# 1.4 Water, carbon, climate and life on Earth

Carbon forms the key component for all known life on Earth. It bonds with other elements such as oxygen, hydrogen and nitrogen to form complex molecules. Water too makes life as we know it possible. Every drop cycles continuously through air, land and sea to be used by someone (or something) else in the cycle. Although there is a lot of water on Earth, only a fraction of one per cent supports all life on land. Climate change and growing populations are increasing the pressures on that reserve.

## Water and carbon cycles and the atmosphere

As stated above, the increased emission of $CO_2$ is warming the atmosphere. This increased temperature results in higher evaporation rates and a wetter atmosphere, which leads to a positive feedback situation of further warming. Carbon dioxide causes about 20 per cent of the Earth's greenhouse effect, water vapour accounts for about 50 per cent and clouds 25 per cent. The rest is caused by small particles (aerosols) and minor greenhouse gases like methane.

When carbon dioxide concentrations rise, air temperatures go up. The oceans warm up and more water vapour evaporates into the atmosphere, which then amplifies greenhouse heating. Although $CO_2$ contributes less to the overall greenhouse effect than water vapour, scientists have found that it is $CO_2$ that sets the temperature. It controls the amount of water vapour in the atmosphere and therefore the size of the enhanced greenhouse effect.

This is summarised in Figure 1.56.

This rise in temperature is not all the warming that we will see based on current $CO_2$ concentrations. There is a time lag between the increase in $CO_2$ and increased warming because the ocean soaks up heat. This means that the Earth's temperature will increase at least another 0.6 °C because of carbon dioxide already in the atmosphere.

## Climate change mitigation

This refers to efforts to reduce or prevent emission of greenhouse gases. The various means of mitigation are summarised in Figure 1.57.

### Carbon capture and sequestration (CCS) technologies

Carbon capture and storage (CCS) is a technology that can capture up to 90 per cent of $CO_2$ emissions produced from the use of fossil fuels in electricity generation and industrial processes, preventing the carbon dioxide from entering the atmosphere.

