BIOZONE

ENVIRONMENTAL SCIENCE

Earth Systems

The Earth's dynamic surface is a result of plate tectonics and weathering.

Changes and variations in the Earth's surface give rise to resources that can be exploited by humans for agricultural, industrial, and domestic uses.

Geological Systems

The age of the Earth

- Measuring geological history
- Using stratigraphy
- Fossil formation and significance

The Earth's surface

- Location and cause of earthquakes
- Volcanoes and volcanism
- Fault formation and movements

Plate tectonics

- Plate boundaries and movement
- Sea floor spreading and subduction zones
- Movement of the mantle

The study of rocks provides information about past and present geological events

The Atmosphere

The atmosphere

- Gaseous components of air
- Layers of the atmosphere
- Interactions of atmospheric layers

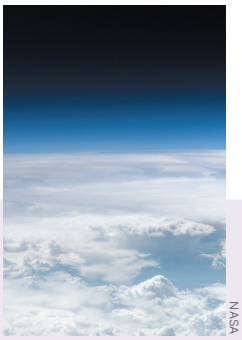
Atmospheric circulation

- Tricellular model
- Effects on climate
- The Coriolis effect
- El Niño-Southern Oscillation

Weather

- Warm fronts and cold fronts
- Cyclones and hurricanes

Movement of the atmosphere creates global and local weather patterns



NASA

Only a tiny proportion of the Earth's water is accessible for human use

Soils are a complex mix of weathered rock and organic matter determined by geology and climate

Global Water Resources

Oceanic water

- Surface movements
- Thermohaline circulation
- Coriolis effect

Freshwater

- Extent and location

Rocks and Soil

Rocks and minerals

- The rock cycle
- Rock types and significance
- Weathering and erosion

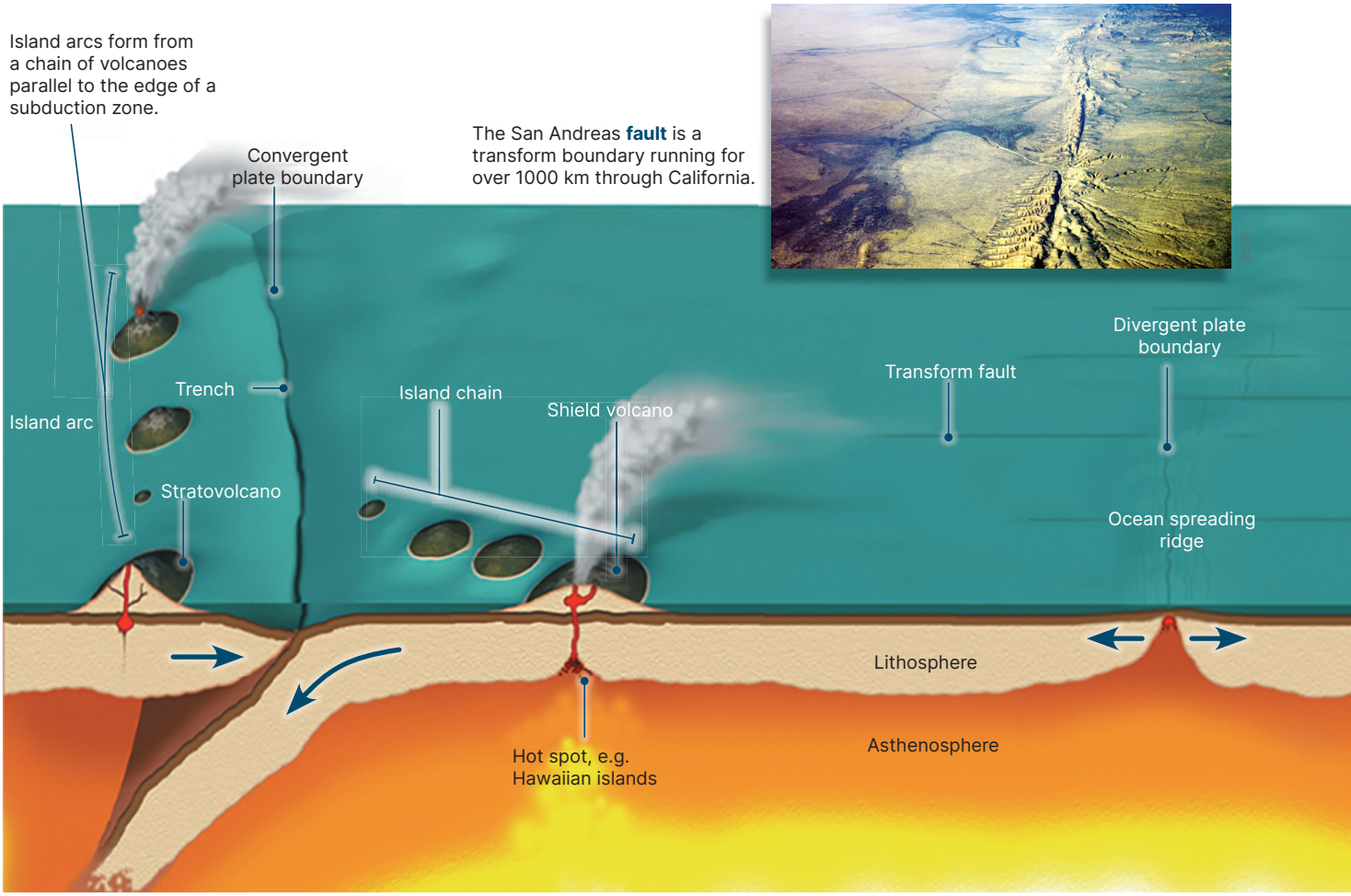
Soil dynamics

- Features of a loam
- Formation and features of horizons
- Climatic influences on soil formation

7 Plate Boundaries

Key Idea: When tectonic plates meet, they form either convergent, divergent, or transform boundaries.

The outer rock layer of the Earth, comprising the **crust** and upper **mantle**, is called the **lithosphere** and it is broken up into seven large, continent-sized tectonic plates and about a dozen smaller plates. Throughout geological time, these plates have moved about the Earth's surface, shuffling continents, opening and closing oceans, and building mountains. The evidence for past plate movements has come from several sources: mapping of plate boundaries, the discovery of sea floor spreading, measurement of the direction and rate of plate movement, and geological evidence such as the distribution of ancient mountain chains, unusual deposits, and fossils. The size of the lithospheric plates is constantly changing, with some expanding and some getting smaller. These changes occur along plate boundaries, which are marked by well-defined zones of seismic and volcanic activity. Plate growth occurs at **divergent boundaries** along sea floor spreading ridges, e.g. the Mid-Atlantic Ridge and the Red Sea, whereas plate attrition occurs at **convergent boundaries** marked by deep ocean trenches and subduction zones. Divergent and convergent zones make up approximately 80% of plate boundaries. The remaining 20% are called transform boundaries, where two plates slide past one another with no significant change in the size of either plate.



