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European CO_2 **Capture** and **Storage** projects

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Contents

Research objectives

Europe's energy supply is characterised today by structural weaknesses and geopolitical, social and environmental shortcomings, particularly as regards security of supply and climate change. Energy is a major determinant of economic growth and these deficiencies can have a direct impact on EU growth, stability and the well-being of Europe's citizens. Therefore, energy supply security, mitigating climate change and economic competitiveness are the main drivers for energy research, within the context of sustainable development, which is a high-level EU objective.

Within this perspective, it is recognised that fossil fuels will continue to be used for the foreseeable future and it is therefore imperative that cost-effective solutions are found to establish near zero emission technologies of a high environmental standard. Accordingly, the capture and storage of CO_2 associated with cleaner fossil fuel power plants is deemed to be an essential factor for fossil fuels to be part of the sustainable energy scenario. The approach, which is a priority topic within the Sixth Framework Programme (FP6, 2002-2006), includes both cost-effective, safe and environmentally compatible disposal options together with the technology for CO_2 capture, thereby enabling cleaner and more efficient fossil fuel plants.

There are significant costs involved in CO_2 capture and storage, with capture representing 70-80% of total costs. Therefore, one primary RTD objective for the EU is to decrease the cost of capture. The target is to reduce the costs from € 50-60 to € 20-30 per tonne of CO_2 captured, whilst aiming to achieve capture rates above 90%. Methods include pre-combustion capture (applicable to gasification systems), post-combustion capture, and oxyfuels combustion.

There is also a strong need to assess both the reliability and long-term stability of CO_2 storage in order to map geological storage potential, determine safety aspects and to build public confidence to ensure acceptability. CO_2 storage options of interest to the EU include geological-based storage in aquifers, depleted oil and gas reservoirs (with the possibility of enhanced oil recovery) and deep un-mined coal beds (that offer the benefit

The Framework Programmes for Research

The main EU funding mechanism for research, technological development and demonstration is the Framework Programme (FP) which is mainly implemented through calls for proposals. Based on the Treaty establishing the European Union, the Framework Programme has to serve two main strategic objectives: strengthening the scientific and technological bases of industry, and encouraging its international competitiveness while promoting research activities in support of other EU policies.

Projects from the previous FP5 (1998-2002) are well advanced, with many entering the critical phase of exploiting and disseminating their results. The total expenditure on CO_2 capture and storage research within FP5 is of the order of €32 million, with a maximum EC contribution of €16 million.

The main objective of FP6, which runs from 2002 to 2006, is to contribute to the creation of a true European Research Area (ERA). ERA is a vision for the future of research in Europe, an internal market for science and technology. It fosters scientific excellence, competitiveness and innovation through the promotion of better co-operation and coordination between relevant actors at all levels.

FP6 is structured into 'Thematic Priorities'. RTD, including demonstration on CO_2 capture and storage, is being implemented within Thematic Priority 6.1 'Sustainable energy systems', which has a total budget of around €890 million. Currently, €37 million of EU funding, matched by an equivalent amount of public and private investment, has been awarded to RTD and demonstration projects for CO_2 capture and storage in FP6. This will be reinforced via further calls (see Chapter 4 on 'Future priorities').

More information on the FPs can be found on: **www.cordis.lu**

of enhanced coal bed methane recovery). In addition, there are certain chemical techniques and other innovative ways that appear to be promising.

It is further recognised that while the sustainable energy economy is under development, hydrogen is likely to be produced mainly from fossil fuels during a transitional period.

For fossil fuel based gasification technologies, when CO_2 is removed from the gas stream the fuel that remains is hydrogen. Thus, within FP6, there is strong complementarity between the work on capture and storage of CO_2 from fossil fuels and another strategic priority, namely the development of new technologies for future energy carriers and converters such as hydrogen and fuel cells.

Building upon the experience of the Fifth Framework Programme (1998-2002)

The Fifth Framework Programme was conceived to help solve problems and to respond to the major socio-economic challenges facing Europe. To maximise its impact, it focused on a limited number of research areas combining technological, industrial, economic, social and cultural aspects. A major innovation in the Fifth Framework Programme was the concept of 'Key actions' which mobilised a wide range of scientific and technological disciplines – both fundamental and applied – required to address a specific problem.

Research into CO_2 capture and storage was carried out under the key action 'Cleaner energy systems, including renewables' of the 'Energy, environment and sustainable development' programme.

The current portfolio of FP5-funded research projects in the field of CO_2 capture and storage is summarised in Table 1.

The EU is thus contributing some €16 million to support nine projects, worth over €30 million of total investment. This

Table 1: The current portfolio of FP5 funded research projects

European project acronym	Topic	Total cost (€ million)	EC funding (€ million)	Coordinator
AZEP	Advanced membrane cycles	9.3	3.4	Siemens
GRACE	Capture in processes	3.2	2.1	BP
GESTCO	Geological storage potential	3.8	1.9	GEUS
CO_2STORE	SACS2 follow up on land	2.4	1.2	Statoil
NASCENT	Natural storage analogues	3.3	1.9	BGS
RECOPOL	Enhanced coal bed methane	3.4	1.7	TNO
WEYBURN	Weyburn monitoring	2.2	1.2	BGS
SACS2	Monitoring of Sleipner	2.1	1.2	Statoil
CO_2NET	Thematic Network	2.1	1.4	Technology Initiatives

includes two projects on CO_2 capture, six projects covering CO_2 storage and storage monitoring, and one Thematic Network.

