Utilization of Coastal Sediment Microbial Fuel Cells for Climate Change Adaptation

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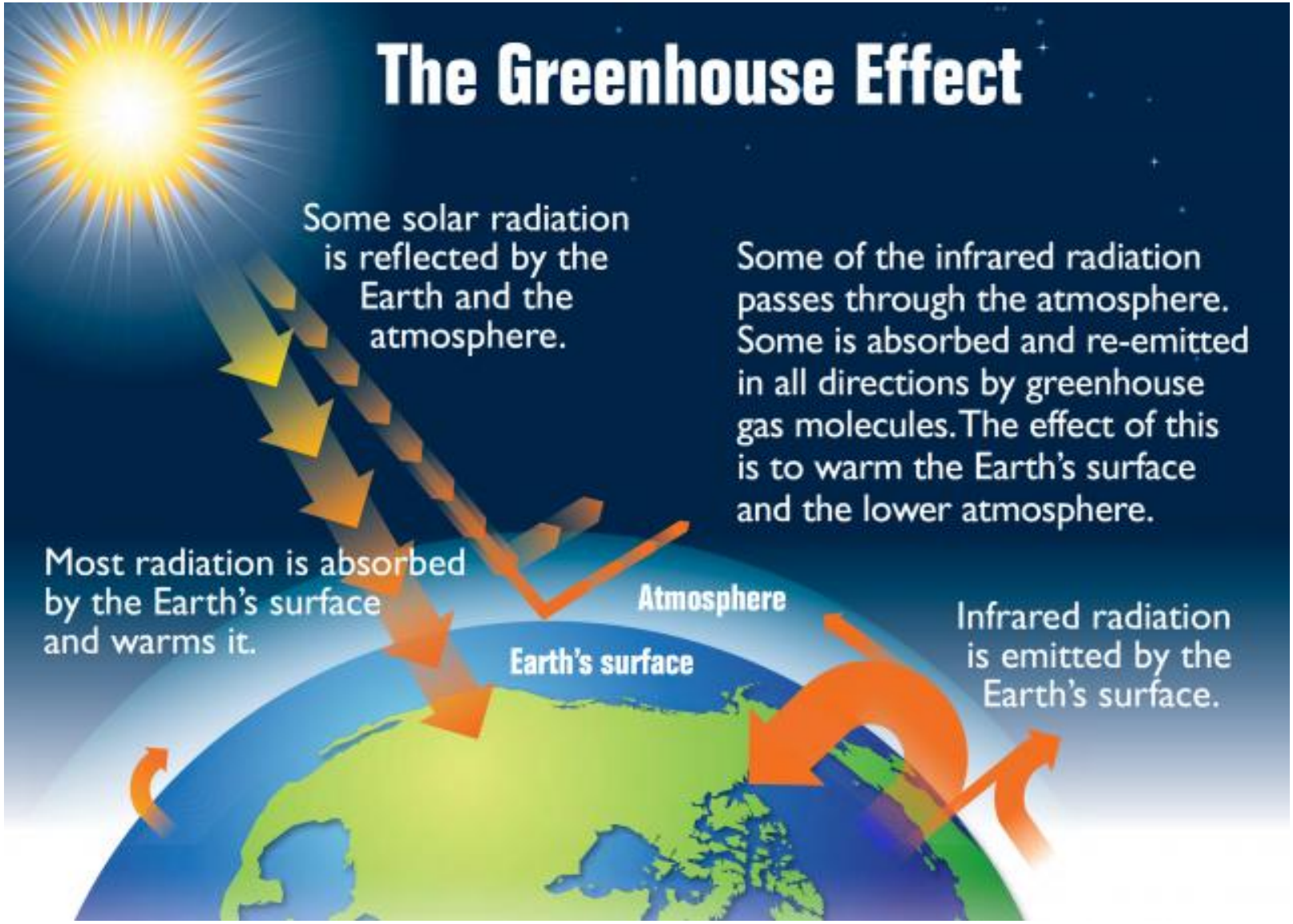
Chap. 3 Sediment Microbial Fuel Cells

Why should we develop renewable energy?

Climate Change

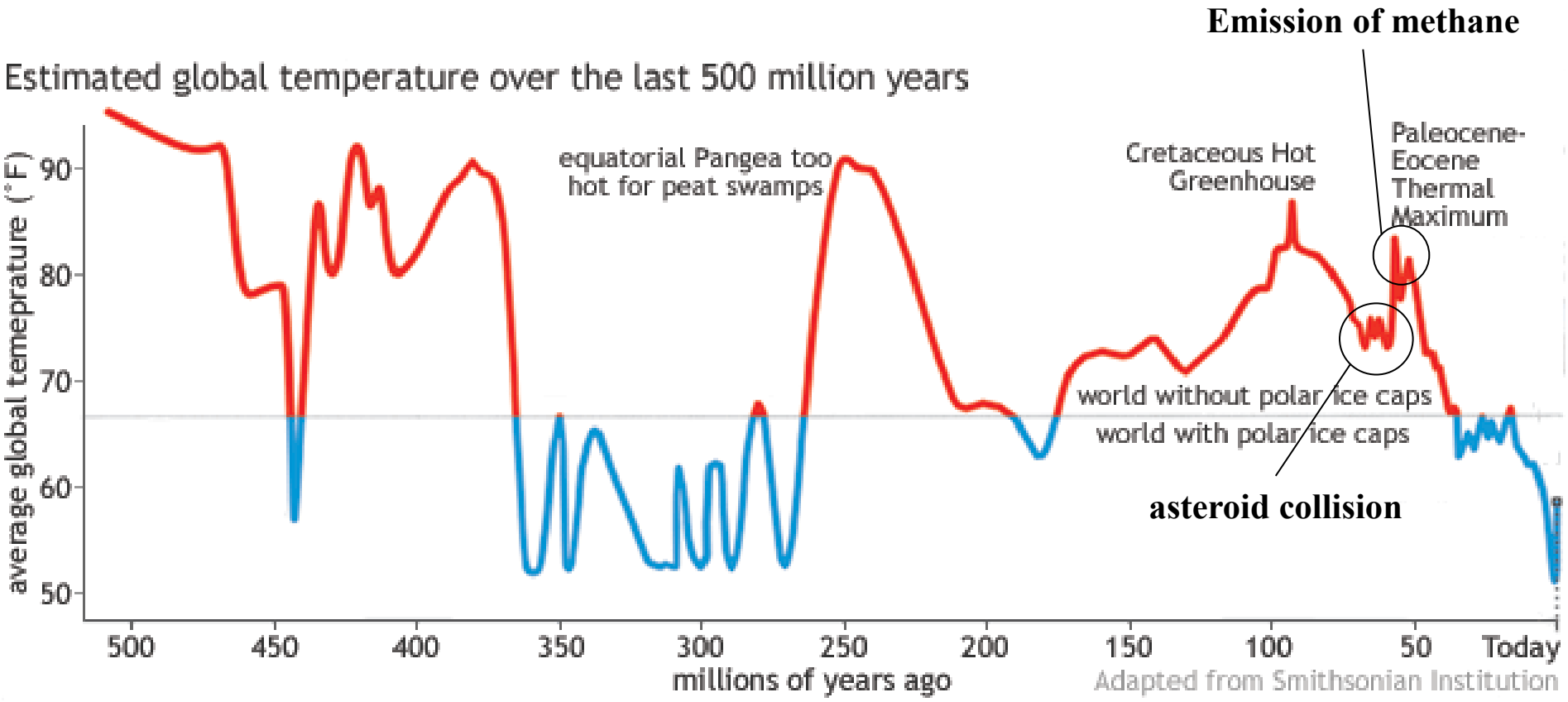
- Progressive increase of the Earth's average temperature due to the accumulation of greenhouse gases.
- Greenhouse gases (GHG) (carbon dioxide, methane, etc.) can trap the heat from the sun, preventing its escape into space.
- Driven by human activity, the warming leads to glacier melting, sea level rise, and extreme weather phenomena.

The greenhouse effect

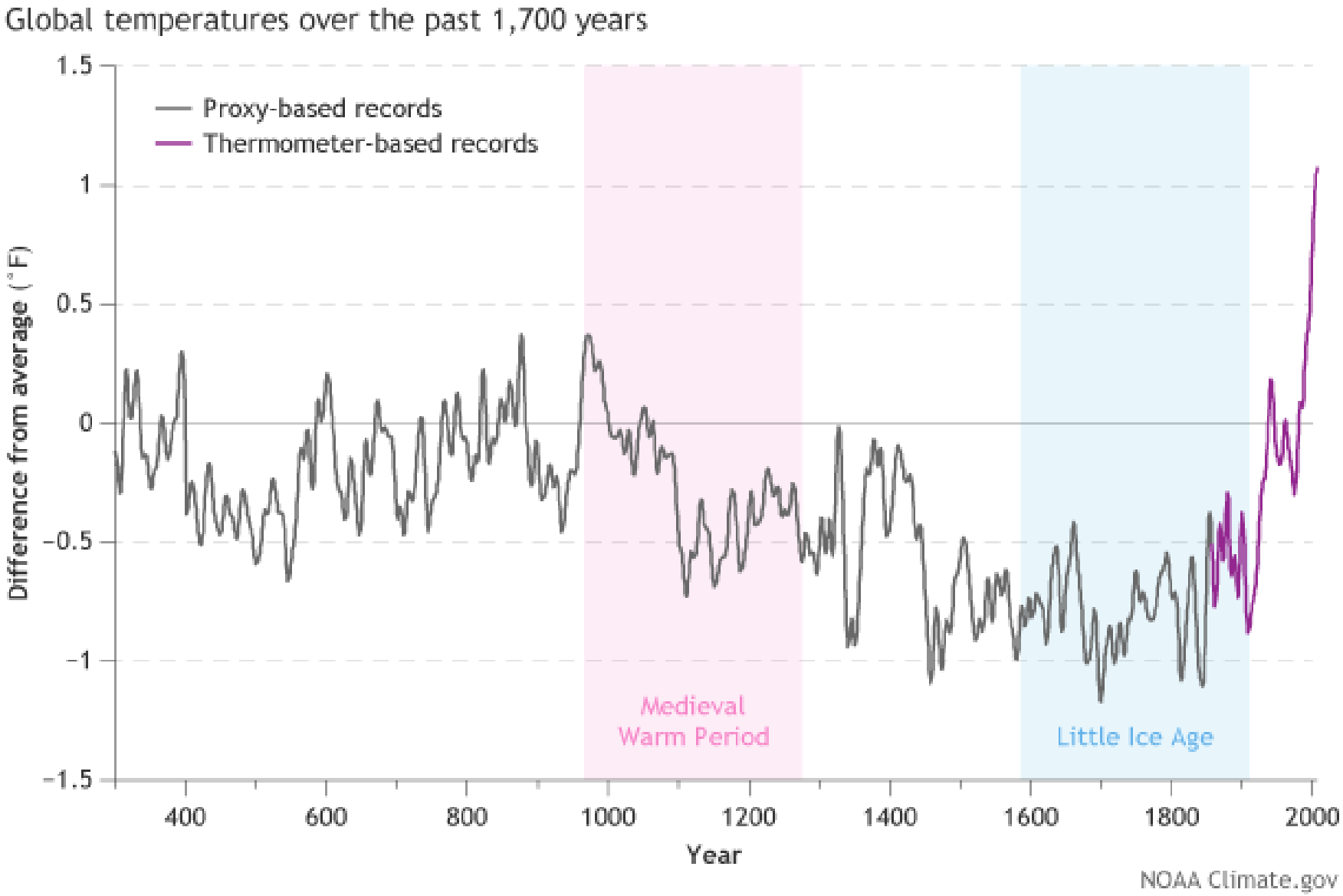


Source: U.S. EPA (Environmental Protection Agency)

