



Scientific Facts on CO₂ Capture and Storage

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Summary & Details:
GreenFacts

Level 2 - Details on CO₂ Capture and Storage

- 1. **What is carbon dioxide capture and storage?.....3**
 - 1.1 What is CO₂ capture and storage and what could its applications be?.....3
 - 1.2 What role could CO₂ capture and storage play in the fight against climate change?.....3
- 2. **What sources of CO₂ emissions are suitable for capture and storage?.....4**
 - 2.1 What are the characteristics of suitable emission sources?.....4
 - 2.2 To what extent could future CO₂ emissions be captured?.....5
- 3. **How do CO₂ capture technologies work?.....5**
 - 3.1 What capture technologies are currently available?.....5
 - 3.2 What are the costs of CO₂ capture?.....6
- 4. **How can CO₂ be transported once it is captured?.....6**
 - 4.1 What are the methods of CO₂ transport?.....6
 - 4.2 How expensive is CO₂ transport?.....7
- 5. **How can CO₂ be stored underground?.....7**
 - 5.1 What are the possibilities of geological storage?.....7
 - 5.2 How expensive is geological storage?.....8
- 6. **Could CO₂ be stored in the deep ocean?.....8**
 - 6.1 What are the methods of ocean storage?.....8
 - 6.2 What are possible environmental impacts and costs of ocean storage?.....9
- 7. **How can CO₂ be stored in other materials?.....9**
 - 7.1 Can CO₂ be transformed and stored in solid form?.....9
 - 7.2 What are the industrial uses of CO₂ and can they reduce CO₂ emissions?.....10
- 8. **How cost-effective are different CO₂ capture and storage options?.....10**
- 9. **How could emission reductions be quantified?.....11**
- 10. **Conclusion: the future of CO₂ capture and storage.....12**
 - 10.1 What knowledge gaps remain?.....12
 - 10.2 How much could CO₂ capture and storage contribute to climate change mitigation?.....12

This Digest is a faithful summary of the leading scientific consensus report produced in 2005 by the Intergovernmental Panel on Climate Change (IPCC): *"Special Report on Carbon Dioxide Capture and Storage: Technical Summary"*

The full Digest is available at: <https://www.greenfacts.org/en/co2-capture-storage/>



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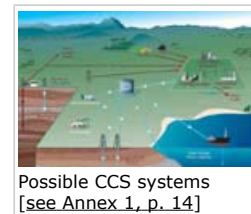
- Each question is answered in Level 1 with a short summary.
- These answers are developed in more detail in Level 2.
- Level 3 consists of the Source document, the internationally recognised scientific consensus report which is faithfully summarised in Level 2 and further in Level 1.

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1. What is carbon dioxide capture and storage?

1.1 What is CO₂ capture and storage and what could its applications be?

Carbon dioxide (CO₂) is a greenhouse gas that occurs naturally in the atmosphere. Human activities are increasing the concentration of CO₂ in the atmosphere thus contributing to Earth's global warming. CO₂ is emitted when fuel is burnt – be it in large power plants, in car engines, or in heating systems. It can also be emitted by some other industrial processes, for instance when resources are extracted and processed, or when forests are burnt.



Carbon dioxide capture and storage (CCS) is one of the techniques that could be used to reduce CO₂ emissions from human activities. It could be applied to emissions from large power plants or industrial facilities.

The process involves three main steps:

1. capturing CO₂, at its source, by separating it from other gases produced by an industrial process
2. transporting the captured CO₂ to a suitable storage location (typically in compressed form)
3. storing the CO₂ away from the atmosphere for a long period of time, for instance in underground geological formations, in the deep ocean, or within certain mineral compounds.

Some of the technologies needed for this process are more mature than others. By mid-2005, three commercial projects had already been implemented that store CO₂ captured in underground geological formations as part of oil and gas extraction or processing projects.

1.2 What role could CO₂ capture and storage play in the fight against climate change?

Most scenarios for global energy use project a substantial increase of CO₂ emissions throughout this century in the absence of specific actions to mitigate climate change. They also suggest that the supply of primary energy will continue to be dominated by fossil fuels until at least the middle of the century.

Therefore, techniques to capture and store the CO₂ produced combined with other technological options could play a role in the fight against climate change.

However, no single technology option will provide all of the emission reductions needed to stabilize greenhouse gas concentrations in the atmosphere at a level that prevents dangerous interference with the climate system.

Other technological options to stabilize greenhouse gas concentrations in the atmosphere include:

- reducing energy demand by increasing energy efficiency;
- switching to less carbon-intensive fuels (from coal to natural gas, for example),

- increasing the use of renewable energy sources and/or nuclear energy (each of which, on balance, emit little or no CO₂);
- enhancing natural carbon sinks (such as forest); and
- reducing greenhouse gases other than CO₂ (such as methane).

CO₂ capture and storage would be an option for developed countries which need to reduce CO₂ emissions and have significant sources of CO₂ suitable for capture, access to storage sites and experience with oil or gas operations. But there are many barriers to deployment in developing countries. Creating conditions that would facilitate diffusion of this technology to developing countries would, therefore, be a major issue for the adoption of CO₂ capture and storage worldwide.

2. What sources of CO₂ emissions are suitable for capture and storage?

2.1 What are the characteristics of suitable emission sources?

Several factors determine whether carbon dioxide capture is a viable option for a particular emission source:

- the size of the emission source,
- whether it is stationary or mobile,
- how near it is to potential storage sites, and
- how concentrated its CO₂ emissions are.

CO₂ could be captured from large stationary emission sources such as power plants or industrial facilities. If such facilities are located near potential storage sites, for example suitable geological formations, they are possible candidates for the early implementation of CO₂ capture and storage (CCS).

Small or mobile emission sources in homes, businesses or transportation are not being considered at this stage because they are not suitable for capture and storage.

