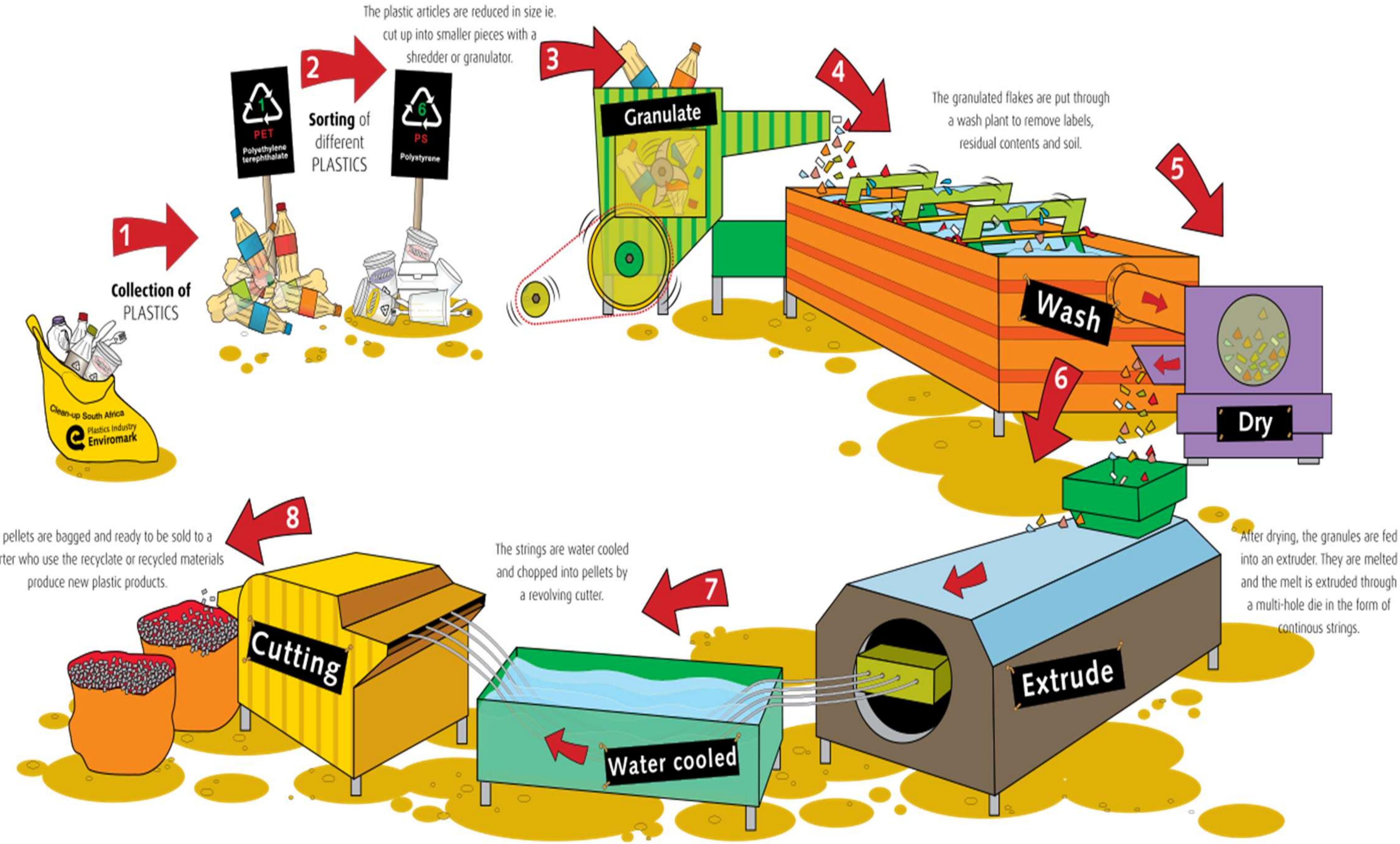
Recycling plastics

- Conversion of high value engineering plastics from complex streams of goods such as computers, electronics, appliances, and automobiles into pellets.
- Plastic pellets are cheaper than virgin plastics since the processing technology uses 90% less energy than that needed to make a new plastic.
- Also the raw material is cheap or free junk.
- Environment friendly since greenhouse gas emissions are much lower than those from making virgin plastics.
- Recycling waste plastics further reduces the need to incinerate them or bury them in landfills.

Plastics recycling sequence



Plastics have several lives

The good and bad of recycling

Trade-Offs

Recycling

Advantages

Reduces air and water pollution

Saves energy

Reduces mineral demand

Reduces greenhouse gas emissions

Reduces solid waste production and disposal

Helps protect biodiversity

Can save landfill space

Important part of economy

Disadvantages

Can cost more than burying in areas with ample landfill space

May lose money for items such as glass and some plastics

Reduces profits for landfill and incinerator owners

Source separation is inconvenient for some people

Promoting reuse and recycling

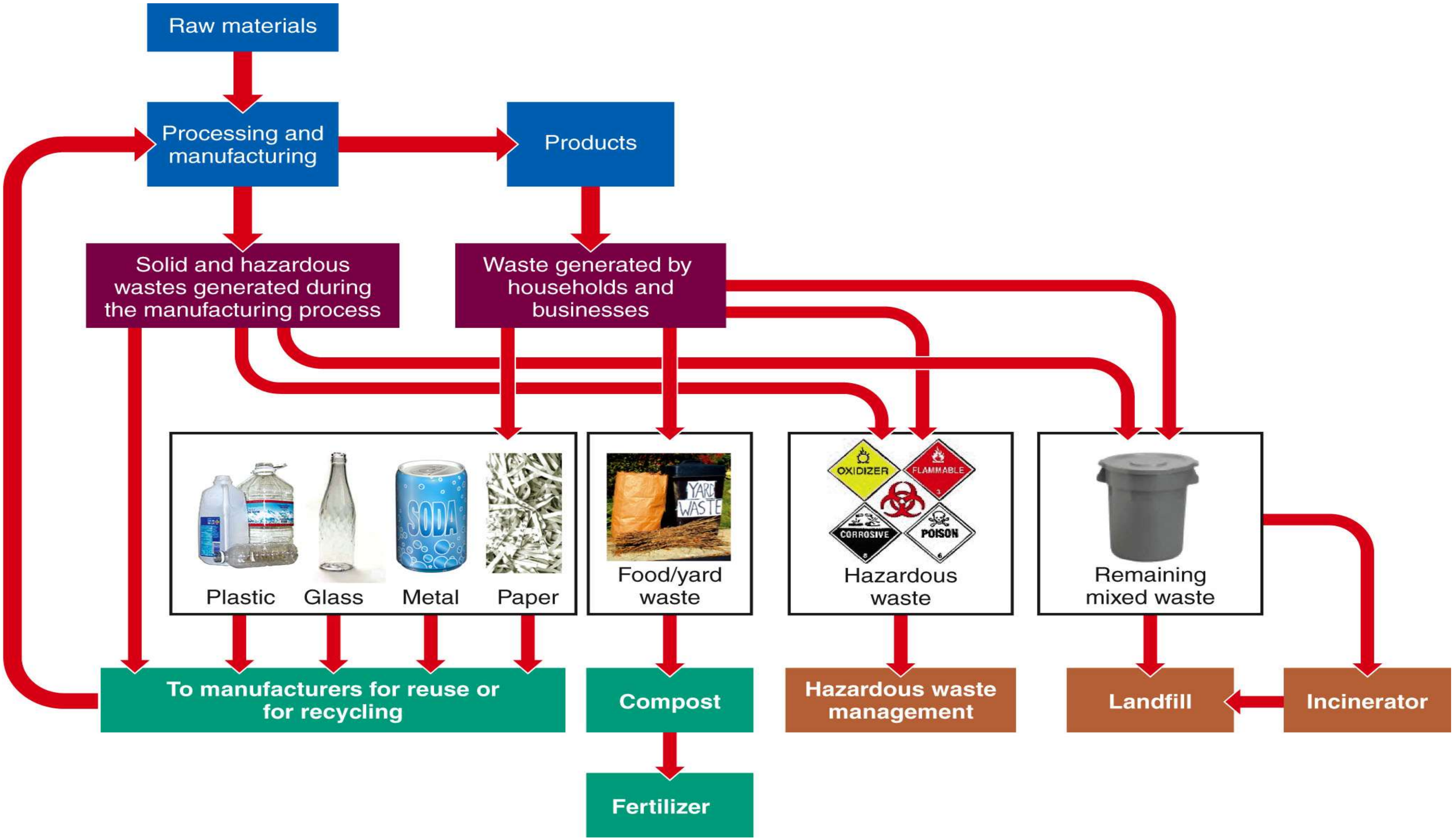
- Governments can encourage reuse and recycling by adopting the following strategies:
  - increase subsidies and tax breaks for reusing and recycling materials.
  - decrease subsidies and tax breaks for making items from virgin sources.
  - greatly increase the fee-per-bag waste collection system.
  - encourage or require government purchases of recycled products.
  - pass laws requiring companies to take back and reuse or recycle packaging and electronic waste discarded by consumers.
  - informing the public about the merits of reuse and recycling.

Waste reduction

- Seven strategies that industries and governments can use to reduce resource use, waste and pollution:
  - redesign manufacturing processes and products to use less material and energy
  - redesign manufacturing processes to produce less waste and pollution
  - develop products that are easy to repair, reuse, remanufacture, compost or recycle
  - eliminate or reduce unnecessary packaging
  - use fee-per-bag waste collection systems
  - establish cradle-to-grave responsibility laws
  - restructure urban transportation systems

Integrated waste management

- Wastes are reduced through reuse, recycling, and composting, or managed by burying them in landfills or incinerating them.



Dealing with hazardous waste

- Priorities suggested by the US National Academy of Sciences for dealing with hazardous waste.

Produce Less Hazardous Waste

- Change industrial processes to reduce or eliminate hazardous waste production
- Recycle and reuse hazardous waste

Convert to Less Hazardous or Nonhazardous Substances

- Natural decomposition
- Incineration
- Thermal treatment
- Chemical, physical, and biological treatment
- Dilution in air or water

Put in Perpetual Storage

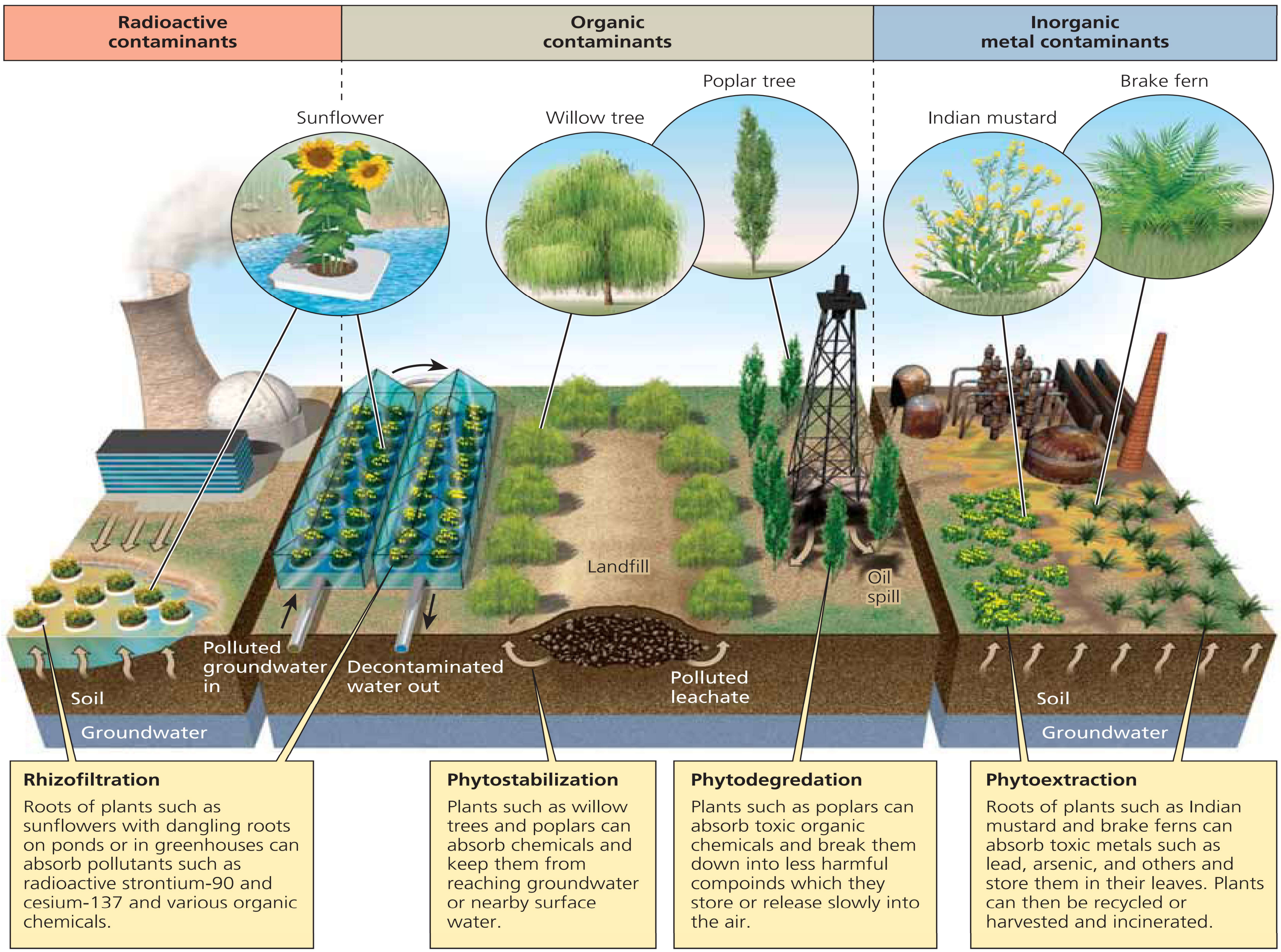
- Landfill
- Underground injection wells
- Surface impoundments
- Underground salt formations

Dealing hazardous waste

- Detoxification
  - Bioremediation: bacteria or enzymes help destroy toxic and hazardous waste or convert them to more benign substances.
  - Phytoremediation: involves using natural or genetically engineered plants to absorb, filter and remove contaminants from polluted soil and water.
  - Incineration: heating many types of hazardous waste to high temperatures – up to 2000°C – in an incinerator can break them down and convert them to less harmful or harmless chemicals.
  - Plasma arc torch: passing electrical current through gas to generate an electric arc and very high temperatures can create plasma which can decompose liquid or solid hazardous organic material.