Although some of these projects are still running, the main results can be summarised as follow:

In the capture field, advances have been made in the reduction of the costs associated with amine-based post-combustion adsorption which can be used in the power generation sector, as well as in other industries. Another project has developed gas turbine-based cycles with a mixed conducting membrane air separator, a high-temperature transfer unit ($CO_2/HO_2/O_2$ to air), and a combustor for NG with O_2, producing a CO_2/H_2O exhaust gas at a high temperature, all of this with integrated CO_2 capture.

In storage, where most of the efforts in FP5 were concentrated, substantial advances were made in the identification of the potential for geological storage in some European countries in terms of the various types of geological formations where CO_2 could be stored. Substantial information has been obtained from the study of natural analogues of CO_2 storage, as an example of how nature has stored CO_2 for long periods. This has also provided some insight into the leakage mechanisms whereby the stored CO_2 could escape. The biggest efforts have gone into the monitoring of injection experiments in saline aquifers, as well as for enhanced coal bed methane and enhanced oil recovery, by seismic and other techniques, to actually 'see' what happens to the CO_2 after injection in the geological formation. This has formed the basis for a 'best practice manual' which is a starting point for standards allowing CO_2 storage to get credits in international emission trading schemes.

From the networking point of view, additional coherence has been achieved by the promotion of exchanges of information between all the FP5 contractors in the field. This has promoted the submission of good-quality proposals to the first call of FP6, with as few overlaps as possible.

Projects funded under the Sixth Framework Programme (2002-2006)

The Sixth Framework Programme (FP6) differs significantly from previous ones. A key difference is its role in contributing to the creation of the European Research Area (ERA) in sustainable energy systems. This means that the aim is to assemble a critical mass of resources, to integrate research efforts by pulling them together, and to make this research more coherent on the European scale.

To ensure concentration of effort and maximise the impact of the programme, the intention is to focus research on a limited number of priority topics. In the field of CO_2 capture and storage, the priorities are:

- **post-combustion CO_2 capture**
- **pre-combustion CO_2 capture**
- **geological storage of CO_2**
- **chemical/mineral sequestration of CO_2**

Following the first FP6 call for proposals in December 2003, five projects were selected for EC funding in this area, with a total EC contribution of up to €35 million. The emphasis on the new instruments of FP6 – Integrated Projects and Networks of Excellence – highlights the scale of the effort required and the need for critical mass in order to achieve significant progress.

The projects selected are shown in the table below. Brief presentations of the projects, prepared by the project co-ordinators, are presented in the annex.

A further project (INCA-CO_2, a Specific Support Action on the international collaboration in the field of CO_2 capture and storage) is currently under negotiation following the second call for proposals in September 2003.

Table 2: Projects funded after the first call in FP6

Project acronym	Type of action	Topic	EU indicative funding (€ million)	Coordinator	Contact details
ENCAP	IP	Enhanced capture of CO_2	10.7	Vattenfall	Leif Brandels Vattenfall AB Leif.Brandels@vattenfall.com +46 8 739 6040
CASTOR	IP	CO_2 from capture to storage	8.5	Institut Français du Pétrole	Pierre Le Thiez Institut Français du Pétrole (IFP) pierre.le-thiez@ifp.fr +33 1 4752 6723
CO_2SINK	IP	In-situ laboratory for capture and storage of CO_2	8.7	GeoForschungs-Zentrum Potsdam	Prof Günter Borm GFZ Potsdam gborm@gfz-potsdam.de +49 331 288 1500
CO_2GeoNet	NoE	Network of excellence on geological sequestration of CO_2	6	British Geological Survey	Dr. Nick Riley BGS NRiley09@aol.com +44 (115) 914 8034
ISSC	STREP	Innovative in-situ CO_2 capture technology for solid fuel gasification	2	University of Stuttgart	Roland Berger University of Stuttgart +49 (0)711 685 3492 berger@ivd.uni-stuttgart.de

Current and future research priorities

1. Remaining calls for proposals in FP6

The final major FP6 call for proposals for research projects in the area of CO_2 capture and storage is planned to close in December 2004. A further limited call for Coordination and Specific Support Actions may take place in Autumn 2005, if considered necessary.

The call text and Work Programme provide full details of the research areas open in the call and the conditions of participation. These, and other useful documents, are available on the dedicated call page on the CORDIS website, accessible at: http://www.cordis.lu/sustdev/energy/

The research topics open in the field of CO_2 capture and storage are:

- **CO_2 capture and hydrogen production from gaseous fuels**
- **The monitoring and verification of CO_2 geological storage**
- **Preparing for large-scale H_2 production from decarbonised fossil fuels including CO_2 geological storage**
- **Advanced CO_2 separation techniques**
- **Mapping geological CO_2 storage potential, matching sources and sinks**
- **European coordination and networking activities in CO_2 capture and storage**

2. Looking towards the Seventh Framework Programme

At the beginning of 2005, the European Commission will present its proposal for the Union's Seventh Research Framework Programme (2006-2010). Along with specific information about the financial support schemes and implementation instruments, it will include the Commission's proposals for thematic research priorities.

The Commission has made strengthening European research a major objective in its Communication on the future financial framework of the Union[1], proposing to increase the European Union's research budget significantly. At the Barcelona European Council in March 2002, the EU set itself the objective of increasing the European research effort to 3% of the EU's GDP by 2010, two-thirds coming from private investment and one-third from the public sector.