Climate Change



Climate Change



Climate Change



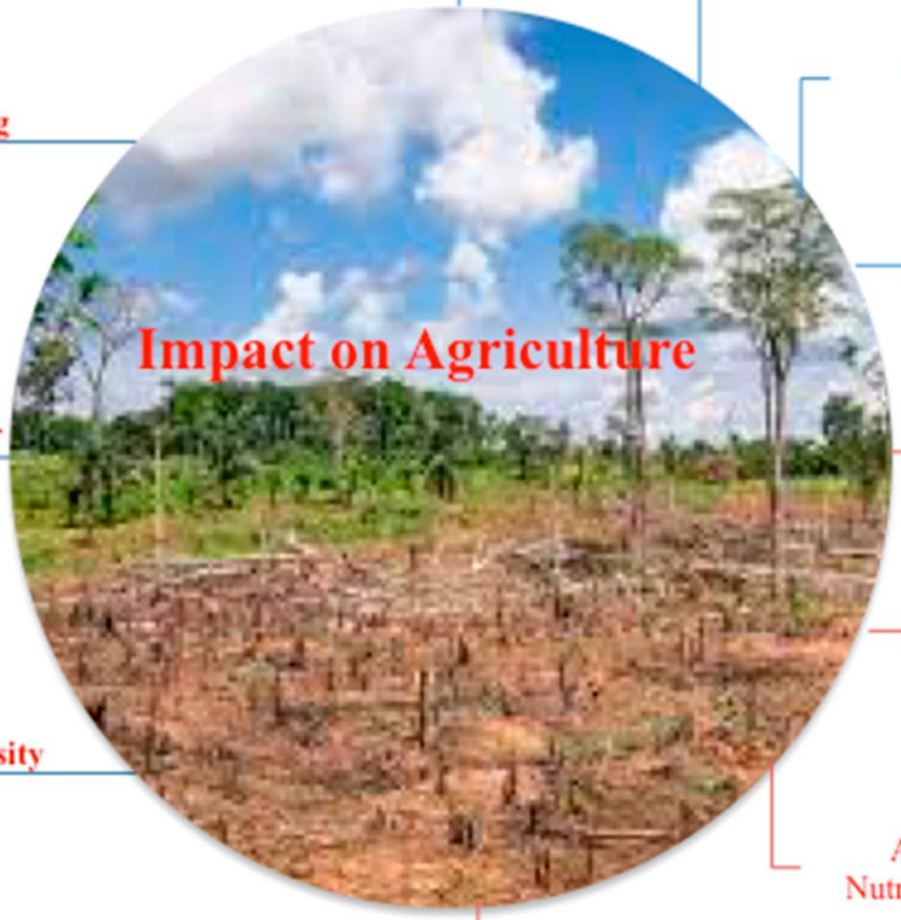
Global Warming



Extreme Weather



Rainfall Intensity



Loss of soil organic Carbon

Soil Erosion

Increase in soil wetness

Loss of soil Nutrients

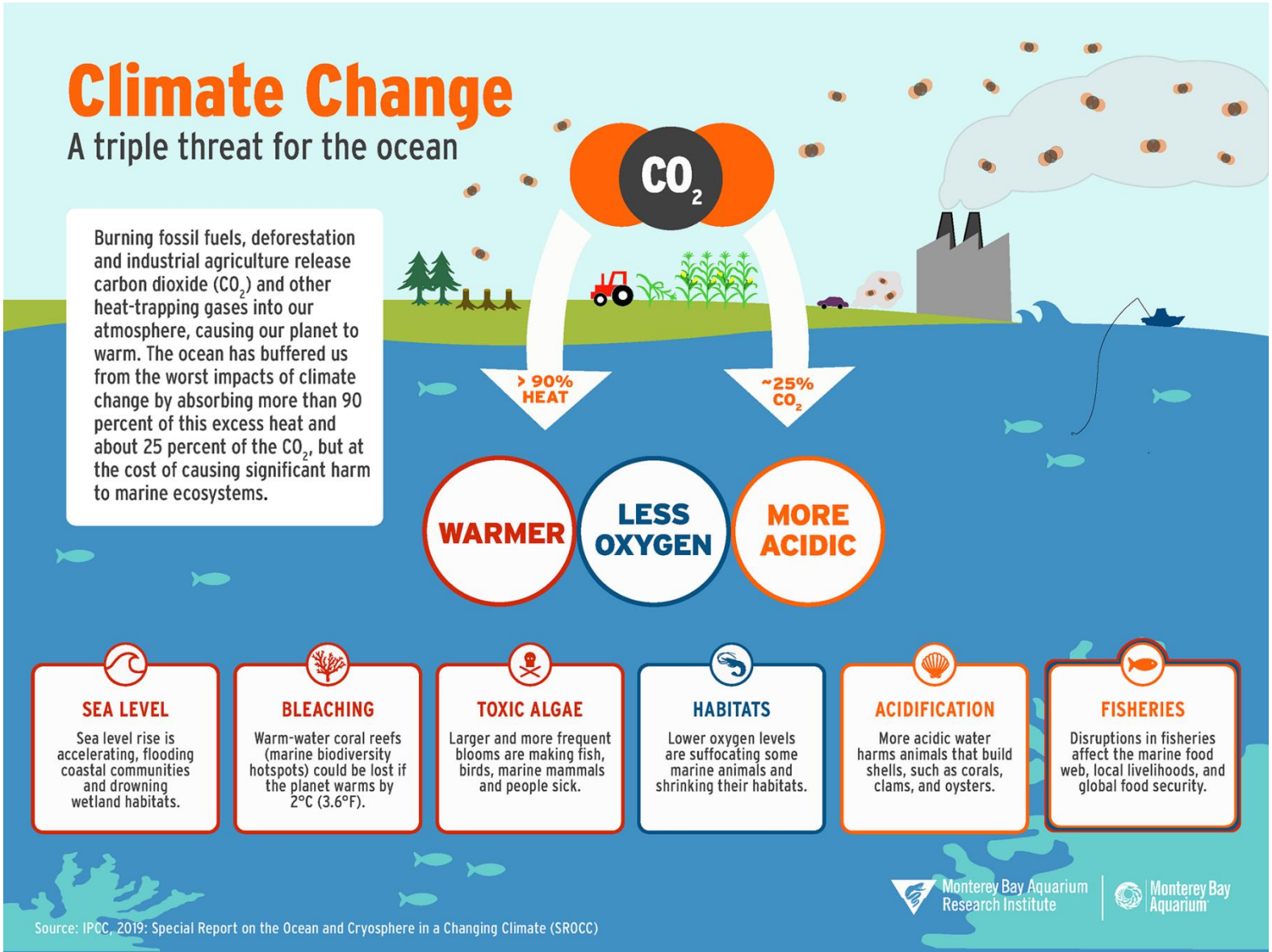
Halts seedling growth & development

Decrease in Photosynthesis

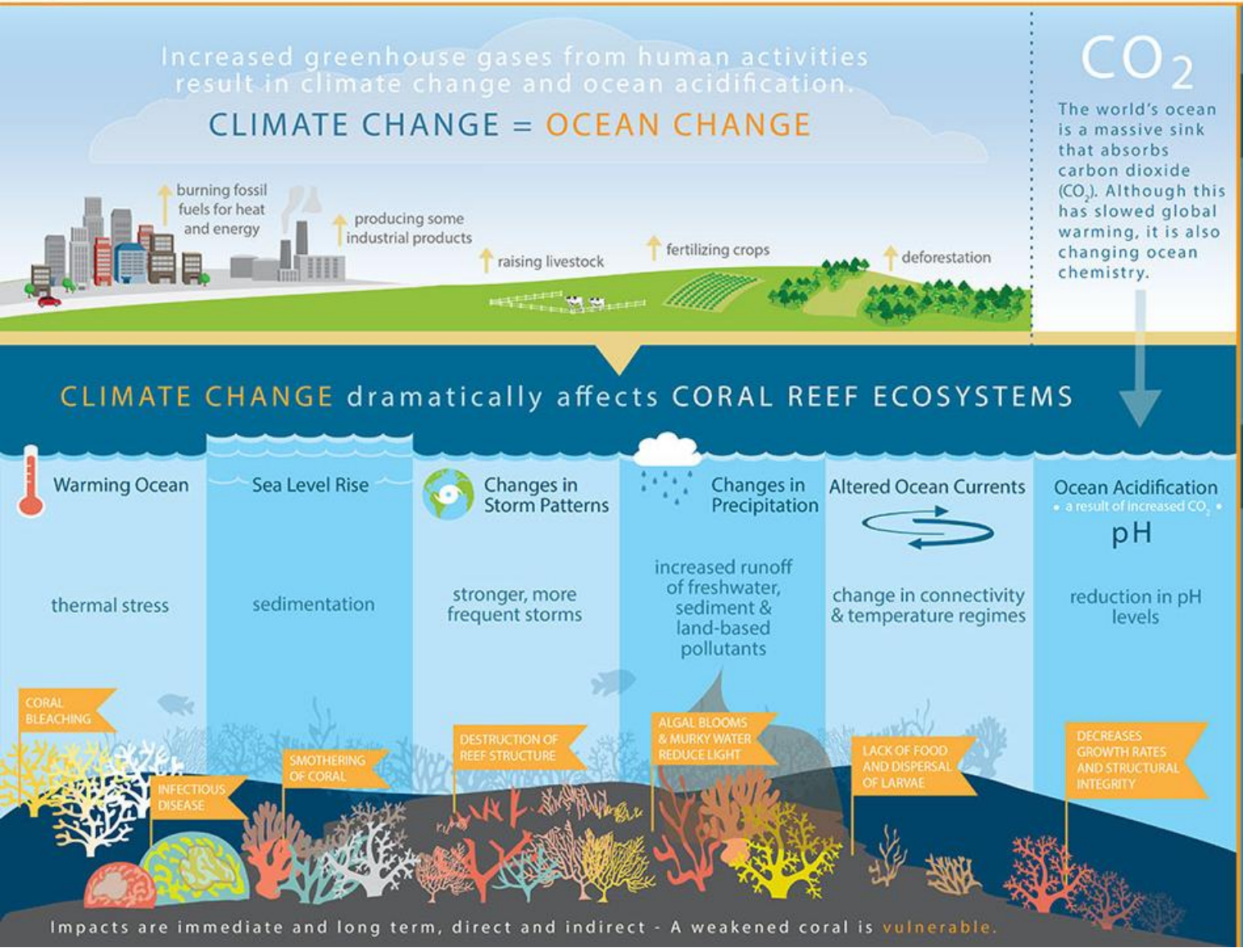
Alteration in Nutrients dynamics

Loss of overall crop yield

Climate Change



Climate Change



HOW YOU CAN HELP

Shrink your carbon footprint to reduce greenhouse gases.

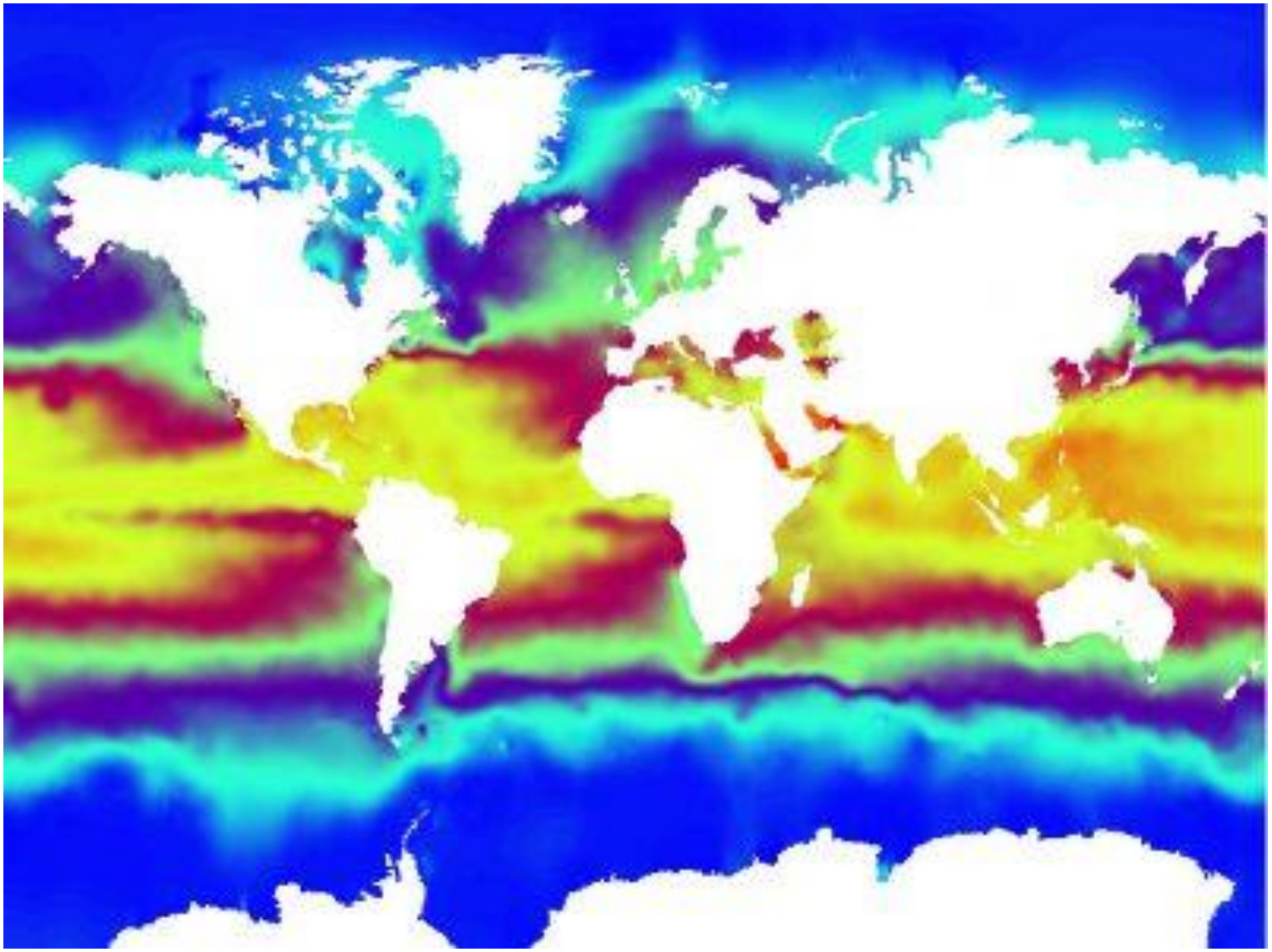
- Drive less.
- Reduce, reuse or recycle.
- Purchase energy-efficient appliances and lightbulbs.
- Print less. Download more. Use less water.

Do your part to help improve overall coral reef condition.

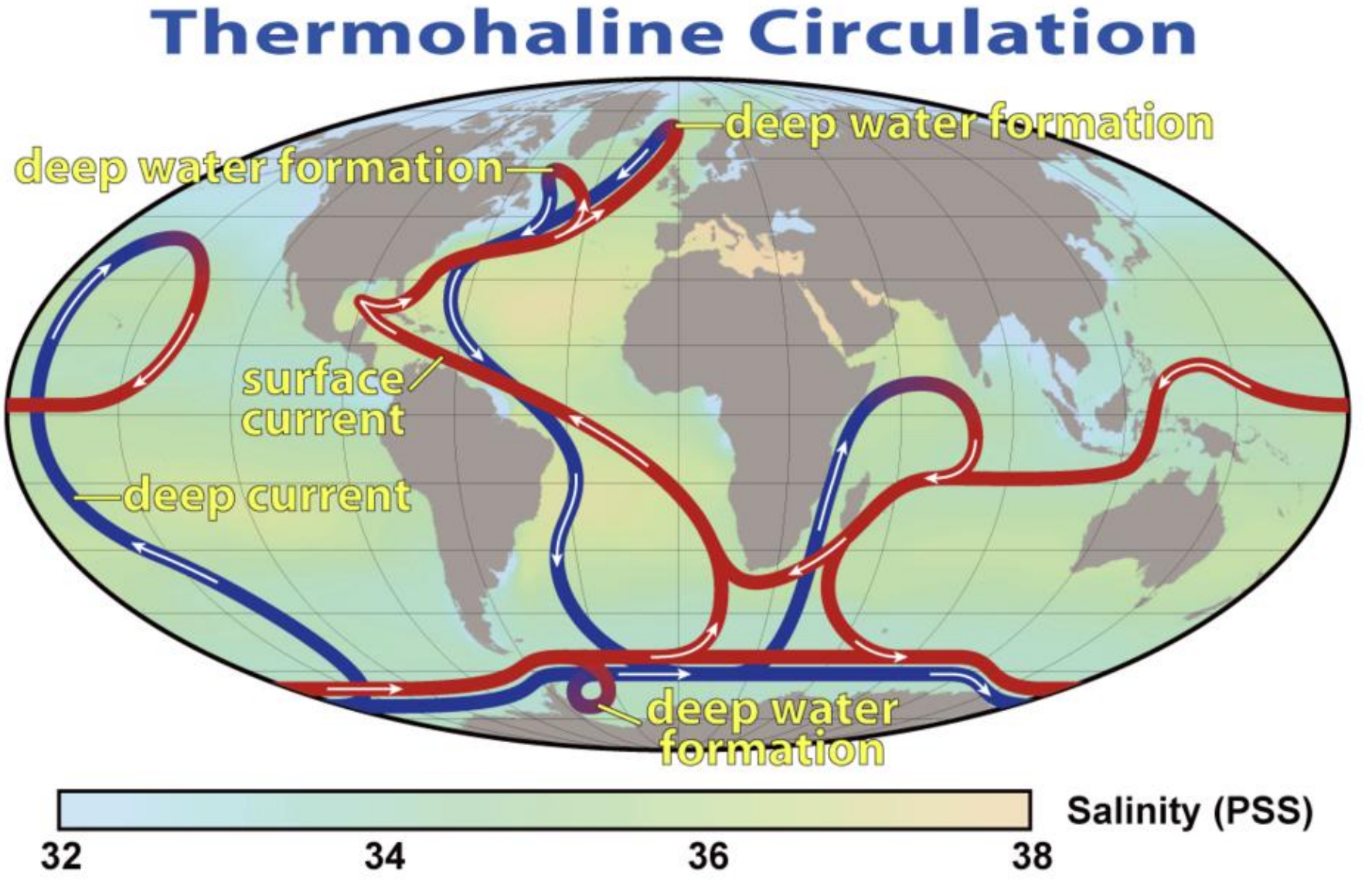
- Reduce the use of lawn and garden chemicals.
- DO NOT dump household chemicals in storm drains.
- Choose sustainable seafood. www.FishWatch.gov
- Learn about good reef etiquette and practice it when in the water.
- Volunteer for beach and waterway clean ups.

Climate Change

equator



Climate Change



Climate Change



Problems caused by black carbon

1.Climate Change: emission of carbon dioxide.

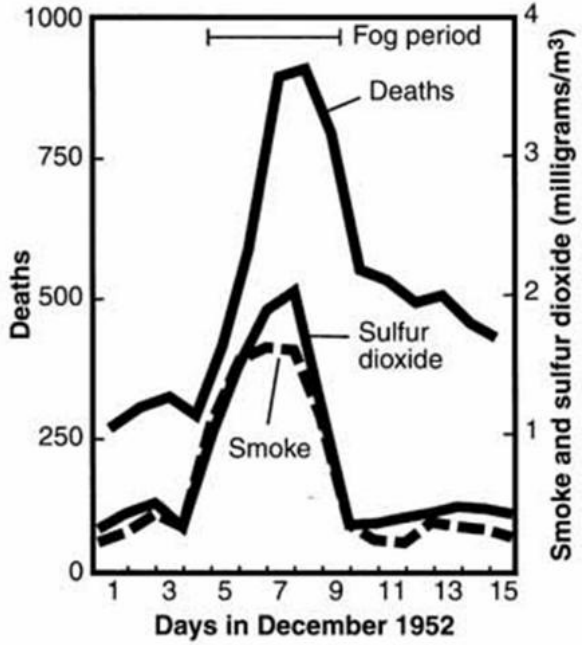
2. Air Pollution and Health Risks: particles are very small.

