Carbon dioxide capture and geological storage

The world's primary energy consumption is currently estimated at 10.5 GtOE[1], of which about 80% is in the form of fossil fuels (oil, gas and coal). Whether issued by the International Energy Agency (IEA), the World Energy Council (WEC), the European Commission or the United States Department of Energy (DOE), most forward-looking scenarios agree that energy consumption will rise (to between 16 and 18 GtOE by 2030), with fossil fuels continuing to dominate the energy mix. However, even though the combustion of fossil fuels contributes to anthropogenic emissions of carbon dioxide (CO_2), mankind cannot do without energy to support its development. In response to this paradox – and until alternative energy solutions reach full maturity – one possible means of climate change mitigation consists of storing the CO_2 generated by large point sources of emissions. This measure must also be accompanied by efforts to improve energy efficiency and diversify energy sources in order to stabilize atmospheric concentrations of greenhouse gases.

What is carbon dioxide capture and geological storage?

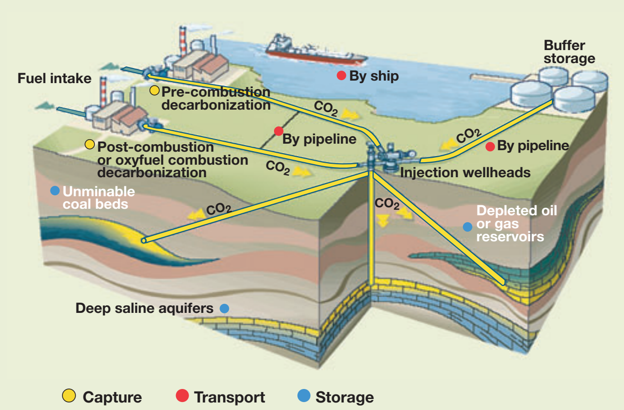
The capture and geological storage of CO_2 is a process that consists of separating and recovering the CO_2 from process gases or flue gases at large industrial installations, then transporting it and injecting it into a suitable underground formation for storage.

Of the three main steps involved in the process (i.e., capture, transport and storage), the first phase in which the CO_2 is separated from the other constituents of flue gases or other gas streams (mainly water vapor and nitrogen) is by far the most costly, estimated by the IPCC[2] to amount to two-thirds of the overall cost. Yet this step is crucial for at least two reasons:

1. Combustion gases contain an average of 3 to 15% CO_2, so removing the CO_2 reduces the volume that must be transported, and therefore the associated costs;

2. Only a limited number of formations meet the specifications for CO_2 storage, so isolating the CO_2 is a means of optimizing the available storage capacity.

CO_2 capture and storage



Capturing CO_2 from large fossil-fueled combustion installations

Due to their high investment costs, CO_2 capture technologies are appropriate above all for large, concentrated emission sources; they appear unsuitable for diffuse emission sources.

Worldwide, fossil-fueled power generation alone accounts for just over 42% of overall anthropogenic CO_2 emissions (and about 80% of CO_2 emissions from the industrial sector). Conventional power plants (particularly coal-fired units) and, to a lesser degree, certain other industrial facilities such as cement mills, refineries, fertilizer factories, steel mills and petrochemical plants, are currently viewed as the installations where CO_2 capture appears to be the most applicable.

Annual carbon dioxide emissions from major industrial sources

	In Mt CO_2/yr
Power	10,539
Iron & steelmaking	646
Cement manufacture	932
Oil refining	798
Petrochemicals	379
Oil & natural gas processing	50
Other sources (including biomass)	124
Aggregate worldwide large stationary sources of CO_2 emissions	**13,468**

Source: IPCC report - 2005

[1] Giga (metric) tons of Oil Equivalent
[2] Intergovernmental Panel on Climate Change

CO_2 capture and transport

Some activities, such as natural gas treatment and ammonia and hydrogen production, already separate CO_2 from the gas streams when concentrations exceed a prescribed threshold. In those examples, however, the aim is to purify other gases, and the CO_2 is often discharged to the atmosphere. Today's challenge is to develop more efficient and larger-scale technologies that will permit storage of CO_2. As for transport, there are two options – by pipeline or by ship – the choice of which depends on the distance between the emission source and the storage site.

The three capture techniques

According to the type of installation, CO_2 capture may take place at three different stages, termed post-combustion, precombustion, or oxyfuel combustion decarbonization. Each of these techniques is at a different stage of maturity and offers its own advantages and drawbacks (cost, energy consumption, etc.).

