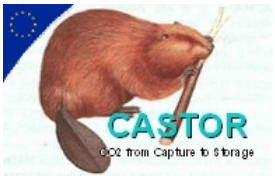

CASTOR

CO_2, From Capture to Storage

PUBLISHABLE EXECUTIVE SUMMARY

(1 Feb. 2007 to 31 Jan. 2008)

Project co-ordinator name: Pierre LE THIEZ
Project co-ordinator organisation name: IFP

Introduction - Project outline

The overall goal of this project is to develop and validate, in public/private partnerships, a substantial part innovative technologies needed to capture CO_2 at the post-combustion stage and to store CO_2. The CASTOR R&D target is to enable the capture and geological storage of 10% of the CO_2 emissions of Europe, which corresponds to about 30% of CO_2 emitted by European power and industrial plants. To reach this goal, CASTOR will improve current techniques and develop, validate and generalise previously non existent methodologies and technologies for the capture of CO_2 and its subsequent secure underground storage.

Key targets of CASTOR are the following:

- A major reduction in post-combustion capture costs, from 50-60 € down to 20-30 € per ton of CO_2 (large volumes of flue gases need to be treated with low CO_2 content and low pressure)
- To advance general acceptance of the overall concept in terms of storage performance (capacity, CO_2 residence time), storage security and environmental acceptability.
- To start the development of an integrated strategy connecting capture, transport and storage options for Europe.

CASTOR will last 4 years (Feb. 2004- Feb. 2008) and has been accepted for funding by the European Commission within the 6th European Framework Program. The total project budget is 16 M€ (8,5 M€ funded by EU). 30 partners, representing 11 European countries, will carry out the work - R&D organisations, oil & gas companies, power companies and manufacturers.

For capture, a pilot plant will be built in an existing coal-fired power plant operated by DONG Energy in Denmark and will be operated over a 2-year period to validate the gas processes developed (new solvents, new membrane contactors, new process flow sheets, integration methods) in the project.

Work on storage aims to study European injection sites and perform risk assessment studies. New methodologies will be developed by improving the knowledge with 4 new storage cases.

The project consortium is the following:

R&D organisations	**Oil & Gas companies**	**Power companies**	**Manufacturers**
IFP (FR)	StatoilHydro (NO)	Vattenfall (SE)	Alstom Power (FR)
TNO (NL)	Gaz de France (FR)	DONG Energy (DK)	Doosan Babcock (UK)
SINTEF (NO)	RIPSA (SP)	Vattenfall AS (DK)	Siemens (DE)
SINTEF Ener. Res. (NO)	Rohoel (AT)	Vattenfall RD (SE)	BASF (DE)
SINTEF Pet. Res. (NO)	ENI (IT)	RWE (DE)	GVS (IT)
NTNU (NO)		PPC (GR)	
BGS (UK)		E.ON UK (UK)	
BGR (DE)			
BRGM (FR)			
GEUS (DK)			
IMPERIAL (UK)			
OGS (IT)			
Univ. Stuttgart (DE)			
Univ. Twente (NL)			

CASTOR web site: https://www.co2castor.com/

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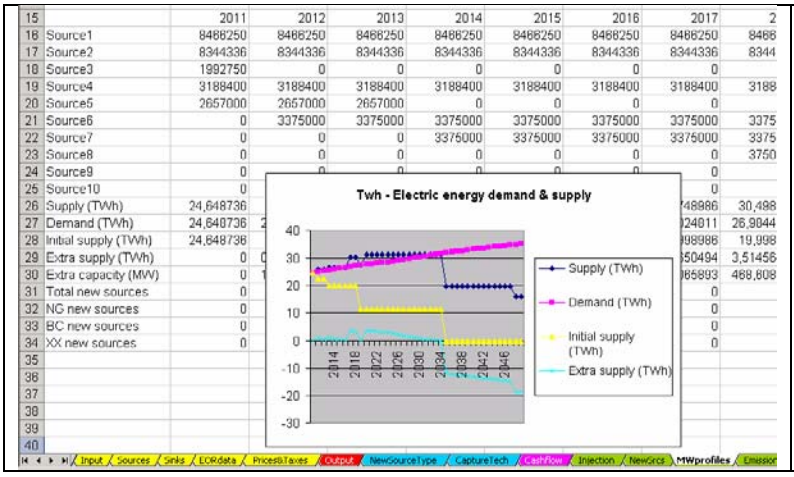
Work performed and main results obtained

