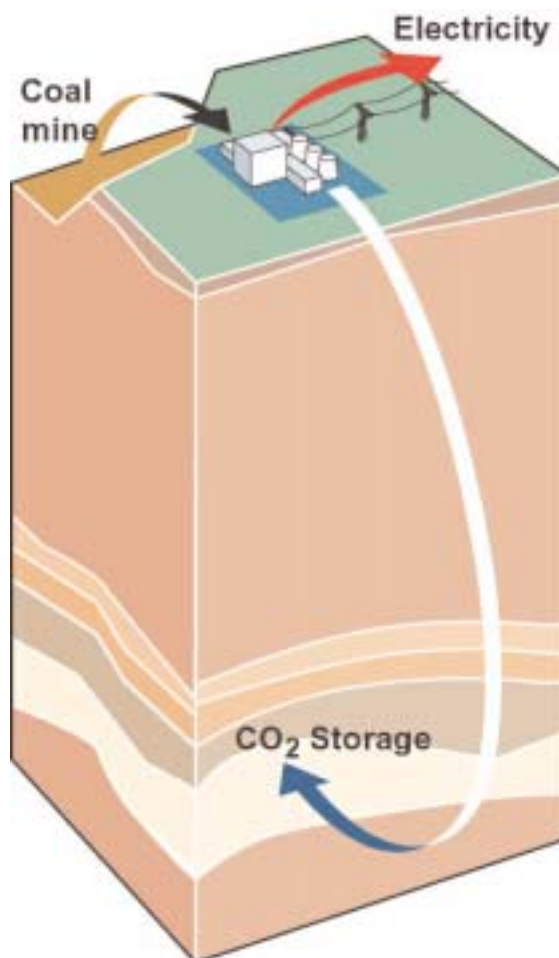


BRI DGI NG TO THE FUTURE



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WELCOME TO THE NEWSLETTER ABOUT VATTENFALL'S WORK FOR CO₂ FREE POWER!

This is the second issue of *Bridging to the future*, Vattenfall's newsletter on the CO₂-free power project.

The work for a CO₂-free power plant is proceeding in all the three subprojects; Capture, Storage and Transport and Environment. Since the latest issue, Vattenfall has decided to build a 30 MW pilot plant with CO₂ capture. The plans are presented on the following pages.

This issue also contains extended information about the EU-funded project ENCAP.



Photo: Bruno Ehrns

Prof. Lars Strömberg is Vattenfall's project manager and also legally responsible for this newsletter. If you have any questions about the CO₂-free power plant project, please contact the project group at:

CO2.free.plant@vattenfall.com

Vattenfall AB is the fifth largest electricity generator and the largest district-heating company in Europe. Its vision is to be a leading European energy company.

Vattenfall puts a lot of effort into the CO₂-free power plant project, as the technology is one of many ways of reducing emissions of CO₂. The capture and underground storage of CO₂ is a way of bridging over to other, renewable technology.

Vattenfall's CO₂-free power plant project consists of three sub-projects:

- Capture, where three main approaches for CO₂-separation have been identified; post-combustion capture, pre-combustion capture and oxygen combustion.
- Storage and transport, which investigates the possibilities of storing CO₂ in deep saline aquifers or old oil and gas fields. Also includes investigations of long-term effect, safety and transportation of CO₂.
- Environment, which focuses on any environmental problems relating to CO₂ capture, storage and transport.

Vattenfall is involved in 5 EU-sponsored CO₂-related R&D-projects.

This newsletter is distributed three times a year and can be found on www.vattenfall.com. If you would like a copy by e-mail, please contact the editor Stina Rydberg at: stina.rydberg@vattenfall.com

Vattenfall builds a 30 MW thermal oxyfuel pilot plant for CO₂ capture in Schwarze Pumpe, Germany

Vattenfall's decision to build the first power plant unit ever with carbon dioxide capture was announced by President and CEO Lars G Josefsson and Dr Klaus Rauscher, Chairman of the Management Board at Vattenfall Europe, at a press conference in Berlin on May 19, 2005. On May 13, 2005 the Vattenfall Board decided on the pilot plant investment including the cost for a three years test operation period. The required investment will amount to approximately 40 million Euro (SEK 370 Million).