3. Environmental Damage: poor air quality, smog, and reduced visibility.

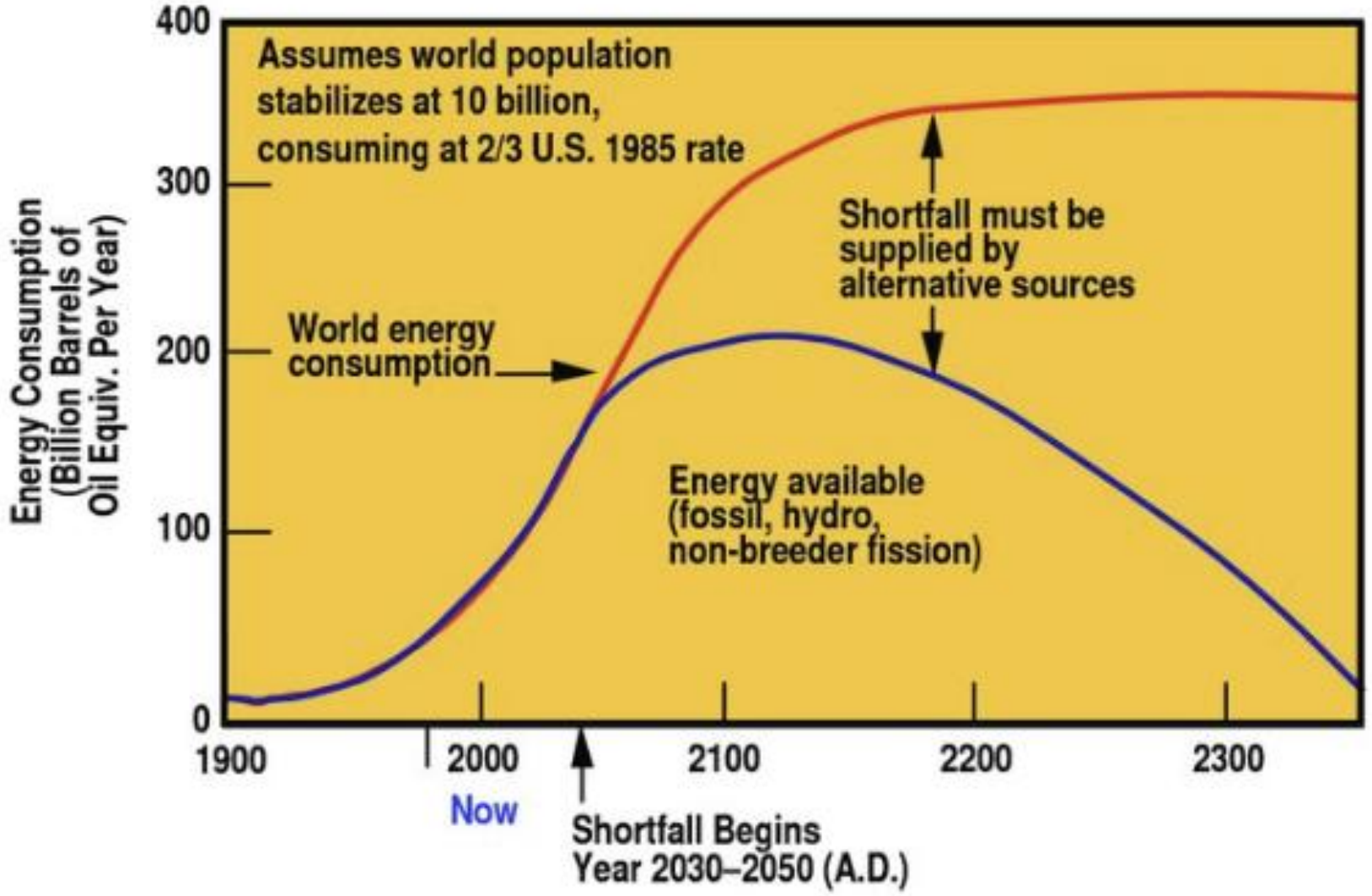


London smog

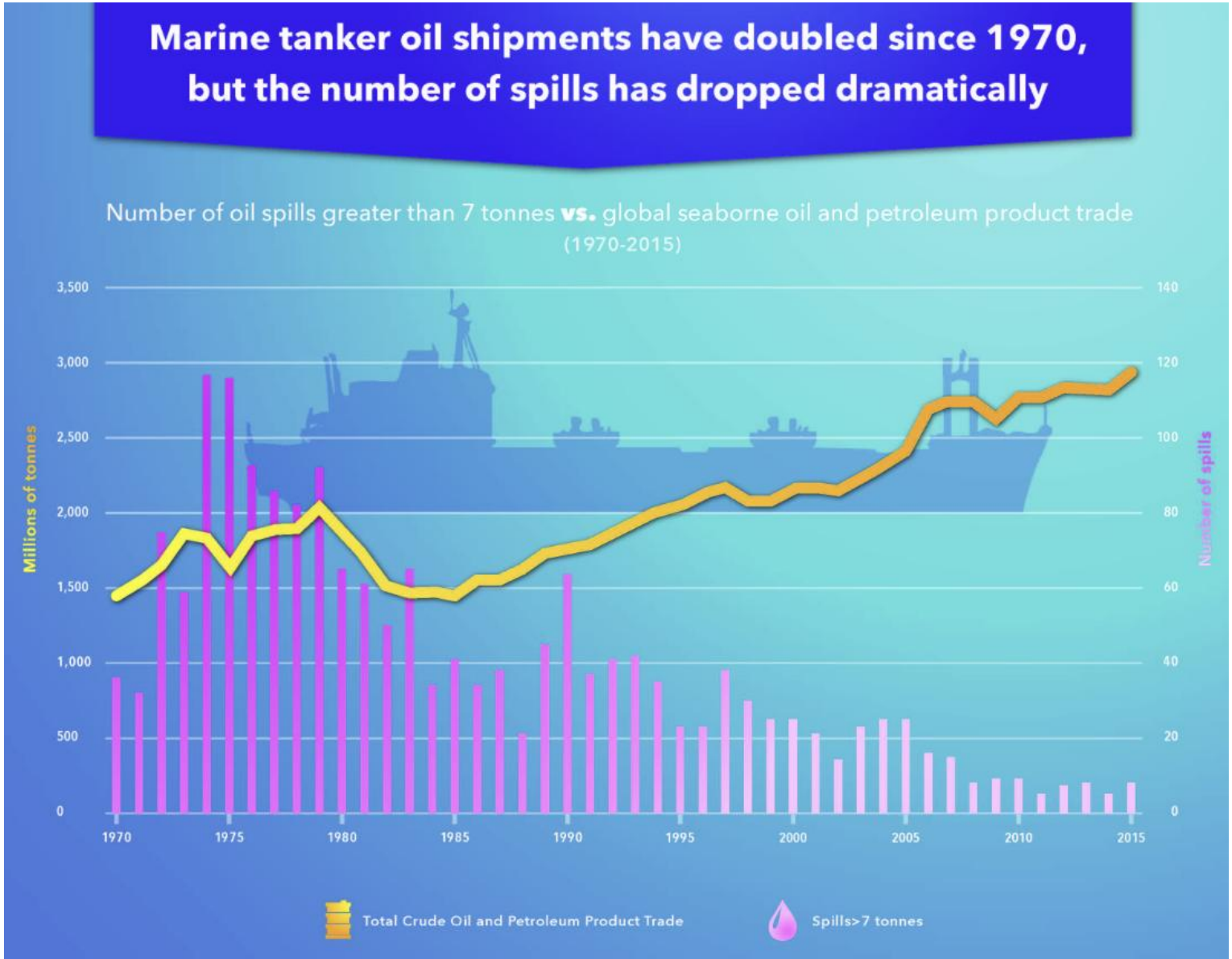




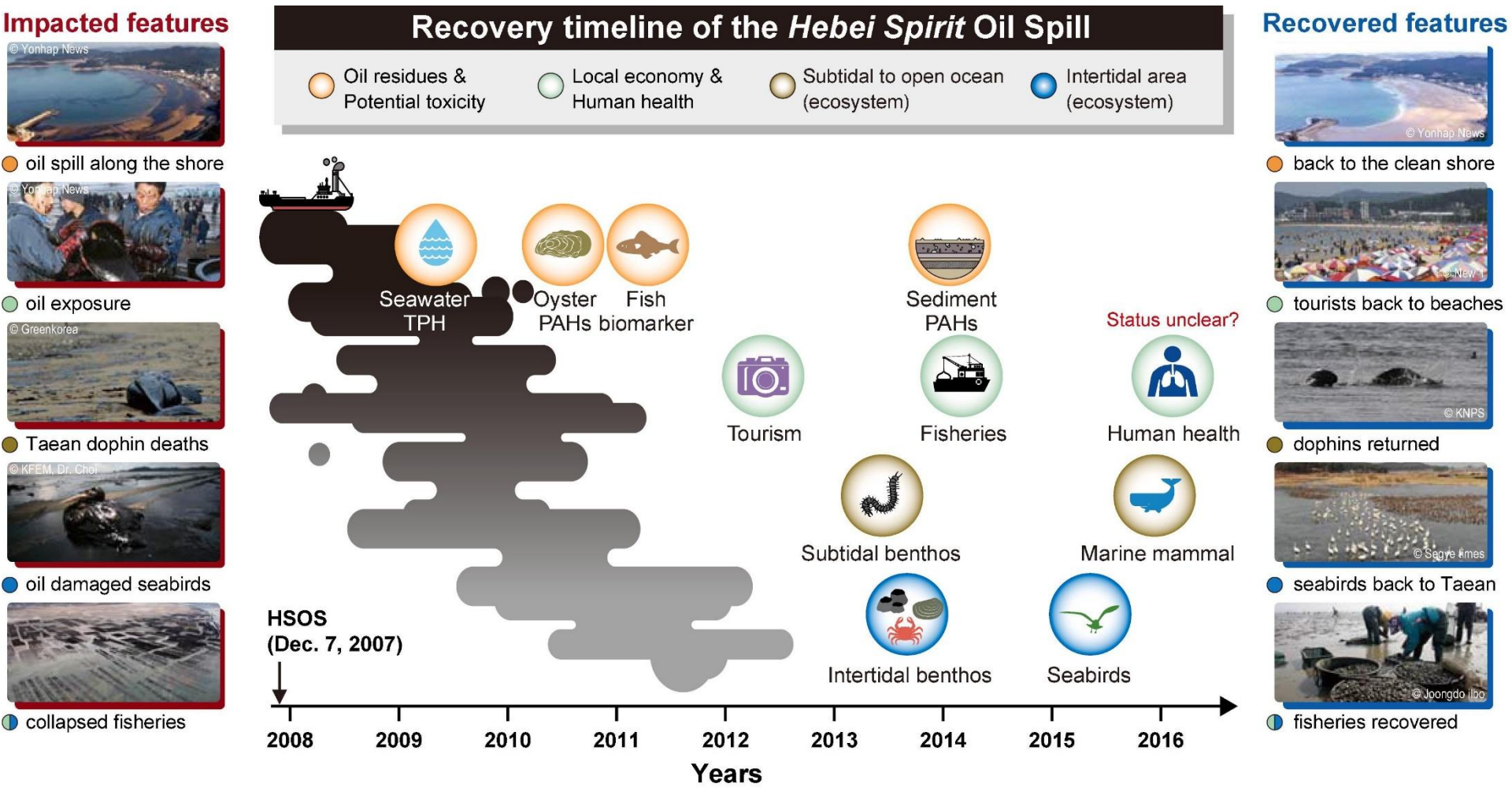
Depletion of fossil fuels



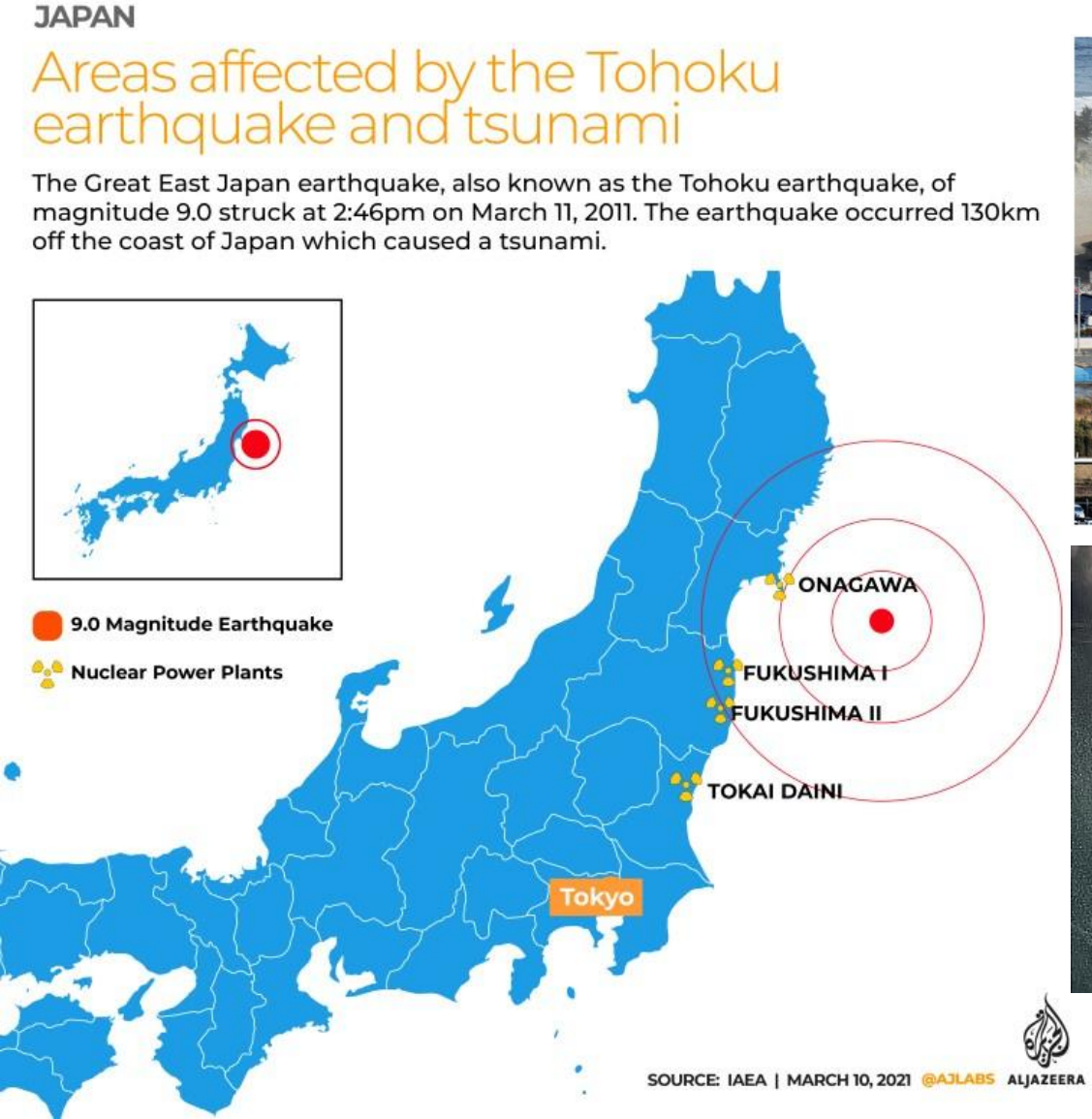
Fuel transport accident



Fuel transport accident



Fukushima accident





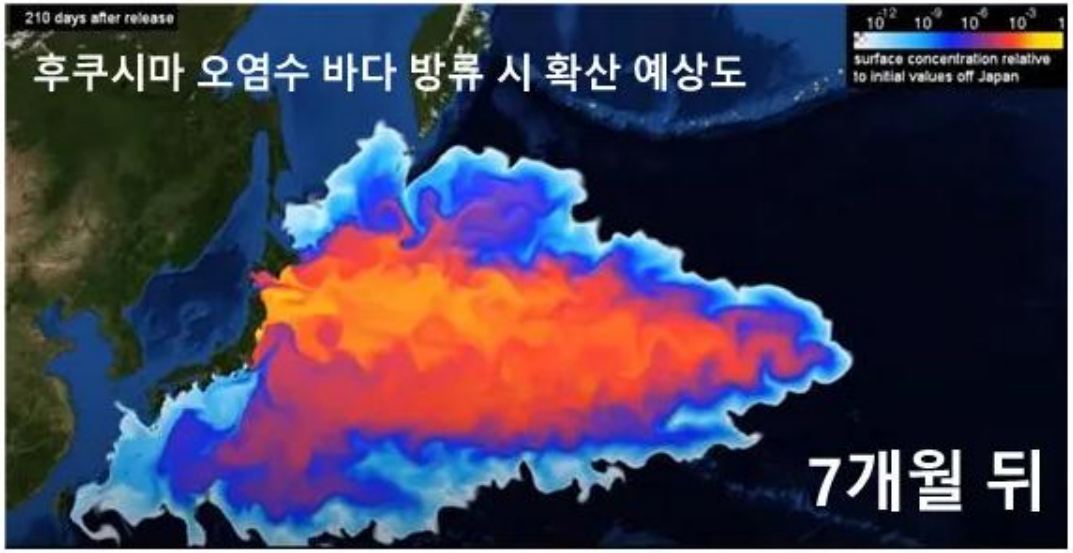


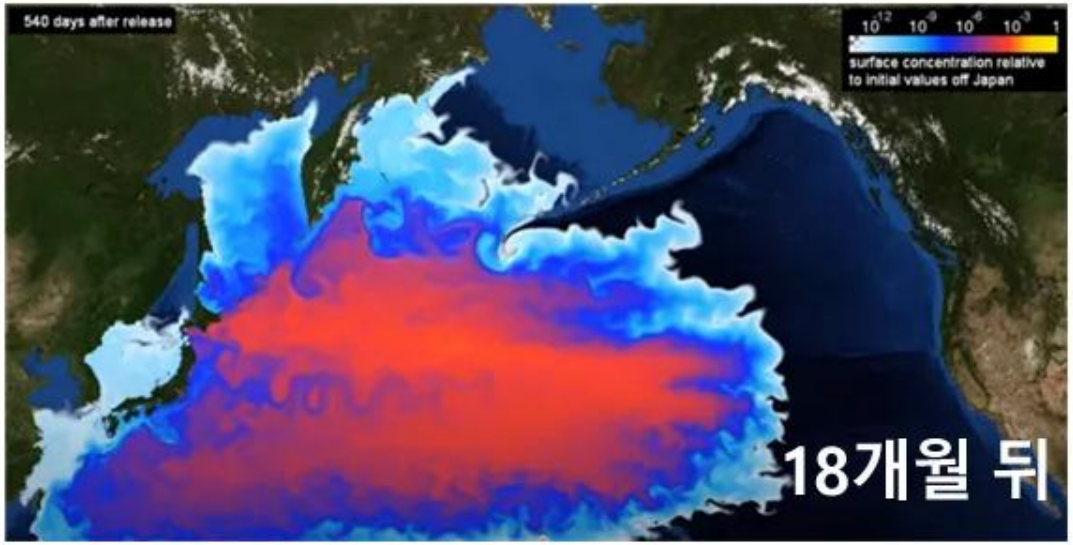
Fukushima accident



Source: @60MinutesAU

Fukushima accident





자료 출처 : 독일 헬름홀츠 해양연구소

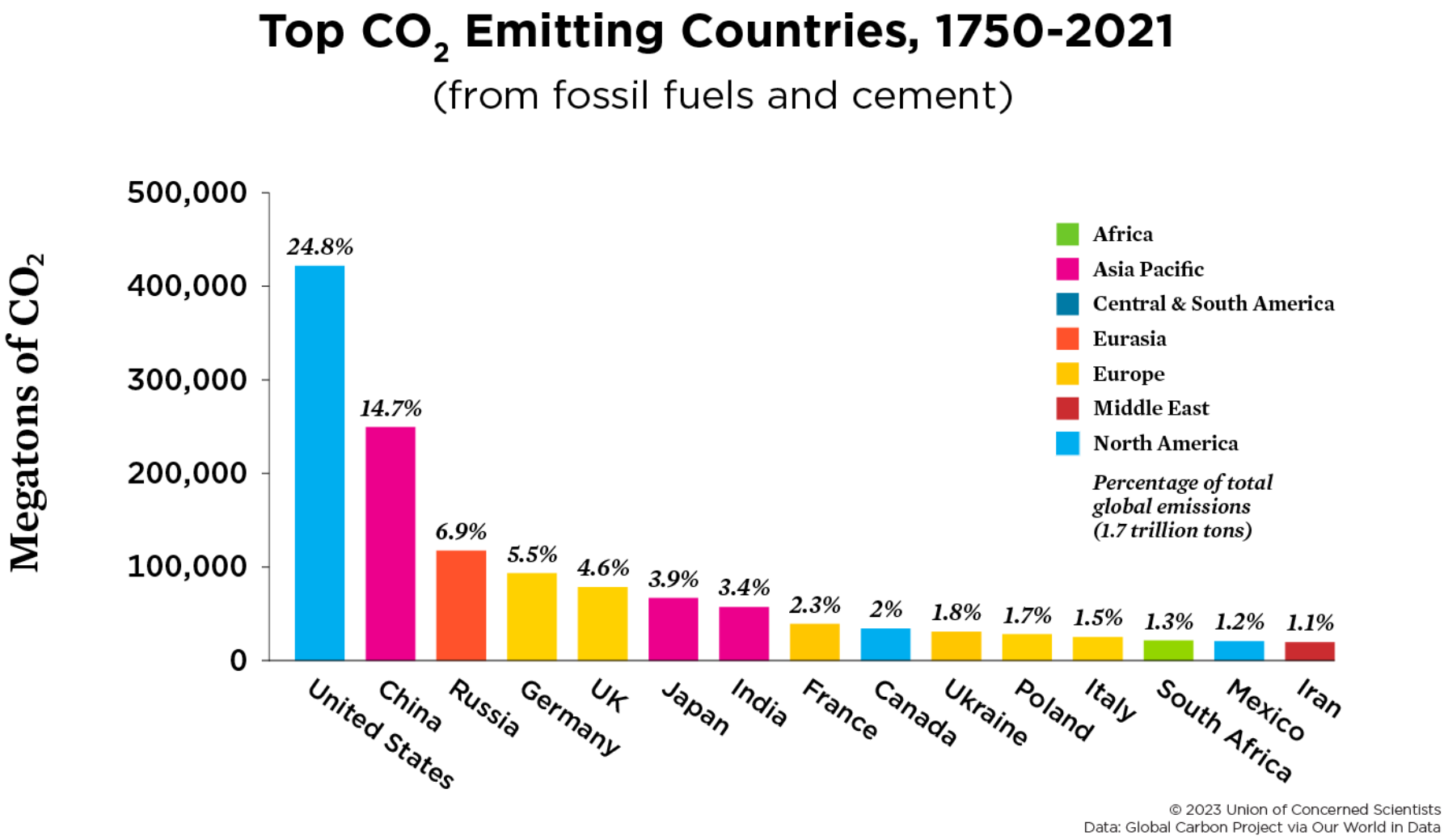
Weaponization of fossil fuels







Countermeasures for global warming

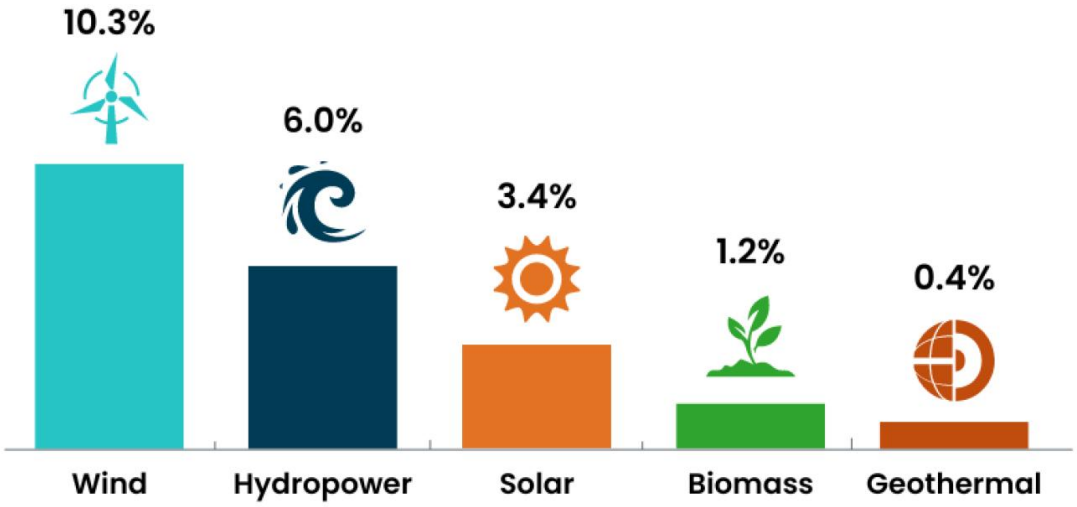


Countermeasures for global warming

1. Energy Transition

•**Expand renewable energy**: Use clean energy such as solar, wind, and hydropower to reduce dependence on coal, oil, and gas.

•**Improve energy efficiency**: Save energy through LED lighting, efficient appliances, and the spread of electric vehicles.

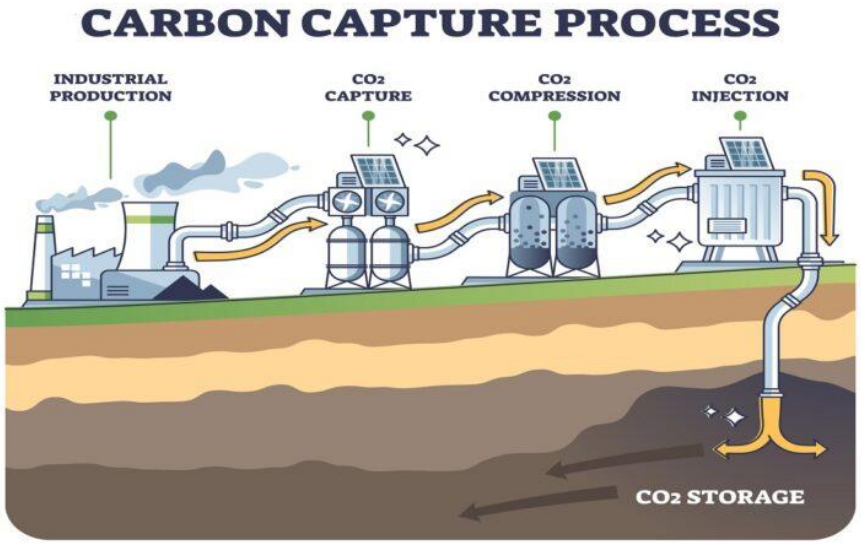


Countermeasures for global warming

2. Changes in Transportation and Industry

•**Eco-friendly transportation**: Use public transport, bicycles, and electric vehicles to reduce carbon emissions.