Dealing hazardous waste

- Various types of plants can be used as pollution sponges to clean up soil and water and radioactive substances (left), organic compounds (center), and toxic metals (right).



The good and bad of phytoremediation

TRADE-OFFS

Phytoremediation

Advantages	Disadvantages
Easy to establish	Slow (can take several growing seasons)
Inexpensive	Effective only at depth plant roots can reach
Can reduce material dumped into landfills	Some toxic organic chemicals may evaporate from plant leaves
Produces little air pollution compared to incineration	Some plants can become toxic to animals
Low energy use	

Dealing hazardous waste

- Storing hazardous waste
  - Deep-well disposal: liquid hazardous wastes are pumped under pressure into dry porous rock far beneath aquifers.
  - Surface impoundments: excavated depressions such as ponds, pits, or lagoons into which liners are placed and liquid hazardous wastes are stored.
  - Long-term retrievable storage: some highly toxic materials cannot be detoxified or destroyed. Metal drums are used to stored them in areas that can be inspected and retrieved.
  - Secure landfills: hazardous waste are put into drums and buried in carefully designed and monitored sites.

The good and bad of deep-well disposal

TRADE-OFFS

Deep-Well Disposal

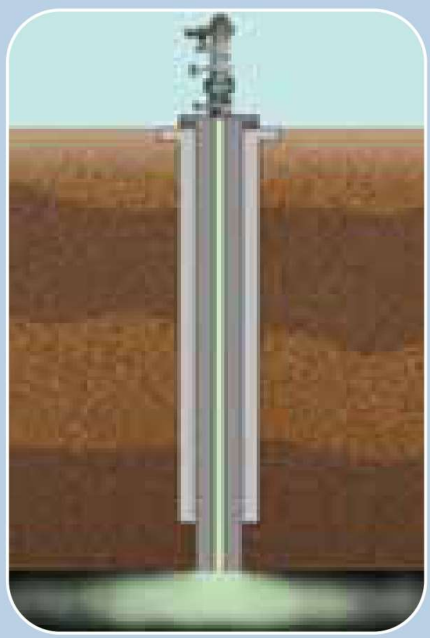
Advantages

Safe method if sites are chosen carefully

Wastes can often be retrieved if problems develop

Easy to do

Low cost



Disadvantages

Leaks or spills at surface

Leaks from corrosion of well casing

Existing fractures or earthquakes can allow wastes to escape into groundwater

Output approach that encourages waste production

The good and bad of surface impoundments

TRADE-OFFS

Surface Impoundments

Advantages

Low construction costs

Low operating costs

Can be built quickly

Wastes can often be retrieved if necessary

Can store wastes indefinitely with secure double liners

Disadvantages

Groundwater contamination from leaking liners (or no lining)

Air pollution from volatile organic compounds

Overflow from flooding

Disruption and leakage from earthquakes

Output approach that encourages waste production

Reducing hazardous waste

What Can You Do?

Hazardous Waste

- Avoid using pesticides and other hazardous chemicals, or use them in the smallest amounts possible
- Use less harmful and usually cheaper substances instead of commercial chemicals for most household cleaners. For example, use vinegar to polish metals, clean surfaces, and remove stains and mildew; baking soda to clean utensils and to deodorize and remove stains; and borax to remove stains and mildew.
- Do not dispose of pesticides, paints, solvents, oil, antifreeze, or other hazardous chemicals by flushing them down the toilet, pouring them down the drain, burying them, throwing them into the garbage, or dumping them down storm drains. Instead, use hazardous waste disposal services available in many cities.

Transition to a low-waste society

- Grassroots actions: Keep large numbers of incinerators, landfills, and hazardous waste treatment plants from being built in local areas.
- Environmental justice: Every person is entitled to protection from environmental hazards without discrimination.
- International treaties: Calls for phasing out the use of harmful persistent organic pollutants (POPs).
- New vision:
  - Everything is connected
  - There is no away, as in to throw away, for the wastes we produce
  - Polluters and producers should pay for the wastes they produce
  - Hazardous waste and recyclable waste should not be mixed
  - Mimic nature by reusing, recycling, or composting

EV20001: ENVIRONMENTAL SCIENCE

Lecture #8

Water Resources & Water Pollution

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30 March 2022

Importance and availability of water

- Water is crucial for all aspects of life, the defining feature of our planet.
- About 71% of the Earth’s surface is covered with water, and the oceans hold about 96.5% of all the Earth's water.
- Only 3% of the total water in the world is freshwater and less than 1% is readily available in rivers, lakes, and streams.
- The world’s freshwater supply is continually collected, purified, recycled, and distributed in the Earth’s water cycle.

Importance and availability of water

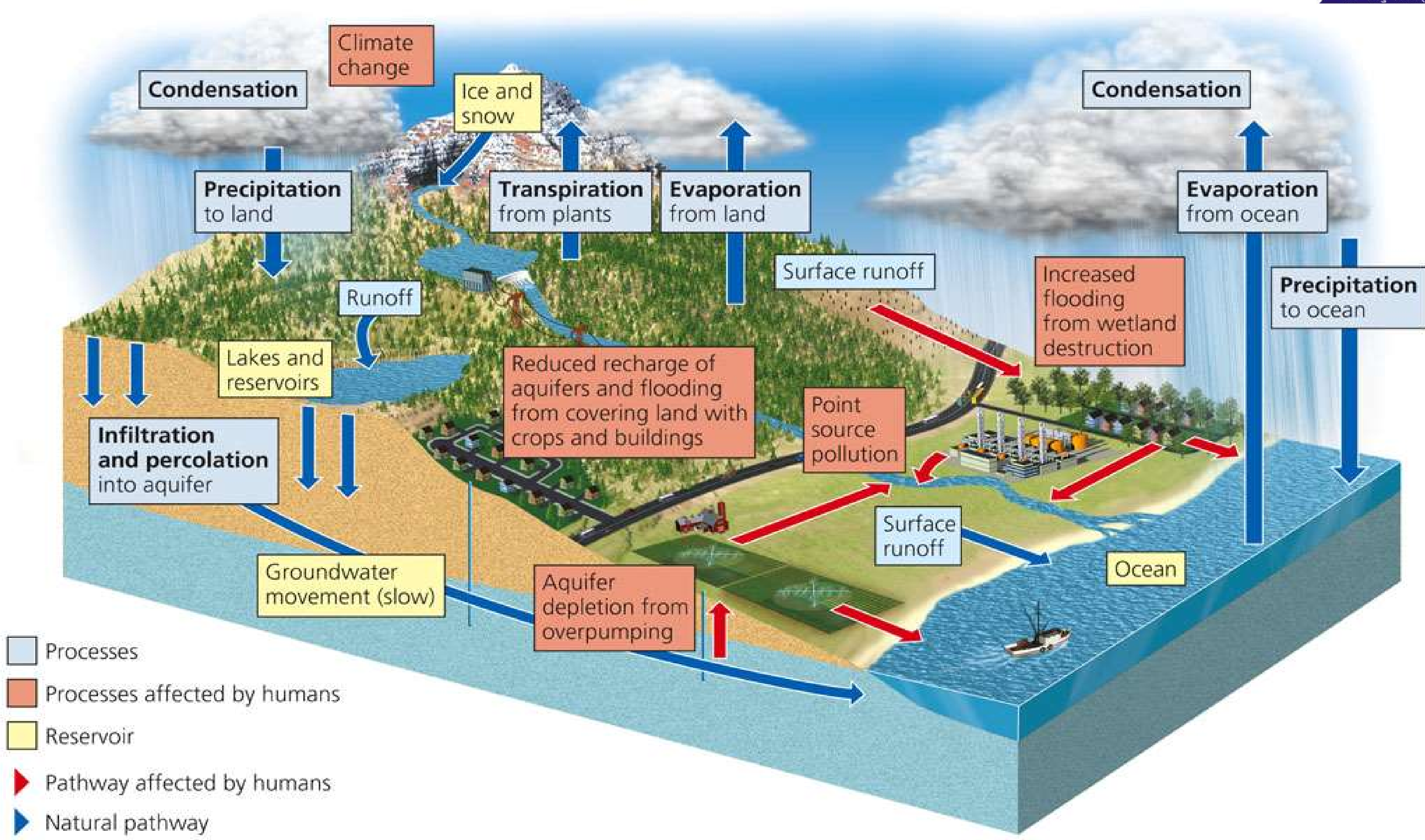
- Freshwater is an irreplaceable resource that is most poorly managed. We waste it and pollute it. We also charge too little for making it available.

- Water is an economic issue because it is vital for reducing poverty and producing food and energy.

- Water is a national and global security issue because of increasing tensions within and between nations over access to limited waster resources that they share.

- Water is an environmental issue because excessive withdrawal of water from rivers and aquifers results in dropping water tables, shrinking lakes, and loss of wetlands.

- Some of our actions purposefully affect the water cycle and other human activities have unintentional consequences on the water cycle.



Groundwater

- Water located beneath Earth's surface in soil pore spaces and in the fractures of rock formations.

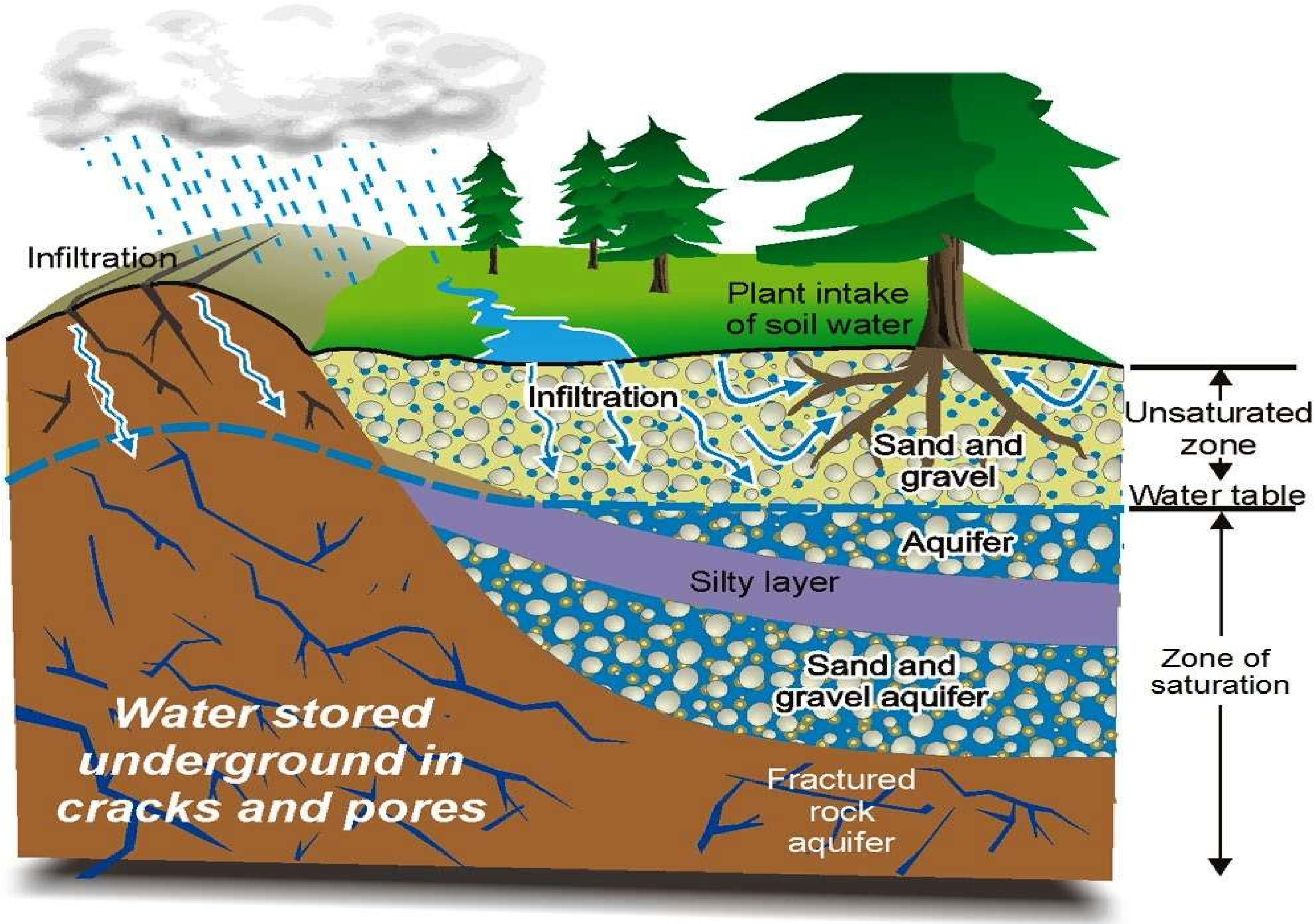
- Water table is the level beneath the Earth's surface below which all pore spaces are filled with water, and above which the pore spaces are filled with air.

