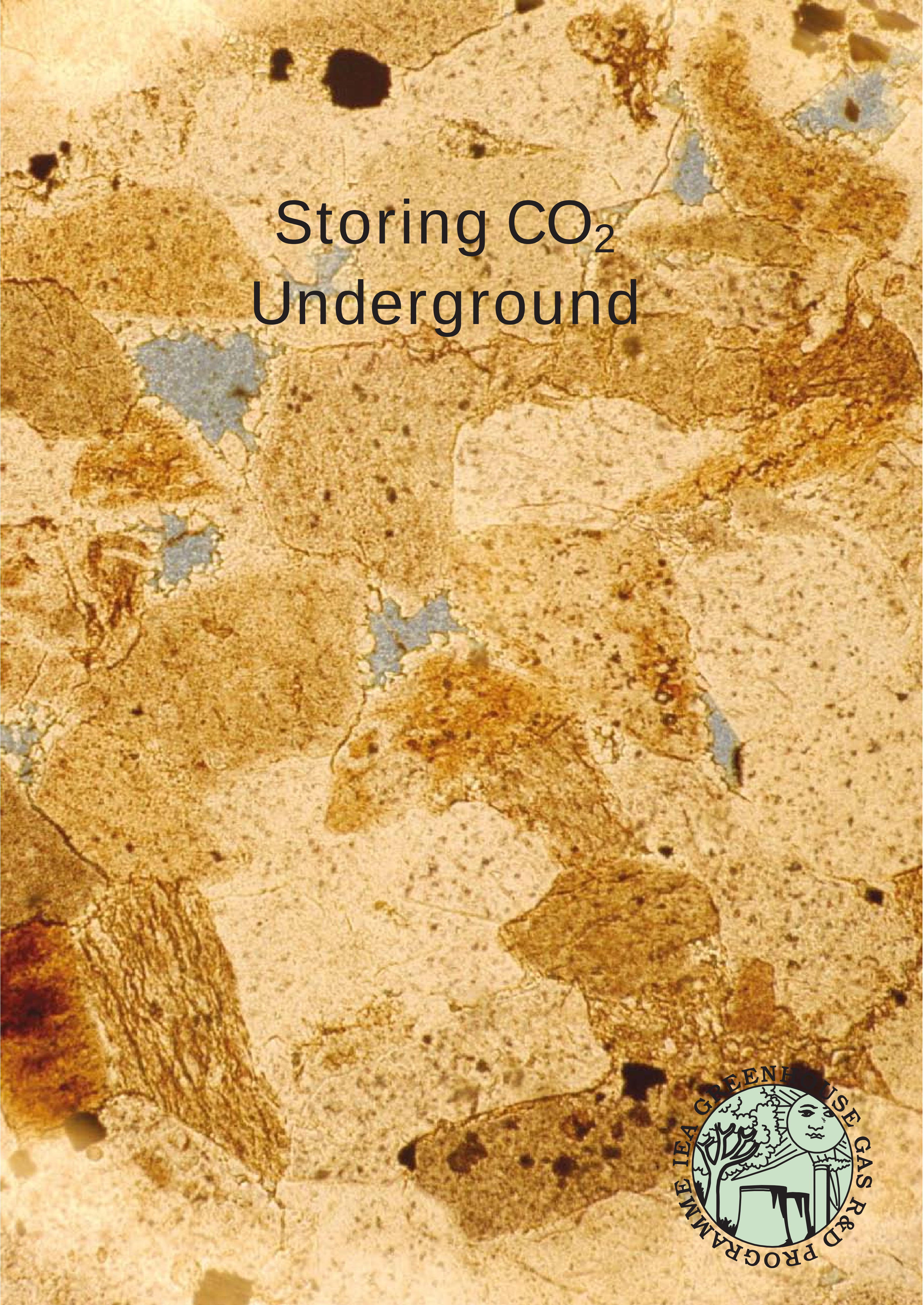
Storing CO_2 Underground



IEA GREENHOUSE GAS R&D PROGRAMME

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. The IEA fosters co-operation amongst its 26 member countries and the European Commission, and with the other countries, in order to increase energy security by improved efficiency of energy use, development of alternative energy sources and research, development and demonstration on matters of energy supply and use. This is achieved through a series of collaborative activities, organised under more than 40 Implementing Agreements. These agreements cover more than 200 individual items of research, development and demonstration. The IEA Greenhouse Gas R&D Programme is one of these Implementing Agreements.