In the chosen oxyfuel approach combustion takes place in pure oxygen and re-circulated flue gases. This results in a flue gas with carbon dioxide and water vapour as main components. The oxygen will be produced on-site in a commercially available air separator.

Background

The construction of the 30 MW_{th} pilot plant is an important milestone for "The CO₂ Free Power Plant Project". It is the link between initial engineering and successful operation of the future 250 MW_{eI} demo plant.

Ever since the project started in 2001, more than 20 engineers in Sweden and Germany have worked between half and full time with GAP analyses, research and engineering. Test projects all around the world have been covered either by distance or by participation in the projects.

All these activities have gained knowledge to the project and given fruitful input to the engineering processes. Now, 2005, the project has gathered enough knowledge to construct a 30 MW_{th} pilot plant for capture of CO₂. Parallel, the concept studies for a 250 MW_{eI} demo plant continue.



Time schedule, location and operation

Engineering of the 30 MW_{th} pilot plant started already in 2003. Applications for necessary permits are now (late spring 2005) written and negotiations with the authorities have started. According to the plans the construction can start 2006, and operation is scheduled to start mid 2008. The initial testing programme will run for three years and thereafter the pilot plant will be available for other tests. The plant is believed to be in operation for at least 10 years.

The pilot plant will be located near-by the existing lignite fired 1,600 MW_{el} power plant in Schwarze Pumpe, Germany. The pilot plant will be decommissioned when there are no more needs for further tests at the lower 30 MW_{th} scale.

Lignite and bituminous coal will be combusted in a mixture of oxygen and re-circulated captured carbon dioxide, which also contains water vapour. The non-re-circulated captured carbon dioxide will first be transformed to a liquid and then initially be released to the atmosphere. The captured carbon dioxide from the pilot plant will have the right properties to be transported and permanently stored deep underground.

The air separation equipment that is going to be used at the pilot plant is commercially available. It is not optimised for the oxyfuel process and is therefore too expensive to be used in the commercial concept that is the aim for the project. However, it fulfils the purposes of the pilot plant.

At this stage of engineering the pilot plant is considered to produce steam that can be utilised in the existing near-by power plant or the industrial park process steam network. However, the main purpose for the pilot plant is not to produce electricity, but to verify and validate all knowledge of the technology and to establish solid design criteria for a large plant.

Emissions

Initially there will be emissions to air from the pilot plant. However, they will be very small. Emissions of sulphur and particulates will be lower than in any commercial boiler plant. Sulphur and particulates will correspond to a few ppm in a conventional plant.

At present Vattenfall investigates in several optional storage sites for the captured carbon dioxide together with the EU funded projects CO₂SINK and CO₂STORE. Once the captured carbon dioxide is transported away and stored underground there will be almost no emissions to air. Particulates, nitrogen oxides and sulphur dioxide will all be captured together with carbon dioxide and then removed for further treatment.

