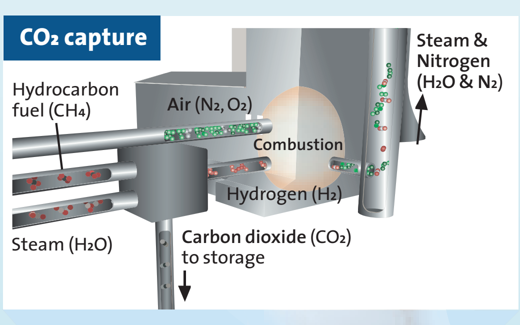



# $CO_2$ capture and geological storage

## Some key principles for policymakers

Energy from fossil fuels (oil, gas, coal) has enabled the developed world to achieve a high standard of living, and many developing countries aspire to achieve the same. The combustion of fossil fuels releases carbon dioxide ($CO_2$) into the Earth's atmosphere, which was previously trapped for millions of years in deep geological formations. Increasing levels of atmospheric $CO_2$ (a greenhouse gas) are contributing to global warming.


## Technology exists today to return $CO_2$ to deep geological formations

$CO_2$ from fossil fuel use can be captured and stored deep beneath the Earth's surface. The process is known as $CO_2$ Capture and Storage (CCS), and it has the potential to reduce some of the world's greenhouse gas emissions. The necessary technologies exist, and several projects are already underway, but widespread deployment requires policy and regulatory frameworks, so that business can make the required investments.

The best applications for capture technology are large stationary sources of $CO_2$, such as power stations and steel works, which contribute more than half of the man-made $CO_2$ emissions.

**What do we need to enable this long-term option for greenhouse gas mitigation?**

- A framework for regulating geological storage sites for $CO_2$
- Practical restrictions on impurities in the stored $CO_2$
- Transitional financial incentives to kick-start commercial investment in CCS projects

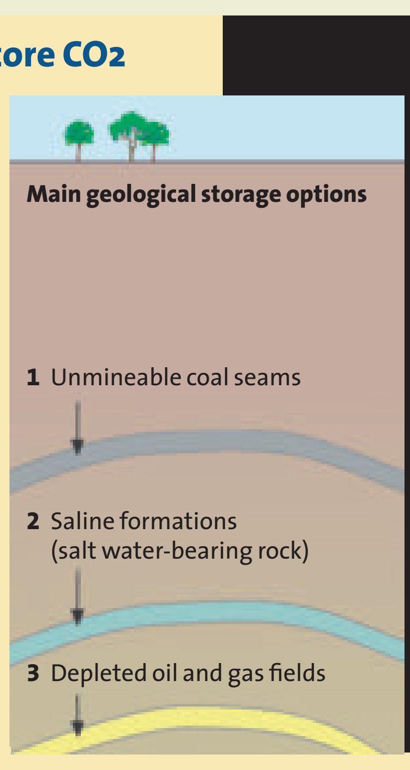
The necessary injection and storage technologies are available and reliable. For decades, oil and gas companies have been injecting $CO_2$ back into partially depleted oil or gas reservoirs, in order to direct the remaining oil or gas (trapped within the deep geological formation) towards producing wells. This injection process is used to support reservoir pressure and to enhance the recovery of oil and gas (EOR and EGR). In these processes, the amount of $CO_2$ injected has been relatively small because the purpose was simply to increase the production of the fields by 'pushing' the oil or gas. This same technology can be used on a much larger scale to return large amounts of $CO_2$ back into the earth.

## Selecting a Good Site to Store $CO_2$

Suitable sites for geological storage of $CO_2$ must be selected on the basis of their quality and capacity.

Depleted or partially depleted hydrocarbon reservoirs are the strongest, initial candidates for geological storage. We know a lot about these sites, and they contain high-quality and large-capacity geological formations, in which the $CO_2$ can be stored safely and permanently. The seal provided by the impermeable cap rock of the reservoir would trap the $CO_2$, as safely as it held the oil or gas for many millions of years.

Knowledge about the characteristics of the existing or depleted oil and gas fields will also provide information that can be used to predict the performance of a storage site.




The oil and gas industry already has decades of operational experience using problem-solving tools and computer models, which examine the chemistry, physics and geology of reservoirs located deep below the Earth's surface. These same technologies can be used to predict how well a $CO_2$ storage system will perform.