Strategy for CO_2 reduction (10% of the budget)

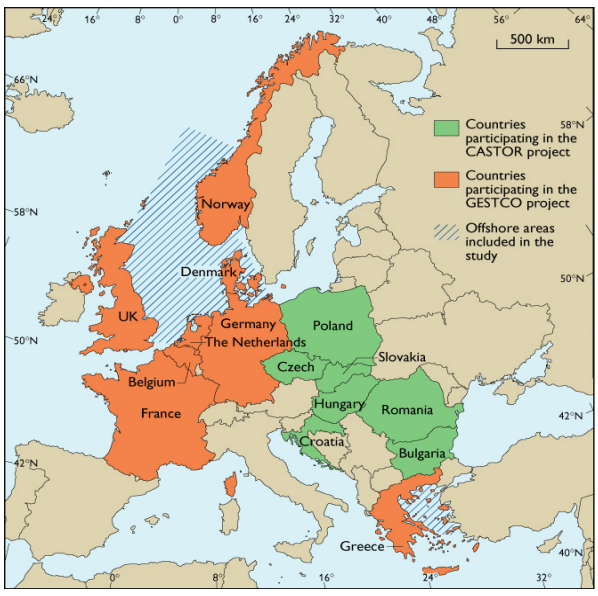
This activity aims to define the overall strategies required to effect a 10% reduction of EU CO_2 emissions and to regularly monitor the effectiveness of the strategies (from capture to storage) from a techno-economical point of view. Research work is also focused on obtaining data on CO_2 sources and potential geological storage capacities from Eastern Europe (an extension of the GESTCO European project). At the same time solutions will be identified for legal and public acceptance of the concept of CO_2 sequestration as a viable option for CO_2 mitigation, by developing and applying a template for exploring the public perceptions toward carbon storage. The overall impact of the project on EU countries, including Candidate Countries, is therefore taken into account. The following results have been obtained during the project:

- Development of an economic tool for CCS,
- Establishment of scenarios for large-scale implementation of CCS in Europe (30% CO_2 emission reduction in European power generation),
- Study of CO_2 geological storage in 8 European countries.



Economic analysis tool for CCS:

- input: *Source and sink data, start year, lifetime, coordinates, capacities etc*
- output: *Emission, injection gaps, investment costs of capture, transport and storage, transport infrastructure etc. in tables and diagrams*

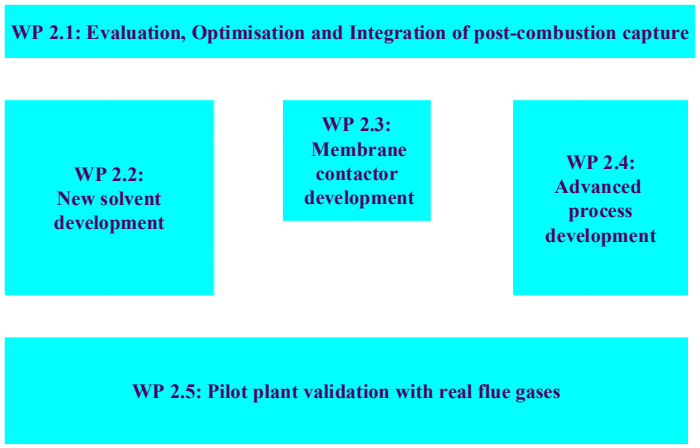


Comprehensive study of geological storage options: data collection, estimates of emissions and storage locations for the 8 countries involved in the study (Czech Republic, Bulgaria, Croatia, Hungary, Poland, Romania, Slovakia and Slovenia).

