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OPERATIONAL CO_2 SEQUESTRATION PROJECTS AT GAZ DE FRANCE

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ABSTRACT

To play its part in preserving the environment and assist its customers in looking ahead to emerging international regulations on the reduction of greenhouse gas emissions, Gaz de France has been investigating opportunities for CO_2 sequestration notably by taking part in several experimental projects.

Gaz de France is a partner of the CASTOR project (CO_2, from Capture to Storage) which focuses on CO_2 capture in flue gases and its geological storage. Launched as part of the European Union 6th Framework Program for Research, the main goal of the project is to reduce the costs of CO_2 capture from €40-60 per ton of CO2 to €20-30 per ton. With regard to geological storage of CO_2, CASTOR aims to validate the concept on different type of underground storage site in Europe : an abandoned oil field in the Mediterranean (Casablanca field operated by Repsol), a deep saline aquifer in the North Sea (Snohvit site operated by Statoil and in which Gaz de France is also involved) and two depleted gas fields (K12-B in the North Sea, operated by Gaz de France and the Atzbach-Schwanenstadt field operated by Rohoel).

The Gaz de France ORC project (Offshore Reinjection of CO_2), which is itself part of a Dutch study known as CRUST (CO_2 Re-use through Underground STorage), has been reinjecting CO_2 since April 2004 into the K12B offshore natural gas field in the North Sea. The K12B field originally contained natural gas with a CO_2 content of around 13 %. It has been in production since 1987 and is now almost depleted. The gas produced is treated on the platform and the CO_2 extracted from the natural gas is re-injected into the reservoir.

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1. INTRODUCTION

Climate experts agree that human activity is contributing to global warming, notably through the consumption of fossil fuels. The concentration of CO_2 in the atmosphere has risen from 280 ppm (parts per million) before the start of the industrial era, to around 370 ppm today. If nothing is done to curb emissions, a level of more than 700 ppm could be reached by 2100.

To limit global warming, the United Nations Framework Convention on Climate Change (UNFCCC) was signed in Rio by most countries present at the Earth Summit in 1992. The aim of this convention is to stabilize greenhouse gas emissions at a level that protects the planet from dangerous climate change. In 1997, negotiators meeting in Kyoto, Japan, for the third Conference of the Parties (COP 3) made a series of commitments (Kyoto Protocol) aiming to implement the Convention. Under this protocol, industrialized countries are required to reduce world greenhouse gas emissions by 5.2% between 2008 and 2012 (first commitment period), with 1990 emissions serving as a baseline. This protocol came into force on 16 february 2006.

There are three technical solutions for reducing industrial CO_2 emissions that can be applied in parallel:

- Energy management through improvements in energy efficiency and rational energy use,
- A change in the energy "mix", with the replacement of high carbon content fuels (coal, oil) by fuels with lower carbon content (such as natural gas) and energies with no net CO_2 emissions, such as renewables,
- Carbon cycle management, with improved management of natural carbon stocks (development of natural carbon sinks or biological sequestration: forest, soil) and the development of industrial techniques for capturing and storing CO_2 emissions.

This last solution includes geological CO_2 sequestration, an option widely studied across the world over recent years, in the USA and Japan especially. This technique involves capturing CO_2 at its point of emission (power station, cement works, steelworks, etc.) concentrating it and transporting it to an appropriate geological site for storage. Technologies for CO_2 capture and storage are already available.

2. CO_2 CAPTURE, TRANSPORT and STORAGE (CCS)

In principle, CCS is best applied to major CO_2 emission sources, which represent around one-third of total emissions in France. This sequestration method is complementary to biological sequestration, which is more appropriate for dealing with diffuse emission sources (transport, home heating, etc.).