- Zone of saturation is the area beneath the water table where all pore spaces are completely filled with water.

- Aquifers are underground caverns and porous layers of sand, gravel, or bedrock through which groundwater flows.

- Most aquifers are replenished by natural recharge. Others are recharged by lateral recharge.

- Groundwater can become polluted with nutrients or chemicals when surface water carrying these substances drains into the groundwater environment.



Surface water

- Water from precipitation and snowmelt that flows across the Earth's land surface and into lakes, wetlands, streams, rivers, estuaries, and ultimately to the oceans.

- Surface runoff – precipitation that does not infiltrate the ground or return to the atmosphere by evaporation.

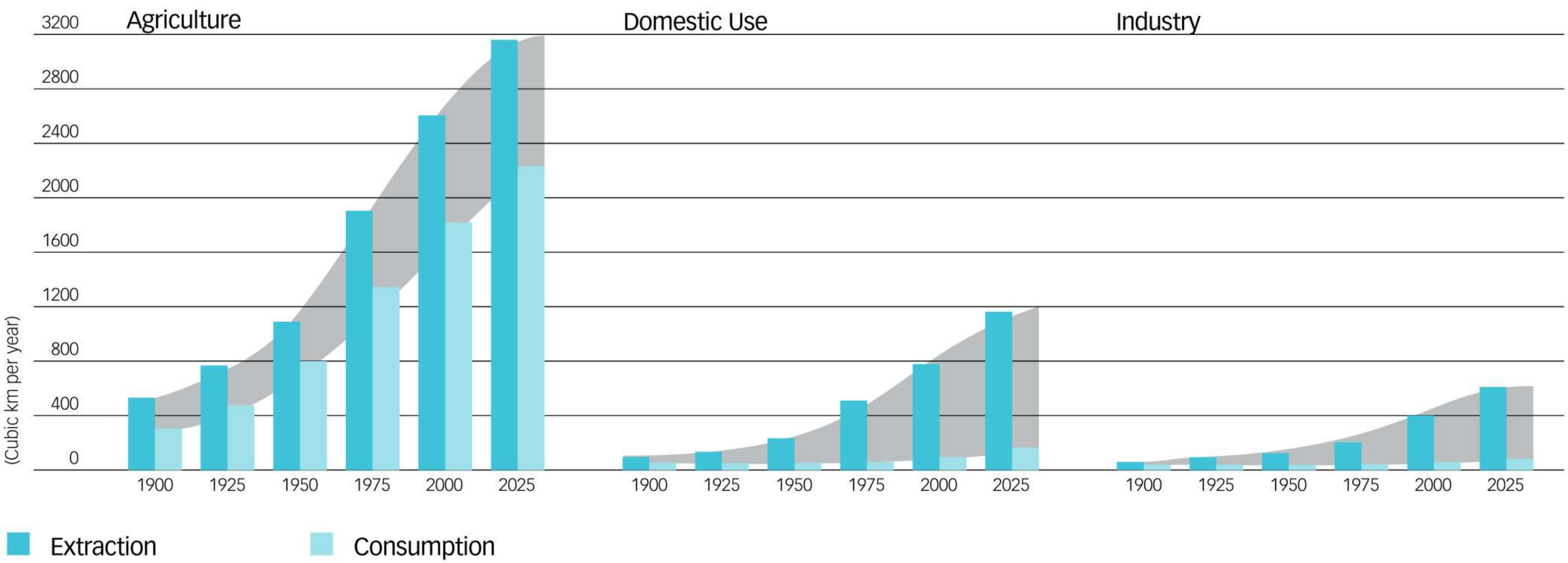
- Two third of the annual surface runoff in rivers and streams is lost by seasonal floods and is not available for human use.

- Remaining one third is reliable surface runoff – source of freshwater from year to year.

- Watershed/Drainage basin is the land from which surface water drains into a particular river, lake, wetland, or other body of water.

Global water use

- Water may be extracted, used, recycled (or returned to rivers or aquifers) and reused several times over. Consumption is the final use of water, after which it can no longer be reused.
- That extraction has increased at a much faster rate, is an indication of how much more intensively we now exploit water. Only a fraction of water extracted is lost through evaporation.



Global water crisis

- Main factors causing water scarcity: (i) dry climate, (ii) drought, (iii) too many people using a water supply, and (iv) wasteful use of water.
- Currently, about 1 billion people – one of every seven – in the world lack regular access to clean water.
- There will be a 40% gap between water demand and water available by 2030.
- 1.8 billion people now use water as drinking source that is contaminated by faeces.
- 80% or more of wastewater returns to the environment without adequate treatment.
- 30% of global water abstraction is lost due to leakage.
- Water scarcity currently affects 40% of the global population.
- 70% more food will be needed to feed the world's population by 2050, and therefore 70-90% of all water globally will be used for agriculture.

Common effects of water scarcity

- The effects of water stress and water scarcity can be felt in many ways, both immediate and long-term.

Increasing freshwater supplies

Solutions

Reducing Water Waste

- Redesign manufacturing processes to use less water
- Recycle water in industry
- Landscape yards with plants that require little water
- Use drip irrigation
- Fix water leaks
- Use water meters
- Raise water prices
- Use waterless composting toilets
- Require water conservation in water-short cities
- Use water-saving toilets, showerheads, and front-loading clothes washers
- Collect and reuse household water to irrigate lawns and nonedible plants
- Purify and reuse water for houses, apartments, and office buildings

Increasing freshwater supplies

Trade-Offs

Withdrawing Groundwater

Advantages

Useful for drinking and irrigation

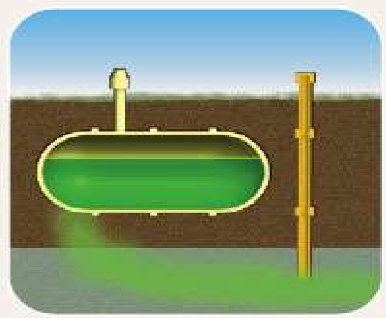
Available year-round

Exists almost everywhere

Renewable if not overpumped or contaminated

No evaporation losses

Cheaper to extract than most surface waters



Disadvantages

Aquifer depletion from overpumping

Sinking of land (subsidence) from overpumping

Aquifers polluted for decades or centuries

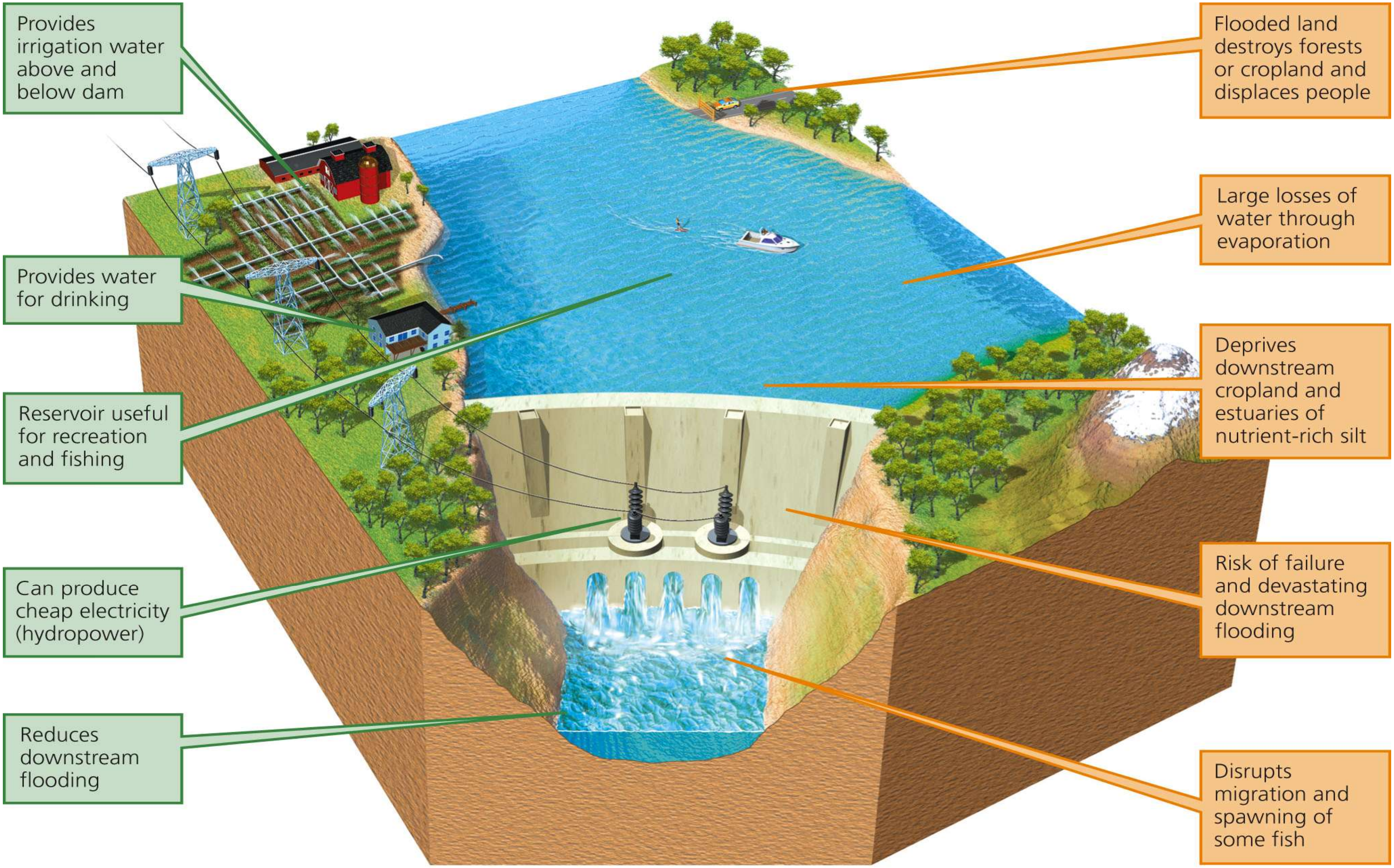
Saltwater intrusion into drinking water supplies near coastal areas