Post-combustion capture (65% of the budget)

The objectives of work on post-combustion capture are:

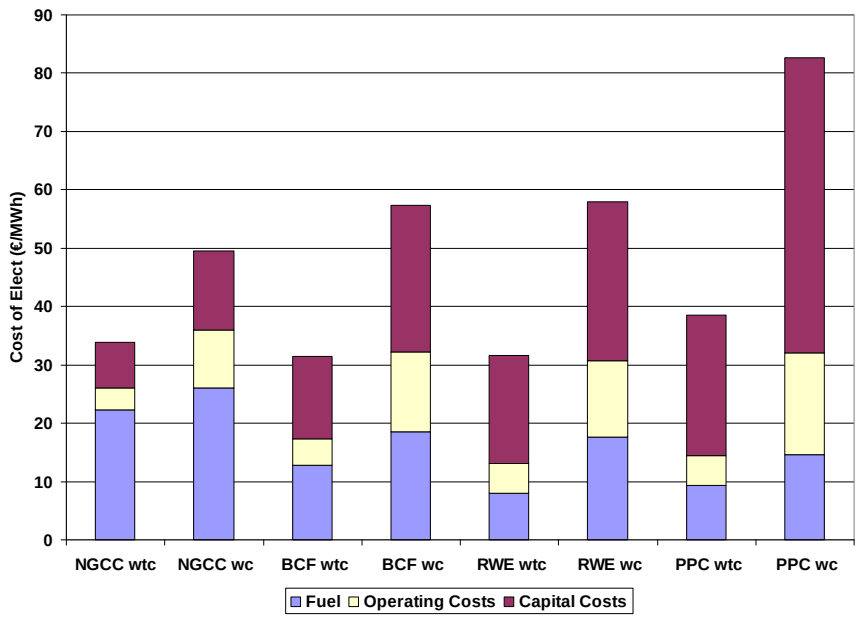
- Development of absorption liquids, with a thermal energy consumption of 2.0 GJ/tonne CO_2 at 90% recovery rates
- Resulting costs per tonne CO_2 avoided not higher than 20 to 30 €/tonne CO_2, depending on the type of fuel
- Pilot plant tests showing the reliability and efficiency of the post-combustion capture process.



Main deliverables:

- New solvents resulting in less heat for regeneration
- Advanced processes resulting in lower power output losses
- Advanced equipment (membrane contactors) resulting in lower investment costs
- Pilot plant operating with real flue gas allowing hands-on-experience with absorption technology
- Methods for integration and optimisation resulting in lower power output losses

WP2.1: Evaluation, optimisation and integration of post-combustion capture

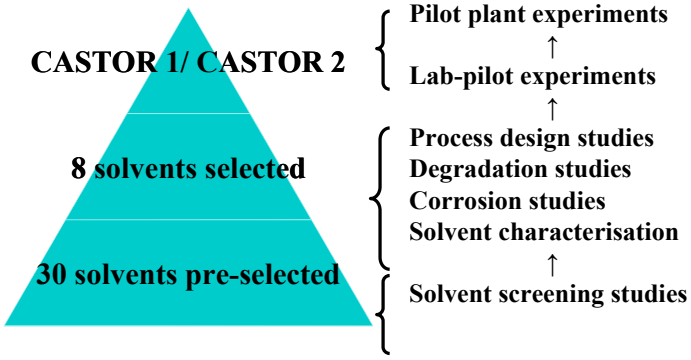


Integration of carbon capture in power plants has been carried out for following base cases:

- 393 MWe NGCC (Siemens)
- 600 MWe bituminous (Doosan Babcock)
- 1000 MWe lignite (RWE/Alstom)
- 380 MWe lignite (PPC)

Cost of electricity with and without CO_2 capture

WP2.2: Solvent development and selection

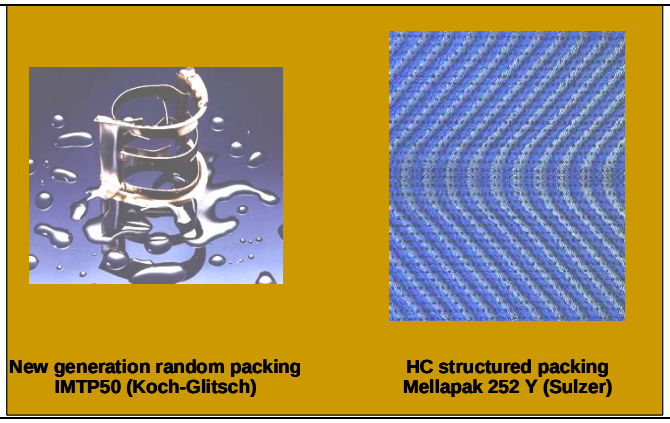


- Several solvents tested
- Models developed and validated
- Three solvents tested in the pilot plant:
  - MEA
  - CASTOR-1
  - CASTOR-2

WP2.3: Membrane contactor development

- Three membrane types developed and tested:
  - Transversal flow module
  - Flat membrane module
  - Fibre module
- Practical data generated
- Small pilot test installed and run at the Esbjerg power station.