In 2000, close to 60% of the CO₂ emissions due to the use of fossil fuels were produced by large stationary emission sources, such as power plants and oil and gas extraction or processing industries (see Table TS.2 [see Annex 11, p. 21] for details).

Four major clusters of emissions from such stationary emission sources are: the Midwest and eastern USA, the northwestern part of Europe, the eastern coast of China and the Indian subcontinent (see Figure TS.2a [see Annex 9, p. 20]).

Large-scale biomass conversion facilities, for instance for the production of bio-ethanol, also generate emissions with high CO₂ content. Though such facilities are much smaller and rarer, they could also be suitable for CO₂ capture and storage.

Many stationary emission sources lie either directly above, or within reasonable distance (less than 300km) from areas with potential for geological storage (see Figures T.S. 2a/2b [see Annex 9, p. 20]).



The Gibson coal power plant, a good example of a large stationary source.
Source: John Blair, valleywatch.net [see <http://valleywatch.net>]



Global Distribution of large CO₂ sources
[see Annex 9, p. 20]



Possible storage sites
[see Annex 9, p. 20]

2.2 To what extent could future CO₂ emissions be captured?

Considering different emission scenarios, the projected potential of CO₂ capture is 9–12% of global CO₂ emissions in 2020, and 21–45% in 2050.

Moreover, within several decades, energy carriers such as electricity or hydrogen, which do not emit carbon when used, could potentially begin replacing fossil fuels currently used by small, distributed sources in homes, businesses or transportation.

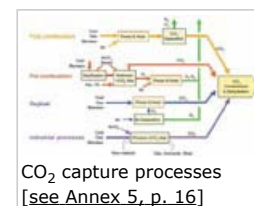
These energy carriers could be produced from fossil fuels and/or biomass in large centralized plants that would generate large point sources of CO₂ suitable for carbon dioxide capture. Such applications could reduce dispersed CO₂ emissions from transport and from distributed energy supply systems increasing the potential of carbon dioxide capture and storage (CCS).

3. How do CO₂ capture technologies work?

3.1 What capture technologies are currently available?

To capture carbon dioxide (CO₂) it is first separated from other gases resulting from combustion or processing. It is then compressed and purified to make it easier to transport and store.

Carbon dioxide resulting from combustion, particularly in the electricity sector, can be captured using one of three systems:



System	Status	Net amount of CO ₂ "avoided"
Post-combustion	In commercial use for decades in other, related applications	80-90%
Pre-combustion		
Oxyfuel combustion	Demonstration phase	90%

In a **post-combustion** system, the flue gas produced by combustion of the fuel with air only contains a small fraction of CO₂. It is captured by injecting the flue gases in a liquid that selectively absorbs the CO₂ (such as a cooled or compressed organic solvent). Nearly pure CO₂ can then be released from the liquid, typically by heating it or releasing the pressure. Similar separation processes are already used on a large scale to remove CO₂ from natural gas.

In a **pre-combustion** system, the primary fuel is first converted into gas by heating it with steam and air or oxygen. This conversion produces a gas containing mainly hydrogen and CO₂, which can be quite easily separated out. The hydrogen can then be used for energy or heat production.

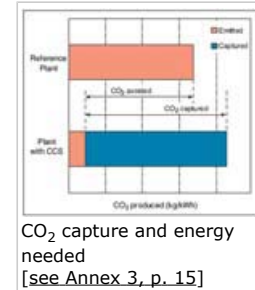
Oxyfuel combustion uses pure oxygen to burn the fuel instead of using air which only contains 20% of oxygen and a lot of nitrogen. It results in a gas mixture containing mainly water vapour and CO₂. The water vapour is then easily removed from the CO₂ by cooling and compressing the gas stream. However, for this process one must first separate oxygen from the air, which is fairly complex process.

Similar capture systems are already used in several industrial processes, such as hydrogen or urea production, and coal gasification.

3.2 What are the costs of CO₂ capture?

Capture systems reduce the CO₂ emissions from combustion plants by about 80 to 90%. These figures take into account the fact that capture systems require additional energy (see Figure TS.11).

For new fossil fuel power plants, CO₂ capture can increase the cost of **electricity production** by 35 to 85% depending on different assumptions in plant design, operation and financing. This represents 0.01 to 0.03 US\$ per kWh of electricity produced.



	Cost in US\$/kWh
New fossil fuel plants without capture	0.03 – 0.06
New fossil fuel plants with capture	0.04 – 0.09
Capture alone	0.01 – 0.03

Capture costs can also be expressed in US\$ per net tonne of CO₂ captured. This unit cost varies greatly for different types of combustion plants and for industrial processes. The unit cost of capture is generally lower where a relatively pure CO₂ stream is produced, such as in natural gas processing, hydrogen production, and ammonia production.

4. How can CO₂ be transported once it is captured?

4.1 What are the methods of CO₂ transport?

Except when the source is located directly over the storage site, the CO₂ needs to be transported to the storage site. There are several ways of doing this.

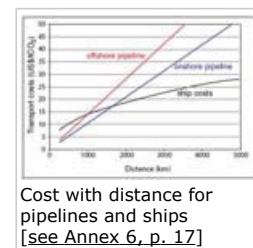
Concentrated streams of CO₂ can safely be transported through **pipelines** at high pressure. Such pipelines have been used in the USA since the early 1970s for enhanced oil recovery (EOR) and are currently the main method for transporting CO₂. Experience over the past decades, mainly with gas pipelines, has shown that very few accidents occur and that risks associated with appropriately designed pipelines are low.

CO₂ can also be transported as a liquid, in **ships** similar to those transporting liquefied petroleum gas (LPG).

In liquid form, CO₂ could technically also be transported on road tankers or railcars in insulated tanks at low temperature and at much lower pressure than in pipelines, but this option is not economical for large scale CO₂ transport.

