

IFP Innovation News

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Each day, the number of people living on our planet swells by around 200,000,

generating a corresponding increase in the demands placed on global energy resources. Currently we rely primarily on fossil fuels to meet our needs.

For example, coal is used to provide 40% of all our electricity requirements, a trend that is set to continue for the foreseeable future; in 2007, China built the equivalent of almost one 600 MW coal-fired power plant every three days.

With a life-span of 50 years, these reactors will still be in service beyond the first half of this century.

What should be done?

Wait for replacement solutions to be developed in the full knowledge that it will take several decades to change the entire energy system?

Such an approach would be irresponsible.

We must act now to reduce the impact of CO₂ emissions on climate change.

And at the same time, we need to speed up the development of carbon-free solutions. Against this backdrop, CO₂ capture/storage (CCS) technology, which will be launched on an industrial scale for the first time from 2020, emerges as a key measure that deserves to be given priority.

Future generations will thank us for having had the foresight to make the right choices at the right time.

*François Kalaydjian
Director of*

Sustainable Development Technologies

■ In brief

Resounding success for Geogreen

It has been an outstanding start for Geogreen! Created in August 2007 by IFP, Géostock and BRGM, the consulting and strategy company specializes in carbon management and engineering services for the transport and storage of CO₂. As well as being a partner in the Veolia project — the capture/storage pilot industrial site in Seine-et-Marne — in 2008, Geogreen carried out numerous feasibility studies on behalf of a range of customers both in France and abroad: electricity and oil companies as well as sites hosting several greenhouse gas emitters such as the Port of Le Havre, for example. ■

Towards coal-fired power plants incorporating CCS in China?

IFP spent three years coordinating the Europe-China Coach project, that has just delivered technico-economic recommendations about the feasibility of incorporating in China CCS technologies in an IGCC coal-fired power plant equipped with pre-combustion CO₂ capture technology. The study has considered as well options for an associated production of methanol and proposed CCS scenarios for transporting and storing the CO₂ captured either in a mature oil field for EOR purposes or in deep saline formations. Eight Chinese partners and twelve European industrial, research and state partners (Air Liquide, Alstom, BP, Schlumberger, Shell, StatoilHydro, etc.) joined forces on the project to pool their knowledge and expertise in the field. ■

Special issue
IFP and CCS

■ Close-up

Simulating storage

Developed by IFP, the *Coores* software has been designed to evaluate the long-term effects of CO₂ storage in a geological site. The ultimate success of the software depends to a large extent on experiments conducted in the laboratory. Hence IFP's laboratories have played a significant role in building the geochemical models required to simulate reactive flows, study the effects of CO₂ on the mechanical resistance of rocks and validate *Coores* by experimenting with rock samples.

After several years of development, *Coores* has become a benchmark tool used in several projects. The aim of the European Dynamis project (2006-2009), for example, is to conduct a feasibility study towards the combined production of hydrogen and electricity with CO₂ capture and storage. IFP's scientists have used *Coores* to simulate CO₂ injection over a period of thirty years, and in three different geological structures, two aquifers and an old oil field, located off the English and Danish coasts. Using the software, it has been possible to reproduce the behavior of CO₂ injected into these sites in order to ensure and optimize secure storage for 1,000 years. ■

IFP is a world-class public-sector research and training center, aimed at developing the technologies and materials of the future in the fields of energy, transport and the environment.



Post-combustion capture processes: from one generation to another

A key aspect of CCS, capture consists in recovering and then compressing the CO₂ produced by emitting companies. One of the solutions being developed is post-combustion, which is designed to extract CO₂ diluted in combustion flue gases. The technique is the focus of a significant amount of research being carried out by IFP today.