Disclaimer

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Cover Picture : Photograph of sandstone from deep underground in Canada magnified over 100 times. This is the type of rock that could be used for CO_2 storage - the CO_2 becomes trapped in the pore spaces (highlighted in blue) between the grains of rock.

CONTENTS

INTRODUCTION

Carbon dioxide (CO_2) is the main cause of global warming and the level of CO_2 in the earth's atmosphere is rising as a result of human activities. Experts agree that a range of actions will have to be taken soon in order to reduce the amount of CO_2 entering the atmosphere. Part of the solution could be to capture millions of tonnes of CO_2 produced by industrial processes and store the CO_2 deep underground - this is known as CO_2 Capture and geological Storage (CCS). This booklet explains the geological storage of CO_2 and answers the most frequently asked questions:

- Can CO_2 be stored deep underground?
- What difference could CCS make to global warming?
- How can CO_2 be captured from industry?
- Where can CO_2 be geologically stored?
- Why does CO_2 stay underground?
- Where are the good geological storage sites?
- Where is CO_2 geological storage happening today?
- What is the future of CO_2 geological storage?

More detailed information is available from the United Nations Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Dioxide Capture and Storage (www.ipcc.ch).

CAN CO_2 BE STORED DEEP UNDERGROUND?

Several projects are already storing millions of tonnes of CO_2 underground and many more are now being planned (see pages 10 and 11 for details). Oil and gas companies have many decades experience of storing natural gas deep underground and using CO_2 in oilfields, to 'push' oil towards producing wells - a technique known as Enhanced Oil Recovery (EOR). The success of these projects provides a great deal of confidence in the potential to store large quantities of CO_2 underground - safely and securely. Using CCS on an industrial scale to reduce CO_2 emissions involves adapting technologies that already exist and are widely used by several industries (such as fertilizer manufacture and oil production).

WHAT DIFFERENCE COULD CCS MAKE?

The IPCC graphs below show the vital role that CCS could play to help reduce CO_2 emissions during this century (along with other techniques such as renewable energy and improved energy efficiency). In each case, CCS contributes around a quarter of the emissions reduction required to control global warming.