Reduced water flows into surface waters

Increased cost and contamination from deeper wells

Increasing freshwater supplies

- Building dams and reservoirs to store runoff in rivers

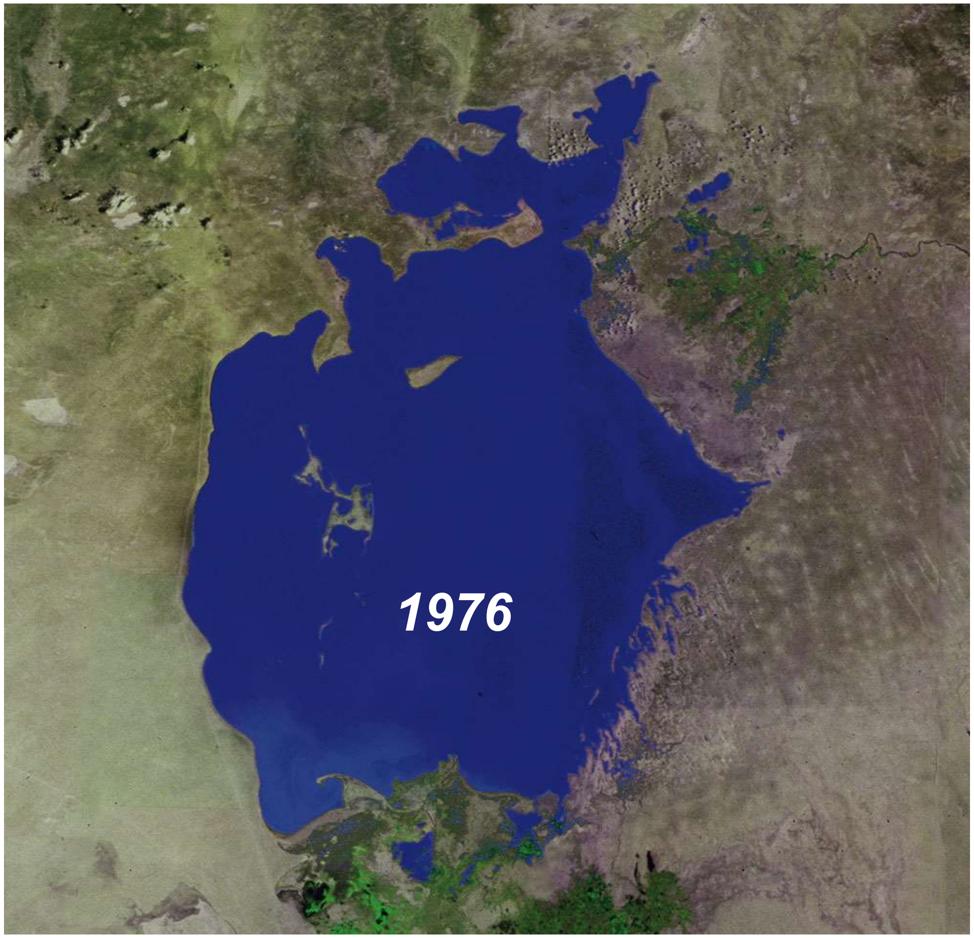


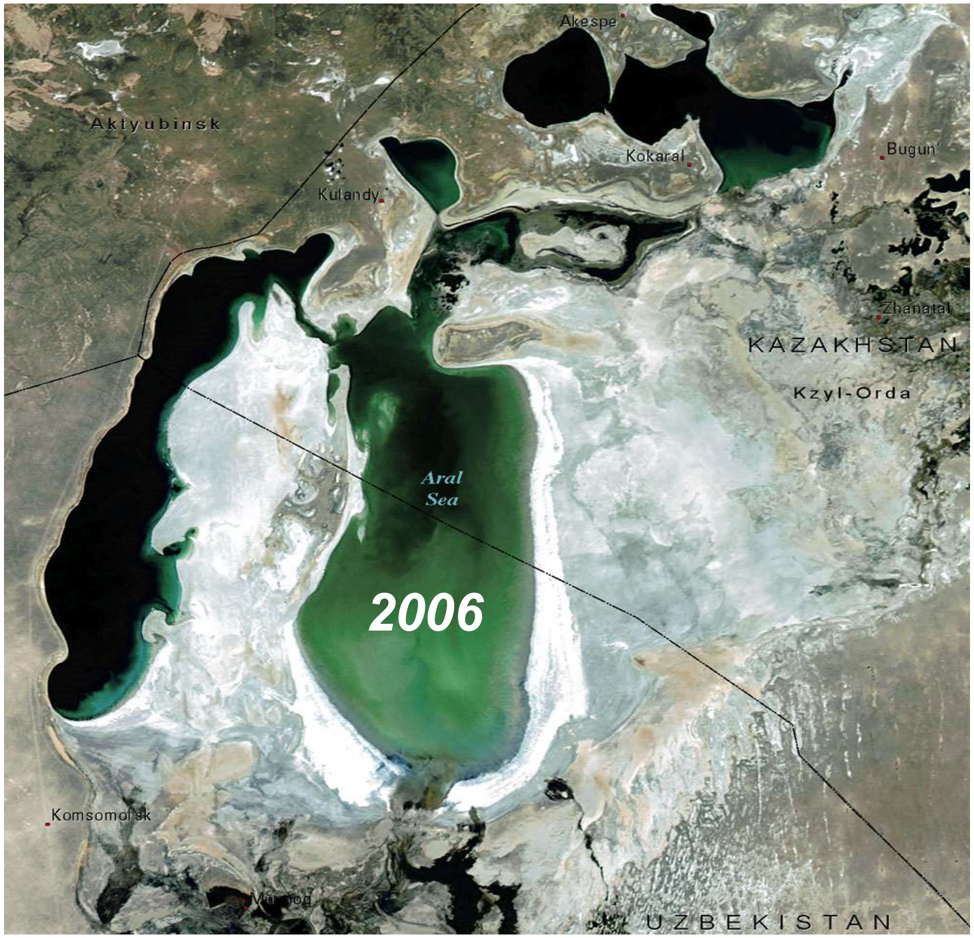
Increasing freshwater supplies

- Transporting surface water from one area to another

California Water Project and the Central Arizona Project transfer massive amounts of water from water-rich areas to water-poor areas.

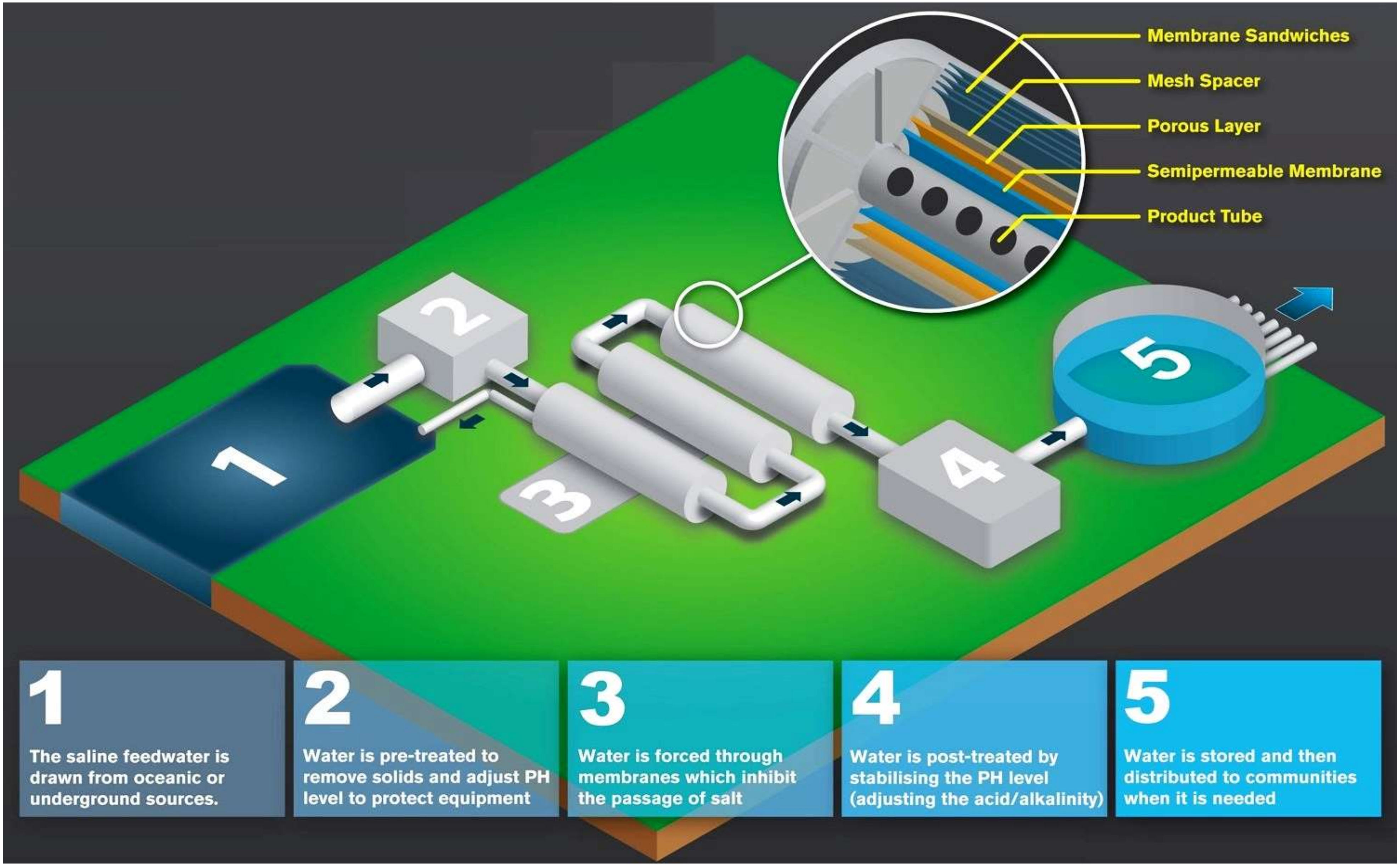
- **Aral Sea Disaster:** The Aral Sea was one of the world's largest saline lakes. Since 1960, it has been shrinking and getting saltier because most of the water from the rivers that replenish it has been diverted to grow cotton and food crops. As the lake shrank, it split into two lakes and left behind a salty desert, economic ruin, increasing health problems, and severe ecological disruption.





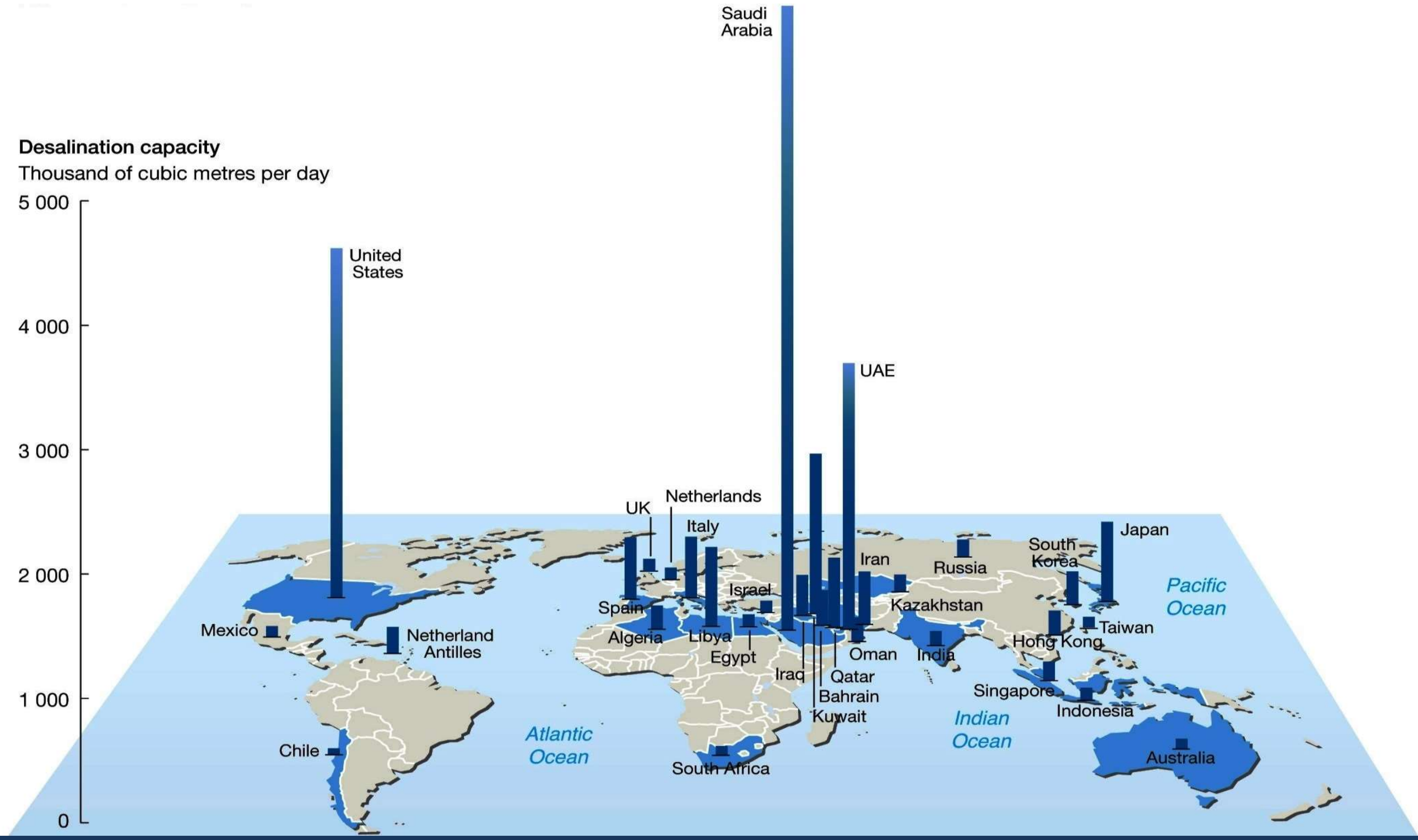
Increasing freshwater supplies

- Converting saltwater to freshwater (desalination)



- Two leading technologies for desalinating water:
  - **Distillation**
    - Heating saltwater until it evaporates (leaving behind salts in solid form) and condenses as freshwater
    - Complete rejection of non volatiles (e.g., salts, ions, colloids, cells, and organic non volatiles)
    - Less commercialised for large scale desalination plant
  - **Reverse Osmosis**
    - Uses high pressure to force saltwater through a membrane filter with pores small enough to remove the salt
    - Higher productivity of water and high water efficiency
    - Highly commercialised for large scale desalination plant

- About 13,000 desalination plants operate in more than 125 countries, especially in the arid nations of the Middle East, North Africa, the Caribbean, and the Mediterranean.



Using water sustainably

Solutions

Sustainable Water Use

- Waste less water and subsidize water conservation
- Do not deplete aquifers
- Preserve water quality
- Protect forests, wetlands, mountain glaciers, watersheds, and other natural systems that store and release water
- Get agreements among regions and countries sharing surface water resources
- Raise water prices
- Slow population growth

Individual choices make a difference

What Can You Do?

Water Use and Waste

- Use water-saving toilets, showerheads, and faucet aerators
- Shower instead of taking baths, and take short showers
- Repair water leaks
- Turn off sink faucets while brushing teeth, shaving, or washing
- Wash only full loads of clothes or use the lowest possible water-level setting for smaller loads
- Use recycled (gray) water for watering lawns and houseplants and for washing cars
- Wash a car from a bucket of soapy water, and use the hose for rinsing only
- If you use a commercial car wash, try to find one that recycles its water
- Replace your lawn with native plants that need little if any watering
- Water lawns and yards only in the early morning or evening
- Use drip irrigation and mulch for gardens and flowerbeds

Water pollution

- Water pollution is any change in water quality that harms humans or other living organisms or makes water unsuitable for desired uses.

