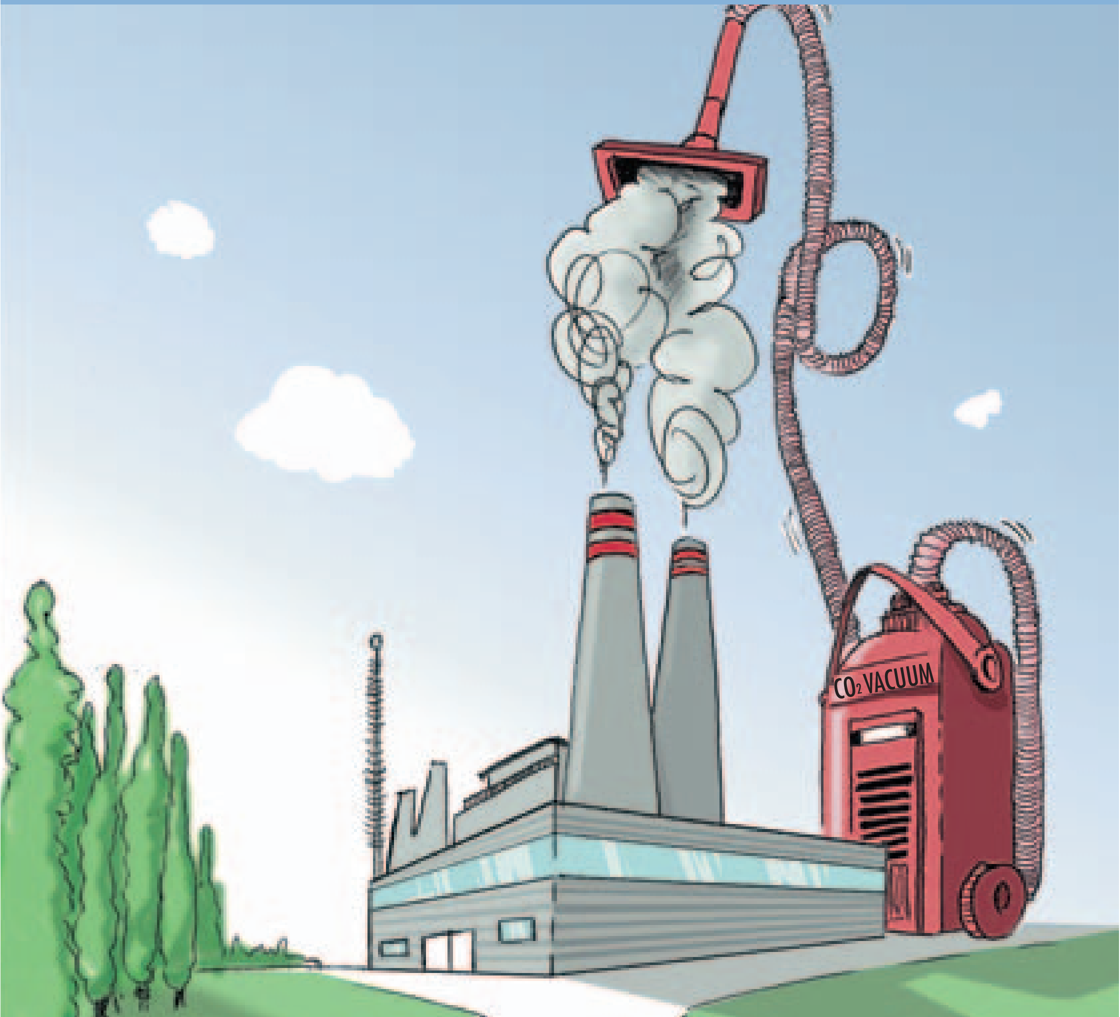
Can carbon dioxide storage help cut greenhouse emissions?



➤ A simplified guide to the IPCC's "Special Report on Carbon Dioxide Capture & Storage"

About the IPCC

The Intergovernmental Panel on Climate Change was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The IPCC does not conduct new research. Instead, its mandate is to make policy-relevant assessments of the existing worldwide literature on the scientific, technical and socio-economic aspects of climate change. Most of this expert literature has appeared in peer-reviewed publications.