Post-combustion decarbonization is the most mature, but also the most costly of the three techniques, and is appropriate for existing installations. It involves separating the CO_2 contained in combustion gases, usually by means of a liquid solvent such as mono ethanol amine (MEA).

Pre-combustion decarbonization yields two separate concentrated streams of hydrogen and CO_2, thereby facilitating CO_2 capture. The process consists of treating the fuel either with steam and air (steam reforming) or with oxygen (partial oxidation) to produce a synthesis gas that contains mainly carbon monoxide (CO) and hydrogen, a potential energy carrier that generates no CO_2 emissions. A second step converts the CO in the presence of water (H_2O) then separates the resulting CO_2 for capture and storage.

Oxyfuel combustion decarbonization is still in the pilot phase. This technique yields a combustion gas highly concentrated in CO_2 (between 80% and 90% by volume) and could constitute a suitable retrofit technology for existing installations. The process uses high-purity oxygen instead of air for combustion, the main difficulty being to extract the oxygen from the air. Due to the high cost of this separation step, a "chemical looping" process is being investigated in which the oxygen supply is derived from a reaction involving a metal oxide, using metal particles such as iron filings, which would serve as the oxygen carrier from air to fuel.

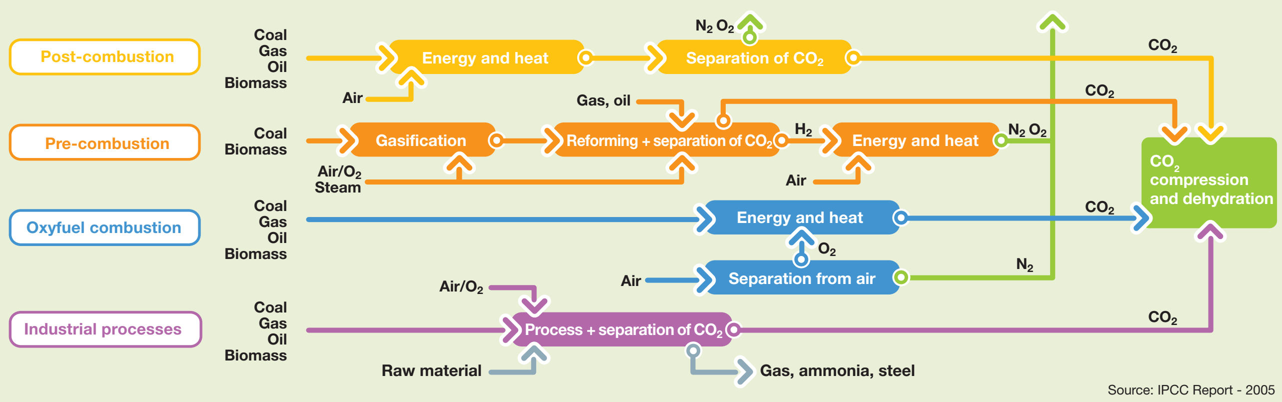
CO_2 transport options

CO_2 is already transported via dedicated pipelines in the United States, where more than 40 million tonnes are conveyed each year over a 2,500-kilometer network. The CO_2 must then be pressurized to at least 73 bar to reach a supercritical state and high density, giving it properties similar to the liquid state.

When transport distances exceed 500 to 1,000 km (the threshold varies according to the source quoted), transport by ship is considered a more economical option. In this case, CO_2 is transported in the liquid state under conditions comparable to those of LPG (liquefied petroleum gas) transport.

> "Available technology captures about 85-95% of the CO_2, but a power plant equipped with a carbon capture and storage system would need roughly 10-40% more energy than a plant of equivalent output without such a system, of which most is for capture and compression.
>
> (IPCC Report-2005)"

CO_2 capture techniques



Source: IPCC Report - 2005

Geological storage of CO_2

A portion of the captured CO_2 can be reused by the food and chemical industries. However, the needs of industry fall far short of the quantities potentially recoverable. Although the various possible options for geological storage are at different stages of maturity, all solutions will have to store the CO_2 at sufficient depth (more than 800 meters) in order for the gas to reach the supercritical state and thus occupy the smallest possible volume.