Jorge Fusaro

Sources of water pollution

- Pollutants entering water bodies come from two types of sources:
  - **Point sources**
    - Discharge pollutants at specific locations through drain pipes, ditches, or sewer lines into bodies of surface water
    - Easier to identify, monitor, and regulate
    - Example: factories, underground mines, oil tankers
  - **Nonpoint sources**
    - Broad, diffuse areas from which pollutants enter bodies of surface water
    - Little progress in controlling water pollution from nonpoint sources because of the difficulty and expense of identifying and controlling discharges from such sources
    - Example: runoff of chemicals and sediments from cropland, livestock feedlots, logged forests, urban streets, parking lots, lawns, and golf courses

Major water pollutants and their sources

Type/Effects	Examples	Major sources
Infectious agents (pathogens) *Cause diseases*	Bacteria, viruses, protozoa, parasites	Human and animal wastes
Oxygen-demanding wastes *Deplete dissolved oxygen needed by aquatic species*	Biodegradable animal wastes and plant debris	Sewage, animal feedlots, food processing facilities, pulp mills
Plant nutrients *Cause excessive growth of algae and other species*	Nitrates (NO_3^-) and phosphates (PO_4^{3-})	Sewage, animal wastes, inorganic fertilizers
Organic chemicals *Add toxins to aquatic systems*	Oil, gasoline, plastics, pesticides, cleaning solvents	Industry, farms, households
Inorganic chemicals *Add toxins to aquatic systems*	Acids, bases, salts, metal compounds	Industry, households, surface runoff
Sediments *Disrupt photosynthesis, food webs, other processes*	Soil, silt	Land erosion
Heavy metals *Cause cancer, disrupt immune and endocrine systems*	Lead, mercury, arsenic	Unlined landfills, household chemicals, mining refuse, industrial discharges
Thermal *Make some species vulnerable to disease*	Heat	Electric power and industrial plants

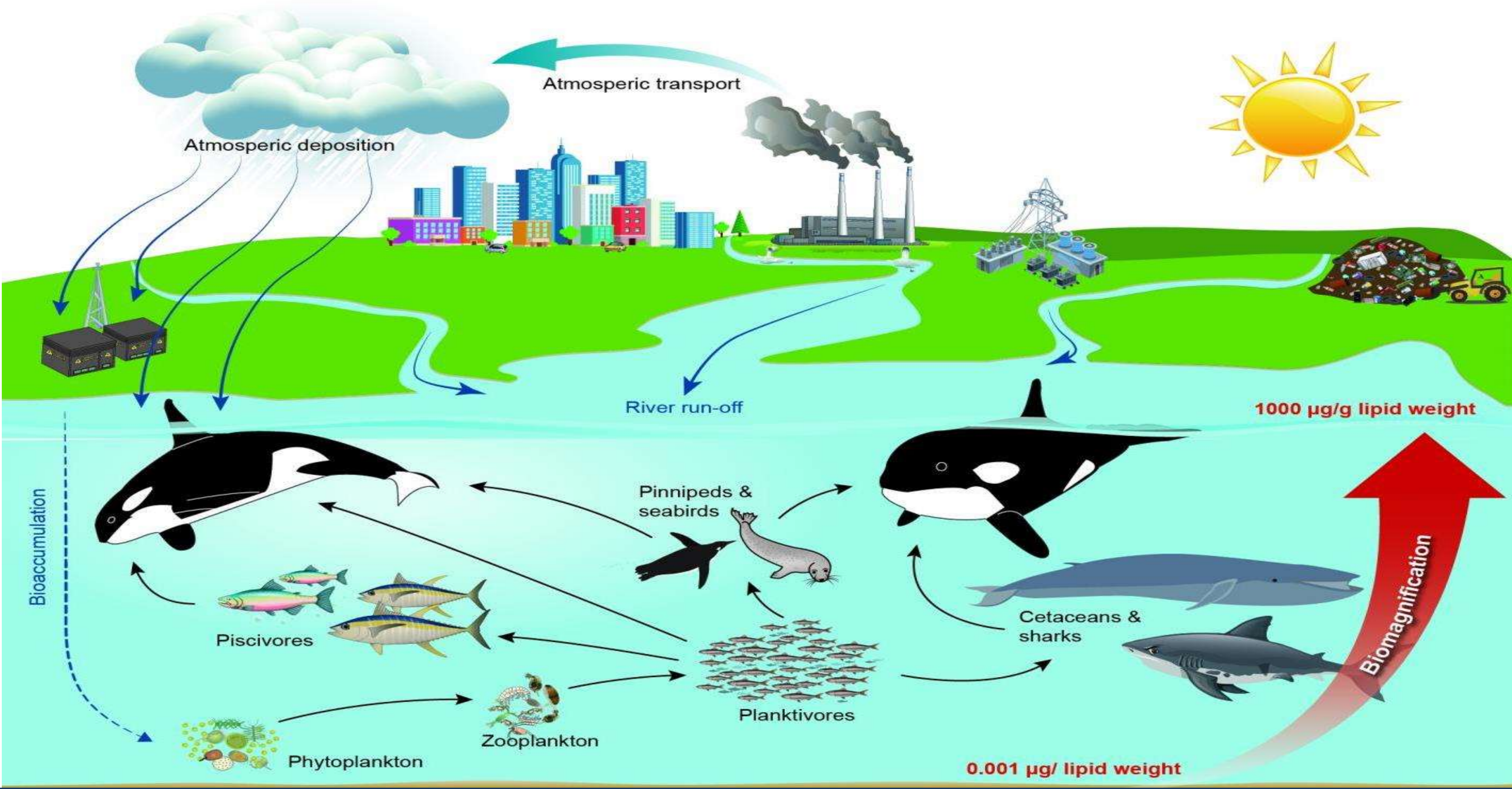
Endocrine disruptors

- Endocrine disrupting compounds (EDCs) are chemicals which can interfere with the normal function of hormones in aquatic animals. They can enter water courses through wastewater discharges from industry and sewage and also in agricultural run-off.

- EDCs are found in various materials such as pesticides, metals, additives or contaminants in food, and personal care products.

- They are known to impair growth and development in animals, lead to reproductive abnormalities and can even cause some species to change sex.

- An important process by which chemicals can affect living organisms is through bioaccumulation. **Bioaccumulation** is the increase in the concentration of a chemical over time in the tissues of organisms compared to the chemical's concentration in the environment. It results from a dynamic equilibrium between exposure from the outside environment and uptake, excretion, storage, and degradation within an organism.



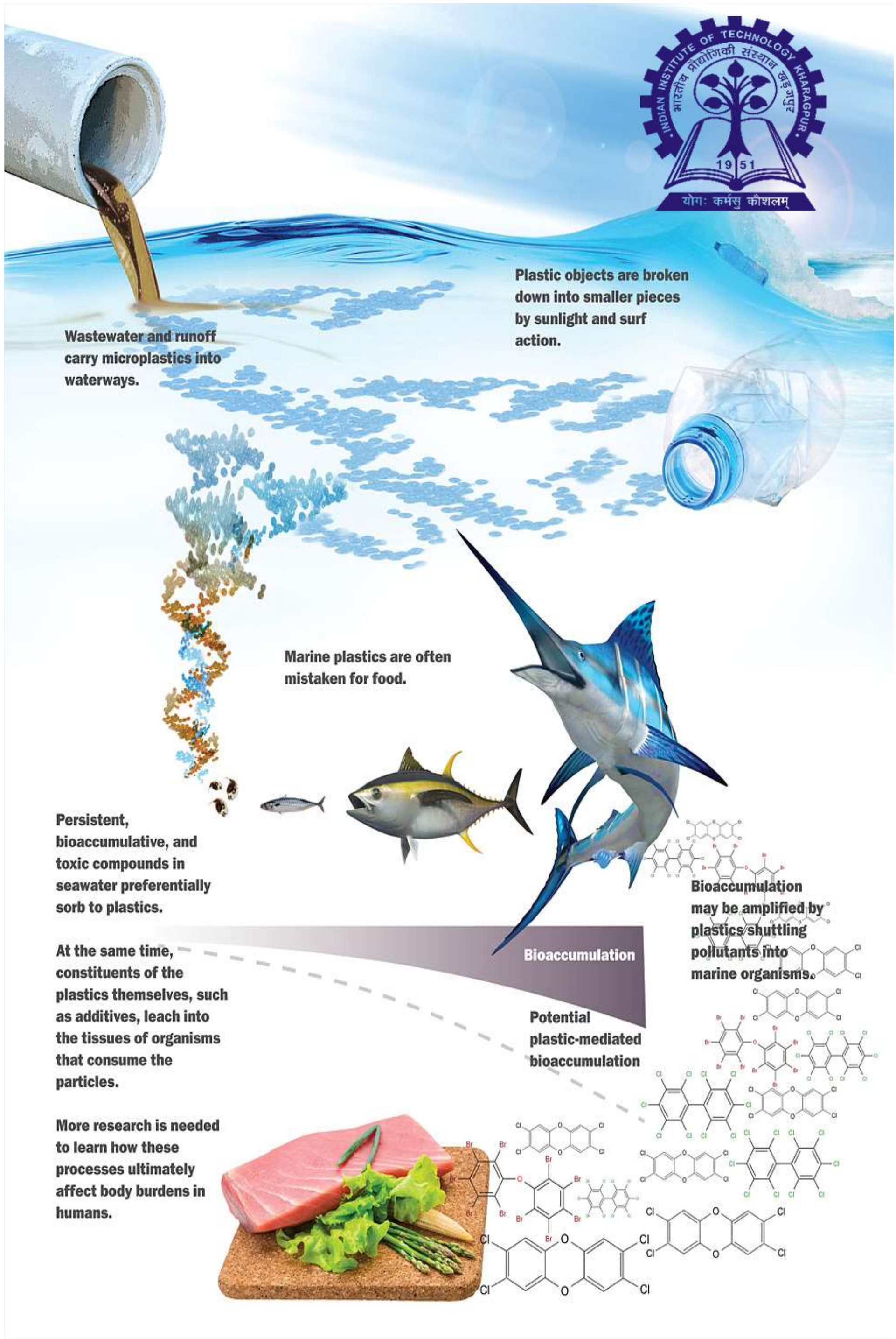
- The extent of bioaccumulation depends on the concentration of a chemical in the environment, the amount of chemical coming into an organism from the food, air or water, and the time it takes for the organism to acquire the chemical and then excrete, store, and/or degrade it.

- The nature of the chemical itself, such as its solubility in water and fat, affects its uptake and storage.

- Equally important is the ability of the organism to degrade and excrete a particular chemical.

- When exposure ceases, the body gradually metabolizes and excretes the chemical.

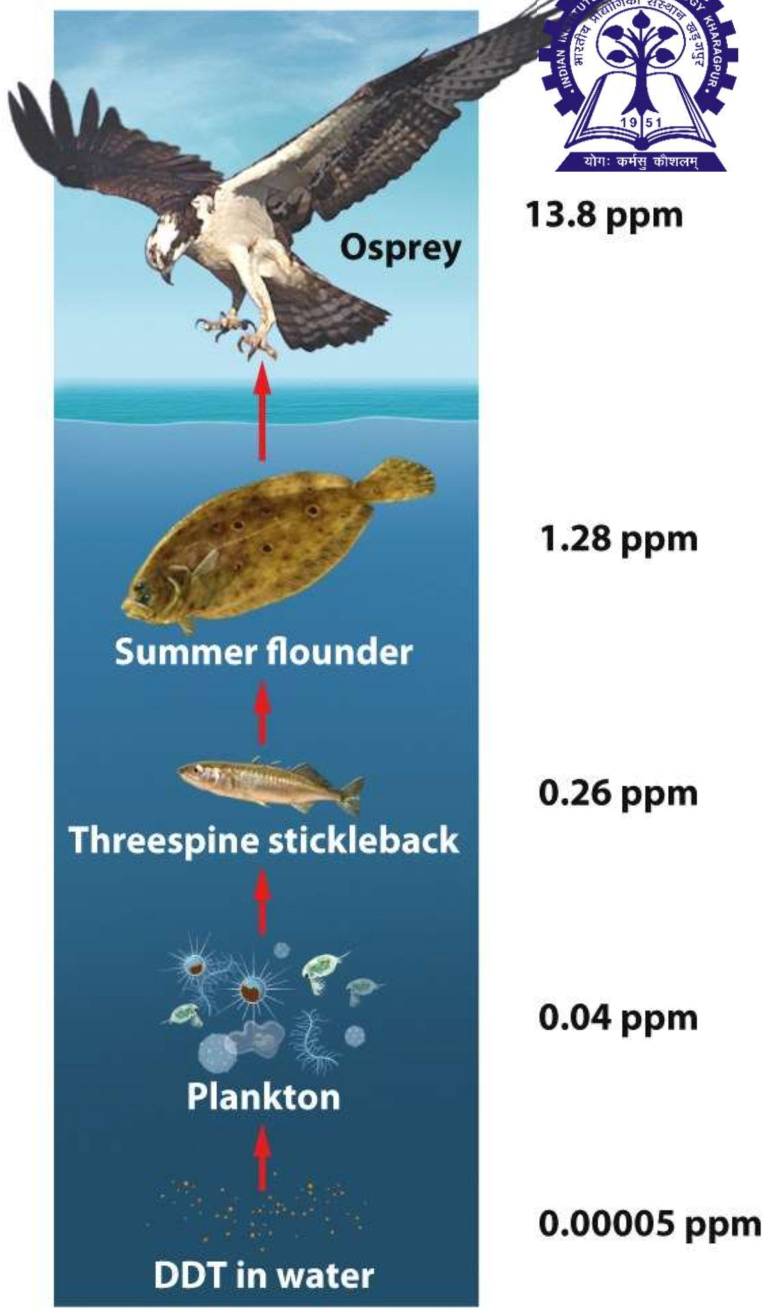
- When a harmful substance gets absorbed by an organism at a higher rate than it can be excreted, the organism is at risk of chronic poisoning.