The IPCC has produced a series of assessment reports, special reports, technical papers and methodologies that have become standard works of reference for climate change policymakers, experts and students. The Panel is organized into three Working Groups: Working Group I focuses on the science of the climate system; Working Group II on impacts, vulnerability and adaptation; and Working Group III on mitigation, a term used to describe human interventions to reduce new greenhouse gas emissions.

The IPCC's First Assessment Report was completed in 1990 and helped to inspire the intergovernmental talks that led to the 1992 United Nations Framework Convention on Climate Change. Its Second Assessment Report was published in 1996 and played a role in the Kyoto Protocol negotiations. The 2001 Third Assessment Report concentrated on new findings since 1995 and paid special attention to what is known about climate change at the regional level. The Fourth Assessment Report will be finalized in 2007.

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Introduction

Fossil fuels account for 75 - 80% of today's global energy use and three quarters of humanity's total carbon dioxide emissions. Without specific actions to minimize our impact on the climate, carbon dioxide (CO_2) emissions from fossil-fuel energy are projected to swell over the course of the 21st century. The consequences – a global temperature rise of 1.4 - 5.8°C and shifting patterns of weather and extreme events – could prove disastrous for future generations.

Stabilizing or reducing global emissions of carbon dioxide and other greenhouse gases over the coming decades will challenge human ingenuity. Fortunately, the IPCC's Third Assessment Report, published in 2001, concluded that existing and emerging technologies for limiting emissions could – if supported by the right policies – stabilize atmospheric concentrations of greenhouse gases by the end of the century at levels that would limit further climate change.

No single technology will suffice by itself; instead, a combination of technologies will be required. Many of the most promising technologies will contribute by improving the energy efficiency of certain processes and products or by converting solar, wind and other non-carbon power sources into usable energy.

But with oil, coal and gas set to remain the primary sources of energy for decades to come, governments and industry are also examining technologies for reducing emissions from these fuels. One such technology is known as carbon dioxide capture and storage. Abbreviated as CCS, this technology could be used by large stationary “point sources” such as fossil fuel-fired power plants and industrial facilities to prevent their CO_2 emissions from entering the atmosphere and contributing to climate change.

To learn more about this technology’s potential, the member governments of the United Nations Framework Convention on Climate Change asked the IPCC to assess the current state of knowledge about carbon dioxide storage and capture. The IPCC responded by assembling some 100 experts from over 30 countries to write the “IPCC Special Report on Carbon Dioxide Capture and Storage”. Numerous experts and governments reviewed the text before it was finalized in September 2005. The Report was then presented to governments at their annual Conference of the Parties to the Convention in December.

UNEP has produced this short public information booklet with the aim of making the Report’s technical findings more accessible to the general reader.

What is carbon dioxide capture and storage?

Carbon dioxide capture and storage technology involves capturing carbon dioxide before it can be emitted into the atmosphere, transporting it to a secure location, and isolating it from the atmosphere, for example by storing it in a geological formation.

1 – Capturing the carbon dioxide. The CO_2 must first be separated from other gases resulting from combustion or processing. It is then compressed and purified to make it easier to transport and store. Some gas streams resulting from industrial processes, such as natural-gas purification and ammonia production, are very pure to begin with, although others are not.

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

A post-combustion system separates the CO_2 from the other flue gases using an organic solvent.

A pre-combustion system starts by processing the primary fuel with steam and air or oxygen. The resulting carbon monoxide then reacts with steam in a second reactor. This produces hydrogen for making energy or heat as well as CO_2, which is separated out and captured.