Tested on a pilot facility in Denmark and then improved between 2004 and 2008 as part of the European Castor project coordinated by IFP, capture with MEA (monoethanolamine) is currently one of the few post-combustion methods already available on the market. On the basis of the results obtained by Castor, IFP developed the *HiCapt* process, marketed by Prosernat. *HiCapt* consists in passing flue gases into the bottom of an absorption column in order to wash them in a solution of water and amine. This solvent, that fixes the CO₂, is then heated in a regeneration tower, where it releases the CO₂ which can then be compressed for transportation and subsequent storage. IFP has conducted research to improve this process: *HiCapt+* makes it possible to reduce the size of the facilities and limit the amount of energy used by an MEA concentration increase up to 40% wt and by the use of anti-degradation additives. It will be tested on the industrial pilot in Brindisi (Italy) within the context of the partnership between IFP and ENEL. This pilot will capture



IFP is using a pilot unit to study the hydrodynamics of gas/liquid contactors to optimize CO₂ capture by solvents. © Alexis Chézière

between 2 and 2.5 metric tons of CO₂ per hour at a coal-fired plant operated by the Italian power company.

Other post-combustion capture solutions are also being studied by IFP with the view of cutting the cost of capture. Hence scientists are working with demixing solvents, molecules that have the property of separating into two liquid phases once loaded with CO₂. One of these contains the amine that has reacted and thus has a very high CO₂ concentration. This is the only phase that is regenerated, requiring far less energy. The technology has been the focus of numerous laboratory studies and testing on an industrial pilot is currently under investigation. In addition, while retaining a solvent-based technology, scientists are studying the possibility of implementing some very original chemical reactions that are less energy-guzzling.

The other technology being examined is separation by adsorption. By passing flue gases over a bed of solid particles having a high CO₂ affinity, researchers are hoping to reduce the size of the facilities required for capture.

Finally, IFP's specialists are working on hydrates* formed by CO₂ in a water solution or a water-oil mixture in specific pressure and temperature conditions. They are studying ways of processing flue gases to obtain hydrates and produce a *slurry***.

The CO₂ is then separated by heating at low temperature. Much of this research is being conducted within national and European projects involving IFP, industry and university laboratories. ■

* Gas hydrates are solid compounds similar to ice, in which gas molecules are contained in cages formed by water molecules.

** Liquid comprising a dispersed solid forming a type of molten ice.

HYGENSYS™: producing hydrogen and electricity without emitting CO₂

Pre-combustion capture is not designed to recover the CO₂ contained in flue gases emitted by factories but rather to deal with the problem at source; the principle here is to avoid the need to burn hydrocarbons by transforming them beforehand into a synthetic gas, a mixture of carbon monoxide (CO), hydrogen and water. There then follows a conversion stage during which the CO reacts with water to produce CO₂ and additional hydrogen, which are then separated. The CO₂ is compressed and stored and the hydrogen can be

burned by combustion with air, without CO₂ production, to generate electricity.

IFP is studying this as a potentially interesting option but one which requires further technological progress. As part of the European Cachet program (2006-2009) dedicated to carbon emission-free electricity generation from natural gas, IFP coordinated research on one of these pre-combustion capture technologies. Called HyGenSys™ and patented by IFP in 2003, the technology is an improvement to the industrial hydrogen production process by the steam reforming of natural gas. The traditional method involves heating tubes containing a catalyst and passing

natural gas and steam through them. This requires large furnaces that consume significant amounts of energy and therefore generate considerable CO₂ emissions. Hence IFP's researchers came up with the idea of replacing these furnaces with a cleaner, more compact system whereby the heat comes from flue gases from a gas turbine powered by hydrogen.

This technology is currently being tested by IFP's scientists in a simplified form, prior to the construction of an industrial pilot. The planned market launch is for some time between 2012 and 2015. ■

CLC: easier, more energy-efficient capture

CLC (Chemical Looping Combustion) is a promising CO₂ capture technology, but its industrial application will only become a reality between 2015 and 2020 at the earliest. Designed in particular for use in power plants, CLC should make it possible to recover CO₂ while being far less costly in terms of energy consumption.

In traditional combustion processes, heat is produced by combustion with the oxygen present in air. The CO₂ in flue gases is therefore diluted in the nitrogen contained in air. With oxycombustion, the same thing happens but air is replaced by pure oxygen. The advantage of this solution is that it generates concentrated flue gases with a high CO₂ content, thereby facilitating capture. But the separation of pure oxygen from air requires a substantial amount of equipment and the associated excess energy consumption is considerable.