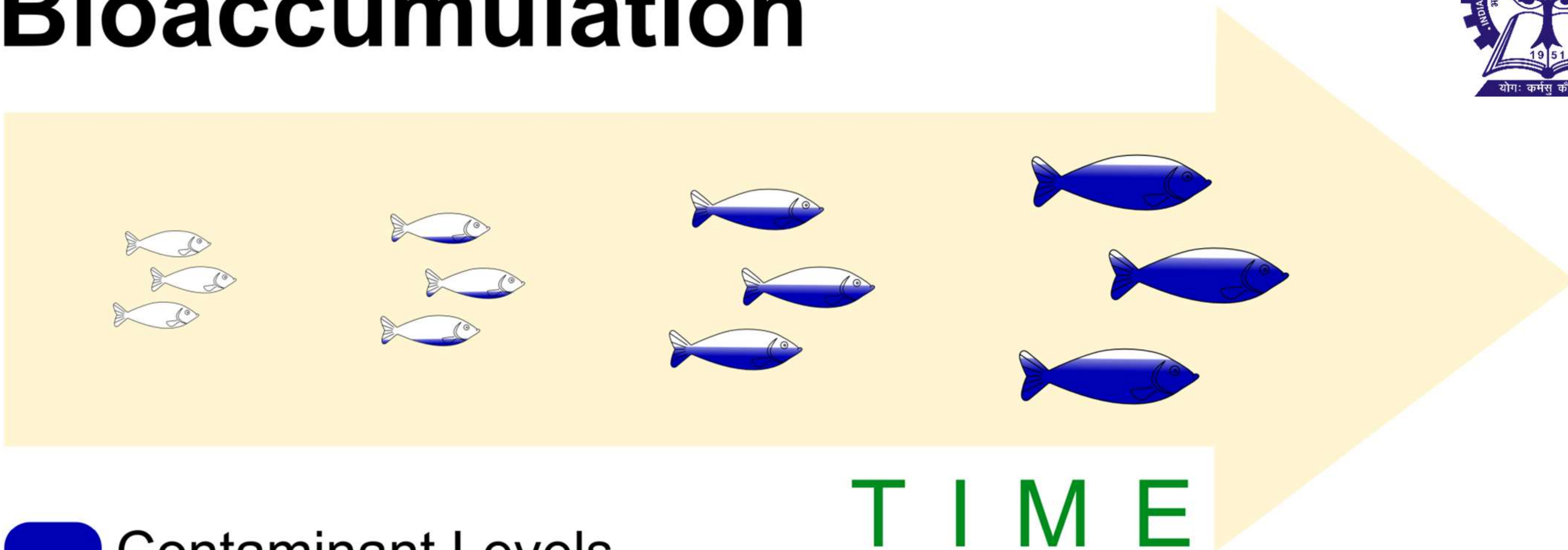
- **Biomagnification** is the process by which toxic chemicals build up within predators. This typically occurs across an entire food chain and affects all of the organisms but animals higher up in the chain are more impacted.

- The initial exposure is primarily in a low trophic group such as the plankton in a lake. Consumption causes the upward movement of the chemical where it is accumulated in the bodies at each trophic level. The combination of bioaccumulation at each trophic level and upward movement by consumption allows the concentration to magnify to the point where it can be substantially more concentrated in the top predator than it was in the water.

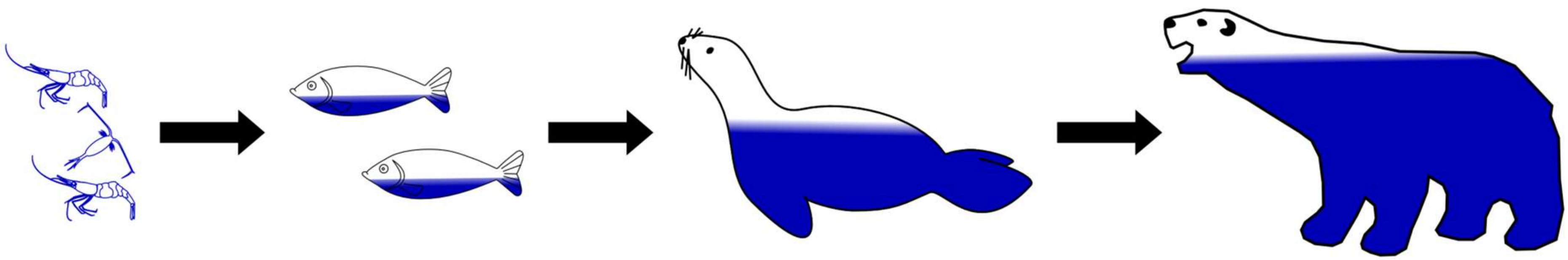
- Biomagnification can, therefore, be considered the result of bioaccumulation.



Bioaccumulation



Contaminant Levels

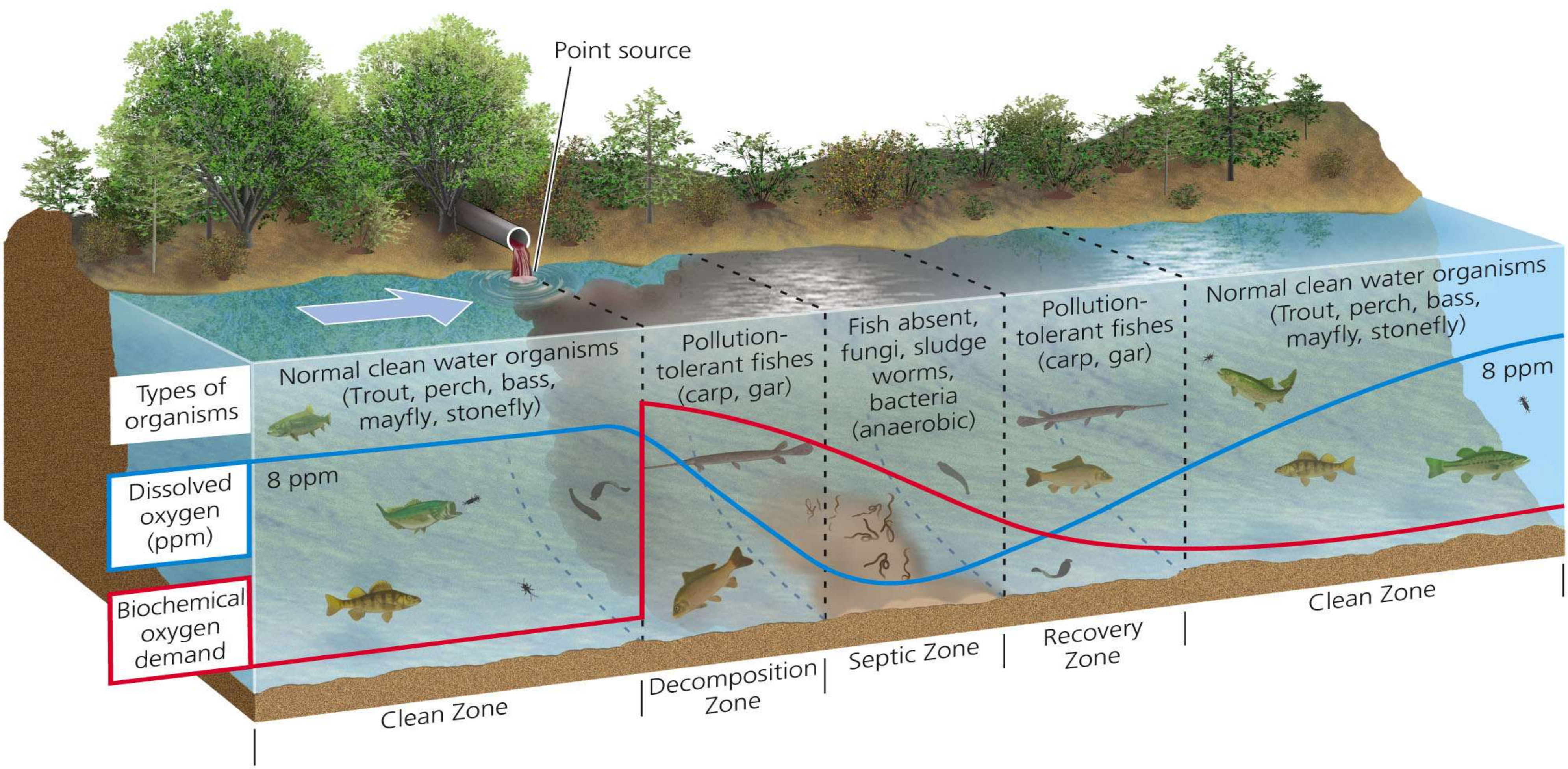


Contaminant Levels

Biomagnification

Streams can cleanse themselves

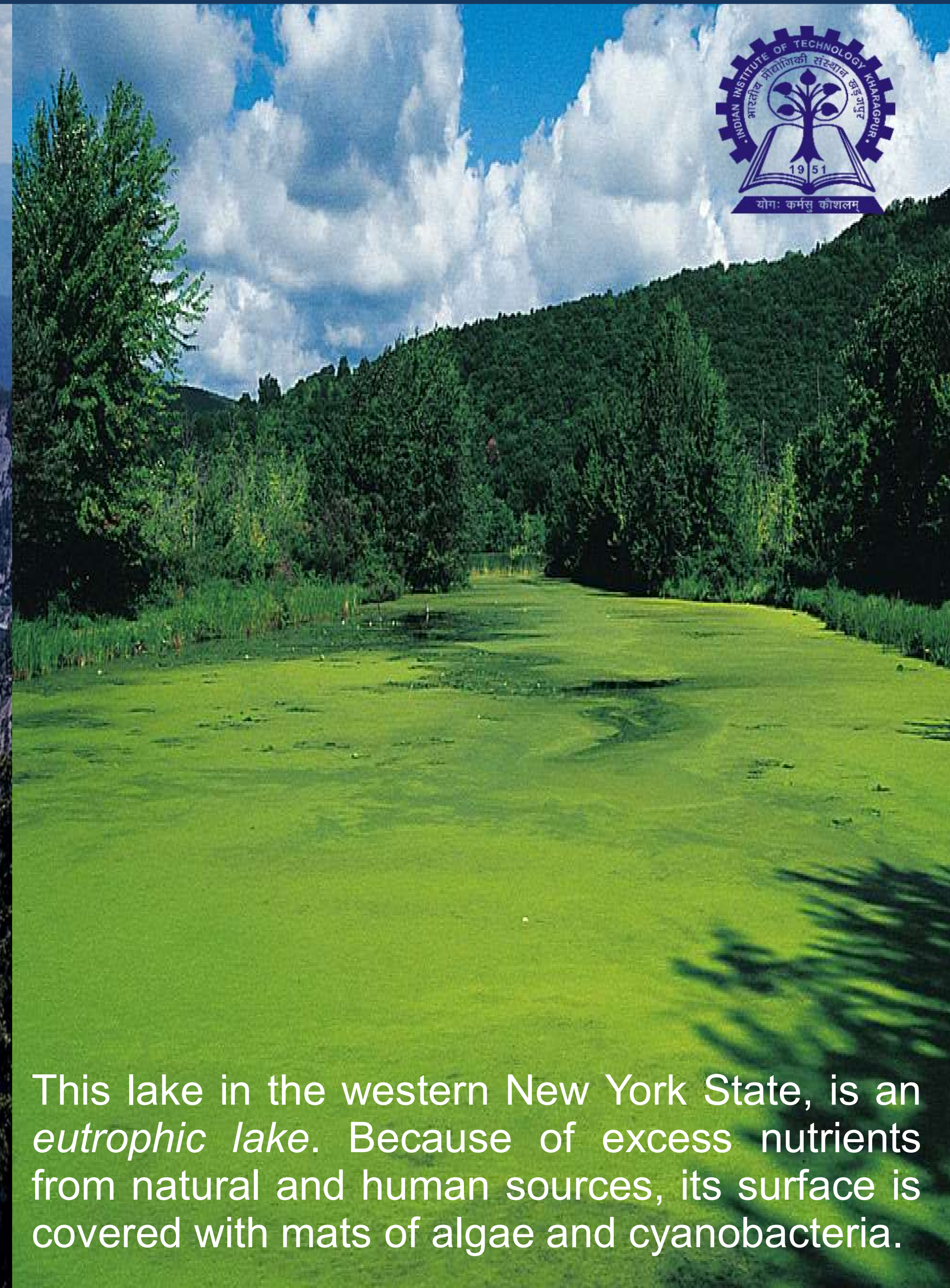
- In a flowing stream, the breakdown of biodegradable wastes by bacteria depletes dissolved oxygen and creates and oxygen sag curve (blue). This reduces or eliminates populations of organisms with high oxygen requirements. Depending on flow rates and the amount of biodegradable pollutants, streams recover from injection of oxygen demanding wastes or heated waste if they are given enough time and are not overloaded



Lakes cannot cleanse themselves

- Lakes and reservoirs less effective at diluting pollutants because
  - they contain stratified layers that undergo little vertical mixing.
  - they have little or no flow.
- Lakes and reservoirs are more vulnerable than streams to contamination by runoff or discharge of plant nutrients, oil, pesticides, and non-degradable toxic substances.
- Eutrophication:
  - enrichment of bodies of fresh water by inorganic nutrients
  - caused mostly by runoff of plant nutrients such as nitrates and phosphates from surrounding land.
  - particularly evident in slow-moving rivers and shallow lakes

Crater Lake in the US state of Oregon (left) is an *oligotrophic lake*, which is low in nutrients. Because of the low density of plankton, its water is quite clear.