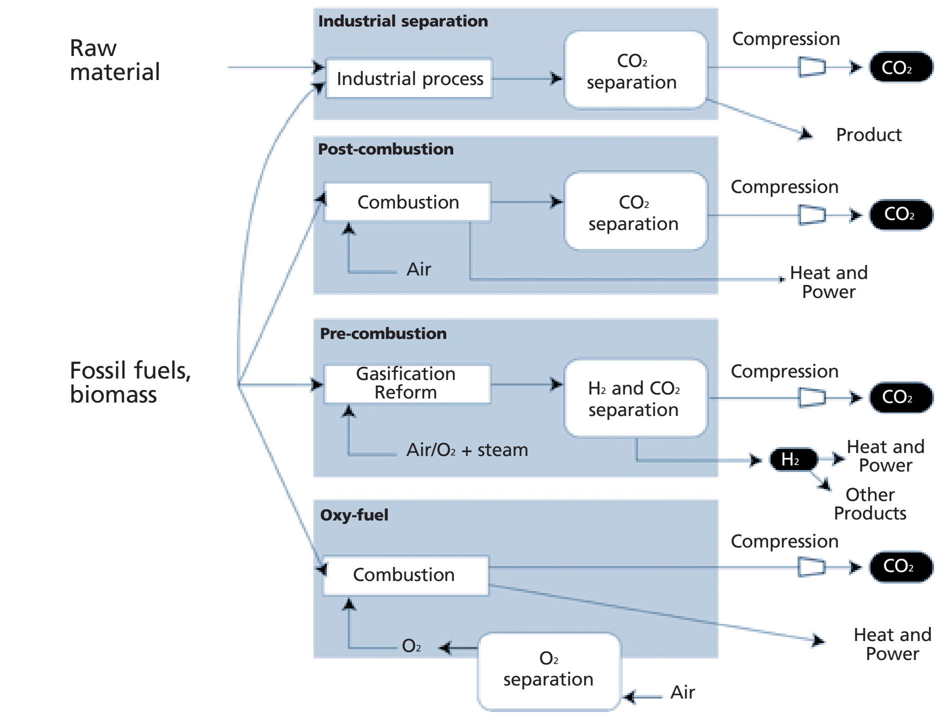
These two technologies have been in commercial use for decades in other, related applications. Current post-combustion and pre-combustion systems for power plants can capture 85-95% of the CO_2 produced. However, because CCS needs roughly 10 - 40% more energy than does the equivalent plant without capture, the net amount of CO_2 "avoided" is approximately 80 - 90%.

The third capture system is called ***oxy-fuel combustion*** because it uses oxygen instead of air to burn the fuel. It results in a flue gas containing mainly water vapour and CO_2. The water vapour is removed by cooling and compressing the gas stream. This technology, which is still in its demonstration phase, can capture nearly all the CO_2 produced, although the need for additional gas treatment systems to produce the oxygen and to remove pollutants such as sulphur and nitrogen oxides lowers the CO_2 avoided to about 90%.

2 – Transporting the CO_2. Except when the source is located directly over a storage site, the CO_2 needs to be transported. There are several ways of doing this.

Concentrated streams of CO_2 can be moved safely at high pressure through pipelines. Pipelines have been in use since the early 1970s and are currently