WP2.4: Advanced Processes



- Process optimization of the absorption / desorption loop
- Packing material characterization
  - ➢ Two packings fully characterized (IMTP50 & ME252Y)
  - ➢ Hydrodynamic test on pilot plant (Esbjerg) equipped with IMTP50.

WP2.5: Pilot plant in Esbjerg power station, Denmark, operated by Dong Energy

Capacity: 1 t CO2/h

5000 Nm3/h flue gas (coal combustion)

In operation since early 2006

- January - March 2006: MEA-testing for 1000 hrs
- September - November 2006: 2nd MEA-testing for 1000 hrs
- March - June 2007: CASTOR1-testing for 1000 hours
- September - December 2007: CASTOR2-testing for 1000 hours

Conclusions on work performed on post-combustion capture:

1. Development of new solvents (absorption liquids) with a thermal energy consumption of 2 GJ/tonne CO_2 at 90% recovery rates
    a. Reference process: ~4GJ/tonne CO_2
    b. With CASTOR-2 solvent: down to 3.5GJ/tonne CO_2 (12%)
    c. With integration: down to 3.2 GJ/tonne CO_2 (20%)
    d. 90% recovery rate is feasible and has been proven in the pilot tests.

2. Resulting costs per tonne CO_2 avoided not higher than 20 to 30 €/tonne CO_2, depending on the type of fuel
    a. Reference process: 40-50 €/tonne CO_2
    b. With MEA process optimization: 35-37 €/tonne CO_2 (2005 ref)

3. European pilot plant tests showing the reliability and efficiency of the post-combustion capture process
    a. Operational pilot plant
    b. Validation procedures
    c. Validation experience
    d. Validation results
    e. Environmental awareness
    f. Queue of requests from industry

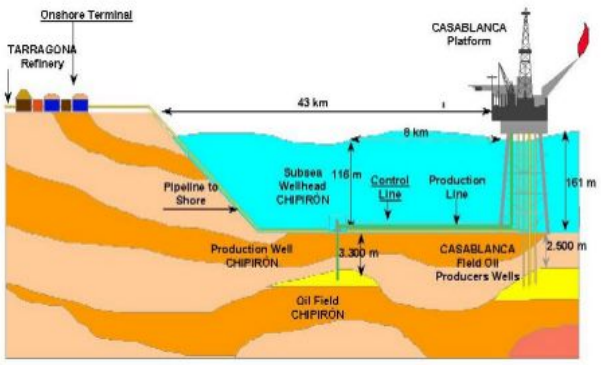
4. CASTOR made validation basis for Post-Combustion-Capture development.

Storage performance and risk assessment studies (25% of the budget)

The objective is to develop and apply a methodology for the selection and the secure management of storage sites by improving assessment methods, defining acceptance criteria, and developing a strategy for safety-focussed, cost-effective site monitoring. Items for improvements will include: the prediction of seal efficacy prior to injection, the effects of CO_2 on the seal integrity and on mechanical site stability, the leakage potential of wells and methods to improve well safety, the improvement of reaction-transport simulation models, and development of cost-effective monitoring strategy and site completion criteria. The large majority of work will be related to four sites for CO_2 storage, with a large variety of situations and characteristics:

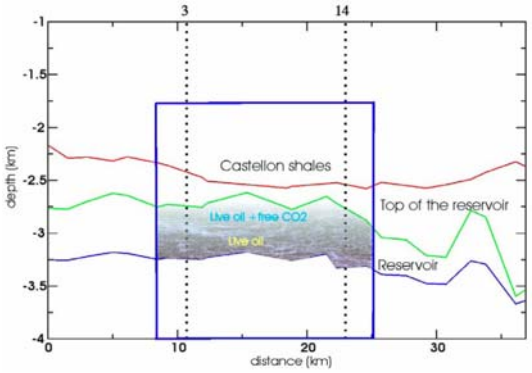
- Storage in a depleted oil reservoir in Mediterranean Sea: *Casablanca* oil field, Spain (operated by Repsol);
- Storage in a depleted gas field: *Atzbach-Schwanenstadt*, Austria (operated by Rohoel);
- Storage in a depleted gas field: *K12B*, North Sea, The Netherlands (operated by Gaz de France);
- Storage in a deep aquifer: *Snøhvit*, Norwegian Sea (operated by StatoilHydro).

Casablanca oilfield (Spain, operated by Repsol ypf).

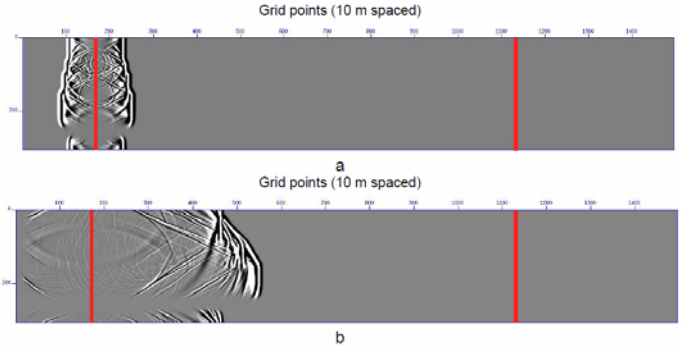


The Casablanca oil field is situated offshore north-eastern Spain. This carbonate oil field at a depth of approximately 2500 m below the sea floor has reached its production tail, and production will soon cease. Repsol considers using this field for storage of approximately 500,000 tonnes CO_2 per year, which is to be captured at the Tarragona refinery at 43 km distance from the field.

Example of work performed for Casablanca:

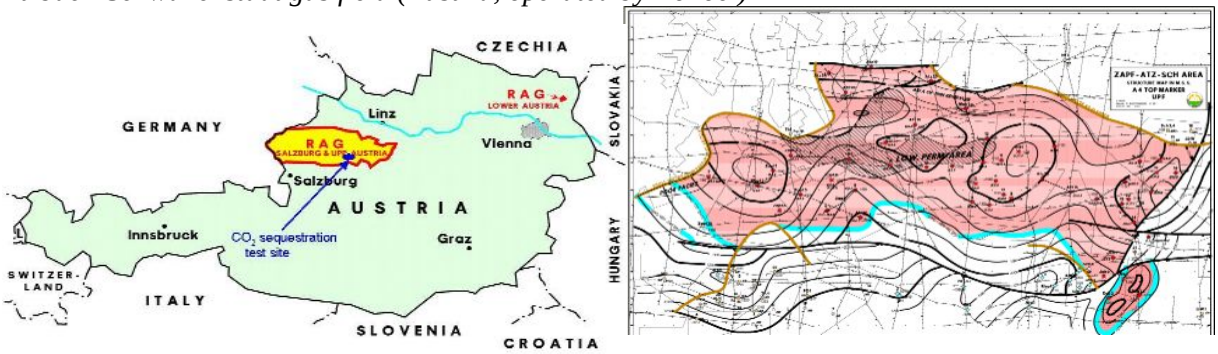


View of 2D section used to model cross-well seismic acquisition in the Casablanca field.



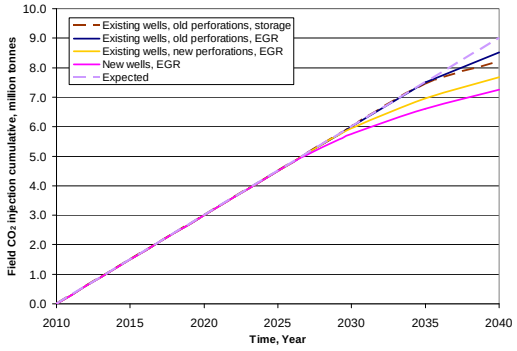
Two snap-shots of seismic modelling process.