CO_2 capture

The main problem associated with recovering CO_2 from gaseous effluents is its low concentration in the flue gases, which may vary from a few percent to around 20 percent, depending on the type of process concerned. Several techniques can be used to capture the CO_2 present in combustion products: post-combustion capture (for flue gases with low CO_2 concentrations), fuel decarbonization (combustion of hydrogen produced by gasification and capture of the resulting CO_2) and oxy-fuel (combustion with oxygen). A wide range of industrial methods are available, each with a specific field of application (composition, flue gas temperature and/or pressure, etc.).

The cost of CO_2 capture depends, among other things, on effluent composition (type of fuel used, excess air, etc.), on the volume of effluent to be treated (installation power) or the type of facility concerned. Several economic analyses have been performed, generally for power stations: for a 500 MW thermal plant, the cost of CO_2 capture (including initial CO_2 compression) varies between € 30 and € 60 per tonne of CO_2.

CO_2 transport

The most convenient way to transport CO_2 is by pipeline. This method makes use of relatively well-known technologies and is currently used in the USA, where more than 1,000 km of carbon dioxide transport pipelines have already been laid. The cost of transporting large volumes of CO_2 is between € 2 and € 7 per tonne of CO_2 per 100 km of pipeline.

CO_2 storage

There are a number of possible options for storing CO_2. They include natural underground reservoirs (depleted oil and gas fields, unminable coalbeds, saline aquifers…).

Depleted oil and gas fields offer an estimated storage potential of between 500 and 2,000 giga tonnes of CO_2 (10^9 tonnes), for an estimated storage cost of a few euros per tonne of CO_2.

For injection in saline aquifers, the scope is even broader: between 320 and 10,000 giga tonnes of CO_2. This solution is being tested at the Sleipner site in the Norwegian North Sea, where a million tonnes of CO_2 have been injected annually for several years now.

One form of geological storage involves injecting carbon dioxide into oil fields to drive out the remaining oil (EOR:enhanced oil recovery), or into unminable coal seams (ECBM: enhanced coalbed methane) or natural gas fields (EGR enhanced gas recovery) to recover natural gas. This is a newly emerging solution whose potential has not yet been assessed. However, the opportunities for using CO_2 in this way still appear to be limited (a few giga tonnes per year).

The cost of developing a storage site depends largely on the type of reservoir involved. These costs (storage alone) may range from a few euros per tonne of CO_2 to 10 euros per tonne of CO_2 or more (case of injection in an offshore aquifer).

3. CO_2 Capture and Storage : the CASTOR project

Gaz de France is a partner of the CASTOR integrated project (*CO_2, from Capture to Storage*) which focuses on CO_2 capture in flue gases and its geological storage. Launched as part of the European Union 6th Framework Program for Research (FP), the main goals of the project are to reduce the costs of CO_2 post-combustion capture from € 40-60 per ton of CO_2 to € 20-30 per ton and to build confidence in the overall concept in terms of storage performance, security and environmental acceptability.

Headed by the *Institut Français du Pétrole* (IFP), the CASTOR project involves 30 private and public partners from 11 european countries:

Oil&Gas Companies	**Power Companies**	**Manufacturers**	**R&D Organisations**
Statoil (No)	Vattenfall (Se)	Alstom Power (Fr)	IFP(Fr)
Gaz de France	Elsam (Dk)	Mitsui Babcock (UK)	TNO (Nl)
Eni Tecnologie (It)	Energi-E2 (Dk)	Siemens AG (De)	SINTEF (No)
RIPSA (Sp)	RWE Power (De)	BASF (De)	SINTEF Energy (No)
Rohoel (At)	PPC (Gr)	GVS (It)	SINTEF Petroleum (No)
	E.On UK (UK)		NTNU (No)
			BGS (UK)
			BGR (De)
			BRGM (Fr)
			GEUS (DK)
			Imperial College (UK)
			OGS (It)
			Univ. of Stuttgart (De)
			Univ. of Twente (Nl)

The total project budget is € 15,800,000 over a period of four years (2004-2008), with a European Union contribution of € 8,500,000.