Schematic representation of capture systems

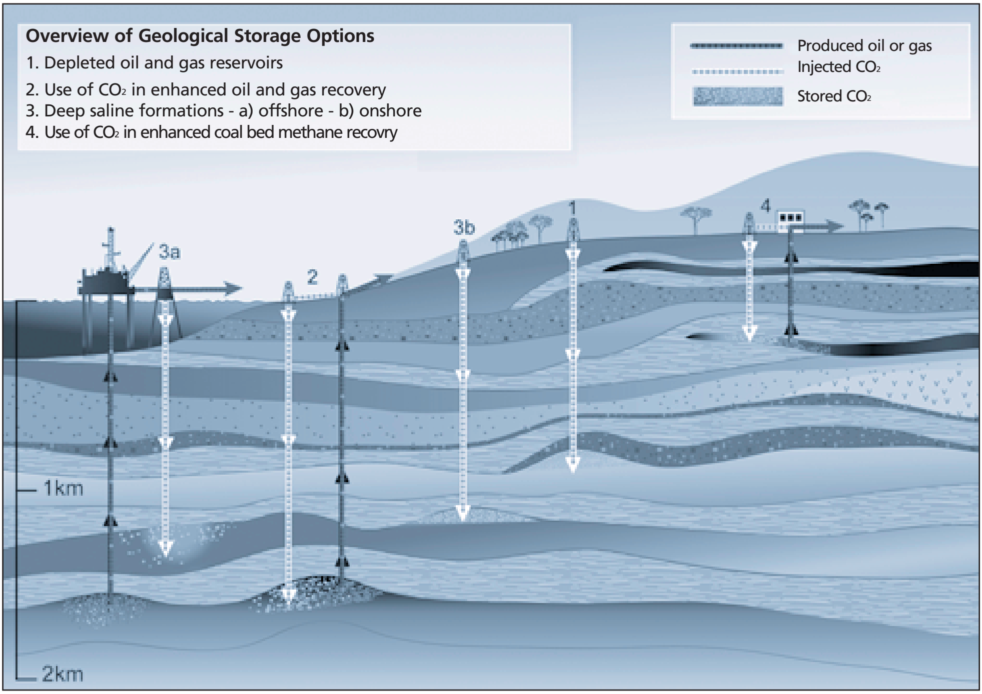


the main method for transporting CO_2. The US, for example, now has over 2,500km of CO_2 pipelines, primarily in Texas for Enhanced Oil Recovery (EOR) projects. Costs are higher when the pipeline is offshore or routed across heavily congested areas, mountains or rivers.

CO_2 can also be transported as a liquid in ships, similar to the way in which liquefied petroleum gas (LPG) is often transported. Road tankers or railcars with insulated tanks are technologically feasible but not economical.

3 – Storing the CO_2. Geological formations are the most economically feasible and environmentally acceptable storage option for CO_2, particularly given the experience already gained by the oil and gas industry. Compressed CO_2 can be injected into porous rock formations below the earth's surface using many of the same well-drilling technologies and monitoring methods already used by the oil and gas industry.

The three main types of geological storage are oil and gas reservoirs, deep

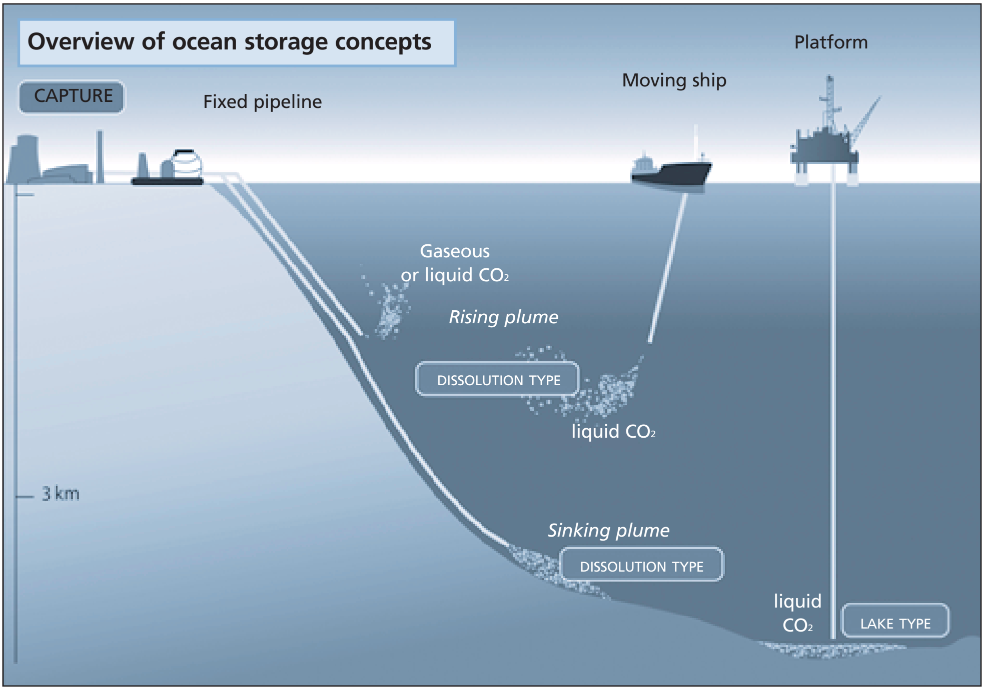


saline formations and unminable coal beds. Storage sites must generally start at a depth of 800m deep or lower, where prevailing pressures and temperatures usually keep CO_2 in a liquid-like state.