ENCAP - ENhanced CAPture of CO₂

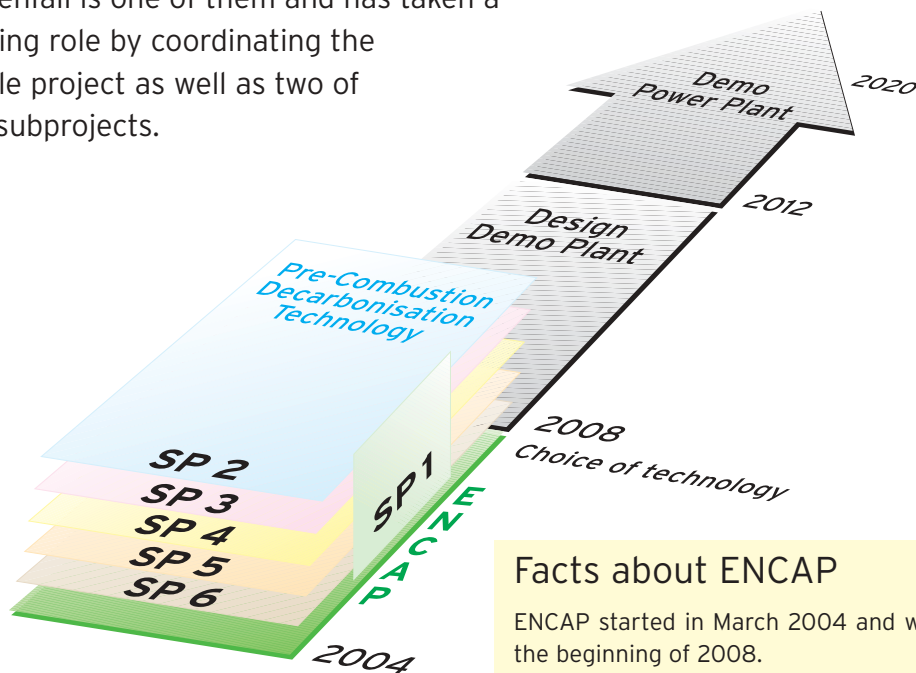
ENCAP is one of the projects partly funded by the European Commission that Vattenfall is involved in. The main objective is to develop new pre-combustion technologies and processes for CO₂-capture for power generation based on fossil fuels.

The technology needed for capture and storage already exists, however on a smaller scale and for other applications. Therefore, the costs for large-scale applications are still too high to be economically feasible. The technologies for capture have a greater potential for further development than the technologies for the storage of CO₂. ENCAP aims at technologies that meet the target of at least 90 per cent CO₂ capture rate, with a 50 per cent cost reduction, compared to today's technology.

The ENCAP project is divided into six subprojects that study different pre-combustion technologies for CO₂-capture. The work is also separated into two phases and the first phase is due to end this autumn. It will then be decided which technologies are worth further studies and which can be regarded as less interesting for the specific task. On the next page you can read more about the sub-projects and the technical development within them.

ENCAP involves many participants across Europe.

Vattenfall is one of them and has taken a leading role by coordinating the whole project as well as two of the subprojects.



Facts about ENCAP

ENCAP started in March 2004 and will proceed until the beginning of 2008.

ENCAP has a total budget of 22 million €, of which 10.7 million € are provided by the European Commission and the rest from the participating partners.

The following participants are involved in ENCAP:

Energi E2, RWE Power, PPC, Statoil, Vattenfall, ALSTOM, Siemens, Mitsui Babcock, Linde, Air Liquide, Lurgi, BOC, DLR, CERTH/ISFTA, TNO, IPF, SINTEF, Chalmers, NTNU, University of Paderborn, University of Stuttgart, University of Twente, University of Ulster.

SP1: Process and Power Systems

The first subproject (SP) has an overall responsibility towards the other SPs. Guidelines regarding methodology and prerequisites have been established by SP1 in order to enable a final comparison of the different technologies developed within the other SPs.

Another objective of SP1 is to consider the impact of CO₂ pre-combustion capture on human health, the environment and safety aspects.

Vattenfall manages SP1.

SP2: Pre-Combustion Decarbonisation Technologies

Using almost pure oxygen and steam, natural gas can be separated into CO₂ and H₂, hydrogen gas, where the latter is combusted in gas turbines for electricity production while the former is removed. This so called IRCC (Integrated Reforming Combined Cycle) process has its analogue for solid fossil fuel in the IGCC (Integrates Gasification Combined Cycle). These two processes are being investigated in SP2 concerning the possibility of using the technologies for pre-combustion CO₂ capture.