According to the UN's Intergovernmental Panel on Climate Change (IPCC) Special Report on $CO_2$ Capture and Storage (SRCCS), geological formations provide at least 2,000 gigatonnes $CO_2$ (545 gigatonnes carbon) of potential storage capacity. This estimate is based on the capacity of oil and gas reservoirs. At first, geological storage projects will be combined with oil fields that are already using EOR or injection for pressure support. These are often well-understood fields that have been operating for a long time or have been decomissioned and then reactivated as recovery techniques have improved.

Saline formations (permeable rock formations, which contain salty water in their pore spaces) provide even greater storage capacity and are more widely distributed. However, both the upper capacity limit of suitable saline formations and the length of time that the $CO_2$ will stay locked into a saline formation are less well understood. Another possible geological storage option, which is smaller in capacity, is the injection of $CO_2$ into coal beds. However, only small amounts of $CO_2$ have been injected into coal so far, and the effects of greater injection rates need to be addressed before the storage of larger volumes of $CO_2$ in coal seams can be considered.

## How safe is $CO_2$ injection?

Industry has injected $CO_2$, natural gas, hydrogen sulphide and other fluids (including water and steam) into the Earth's subsurface for many years, and regulations already exist to protect the health and safety of workers, the local community and the environment.

The injection wells will be monitored and kept secure in the same way that oil wells are kept safe from leakage.

*With appropriate site selection based on available subsurface information, a monitoring programme to detect problems, a regulatory system and the appropriate use of remediation methods to stop or control $CO_2$ releases if they arised, the local health, safety and environment risks of geological storage would be comparable to the risks of current activities such as natural gas storage, EOR and deep underground disposal of acid gas.*
— IPCC SRCCS

## Will the $CO_2$ remain deep underground?

According to the SRCCS, both industrial and natural analogues, as well as numerical models, suggest that it is 'very likely' that the amount of $CO_2$ retained in geological storage will exceed 99% over 100 years, and it is 'likely' that it will exceed 99% over 1000 years.

*The proportion of $CO_2$ retained in appropriately selected and managed geological reservoirs is likely to exceed 99% over 1,000 years.*
— IPCC SRCCS

*For well-selected, designed and managed geological storage sites, the vast majority of the $CO_2$ will gradually be immobilized by various trapping mechanisms and, in that case, could be retained for up to millions of years. Because of these mechanisms, storage could become more secure over longer time-frames.*
— IPCC SRCCS

## Why will the $CO_2$ stay underground?

There are multiple mechanisms by which $CO_2$ can be trapped for long periods of geological time, deep within the Earth. Depending on site-specific characteristics and the way in which $CO_2$ is injected, these mechanisms come into effect at different rates.

### Structural Trapping

Pressure increases with depth below the Earth's surface and, as the $CO_2$ is pumped down into the injection well, the gas is compressed by the increasing pressure and essentially becomes a liquid. This fluid $CO_2$ is pumped deep into the Earth until it reaches the storage formation. The rocks of the storage formation are like a rigid sponge—they are both porous and permeable. When the fluid $CO_2$ reaches the storage rocks, it tends to rise towards the top of the formation, where it will be trapped by an impermeable cap-rock, such as shale. This is referred to as 'structural trapping'.

### Residual Trapping

Another natural process traps the $CO_2$ further. Residual storage occurs when the liquid simply becomes stuck in the pore space and cannot move. Residual storage is somewhat analogous to air that becomes trapped in a sponge. Think of the fact that you need to squeeze a sponge several times before it will take up water. This is because air has become trapped in the pore spaces, and you must to squeeze it and increase pressure to remove the air. Thankfully, in the case of the rocks, they are already at a constant pressure, even though it is higher than that at the Earth's surface. Once the $CO_2$ is trapped, it will stay because the pressure will not change, and the rock structure is solid, unlike a sponge.

### Dissolution and Mineral Trapping

Two additional mechanisms also trap the $CO_2$. First the $CO_2$ dissolves in the salty water in geological formations much like sugar does in tea. The saline water that has combined with the $CO_2$ is significantly heavier than that without $CO_2$, so it sinks towards the bottom of the formation over time.

When $CO_2$ dissolves in the saline water the resulting solution is a weak acid. It reacts with the minerals in the rock grains around the pore spaces and forms new minerals over time, which binds the $CO_2$ to the rocks permanently.

## What if the site leaks?

If the site is carefully selected and managed, there will be no leakage to remediate. The most likely leakage path would be via failed wells, and there is an industry track record of remediating such wells. However, a remediation plan should be developed early in the site certification phase of a project and it should be updated through the lifetime of the project and after closure. The remediation plan could be turned over to a government authority after closure.