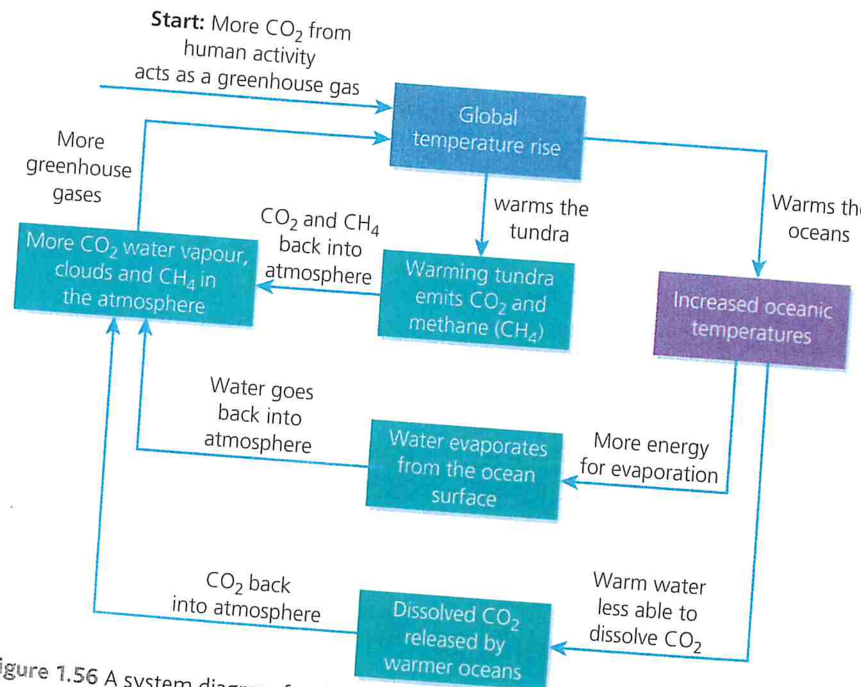


**Figure 1.56** A system diagram for the impact of water and carbon on climate change showing positive feedback

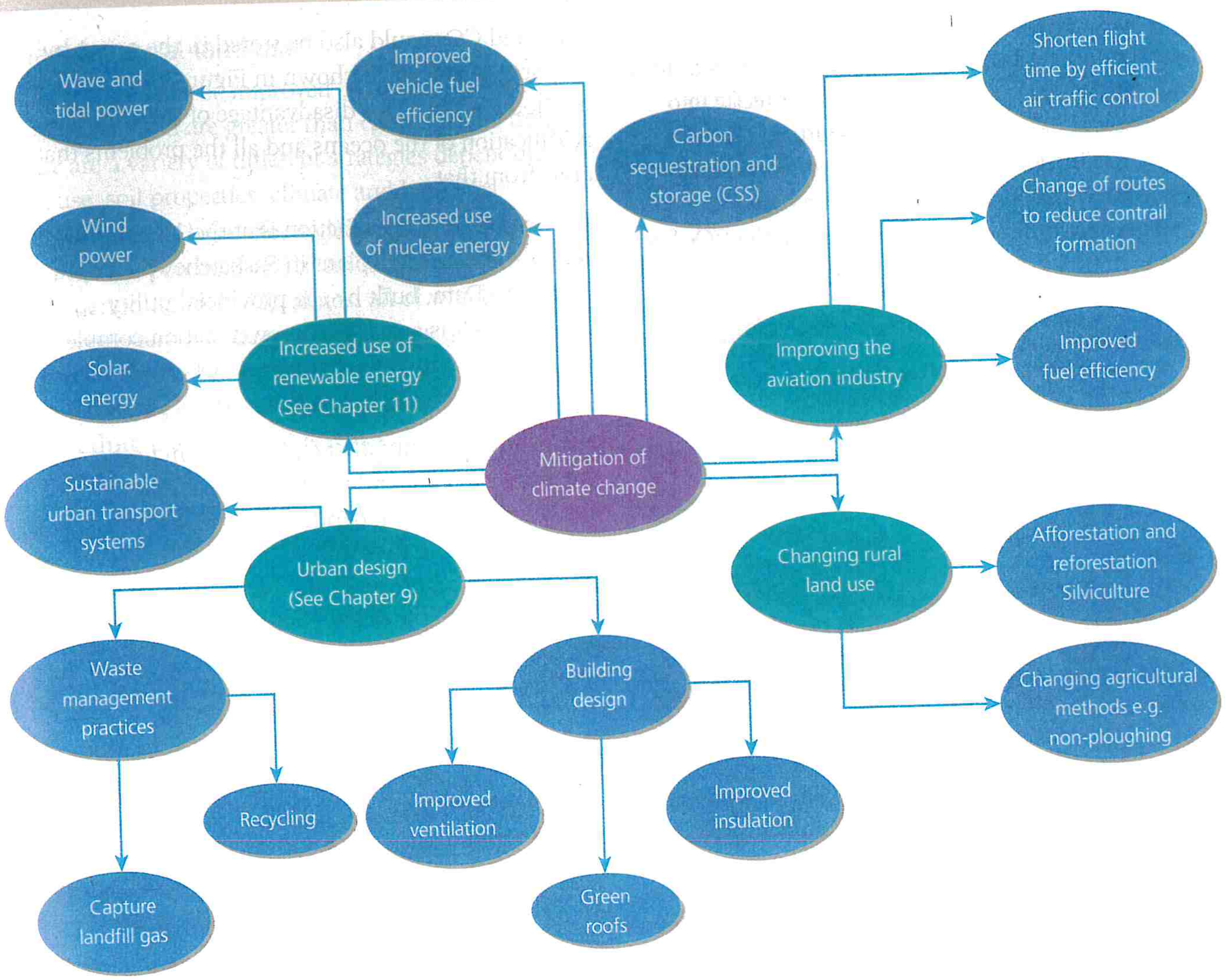


Figure 1.57 Management of climate change

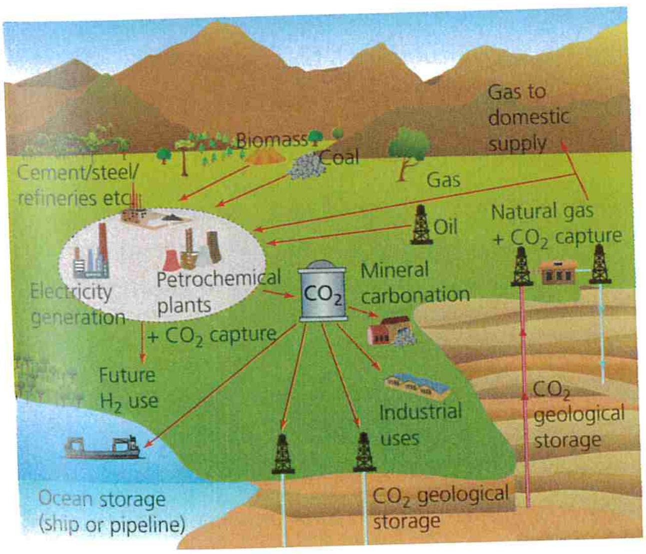


Figure 1.58 Possible CCS systems

The CCS chain consists of three parts (see Figure 1.58):

- **Capturing** the $CO_2$: Capture technologies allow the separation of $CO_2$ from gases produced in electricity generation and industrial processes by one of three methods: pre-combustion capture, post-combustion capture and oxy-fuel combustion.
- **Transporting** the $CO_2$ by pipeline or by ship to the storage location: Millions of tonnes of $CO_2$ are already transported annually for commercial purposes by road tanker, ship and pipelines.
- Securely **storing** the carbon dioxide emissions underground in depleted oil and gas fields, deep saline aquifer formations several kilometres below the surface or the deep ocean.

CCS systems could be used to extract a greater percentage of oil and gas out of existing reservoirs by the $CO_2$ being injected under such pressure as to force the oil or gas out. Although this would partly pay for the CCS technology, it would also enhance the original problem by producing more fossil fuel for burning. When $CO_2$ is stored in deep geological formations it is known as **geo-sequestration** (see Figure 1.59, page 42).