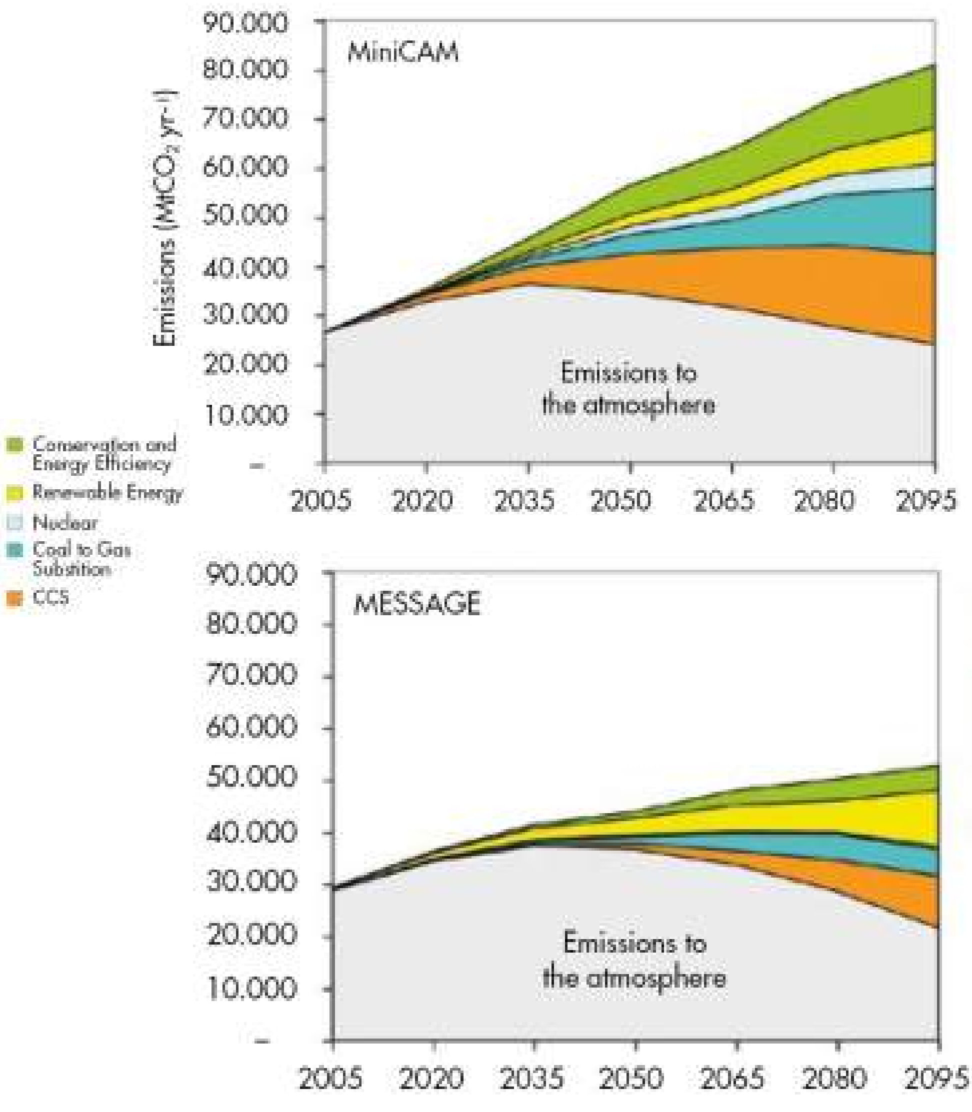


Figure 1 Illustrative examples of the potential global contribution of CCS based on two alternative integrated assessment models (MESSAGE and MiniCAM) from the IPCC Special Report on Carbon Dioxide Capture and Storage

HOW CAN CO_2 BE CAPTURED FROM INDUSTRY?

CCS involves capturing the CO_2 produced by the burning of hydrocarbons (such as natural gas and coal) before it enters the atmosphere, and storing it deep underground in rock formations where it would remain indefinitely. CCS is most cost-effective when applied to large, stationary sources of CO_2 (such as power stations and steelworks), which account for more than half of all man-made CO_2 emissions. The CO_2 can be captured from hydrocarbons before, during or after burning and the technology to do this is already widely used in many industries (such as gas processing and fertiliser production).The illustrations below show the three methods of capturing CO_2 – applied to a gas-fired power station.

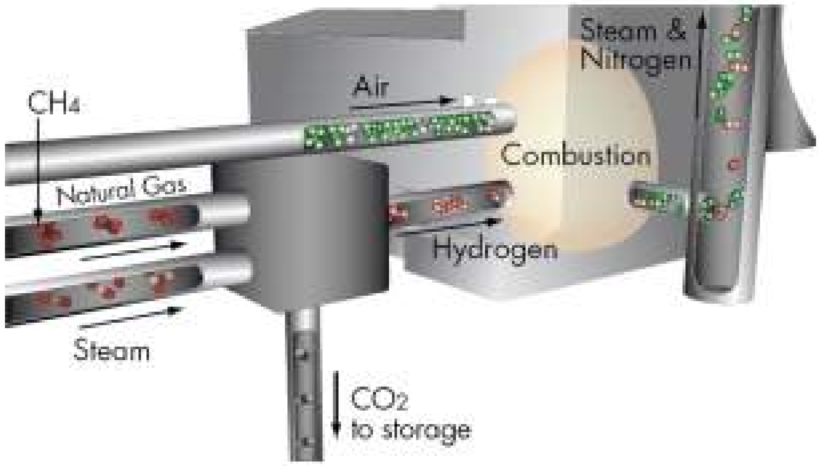


Figure 1 Before burning - Pre-combustion capture
(Figures 1-3 Courtesy of the CO_2 Capture Project)