In order to increase the impact of the European Union's action, it is proposed to organise FP7 around six major objectives:

Objective 1. Creating European centres of excellence through collaboration between laboratories.

Programmes to support transnational collaboration between research centres, universities and companies will be implemented using the FP6-type instruments, such as Networks of Excellence and Integrated Projects.

Objective 2. Launching European technological initiatives

Technology platforms are being set up. They bring together different stakeholders to define a common research agenda which should mobilise a critical mass of public and private resources. This approach has been adopted in areas such as the hydrogen economy, with the creation of the 'European Hydrogen and Fuel Cell Technology Platform'.

Often, it will be possible to implement the research agenda by means of Integrated Projects. In a limited number of cases, a 'pan-European' approach appears appropriate, involving the implementation of large-scale 'joint technology initiatives'. An appropriate framework for their implementation is that of structures based on Article 171 of the Treaty[2], including possible joint undertakings.

Objective 3. Stimulating the creativity of basic research through competition between teams at European level

Open competition between individual research teams and support for them at European level would boost the dynamism, creativity and excellence of European research whilst increasing its visibility.

The Commission suggests the creation of a support mechanism (e.g. a European Research Council) for research projects conducted by individual teams which are in competition with each other at European level.

Objective 4. Making Europe more attractive to the best researchers

The European Union's objective is to promote the development of European scientific careers[3] while, at the same time, helping to make sure that researchers stay in Europe and attracting the best researchers to Europe. Against the background of growing competition at world level, it is necessary to strengthen the 'Marie Curie' actions which are being conducted for this purpose.

Objective 5. Developing research infrastructure of European interest

With the creation of the ESFRI Forum[4], an important step has been taken in the field of research infrastructures in Europe. It is proposed to strengthen this action through the introduction of support for the construction and operation of new research infrastructures of European interest.

Objective 6. Improving the coordination of national research programmes

Efforts have successfully been made to improve the coordination of national research programmes in the context of the FP6 – such efforts must be strengthened. This involves increasing the resources allocated to the ERA-NET activities for the networking of national programmes, extending the financial support they offer to research activities, and an increased effort towards the mutual opening-up of programmes.

1. "Building our common future – policy changes and budgetary means of the enlarged Union 2007-2013", COM (2004) 101 of 10.2.2004.
2. "The Community may set up joint undertakings or any other structure necessary for the efficient execution of Community research, technological development and demonstration programmes."
3. As indicated in the Commission's Communication "Researchers in the European Research Area, one profession, multiple careers", COM (2003) of 18.07.2003.
4. ESFRI: European Strategy Forum on Research Infrastructure.

FP6 Project Descriptions

Enhanced capture of CO_2 (ENCAP)

Contract number: SES6-CT-2004-502666

Type of instrument: Integrated Project

List of participants:
- Vattenfall AB (SE)
- SINTEF Energy Research (part of SINTEF Group) (NO)
- ENERGI E2 A/S (DK)
- Public Power Corporation SA (EL)
- RWE Power AG (DE)
- Statoil ASA (NO)
- L'AIR LIQUIDE (FR)
- ALSTOM Power Boilers SA (FR)
- ALSTOM Power Centrales SA (FR)
- ALSTOM Power Boiler GmbH (DE)
- ALSTOM POWER LTD – Technology Centre (UK)
- ALSTOM POWER (Switzerland) Ltd
- BOC Ltd (UK)
- Linde AG/Linde Engineering Division (DE)
- mg engineering Lurgi Oel, Gas, Chemie (DE)
- Mitsui Babcock Energy Ltd (UK)
- Siemens Aktiengesellschaft (DE)
- Centre for Research & Technology Hellas/Institute for Solid Fuels Technology & Applications (EL)
- Chalmers University of Technology (SE)
- Deutsches Zentrum fuer Luft- und Raumfahrt e. V (DE)
- SINTEF Materialteknologi (Part of the SINTEF Foundation) (NO)
- Institut Français du Pétrole (IFP)
- Netherlands Organisation for Applied Scientific Research (NL)
- The Norwegian University of Science and Technology (NO)
- University of Stuttgart (DE)
- University of Twente (NL)
- University of Ulster (UK)
- Universität Paderborn (DE)

Projected total cost: €22.2 million

Maximum EC contribution: €10.702 million

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Project main goals

The stated **target of ENCAP** is to provide pre-combustion decarbonisation technologies in power cycles operated by **natural gas, residue oil, hard coal and lignite** with the objective of achieving:

1. **at least 90% capture rate for CO_2**

2. **50% capture cost reduction**[5] – from a current level of €50-60 per tonne of CO_2 captured, covering **technical validation including all steps of research** of selected prospective concepts with economical assessment and HSE-conformance – with links to transportation and storage.

The scientific objective is to **generate new knowledge and comprehension** of systems, processes, materials and matter by characteristics of potentiality, constraints and governing mechanisms pertaining to pre-combustion decarbonisation of fossil fuels, with a bearing on solutions that (might) facilitate sequestering of CO_2. This objective requires **targeted** fundamental and applied **research**, and **topical involvement** by leading European R&D institutions.