1. Storage in depleted oil and natural gas reservoirs. This type of storage offers numerous advantages, the most significant being that the cap rock is impermeable and its characteristics well known. Indeed, natural reservoirs have proven their capacity to contain hydrocarbons for several million years. Moreover, CO_2 storage in this type of formation is a practice which, although not widespread, is at least known to the oil and gas industry, which already injects CO_2 into oilfields to reduce crude oil viscosity, improve mobility and thereby boost the recovery rate – a technique known as Enhanced Oil Recovery (EOR). Finally, some of the infrastructure in place for exploration and production of crude oil (such as pipes and wells) can be reused for CO_2 storage operations, thereby helping to control costs.

However, reservoirs are not always located near the source of CO_2 emissions; nor is the available storage capacity sufficient to meet all needs.

2. Storage in unminable coal beds. In this option, the coal bed is not used as a reservoir, but stores the CO_2 by absorption of the gas. Provided the coal bed is adequately covered over by impermeable cap rock, this technique would allow not only storage of CO_2, but also methane recovery (ECBMR – Enhanced Coal Bed Methane Recovery).

However, present understanding of this type of storage is still incomplete.

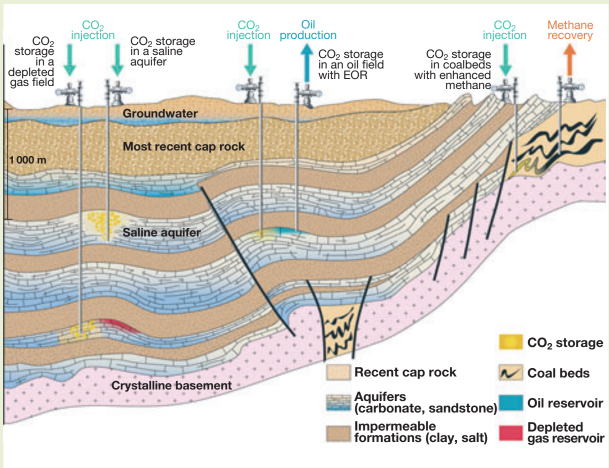
3. Storage in saline aquifers. There are numerous such aquifers located in sedimentary basins, with areas of up to several thousand square kilometers. They can be either offshore or onshore. Formed of porous, permeable rock often saturated with brackish water or brine that is unfit to drink, these aquifers are potential storage sites for considerable quantities of CO_2, provided they are at a sufficient depth (> 800 meters) and have overlying impermeable layers.

However, extensive work is still needed to gain better knowledge of these aquifers.

Key projects under way:

- Weyburn (Canada): injection of CO_2 into an oil reservoir and EOR.
- In-Salah (Algeria): storage in an onshore aquifer.
- Sleipner (Norway): separation of CO_2 from a natural gas field and storage in an offshore saline aquifer.

The various types of geological storage



The main issues to be resolved

Today, there are three broad issues that must be resolved in order for CO_2 capture and geological storage technology to reach maturity:

- cost reduction, especially in relation to the CO_2 capture phase;
- establishment of a framework to better define the conditions for the monitoring of storage sites and the long-term responsibility for the site;
- public acceptance.

Total's **commitment**

Backed by its expertise in industrial processes and its knowledge of subsoil geology, Total turned its attention early on to the potential of CO_2 capture and storage technology and has teamed up with various experts in a number of national and international R&D projects in this field. The Group aims to contribute to the emergence and mastery of this technology, vital to the sustainable pursuit and growth of its own activities, but offering applications in many other industrial processes as well. Total is currently devoting much of its effort to the oxyfuel combustion option, with a high-profile demonstration pilot in preparation in the Lacq basin in southwest France, without neglecting the possibilities of post-combustion and chemical-looping technologies.

Research programs

The various studies that Total has undertaken jointly with French and international research partners focus on aspects including capture technologies; the physical-chemical properties of CO_2 in the storage formation; the long-term integrity of reservoirs and boreholes; and methods of risk analysis. In addition to its involvement in numerous research projects being pursued under the programs of the French National Research Agency (ANR) – including the Géocarbone-Picoref project aimed at identifying potential geological storage sites in France, Total is participating in projects at the European level, such as ENCAP (Enhanced CAPture of CO_2) and CO_2 ReMove. The Group is involved in CO2NET, a network of industries and research bodies dedicated to promoting the deployment of geological CO_2 storage applications in Europe and neighboring countries.