1. Describe what is happening at each of the following plate boundaries and identify an example in each case:

   (a) Convergent plate boundary: _____

   _____

   _____

   (b) Divergent plate boundary: _____

   _____

   _____

   (c) Transform plate boundary: _____

   _____

   _____

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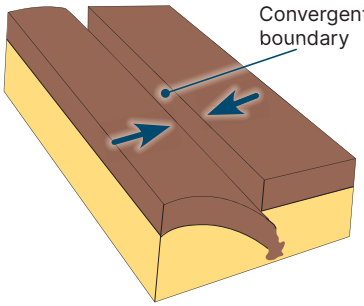
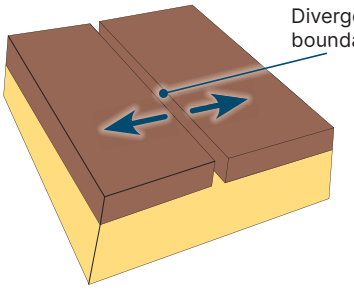
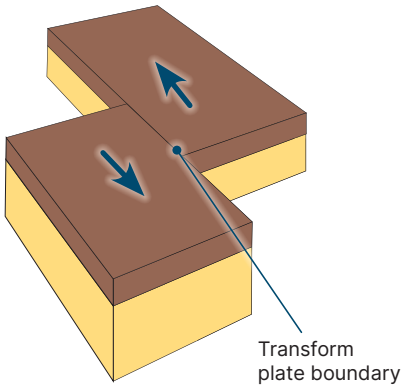


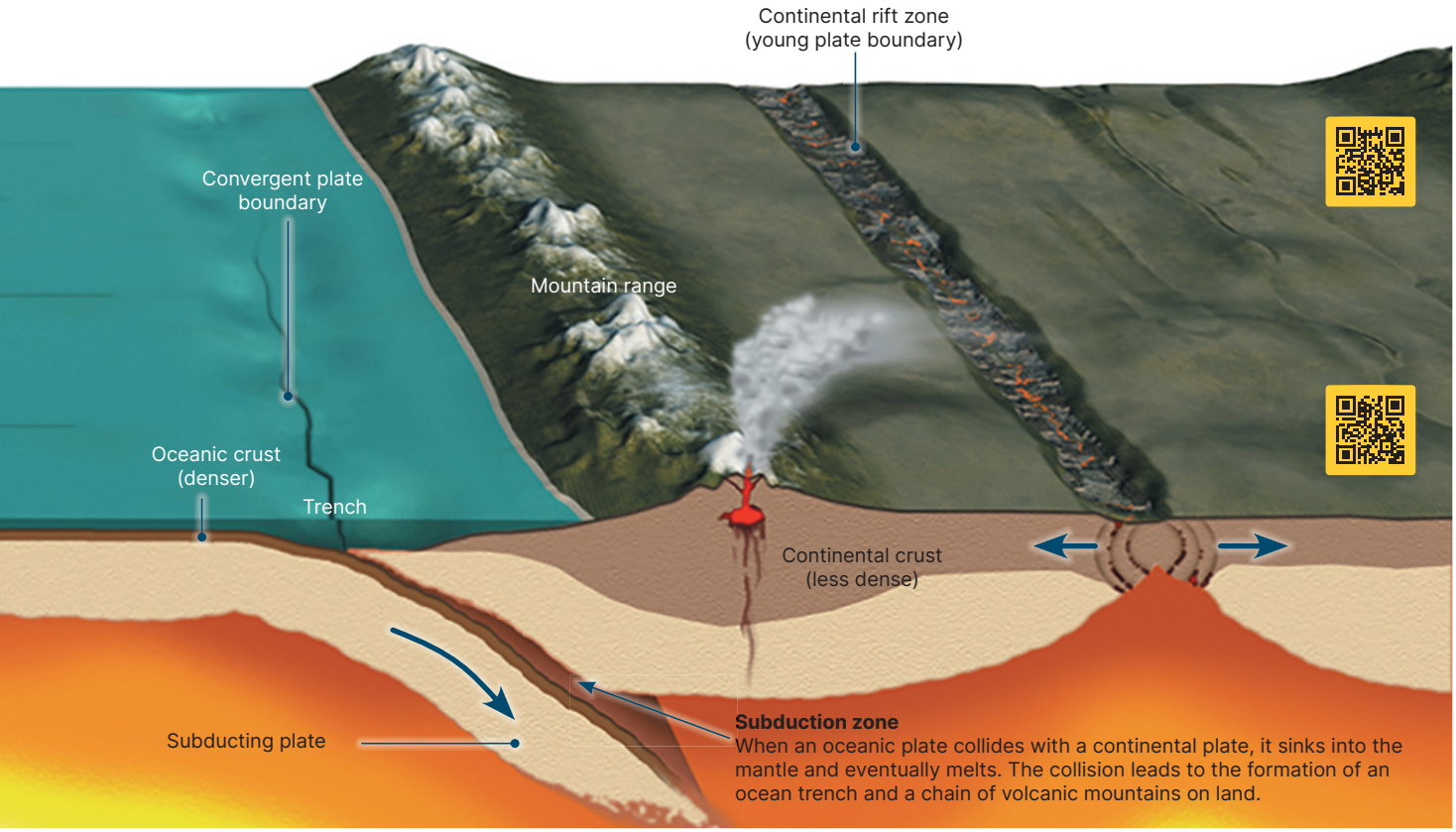
Plate boundaries moving towards each other are called convergent plate boundaries. Where oceanic **crust** and continental crust meet, the oceanic crust will subduct under the continental crust, creating a subduction zone. Volcanoes normally form along the continental border of a subduction zone. When continental crusts collide, huge mountain ranges such as the Himalayas can form.



Divergent plate boundaries form where the tectonic plates are moving away from each other. These are commonly found along the mid ocean ridges, but occasionally are seen on land, as in the Great Rift Valley and Iceland. Divergent boundaries are also known as constructive boundaries as they produce new crust from the upwelling of magma.