Each geological storage site should have a report that identifies places where leaks might occur, such as faults and pre-existing wells. This report must include the following:

1 a model of the way the fluid and gas travel through the reservoir, which will then be used to predict where the $CO_2$ will move after storage, and

2 enough data to make a computer model of the site and surrounding area, in order to predict how well the reservoir will hold the $CO_2$.


$CO_2$ Capture Project
www.co2captureproject.org

## Summary of the $CO_2$ Capture Project's Position

- The first CCS projects will carry significant technical and commercial risk, so government incentives, such as pricing structures, tax breaks, royalty relief, direct funding and active partnerships will be essential.
- Successful CCS will reduce the quantity of $CO_2$ entering the atmosphere. CCS must be carried out, recognizing the rights of local communities to have a safe living space, safe drinking water, a good quality of life and stable property values.
- New CCS regulations should protect the environment without discouraging CCS. They should be simple, based on sound science and should reflect true risk.
- Financial incentives should only be available to projects that aim to store man-made $CO_2$ (rather than projects that inject natural $CO_2$).
- EOR projects that store $CO_2$ (rather than reproduce it) should be rewarded for storing $CO_2$.
- CCS must be accepted and supported as a viable option for reducing greenhouse gas emissions.

$CO_2$ Capture Project

For further information, please see **www.co2captureproject.org**

## Building a framework to regulate CCS

*Widespread deployment of $CO_2$ Capture and Storage (CCS) will require standards and criteria to provide assurance of the long-term security of $CO_2$ Geological Storage (CGS).*
— $CO_2$ Capture Project, *Policy Principles Paper: A Framework for Certification and Operation of $CO_2$ Geological Storage Sites*

**1** Site certification
**2** Operation
**3** Closure
**4** Post closure

▲ An operational framework

### Site certification

**Necessary preliminary steps before initial site certification:**

1. Local and national authorities must grant the right to store $CO_2$.
2. The government and the operating company will need to agree to both the initial site conditions and the operational limits of the site.
3. The capacity of the site must be determined.
4. The quality of the site must be assessed. The risk of leakage will need to be evaluated.
5. A risk assessment should address factors, such as the strength of the seal and the pressure and chemistry of fluids and gases within the reservoir.

**A high-quality storage site should fit the following criteria:**

- The site must be of sufficient depth not to endanger underground sources of drinking water. The ideal depth would be between one and three thousand metres.
- The formation should contain a large amount of potential storage space.
- The site should have an effective trapping mechanism with thick, impermeable confining rock layers (such as shales) that are free of major (non-sealing) faults.

### Operation

The length of time it takes to inject the $CO_2$ into the site could vary from a few years to decades.

Meter → Regulate → Examine → Comply → Adhere → Report

▲ Operational tasks

Site operators should undertake the following operational tasks:

- Meter the pressure and regulate the flow-rate.
- Examine the composition of the $CO_2$ stream to detect impurities. $CO_2$ from industrial sources could be mixed with other gases and trace elements, which may need to be removed before the $CO_2$ is stored.
- Comply with local regulations on the use of $CO_2$-resistant construction materials in wells, cement plugs and surface facilities.
- Adhere to a monitoring regime that will include updates to, and validation of, the reservoir modelling.
- Report performance results to a government regulator. (The regulator may intervene if performance measurements differ markedly from the modelling predictions).

### Closure

- Commercial businesses may not exist for very long, so to ensure public acceptance of geological storage, it is important that long-term stewardship of storage sites remain with nations or states.
- When the injection of $CO_2$ has ended, the operator should apply to the regulator for a closure certificate.
- After certification has been agreed, the operator can remove the equipment and buildings above the site, unless long-term monitoring is required.
- Site stewardship should revert to the appropriate government authority.

### Post-Closure

- Post-closure requirements will differ from one site to the next because some sites will present no risk and others may require long-term monitoring.
- A well-chosen site, which has performed as expected and required, may not need long-term monitoring.
- A poorly performing site may need continued monitoring and possibly remediation or mitigation.

## Impurities in the $CO_2$ stream

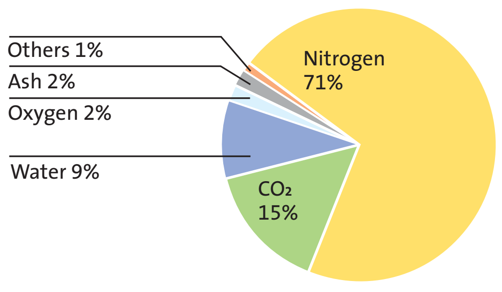
Today, the combustion of fossil fuels leads to flue gases containing $CO_2$, oxygen and nitrogen, along with traces of metals.