Within the R&D activities on the post-combustion capture process, studies aiming to develop, test and optimize new processes are conducted by partners : Absorption liquids with thermal energy consumption of 2 GJ per tonne of CO_2 will be developed. A large capture pilot plant (Figure 1) has been built in a modern coal-fired power plant operated by ELSAM in Esbjerg (Denmark). This pilot plant with a capacity of 1 t CO_2/hour is operating since early 2006 in order to validate the new processes developed within the project.

With regard to geological storage of CO_2, CASTOR aims to validate the concept on different type of underground storage site in Europe :

- An abandoned oil field in the Mediterranean (Casablanca field operated by Repsol),
- A deep saline aquifer in the North Sea (on the Snøhvit site operated by Statoil and in which Gaz de France is also involved),
- Two depleted gas fields (K12-B in the Dutch North Sea, operated by Gaz de France (see below) and the Atzbach-Schwanenstadt field in Austria, operated by Rohoel).

4. CO_2 Storage : The K12-B and PICOREF projects

The CRUST project : K12-B CO_2 re-injection

This Gaz de France ORC project (*Offshore Reinjection of CO_2*) forms part of a Dutch study known as the CRUST program (*CO_2 Re-use through Underground STorage*). Launched by the Dutch government in 2002, CRUST aims to make an inventory of possible sequestration sites, to study legal and environmental aspects and the possibilities for CO_2 re-use [1].

Gaz de France Production Netherland B.V. (ProNed) is currently producing natural gas from the Dutch sector of the North Sea. The gas produced at one of ProNed's platform, the K12-B platform, located 150 km NW of Amsterdam (Figure 2), contains a relatively high concentration of CO_2 (about 13%). In order to meet export pipeline specifications, the produced gas is treated on the platform and the CO_2 removed from the natural gas used to be vented (Figure 3). The treated natural gas is subsequently transported to shore by a pipeline to Groningen Discovered in 1981, this gas field has been in production since 1987 and is now almost depleted. Preliminary assessment done in 2001 have shown that it might be relatively easy to re-inject this carbon dioxide into the Rotliegende sandstone reservoir located at a depth of about 3800 meters.

In association with TNO, the ORC project aims to investigate the feasibility of CO_2 injection in a nearly depleted natural gas field. It consists of three phases [2]:

- A **feasibility study** was carried out in 2002 (phase 1). The purpose of phase 1 of the ORC project was to investigate the feasibility of CO_2 re-injection and storage in an offshore and a nearly depleted natural gas field, by using existing installations, with the aim of creating a permanent CO_2 injection facility. In this phase, ProNed investigated technical, economical and legal aspects of CO2 injection in the K12-B gas field. Main conclusions were that excellent facilities were available for a demonstration project, reservoir has good characteristics for the CO_2 re-injection and storage and no significant legal or social problems [3].

  First costs estimates indicated that the costs for a full-scale injection will range between € 5-10 per ton of CO_2. The Feasibility Study report is available at http://www.co2reductie.nl/.

- The **pilot injection phase** (phase 2) began in on the 6th of May 2004 and is underway. It was the first time worldwide that CO_2 has been re-injected into the same reservoir from which it was initially in place (Figure 3). The total costs of this pilot injection phase is funded by the Dutch Ministry of Economic Affairs and by Gaz de France. Phase 2 consists of two tests at different locations in the K12-B reservoir.

Test 1 (May – December 2004, 11,000 ton CO_2) is a CO_2 injection into a single-well depleted reservoir compartment (K12-B8 - Figure 2). Test 1 showed that CO_2 injectivity is quite good despite the low permeability of the reservoir. The reservoir response and the behavior of injected CO_2 are within the expected range [4].

Results of test 1 were used to optimize the measurement program of test 2 (March 2005 - underway) with CO_2 injection into a nearly depleted reservoir compartment (two producing gas wells, K12-B1 and K12-B5, and a CO_2 injection well, K12-B6). Objectives of test 2 are to test predictability and enhanced gas recovery potential with simulation and tracers injections [5] [6]. Furthermore, well integrity studies are underway within the CASTOR project.