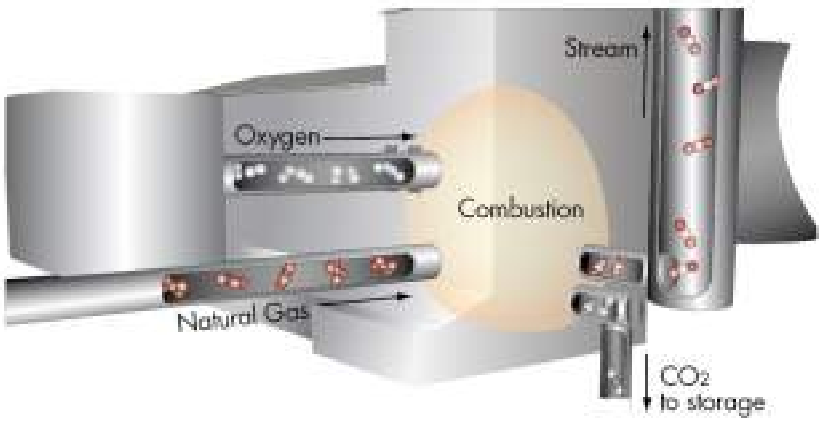


Figure 2 During burning - Oxyfuel capture

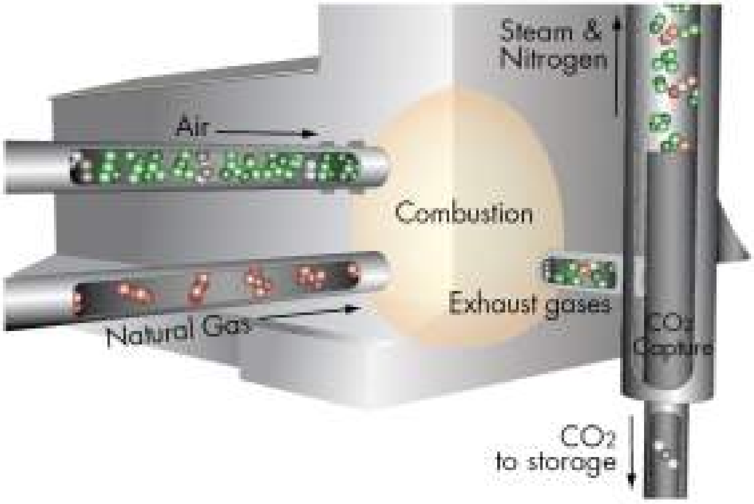


Figure 3 After burning - Post-combustion capture

One of the advantages of capturing the CO_2 before burning (pre-combustion capture) is that this technique separates hydrogen from hydrocarbon fuels. Hydrogen is a 'clean' fuel, producing only water when burned. Another possibility is to use CCS with biomass fuels (such as crop residues). Plants capture CO_2 from the atmosphere (by photosynthesis) but when they die, most of that CO_2 is returned to the atmosphere. Capturing and geologically storing the CO_2 produced from burning biomass would represent the opposite of today's fossil fuel economy – permanently removing CO_2 from the atmosphere and storing it deep underground.

WHERE CAN CO_2 BE GEOLOGICALLY STORED?

The best rocks for CO_2 storage are depleted oil and gas fields and deep saline formations. These are layers of porous rock (such as sandstone) over 1km underground (either on land or far below the sea floor), located underneath a layer of impermeable rock (known as a cap-rock) which acts as a seal. In the case of oil and gas fields, it was this cap-rock that trapped the oil and gas underground for millions of years.

Depleted oil and gas fields are the best places to start storing CO_2 because their geology is well known and they are proven traps.

