

# Introduction on CO<sub>2</sub> Geological Storage. Classification of Storage Options

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**Résumé — Introduction au stockage géologique du CO<sub>2</sub> - Classification des options de stockage —**  
Après les étapes de capture et de transport, le CO<sub>2</sub> est stocké dans des formations géologiques. Cet article présente les différentes options de stockage : les réservoirs d'hydrocarbures déplétés, les aquifères salins profonds, les veines de charbon, les cavernes et les mines. Chaque option fait l'objet d'un article détaillé.

**Abstract — Introduction on CO<sub>2</sub> Geological Storage - Classification of Storage Options —** Following the capture and transport processes, CO<sub>2</sub> is stored in geological formations. This paper reviews the various underground storage options: depleted oil and gas reservoirs, deep saline aquifers, deep seated coal beds, caverns and mines. Each option is detailed in a separated paper following this introduction.

## 1 SCOPE

The energy consumption of the world is still depending on fossil fuels and will continue to be so for a long time yet to come. However, the use of fossil fuels has led to a significant increase in the amount of carbon dioxide in atmosphere, contributing up to 50% of the greenhouse effect. Other major greenhouse gases are nitrous oxide, CFCs, methane and ozone. The combustion of fossil fuels is responsible for 73% of the carbon dioxide production. The other main source is deforestation (25%). Consequently, the development of greenhouse gas mitigation technologies plays an important role as a potential response to global warming (Kyoto Agreement). In this respect, carbon dioxide capture and storage (CCS) is gradually becoming an important concept to reduce these greenhouse gas emissions, next to other options, such as the large scale use of renewable energy, nuclear energy and energy efficiency improvements.

The development of technology for CO<sub>2</sub> capture and storage (CCS) could make a significant contribution towards

the reduction of anthropogenic greenhouse gas emissions within a relatively short period.

The general concept of carbon dioxide capture and storage comprises three steps:

– **Capture of CO<sub>2</sub>**: Power plants are the largest point sources of CO<sub>2</sub> emissions to the atmosphere and hence CO<sub>2</sub> capture from power plants can have a large impact on emission reduction. CO<sub>2</sub> emissions from power production are around 30% of overall emissions. Large amounts of CO<sub>2</sub> are emitted in diluted streams of flue gases at atmospheric pressure, as the fuel is usually burned in air. Other large single point sources of diluted CO<sub>2</sub> are furnaces, industrial boilers and cement production plants. The emitted CO<sub>2</sub> is captured at the source.

In order to simplify the ensuing steps of transport and storage a near pure CO<sub>2</sub> product at an absolute pressure of 100 bar needs to be produced by the capture process. Therefore a compression step is also needed to achieve the right transport/storage conditions.

- **Transport of CO<sub>2</sub>:** Transport of CO<sub>2</sub> is needed as the emissions of CO<sub>2</sub> will not necessarily be at the same location as the storage site. A transport system (via pipelines and/or shipping) is therefore needed to link the CO<sub>2</sub> sources to the CO<sub>2</sub> storage sites.
- **Storage of CO<sub>2</sub>:** Storage of CO<sub>2</sub> should be such that it remains isolated from the atmosphere for a suitably long period. The options for this are mainly underground, *i.e.* (depleted) oil and gas fields, aquifers and deep seated coal bearing layers.

Various aspects and components of the CCS process chain have been researched over the past 15 years, both practically and theoretically. This has revealed that CCS can be a valuable part in the portfolio of technologies to reduce CO<sub>2</sub>-emissions. It is also accepted that capture, transport and underground storage of CO<sub>2</sub> can be achieved using technologies which are commercially available. However, there is a need to adapt and optimise these technologies for cost effective CCS.

This report reviews the technological state-of-the-art of the various underground storage options. A separate chapter is dedicated to monitoring technology that is available for underground storage, another one to the injection processes and technologies. Some other areas of research, such as ocean storage, economics, health, safety and environmental aspects of CO<sub>2</sub> injection and storage are not included in the report.

## 2 GEOLOGICAL CO<sub>2</sub> STORAGE OPTIONS

Following the capture and transport processes, CO<sub>2</sub> needs to be stored in order not to be emitted into the atmosphere. Storage in underground rock structures is one of the items towards which research is concentrated.

The main geological storage options are: oil and gas reservoirs, deep saline aquifers, deep seated coal beds (enhanced coal-bed methane recovery), caverns and mines.

The technologies for these storage options are at various stages of development. The know-how related to the exploration and production of hydrocarbons is of utmost importance, because these techniques are directly applicable to CO<sub>2</sub> storage. EOR by injection of CO<sub>2</sub> into oil fields has already been practiced in the USA as a commercial tertiary recovery technique, whereas the first commercial application of CO<sub>2</sub> storage in an off-shore aquifer has been running successfully since 1996 at the Sleipner gas field in Norway. Other storage options are currently studied as well, as in the EU supported pilot of the storage of CO<sub>2</sub> in a coal bed in Poland.

An important challenge is the estimation of the capacity of geological storage. Much work on the mapping of storage options has already been carried out during the past 10 years. A major contribution towards the storage potential in Europe was the EU supported GESTCO study. Based on this study the storage capacity is not a limiting factor. Altogether more than 40 Gt CO<sub>2</sub> can be stored in (depleted) oil and gas fields

in Western Europe and 150 to 1500 Gt CO<sub>2</sub> of theoretical potential is estimated for deep saline aquifers in Western Europe<sup>1</sup> [IEA GHG (2005) Building the Cost Curves for CO<sub>2</sub> Storage: European sector. Report Number 2005/2].