Atzbach-Schwanenstadt gas field (Austria, operated by Rohoel)

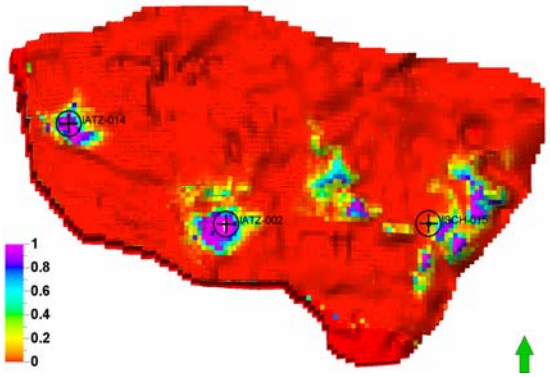


The Atzbach-Schwanenstadt gas field is situated in central northern Austria, between Salzburg and Linz. This onshore sandstone gas field at approximately 1600 m below the surface is almost empty. Rohoel AG considers its transformation into a CO_2 storage site and possibly tests the suitability of CO_2 injection for Enhanced Gas Recovery. Potential CO_2 sources are a paper mill (emitting about 200 000 tonnes CO_2 per year) and a fertiliser plant (emitting about 100 000 tonnes CO_2 per year). Transport of CO_2 may be by trucks. Injection into the field may start towards the end of the project period, given positive results of the study and financing by industrial partners.

Example of work performed for Atzbach:

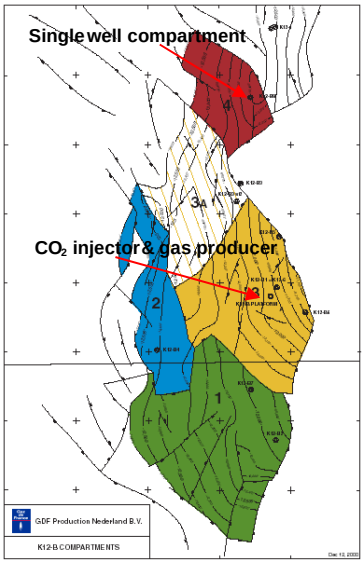


Simulated cumulative CO_2 injection for different scenarios with and without EGR, compared with constant injection at 300 kt/year.

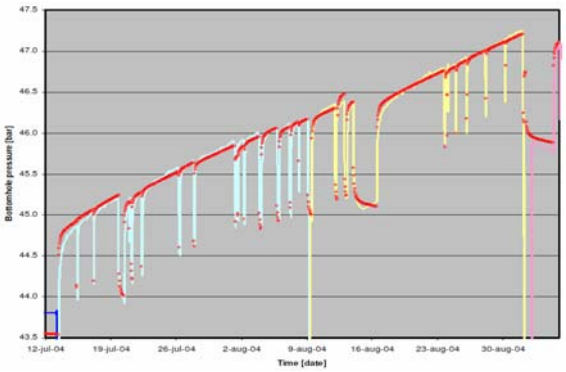


Distribution of CO_2 (molar fraction) at end of 30 year of injection without EGR.

K12B gas field (The Netherlands, operated by Gaz de France)



The K12B gas field is situated offshore the Netherlands. Gaz de France has carried out a feasibility study for Enhanced Gas Recovery. Small scale CO_2 injection of about 30 000 tonnes/year has started in mid 2004 and large scale injection of approximately 400 000 tonnes/year is intended to start in 2006 with a duration of up to 20 years. The reservoir is at 3500 - 4000 m in Rotliegend clastics. A seismic baseline survey exists.



Comparison between well observation and simulations with history matched model for CO_2 injection period.