Man-made $CO_2$ can be captured from industrial sources that may contain different impurities, so we must decide whether these impurities can be safely stored along with $CO_2$ or whether they require separate treatment.

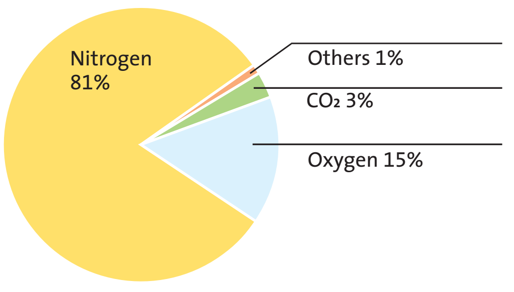
The $CO_2$ captured from a gas-fired power plant generally includes significantly fewer impurities than the $CO_2$ from a coal-fired power plant. The $CO_2$ with more impurities will require different regulations than the purer $CO_2$.

▼ Pie charts illustrating composition of flue gases emitted by coal- and gas-fired plants

Flue gas from **Coal-fired plants**




Flue gas from **Gas-fired plants**




### How to classify stored $CO_2$

$CO_2$ is about as dangerous as water. Everyone's breath contains $CO_2$, and it is heavier than air. If you were to breathe in pure $CO_2$, you would drown in a few minutes. However, like water vapour, $CO_2$ dissipates rapidly in open air. $CO_2$ mixed with water becomes about as acidic as orange juice.

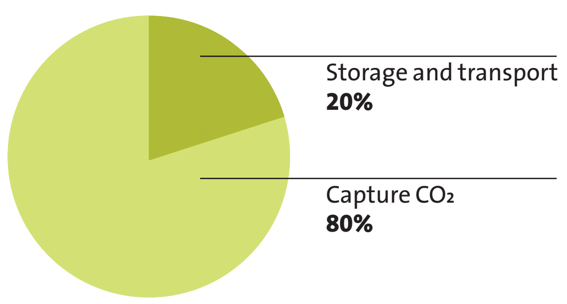
If the $CO_2$ stream is defined as a waste, the operator of a storage site will have to comply with waste management requirements (which may be inappropriate for $CO_2$). Transport of $CO_2$ for injection into deep geological formations under the seabed has been clarified and is allowed under international treaties.

### High cost of $CO_2$ capture

Impurities may cause the $CO_2$ stream to corrode transport and storage equipment. Once the $CO_2$ stream reaches the geological storage formation, different impurities could enhance or degrade different trapping mechanisms. Therefore, increased scrubbing of the $CO_2$ stream could be required, which could significantly add to the cost of greenhouse gas mitigation. If the $CO_2$ is not scrubbed, before injection, extra costs could be passed on to the storage-site operator (extra monitoring, corrosive-resistant equipment, etc.). This may trigger a special class of hazardous $CO_2$ storage, which could greatly increase the costs of monitoring for those sites.

## How to pay for CCS

CCS represents an additional cost in the creation of products, such as electricity, steel and cement, so if businesses were to invest in CCS projects, financial incentives would be required to justify those commercial investments and encourage the widespread use of CCS.




▲ Operating costs associated with $CO_2$ capture represent over 80% of the total costs associated with the $CO_2$ capture, transportation and storage cycle.

The current value of $CO_2$ credits is too small (and its future is too uncertain) to justify the significant commercial investments required for industrial-scale CCS projects. A fully integrated CCS project (capture, transport, and storage) requires significant up-front capital investment ($billions). It would take three to five years to build and would be expected to operate for ten to fifty years.

However, the future of emissions trading is very uncertain beyond the next few years, so potential CCS project developers do not know if they will receive long-term financial credit for the extra costs of CCS.

Without a policy framework to support low-carbon products, CCS projects will remain uneconomic for commercial investors. Many countries have introduced portfolio standards that have created new markets for low-carbon products and kick-started other technologies such as wind and solar, that deliver low-carbon electricity.

In the power sector, transitional financial incentives such as portfolio or performance standards, could stimulate commercial investment in a programme of early-mover CCS 'demonstration' projects. In turn, that programme would create a market for CCS technologies that would allow companies to compete to develop technologies that would reduce cost and improve reliability. Ultimately, as costs come down and business confidence improves, the only financial incentive required to deliver CCS projects should be emissions trading, but without transitional financial incentives to create a market for the technology, that would take decades.

## Co-operating for a better environment

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# $CO_2$ capture and geological storage in depth