Potential geological 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 CO_2 emissions at current levels. Furthermore, a large proportion of existing power plants and other point sources lie within 300km of areas that potentially contain storage reservoirs.

While the available storage capacity in geological reservoirs is "likely" to be sufficient for contributing significantly to CO_2 emission reductions in the future, the true amount is as yet uncertain. This is particularly so in some regions that are experiencing rapid economic growth, such as South and East Asia.

Another way to store captured CO_2 may be to inject it into the oceans. The CO_2



can be released into the ocean water column via a fixed pipeline or from a moving ship. Alternatively, it can be deposited onto the deep seafloor at depths below 3,000m, where CO_2 is denser than water. These technologies, however, are still in the research phase, have not undergone full-scale testing and could have negative impacts on the ocean environment.

Technologies for storing CO_2 virtually permanently by converting it into inorganic mineral carbonates through chemical reactions are also in the research phase. Certain applications have been demonstrated on a small scale. Large amounts of energy and minerals, however, are required for this technology. Greater improvements would be needed before it could become a real option.

Finally, using captured CO_2 for chemical processes in industry is technically possible, but it has only modest potential for actually reducing emissions.

Who are the potential users?

The three main components of the CCS process – capture, transport and storage – are already used individually. Currently, CO_2 is typically removed to purify other industrial gas streams, such as natural gas or ammonia. However, as of mid-2005 there are three commercial projects that do combine all three components for the purpose of limiting CO_2 emissions to the atmosphere (see box on page 10).

In the future, the main potential users of CCS will be certain large, stationary point sources of CO_2. This is not as limited a group as it may sound: power stations, industrial plants and other large point sources account for close to 60% of global fossil-fuel CO_2 emissions. The qualities that make a source a particularly suitable candidate for CCS technology are the following:

• **Large size.** Systems for capturing CO_2 are currently in operation for smaller scale facilities and will require further demonstration in larger facilities over the coming years and decades. But clearly, the larger the facility, the greater the economies of scale, and the lower the cost for each tonne of CO_2 avoided by an investment in CCS technology. Large candidates for CCS are distributed around the world. However, there are four noteworthy clusters: eastern and Midwestern North America, northwest Europe, the eastern coast of China, and South Asia. East Asia and South Asia in particular are likely to see a significant increase in large power stations and industrial plants from now until 2050.

• **Highly concentrated CO_2 stream.** Purer CO_2 emission streams also lend themselves to economic efficiency. However, the vast majority of potential sources produce streams with CO_2 concentrations under 15%. Fewer than two percent of all fossil fuel-based industrial sources have CO_2 concentrations greater than 95%. These sources have the greatest early potential for CCS because only dehydration and compression would be needed for capture.

- **Located near storage site.** Globally, there is a potentially good correlation between major sources and prospective storage sites, with many sources lying either directly above, or within less than 300km of, a potential storage site.

The first three CCS projects

To avoid a Norwegian CO_2 emissions tax applied to offshore facilities, the Norwegian state oil and gas company Statoil established ***the Sleipner Project*** in the North Sea, about 250km off the coastline. The 9% concentration of CO_2 contained by the natural gas flowing from the Sleipner West Gas Field is separated out. It is then injected into a large, deep, saline formation some 800m below the seabed.

The CO_2 injection operation started in October 1996. By early 2005, more than seven million metric tonnes of CO_2 had been injected at a rate of approximately 2,700 tonnes per day. The project is expected to store a total of 20 million tonnes of CO_2 over its lifetime.