4.2 How expensive is CO₂ transport?

For both pipeline and marine transportation of CO₂, costs depend on the distance and the quantity transported. For pipelines costs are higher when they are routed offshore or across heavily congested areas, mountains or rivers. Fluctuations in the price of steel would also have an impact on the cost of pipeline transport. For a distance of 250 km (about 155 miles), the estimated cost of pipeline transport typically ranges from 1-8 US\$ per tonne CO₂.

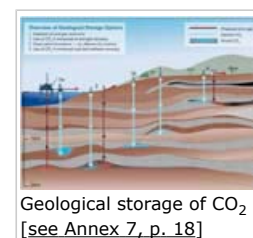


In ship transport, costs depend on characteristics such as tanker volume. If transport by ship is possible, it is generally cheaper than pipeline transport for distances over 1000 km and for amounts of CO₂ smaller than a few million tonnes per year (see Figure TS.6 [see Annex 6, p. 17]).

5. How can CO₂ be stored underground?

5.1 What are the possibilities of geological storage?

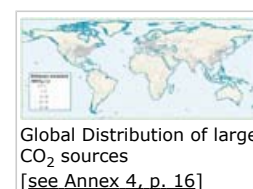
5.1.1 Geological formations suitable for the storage of CO₂ are oil and gas reservoirs, deep saline formations, and un-minable coal seams. Storage sites must generally be located at a depth of 800m or deeper, where prevailing pressures keep CO₂ in either a liquid or a supercritical state. Under such conditions, CO₂ is less dense than water and it must be trapped from above to prevent it from moving back up to the surface. It can for instance be physically trapped under a well-sealed cap rock and in pore spaces within the rock, or chemically by dissolving in water and reacting with rock minerals to form carbonate minerals.



Compressed CO₂ can be injected into porous rock formations below the earth's surface using many of the same methods already used by the oil and gas industry: well-drilling technology, injection technology, computer simulation of storage reservoir dynamics and monitoring methods.

Industrial scale storage projects are underway in the North Sea, Canada, Algeria and in Texas, each storing every year more than a million tonnes of CO₂ that would otherwise be released into the atmosphere.

5.1.2 Potential geological storage sites exist around the globe both onshore and offshore. Estimates of the **total storage space available** vary widely, but they generally indicate that space exists for tens to hundreds of years of CO₂ emissions at current levels. Furthermore, a large portion of existing power plants and other industrial sources lie within 300 km of areas with storage potential (see Figure TS.2a/2b [see Annex 9, p. 20])



While the available storage capacity in geological reservoirs is "likely" to be sufficient for contributing significantly to CO₂ emission reductions, the true amount is yet uncertain.

5.1.3 Leakage of CO₂ from storage entails global risks for the climate, but also potential local risks for humans, ecosystems and groundwater in the case of sudden and rapid CO₂ releases. These risks are expected to be quite small: most of the CO₂ should remain underground for centuries, and leakages should be controlled well before causing local damage. Monitoring of storage sites may however be required for very long periods and methods are expected to evolve as technology improves. A legal framework with a long-term perspective is also needed as storage times extend over many generations. The general public appears not to know much about this technological option, and is "reluctant" to accept it, sometimes because of the perception that CO₂ storage is required because of a failure to reduce CO₂ emissions in other ways.

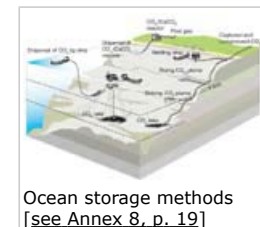
5.2 How expensive is geological storage?

Storage in geological formations is the cheapest and most environmentally acceptable storage option for CO₂. The cost of storage in saline formations and depleted oil and gas fields would typically be between 0.5–8 US\$/tCO₂ injected, with additional monitoring costs of 0.1–0.3 US\$/tCO₂. The lowest storage costs are for onshore, shallow, high permeability reservoirs, and/or storage sites where wells and infrastructure from existing oil and gas fields may be re-used. The geological storage of CO₂ could even yield net benefits, for instance in the case of enhanced oil or gas recovery where CO₂ could be injected underground to displace and recover the fuel.

6. Could CO₂ be stored in the deep ocean?

6.1 What are the methods of ocean storage?

Because CO₂ is soluble in water, there are **natural exchanges between the atmosphere and the surface of the ocean** that occur until a balance is reached. If the atmospheric concentration of CO₂ increases, the oceans are expected to take up additional CO₂ gradually over several centuries until a new equilibrium is reached. The CO₂ would first be dissolved in the upper ocean layer and later be mixed with deep ocean waters. In this way, the oceans have taken up about 500 GtCO₂ of the total 1 300 GtCO₂ released by human activities into the atmosphere over the past 200 years. Oceans are currently taking up about 7 GtCO₂ per year. Most of this carbon dioxide now resides in the upper ocean layer which has become somewhat more acidic as a result (a decrease of 0.1 in pH). To date, however, there has been virtually no change in acidity in the deep ocean.



Ocean storage methods
[see Annex 8, p. 19]

Captured CO₂ could potentially **be injected directly into the deep ocean**, where most of it would be isolated from the atmosphere for centuries. This could be achieved by transporting CO₂ via pipelines or ships to an ocean storage site, where it would be injected into the water column of the ocean or at the sea floor. The dissolved and dispersed CO₂ would then become part of the global carbon cycle. Ideas for storing CO₂ away in the deep ocean for even longer periods of time include forming solid CO₂ hydrates and/or liquid CO₂ lakes on the sea floor, and dissolving alkaline minerals such as limestone to neutralize the acidic CO₂.

6.2 What are possible environmental impacts and costs of ocean storage

The injection of a few GtCO₂ would produce a measurable change in ocean chemistry in the region of injection, whereas the injection of hundreds of GtCO₂ would eventually produce measurable changes over the entire ocean volume. Over centuries, ocean mixing would result in a gradual release of CO₂ into the atmosphere. Experiments have shown that the addition of CO₂ can harm marine organisms close to injection points or CO₂ lakes. Long term effects of direct CO₂ injection on large ocean areas have not yet been studied. It is, however, expected that **impacts on ocean ecosystems** would increase with increasing CO₂ concentrations and decreasing pH, and it is unclear how or whether species and ecosystems would adapt to the chemical changes.