SP3: OxyFuel Boiler Technologies

In the OxyFuel process, the fossil fuel is combusted with almost pure oxygen mixed with recirculated flue gas. The recirculation serves to moderate the combustion temperature. The resulting flue gas from the OxyFuel process is a practically pure stream of CO₂ and water, where condensing easily can separate the water.

Challenges involved with the OxyFuel process are to find ways to improve the overall electrical efficiency of the plant. This can, for example, be done using new technologies for oxygen separation and ways of recovering the low temperature heat in the process.

Vattenfall manages SP3.

SP4: Chemical Looping Combustion

Chemical looping is a combustion technology where the fuel and combustion air never really come into contact and thereby the CO₂ is automatically separated and no formation of nitrogen oxides takes place.

This technology is being further investigated in SP4 in order to develop a concept for CO₂ capture.

SP5: High-Temperature Oxygen Generation for Power Cycles

SP5 investigates promising oxygen generation process options that could be further developed for possible use in the power plant processes of SP2 and SP3. The technologies available today for oxygen generation are expensive and if the cost for this part of the process could be cut, the whole concept of CO₂ capture would take a large step closer to implementation.

SP6: Novel Pre-Combustion Capture Concepts

The work in SP6 focuses on new, emerging technologies for pre-combustion capture in order to evaluate the potential for capture at a low cost. The research follows a vertical, three-step approach by screening, modelling and verifying new technologies.

Interview with the co-ordinator of ENCAP

Vattenfall co-ordinates the work within ENCAP and the assigned co-ordinator is Leif Brandels, who works at Vattenfall Utveckling in Råcksta, Stockholm. *Bridging to the Future* met him to talk about European co-operation, administration and visions.



The conversation began with Mr Brandels giving us an insight into the work of the co-ordinator and it became clear that there is quite a lot of administrative work to be done. The co-ordinator is responsible for legal documents, such as

the Consortium Agreement between the 28 ENCAP legal entities and the contract with the European Commission. Progress reports from the sub-project leaders have to be collected and reviewed once every quarter. Organising meetings for the General Assembly once a year and the Executive Board twice a year is also part of the assignment. The General Assembly consists of all the participating partners of ENCAP, whereas the Executive Board is a smaller group consisting of nine of the ENCAP partners. Decisions regarding budget issues, SP direction and other tactical questions are made within this group. The co-ordinator is also responsible for the communication between the project partners and the European Commission.

As ENCAP involves many partners in countries across Europe and the group therefore is very heterogeneous, this communication does not always run as smoothly as could be wished. The amount of reports that have to be read is also sometimes huge. At the moment, a number of deliverable reports from every sub-project manager have to be sent in, as the whole project will soon be moving on to the next phase. The R&D work has now been accomplished on a broad basis, but this autumn a decision will be made about which technologies are worth continued research. The European Commission needs extensive material in order to make this decision, and as the co-ordinator is the link between the Commission and the ENCAP partners and a part of the Project Management Team, it is his job to read and review all 30 technical reports.

We continued our talk by asking whether it is worth all the effort; for Vattenfall, the partners across Europe and for technical development. European projects of this size do involve an extensive amount of administration, but Leif Brandels strongly believes that it is worth it. For Vattenfall the answer is clear, the company is put on the map on this issue, both in relation to the Commission and to competitors and collaborators across Europe and also outside the continent. Competitive technical rese-

arch is the core of Vattenfall's work, but the co-ordination work is also a part of the project and must be done.

He also believes that technical development can definitely benefit from this type of project. As the work, information and results are performed and integrated in a project by RTD (Research and Technology Development) providers, manufacturers and power companies, a technology can develop at a higher speed. Other advantages of European projects are the important contacts between the partners that can lead to other co-operation opportunities and business possibilities.