$CO_2$ is converted into a high pressure liquid-like form known as 'supercritical $CO_2$' which behaves like a runny liquid. This supercritical $CO_2$ is injected directly into sedimentary rocks. The rocks may be in old oil fields, gas fields, saline formations or thin coal seams. Various physical (for example, impermeable 'cap rock') and geochemical trapping mechanisms prevent the $CO_2$ from escaping to the surface.

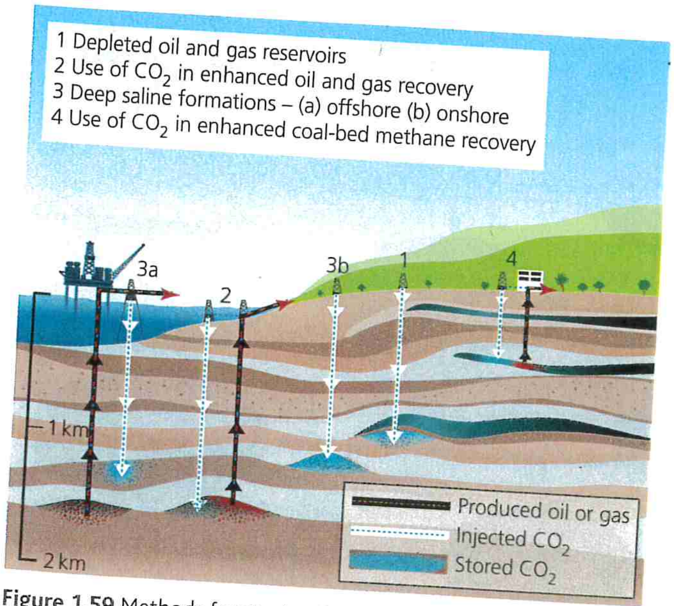


**Figure 1.59** Methods for storing $CO_2$ in deep underground geological formations

*Source: IPCC*

Captured $CO_2$ could also be stored in the ocean by a variety of means, as shown in Figure 1.60. This method has the main disadvantage of the $CO_2$ causing acidification of the oceans and all the problems that arise from that.

An example of CCS in action is at the 110-megawatt coal power and CCS plant in Saskatchewan, called Boundary Dam, built by the provincial utility SaskPower. It is a coal-fired power station complex that has been retrofitted to capture 90 per cent of its $CO_2$ output (approximately 1 million tonnes per year).