•**Industrial innovation**: Apply carbon capture and storage (CCS) and eco-friendly manufacturing processes to minimize emissions.

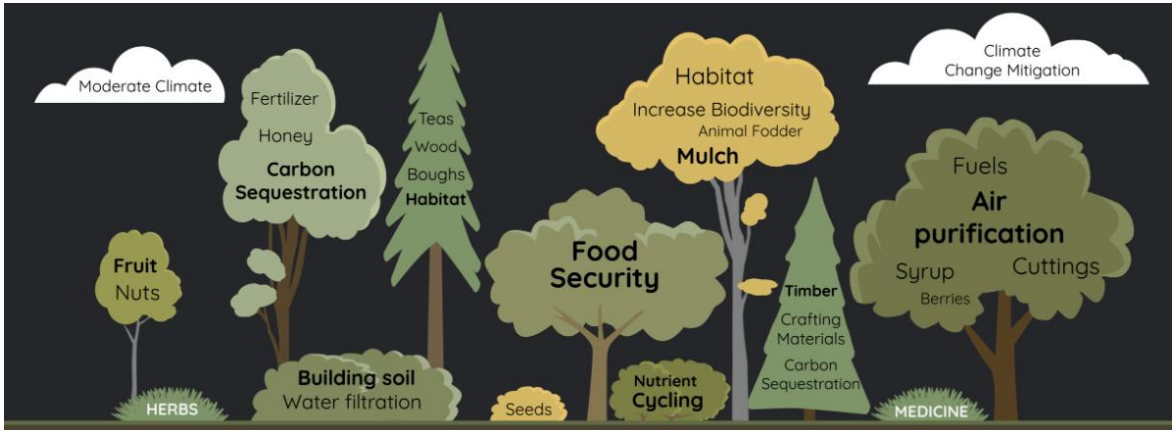


Countermeasures for global warming

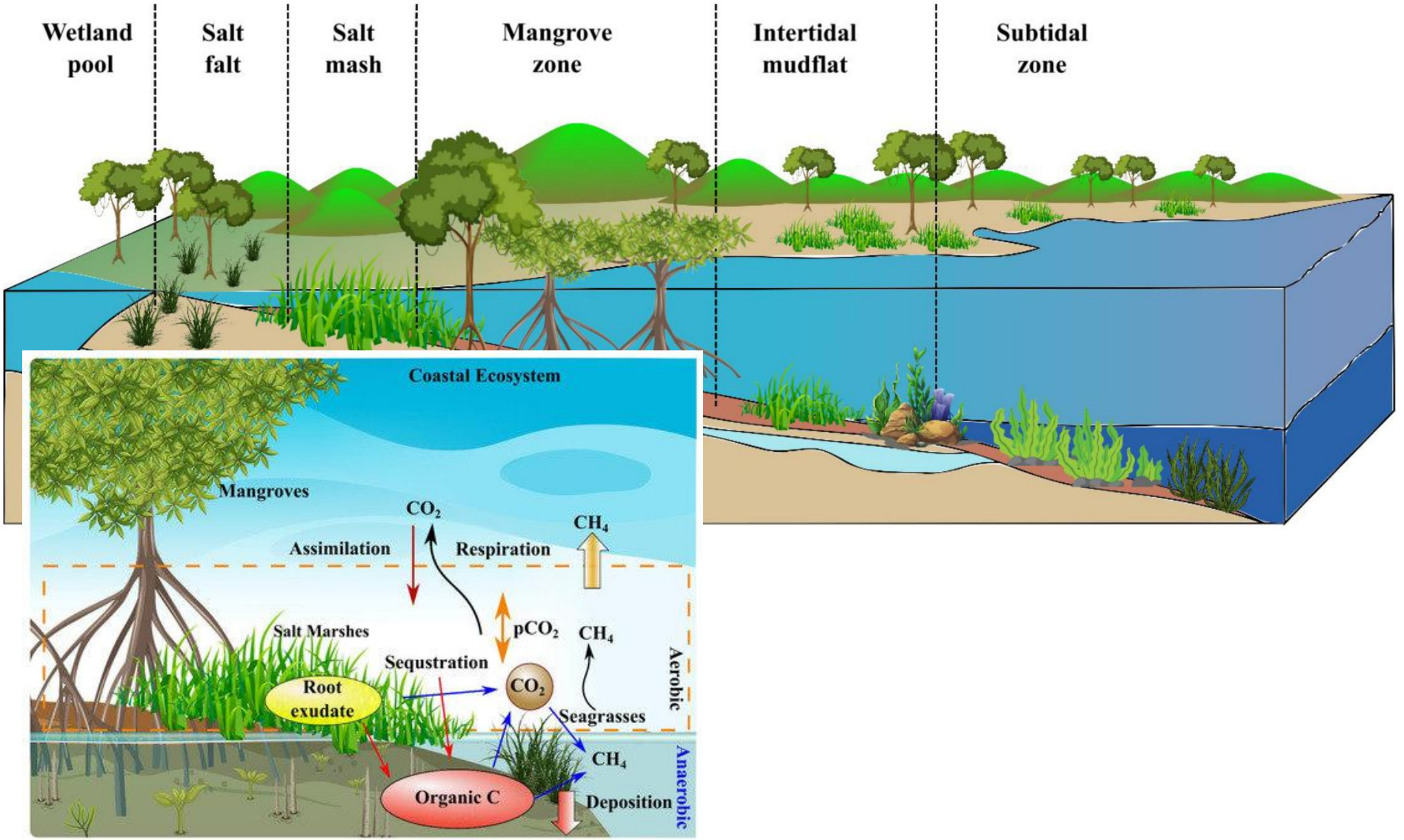
3. Living in Harmony with Nature

•**Forest preservation and tree planting**: Trees absorb carbon dioxide and play a big role in mitigating global warming.

•**Protect ecosystems**: Conserve oceans, wetlands, and grasslands to maintain natural carbon absorption capacity.



Countermeasures for global warming



Countermeasures for global warming

4. Policies and International Cooperation

•**Carbon tax and emissions trading systems**: Put a cost on carbon emissions to encourage companies to adopt eco-friendly practices.

•**Global agreements**: Cooperate internationally through agreements like the Paris Agreement to set targets and reduce greenhouse gases together.

Countermeasures for global warming

Kyoto Protocol & Paris Agreement

Kyoto Protocol	Paris Agreement
Was created in 1997 and ratified in 2005. Had two periods from 1997-2020.	Signed in November of 2016. New commitments are due every 5 years
Legally binding agreement to decrease GHG	Not legally binding commitment to reduce emissions, increase accountability
Original commitment to decrease overall emissions by 5% from 1990 levels	Overall goal to limit global temperatures to 1.5 degrees celcius above pre-industrial levels
Only required developed nations to reduce emissions	Asked all nations to reduce emissions
Targets are set but no determined time frame	New set of targets declared after 5 years (these are now due in

Marine Renewable Energies

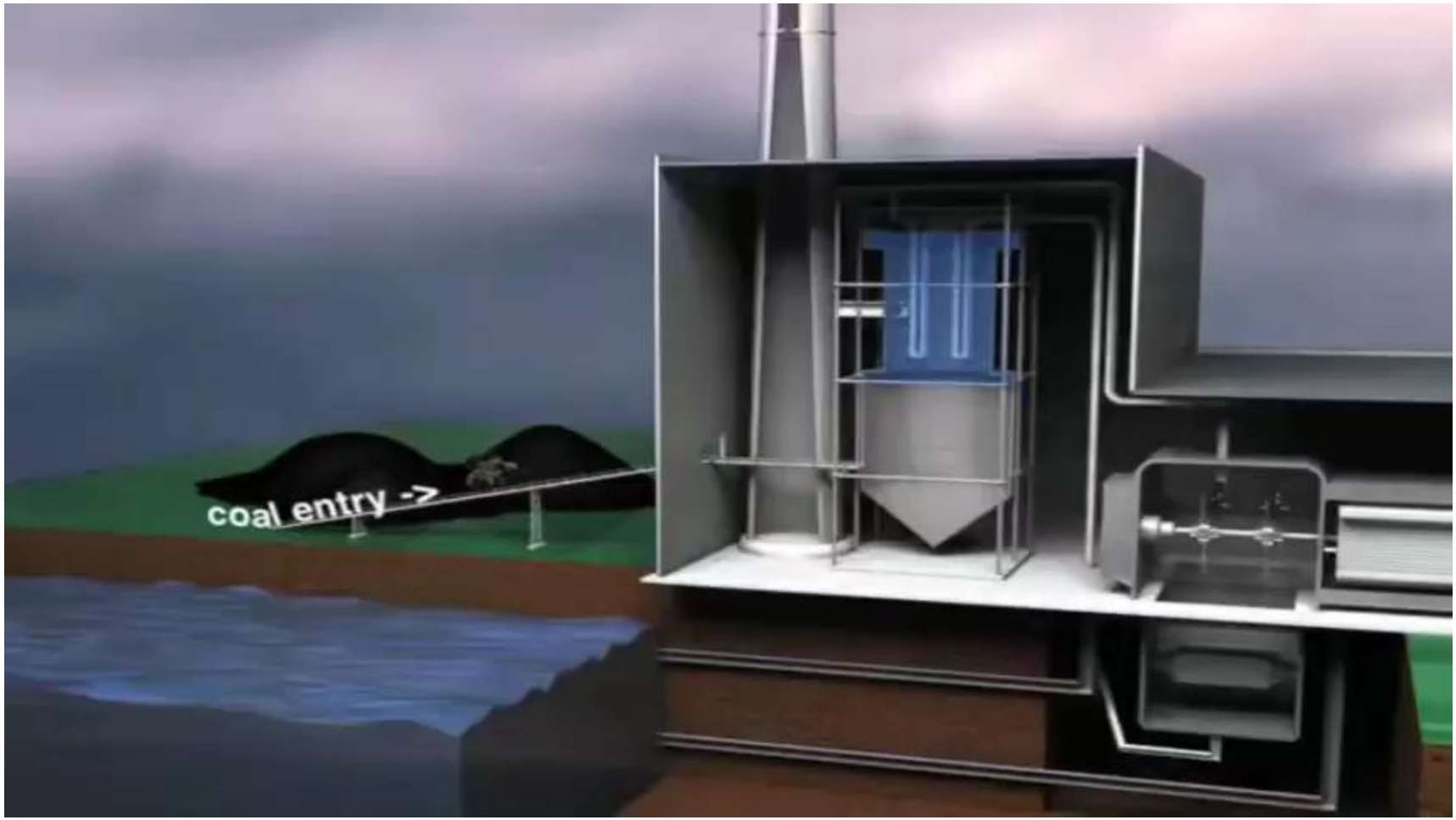
What is renewable energy?

Renewable energy is **energy that comes from natural sources** which are **constantly replenished** and **never run out** on a human timescale. Unlike fossil fuels (coal, oil, and gas), which take millions of years to form and release harmful emissions when burned, renewable energy sources are **cleaner and sustainable**.

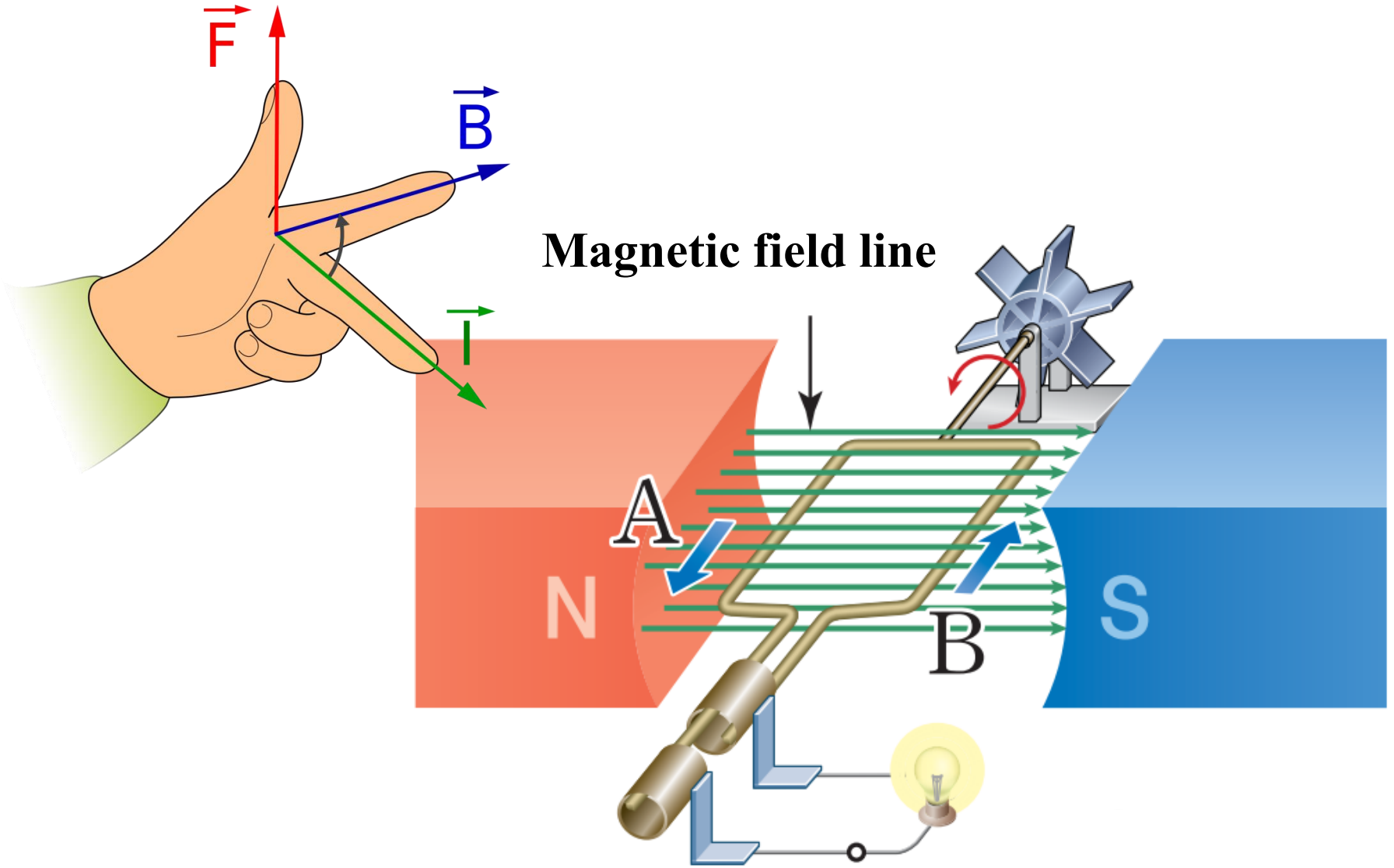
Types of Renewable Energy:

- **Solar Energy** – power from the sun, captured using solar panels.
- **Wind Energy** – electricity generated by wind turbines.
- **Hydropower** – energy from moving water, such as rivers or dams.
- **Biomass** – energy from organic materials like plants, wood, and agricultural waste.
- **Geothermal Energy** – heat from beneath the Earth's surface.

How to generate electricity?

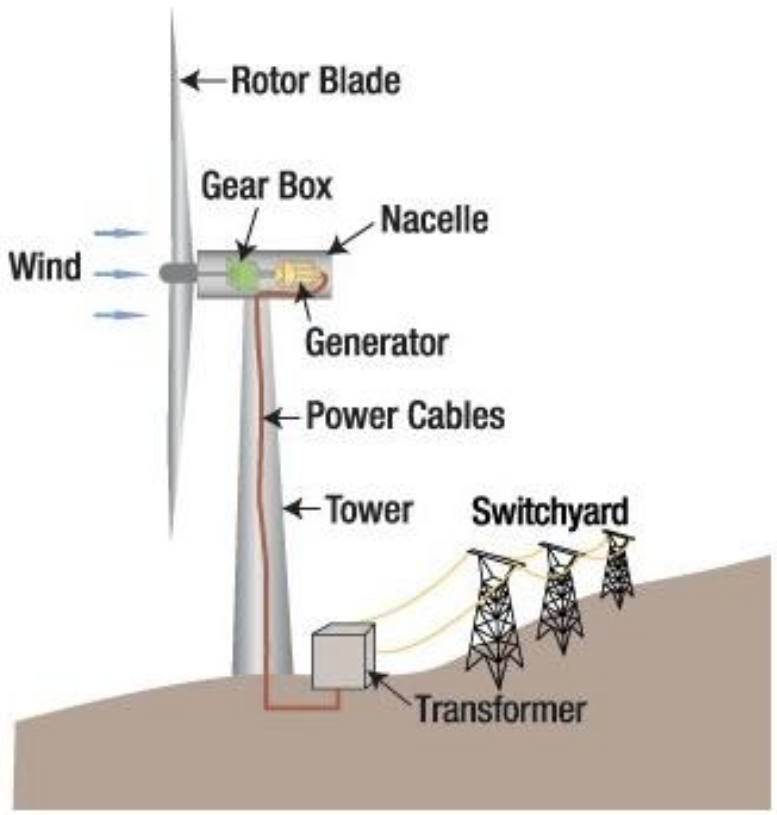


How to generate electricity?



Wind turbine

A wind turbine is a device that converts the kinetic energy of wind into mechanical energy, which can then be used to generate electricity. It essentially works like a giant windmill, but instead of grinding grain, it spins a generator to produce power.



Wind turbine

Transition from onshore wind power to offshore wind power

Considering the spacing between large wind turbine blades (approximately 450 m for a 3 MW wind installation), generating 1,000 MW of power would require a land area of 1,280 km².

Global trend shift from onshore to offshore wind power

•Strong winds, large transport capacity of turbines, fewer environmental issues



Wind turbine

✅ **Advantages of Wind Power**

1. **Renewable and sustainable** – Wind is an inexhaustible natural resource.
2. **Environmentally friendly** – Produces no greenhouse gas emissions during operation.
3. **Low operating costs** – Once installed, turbines have relatively low maintenance and operating expenses.
4. **Energy independence** – Reduces reliance on fossil fuels and imported energy.