The objectives will be achieved by the selection of at least one **candidate technology concept** – provided sufficiently high potentiality is attributed so that it **could be developed** up to a level that is required and sufficient to ensure viability. Methodology for the **ranking** of concepts will be developed including **cost assessment**, and validation of **critical elements.**

Key issues

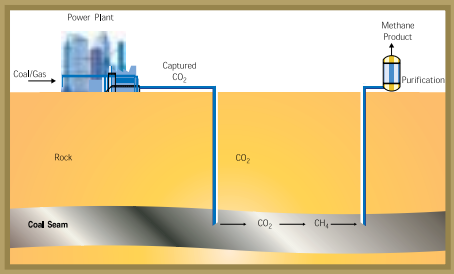
The research activities of the project are structured within six subprojects that directly meet the project objectives:

• SP1 Process and Power Systems
Aimed at techno-economic impact-and-feasibility assessment of options with recommendations for subsequent demonstration and scale-up

• SP2 Pre-combustion Decarbonisation Technologies
Research on new technological features on added CO_2-capture-related components – emphasising cryogenic technology for oxygen production

• SP3 OxyFuel Boiler Technologies
The use of oxygen in large boilers constitutes a new research area. One obstacle of pre-combustion decarbonisation in large-scale oxy-fuel (boiler) power generation is the energy penalty associated with current cryogenic technology. Therefore, new non-cryogenic oxygen production technologies are needed that could offer significant improvements to the power cycle efficiency

Sleipner - CO_2 injection in the Utsina formation - Courtesy Statoil



Enhanced Coal Bed Methane

• SP4 Chemical Looping Combustion
Emphasising cyclic materials, reactors, and operational aspects

• SP5 High-temperature Oxygen Generation for Power Cycles
Research on new promising low-cost oxygen production technologies – emphasising non-cryogenic technology for oxygen production

• SP6 Novel pre-combustion capture concepts
Addressing new concepts and required knowledge that is needed and required in order to make relevant decisions for pilot tests

Technical approach

To meet the objectives of ENCAP critical scientific actions must be undertaken and resolved – including:

- Assessment studies of **materials** and **cycle working media** versus emerging concepts necessary to determine the potentiality and impacts of candidate materials on performance and cost of **actual capture concepts**, including criteria for **materials selection** and **testing** conditions

- Research on **absorbents** and permeable **membranes** (polymeric and ceramic) having a significant impact on large-scale absorption and separation of selected gas fractions

- Research and qualification of **oxygen carriers** and **oxygen transport dense ceramic membranes** to facilitate oxygen production – including methods and materials for **high-temperature oxygen generation**, utilising either **oxygen transport ceramic membranes** or using **ceramic autothermal recovery** processing (CAR) – especially perovskite materials[6] aimed at a **cost reduction of 40%** and **efficiency improvement of 40%**, as compared to state of the art

- **High-temperature heat exchangers in boilers**, and materials for vapour and CO_2-enriched atmospheres in order to withstand the high temperatures resulting from the combustion of fossil fuels in denitrogenised air, and parts exposed to **high-temperature-reducing atmosphere**, including innovative **combustion schemes** aimed at increasing the content from **30%** to almost **100% hydrogen in gas turbines**

- **Thermo-fluid-reactive** modelling of oxygen carriers that includes heat-and-mass balancing models for oxygen carriers required for the determination of the relationship between performance-stability of **oxygen-adsorption** and **membrane materials** at relevant conditions in order to achieve the objectives of ENCAP

- Identification of technical and economic **barriers** that might reduce the pîrmance and cost of actual concepts

Expected achievements

- Performing research and development on pre-combustion CO_2 capture and validating it by testing technical and economic feasibility of concepts, and also interacting with research-related networks and carrying out training and dissemination

- ENCAP will generate knowledge and results that enable power companies to decide to launch a new design project by 2008-2010 aimed at a large-scale demonstration plant.

- Enhancing the competitiveness of European industry

- Contributing to the creation of a European Research Area for CO_2 capture.

5. Provided there is a market that is ready to pay the additional cost, and the R&D/industrialisation can be written off, and the learning curve is established at a realistic level (ref. Section 5)
6. I.e. powder, thick ceramic disc material supported with a thin layer on a porous substrate

CO_2 from capture to storage (CASTOR)

Contract number: SES6-CT-2004-502586

Type of instrument: Integrated Project

List of participants:
- Institut Français du Pétrole - (IFP)
- Statoil ASA - (Statoil)
- Netherlands Organisation for Applied Scientific Research - (TNO)
- SINTEF – Stiftelsen for industriell og teknisk forsking ved Norges Tekniske Hogskole - (SINTEF)
- SINTEF – Energy Research - (SINTEF-ER)
- SINTEF Petroleumsforskning AS (SINTEF Petroleum Research) - (SINTEF-PR)
- Norwegian University of Science and Technology - (NTNU)
- Natural Environment Research Council (British Geological Survey) - NERC (BGS)
- Bundesanstalt für Geowissenschaften und Rohstoffe - BGR
- Bureau de Recherches Géologiques et Minières - (BRGM)
- Geological Survey of Denmark and Greenland - (GEUS)
- Imperial College of Science, Technology and Medicine - (Imperial)
- Gaz de France - (GDF)
- Universitaet Stuttgart - (USTUTT)
- Vattenfall AB (publ) - (VAB)
- Elsam A/S - (ELSAM)
- ENERGI E2 A/S - (E2)
- Repsol Investigaciones Petroliferas, S.A. - (RIPSA)
- RWE Power Aktiengesellschaft - (RWE Power)
- Public Power Corporation S.A. - (PPC)
- Powergen/E. On Engineering - (PG/E.On)
- ALSTOM Power Centrales - (AP-P)
- Instituto Nazionale di Oceanografia e di Geofisica Sperimentale - (OGS)
- Mitsui Babcock Energy Limited - (MBEL)
- Siemens Aktiengesellschaft - (Siemens)
- BASF Aktiengesellschaft - (BASF)
- GVS S.p.A. - (GVS)
- Enil Technologie S.p.A. - (ET)
- Rohoel Aufsuchungs AG - (RAG)
- Universiteit Twente - (UT-OOIP)