Transform boundaries are formed when the tectonic plates are moving past each other. They are, therefore, neither constructive nor destructive. Examples include the San Andreas fault in California and the Alpine Fault in New Zealand.



2. Identify the type of plate boundary at which each of the following occurs:

   (a) Mountain building: _____ (c) Creation of new ocean floor: _____

   (b) Subduction: _____ (d) Island arc: _____

3. (a) Explain why the oceanic crust subducts under the continental crust in a subduction zone:

   _____

   _____

   (b) What causes volcanoes to form along the continental plate boundary of a subduction zone?

   _____

   _____

   _____

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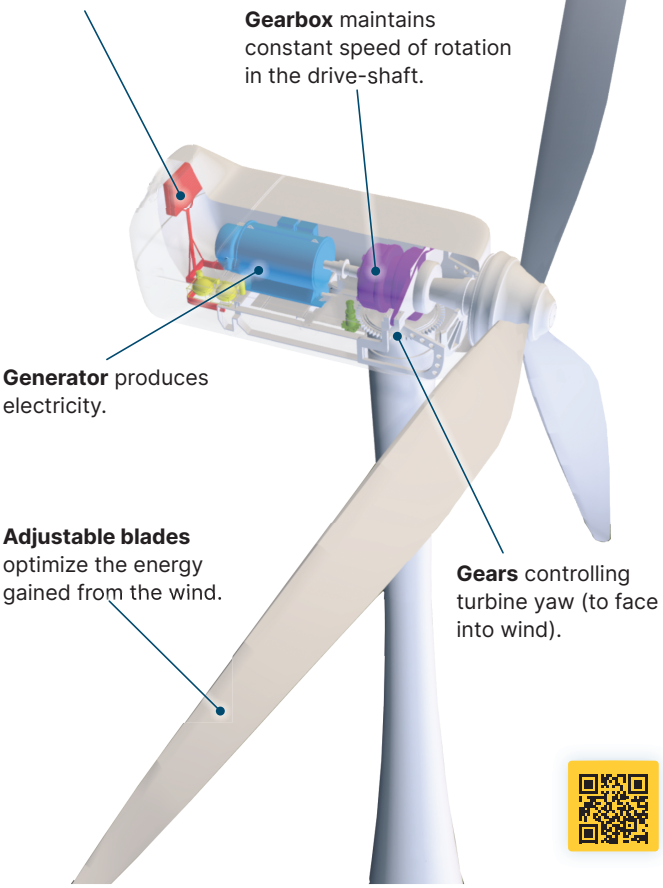
126 Wind Power

Key Idea: Wind power provides a relatively simple and scalable way to produce electricity.

Wind power has been used for centuries to provide the mechanical energy to pump water or run milling machinery. Today, it is mainly used to produce electricity. Wind power is becoming increasingly reliable and cost effective as the technology develops and turbines are able to operate in a range of conditions and wind speeds. In fact, wind energy is one of the cheapest types of energy to build, maintain, and use. Globally, wind power is steadily increasing in generation capacity, but wind is a variable energy provider. There can be problems matching output to demand, such as during seasonal demands and low (or extremely high) winds. This means systems for managing and distributing electricity will be required as well as back up or base load electricity supplies, e.g. hydro or geothermal power.

Wind turbine



Wind farms often cover large areas of land but turbines can be designed to operate at sea and, on a smaller scale, along highway edges. The scalability of wind turbines makes them simple to install in many locations, with turbine sizes ranging from a few meters to over 200 meters in diameter.

At the end of 2022, the power output from wind turbines was around 7% of the global production of electricity. Global installed capacity was more than 800 GW. Electricity generation from wind is rising every year.

1. A typical wind turbine produces around 2.3 MW. The average house uses 30 kWh of energy per day (a kilowatt hour is the equivalent of 1000 joules of energy per second (1kW) running for 1 hour). Calculate the following:

   (a) The minimum number of wind turbines required to power a town of 20,000 households:

   _____

   _____

   (b) Wind turbines cost around $1.3 million per MW of energy production to build. What will the be the cost of (a) above?

   _____

   (c) The cost of building, running, and maintaining wind turbines over their 20 year lifetimes is about $50 per MWh. What could the 20,000 households using the wind turbines above expect to pay in dollars per year for the use of electricity provided by the wind turbines?

   _____

   _____

   (d) Why can households actually expect to pay a lot more than this? _____

   _____

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Environmental effect of wind turbines

- Over their entire life cycle, wind turbines produce some of the lowest greenhouse gas emissions of any electricity production facility. This includes mining of minerals, manufacture and installation, and lifetime use.
- In the same way as solar power plants, wind farms require large, open spaces and therefore tend to be in rural areas. This has led to what is often called 'industrialization of the country' and 'energy sprawl'. This includes the spreading of access roads and transmission networks, all of which affect the visual appeal of the areas around wind farms.
- There is documented evidence of wind farms affecting flying animals, especially where they are placed at the top of hills. Birds and bats following the contours of these hills are struck by the turbine's blades and killed.
- The blades have a service life of between 10 and 20 years and are generally made of fiberglass or, increasingly, carbon fiber. There is no easy way to recycle them so they are disposed of in landfills at the end of their lifecycle.
- Because wind turbines sit on single, tall towers well above the ground, the area underneath them is minimally affected. Therefore, if they are sited on agricultural ground, the land can continue to be used for agriculture (right).

Wind Power	
Advantages	**Disadvantages**
No emissions	Production of visual and noise pollution
Little ground disturbance during or after construction	Requires steady winds
Compact and transportable to most locations	Can interfere with the flight paths of flying animals
Can be located in many areas (even at sea)	Much of actual cost to user is repaying start up costs.
Cost certainty. Operating cost is not affected by fuel prices	Back up systems are required in low winds

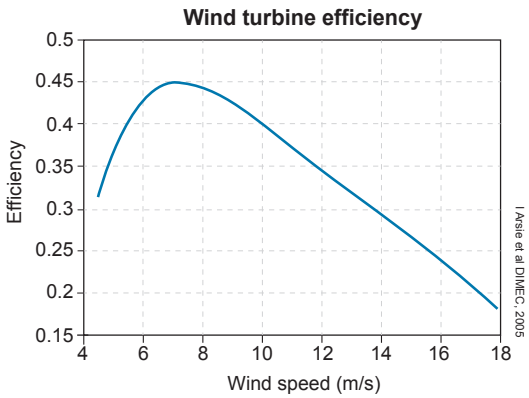
2. A major problem with generating electricity is the effect of the facility on the environment. Describe how wind power solves some of these problems. What problems does it create?