Deep saline formations are rocks with pore spaces that are filled with very salty water (much saltier than seawater). They exist in most regions of the world and appear to have a very large capacity for CO_2 storage. Currently the geology of saline formations is less well understood than for oil and gas fields so more work needs to be done to understand which formations will be best suited to CO_2 storage.

The photograph below shows a sandstone that would be suitable for geological storage of CO_2.

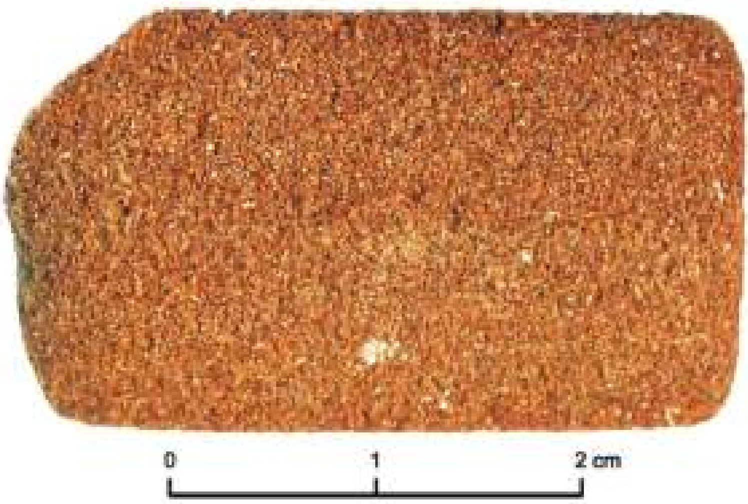


Figure 4 *Sandstone, typical of the type of rock that would be suitable for geological storage of* CO_2

Many natural geological stores of CO_2 have been discovered underground (often by people looking for oil and gas). In many cases the CO_2 has been there for millions of years. In other situations (volcanoes, geysers), CO_2 does leak naturally from underground. Indeed the world's natural carbonated mineral waters, long prized and bottled for drinking, come from natural CO_2 sources. The reasons why some rock formations trap the CO_2 permanently and some do not are well understood and this understanding can be used to select and manage storage sites to minimise the chance of leakage.

Potential storage sites will need to be carefully selected and managed in order to minimise any chance of CO_2 leakage. Once the CO_2 has been placed in the storage location, the wells will have to be sealed to ensure that the CO_2 stays in place. On the surface, air and soil sampling can be used to detect potential CO_2 leakage whilst changes deep underground can be monitored by detecting sound (seismic), electromagnetic, gravity or density changes within the rock formations.

WHY DOES CO_2 STAY UNDERGROUND?

As CO_2 is pumped deep underground it is compressed by the higher pressures and becomes essentially a liquid, which then becomes trapped in the pore spaces between the grains of rock by several means, summarised below. Depending on the physical and chemical characteristics of the rocks and fluids, all or some of these trapping mechanisms will take place. Structural storage has immediate effect, the others take time, but provide increased storage security. The longer the CO_2 remains underground, the more securely it is stored.

Structural Storage

When the CO_2 is pumped deep underground, it is initially more buoyant than water and will rise up through the porous rocks until it reaches the top of the formation where it can become trapped by an impermeable layer of cap-rock, such as shale. The wells that were drilled to place the CO_2 in storage can be sealed with plugs made of steel and cement. Figure 6 is an illustration of the In Salah Methane gas for electricity generation project in Algeria, where 1 million tonnes of CO_2 per year (equivalent to the emissions from a quarter of a million cars) is being stored in a producing gas field. The natural gas produced from the deep rock formations is a mixture of methane (CH_4) and CO_2. Once it reaches the surface, the natural gas is separated into methane (which is piped to a power plant for electricity generation) and CO_2 (which is pumped back into the deep rock formations for storage). The cap-rock that kept the natural gas in the rock formation for millions of years keeps the liquid CO_2 stored in the underground reservoir.