Projected total cost: €15.8 million

Maximum EC contribution: €8.5 million

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Project main goals

The project's objective is to make possible the capture and geological storage of 10% of European CO_2 emissions, or 30% of the emissions of large industrial facilities (mainly conventional power stations). To accomplish this, two types of approach must be validated and developed: new technologies for the capture and separation of CO_2 from flue gases and its geological storage, and tools and methods to quantify and minimise the uncertainties and risks linked to the storage of CO_2. In this context, the CASTOR project is aimed more specifically at reducing the costs of capture and separation of CO_2 (from €0-60/tonne CO_2 to €20-30/tonne), improving the performance, safety, and environmental impact of geological storage concepts and, finally, validating the concept at actual sites.

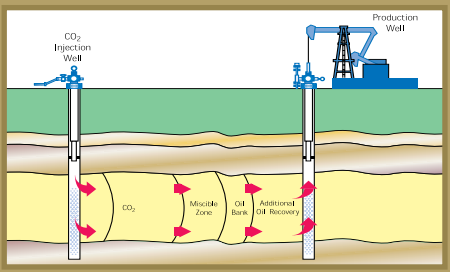
The R&D work is divided into three sub-projects:
- Post-combustion capture (65% of the budget)
- Geological storage (25% of the budget)
- Strategy for CO_2 reduction (10% of the budget).

Key issues

Work on capture is aimed at developing new CO_2 post-combustion separation processes suited to the problems of capture of CO_2 at low concentrations in large volumes of gases at low pressure. The processes will be tested in a pilot unit capable of treating from 1 to 2 tonnes of CO_2 per hour, from real fumes. This pilot will be implemented in the Esbjerg power station, operated by Elsam in Denmark. 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.

An advanced fossil fuel power plant



Enhanced Oil Recovery

The work on storage will provide the European industrial community with four new storage facility case studies representative of the geological variety of existing sites across Europe:

- storage in an abandoned reservoir in the Mediterranean (Casablanca field, operated by Repsol, Spain)
- storage in a deep saline aquifer (Snohvit, North Sea, operated by Statoil, Norway, injection in 2006)
- storage in two depleted gas reservoirs, one deep, 2 500 m down (K12b, North Sea, Netherlands, operated by Gaz de France, injection in 2004), and the other closer to the surface and on land, 500 m down (Lindach, Austria, operated by Rohoel).

Risk and environmental impact studies will be conducted and methodologies for predicting the future of these sites and for monitoring them will be developed, thereby enriching current knowledge in these fields. During the time-line of the CASTOR project, CO_2 injection will be performed in at least two sites: K12b and Snohvit.

The activity under "Strategy for CO_2 reduction" 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 (extension of GESTCO European project).

Technical approach

Expected achievements/impact

CASTOR will yield major impacts in at least three areas:

- It will make **energy systems cleaner**. A CO_2 reduction of 10% Europe-wide is achievable by reducing emissions to near zero for about 30% of European fossil-fuel power plants (in 2010). It will thereby help to reach internationally agreed emission targets. CASTOR will also facilitate a more general move towards hydrogen energy systems, for which CO_2 capture and storage technology is also required for environmental reasons. CASTOR will further assist the smooth transition to an energy system based predominantly on renewables, thereby reducing the likely adverse economic impacts of a rapid system transfer. As a consequence, CASTOR can make key contributions to the solution of major environmental, economic and societal problems.
- It will also contribute to **European security of supply** – in this way it will be possible to continue to use coal-fired plants as carbon-low infrastructure for energy.

The **present market position** of European research and industry in the fields of capture and underground storage of CO_2 needs to be further developed, strengthened and exploited. These market segments are expected to gain substantial importance in the medium- to long-term future. Application of such technologies will probably become a requirement for new industrial energy installations and, with CO_2 trading starting in 2005, also for existing power plants based on fossil fuels. We foresee that by reinforcing the competitiveness of European players in this market segment, a world market share of perhaps 80% in this field can be achieved. This will only be possible by active participation in technological innovation and development. Exploitation of CASTOR results and products is guaranteed by the active participation of industrial partners. The United States has just announced FutureGen, a US$ 1 billion investment to develop technologies for joint power and hydrogen production, combined with CO_2 capture, to maintain coal as a fuel for the future. The USA has not signed the Kyoto Protocol, and will probably aim at the European market. A large integrated research effort is needed to counterbalance this – this is what CASTOR is all about.