## 3 OIL AND GAS FIELDS

Oil and gas fields have proven their capability to hold oil and gas over long (geological) time periods and therefore can act as long-term storage sites for CO<sub>2</sub> as well. This option is particularly interesting when one can take advantage of CO<sub>2</sub> injection to effect enhanced oil (or gas) recovery. Improvement of gas recovery (EGR) with the help of CO<sub>2</sub> injection is still in the phase of desk studies. In addition, the level of knowledge of oil and gas fields is high, which supports the predictability of the reservoir as a potential CO<sub>2</sub> storage structure.

The theoretical storage potential is considerable; an estimate resulted in a theoretical potential of more than 40 Gt CO<sub>2</sub> in European hydrocarbon reservoirs (IEA GHG, 2005), 7 Gt of which can be stored in oil fields. A drawback of oil and gas fields is that the majority of them are at considerable distance (the North Sea region) from the CO<sub>2</sub> emitting power plants.

There are no principle technical barriers for storage in gas fields although it has not been implemented to date. Storage of natural gas is routine business in many countries like the US, France and Germany. A pilot project for CO<sub>2</sub> storage in gas fields has started in the Dutch sector of the North Sea (K12-B gas field). Underground storage of natural gas is competing for space with storage of CO<sub>2</sub>.

CO<sub>2</sub> injection has been applied for many years already to enhance the production of oil from oil reservoirs (EOR), in particular in the United States. In conventional CO<sub>2</sub>-EOR, the main aim is to inject a minimum amount of CO<sub>2</sub> to maximise oil production. Conversely, in the case of CO<sub>2</sub> storage, one tries to inject the maximum amount of CO<sub>2</sub> and possibly increase oil production. This difference is demonstrated in the Canadian Weyburn project, which is directed to the co-optimisation of oil production and CO<sub>2</sub> injection. For the owners and the operator of the Weyburn oil field, increased oil production is paramount; while an international consortium is studying the aspects of optimising the net amount of injected CO<sub>2</sub>.

With regard to safety and environmental impact, particular attention should be directed to the integrity of the wells that were drilled for the exploitation of natural gas or oil. They might form locations of unintended CO<sub>2</sub> leakage. Specific attention should also be directed to unintended fracturing of

(1) The estimate of the theoretical aquifer storage potential is marked by large uncertainty, which is caused by a lack of suitable data and by uncertainty in the aquifer storage concept that is applicable (physical trapping, dissolution, mineralization or a combination of these).

the seal as a consequence of the pressure fluctuations in the reservoir and possible degradation of seal integrity due to reaction with CO<sub>2</sub>-loaded fluids.

#### 4 DEEP SALINE AQUIFERS

This solution has great potential in terms of storage capacity, although the uncertainty in the available estimated potential is high. This is caused by the generally low level of knowledge for deep-seated saline aquifers. Due to the high salt content of these formations, they cannot be used as sources of drinking or irrigation water.

An estimate of the theoretical storage potential revealed a potential of 150 to 1500 Gt CO<sub>2</sub> in West-European aquifers (IEA GHG, 2005). A major characterization and testing effort is called for, in order to qualify this type of aquifer for geological storage, especially onshore. The low level of reconnaissance will increase the lead times for the implementation of CO<sub>2</sub> storage in saline aquifers.

The first large-scale CO<sub>2</sub> storage plant injects CO<sub>2</sub> in an aquifer, which is at a depth of 800 to 1000 m below the sea bottom (near the Sleipner gas field in the Norwegian North Sea).

#### 5 DEEP COAL SEAMS

In recent years, the use of CO<sub>2</sub> for Enhanced Coal-Bed Methane Recovery (ECBM) has attracted a lot of attention for some obvious reasons. The Earth's sedimentary basins contain an enormous amount of coal. The challenge is to unlock the coal-bed methane resources in an economically viable manner. One of the attractive aspects of ECBM is that

for each molecule of gas produced; at least two CO<sub>2</sub> molecules can be absorbed in the coal matrix. One of the main problems associated with developing ECBM is the low permeability of most unminable coals.

The theoretical CO<sub>2</sub> storage potential of European coal seams is estimated at about 6 Gt (IEA GHG, 2005). In many instances the coal reserves are close to industrial centres with CO<sub>2</sub> emitting power plants.

In general, the development of this storage technology is behind those of the other reservoirs. An ECBM pilot project, which is funded by the EC and industry, is running in Poland (RECOPOL).

#### 6 CAVERNS AND MINES

Caverns in rock-salt and abandoned coal mines can serve as potential CO<sub>2</sub> storage structures, although the storage capacity will be limited. Salt caverns might be used for temporary storage to buffer exhaust CO<sub>2</sub> streams or to use CO<sub>2</sub> for other commercial purposes. These structures are considered to be less suitable for long-term CO<sub>2</sub> storage; at the same time they must compete with other applications like waste disposal.

Abandoned coal mines are present in the former German, British, Belgian and Dutch coal mining districts. These mined coal zones have increased permeability, which improves the CO<sub>2</sub> injectivity. The sealing capacity of the overburden is however questionable. In Germany and Britain there is abundant evidence of gas leakage to the surface in the major coal mining areas, which makes CO<sub>2</sub> storage in abandoned coal mines less attractive for these regions.

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