The $CO_2$ will eventually be piped 66 km to the Weyburn Oil Unit and injected into an oil-bearing formation at 1,500 m depth. This will add pressure to the oil-bearing rock and so help push more oil out of the ground, a process called enhanced oil recovery (EOR). Until that is ready it will be injected into local salt formations. The capture process was started in October 2014 and $CO_2$ injection started in April 2015.

CCS imposes big costs and energy penalties: the Boundary Dam plant's CCS unit cost $800 million to build and consumes 21 per cent of the coal plant's power output in order to scrub out the carbon dioxide and compress it into a liquid for burial. It is hoped that this extra cost will be offset by the extra oil recovered from the Weyburn oil field.

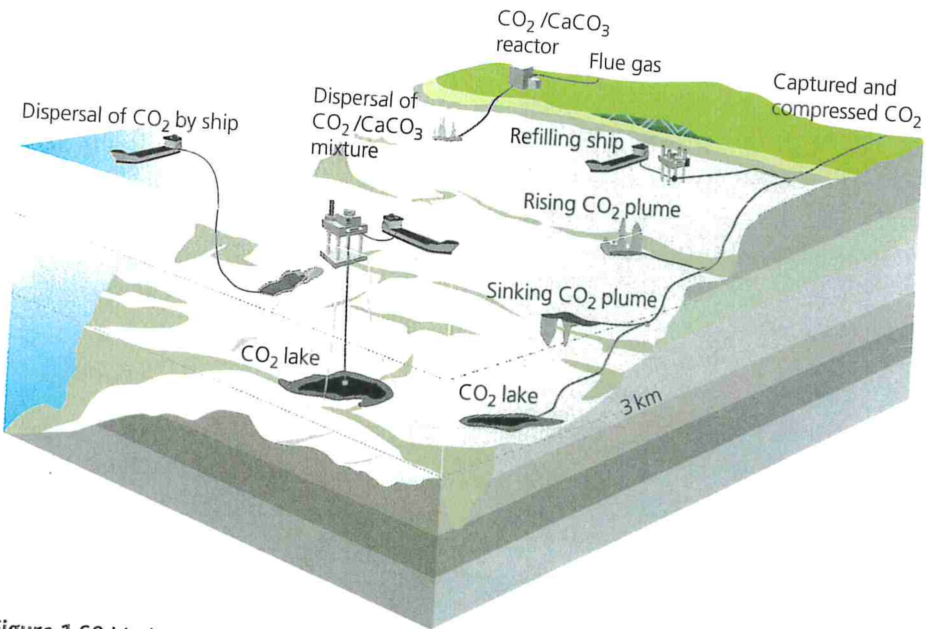


**Figure 1.60** Methods of ocean storage

*Source: IPCC*

## Changing rural land use

Carbon stores can be improved by ensuring that carbon inputs to the soil are greater than carbon losses from it. There are a variety of different strategies depending on land use, soil properties, climate and land area.

- **Grasslands:** These offer a global greenhouse gas mitigation potential of 810 million tonnes of $CO_2$ (in the period up to 2030), almost all of which would be sequestered in the soil. Soil carbon storage in grasslands can be improved by:
  - avoidance of **overstocking** of grazing animals
  - **adding manures and fertilisers** that have a direct impact on **soil organic carbon (SOC)** levels through the added organic material. There are also the indirect benefits of increasing plant productivity and stimulating soil biodiversity (for example with earthworms that help degrade and mix the organic material)
  - **revegetation**, especially using improved pasture species and legumes, can increase productivity, resulting in more plant litter and underground biomass, which can add to the SOC stock
  - **irrigation** and water management can improve plant productivity and the production of SOM.
- **Croplands:** Techniques for increasing SOC include the following:
  - **Mulching** can add organic matter. If crop residues are used, mulching also prevents carbon losses from the system.
  - **Reduced or no tillage** (ploughing and harrowing) avoids the accelerated decomposition of organic matter and depletion of soil carbon that can otherwise occur. Reduced tillage also prevents the break-up of soil aggregates that protect carbon.
  - Some **use of animal manure** or chemical fertilizers can increase plant productivity and thus SOC.
  - **Rotations of cash crops** with pasture or the use of cover crops and green manures have the potential to increase biomass returned to the soil.
  - Using **improved crop varieties** can increase productivity above and below ground, as well as increasing crop residues, thereby enhancing SOC.
- **Forested lands and tree crops:** Forests are able to reduce $CO_2$ emissions to the atmosphere by storing large stocks of carbon both above and below ground.
  - **Protection** of existing forests will preserve current soil carbon stocks.
  - **Reforesting** degraded lands and increasing tree density in degraded forests increase biomass density and therefore carbon density, above and below ground.
  - **Trees in croplands** (silviculture) and orchards can store carbon above and below ground. $CO_2$ emissions can be reduced if they are grown as a renewable source of fuel.