In-situ R&D Laboratory for Geological Storage of CO_2 (CO_2SINK)

Contract number: FP6-502599

Type of instrument: Integrated Project

List of participants
- GeoForschungsZentrum Potsdam (DE)
- G.E.O.S. Freiberg Ingenieurgesellschaft mbH (DE)
- Geological Survey of Denmark and Greenland, Copenhagen (DK)
- Mineral & Energy Economy Research Institute, Cracow (PL)
- Det Norske Veritas, Hoevik (NO)
- Statoil ASA, Trondheim (NO)
- Shell International Exploration and Production B.V., Rijswijk (NL)
- Stuttgart University (DE)
- Vibrometric Oy Cosma, Helsinki (FI)
- University of Kent, Canterbury (UK)
- Uppsala University (SE)
- RWE Power AG, Köln (DE)
- IEA Greenhouse Gas R&D Programme, Cheltenham (UK)
- Vattenfall Europe Mining AG, Cottbus (DE)

Projected total cost: €13.3 million

Maximum EC contribution: €8.7 million

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Main goals

The aim of the CO_2SINK project is in-situ testing of the geological storage of CO_2. It will advance the understanding of the science and of the practical processes involved in underground storage of CO_2 in a saline aquifer as a means of reducing emissions of greenhouse gases to the atmosphere. The storage site near the town of Ketzin, close to Berlin, includes industrial land and some infrastructure which also makes it suitable as a testing ground for the small-scale demonstration of CO_2 capture processes.

The work programme involves intensive monitoring of the fate of the injected CO_2 using a comprehensive range of geophysical and geochemical techniques, and a systematic assessment of the environmental performance of the storage project. This will be accompanied by a public outreach programme.

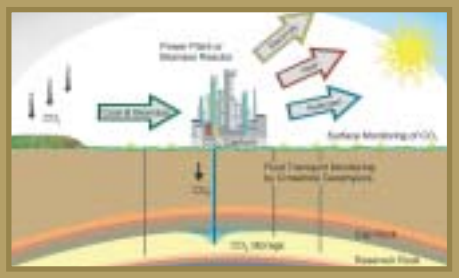
Being close to a metropolitan area, the test site provides a unique opportunity to develop a European showcase for onshore CO_2 storage. It will accelerate public acceptance of the geological storage of CO_2 as a greenhouse gas mitigation option for the benefit of the Europe Community.

CO_2 capture and geological storage is widely seen as a cost-effective way to reduce industrial CO_2 emissions into the atmosphere. The development of capture and storage systems requires targeted research on pilot projects specifically set up to observe the fate of carbon dioxide injected underground as regards the quality of the seals, including the chance of leakage through overlying strata, upward migration of gas along artificial pathways, migration of the CO_2 within the reservoir, and the rate at which CO_2 dissolves in brine-filled reservoirs or reacts with indigenous minerals.

The CO_2SINK project aims to develop such an in-situ laboratory for CO_2 storage to fill the gap between numerous conceptual engineering and scientific studies on geological storage and a fully fledged onshore storage demonstration which, because of its cost and risk, is unlikely to be undertaken by those industries currently involved.

Technical approach

The development of the CO_2 storage facility at Ketzin makes use of existing infrastructure at the gas storage facility in addition to three new wells which are planned to be drilled to inject CO_2 and monitor changes in the reservoir. Setting up the storage facility, surveying the site, characterising the sub-surface rocks and fluid, overseeing drilling, and managing the flow of information within the project are all part of the work plan.



Co_2 SINK - Conceptual diagram

CO_2 injection in deep saline aquifers

The work programme of CO_2SINK will start with preparation of a baseline survey of the site and the target reservoir and the carrying out of a detailed risk assessment to ensure that the experiment can be conducted safely. The necessary approvals and consent of local authorities and residents will be sought. The plan is to inject some 10 to 30 kilotonnes per year of pure CO_2 into the reservoir for a period of approximately three years. If feasible, the source of CO_2, which is still under negotiation, will come from the combustion of a renewable fuel. Detailed laboratory testing will be made of samples of rocks, fluids and micro-organisms from the underground. In-situ measurements and experiments will be conducted in boreholes. Surface seismic imaging and borehole seismics will be used together with novel permanent monitoring instruments at the surface and downhole. The test site will be used for upscaling the laboratory results to the field scale, for the development of monitoring methods, and as a basis for modelling scenarios. All these steps will help to prepare for the injection of CO_2 underground, to follow its fate over long periods of time, and to evaluate the reservoir's stability and integrity.

Key issues

Direct sampling and in-situ observation of key parameters, as well as critical testing of geological models based on surface observations, are indispensable for the safe and sustainable use of the subsurface. An integrated drilling technology, including time- and cost-saving drilling procedures, selection of completion layout and materials tailored to provide long-term sealing of wells, in-situ down-hole measurement, and monitoring of physical and chemical parameters combined with surface investigations, comprises the appropriate combination of tools. Tasks include the development of special logging strategies, the development of specific sample handling and field laboratory techniques, and the installation of project-designed internet-based data and information systems to enable immediate access to the data for all project participants.

Thus, the main topics to be addressed by CO_2SINK are storage site development, including securing the necessary permits, baseline surface geochemistry of CO_2 and geomicrobiology, geological and geophysical site pre-survey, laboratory studies on rock-/fluid interactions, numerical modelling of dynamic flow behaviour, risk-assessment, drilling, logging and casing, design and installation of permanent downhole sensors, in-situ monitoring of the CO_2 migration in the reservoir rock, development of a drilling and storage information system, and public outreach.

Expected achievements/impact

The location of CO_2SINK at Ketzin has a number of appealing features: the existing surface infrastructure from the gas storage site greatly reduces the need for new developments; the geology of the site is known and is representative of large parts of Europe, which facilitates the transfer of results; and the local political community strongly supports the project. The strategic impact of the proposed CO_2SINK project will be to show policy-makers and the general public that CO_2 capture and geological storage can be undertaken cost-effectively and with no adverse affect on the local population and the natural environment.