The Weyburn CO_2-enhanced oil recovery project is located in the Williston Basin, a geological structure extending from south central Canada into the US. The CO_2 comes from the Dakota Gasification Company, located approximately 325 km south of Weyburn in the US state of North Dakota. The facility gasifies coal to make synthetic gas (methane), with a relatively pure stream of CO_2 as a by-product. This CO_2 stream is dehydrated, compressed, and piped to Canada for use in the Weyburn oil field, where it is injected to assist the extraction of oil.

The Weyburn project is designed to use CO_2 for 15 years and to keep it securely stored thereafter. Extensive monitoring of the storage site is based on high-resolution seismic surveys and surface monitoring. To date, there has been no indication of CO_2 leakage to the surface or near-surface environment.

The In Salah Gas Project in Algeria's central Saharan region is a joint venture among Sonatrach, British Petroleum and Statoil. The Krechba Field at In Salah produces natural gas containing up to 10% CO_2 from several geological reservoirs. The gas is delivered to European markets after it is processed and the CO_2 is stripped to meet commercial specifications.

Since April 2004, the CO_2 has been re-injected via three wells into a sandstone reservoir at a depth of 1,800m. Some 17 million metric tonnes of CO_2 will be geologically stored over the life of the project. The injected CO_2 is expected to migrate eventually into the area of the current gas field after the gas zone has been depleted. The field has been mapped using 3D seismic and other data.

What are the potential benefits?

For policymakers faced with the complex and enormous challenge of reducing or limiting greenhouse gas emissions, CCS technology offers two potential benefits. First, it can expand their portfolio of options, giving them more flexibility and more opportunities. Second, it can reduce the overall costs of mitigation.

A number of studies based on modeled projections suggest that using CCS in conjunction with other technological options – such as increasing the efficiency of energy conversion, switching to less carbon-intensive fuels and using more renewable energy sources – could significantly reduce the cost of stabilizing atmospheric concentrations of carbon dioxide.

They find that CCS could lower the cost of mitigating climate change over the next 100 years by 30% or more. They also conclude that CCS systems will be competitive with other large-scale technologies, such as nuclear power and renewable energy technologies.

One attraction of CCS is that it could complement and facilitate the deployment of other potentially important technologies that can reduce CO_2 emissions over the long term. These include low-carbon or carbon-free facilities that produce hydrogen from carbonaceous fuels for the transport sector, and large-scale biomass energy systems that – equipped with CCS – could actually lead to “negative CO_2 emissions”, since sustainably grown biomass removes CO_2 from the atmosphere.

Given its cost competitiveness and the likely amount of capacity, geological storage using CCS could account for a large amount – 15 - 55% – of all emission reductions needed between now and 2100 for stabilizing greenhouse gas concentrations in the atmosphere. This would equal 220 to 2,200 billion tonnes (Gt) of CO_2.

For the owners and operators of large power generators and industrial plants, CCS technologies could one day offer a cost-effective tool for limiting their emissions. However, unless governments adopt national climate change policies that put a cost on emitting CO_2, there will be no incentive for private operators to use such mitigation technologies. All studies indicate that CCS systems (and many other mitigation measures) are unlikely to be used on a large scale unless there are explicit policies for substantially limiting greenhouse gas emissions to the atmosphere. Without this incentive, CCS may offer only small niche opportunities.

What are the costs?

The IPCC report finds that estimates for the current and future costs of CCS have significant uncertainties. The cost of capture and compression is normally the largest cost component. This and other costs will depend not only on the particular CCS system used – including the type of storage and the transport distance – but on such variables as the plant's design, operation, financing, size, location, fuel type and fuel cost.

Under current conditions, producing electricity costs about US$0.04 – 0.06/kWh (kilo-watt hour). Adopting today's CCS 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 CCS costs.

When CCS is compared to other technical options for reducing CO_2 emissions, the 10 - 40% additional energy that CCS systems require for producing the same amount of electricity has to be taken into account. The costs of CCS systems per tonne of CO_2 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 CCS system could influence the type of plant chosen. CCS 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 CCS is integrated into emerging technologies such as integrated gasified 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 CCS could decline as technology advances and economies of scale are achieved – perhaps by 20 - 30% over the next decade. On the other hand, rising fossil fuel prices could push CCS costs up.