- The **scale-up to subsequent industrial phase** (phase 3) will also include the possibility for future re-use of injected CO_2. The injection potential is about 310,000 to 475,000 t/year of CO_2.

The PICOREF project

The PICOREF project (*CO_2 trapping in reservoir in France*) is a French R&D programme on CO_2 storage funded by the French Ministry of Industry in 2005 within the framework RTPG (*Réseau des Technologies Pétrolières et Gazières* - Network of Oil and Gas Technologies) and by a consortium of companies and research institutions :

Industry	**R&D Organisations**	**University**
Air Liquide	BRGM	School of Mines in Saint Etienne (ARMINES-ENSM-SE)
Alstom	IFP	Bordeaux Instit. of Cond. Matter Chemistry (ICMCB-CNRS)
CFG Services	INERIS	Toulouse Univ. (LMTG-CNRS)
CGG		Lab. of Geophysics and Tectnophysics of Grenoble (LGIT-CNRS),
Correx		Montpellier University (TPHY-ISTEEM)
Gaz de France		Technological University of Lorraine in Nancy (LAEGO-INPL).
Géostock		
Magnitude		
La SNET		
Total		

The total project budget was € 3,750,000 for 2005. This PICOREF project follows a four-year study of the geological storage of CO_2, supported by the RTPG, industry and French research organizations (PICOR project). Headed by IFP, this project has two main objectives [7] :

- **Evaluation of potential CO_2 injection sites in the Paris Basin** where pilot operations of CO_2 injection and storage can be defined (work package WP 1 – Sites characterization),
- **Elaborate and test a methodological work-flow chart** able to address, from either the technical and legal viewpoints, a site evaluation for a CO_2 storage project in permeable reservoirs (work package WP 2 - Methodology).

Two types of potential sites for CO_2 storage are under investigation within WP 1 : depleted hydrocarbon fields (WP 1.1) and deep saline aquifers (WP 1.2).

A quick screening of the French hydrocarbon fields in terms of CO_2 capacity done in a prior RTPG project (2004) highlighted a set of oil-field structures as potential sites for a pilot project with appropriate features (burial depth, temperature, pressure, fluids, reservoir lithology). In the SE part of Paris, several candidates are available. Most of the oil fields are located either in the limestone unit of the Dogger formation or in sand-rich units of the Keuper formation. In 2005, WP 1.1 investigated the feasibility of CO_2 re-injection and storage in a depleted oil field with reservoir engineering, well characterization and monitoring perspectives.

A preliminary inventory of French aquifers was made by the BRGM (*Bureau de Recherches Géologiques et Minières* - French geological survey) within the European GETSCO project (FP 5, 2000-2003) of which Gaz de France was end-user. The Paris Basin appeared as a big potential CO_2 when considering both the amount of CO_2 produced and the availability of deep saline aquifers. Two aquifers seems to be potential candidates for CO_2 storage, the Dogger Formation and the Keuper Formation. In 2005, WP 1.2 (geological synthesis) focused on the SE part of the Paris Basin where subsurface is the best known. First, because petroleum exploration has been active in this basin for more than thirty years and secondly, because subsurface has been also investigated for geothermal resources. Lastly, industrial sources of pure CO_2 are present in the region, which could reduce the capture cost during the pilot operation.

Furthermore, the project is drawing up a "site documentation" which shall identify all the requested parameters (existing French regulations, risk assessment, authorizations…) for a CO_2 storage site [8] in collaboration with the French Administration.

This project PICOREF will continue in 2006-2007 within the French National Research Agency (ANR).
The preliminary inventory done within the European GETSCO project, will be completed by a new French project funded by ADEME (French Agency for Environment) METSTOR (*Methodology for CO_2 Storage*) began in 2006 for site selection in France.