Hence the idea of using an alternative to oxycombustion, CLC, a process that is far more fuel efficient. CLC is based on the use of materials — metal oxides — capable of providing oxygen *in situ*. They are subject to separate and

successive oxidation and reduction reactions in reactors operating at very high temperatures (800 to 1000°C). On contact with the fuels, the material is reduced and provides the oxygen required for combustion. On contact with air, the material is oxidized and converted back to the metal oxide for use in the following cycle.

IFP first began working on this technology a few years ago, firstly internally and then as part of partnerships. IFP has just built a new 10 KWth pilot facility at its Lyon site.

A number of challenges still need to be addressed before the process can be advanced to an industrial scale. One of the first avenues of exploration concerns the identification of the best metal oxides. These materials have already been the focus of research in the context of the European Encap program in which IFP coordinated CLC-related studies, as well as the CLC-Mat project run by the *Agence nationale de la recherche* (ANR - the French National Research Agency), and coordinated by IFP.

In 2008, IFP launched process development studies in partnership with Total: a collaborative agreement to last several years has been signed aimed at developing CLC with the design of a validation pilot. The first



CLC batch fluidized bed reactor developed by IFP for batch studies.

international CLC conference is due to be held in March 2010 at IFP-Lyon as part of the “*Rencontres scientifiques de l’IFP*”, proof that the field is of interest to scientists and the industrial community alike. ■

Bahia, a CO₂ storage test site for IFP

Located in the State of Bahia, 1,000 km north of Rio de Janeiro, the Recôncavo basin is one of the biggest oil and gas producing regions in Brazil: it was there that the country’s first oil reserves were discovered in 1939. After fifty years of production, some fields began to reach the end of their life forcing Petrobras, the national oil company, to turn to methods that would enable them to keep the fields open. With the Buracica field for example, in 1991 the company decided to use an enhanced recovery technique based on CO₂ injection. Consisting in injecting some 200 metric tons of CO₂ per day via seven wells, the process maintains the pressure in the reservoir, thereby extending and increasing its production. Although the benefits of using such a technique are purely economic, its practical application in this example aroused the interest of those working in the field of CCS research. Scientists

considered it to be a laboratory that they could use to understand the behavior of CO₂ stored underground. Hence a two-year project was launched in 2007 by IFP in partnership with Petrobras. “Hinged around field campaigns, numerical simulations and laboratory analyses, the Bahia project is designed to provide a better understanding of the impact that the injection of 600,000 tons of CO₂ over an 18-year period has had”, explained Yannick Peysson, project manager at IFP. IFP is using samples from the reservoir and the caprock to assess the changes that have taken place to underground rocks over time.

Its researchers are also conducting missions out in the field to gather surface gas samples containing CO₂ and noble gases* and observe the impact at surface level of the injection of CO₂ under pressure. The ultimate objective is to determine whether these gases come from the outside air or deep rocks.

The project also involves seismic studies and numerical analysis. Thanks to the wealth of information relating to decades of CO₂ injection gathered by Petrobras, IFP’s scientists are now in a position to identify, within geophysical data, the distribution of CO₂ in the reservoir. Using the *Coores* software (see page 1), they are able to carry out simulations indicating how the gas has evolved over time with a high degree of accuracy. The findings will be invaluable in terms of determining the conditions that will guarantee the safety and long-term feasibility of CO₂ storage underground. ■

* Noble gases (helium, neon, argon, etc.) provide information about the origin of CO₂ and can thus indicate its migration.

Modeling CO₂ storage underground

The aim of the CO₂ReMoVe European project is to define recommendations to predict and verify the behaviour of a CO₂ storage site. IFP is coordinating the Performance Assessment and Mitigation CO₂ReMoVe's sub-project and is also involved in the Monitoring sub-project. Coordinated by the Dutch institute TNO, this five-year European programme launched in 2006 groups together 27 private and corporate partners. The teams involved, including those from IFP, are working on data obtained on several pilot sites — among them Sleipner in the North Sea, Snøhvit in the Barents Sea and In Salah in Algeria. The technical challenge is the validation of storage scenarios by comparing predictions to real field monitoring feedbacks.