3. Explain why increasing uptake of wind power will require better management of the electrical grid:

4. (a) From the graph on the right, what is the optimum wind speed for wind turbine use?

   (b) What happens to efficiency as wind speed increases?

5. Wind turbine towers have become progressively taller. Suggest why might this help increase reliability of output:



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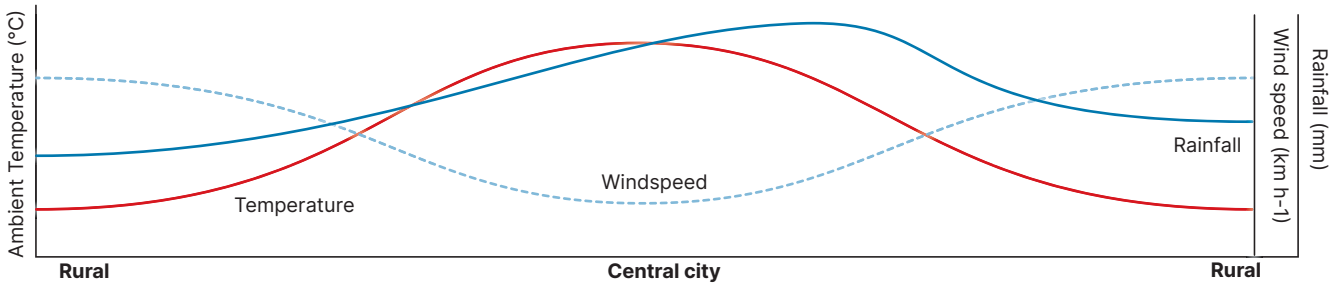
149 Cities and Climate

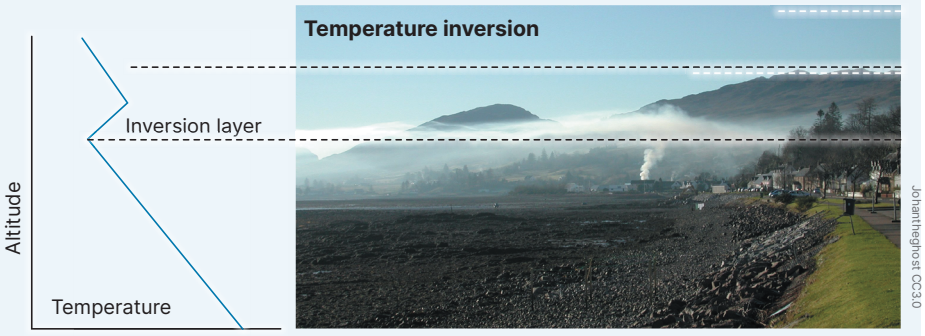
Key Idea: The heat generated from cities can impact the microclimate and trap air pollution in the form of smog.

Cities contain vast amounts of concrete and radiant surfaces so tend to heat up very quickly during the day. This heat modifies the local climate, resulting in quite different weather in and near the city than in the surrounding rural areas, especially in large inland cities. The heat island effect of cities produces a rising current of air, resulting in localized heavier rainfall and higher air temperatures. Photochemical **smog** in cities can cause health problems in some people.



- Most urban areas are covered with concrete, asphalt, and iron so they tend to heat up faster than surrounding rural areas and retain the heat longer. Average temperatures in a city can often be 5-10 °C higher than surrounding rural land.
- City environments also affect rainfall. Hot air rising above a city carries more moisture with it than cool air. Wind moves this air away from the city and, as it cools, the moisture is lost as rain.
- Water runoff after rain is higher in urban environments due to large, paved surface areas. Stormwater systems catch up to 70% of the rain that falls, funnelling it into rivers and causing them to rise and fall rapidly.
- Wind within a city is often hampered or channelled by buildings and some parts of a city act like wind tunnels. However, overall wind speed may be 20-30% lower in the city than in rural areas.

Many areas around the world experience the phenomenon of temperature inversion. This occurs when a layer of warm air sits on top of a layer of cool air and is often seen in valleys. The cool dense air remains close to the ground. When this happens in a city, smoke and other air pollutants can be trapped and concentrated as photochemical smog. This may create serious health issues in some people.



1. (a) Explain why the ambient temperature in a city is often higher than that of the surrounding rural land:

_____

_____

(b) What is the effect of cities on rainfall? _____

_____

2. Explain why an inversion layer above a city can have serious health effects:

_____

_____

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Photochemical smog

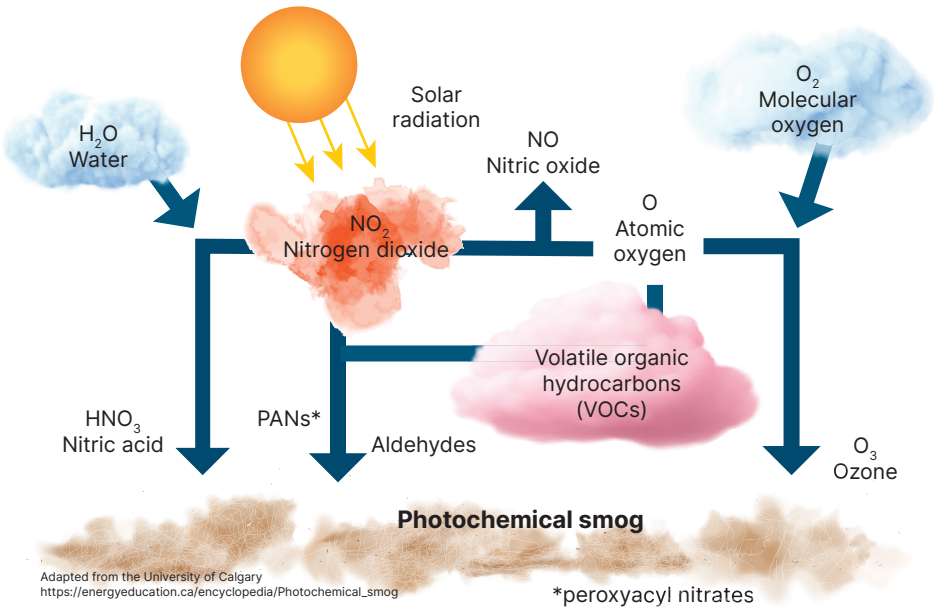
- Smog (a joining of the words smoke and fog) is a type of air pollution.
- Photochemical smog forms mainly in the warmer months. Nitrogen oxides (NOx) from vehicle emissions or pollutants from coal fired industrial processes react in the atmosphere in the presence of sunlight to form secondary pollutants.
- Smog is a serious problem in many large cities around the world as it can cause health problems. It mainly affects the respiratory (breathing) system. Emphysema, asthma, chronic bronchitis, lung infections, and cancers are caused by, or made worse from, exposure to photochemical smog. Eye and nose irritation, birth defects and low birth weights are also linked to prolonged exposure to photochemical smog.