This is summarised in Figure 1.61

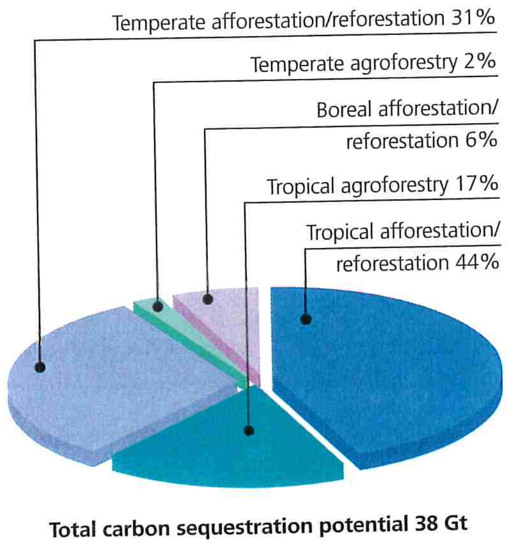


**Figure 1.61** Potential contribution of afforestation/reforestation and agroforestry activities to global carbon sequestration, 1995–2050

*Source: IPCC*

It is important to note that many of these mitigation schemes have different and unwanted side effects.

## Improved aviation practices

In 2013, the global aviation industry carried 3 billion passengers, producing 705 million tonnes of $CO_2$. Although the industry has made major strides in reducing its production of $CO_2$ (for example, the Airbus A380 and the Boeing 787 both use less than three litres of fuel per 100 passenger km), the EU Directorate General for Climate Action predicts that by 2020 the global emissions of $CO_2$ will be 70 per cent more than in 2005 and could be 300 to 700 per cent more by 2050.

The ways that they could reduce their emissions are shown in Figure 1.62 (page 44). These must be treated with caution because many of them are still at the aspirational or theoretical stage.