Re-injecting CO₂ into a natural gas field: the In Salah pilot

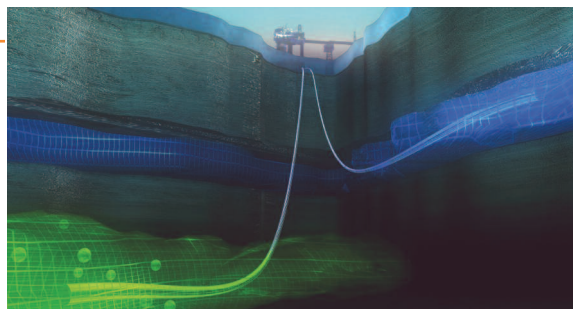
Since the region's gas fields have high CO₂ concentrations (up to 10%), BP, StatoilHydro and Sonatrach, the operators of the Krechba field chose to re-inject, at the periphery of this gas field, the local CO₂ production. The gas is being re-injected (around 17 million metric tons ultimately) into the saline aquifer at a depth of 1,800 meters, which helps maintaining the gas field reservoir pressure while confining the CO₂ underground. This pilot (three injection wells) represents a remarkable underground laboratory where numerous monitoring tools have been deployed to observe and at least anticipate reservoir behaviour during

Since 1996, StatoilHydro has already injected 11 million metric tons of CO₂ from a natural gas field at Sleipner.
© Alligator film / BUG / StatoilHydro

and after injection. Researchers are using the data obtained to constrain their numerical models in order to predict how CO₂ behaves when it arrives underground during the injection phase, and then, reacts at long term, during storage.

Storing CO₂ in a saline aquifer: the Sleipner North Sea pilot

Located in the North Sea, in Norwegian waters, the Sleipner pilot is "the" benchmark in the field of the geological storage of CO₂. Since 1996, StatoilHydro has already injected 11 million metric tons of CO₂ from a natural gas field into an upper saline aquifer — more than 800 meters below the sea floor. IFP researchers and their European partners have been conducting studies to map CO₂ migration and ascertain whether the CO₂ remains confined within the storage structure, beneath the principal cap rock. By comparing two 3D-seismic surveys conducted by StatoilHydro in 1994 and 2006 (before and after injection respectively), the distribution of CO₂ within the aquifer can be imaged in three dimensions. This, together with the quantification of the CO₂ stored will provide a clearer picture of the reservoir's sealing efficiency; a major step prior to the development of a model predicting CO₂ migration in an heterogeneous geological environment. ■



Deployment and economic development of CO₂ capture/storage technology

IFP is involved in numerous ongoing research projects relating to the roll-out and economic development of CCS technology. As part of the ANR's SOCECO₂ project, for example, IFP examined different roll-out scenarios for the CCS chain in France for the period 2020-2050. The technical, economic and environmental assessment carried out is designed to assess the balance between the capture potential of the principal national CO₂ emitters and the storage capacities of the known and available sites today. The scenarios considered take into account forecast emissions for the major industrial regions, transport distances, site storage capacity and public acceptance. The only scenario that would meet the Factor 4 objective (cutting greenhouse gas emissions to a level that is four times lower than currently) in France by 2050 involves the storage of emissions from the regions of Lorraine, Île-de-France, Nord-Pas-de-Calais and Haute-Normandie in the Parisian basin aquifer (or in a North Sea aquifer), as well as the storage of emissions from the PACA region in a Mediterranean aquifer.

Transporting CO₂ by boat

Transporting CO₂ by boat from one port to another or as far as an injection site is technically possible and would be an economically competitive solution. That is the conclusion reached by experts who took part in ANR's TransCO₂ project, coordinated by IFP and involving Air Liquide, GDF Suez, Saipem and STX Europe. The project, designed to examine the technical and economic feasibility of

transporting CO₂ by boat, has just published its findings after three years' work: not only is it possible to design a ship capable of taking on and unloading 30,000 m³ of carbon dioxide quickly and carrying it at a pressure of 15 bars and at a temperature of -30°C; the solution should also be more profitable than an offshore pipeline for journeys in excess of 500 km and an onshore pipeline for distances in excess of 1,000 km. ■

As part of another project — ECCO (European value chain for CO₂), conducted within the framework of FP7 — IFP is working to develop a tool for the economic evaluation of the CCS process with recovery of oil and gas in fields. The objective is to provide manufacturers and governments with an accurate assessment of the technical and economic feasibility of CCS roll-out. ■

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