Enhanced Coalbed Methane : the RECOPOL project

Gaz de France was a partner of the RECOPOL European project (*Reduction of CO_2 bymeans of CO_2 storage in coal seams in the Silesian Basin of Poland* – FP 5),). The RECOPOL project has investigated the technical and economical feasibility of permanently and safely storing CO_2 in coal seams whilst simultaneous producing methane.

Headed by TNO-NITG, the RECOPOL project (total budget was € 3,400,000) involved research institutes, universities and companies from 6 countries :

Industry	**R&D Organisations**	**University**
Air Liquide (Fr)	TNO (NL)	Aachen Univ. of Technology (De)
DBI-GUT (De)	Central Mining Institute (Pol)	Delft University of Technology (NL)
Gazonor (Fr)	CSIRO (Aus)	Faculté Polytechnique de Mons (Bel)
Gaz de France	IEA GHG	
IFP(Fr)	JCOAL (Jap)	
ARI (USA)		
Shell International		

The location of the pilot site in the village Kaniow in the Silesian basin in Poland, about 40 km south of Katowice, was selected at an early stage of the project. A pilot installation was developed for CO_2 injection (one new injection well was drilled) and methane gas production from coal beds (existing production wells). This installation was the very first of its kind in Europe. CO_2 was brought in by trucks and stored on site in liquid form (at a temperature of -20 º C) in two containers (Figure 4). The CO_2 is heated and than by a pump injected into underground coal seams at a depth of 1050-1090 m, several hundreds of meters below the deepest mine workings of the Silesia mine.

Injection tests started in summer 2004, after the development of the pilot site in 2003. The principal targets for CO_2 injection were coal seams between 1 and 3 m thick of Carboniferous age in the depth interval between 900-1100 m. In total about 800 tonnes of CO_2 were injected between August 2004 and the end of June 2005.

5. CONCLUSIONS

Gaz de France is pursuing its research on the capture and storage of CO_2 which is a widely studied option for the reduction of CO_2 emissions in parallel with energy saving and with lower carbon content. Member of networks of excellence (CO_2Net, ClubCO_2…), Gaz de France is taking part in several experimental projects on CO_2 capture and injection in cooperation with European oil & gas companies, manufacturers and research centers. With the K12-B CO_2 re-injection started in 2004 in The Netherlands, Gaz de France has taken its place among the main gas companies working on CO_2 capture and storage.

References

[1] Greenhouse Issues, "*CO_2 Injection into an Existing Gas Field (CRUST* Project)", Number 73, July 2004.

[2] Gaz de France (2003), "*Feasibility Study of Offshore Re-injection of CO_2 into Depleted Gas Field in the North Sea*", available at http://www.co2reductie.nl/.

[3] Van der Meer, L.G.H., Hartman, J., Geel, C., Kreft, E., "*Re-injecting CO_2 into an Offshore Gas Reservoir at a Depth of Nearly 4000 metres Sub-sea*", GHGT-7, Vancouver, 6-9 September 2004.

[4] Van der Meer, L.G.H., Kreft, E., Gell, C., Hartman, J., "*K12-B A Test Site for CO_2 Storage and Enhanced Gas Recovery*", SPE Europe/EAGE Annual Conference, Madrid, 13-16 June 2005.

[5] Hartman, J., "*K12-B A Test Site for CO_2 Storage*", International Symposium : Reduction of Emissions and Geological Storage of CO_2", Paris, 15-16 September 2005.

[6] Kreft, E., Dreux, R., *"K12-B, A Test Site for CO_2 Storage and Enhanced Gas Recovery"*, CO_2NET Final Meeting, Paris, 12-13 September 2005.

[7] Greenhouse Issues, "*PICOREF : A French R&D Programme on CO_2 Geological Storage*", March 2005.