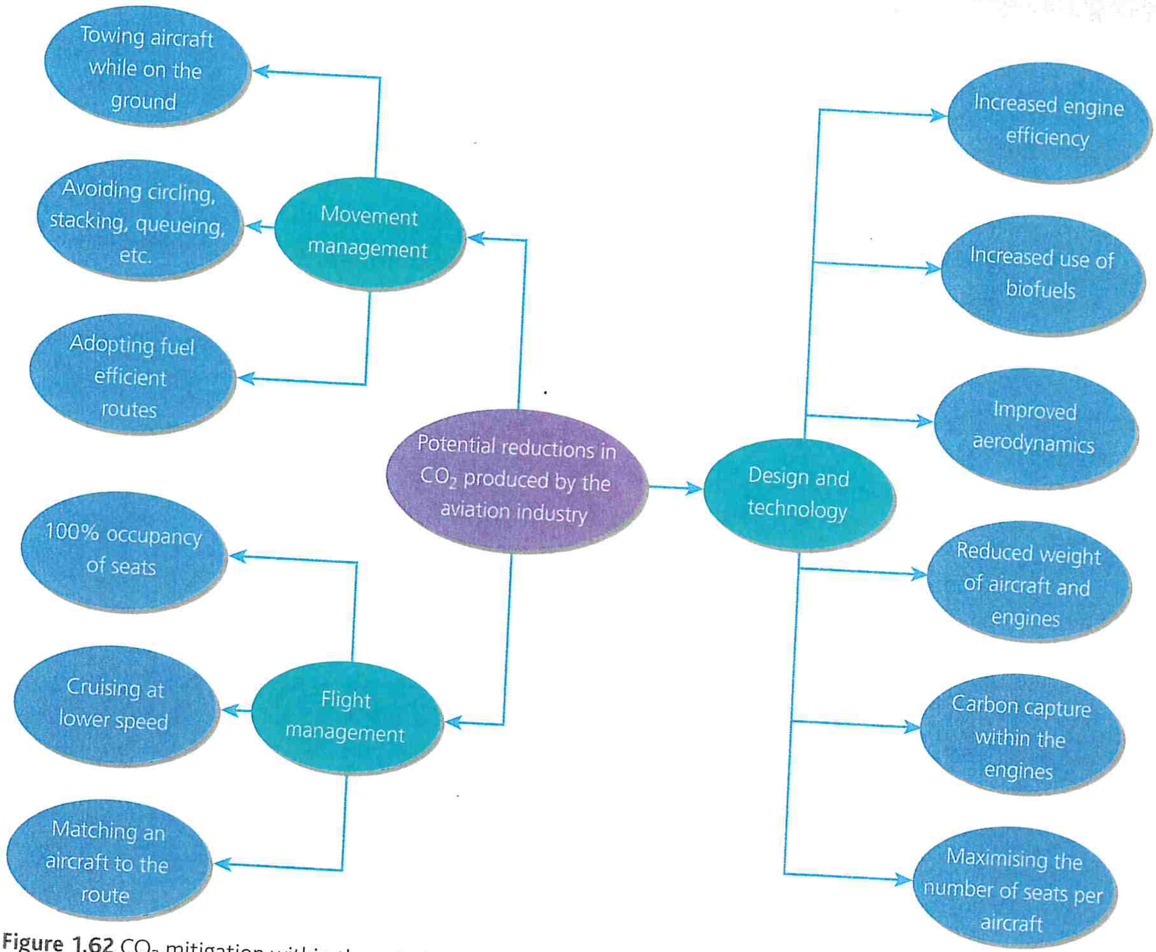


**Figure 1.62** $CO_2$ mitigation within the aviation industry

## Case study of a tropical rainforest setting: Water and carbon in the Amazon

The Amazon Basin is the world's largest rainforest and one of the most biodiverse. Its 300 billion trees and 15,000 species store one-fifth of all the carbon in the planet's biomass. Tropical forests have been present in South America for millions of years and were at one point spread over most of the continent. In the past the forest has shrunk back and then advanced again as ice ages came and went. Today's Amazon rainforest covers around 5.5 million km² and is spread across nine countries.


**Figure 1.63** The location of the Amazon rainforest

# 1.14 Mitigating the impacts of climate change

In this section you will learn how human intervention in carbon cycle transfers can mitigate the impacts of climate change

## Which carbon cycle transfers can be modified by human intervention?

### Modifying industrial combustion

Carbon capture and storage (CCS) uses technology to capture carbon dioxide emissions from coal-fired power stations and industry. The gas is then transported it to a site where it can be stored and prevented from entering the atmosphere. Scientists estimate that this could cut global carbon emissions by up to 19 per cent.

Figure **1** shows how carbon capture works. Once captured, the carbon gas is compressed and transported by pipeline to an injection well. It is then injected as a liquid into suitable geological reservoirs, such as underground aquifers and deposits of fossil fuels.

In 2014 Boundary Dam in Canada's Saskatchewan province became the world's first commercial carbon capture coal-fired power plant (Figure **2**). It aims to cut carbon dioxide emissions by 90 per cent by trapping $CO_2$ underground before it reaches the atmosphere. Saskatchewan's state-owned electricity provider expects to reduce greenhouse gas emissions by about 1 million tons a year, the equivalent of 250 000 cars.

CCS is viewed with suspicion by environmental campaigners because its economic viability, so far, depends on using the $CO_2$ to increase oil production (it can be used to force oil out of the ground). Several projects have been initiated, but face long delays and cost overruns.

### Modifying photosynthesis

Trees act as carbon sinks, removing carbon dioxide from the atmosphere through photosynthesis and storing it within their biomass or the soil. Trees also release moisture into the atmosphere and help to moderate the Earth's climates. Plantation forests, which comprise an estimated 7 per cent of the global forest area, are particularly effective in absorbing carbon dioxide compared to natural forests. For some time, this has been recognised by the IPCC as a legitimate option for countries wishing to reduce their carbon emissions.

### Modifying land use change

Farming practices are the most common cause of land-use change, apart from deforestation. *Carbon farming* is where one type of crop is replaced by another that has greater productivity and can absorb more carbon dioxide from the atmosphere.