Furthermore, in February 2007, Total announced the launch of France's first demonstration pilot spanning the entire capture and storage process for the CO_2 emissions associated with steam generation in the Lacq basin.[3]

A pilot installation in the Lacq area

For the very first time, a French program will test the entire CO_2 capture and storage process, from the CO_2 emissions source (a boiler) to underground storage in a geological formation.

This project entails converting one of the five steam boilers of the Lacq field's steam generating plant to an oxyfuel combustion unit, then capturing and compressing its CO_2 emissions, transporting the gas via a 27-kilometer gas pipeline,[4] for injection into the nearly-depleted Rousse natural gas reservoir in the Lacq area, at a depth of 4,500 meters.

The pilot plant, which will produce some 40 tonnes of steam per hour for use by the industries of the Lacq complex, will emit up to 150,000 tonnes of CO_2 over a two-year period. The Rousse well will be subject to close monitoring, with detectors located throughout the surface and subsoil regions to measure the injection flow, pressure, temperature and concentration of the CO_2.

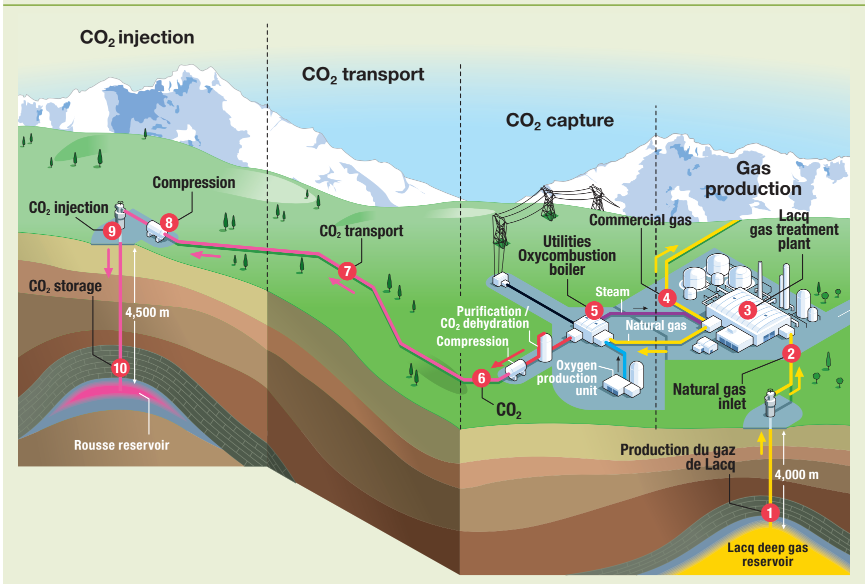
The demonstrator unit is scheduled to start up in late 2008, after two years of studies and preparation. The project has three key objectives:

- to improve mastery of the oxyfuel combustion process, particularly with a view to applications in the production of extra-heavy oils,
- to halve the cost of carbon capture compared to existing processes,
- to develop monitoring methods and instruments to demonstrate on a larger scale the reliability and sustainability of long-term CO_2 storage technology.

The pilot will also contribute to the goal CO_2 emissions-free power generation (Zero Emission Fossil Fuel Power Plant) defined by the European Technology Platform, in which Total is a partner.

The success of this demonstration project also calls for a constructive dialogue with stakeholders, and will therefore be the focus of a preliminary consultation and outreach process.

Operating principle of the Lacq oxyfuel combustion pilot unit



Industrial projects

Even as it pursues the Lacq pilot development, Total is a partner in a number of other industrial demonstration projects.

In addition to being a partner since 1996 in the injection of CO_2 from the Sleipner field into an aquifer (with Statoil as operator), Total is involved in the CO_2 injection project on the Snøhvit gas field in the Norwegian Sea, also operated by Statoil. The CO_2 will be separated onshore in an LNG (liquefied natural gas) plant, then conveyed offshore by pipeline and injected via subsea wells into the saline aquifers of the Tubäen sandstone, at a depth of 2,600 meters.

[3] As part of a technological partnership with Air Liquide, and including several other cooperation agreements with Alstom, IFP, (French Petroleum Institute), BRGM (French bureau of geological and mining research) and CNRS (the French national center for scientific research).

[4] The pilot program will use an existing pipeline, which has been carrying natural gas produced for the Rousse gas field to the Lacq complex for the past three decades.

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