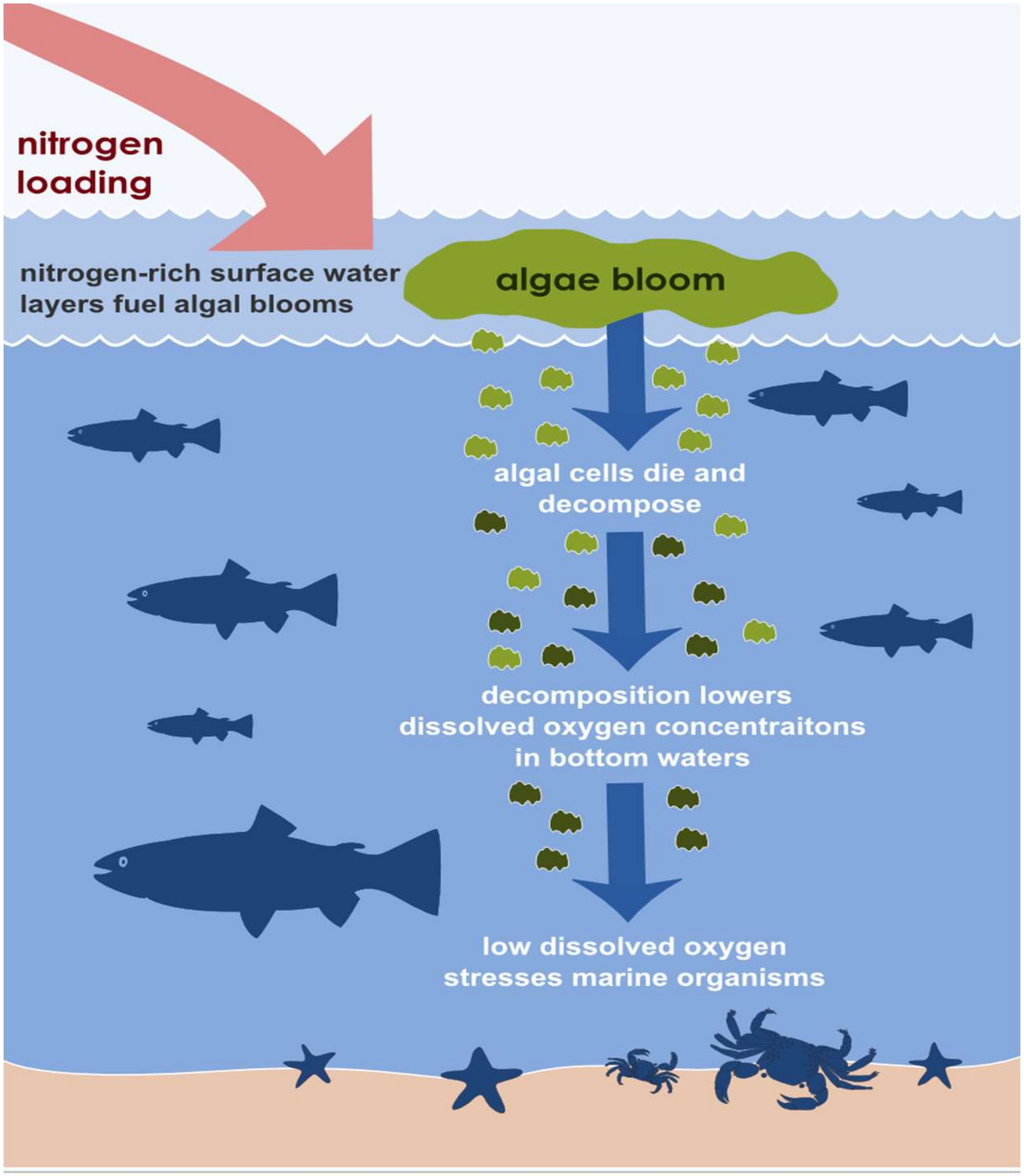


This lake in the western New York State, is an *eutrophic lake*. Because of excess nutrients from natural and human sources, its surface is covered with mats of algae and cyanobacteria.

Cultural eutrophication

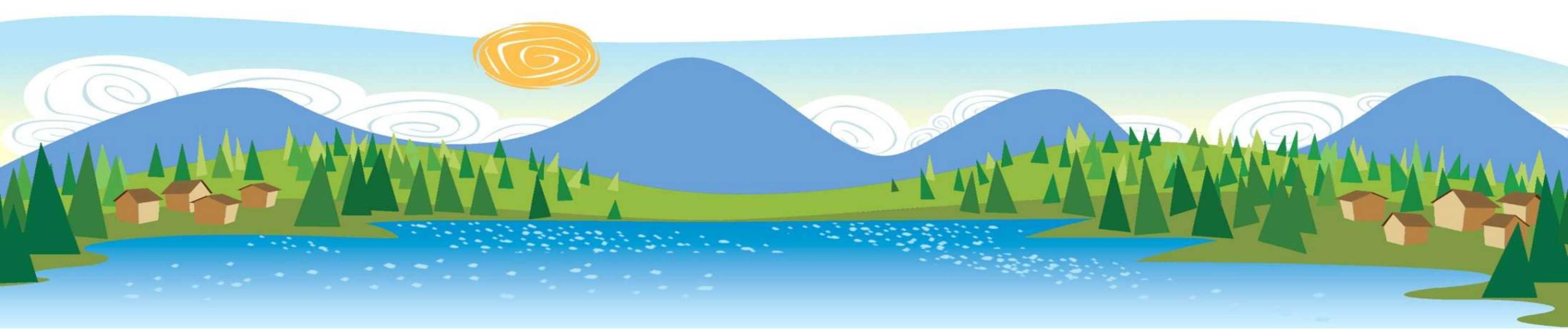
- Human activities can greatly accelerate the input of plant nutrients to a lake – cultural eutrophication.
- Sources include farmland, animal feedlots, chemically fertilized suburban yards, mining sites, and treated and untreated municipal sewage outlets.
- Nutrient overload produces dense growth or ‘blooms’ of organisms such as algae and cyanobacteria that reduce lake productivity by decreasing the input of solar energy.
- When the algae die, they are decomposed by aerobic bacteria which deplete dissolved oxygen killing fish and other aerobic aquatic animals.
- Can be prevented by mechanically removing excess weeds, controlling undesirable plant growth with herbicides and algicides, and pumping air to prevent oxygen depletion.

- Cultural eutrophication can lead to the premature aging and death of a body of water.

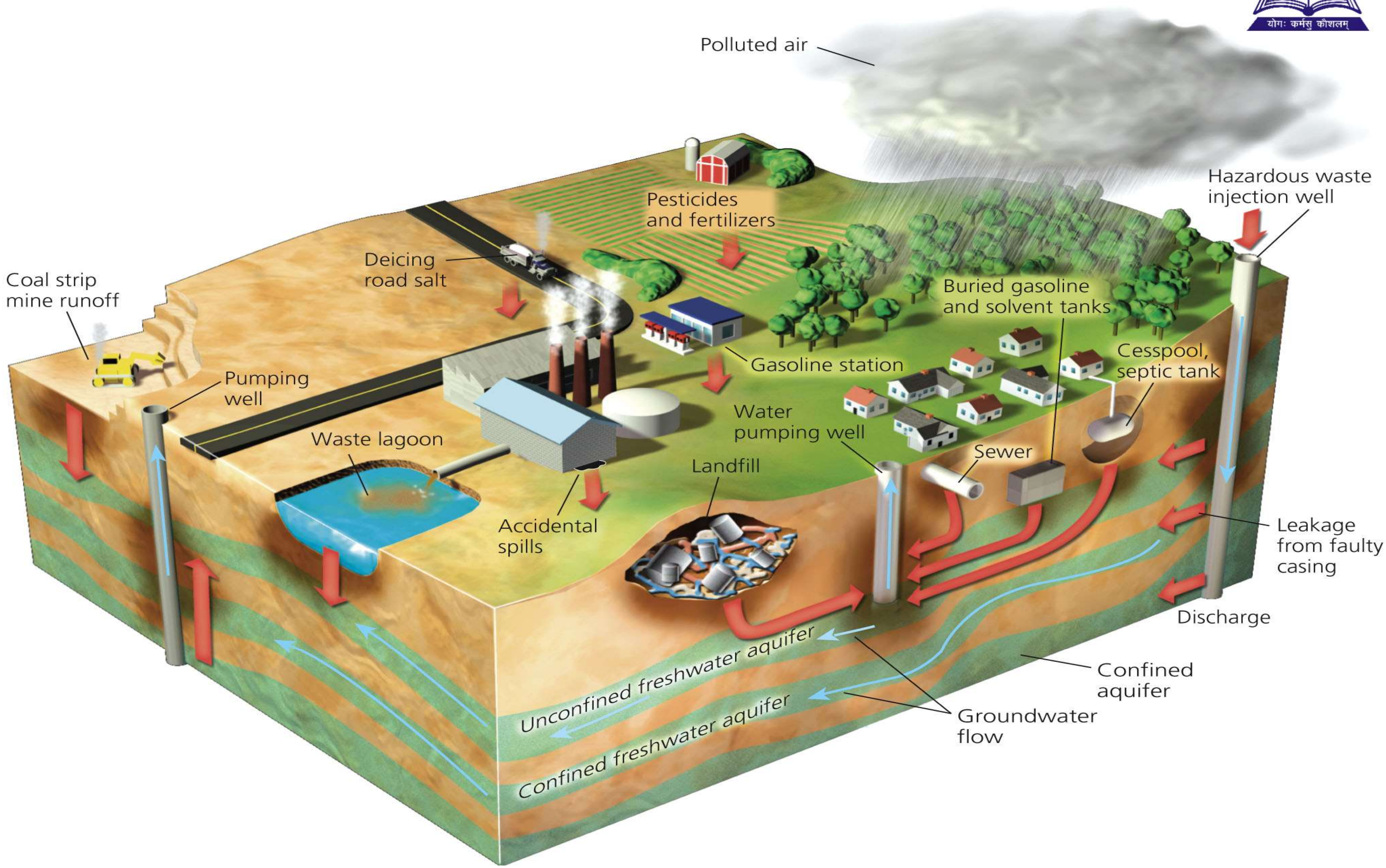


Groundwater too cannot cleanse itself

- Common pollutants such as fertilizers, pesticides, gasoline, and organic solvents can seep into groundwater from numerous sources.
- Groundwater flows very slowly ─ contaminants are not diluted and dispersed effectively.
- Lower concentration of dissolved oxygen (which helps decompose many contaminants) and smaller populations of decomposing bacteria.
- Cold temperatures of groundwater further slow down chemical reactions that decomposes wastes.
- Can take decades to thousands of years for contaminated groundwater to cleanse itself.
- Preventing contamination is the least expensive and most effective way to protect groundwater resources.



- The principal sources and causes of groundwater pollution are under four categories: municipal, industrial, agricultural, and miscellaneous.



Purifying drinking water

- Developed countries
  - Water stored in reservoirs for several days to improve clarity and taste by increasing dissolved oxygen content and allowing suspended matter to settle.
  - Water then pumped to purification plant and treated to meet government drinking water standards.

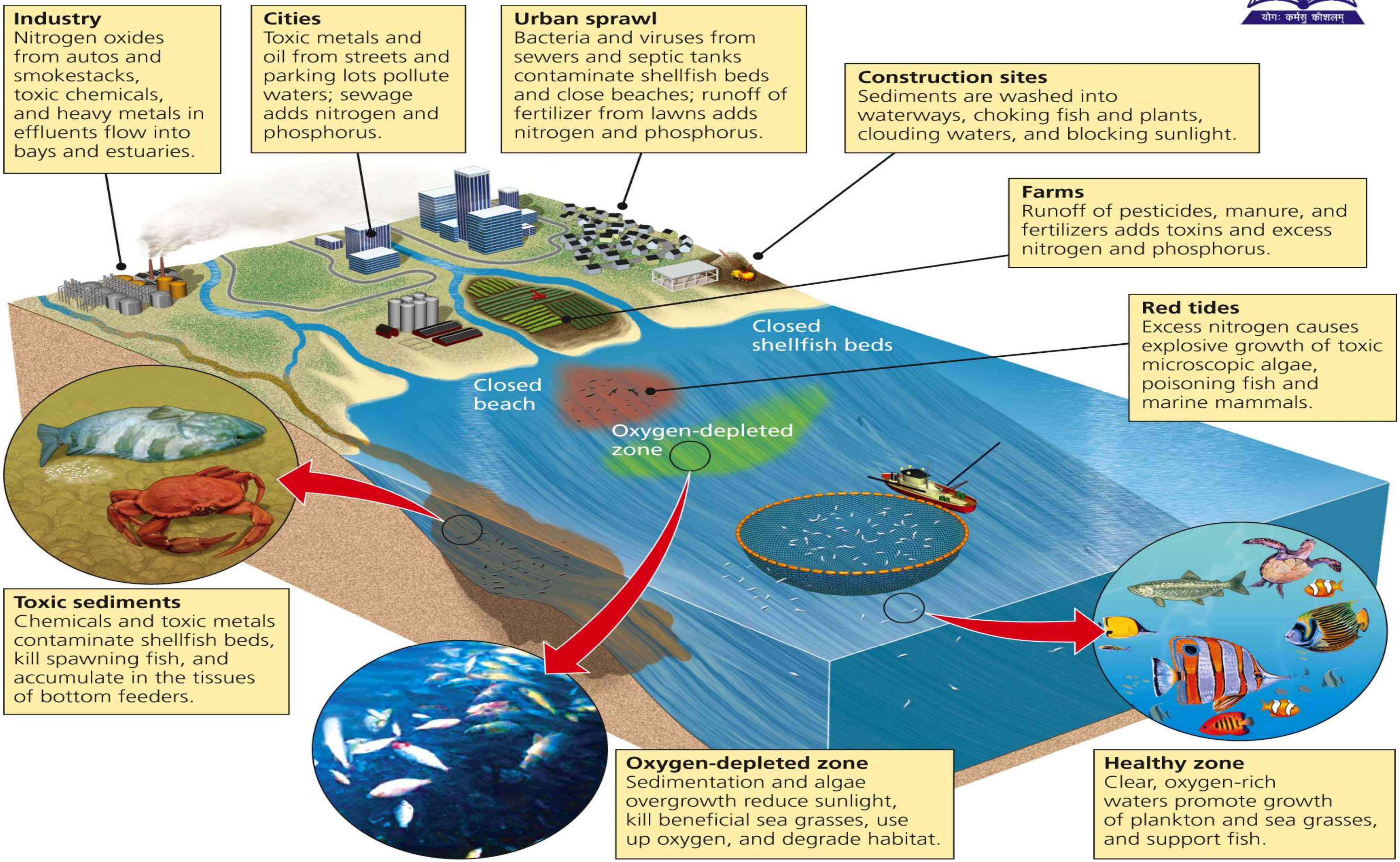
- Developing countries
  - Exposing clear plastic bottle filled with contaminated water to intense sunlight.
  - *LifeStraw* – convert contaminated water into clean, safe drinking water.