❌ **Disadvantages of Wind Power**

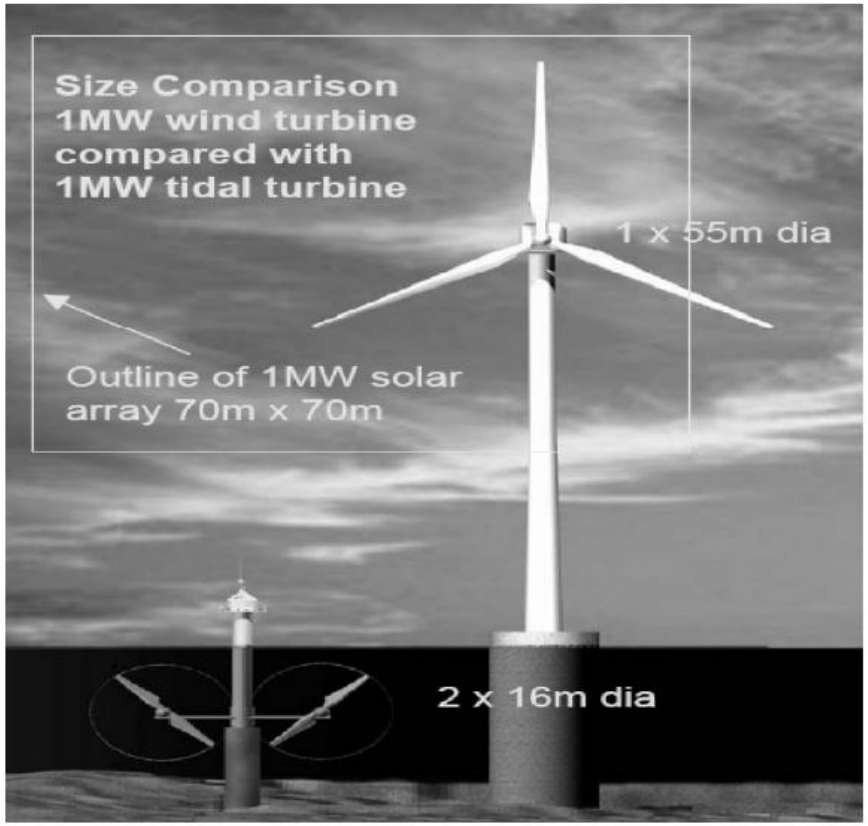
1. **Intermittency** – Wind does not blow consistently, so electricity generation is variable.
2. **High initial costs** – Installation and infrastructure require large investments.
3. **Land use and visual impact** – Onshore wind farms need large areas and can affect landscapes.
4. **Noise issues** – Turbines can produce mechanical and aerodynamic noise.
5. **Impact on wildlife** – Birds and bats may be harmed by turbine blades.

Tidal stream power

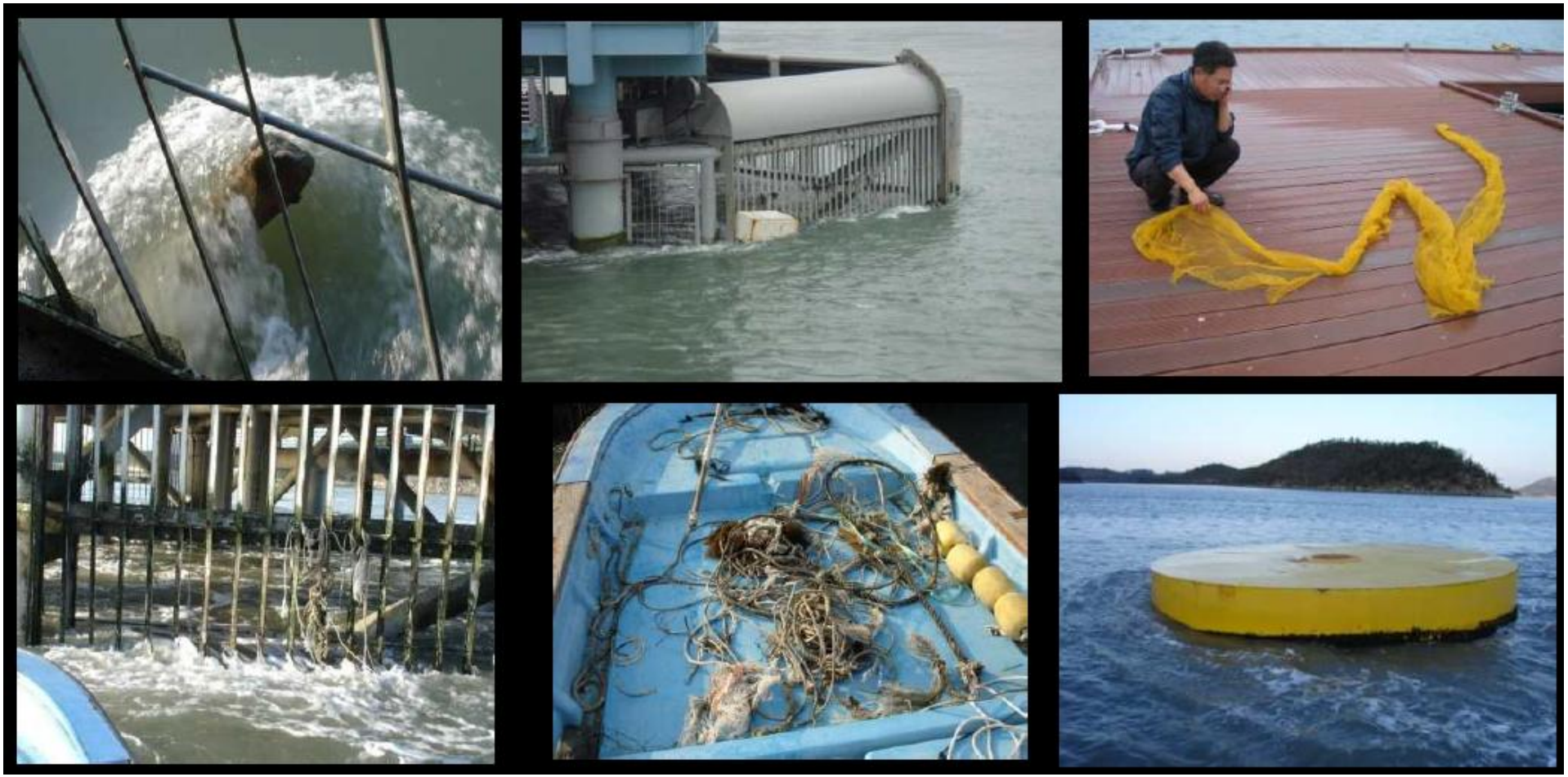
•**Principle**: Uses the kinetic energy of fast-flowing tidal currents created by the rise and fall of tides.

•**Method**: Submerged turbines are placed in tidal streams; the moving water turns the blades, generating electricity.

$$P = \eta \rho A V^3$$



Tidal stream power



Tidal range power

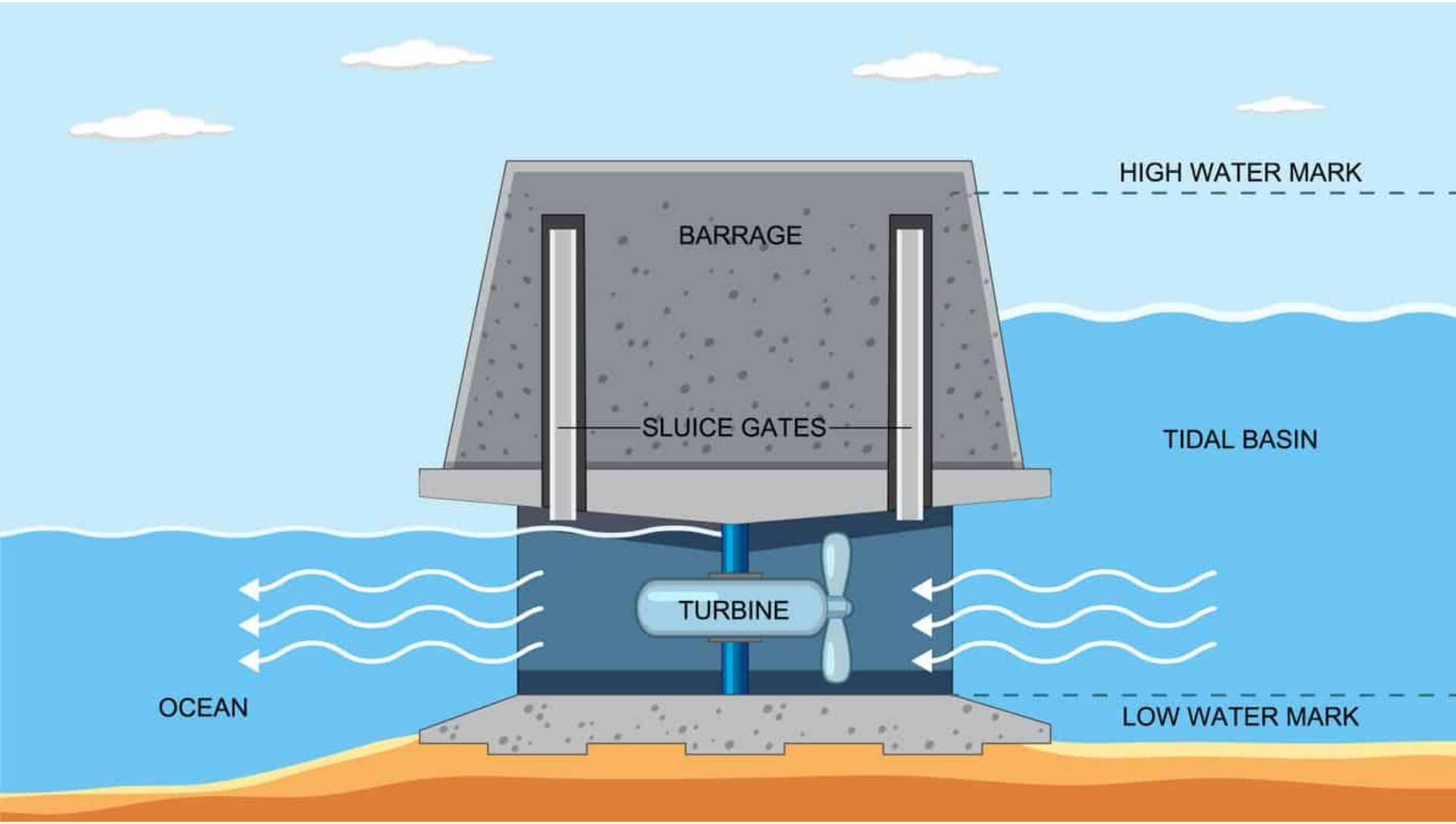
•**Principle**: Uses the difference in sea level between high tide and low tide.

•**Method**: A barrage or sluice gates store water during high tide and release it during low tide, driving turbines to generate electricity.

•**Features**:

- Only feasible in areas with a large tidal range.
- Provides relatively stable power output.
- High construction costs and significant impact on coastal ecosystems.

Tidal range power



Tidal range power

Tidal power

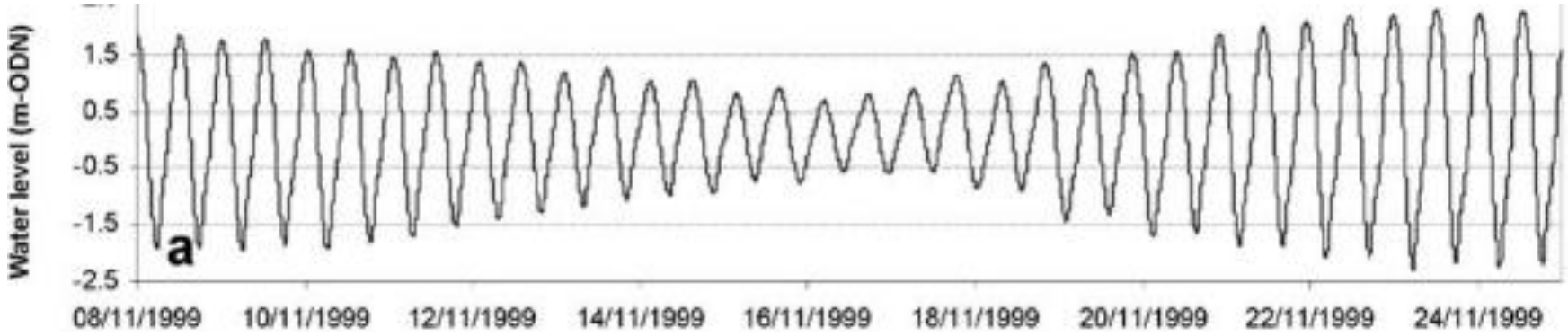
✅ **Advantages of Tidal Power**

•Once a site for tidal power generation is determined, the changes in tidal range at that location can be accurately predicted.

•A clean, renewable, and virtually inexhaustible source of energy.

•Provides stable, long-term electricity supply with low carbon emissions.

•Contributes to energy independence and reduces reliance on fossil fuels.



Tidal power

❌ **Disadvantages of Tidal Power**

•**Low energy efficiency**: The usable energy density is relatively limited.

•**Uneven generation**: The difference between high and low tides is not uniform throughout the year.

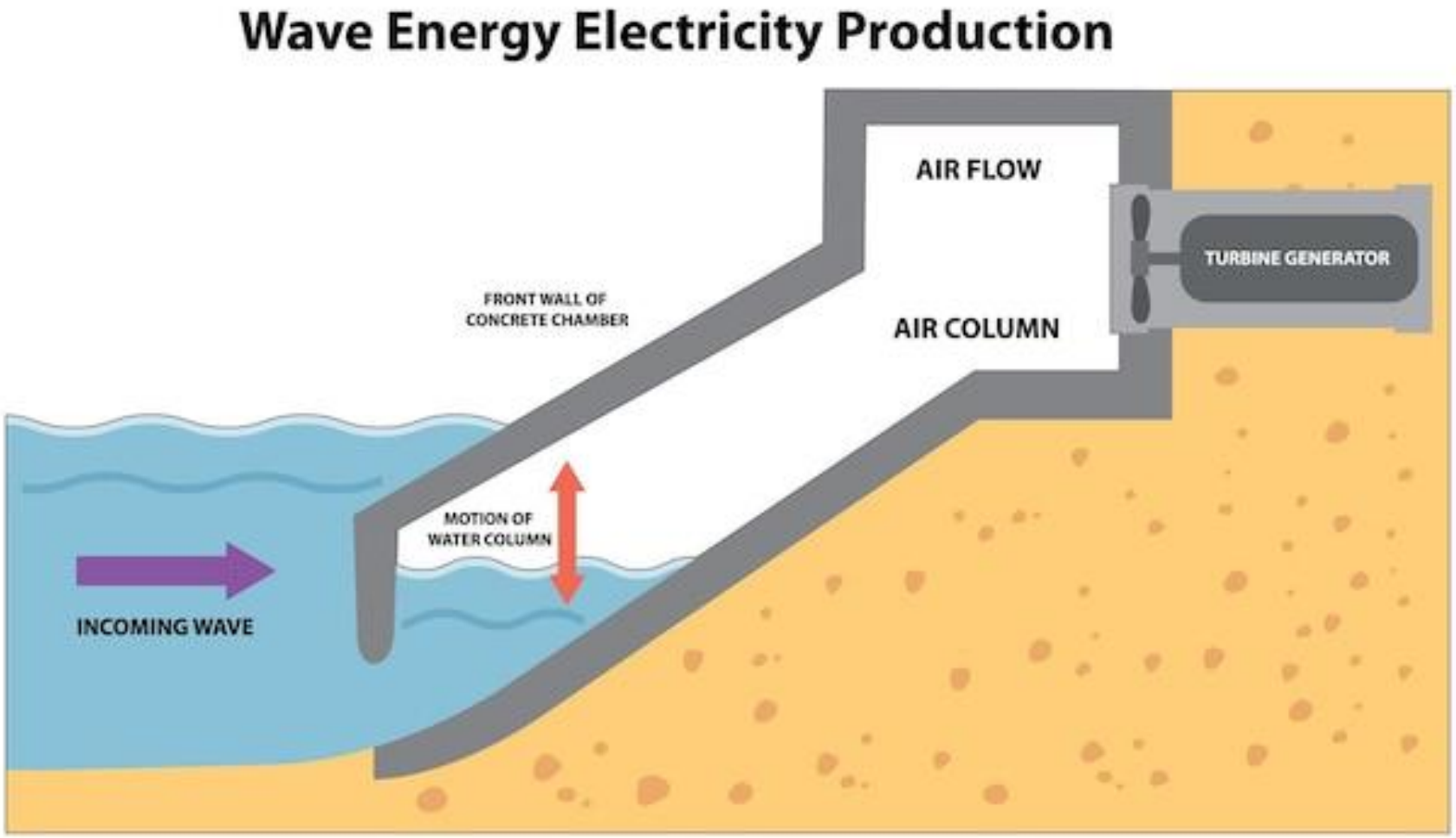
•**Intermittency**: Power cannot be generated continuously; only when there is a sufficient tidal range.

•**Geographic limitations**: Only feasible in areas with significant tidal differences, restricting its application.

•**Environmental impacts**:

- •Changes in river flow and sediment deposition
- •Influence on water quality and salinity levels.
- •Potential harm to local geography, coastal habitats, and marine ecosystems.\

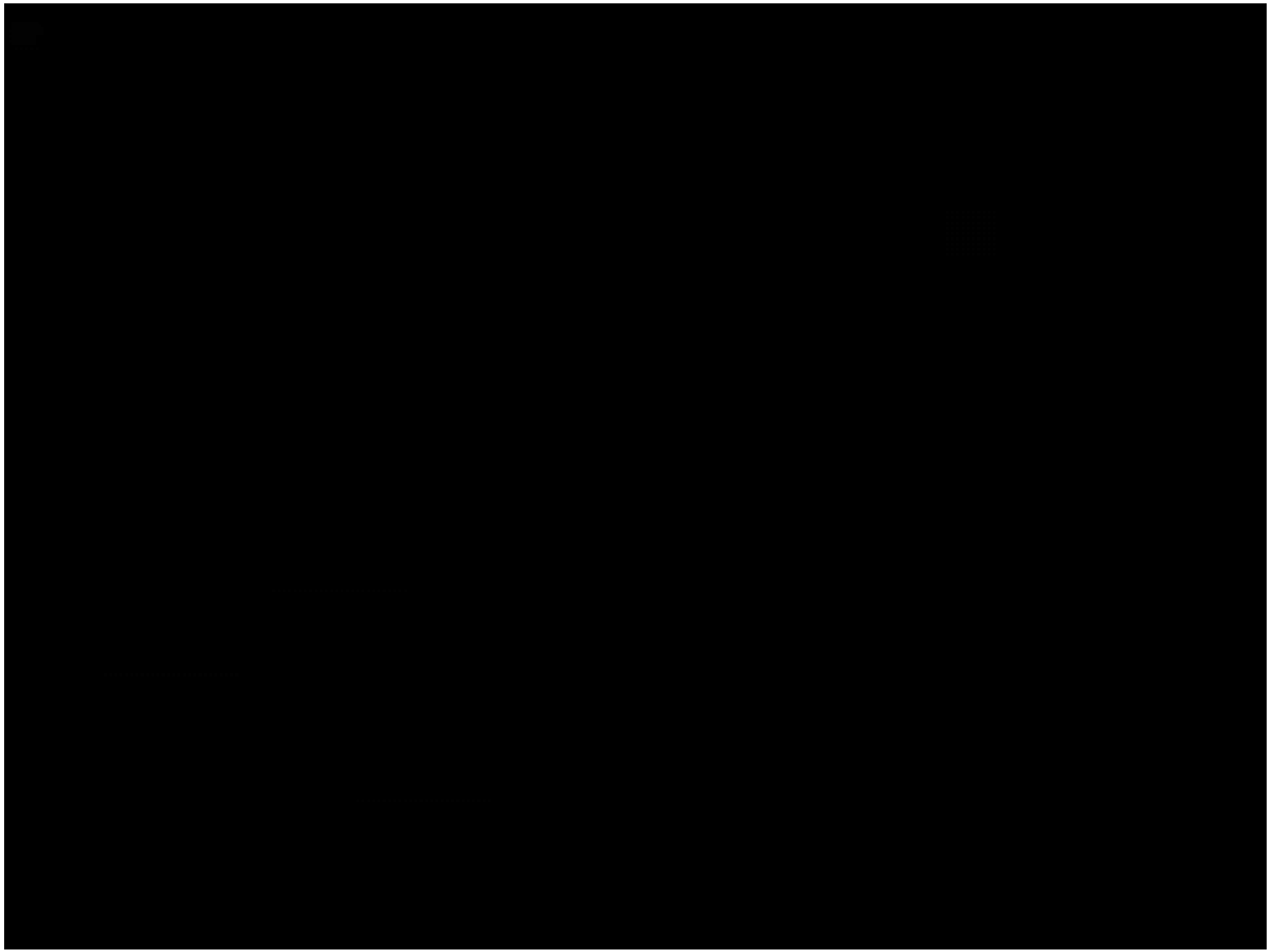
Wave power


Wave Energy Electricity Production
AIR FLOW
TURBINE GENERATOR
FRONT WALL OF
CONCRETE CHAMBER
AIR COLUMN
MOTION OF
WATER COLUMN
INCOMING WAVE