Smog day and clear day (Fanhe, China)

Tomskyinaha CC 4.0

How does photochemical smog form?

- The largest contributor to photochemical smog is vehicle emissions (exhaust fumes). Photochemical smog tends to form in the morning in large cities due to large numbers of people traveling to work in cars and buses, resulting in high vehicle emissions.
- The nitrogen oxides produced by engines enter the atmosphere where, in the presence of sunlight, they react with volatile organic compounds (VOCs), specifically hydrocarbons, to form photochemical smog (below). VOCs are found in the atmosphere as a result of human activity, e.g. burning fossil fuels, and from naturally occurring processes, e.g. they are produced by plants as signaling molecules. A feature of VOCs is that they have a high vapor pressure resulting from a low boiling point. This feature causes VOCs to evaporate (liquid → vapor) or sublimate (solid → vapor) at room temperature so they easily form vapor.
- Nitrogen oxides may also react with sunlight to produce single oxygen atoms (O). These then combine with molecular oxygen (O_2) to produce ozone (O_3). Whereas NO_2 levels peak in the morning, ozone production peaks in mid-late afternoon after the morning exhaust fumes have had time to react in the sunlight. The ozone in photochemical smog is called ground level ozone because it is located relatively close to the ground. This distinguishes it from stratospheric ozone which is formed naturally when sunlight energy splits molecular oxygen (O_2 + sunlight → O + O then O + O_2→ O_3). Ground level ozone is regarded as a pollutant. Other chemicals present in photochemical smog are nitric acid, aldehydes, and PANs (peroxyacyl nitrates).



Adapted from the University of Calgary
https://energyeducation.ca/encyclopedia/Photochemical_smog

Photochemical smog, Mexico, 2010

Fidel Gonzalez cc 3.0

3. Suggest why most cities experience lower levels of smog at weekends compared to weekdays:

4. Use the diagram above to outline how nitrogen oxides form the air pollutants in photochemical smog:

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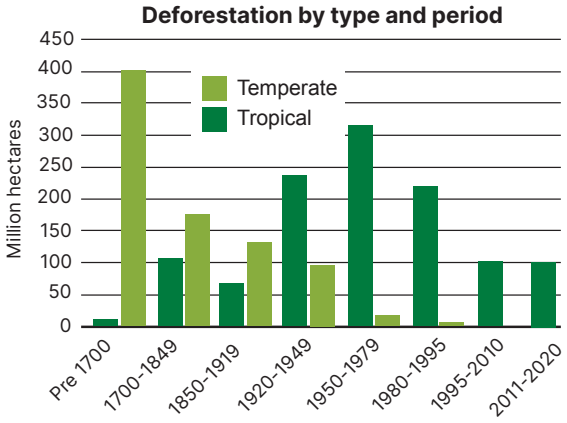
169 Tropical Deforestation

Key Idea: Deforestation continually reduces the world's tropical rainforests, with large areas still at significant risk.

Tropical rainforests account for 45% of the world's forests. They prevail in places where the climate is very moist and warm throughout the year. Almost half of the world's rainforests are in just three countries: Indonesia in Southeast Asia, Brazil in South America, and Zaire in Africa. Much of the world's **biodiversity** resides in rainforests, particularly in **biodiversity hotspots**. **Deforestation** will contribute towards climate change through a large reduction in carbon capture. In the Amazon, 75% of deforestation has occurred within 50 km of Brazil's roads. Many potential drugs could still be discovered in rainforest plants, and loss of **species** through deforestation may mean they will never be found. Rainforests can provide economically sustainable crops for local people.

Deforestation

- At the end of the last glacial period, about 10,000 years ago, forests covered around 45% of the Earth's land surface. Forests now cover about 31% of Earth's surface. These include the cool temperate forests of North and South America, Europe, China, and Australasia, and the tropical forests of equatorial regions.
- Over the last 5000 years, the loss of forest cover is estimated at 1.8 billion hectares. A net loss of around 4.7 million hectares each year of forest has occurred since 2014. Almost 10 million hectares of trees are removed annually and only around half this area is replanted, often with non-native plants.
- Temperate regions where human civilizations have historically existed the longest, e.g. Europe, have suffered the most but now the vast majority of deforestation is occurring in the tropics. Intensive clearance of forests during settlement has extensively altered landscapes and permanently affected biodiversity.



Causes of deforestation

- Deforestation is the end result of many interrelated factors which often center around socioeconomic drivers. In many tropical regions, most deforestation is the result of small scale farming.
- Poverty and a lack of secure land can be partially solved by clearing small areas of forest and creating family plots. However, huge areas of forests have been cleared for agriculture, including ranching and production of palm oil. These produce revenue for governments through taxes and permits, creating an incentive to clear more forest.
- Just 14% of deforestation is attributable to commercial logging, although combined with illegal logging it may be much higher. Removal of trees for fuel accounts for a very small percentage of deforestation.