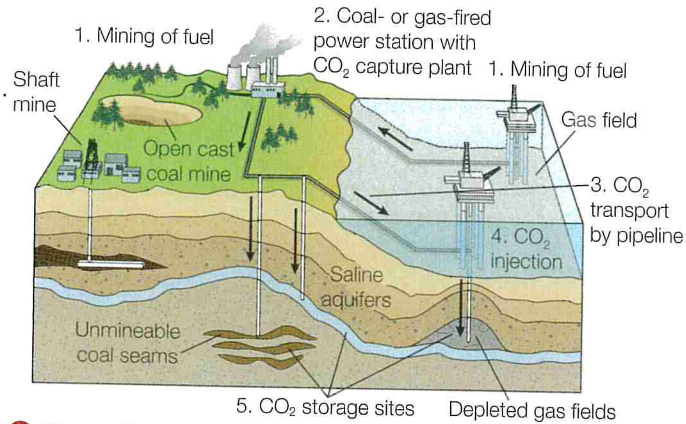


**Figure 1** *Carbon capture and storage*

**Figure 2** *The Boundary Dam CCS power station, Canada*

**Protecting mangroves in Sri Lanka**

In 2015 Sri Lanka became the first nation to protect all of its mangrove forests. Having lost an estimated 76 per cent during the last century, the government decided to conserve the remaining forests and seek to expand their coverage.

Mangroves absorb more carbon dioxide than other forests and fix it into the soil where it is stored for hundreds of years. Furthermore, mangrove forests do not burn due to the swampy environment and the lack of fuel.

The project will cost £2.2 million over five years and will protect over 21 000 acres of mangrove forest. A further 9 600 acres will be replanted.

## Modifying deforestation

There are several strategies aimed at reducing the rate of deforestation, which is a major cause of carbon emissions.

- Consumers are encouraged to only buy wood certified by the Forestry Stewardship Council (FSC) – timber products that have been grown sustainably.
- Countries, organisations and individuals make carbon offset payments to offset their carbon emissions. This might involve paying for existing forests to be protected, developing renewable energy alternatives or planting trees.
- In Malaysia, the Selective Management System is a sustainable approach to logging by felling selected trees and planting replacements.

### Government policies in Brazil

In 2005 the government of Brazil decided to slash the rate of deforestation by 80 per cent (Figure **3**). Landowners are now required to preserve 80 per cent of virgin forest. Infringements are punished by large fines or imprisonment.

Grants for agricultural enterprises are prohibited in areas where deforestation is taking place and farmers are encouraged to be more productive with the land they already use. The government has created protected reserves in the Amazon along frontier areas where deforestation had started.

So far, Brazil has reduced deforestation by 70 per cent and, as a result, has reduced its carbon emissions more than any other country in the world.

**Figure 3** *Cattle grazing on cleared land at the edge of Brazilian rainforest*

### Political initiatives: the Paris Agreement

At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first universal legally binding global climate deal, due to be enforced by 2020. The agreement sets out an action plan.

- Aim to limit the average global temperature increase to 1.5 °C above pre-industrial levels.
- Meet every five years to set more ambitious targets.
- Report to each other and the public on the implementation of their individual plans to reduce emissions.
- Strengthen the ability to adapt to and be resilient in dealing with the impacts of climate change.
- Provide adaptation support for developing countries.
- Developed nations will continue to support initiatives in developing countries aimed at reducing emissions and building in resilience to the impacts of climate change.

## ACTIVITIES

**1** Study Figure **1**.

S **a** Draw a simplified version of the diagram and add detailed annotations to describe the process of carbon capture.

**b** Consider the advantages and disadvantages of carbon capture in reducing carbon emissions.

**2** Describe the reasons why the Sri Lankan government has decided to protect and extend the coverage of mangrove forests.

**3** What is carbon farming and how does it modify carbon transfers?

**4** Reflect on the outcomes of the Paris summit in 2015. Find out the latest situation and discuss whether the agreement is likely to work.

## STRETCH YOURSELF

Find out more about carbon capture and storage. The technology has been around for some time, so why has there been little commercial development? What hurdles need to be overcome and why isn't it popular with environmentalists? Do you think it will ever become a widely accepted alternative?