The costs for non-power applications of CCS can be lower than those for electricity plants. For biomass plants with CCS, the costs would be relatively high in view of their currently small size.

What are the risks and barriers?

In addition to technology and cost issues, the potential users of CCS technology will want to consider health, safety, environmental and legal concerns, as well as public perception. The key barriers and risks that would have to be addressed are:

• **Leakage during capture, transport and storage**. Sudden local leaks of CO_2 from capture installations or pipelines could pose potential hazards to workers and other people in the vicinity, similar to the kinds of situations faced in the oil and gas industry and with gas pipelines. Exposure to air containing CO_2 concentrations greater than 7 - 10% poses an immediate danger to human life and health. The probability of such events, however, is low.

There is also a risk of CO_2 leakage from geological storage. In addition to contributing to climate change, slow leaks could harm plants and animals. The probability of such leaks, however, would be low as long as the reservoirs are carefully selected and the best available technologies are used. At the global level, well-selected geological formations are likely to retain over 99% of their storage over a period of 1,000 years. Overall the risks of CO_2 storage are comparable to the risks in similar existing industrial operations such as underground natural-gas storage and enhanced oil recovery.

• **Environmental impacts of ocean storage**. Injecting carbon dioxide into the oceans could harm marine life. Although the long-term environmental implications of changing the ocean chemistry in this way are unclear, CO_2 injection on a large scale could locally acidify the oceans and negatively affect marine organisms and ecosystems.

• **Lack of legal and regulatory clarity**. There is remaining uncertainty about the legality of injecting CO_2 into or beneath the world's oceans; this issue is being actively considered under several international treaties. The Climate Change Convention and the Kyoto Protocol will also need to establish rules and accounting procedures for CCS systems. At the national level, few countries have set up legal or regulatory frameworks that address geological storage sites. Potential legal issues include liability in the event of accident or leakage and the property rights of owners of the land above geological storage sites.

• **Public scepticism**. At present, the general public is not well informed about CCS. The few studies carried out so far suggest that this technology may be less favourably viewed than other options, such as improving energy efficiency or adopting renewables. It is unclear how the public would respond to better information about CCS, other options for reducing emissions and the broader challenges of climate change.

Conclusion: does CCS have a future?

The IPCC report concludes that CCS is technologically feasible and could play a significant role in reducing greenhouse gas emissions over the course of the current century. But a number of issues would still need to be resolved before CCS technology could be rolled out on a large scale.

First, the technology needs to mature further. While the individual components of CCS 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 and increase knowledge about and experience with CCS. More studies are needed to analyze and reduce the costs and estimate the potential capacity of suitable storage sites, particularly in those areas where data are currently limited.

The right legal and regulatory environment also needs to be further developed. This must include agreed methods for estimating and reporting the amount of CO_2 avoided by CCS, as well as the amounts that may leak over the longer term. CCS will be considered in the next revision of the Guidelines that the IPCC has developed to assist countries with the greenhouse gas inventories required under the Convention.

A particularly critical issue remains that of incentives. CCS 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 CO_2 exceeds $25-30 (in 2002 dollars) over the lifetime of the project. A price on emitting carbon can only result from national policies for limiting CO_2 emissions.

Developing countries, which do not have quantified emission reduction targets under the Kyoto Protocol, may be first introduced to CCS technology through bilateral projects such as the new EU-China initiative to build a CCS facility or (if CCS is deemed eligible) through the Clean Development Mechanism (CDM). Again, accounting rules would have to be elaborated to calculate and account for project-related CCS reductions and to provide the necessary incentives.

If these various conditions are met, CCS systems could be deployed in the power sector on a large scale within a few decades from the start of any significant regime that imposes limits on greenhouse gas emissions. Several hundreds to thousands of CCS systems would be required worldwide to meet the technology's economic potential.

Under most scenarios for stabilizing atmosphere concentrations of CO_2 by 2100, CCS systems would be built in significant numbers in the first half of this century, with the majority of them built in the second half. The consensus of the literature shows that CCS 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.

For further information, see www.ipcc.ch.

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