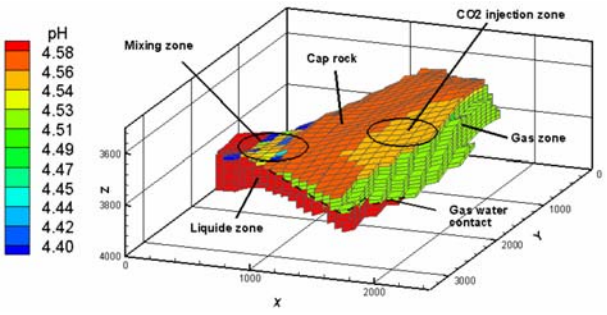
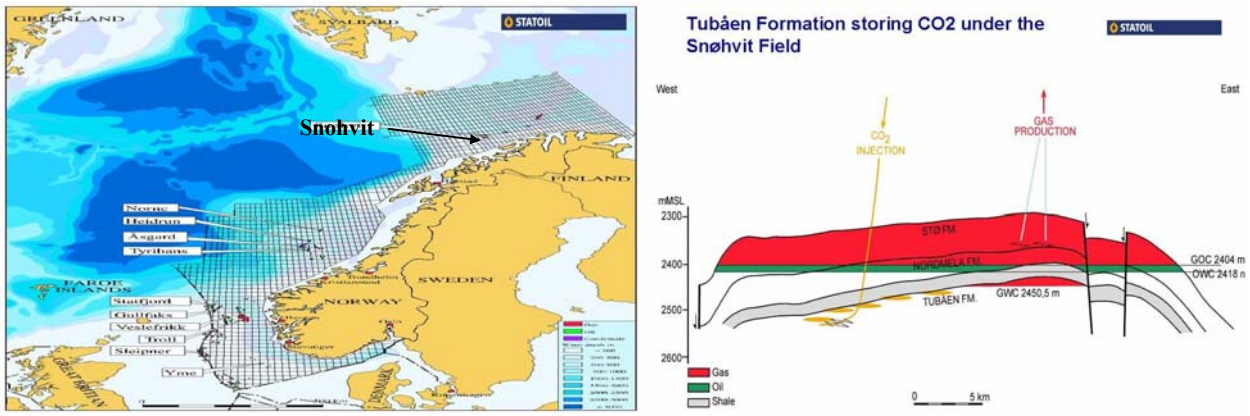


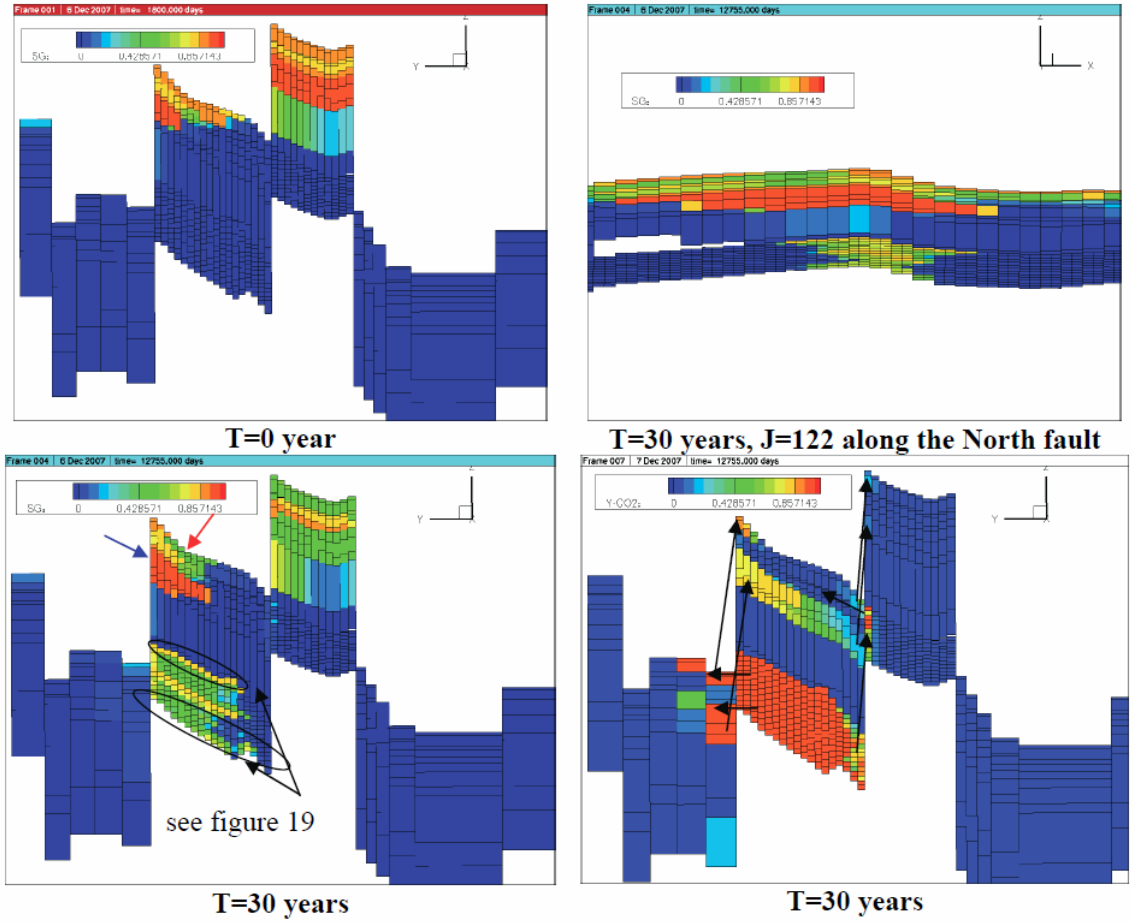
Illustration of results from coupled geochemical and transport simulations. pH values at end of CO_2 injection period for one of the cases. Different zones can be identified.