CO₂ can be injected into the deep ocean from oil platforms.
Source: Stephen Knowles

The **cost of ocean storage** has been estimated based on the cost of offshore pipelines or ships, plus any additional energy costs at 6 to 31 US\$/tCO₂ net injected. For short distances (100 km offshore), the fixed pipeline option would be cheaper. For larger distances (500 km offshore), injection from a moving ship or transport by ship to a platform with subsequent injection would be more attractive.

The global and regional treaties on the law of the sea and marine environment, such as the OSPAR and the London Convention, also concern ocean storage, but the legal status of intentional ocean storage has not yet been decided.

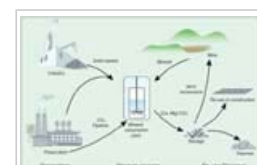
Storage in oceans would thus be a less environmentally acceptable and a more expensive storage option for CO₂. In the few public perception studies conducted so far, the public has expressed greater reservations about ocean storage than geological storage.

Note from the editor: Because of its environmental implications, CO₂ storage in oceans is generally no longer considered as an acceptable option.

7. How can CO₂ be stored in other materials?

7.1 Can CO₂ be transformed and stored in solid form?

CO₂ can be converted virtually permanently into a solid form through chemical reactions with extracted minerals that are naturally occurring, such as calcium oxide (CaO) to produce limestone (CaCO₃) or magnesium oxide (MgO) to produce dolomite (MgCO₃). As a result of the reaction, no CO₂ would be released into the atmosphere, there would be little need to monitor the disposal sites, and the associated risks would be very low. Large amounts of energy and minerals, however, are required for this technology. Greater improvements would be needed before it could become a real option.



Mineral carbonation
[see Annex 2, p. 15]

7.2 What are the industrial uses of CO₂ and can they reduce CO₂ emissions?

Exploiting captured CO₂ in industrial chemical processes in industry is technically possible, but it has only modest potential for actually reducing emissions. The total industrial use of 120 MtCO₂ per year is very small compared to the emissions induced by human activities (over 30 000 MtCO₂ per year). Two thirds are used to produce urea, which is used in the production of fertilizers and other products. Other uses include: horticulture, refrigeration, food packaging, welding, beverages, and fire extinguishers.

In addition, most of these industrial products release their CO₂ content back into the atmosphere after few days or months. Only a small proportion – roughly 20 MtCO₂ per year – is stored for up to several decades and only up to 1 MtCO₂ per year for a century or more. Therefore, CO₂ capture for industrial uses could only bring an insignificant contribution to climate change mitigation.

8. How cost-effective are different CO₂ capture and storage options?

Estimates for current and future costs of CO₂ capture and storage have considerable uncertainties. While some CO₂ capture and storage components are already deployed in mature markets for certain industrial applications, the technology has still not been used in large-scale power plants, the application with most potential.



The Esbjerg Power Station, a CO₂ capture site in Denmark. Source: DONG Energy

In a fully integrated system, the cost of capture and compression would normally be the largest cost component. Generally, geological storage is estimated to be more economical than ocean storage, the most expensive storage option being mineral carbonation.

Overall costs will depend not only on the capture system used, the type of storage and the transport distance, but also on variables such as plant design, operation, financing, size, location, fuel type as well as fuel and electricity costs.

Under current conditions, producing electricity costs about US\$0.04 – 0.06/kWh. Adopting today's CO₂ capture and storage technologies would raise this cost by an estimated US\$0.01 – 0.05/kWh. This could be reduced by about US\$0.01 – 0.02/kWh if the revenues from Enhanced Oil Recovery partly compensated for the costs.

When CO₂ capture and storage is compared to other technical options for reducing CO₂ emissions, it must be kept in mind that 10-40% more energy is needed for producing the same amount of electricity. The costs per tonne of CO₂ avoided show a large range. A significant part of the technology's potential is available at costs that are higher than those of many other options for improving energy efficiency, but lower than those of most solar power options.

When planning the construction of a new plant, calculating the cost implications of adding a CO₂ capture and storage system could influence the type of plant chosen. The technology can be applied to current generation technologies such as pulverized coal or natural gas combined cycle (NGCC). However, the additional costs will be lower when CO₂ capture and storage is integrated into emerging technologies such as integrated gasification combined cycle (IGCC) and pre-combustion hydrogen production facilities. While most existing facilities

could be retrofitted to accommodate CCS systems, the costs will be significantly higher than for new plants with CCS.

The future costs of CO₂ capture and storage could decline as technology advances and once it is used on a large scale— perhaps by 20 - 30% over the next decade. However, rising fossil fuel prices could push costs up. Because biomass plants are currently small in size, the costs of CO₂ capture and storage would be relatively high. Costs for CO₂ capture and storage from industrial processes other than power generation can be lower than those for electricity plants, particularly for process such as hydrogen or ammonia production that already separate CO₂.

9. How could emission reductions be quantified?

An important aspect of CO₂ capture and storage is the development and application of methods to estimate and report the quantities in which greenhouse gas emissions are reduced, avoided, or removed from the atmosphere.

This requires:

- the estimation and reporting of actual emissions for national greenhouse gas inventories, and
- accounting for CO₂ capture and storage under international agreements to limit net emissions.

In the absence of international agreements, it is not clear whether the various forms of CO₂ capture and storage will be treated as reductions in emissions or as removals from the atmosphere. CO₂ capture and storage is markedly different in many ways from CO₂ sequestration in biological carbon sinks (forests, soil etc), and the different forms of carbon capture and storage are markedly different from one another. While one tonne of CO₂ permanently stored has the same benefit in terms of atmospheric CO₂ concentrations as one tonne of CO₂ not emitted, one tonne of CO₂ temporarily stored has less benefit. This difference should be reflected in any system of accounting for reductions in net greenhouse gas emissions. Currently, there are no methods available within the UNFCCC framework for monitoring, measuring or accounting for physical leakage from storage sites.