- The *LifeStraw*, designed by Torben Vestergaard Frandsen, is a personal water purification device that gives many poor people access to safe drinking water.

Ocean pollution

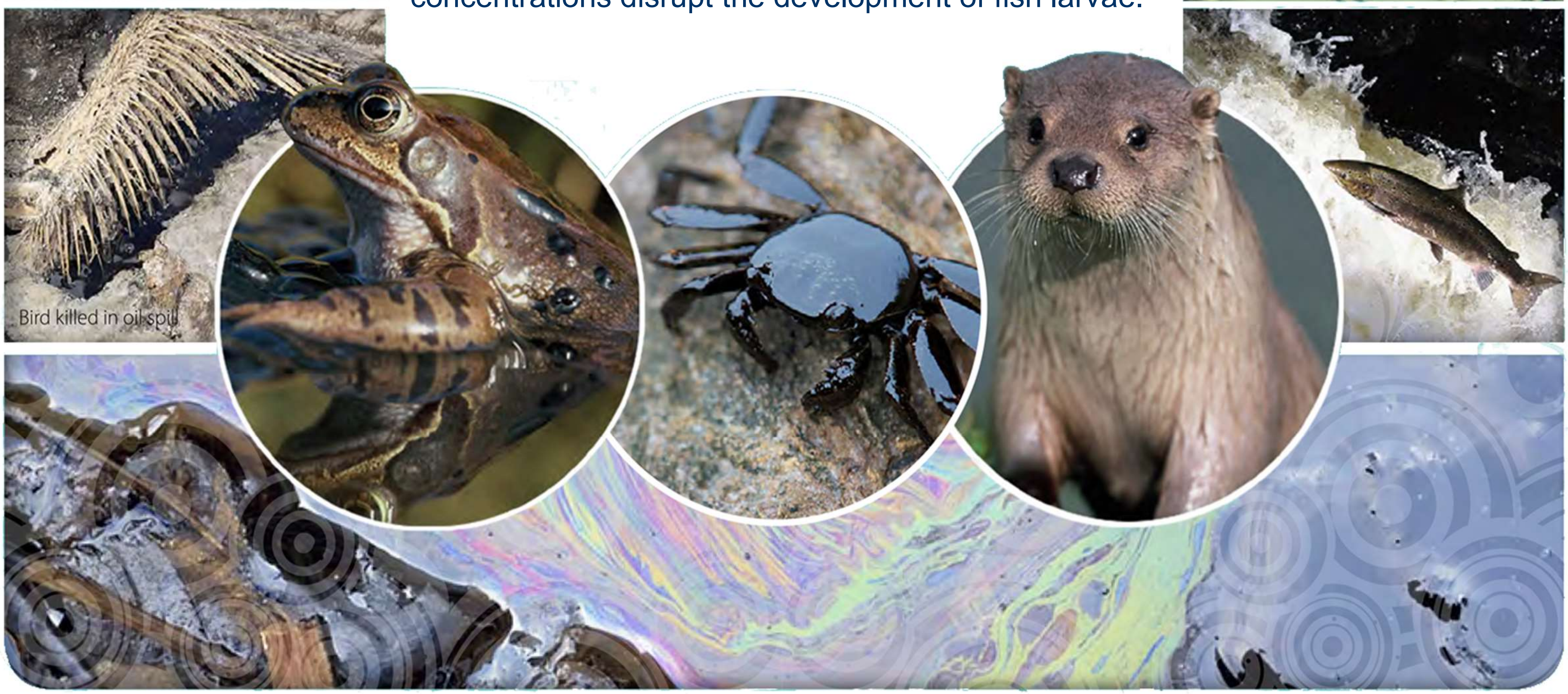
- About 40% of the world's population live on or near a coast and coastal population are projected to double by 2050.
- 80% of marine pollution originates on land and could further rise significantly.
- 80-90% of the municipal sewage from most coastal developing countries and in some coastal developed countries is dumped into oceans without treatment.
- Many cruise ships dump wastes (toxic chemicals, garbage and waste oil) at sea.
- Runoffs of sewage and agricultural wastes into coastal waters can cause explosive growths of harmful algae – algal blooms – creating oxygen depleted zones.
- Key to protecting oceans is to reduce the flow of pollution from land, air, and streams that empty into these waters.

- Residential areas, factories, and farms all contribute to the pollution of coastal waters and bays.



Oil spills

When an oil spill occurs it can cause a lot of harm to all life in the area. It destroys the insulating ability of fur in mammals such as sea otters and the water repelling properties of birds' feathers. This means they are more exposed to the elements which can lead to hypothermia and death. Recently, it has also been shown that polycyclic aromatic hydrocarbons in oil can cause fish to have heart attacks and in lower concentrations disrupt the development of fish larvae.

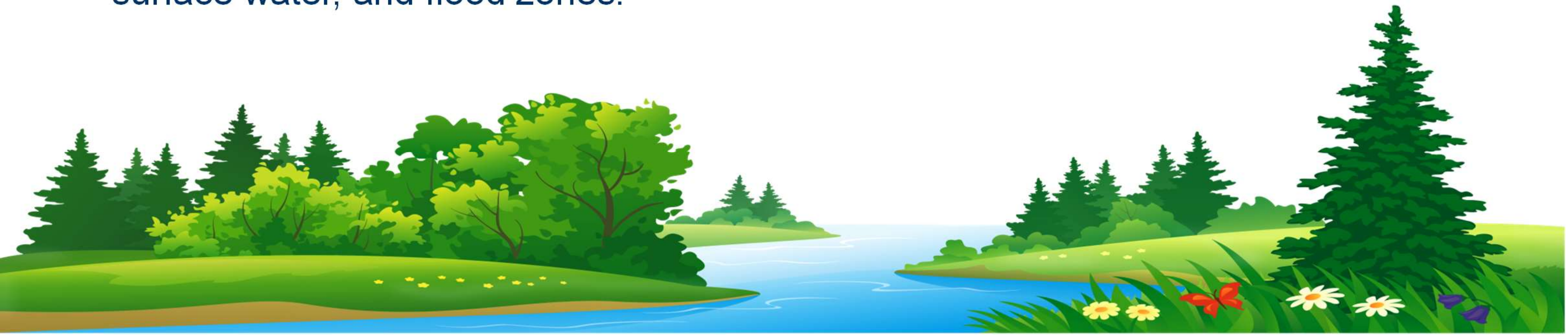


Reducing water pollution from point sources

- Clean Water Act (CWA) & Water Quality Act (WQT)
  - Sets standards for allowed levels of key water pollutants
  - Requires polluters to get permits limiting how much of various pollutants they can discharge into aquatic systems
- Discharge trading policy
  - Uses market forces to reduce water pollution
  - A permit holder can pollute at higher levels than allowed by its permit if it buys credits from permit holders who are polluting below their allowed levels
  - Depends on how low the cap on total pollution levels is set in any given area and how regularly the cap is lowered
  - Could allow pollutants to build up to dangerous levels in areas where credits are bought

Reducing water pollution from nonpoint sources

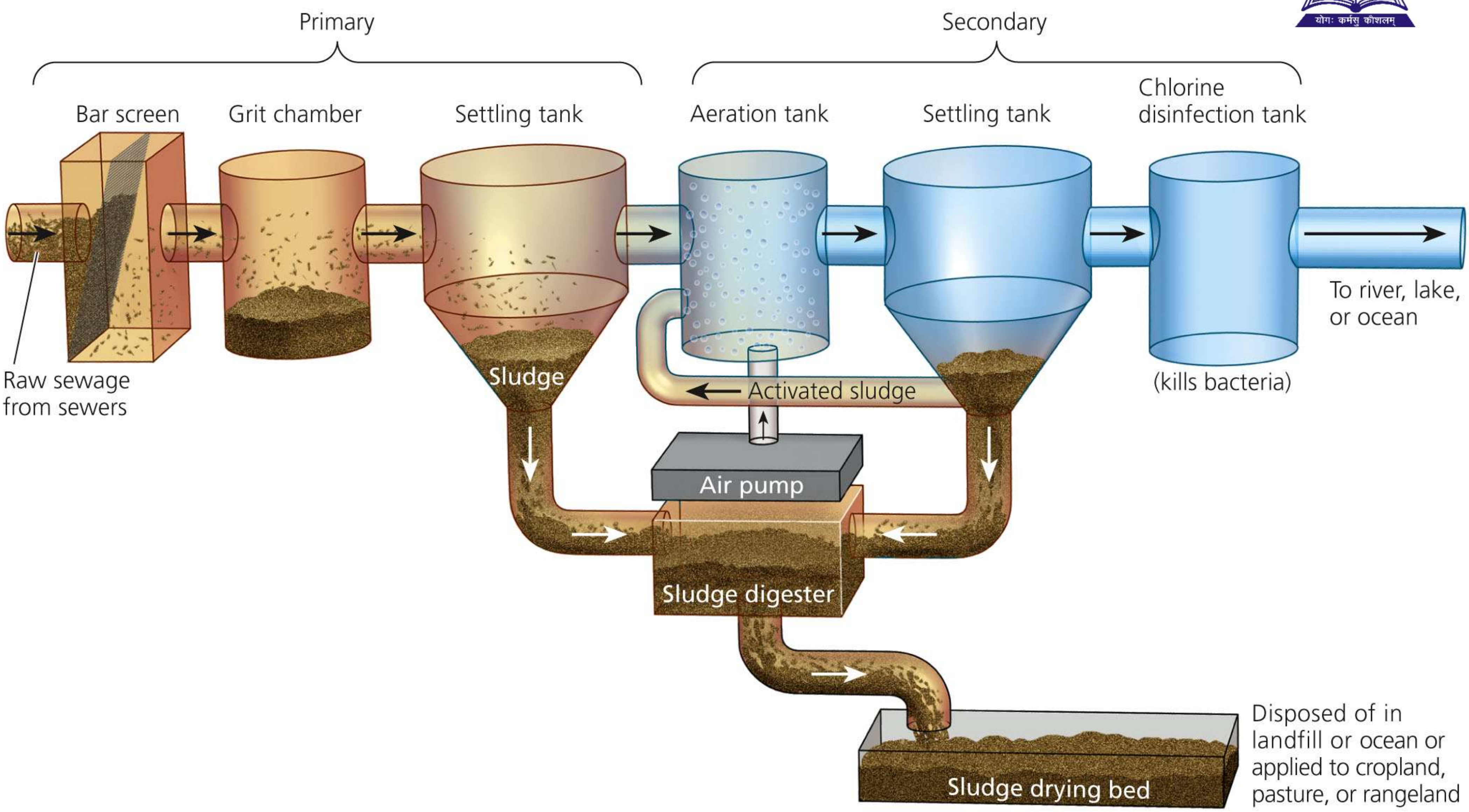
- Reduce soil erosion by keeping cropland covered with vegetation.
- Reduce the amount of fertilizer that runs off into surface waters and leaches into aquifers by using slow-release fertilizer, using no fertilizer on steeply sloped land, and planting buffer zones of vegetation between cultivated fields and nearby surface waters.
- Practice organic farming – does not use commercial inorganic fertilizers.
- Apply pesticides only when needed.
- Rely more on Integrated Pest Management.
- Locate animal feedlots and animal waste sites away from steeply sloped land, surface water, and flood zones.



Sewage treatment systems

- **Rural and suburban areas**
  - Sewage discharged into a septic tank.
  - Grease and oil rise to the top and solids fall to the bottom and are decomposed by bacteria.
- **Urban areas**
  - Wastewater or sewage treatment plants
  - Raw sewage undergoes one or two levels of treatment.
  - Primary treatment: Remove large floating objects and allow suspended solids to settle out.
  - Secondary treatment: Aerobic bacteria remove almost 90% of dissolved and biodegradable, oxygen-demanding, organic wastes.

- Most municipal wastewater treatment facilities use primary and secondary levels of treatment.



Sustainable ways to reduce water pollution

Solutions

Water Pollution

- Prevent groundwater contamination
- Reduce nonpoint runoff
- Reuse treated wastewater for irrigation
- Find substitutes for toxic pollutants
- Work with nature to treat sewage
- Practice the three R's of resource use (reduce, reuse, recycle)
- Reduce air pollution
- Reduce poverty
- Slow population growth

Individual choices make a difference

What Can You Do?

Reducing Water Pollution

- Fertilize garden and yard plants with manure or compost instead of commercial inorganic fertilizer
- Minimize your use of pesticides, especially near bodies of water
- Prevent yard wastes from entering storm drains
- Do not use water fresheners in toilets
- Do not flush unwanted medicines down the toilet
- Do not pour pesticides, paints, solvents, oil, antifreeze, or other products containing harmful chemicals down the drain or onto the ground