Being a real-life project, CO_2SINK will go a long way to advance the deployment of geological storage as an option enabling significant cuts in CO_2 emission in the future. In particular, the project will shed light on the cost-competitiveness of storage compared to other methods of reducing emissions, and whether or not the benefits of implementing the technology outweigh its disadvantages.

The envisaged test facility will attract considerable international interest and will most likely contribute to setting the standards for future large-scale CO_2 capture and storage activities. Successful execution of the CO_2SINK project will provide techno-economic confidence for subsequent full-scale demonstration projects to be undertaken by power companies and hydrogen manufacturers.

Network of Excellence on Geological Sequestration of CO_2 (CO_2GeoNet)

Contract number: SES6-CT-2004-502816

Type of instrument: Network of excellence

List of participants:
- Natural Environment Research Council, BGS (UK)
- Bundesantalt fur GeoWissenschaften und Rohstoffe (DE)
- Bureau de Recherches Geologiques et Minieres (FR)
- Geological Survey of Denmark and Greenland (DK)
- Herriot-Watt University (UK)
- Institut Français du Pétrole (FR)
- Imperial College of Science and Technology (UK)
- Norwegian Institute for Water Research (NO)
- Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (IT)
- Stiftelsen Rogalandsforskning (NO)
- Sintef Petroleumsforskning AS (NO)
- Netherlands Organisation of Applied Scientific Research (NL)
- Università di Roma 'La Sapienza' (IT)

Grant for integration: €6 million

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Project main goals

The initial partnership will be between 13 institutes, most of which have a long and established history of research in geological storage. Some new players are also included, either because they are expected to have significant national strategic profile in future CO_2 storage projects, or they have capabilities which can be realigned to strengthen the network, or even bring uniqueness. For the first time in an EC FP project, marine biologists will be drawn into this research topic. The formation of a durable and complimentary partnership comprising a critical mass of key European research centres is the core aim, and should lead to:

- Improved efficiency through the realignment of national research programmes, prevention of duplication of research effort, and sharing of existing and newly acquired infrastructure and IPR.
- Identification of knowledge gaps and formulation of new research projects and tools to fill these gaps.
- External funding from national and industrial programmes in order to diversify, build and strengthen the portfolio of shared research activities.
- Formation of the authoritative body for technical, impartial, high-quality information on the geological storage of CO_2, to enable public confidence in the technology, participation in policy, and regulatory and common standards formulation.
- Provision of training to strengthen the partners, addition of new network members, and a sustainable replacement supply of researchers for the future.
- Exploitation of network IPR, both as a revenue earner to sustain the network and to equip European industry to be competitive in the emerging global low carbon energy markets.

Key issues

World projections of energy use show that fossil fuel dependency will continue to 2030 and beyond, but sustainability will need a 60% reduction in CO_2 emissions by 2050. This will be difficult and will require various strategies. The associated rise in global CO_2 emissions, without abatement, will be at an average rate of 1.8% per annum (from the current value of 25Gt p.a., to 38Gt by 2030) – a rise of over 50%. This will be catastrophic for the planet's sustainability. Urgent action is needed. Europe's CO_2emissions will rise by an average of 0.6% p.a. up to 2020, from a 2000 level of 3.1Gt to 3.5Gt by 2020. The rocks under the North Sea have a theoretical capacity for storing over 800Gt of CO_2. Capturing CO_2 from industrial point sources and storing it underground (a process that mimics nature) is a very attractive route to making cuts in CO_2 emissions. CO_2 capture and storage allows diverse fuel inputs/outputs, enhances security of supply, and is well aligned with hydrogen production from fossil fuels. Through the Joule 2,

Sleipner - Courtesy of Statoil

The Weyburn enhanced oil recovery project

FP4 and 5 projects, Europe has led the world in R&D in this area, with rapid growth this decade. National programmes are also emerging. But this success has a downside, creating fragmentation through diversification. North America, despite its rejection of Kyoto (except Canada), has recently embraced CO_2 capture and geological storage and is allocating huge resources (over $4bn) over the next ten years. As a result, Europe risks losing its head start. Therefore, we must work more effectively and restructure accordingly. The main aim of CO_2GeoNet will be to integrate, strengthen, and build upon the momentum of previous and existing European R&D, as well as to promote European excellence internationally so as to ensure that Europe remains at the forefront of CO_2 underground storage research.

Technical approach

The project is divided into three main areas – integrating activities, jointly executed research, and the spreading of excellence. In the initial 18 months, work will concentrate on inventories of relevant infrastructure, staff capabilities and the results of CO_2 storage research to date. This will enable identification both of gaps in the research and infrastructure and areas of overlap. Areas of new collaborative research in a wide range of disciplines will be proposed to fill these gaps, and some of these will be carried out in the remaining 42 months. Decisions will also be made as to how best to make such research most efficient. A programme of staff training and deployment will be developed and concerted efforts will be made to disseminate information about CO_2 sequestration both to the general public and to decision- and policy-makers.

Expected impacts

Contribution to standards: The project will impact upon the development and provision of 'best available technology' through its R&D programme in the Joint Programme of Activities and the dissemination of the outputs to commerce, policy-makers and society. These will cover CO_2 storage site selection, injection operations, monitoring, verification, safety and environmental protection. The Network of Excellence will also contribute to training standards. These contributions will not only impact on standards in Europe but on those internationally. If underground storage becomes a recognised technology for carbon storage in terms of carbon trading, then the input of the NoE into monitoring and verification of storage will be vital.