1. Identify the three main human activities that cause tropical deforestation and briefly describe their detrimental effects:

2. Describe the trend in tropical deforestation compared to temperate deforestation over the last 300 years:

3. Deforestation in tropical regions can be hard to reverse even after plantations and crops have been removed and new trees are planted. Suggest why this might be so:

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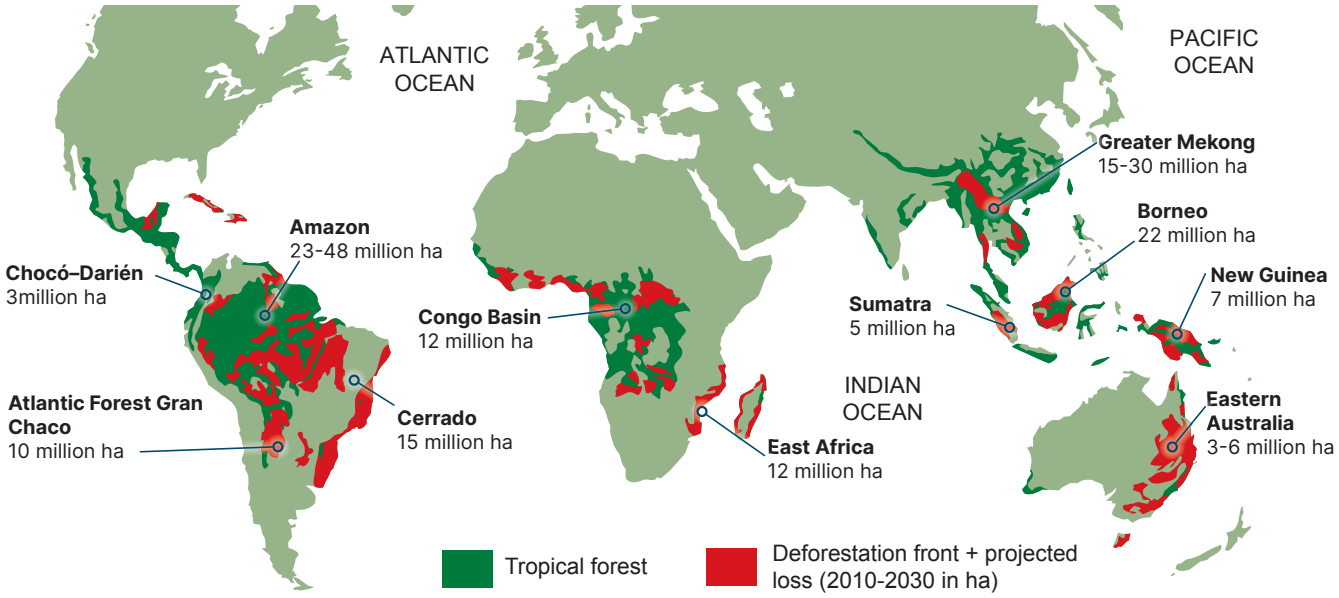
Tropical forest deforestation risk areas - projected 2010-2030



New road to Ilhéus, Bahia, Brazil: The building of new road networks into regions within tropical rainforests causes considerable environmental damage. In areas with very high rainfall there is an increased risk of erosion and loss of topsoil.

Amazon leaf mantis: Up to 80% of Earth's terrestrial species are found in tropical rainforests. Many tropical species are endemic to specific parts of the forest or specific tree species. Loss of these areas could exterminate hundreds of organisms.

Palm oil plantations in deforested rainforest: The soil in tropical rainforests is typically poor and the layer, thin. Once the trees are removed and crops planted, the soil quickly loses its nutrients and productivity decreases within a few seasons.

4. Building roads in tropical forests can have serious negative effects on the forest besides the damage from building the road itself. Suggest why roads through primary forests might be damaging to the ecosystem in the long term:

5. The Borneo orang-utan (*Pongo pygmaeus*) is known as an umbrella species and needs large tracts of land to survive. Suggest some advantages and disadvantages of halting deforestation in Borneo for both animals and humans.

Borneo orang-utan

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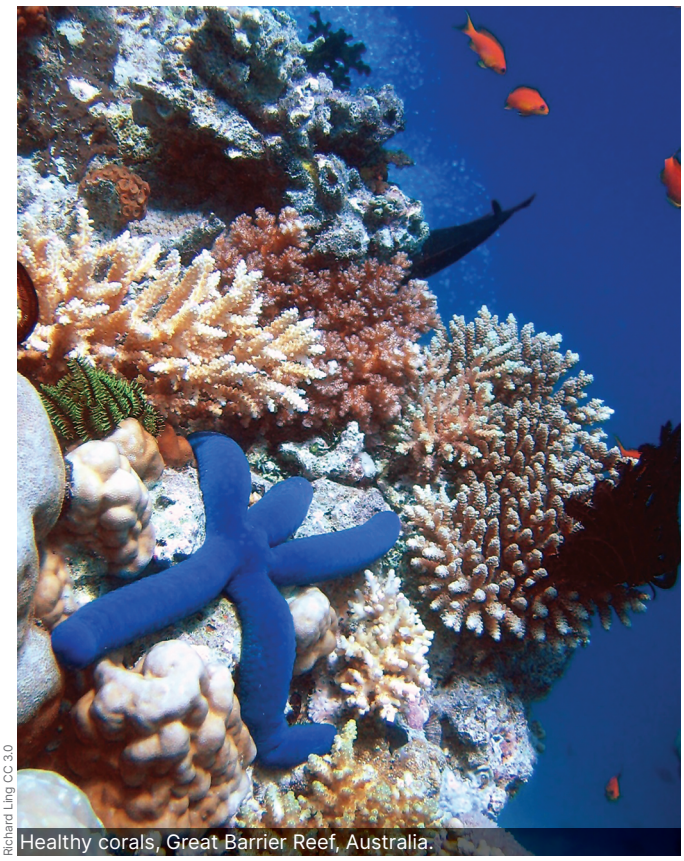
202 Tipping Point: Warm Water Coral Reefs

Key Idea: Warmer oceans are causing thermal stress to coral ecosystems, leading to wide-scale mortality.

An increase in sea temperatures could mean the death of coral reefs. Healthy coral reefs depend on the symbiotic relationship between a coral polyp that builds the reef and photosynthetic organisms called zooxanthellae. Zooxanthellae live within the polyp tissues and provide coral with most of its energy. A 1-2°C temperature increase maintained for weeks is enough to disrupt its photosynthetic enzymes. The zooxanthellae either die or are expelled from the coral. The result is **coral bleaching**. Some coral bleaching is reversible if water temperature cools once more to tolerance levels but this process is much slower than the original bleaching event. If the temperature remains outside tolerable levels, the coral dies. Coral bleaching events can impact more than just the organisms themselves. The coral is essential for transfer of energy through the food chain as it provides habitats for other species to live, breed, and be protected. Although the **tipping point** of each coral reef system is regional and dependent on the temperature of the surrounding ocean, the extent of coral bleaching world-wide has made it a global phenomenon.



Richard Ling CC 3.0

Healthy corals, Great Barrier Reef, Australia.