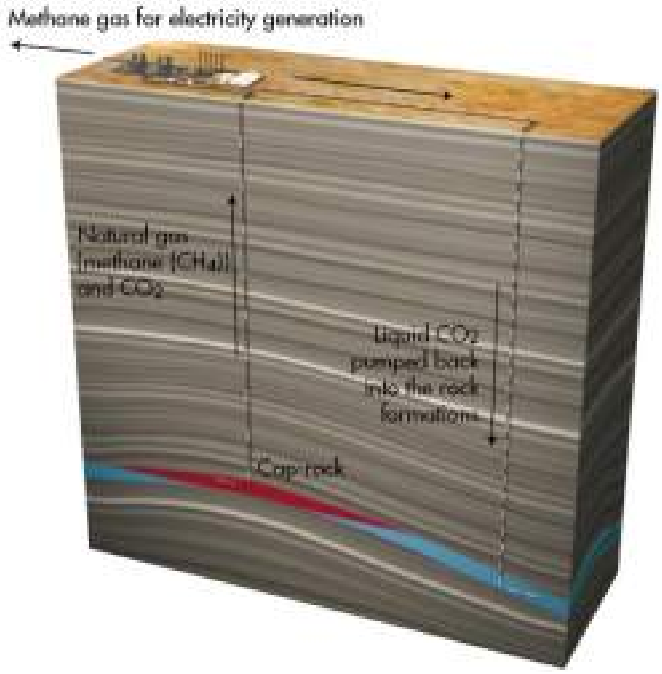
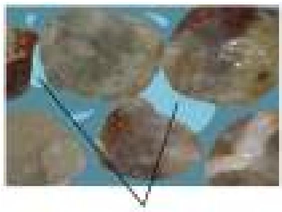


Figure 6 The In Salah CO_2 Storage Project in Algeria

Residual Storage

Reservoir rocks act like a tight, rigid sponge. Air in a sponge is residually trapped and the sponge usually has to be squeezed several times to replace the air with water. When liquid CO_2 is pumped into a rock formation, much of it becomes stuck within the pore spaces of the rock and does not move. This is known as residual trapping.

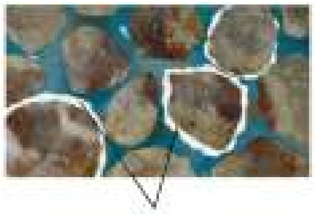

Residual trapping of CO_2

Dissolution Storage

CO_2 dissolves in salty water, just like sugar dissolves in tea. The water with CO_2 dissolved in it is then heavier than the water around it (without CO_2) and so sinks to the bottom of the rock formation, trapping the CO_2 indefinitely.

Mineral Storage

CO_2 dissolved in salt water is weakly acidic and can react with the minerals in the surrounding rocks, forming new minerals, as a coating on the rock (much like shellfish use calcium and carbon from seawater to form their shells). This process can be rapid or very slow (depending on the chemistry of the rocks and water) and it effectively binds the CO_2 to the rocks.


Mineral trapping of CO_2

WHERE ARE THE GOOD GEOLOGICAL STORAGE SITES?

The map below (Figure 7) shows the location of the best rocks for CO_2 storage based on our current knowledge. Total global man-made CO_2 emissions are currently around 24 gigatonnes of CO_2 per year. The CO_2 storage capacity of hydrocarbon (oil, gas and coal) reservoirs is estimated to be around 800 gigatonnes of CO_2. The world's deep saline formations may have a much greater storage capacity than depleted oil and gas fields, although more work needs to be done to assess their full potential for CO_2 storage.

Figure 7 Map showing rocks categorised as highly prospective for CO_2 storage, from the IPCC Special Report on Carbon Dioxide Capture and Storage

WHERE IS CO_2 GEOLOGICAL STORAGE HAPPENING?

Several large-scale geological storage projects are already in operation, and many more have been proposed. The map below (Figure 8) shows the locations of existing and proposed CO_2 storage projects, along with the locations of projects where CO_2 is currently used to enhance oil and gas recovery.