Table TS.12. Global potential contribution of CCS as part of a mitigation portfolio
[see Annex 10, p. 21]

Although methods currently available for national emissions inventories can either accommodate CO₂ capture and storage systems or be revised to do so, accounting for stored CO₂ raises questions about the acceptance and transfer of responsibility for stored emissions. Such issues may be addressed through national and international political processes.

10. Conclusion: the future of CO₂ capture and storage

10.1 What knowledge gaps remain?

CO₂ capture and storage is technologically feasible and could play a significant role in reducing greenhouse gas emissions over the course of this century. Although parts of the technology are tried and tested, increased knowledge, experience, and reduced uncertainty about specific aspects of CO₂ capture and storage would be important to enable its large scale deployment.

First, the technology needs to mature further. While the individual components of CO₂ capture and storage are well developed, they still need to be integrated into full scale projects in the electricity sector. Such projects would demonstrate whether the technology works when fully scaled up, thus increasing knowledge and experience. More studies are needed to analyse and reduce the costs and estimate the potential capacity of suitable geological storage sites. Regarding other forms of storage, pilot scale experiments on mineral carbonation are needed to reduce costs and net energy requirements. In addition, studies concerning the ecological impact of CO₂ in the deep ocean are required.

The adequate legal and regulatory environment also needs to be further developed. This must include agreed methods for estimating and reporting the amount of CO₂ avoided by CO₂ capture and storage as well as the amounts that may leak over the longer term. Long-term liabilities of geological storage and potential legal constraints on storage in the marine environment need to be taken into account.

Other issues to be resolved include the potential for transfer and diffusion of CO₂ capture and storage technologies, opportunities for developing countries to exploit them, application of these technologies to biomass sources of CO₂, and the potential interaction between investment in CO₂ capture and storage and other mitigation options.

10.2 How much could CO₂ capture and storage contribute to climate change mitigation?

If knowledge gaps are filled and various conditions are met, CO₂ capture and storage systems could be deployed on a large scale within a few decades as long as an explicit policy is put into place to substantially limit greenhouse gas emissions to the atmosphere.

A particularly critical issue remains that of incentives. If a "carbon price" is established for each unit of greenhouse gas emissions, this could create incentives to invest in processes which emit less greenhouse gases. CO₂ capture and storage systems are only likely to be widely adopted for power generation – the sector with by far the greatest potential – when the price of emitting a tonne of CO₂ exceeds 25–30 US\$ (in 2002 dollars) over the lifetime of the project. A price on emitting CO₂ can only result from policy decisions for limiting CO₂ emissions. CO₂ capture and storage systems would be competitive with other large-scale mitigation options such as nuclear power and renewable energy technologies.

As part of a portfolio of actions to mitigate climate change, CO₂ capture and storage could reduce the cost of stabilizing the concentration of greenhouse gases in the atmosphere by 30% or more. Most scenarios for achieving such stabilisation at least cost estimate that the

amount of CO₂ that could potentially be stored underground and in oceans during this century ranges between 220 and 2 200 GtCO₂. To achieve this potential, several hundreds or thousands of CO₂ capture and storage systems would be required worldwide over the next century, each capturing some 1 to 5 MtCO₂ per year. Such systems would need to be built in significant numbers in the first half of the century with the majority of them being built in the second half.

In the absence of measures for limiting CO₂ emissions, there would only be small, niche opportunities for carbon capture and storage technologies to deploy with a maximum potential of about 360 MtCO₂ per year. Such opportunities alone are unlikely to contribute significantly to the mitigation of climate change unless extended to the power sector.

Concerning long term leakage from storage, there must be an upper limit to the amount of leakage that can take place if CO₂ capture and storage is to be acceptable as a climate change mitigation measure. A fraction retained on the order of 90–99% for 100 years or 60–95% for 500 years could still make such impermanent storage valuable for the mitigation of climate change.

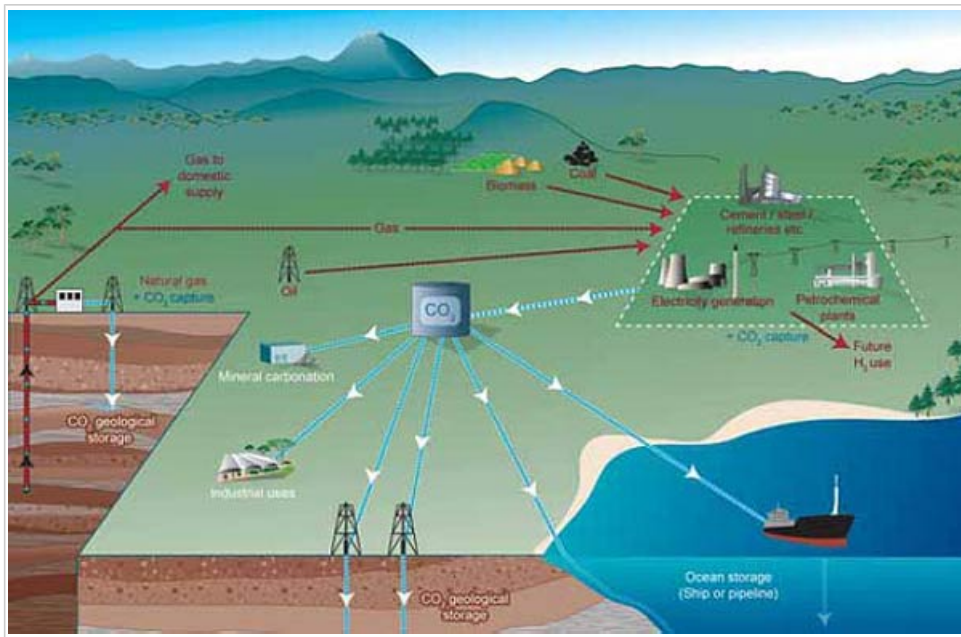
The consensus of the literature shows that CO₂ capture and storage could be an important component of the broad portfolio of policies and technologies that will be needed if climate change is to be successfully addressed at least cost.