[8] Le Thiez, P., Bonijoly, D., *"PICOREF 2005 – Trapping of CO_2 in geological reservoirs in France"*, CO_2NET Final Meeting, Paris, 12-13 September 2005.

Figures

Figure 1 : The CASTOR pilot plant in Esbjerg (ELSAM)

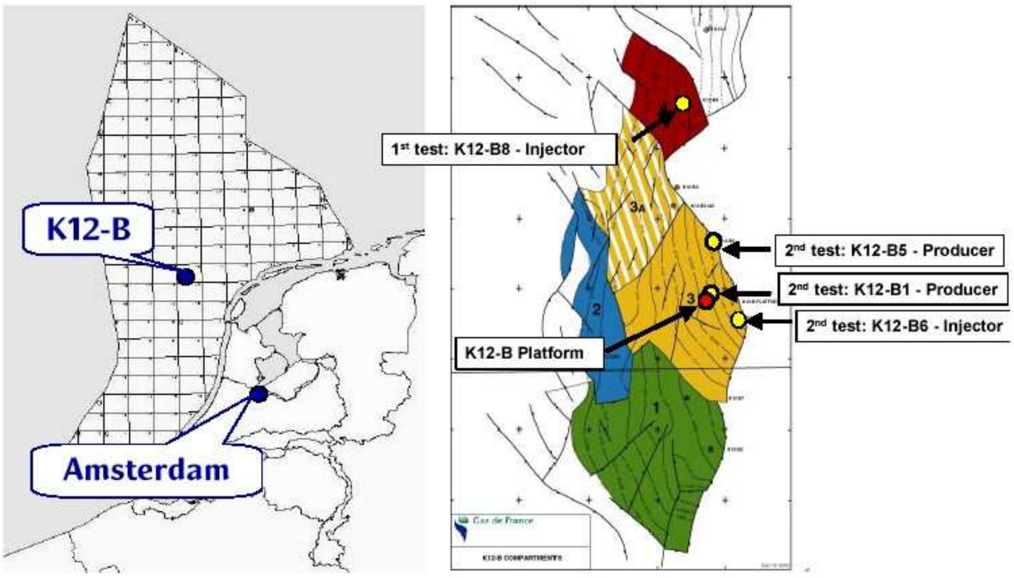

Figure 2 : Location of K12-B platform

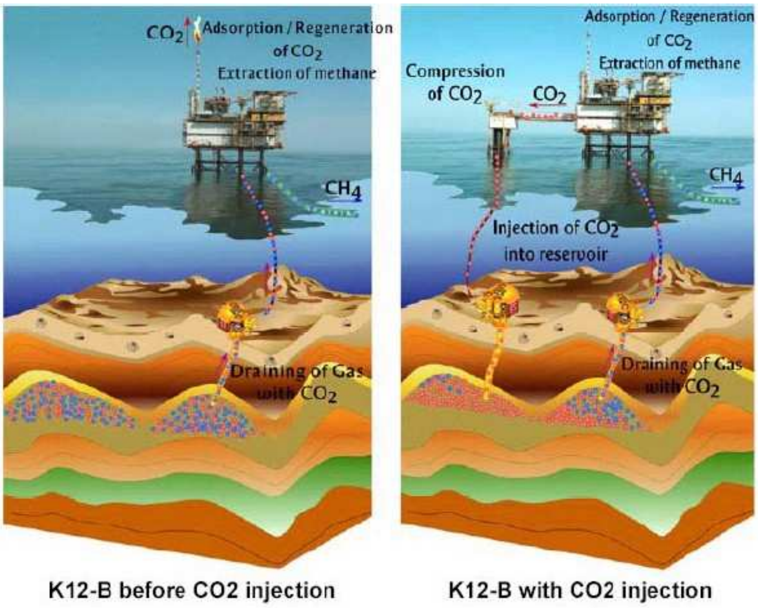

Figure 3 : K12-B CO_2 re-injection

Figure 4 : RECOPOL CO_2 injection site