Coral bleaching in the Great Barrier reef

- Great Barrier Reef, off the coast of eastern Australia, is the largest warm water coral system in the world. It is formed from a patchwork of over 2,900 individual reefs.
- The Great Barrier Reef has experienced five mass bleaching events since 2016, the latest in 2024.
- In some regions of the reef, only a few small areas of coral in deeper water were unaffected by bleaching.
- Record, warm ocean temperatures around the reef, linked to **anthropogenic climate change** by scientists, have coincided with past bleaching events.

Bleaching and dead coral on the Great Barrier Reef, Australia.

1. Summarize the link between ocean warming and coral bleaching:

,

2. Coral ecosystems provide a habitat to around 25% of all marine organisms, including photosynthesizing plankton and bacteria, while only occupying 1% of the ocean. They act as a nursery for many open ocean species of fish. What would be some likely consequences of the coral reefs reaching their climate tipping point?

3. Ocean heatwaves are occurring more frequently. How does that impact a corals reef's ability to recover?

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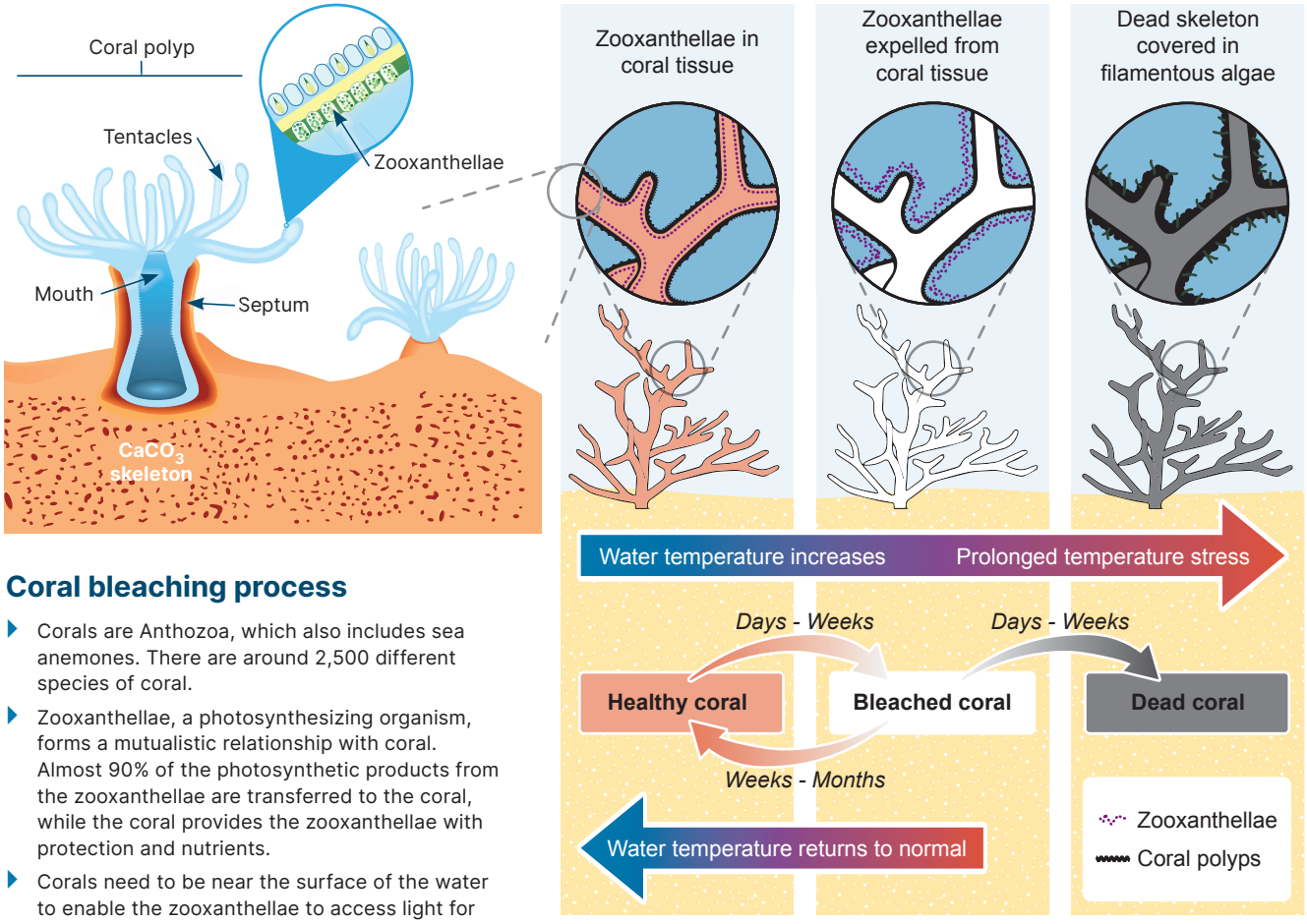

Coral bleaching process

- Corals are Anthozoa, which also includes sea anemones. There are around 2,500 different species of coral.
- Zooxanthellae, a photosynthesizing organism, forms a mutualistic relationship with coral. Almost 90% of the photosynthetic products from the zooxanthellae are transferred to the coral, while the coral provides the zooxanthellae with protection and nutrients.
- Corals need to be near the surface of the water to enable the zooxanthellae to access light for photosynthesis. This surface water warms quickly.
- Increased light and warmth increase the photosynthetic rate of zooxanthellae, overwhelming the coral polyps with waste material. The expulsion of zooxanthellae by the coral occurs as a stress mechanism to avoid tissue damage.
- The removal of zooxanthellae is called bleaching and the coral appears as a distinctive white color. This is because the zooxanthellae pigments give the coral their bright colors.
- Corals can survive in a bleached state for only a limited number of weeks and starve without the zooxanthellae.

Coral bleaching as a tipping point

- Climate scientists project that around 70-90% of warm water corals will be lost once the global temperature threshold reaches 1.5°C for a sustained period. Around 99% of corals will disappear at just half a degree more.
- Some corals are resilient and the zooxanthellae can return once ocean waters cool. However, once enough coral has died because of prolonged temperature stress, a tipping point will be reached where the coral ecosystem will fail to recover. Coral will not reproduce and spawn, therefore there will be no larvae to regenerate new coral colonies. The system will typically tip into a different algae dominated ecosystem.

4. Why does the death of the coral in an area often lead to a tipping point, while this is not necessarily the case with bleached coral?