Contribution to policy developments: Policy-makers and society need confidence in the technology before they will accept CO_2 capture and storage. Regulatory frameworks will need to embrace the technology if it is to succeed. CO_2GeoNet will be actively involved in the review of CO_2 capture and storage commissioned by the Intergovernmental Panel on Climate Change, and will engage with policy-makers and regulators in national governments and the EC. CO_2 capture and storage could also address policy concerns on security of supply and diversity of fuel to meet Europe's primary energy demand. If CO_2 injection is used in enhancing hydrocarbon production, then maximum recovery of Europe's indigenous oil and gas will be possible and hydrocarbon field life will be extended.

Risk assessment and related communication strategy: Even if policy-makers and regulators accept and recognise CO_2 capture and storage as a valid CO_2 mitigation technology, this does not guarantee that society will accept it. CO_2GeoNet therefore needs to engage with society and raise the profile of CO_2 capture and storage technology, and the issues that surround it. The network's R&D outputs will be communicated through technical publications, contribution to policy documents, broadcasting, popular science publications, newspapers, website, brochures and stimulation of public debate through participation in stakeholder meetings. Many CO_2GeoNet members have already begun this process. CO_2GeoNet will collaborate closely with the FP5 Network 'CO_2Net2' to bring this about. It will also engage with other bodies – for example, the International Energy Agency, and the United Nations Economic Commission for Europe-UNECE which encourages annual stakeholder debate on energy issues through its Sustainable Energy Working Group – well attended by industry, NGOs and candidate countries.

Innovative In situ CO_2 Capture Technology for Solid Fuel Gasification (ISCC)

Contract number: SES6-CT-2003-502743

Type of instrument: Specific Technical Research Project

List of participants:
- University of Stuttgart – Institute of Process Engineering and Power Plant Technology (DE)
- National Technical University of Athens/Laboratory of Steam Boilers and Thermal Plants (EL)
- Centre for Solar Energy and Hydrogen Research (DE)
- Glowny Instytut Gornictwa – Central Mining Institute (PL)
- Politechnika WROCLAWSKA – WROCLAW University of Technology (PL)
- Public Power Corporation of Greece
- Technical Research Centre of Finland
- IVE Weimer (DE)
- Energy Research Centre, University of Ulster (UK)
- Technical University of Brandenburg – Cottbus (DE)
- SCS-Technology (AT)
- Consejo Superior de Investigaciones Científicas (ES)
- Kopalnia Węgla Brunatnego "Turów" Spółka Akcyjna (PL)
- Vattenfall Europe Mining AG (DE)

Projected total cost: €2.9 million

Maximum EC contribution: €1.9 million

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Project main goals

The project aims to develop a new process for upgrading high-moisture low-rank brown coals yielding three valuable products:

- A fuel gas consisting mainly of hydrogen
- A purge gas stream containing >95% CO_2, ready for transportation to sequestration (CO_2 capture >90%) or chemical fixation
- A pre-calcinated feed for a cement kiln consisting of CaO, coal ash and required additional minerals.

Expected results are a detailed definition of an environmentally friendly, highly efficient coal technology producing a highly enriched H_2 product gas via in situ CO_2 capture; a detailed technical assessment of process efficiency in terms of energy (coal to H_2) and CO_2 captured (% of input); a life-cycle assessment (LCA) including H_2 production costs and costs per tonne of CO_2 captured; and a European business plan for the exploitation of results.

Key issues/technical approach

Screening of available coal and sorbent material and required product quality: Available coal and possible sorbent material resources in the EC are analysed and assessed in order to select suitable feedstock materials. The quality of process products, as well as the conditions of CO_2 sequestration, will be defined for an economic operation in a technical plant.

Basic process investigations will be carried out in order to develop advanced high-temperature sorbents. Sorption conditions will be studied in order to optimise process efficiency and CO_2 sequestration as well as the economic supply of solid sorbent materials.

Pilot-scale experiments will be carried out to validate the results of the basic investigations and demonstrate the technical feasibility of the integrated process.

Technical and socio-economic evaluation will assess the results of the investigations and compare the process with other low CO_2-emitting power processes, taking into consideration technical, social, ethical and economic criteria. The evaluation will feature an LCA and a European business plan for the exploitation of results.

Sleipner - Courtesy of Statoil

A vision of a CO_2 free world

Expected achievements/impact

The following will be generated in order to evaluate the technical and socio-economic feasibility of a process based on ISCC technology:

- A detailed technical assessment of process efficiency in terms of energy (coal to H_2) and CO_2 captured (% of input)
- Plant design for a semi-technical power facility (1 MW) to investigate the integrated process on a semi-technical level
- A life-cycle assessment (LCA) including H_2 production costs and costs per tonne of CO_2 captured
- A European business plan for the exploitation of results.

If the feasibility can be shown, the development will be continued. Once the process becomes commercial it can be applied in areas where low-grade lignites are available. It has the potential to supply 10-20% of European power production.

European Commission

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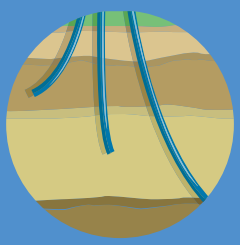

This compilation of project synopses covers research and demonstration projects on **CO_2 capture and storage**, as well as supporting activities such as Co-ordination Actions and Specific Support Actions. The projects concerned are those funded in the first half of the Sixth Framework Programme under the Thematic Priority 6 "Sustainable Development, Global Change and Ecosystems". For each project, basic information is provided with regard to the scientific and technical scope, expected impact, the participating organisations and contact points.

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