Snohvit Aquifer (Norway, operated by StatoilHydro)



The Snøhvit field is located offshore in the northern Norwegian Sea. StatoilHydro has got official approval to inject CO_2 separated from produced gas from the Snøhvit field into an aquifer below the reservoir (depth: 2500 m). Injection of 0.75 Mt/year was initially planned to start in late 2006 and will last for more than 20 years.

Example of work performed for Snohvit:



CO_2 injection simulations, base case. CO_2 can migrate through faults to the north and south of the Tubåen formation, either into connecting aquifers or into the HC gas reservoir. Several variations to the base case, with varying conductive properties of faults and aquifer seal have been run.

Activity		WP3.1 Casa.	WP3.2 Atzbach	WP3.3 K12-B	WP3.4 Snøhvit
Geomodel building, data gathering					
Fluid flow properties analysis	Reservoir rock				
	Cap rock / seal				
	Synthetic well cement		N/A	N/A	N/A
Reservoir simulation	Model building, history matching				
	Simulation of CO_2 injection scenarios				
Geochemical analysis	Experiments				
	Simulations				
Geomechanical analysis	Experiments				
	Simulations				
Well integrity analysis					
Long term modelling and simulations					
Monitoring	Sub-surface (seismic)				
	Soil gas monitoring	N/A		N/A	N/A
Performance assessment					

Completed | Not prioritised | Not applicable / no data | N/A

Workflow used for this performance assessment studies, with the specific actions for each of the four sites.

To this work on performance assessment for the four studied sites, two transverse activities have been completed:

1. Development of preventive and corrective actions (wells, caprock)
2. Development of criteria for storage site selection and management (built on existing European Best Practice for Storage: SACS, SACS2 and CO2STORE EU projects).

Summary of advances in CASTOR:

- Geological characterisation with varied datasets
- Consolidating geochemistry
  - Experiments and numerical modelling (inc. reaction-transport)
- Fluid flow in caprocks
  - Long-term vs transient laboratory methods for gas permeability
- Flow simulations
  - Exact history-matching
  - Far-field containment risks
- Geomechanics
  - Integrated fluid flow and geomechanical simulators
- Monitoring strategies
  - Tracers
  - Focussing on site-specific requirements
- Well integrity / remediation
- Risk analysis methodologies

Dissemination and training activities

The CASTOR project results have been presented in a lot of national, European and international conferences on CCS, Clean Coal, Chemistry, Geology …

Three major events have been organised directly by the CASTOR project:

- Organisation of the official inauguration of the CASTOR pilot plant, Esbjerg, March 15th 2006 (200 attendees).
- Organisation with the ENCAP project of a common training workshop (more than 100 attendies), Billund, March 16th 2006.

- Organisation of a common training workshop for CASTOR, ENCAP, CACHET and DYNAMIS FP6 projects, 22-24 January 2008, Lyon (France). For the CASTOR project, it was the occasion to present to the 180 stakeholders the main results and conclusions of the project.

CASTOR was recognised by the CSLF in September 2004.