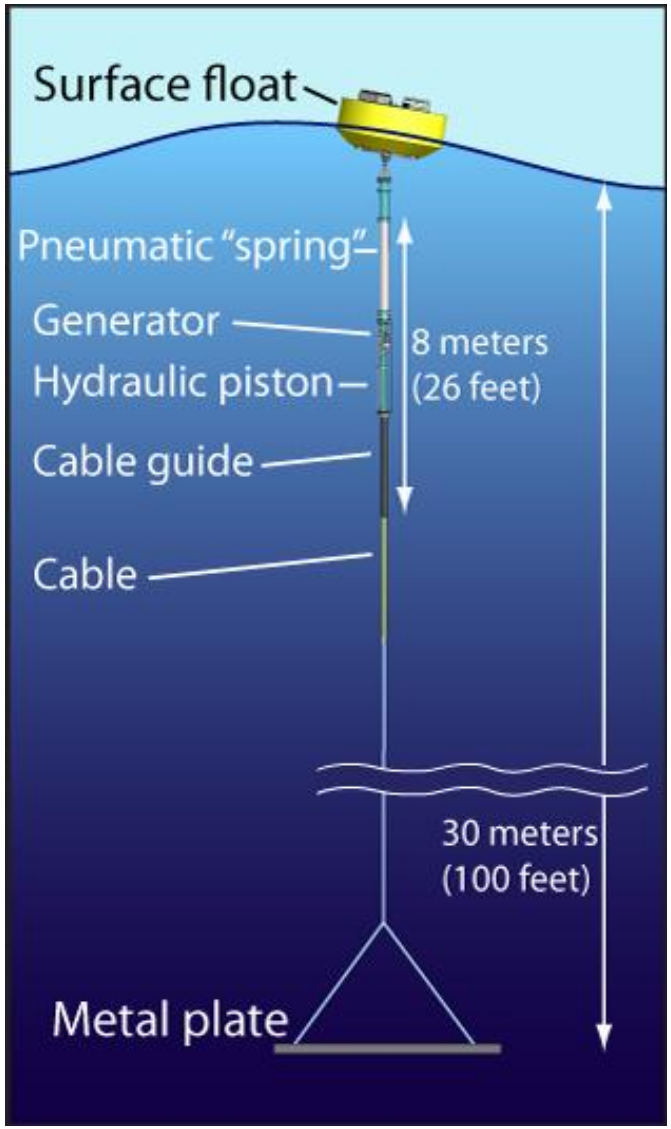
Wave power



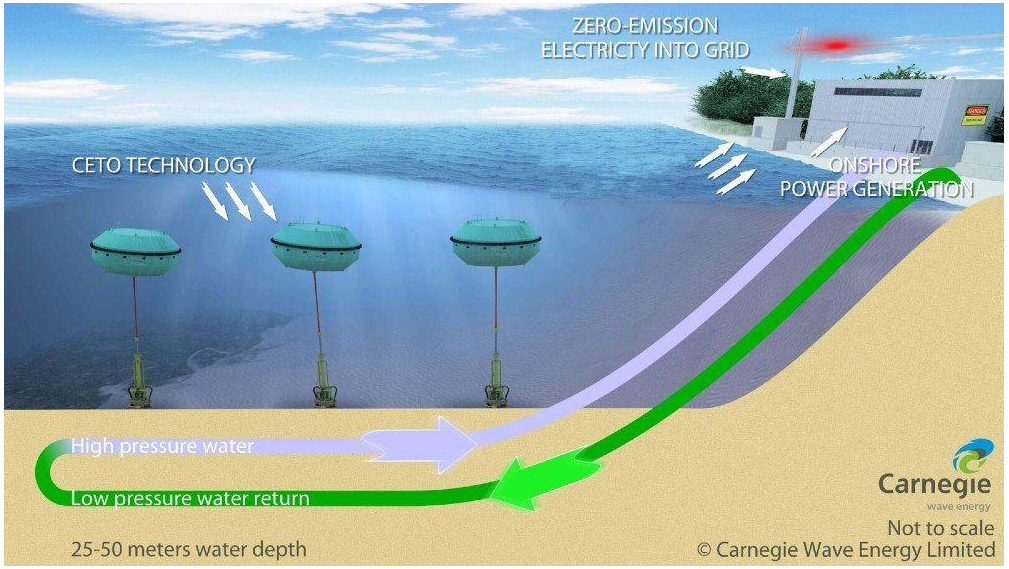
Wave power



Wave power


Surface float
Pneumatic "spring"
Generator
Hydraulic piston
Cable guide
Cable
8 meters
(26 feet)
30 meters
(100 feet)
Metal plate




ZERO-EMISSION
ELECTRICTY INTO GRID
CETO TECHNOLOGY
ONSHORE
POWER GENERATION
High pressure water
Low pressure water return
25-50 meters water depth
Carnegie
wave energy
Not to scale
© Carnegie Wave Energy Limited

Wave power

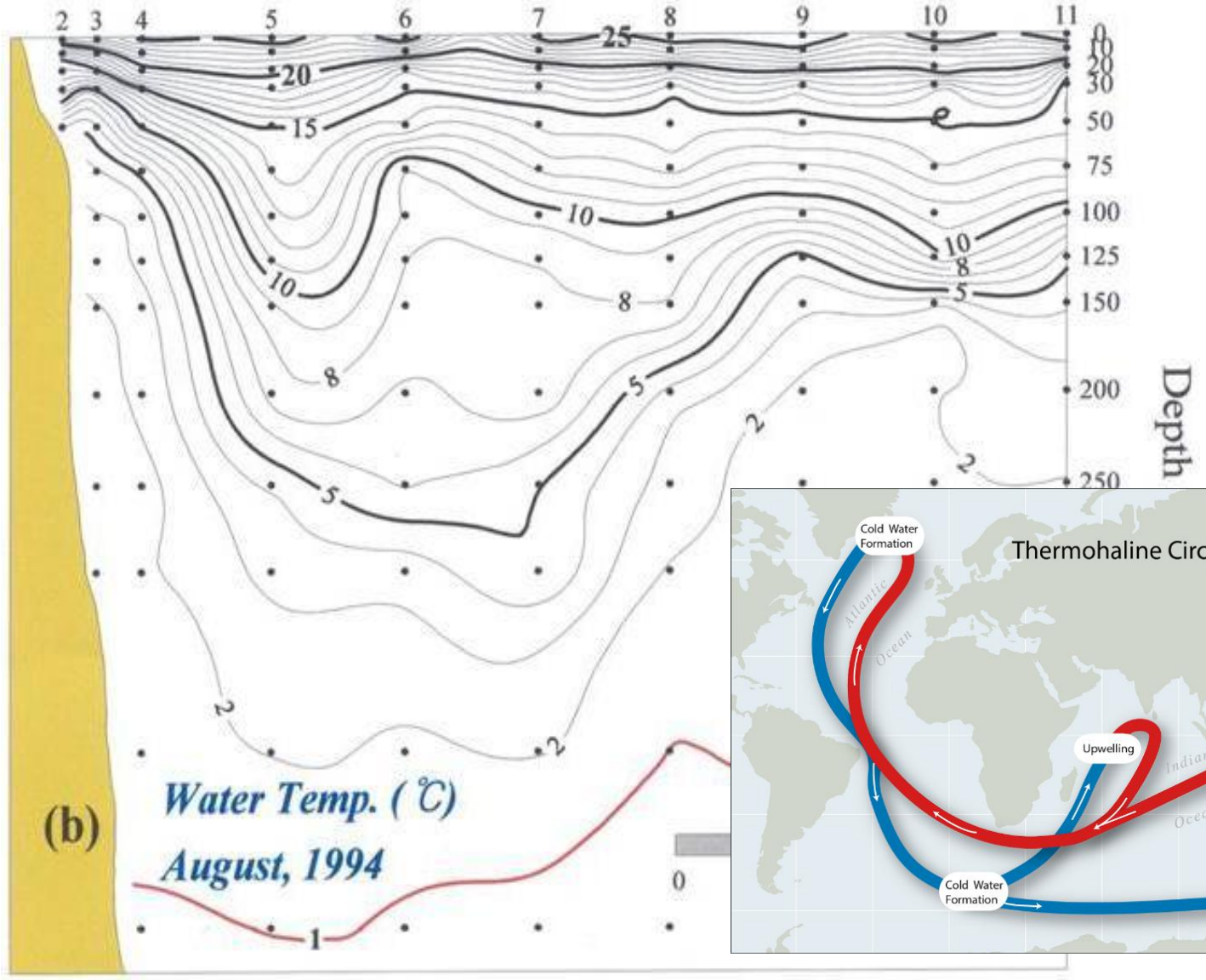
✅ **Advantages**

- **Renewable & sustainable**: Uses the natural motion of the ocean.
- **Predictable**: Wave patterns can be forecast with reasonable accuracy.
- **High energy density** compared to wind or solar in some locations.

❌ **Disadvantages**

- **High cost** of technology and installation.
- **Durability challenges**: Must withstand harsh marine environments.
- **Geographic limitation**: Effective only in coastal areas with strong waves.
- **Potential impact** on marine ecosystems and coastal landscapes.

Ocean Thermal Energy Conversion



Ocean Thermal Energy Conversion

How it works

1.Warm surface water (around 25–30°C) is used to vaporize a working fluid with a low boiling point (like ammonia).

2.The vapor expands and drives a turbine to produce electricity.

3.Cold deep seawater (around 5°C) is then used to condense the vapor back into liquid, and the cycle repeats.

Ocean Thermal Energy Conversion



Salinity gradient power



Biomass energy

Marine biomass energy refers to energy produced from biological resources found in the sea, such as **seaweed, algae, and other marine plants or microorganisms**. These organisms can be processed into biofuels (like ethanol, biodiesel, or biogas) to generate electricity or be used as alternative fuels.

- **Cultivation** – Large-scale farming of seaweed or microalgae.
- **Harvesting** – Collection of biomass from the ocean.
- **Conversion** – Biomass is processed through fermentation, anaerobic digestion, or chemical methods to produce liquid or gaseous fuels.

Biomass energy



Biomass energy

✅ **Advantages**

- **Abundant resource**: Oceans cover 70% of the Earth, offering vast potential.
- **Fast growth**: Seaweed and algae grow rapidly.
- **Carbon absorption**: Marine plants absorb CO_2, helping mitigate climate change.
- **Versatile use**: Can be turned into biofuels, fertilizers, and even food supplements.

❌ **Disadvantages**

- **High cost**: Large-scale cultivation and conversion technologies are still expensive.
- **Environmental impact**: Overharvesting may affect marine ecosystems.
- **Technology development**: Requires further research to improve efficiency.

Discussion

Which type of marine renewable energy is the most suitable to apply in your country?

Sediment Microbial Fuel Cells

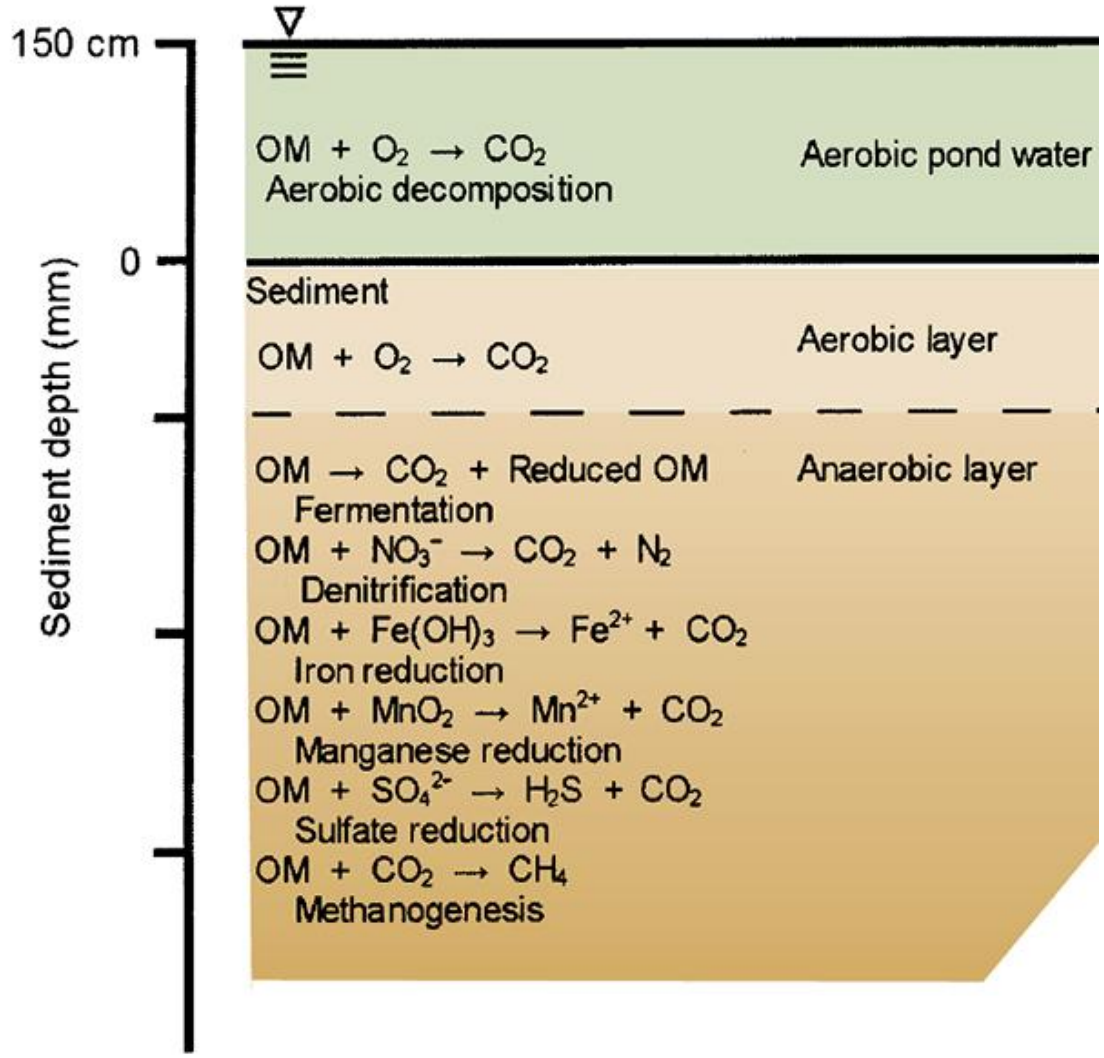
-Concept and applications-

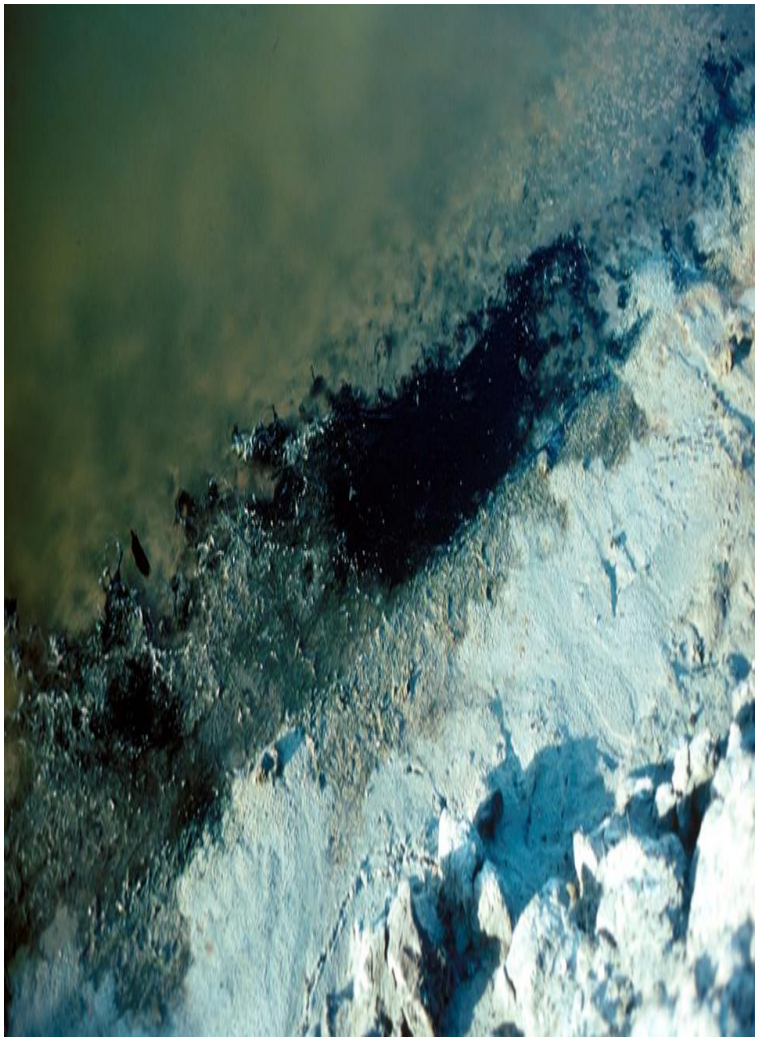
Tiny Microbes That Make Electricity



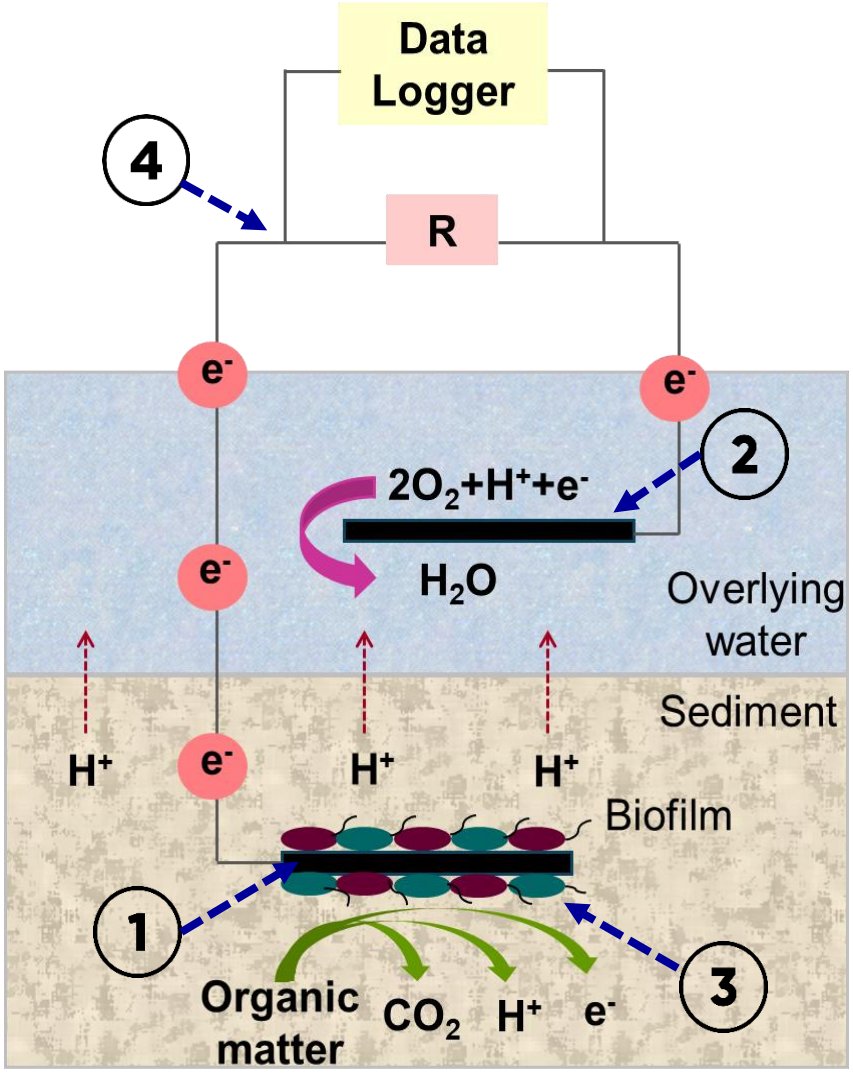
- Microbes are super tiny living thing - smaller than human hair!
- They live in soil, mud & even underwater sediment.
- Some special microbes can release electricity when they breathe.
- We use this electricity to make power from sediment!