5. Why are warm water corals particularly vulnerable to ocean temperature increases?

6. Observe the images of coral reefs on the previous pages. What are some observable differences between bleached and healthy coral? Discuss in pairs and note your ideas below:

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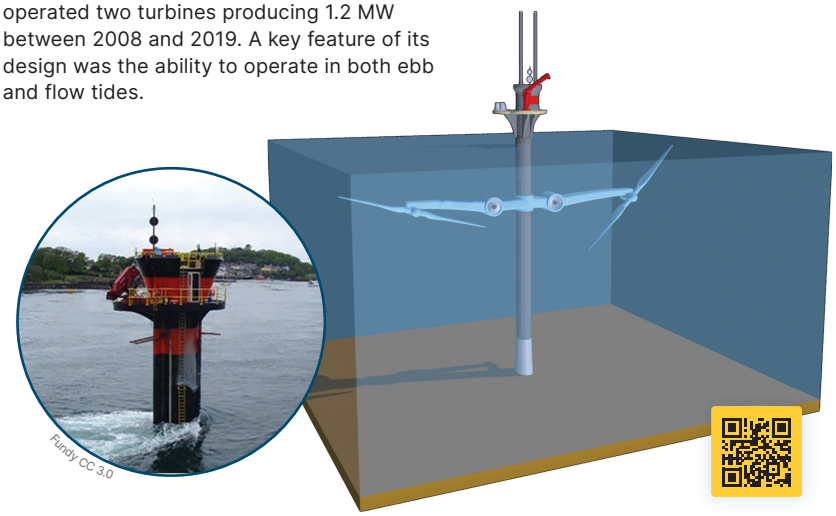
130 Ocean Power

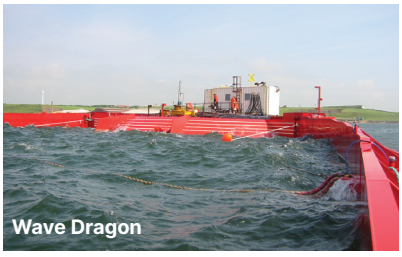
Key Idea: The energy in tides and waves can be used to provide a source of electricity but designing equipment to withstand the sea is difficult.

An enormous amount of energy is stored in the world's oceans. Twice daily, tides move huge volumes of water up and down the coasts of the continents and billions of joules of energy are transferred when waves meet the shore. Many of the world's energy problems might be solved if this energy could be harnessed but problems abound in achieving this. Machinery to harness tidal or wave energy requires certain shoreline contours and seabed features and regular swells. It must also be able to withstand constant immersion in seawater and the relentless and often unpredictable movement of the sea. Many designs have been proposed to exploit various types of seawater movement. While some have shown promise, most have not proved economically viable and there are also concerns over effects on marine life and shorelines. For these reasons, ocean power is unlikely to contribute much to future world energy needs.

Machines to harness tidal or wave energy

The simplest designs for harnessing tidal power use **underwater turbines** which exploit the currents produced by tides. These operate in much the same way as wind turbines. The largest of these designs has been the SeaGen (below). This operated two turbines producing 1.2 MW between 2008 and 2019. A key feature of its design was the ability to operate in both ebb and flow tides.

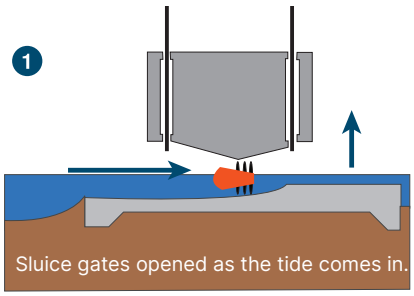


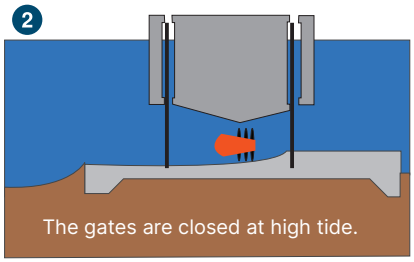


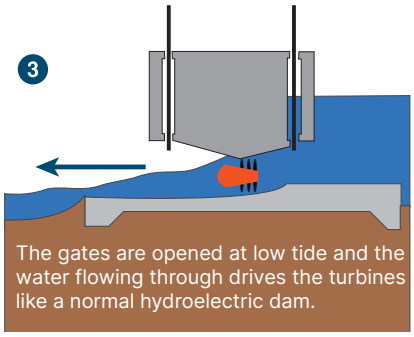
Erik Friis-Madsen CC 3.0

- Producing electricity from wave movement is extremely difficult. Developers must take into account wave height and period. These vary almost continuously, sometimes subtly and sometimes by extremes. Unlike many tidal power stations, wave powered systems need to withstand continual pounding by waves.
- Very few designs have proved economically viable or been able to operate for more than a few years. Pelamis was a promising but ultimately uneconomic design. Wave Dragon is still undergoing testing.

Tidal barrages require several meters of tidal difference, and potentially destroy the estuaries across which they are built. The largest is the Sihwa Lake Tidal Power Station powerplant with an output of 254 MW. It cost over $500 million dollars to build.







1. Describe the technical problems associated with producing energy from the sea:

2. Describe the potential benefits of harnessing ocean power:

3. Explain why ocean power is unlikely to ever produce much of the world's energy:

GR

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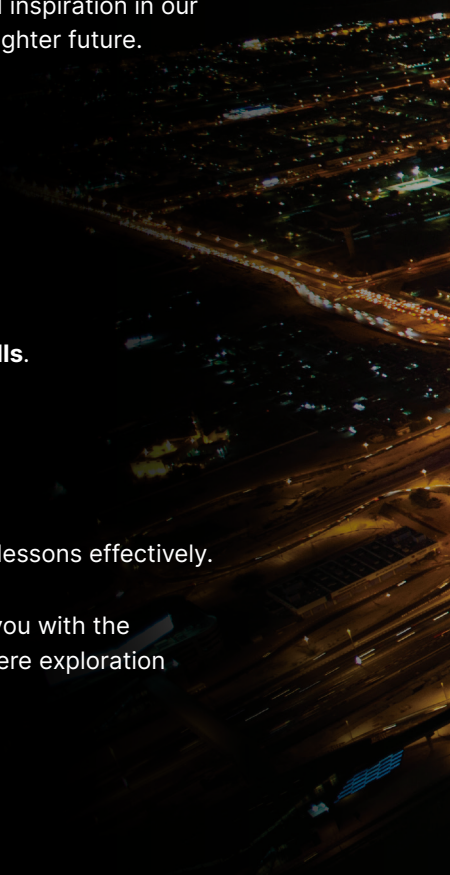

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