Figure 8 Location of sites where geological storage of CO_2 and CO_2-enhanced oil and gas recovery takes place, from the IPCC Special Report on Carbon Dioxide Capture and Storage

WHAT IS THE FUTURE OF CO_2 GEOLOGICAL STORAGE?

The illustration below (Figure 9) shows a CCS project, planned in California that would generate low-carbon electricity using hydrogen manufactured from petroleum coke and store the resultant CO_2 in a nearby mature oil field. This project would generate up to 500 MW low-carbon electricity (enough to power a third of a million homes) and is planned to be operating by 2012. Using CO_2 capture and storage at 700 large power plants would be equivalent (in CO_2 terms) to eliminating all the cars on the planet today.

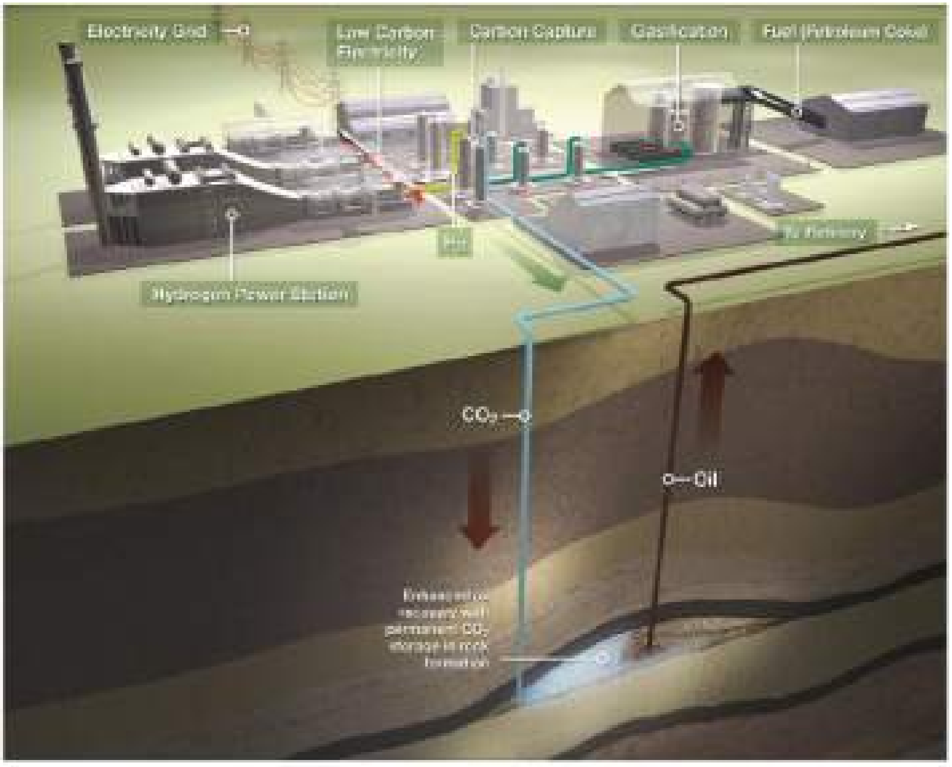


Figure 9 Illustration of a planned power plant in California with CCS. Illustration courtesy of BP and Edison Mission Group)

CONCLUSIONS

CO_2 capture and geological storage could contribute a significant part of the solution to the global warming problem. The required technology has been used by the oil and gas industry for many years – it is proven and available today. CCS could therefore play a significant role in helping to reduce CO_2 emissions over the coming decades. However, CCS is a relatively new concept and therefore not specifically addressed by most laws and regulations (both globally and locally).

Commercial organisations will invest in CCS projects when they are legal and financially viable. In order for CCS to be implemented on a widespread scale, work needs to be done soon to develop appropriate regulations and commercial frameworks for CCS.

IEA Greenhouse Gas R&D Programme
Orchard Business Centre, Stoke Orchard,
Cheltenham, Glos. GL52 7RZ. UK.

Tel: +44 1242 680753
Fax: +44 1242 680758
mail@ieaghg.org
www.ieagreen.org.uk

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