How does it work?



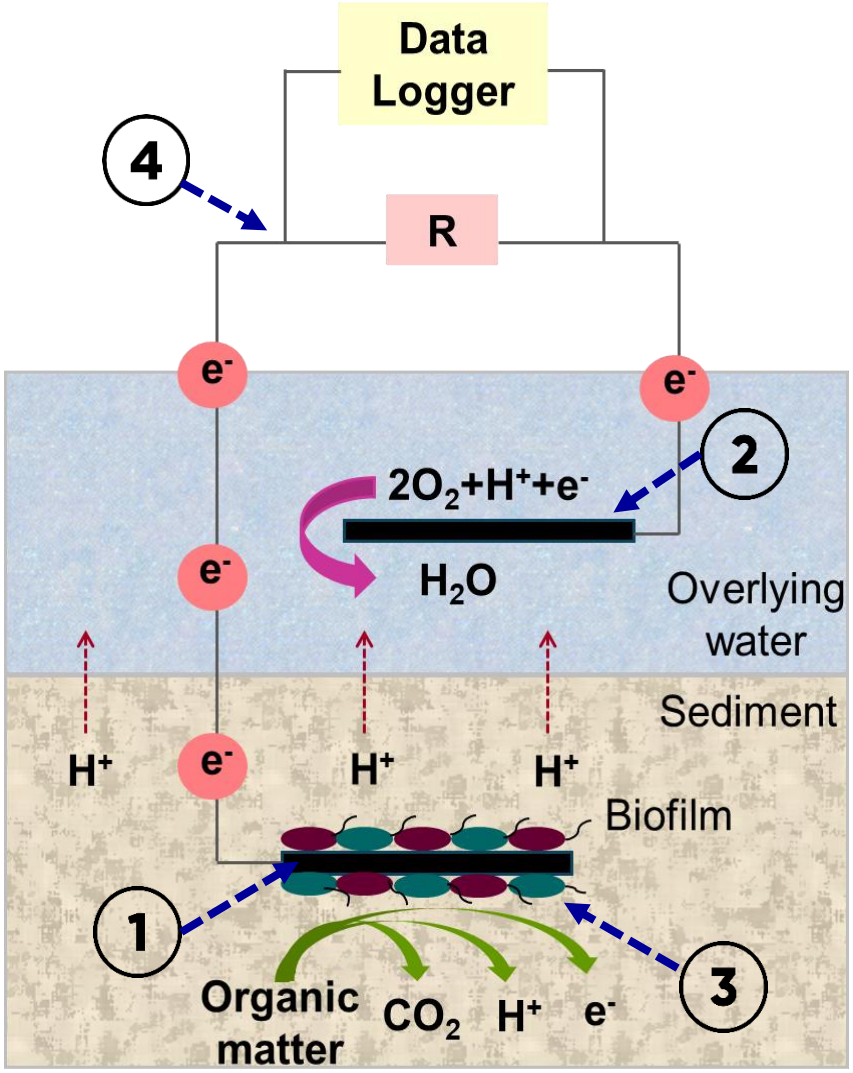


Sediment Microbial Fuel Cells (SMFCs)



1) **Anode:** Bury in polluted sediment (electron donor site).
2) **Cathode:** Place in oxygen-rich water (electron acceptor site).
3) **Microbes:** Exoelectrogenic bacteria transfer electrons.
4) **Circuit:** Connect electrodes & measures voltage/current.

Sediment Microbial Fuel Cells



- Microbes oxidize organic matter in polluted sediment.
- Transfer electron released to anode.
- Electrons travel through external circuit to cathode.
- Protons migrate via sediment.
- Electrons reduce oxygen at cathode, completing the circuit.

Application of SMFCs



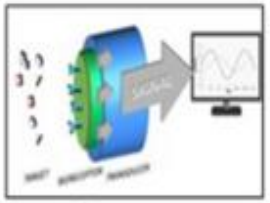
Power Generation



Brewery Industries



Food Industries



Biosensors



Microbial Fuel Cells



Bioremediation



Waste Degradation



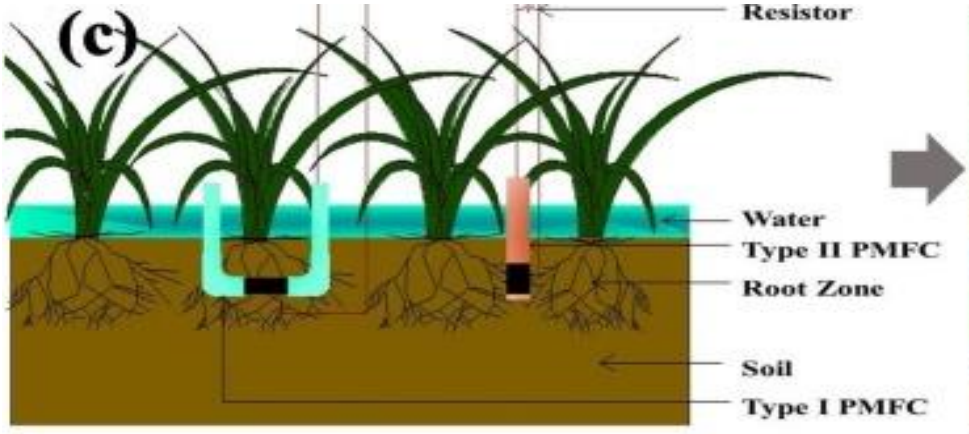
Carbon Sequestration



Environmental Sensor

SMFC in Rice Field

- **2 Designs Tested:** Horizontal (Type-I) & vertical (Type-II) were used in rice fields.
- **Type-II :** Yield better voltage (321.7 mV) & power (16.8 mW/m²).
- **Catholyte Recovery**: Alkaline catholyte & nutrient (ammonium) were collected during early plant growth for water & nutrient reuse.

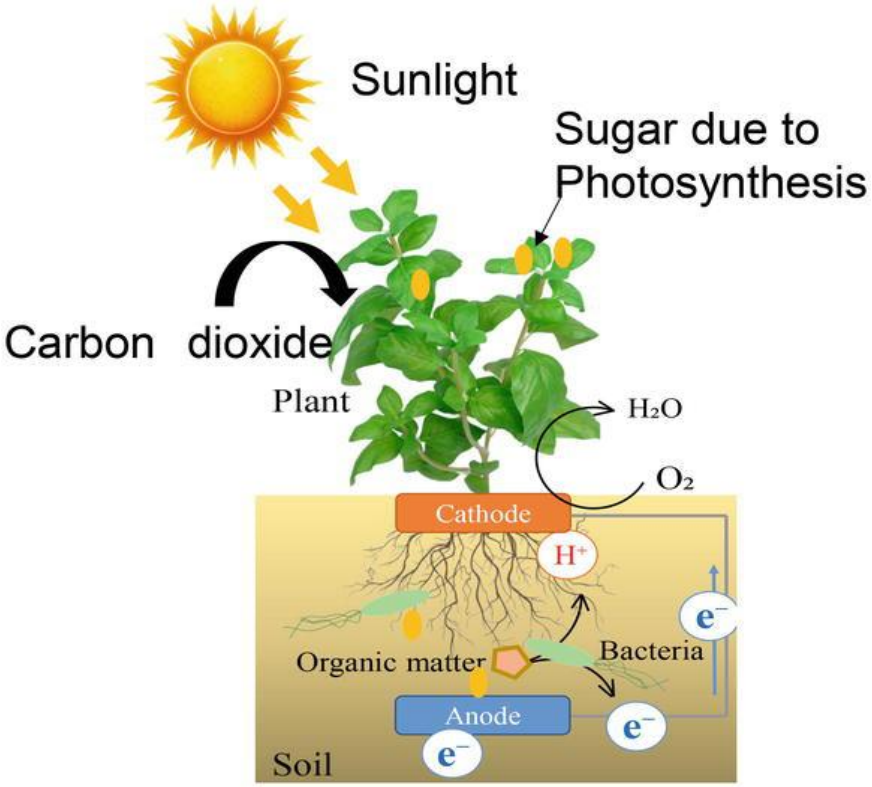




Plant SMFC

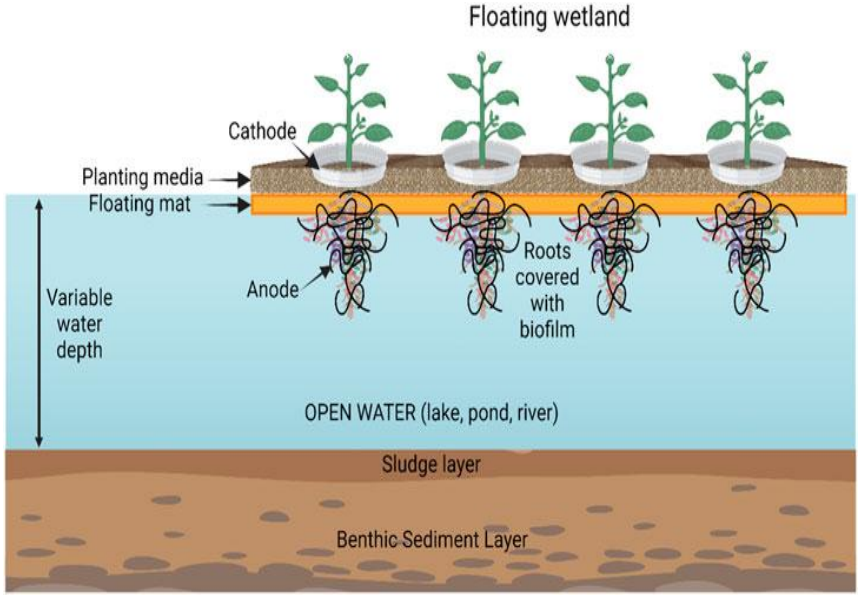
- **Eco-Friendly Energy:** Yield electricity using plants & soil microbes.
- **Natural Waste Treatment:** Clean polluted water/soil during power production.
- **Sustainable Technology:** Combine renewable energy with environmental protection.





Constructed Wetland SMFC

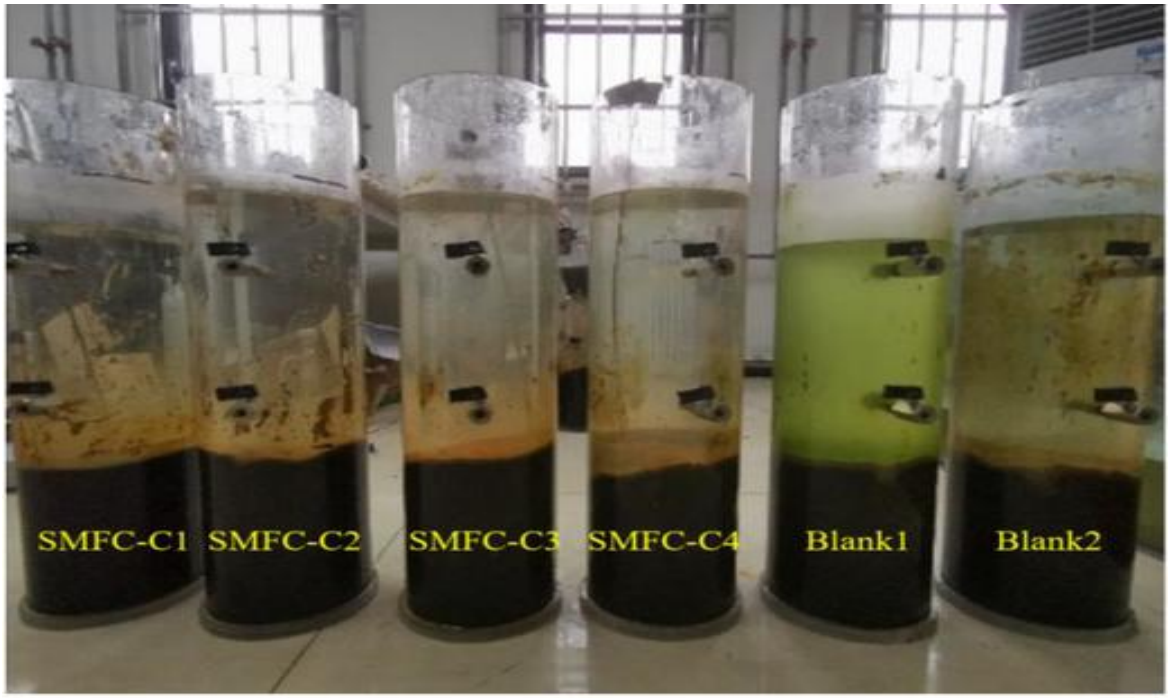
- **Hybrid System:** Combine constructed wetlands with SMFC to treat wastewater & yield electricity.
- **Dual Function:** Clean polluted water using plants, soil & microbes while producing low-level power.
- **Eco-Sustainable**: Green solution for both water purification & renewable energy generation.





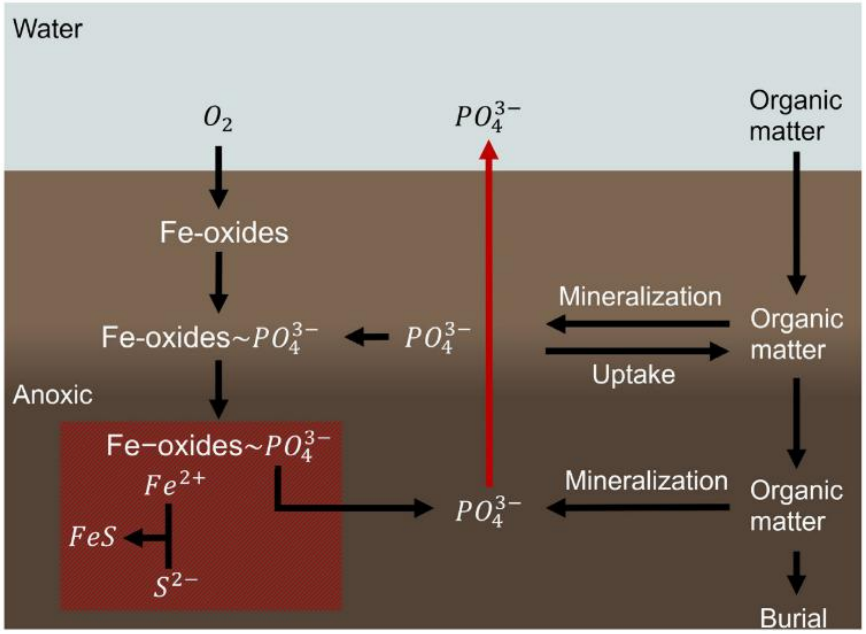
SMFC in Aquaculture Remediation

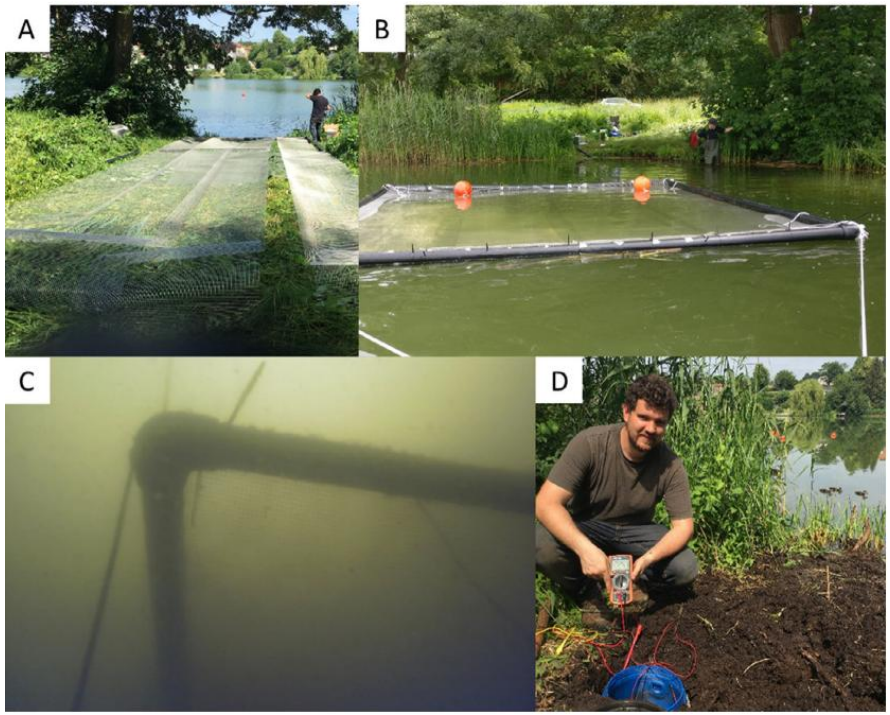
- **Pollutant Removal:** Effectively remove contaminant from water.
- **Sediment Treatment:** Promote organic matter degradation & phosphorus fixation.
- **Eutrophication Control:** Prevent nutrient release, reducing algal bloom.