Annex

Annex 1:

Figure TS.1. Schematic diagram of possible CCS systems

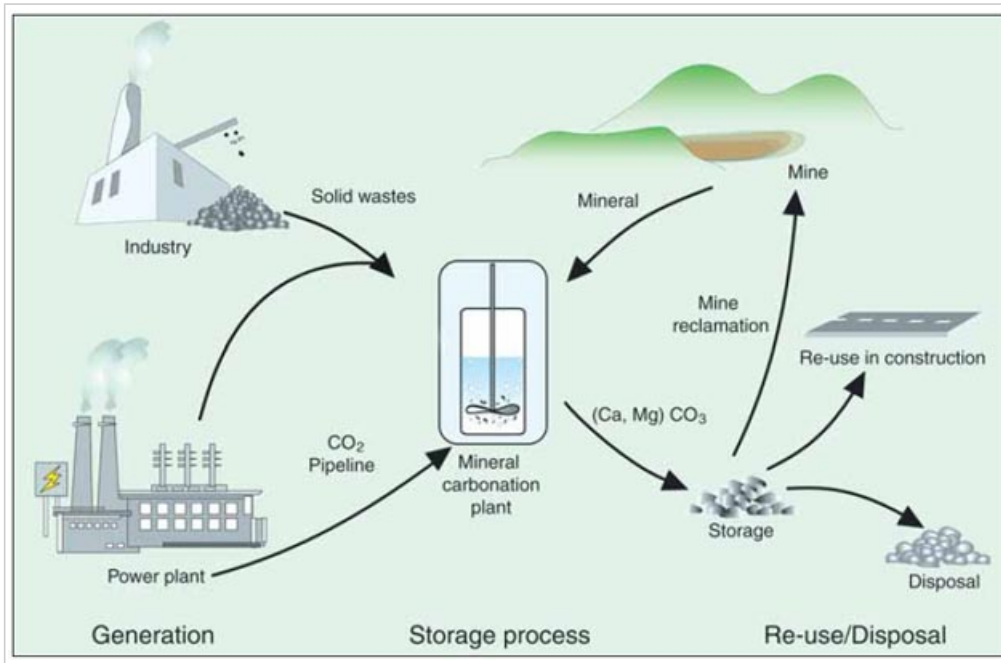
Schematic diagram of possible CCS systems showing the sources for which CCS might be relevant, transport of CO₂ and storage options (Courtesy of CO₂CRC).



Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
1. Introduction and framework of this report, p. 18

Annex 2:

Figure TS.10. Material fluxes and process steps associated with the mineral carbonation of silicate rocks or industrial residues (Courtesy ECN).

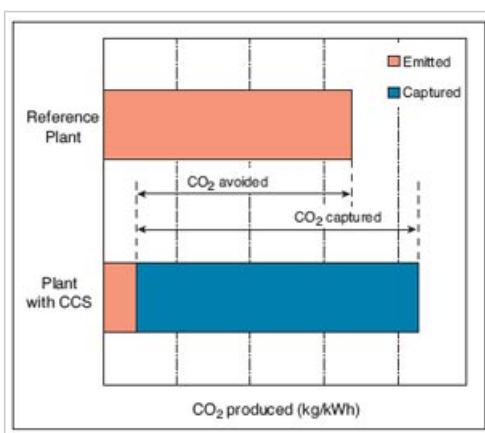


Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
 7. Mineral carbonation and industrial uses, p. 37

Annex 3:

Figure TS.11. CO₂ capture and storage from power plants

CO₂ capture and storage from power plants. The increased CO₂ production resulting from loss in overall efficiency of power plants due to the additional energy required for capture, transport and storage, and any leakage from transport result in a larger amount of “CO₂ produced per unit of product” (lower bar) relative to the reference plant (upper bar) without capture.



Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
 8. Costs and economic potential, p. 41

Annex 4:

Figure TS.2a. Global distribution of large stationary sources of CO₂

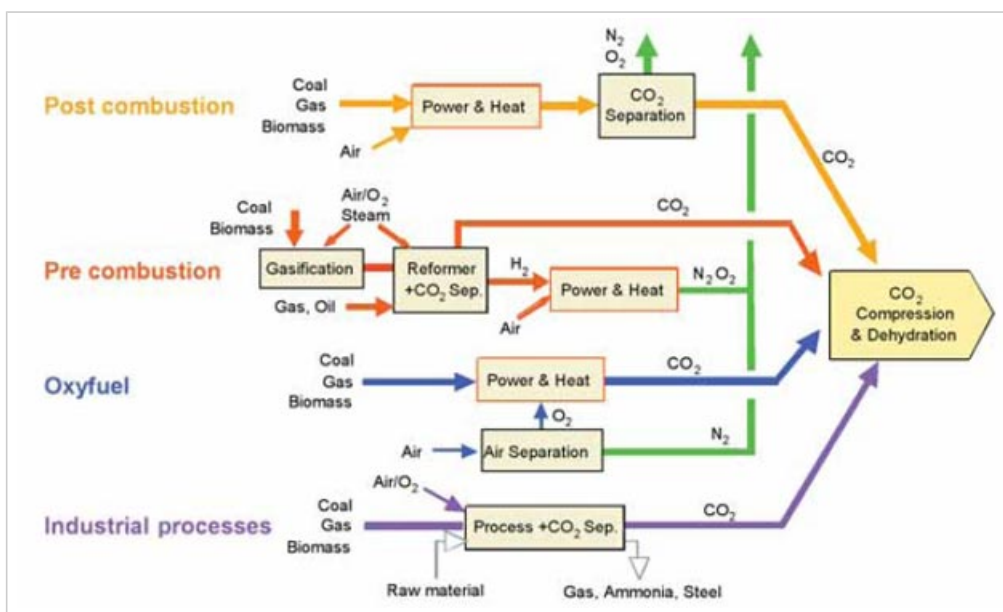
Global distribution of large stationary sources of CO₂ (based on a compilation of publicly available information on global emission sources, IEA GHG 2002)



Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
2. Sources of CO₂, p. 20

Annex 5:

Figure TS.3. Overview of CO₂ capture processes and systems

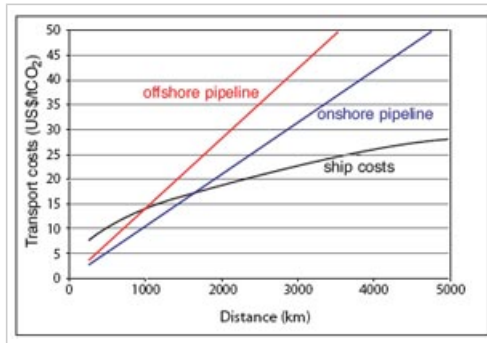


Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
3. Capture of CO₂, p. 25

Annex 6:

Figure TS.6. Costs, plotted as US\$/tCO₂ transported against distance, for onshore pipelines, offshore pipelines and ship transport

Costs, plotted as US\$/tCO₂ transported against distance, for onshore pipelines, offshore pipelines and ship transport. Pipeline costs are given for a mass flow of 6 MtCO₂ yr⁻¹. Ship costs include intermediate storage facilities, harbour fees, fuel costs, and loading and unloading activities. Costs include also additional costs for liquefaction compared to compression.

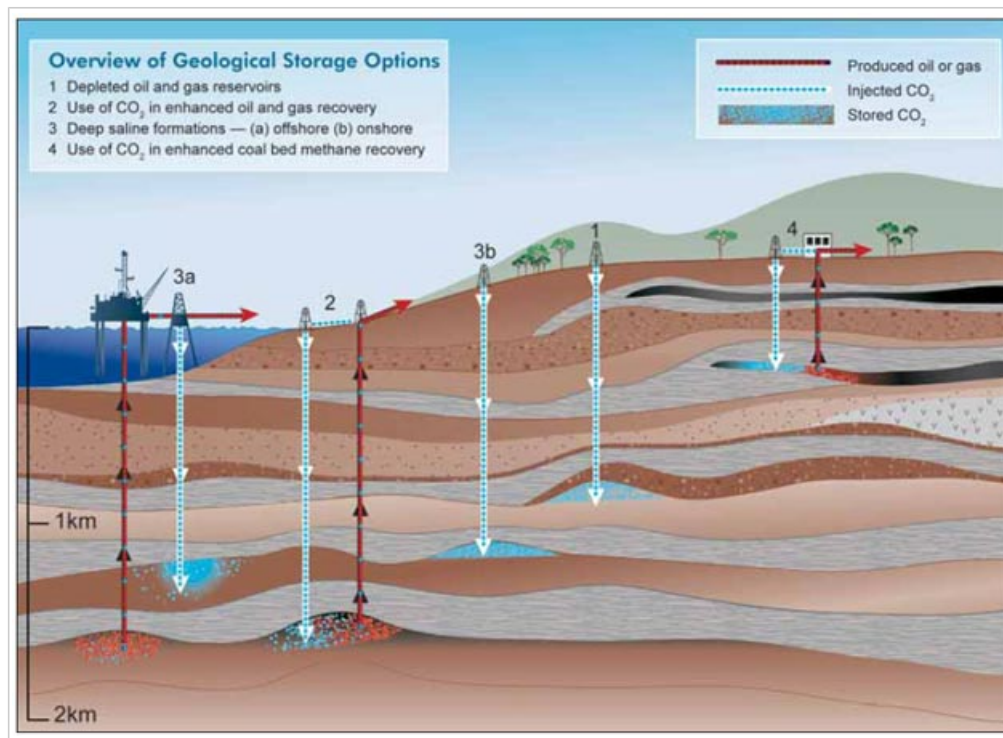


Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
4. Transport of CO₂, p. 28

Annex 7:

Figure TS.7. Methods for storing CO₂ in deep underground geological formations

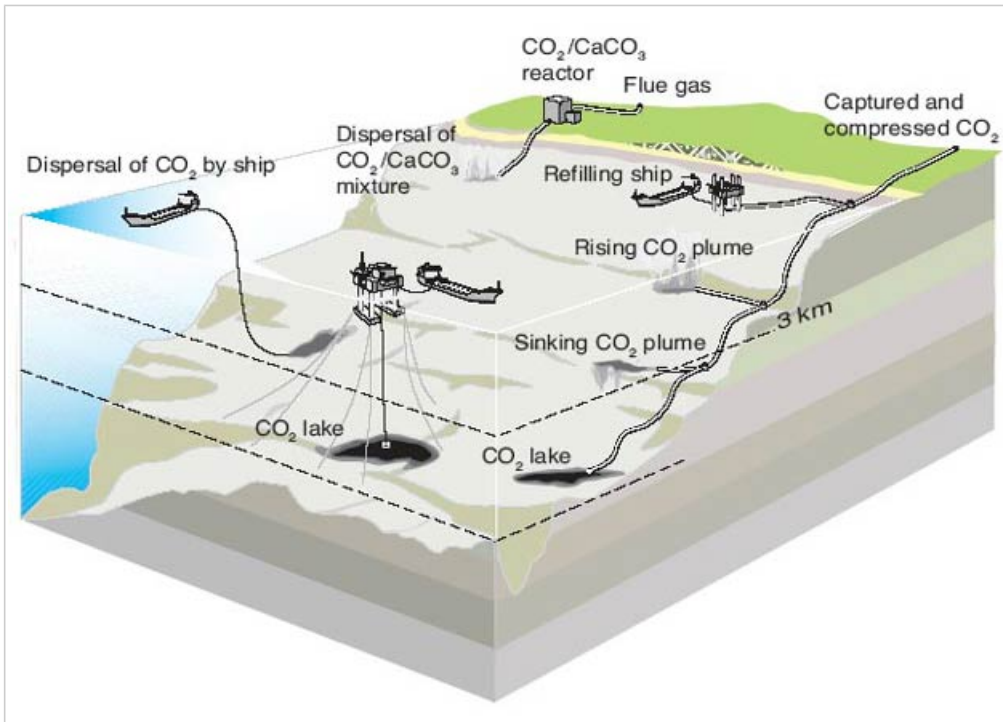
Methods for storing CO₂ in deep underground geological formations. Two methods may be combined with the recovery of hydrocarbons: EOR (2) and ECBM (4). See text for explanation of these methods (Courtesy CO₂CRC).



Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
5. Geological storage, p. 29

Annex 8:

Figure TS.9. Methods of ocean storage



Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
6. Ocean storage, p. 34

Annex 9: Figures TS.2a. & TS.2b.

Figure TS.2a. Global distribution of large stationary sources of CO₂

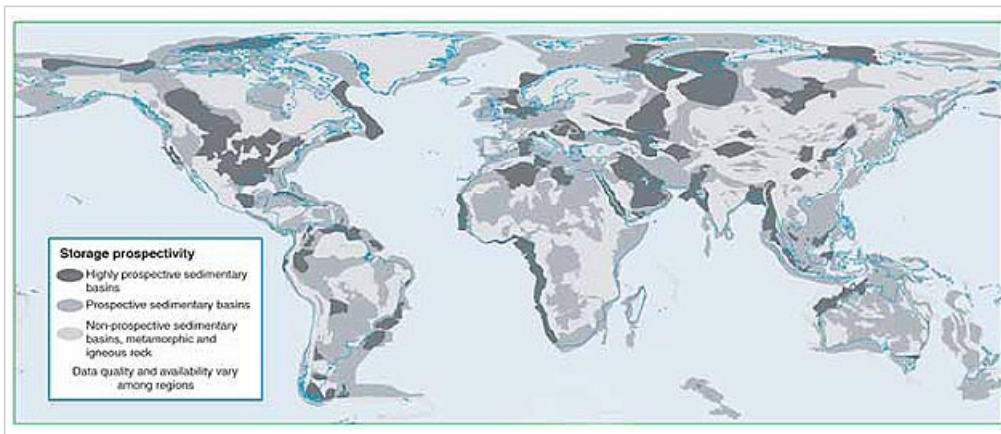
Global distribution of large stationary sources of CO₂ (based on a compilation of publicly available information on global emission sources, IEA GHG 2002)



Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
2. Sources of CO₂, p. 20

Figure TS.2b. Prospective areas in sedimentary basins

Prospective areas in sedimentary basins where suitable saline formations, oil or gas fields, or coal beds may be found. Locations for storage in coal beds are only partly included. Prospectivity is a qualitative assessment of the likelihood that a suitable storage location is present in a given area based on the available information. This figure should be taken as a guide only, because it is based on partial data, the quality of which may vary from region to region, and which may change over time and with new information (Courtesy of Geoscience Australia).



Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
2. Sources of CO₂, p. 21

Annex 10:

Table TS.12. Differences in the forms of CCS and biological sinks that might influence the way accounting is conducted.

Property	Terrestrial biosphere	Deep ocean	Geological reservoirs
CO ₂ sequestered or stored	Stock changes can be monitored over time.	Injected carbon can be measured.	Injected carbon can be measured.
Ownership	Stocks will have a discrete location and can be associated with an identifiable owner.	Stocks will be mobile and may reside in international waters.	Stocks may reside in reservoirs that cross national or property boundaries and differ from surface boundaries.
Management decisions	Storage will be subject to continuing decisions about land-use priorities.	Once injected there are no further human decisions about maintenance once injection has taken place.	Once injection has taken place, human decisions about continued storage involve minimal maintenance, unless storage interferes with resource recovery.
Monitoring	Changes in stocks can be monitored.	Changes in stocks will be modelled.	Release of CO ₂ can be detected by physical monitoring.
Expected retention time	Decades, depending on management decisions.	Centuries, depending on depth and location of injection.	Essentially permanent, barring physical disruption of the reservoir.
Physical leakage	Losses might occur due to disturbance, climate change, or land-use decisions.	Losses will assuredly occur as an eventual consequence of marine circulation and equilibrium with the atmosphere.	Losses are unlikely except in the case of disruption of the reservoir or the existence of initially undetected leakage pathways.
Liability	A discrete land-owner can be identified with the stock of sequestered carbon.	Multiple parties may contribute to the same stock of stored CO ₂ and the CO ₂ may reside in international waters.	Multiple parties may contribute to the same stock of stored CO ₂ that may lie under multiple countries.

Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
9. Emission inventories and accounting, p. 44

Annex 11:

Table TS.2. Profile by process or industrial activity of worldwide large stationary CO₂ sources with emissions of more than 0.1 MtCO₂ per year.

Process	Number of sources	Emissions (MtCO ₂ yr ⁻¹)
Fossil fuels		
Power	4,942	10,539
Cement production	1,175	932
Refineries	638	798
Iron and steel industry	269	646
Petrochemical industry	470	379
Oil and gas processing	N/A	50
Other sources	90	33
Biomass		
Bioethanol and bioenergy	303	91
Total	7,887	13,466

Source: IPCC Carbon Dioxide Capture and Storage: Technical Summary (2005) [see http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_TechnicalSummary.pdf]
2. Sources of CO₂, p. 20

Partner for this publication

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