Lake SMFC

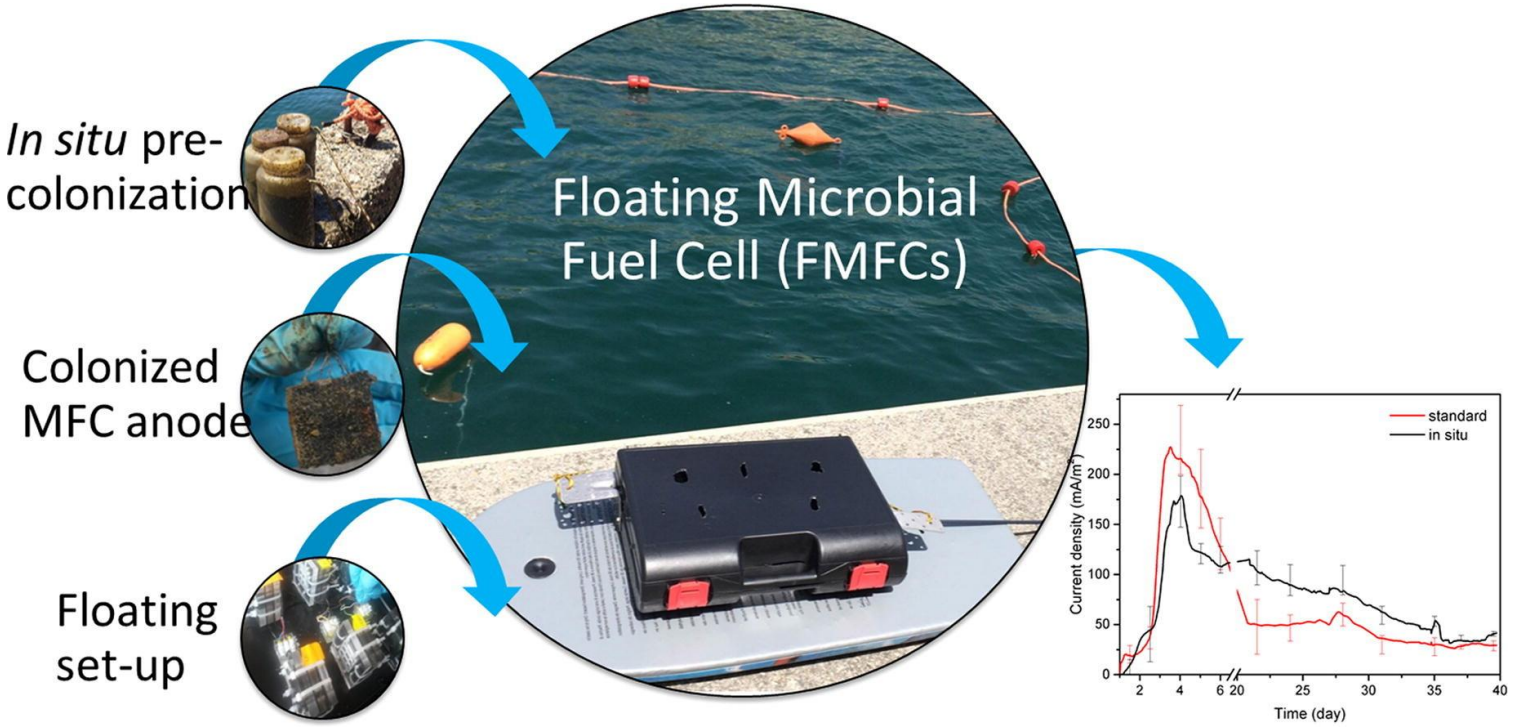
- **Innovative Approach:** To immobilize phosphate in lake sediment using modified stainless steel electrode (16 m²).
- **Phosphate Control:** Reduces 94% phosphate release from sediment.
- **Eco-Technology:** Offer low-energy, sustainable method to improve lake water quality.





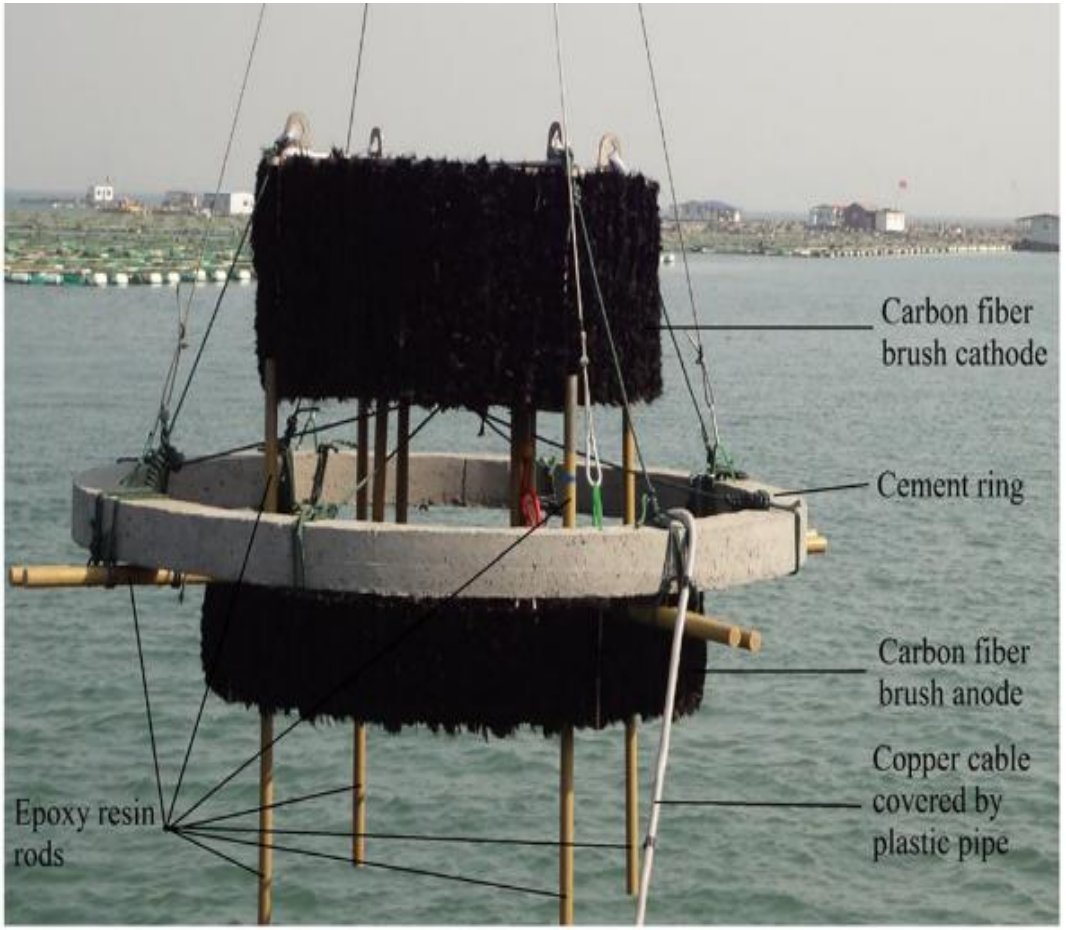
Marine Floating SMFC

- **Portable & Cost-Effective:** A floating SMFC system is designed for easy use in real seawater conditions, using seawater as fuel.
- **Stable Power Output:** Yield steady power (6 mW/m^2) in both summer & winter, with little effect from temperature changes.



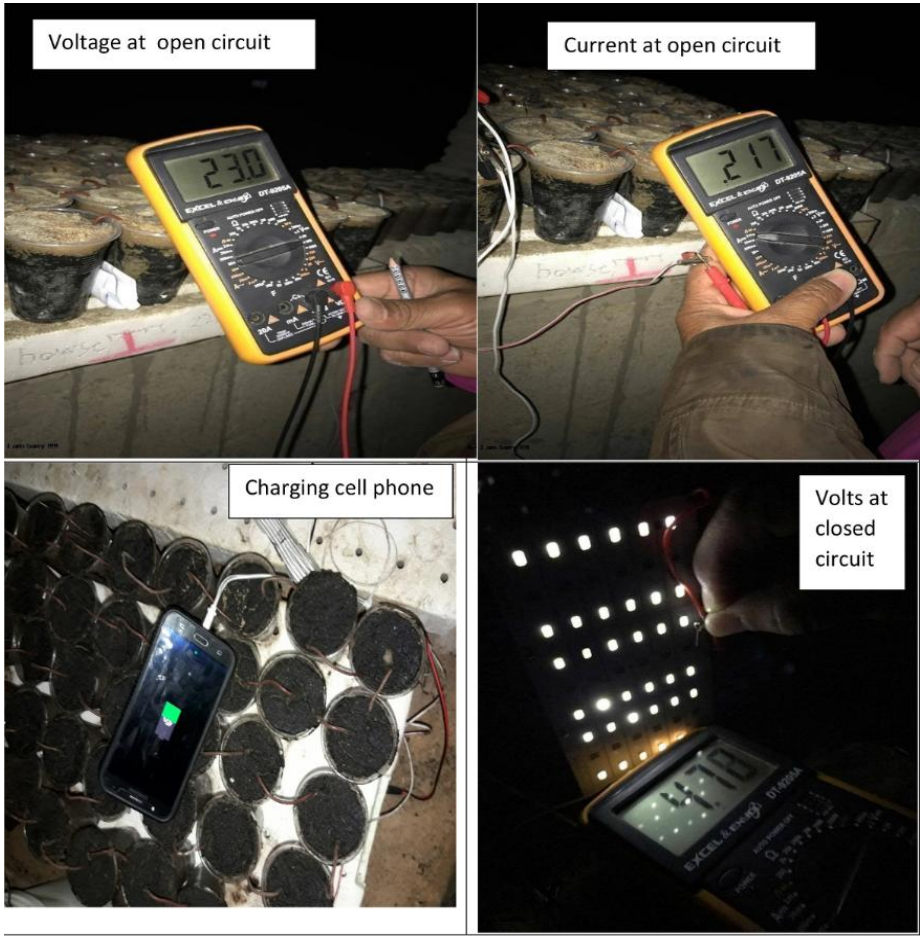
Coastal SMFC

- **In-Situ Pollution Control:** Treat coastal sediment directly at the site using microbial activity.
- **Energy from Waste**: Yield electricity while degrading organic pollutant & nutrient.
- **Sustainable Coastal Management:** Support long term ecosystem health & reduce human impact with minimal infrastructure.

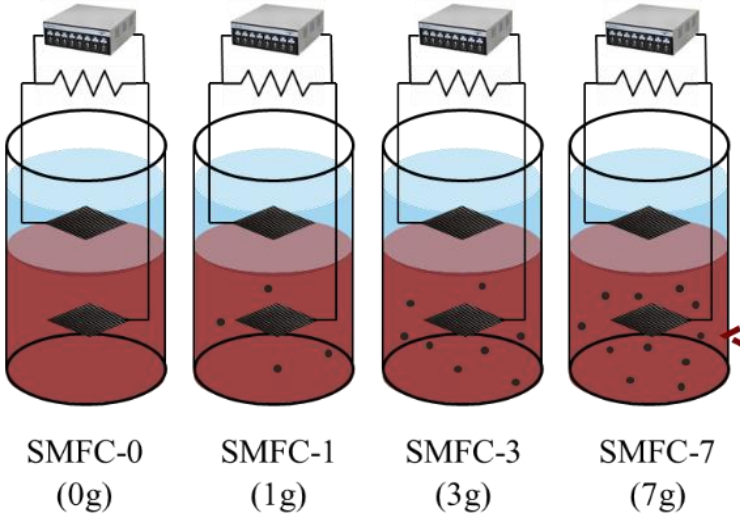


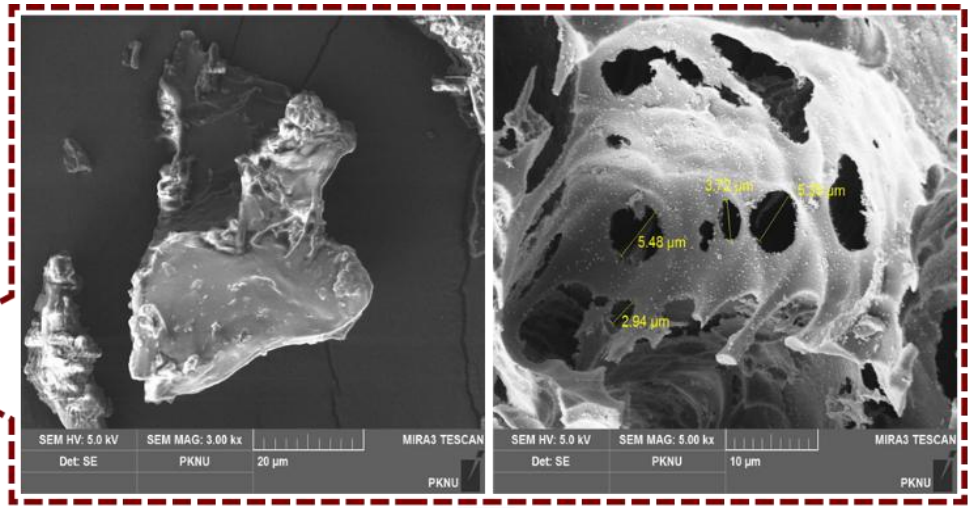
SMFC with Animal Manures

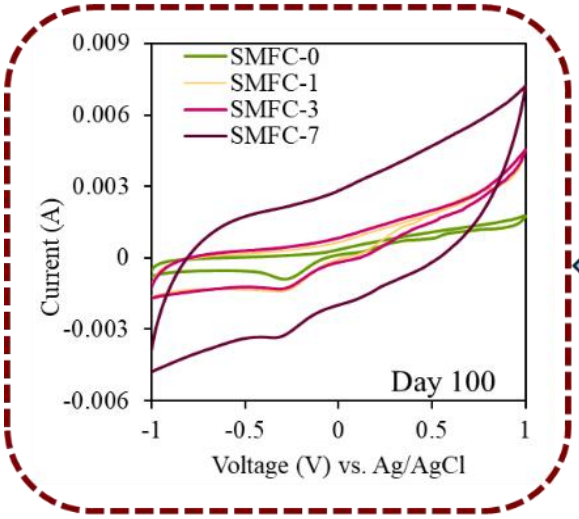
- **Environmental Battery:** Chicken, cattle & horse manure mixed with sand & water are used in connected cups.
- **Good Power Output:** Yield strong voltage and current within 96 hrs.
- **Horse manure** give most power, followed by chicken, cow & sludge.
- The system **works for 40–60 days**.

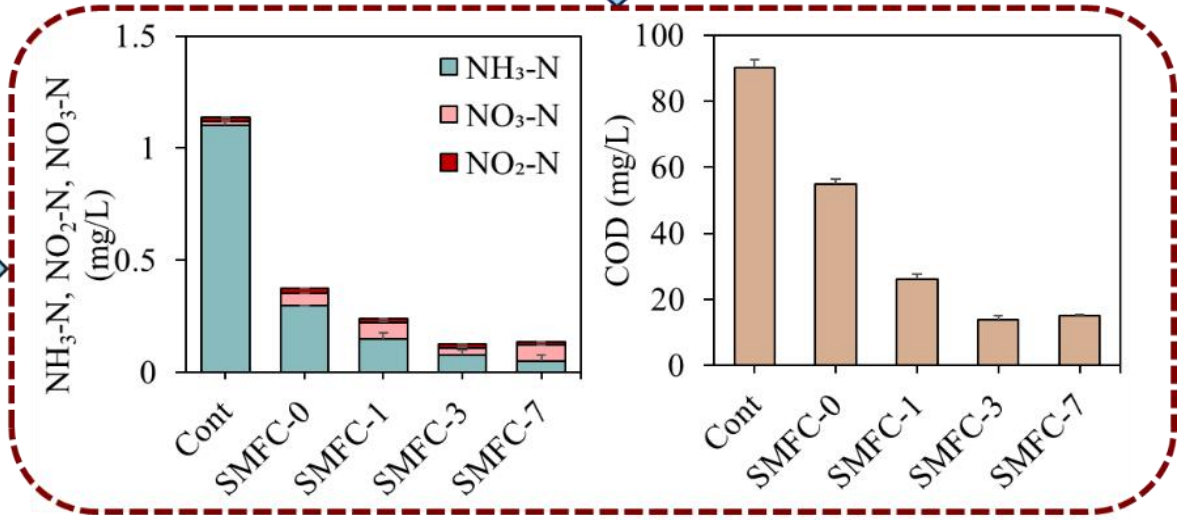


SMFC with Carbonized Coffee Waste



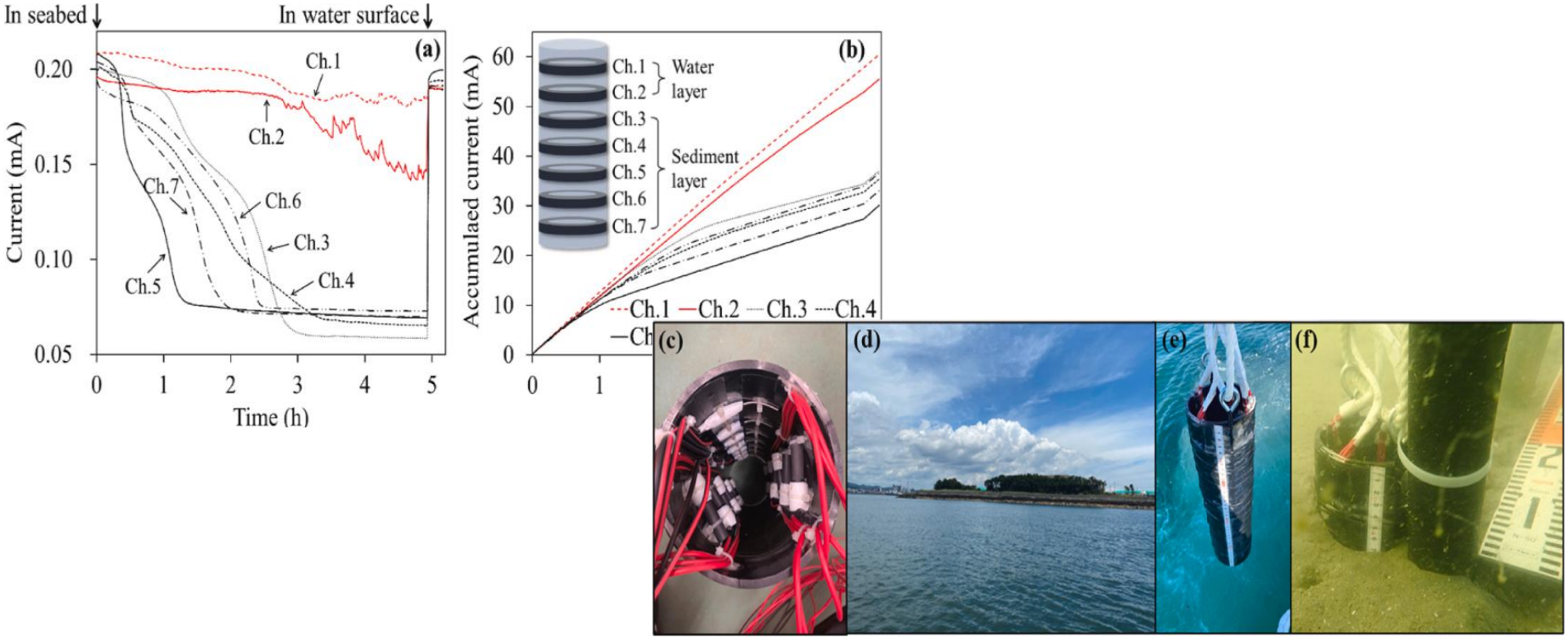






Development of Fuel Cell Type Sensor

- FCT sensor monitor seabed levels or dissolved oxygen.
- Yield continuous data via generation of **spontaneous electric current**.
- Identify **sediment texture** or **dissolved oxygen concentration**.
- Suitable for **extended deployment in coastal environment monitoring**.



Challenges limiting SMFC performance

- Low power output.
- Biofouling & electrode deactivation.
- Scaling for practical applications still under development.
- Sensitive to environmental conditions (temperature, salinity).


Thank you
for your attention