The conversation ended with a discussion regarding visions. Are there any visions left in the work or have they all been lost along the way? Mr Brandels believes that the European Commission has its visions about the development for clean coal power and the secure supply of electricity with low emissions. The development of CO₂ capture and storage technologies is one part of this and the European Commission seems to be managing, through its support to research programmes, to put Europe in a strong position. Although the way forward is not always easy and smooth, the results will hopefully be worth it.

The ENCAP project identification mark is pictured below. More information about the progress of the project can be found at www.encapco2.org



European conference on CO₂ capture and storage

On April 13-15, the conference "Towards the Zero Emission Power Plant" was held in Brussels. The conference was hosted by the European Commission.

More than 30 speeches were held on policy perspectives, industrial perspectives, advances in technologies, international aspects, market conditions, public dialogue and, finally, strategy and future work.

Representing Vattenfall, Lennart Billfalk spoke about the company's view on CO₂ capture and storage and how it fits into Vattenfall's overall strategies. Marie Anheden, Vattenfall Utveckling, reported on the state of CO₂ capture technologies development. Prof. Lars Strömberg, project manager of Vattenfall's CO₂-free power plant project, opened and closed the conference as chairman of the organising committee. Lars Strömberg also gave a speech on the market base for introducing CO₂ capture and storage technologies in Europe.

European Commissioner believes in CCS

At the opening session, the European Commissioner for Energy, Andris Pielbalgs, as well as representatives for the Commissioners for the environment and research, all stated a common view on how Europe should tackle the climate change issue. Pielbalgs told the meeting that CCS, Carbon dioxide Capture and Storage, "must be an EU goal" and that Europe should take the lead in developing the technology.

In his speech, Pielbalgs listed the Commission's priorities for energy R&D. CO₂ capture and storage and clean-coal technologies top the list, which he explained by referring to the importance of meeting the Kyoto obligations and the challenges of the Lisbon agenda (the EU's programme for improving Europe's economic competitiveness). Pielbalgs also stressed that the EU's ability to convince the developing countries to address climate change will depend on our ability to demonstrate that technology for emissions control, combined with economic growth, exists and can be developed.

The Commissioner will, however, not solely concentrate on fossil-based heat and power, and both energy efficiency and the continued support of renewable energy hold top positions among his six key energy priorities.

Read the whole speech at:

<http://europa.eu.int/rapid/pressReleasesAction.do?reference=SPEECH/05/221>

Source: Environment Daily 2005-04-20

Opportunities and Challenges in Oxyfuel Combustion

A paper with the above title was presented by Vattenfall at the 7th International Greenhouse Gas Control Technology Conference arranged by the IEA Greenhouse Gas R&D Programme. The paper describes the reasons why Vattenfall considers oxy-fuel combustion to be one of the most promising alternatives for CO₂ capture from coal-fired plants. The main opportunities identified are that the technology builds on existing boiler and steam turbine technology making it possible to take advantage of the ongoing activities to increase the efficiency of steam turbine plants, reach very high CO₂ capture rates, decrease the boiler heat losses and possibly reduce the investment required for the boiler and the flue gas cleaning equipment. The challenges are mainly related to finding ways of improving the overall electrical efficiency of the plant by finding new technologies, e.g. for oxygen separation, and ways of recovering the low temperature heat in the process and optimizing the flue gas treatment and CO₂ processing to meet CO₂ quality requirements and environmental standards. The paper can be downloaded from the conference website,

<http://uregina.ca/ghgt7/PDF/papers/peer/054.pdf>

Cost analysis of transportation and storage of CO₂

Vattenfall's financial target for the CO₂-Free Power Plant project is to develop a concept at a total cost of 20 €/tonne CO₂. The cost for CO₂ capture is the main part of the estimated total cost. Capture is also the technical element that has the largest potential for improvement, while the transportation and storage of CO₂ is often referred to as known technology. The cost for transportation and storage is still a critical factor for the commercialisation of Carbon dioxide Capture and Storage, CCS.

In two case studies performed in connection with the EU-funded CO₂STORE project, the transportation and storage costs have been analysed in detail. The objective of the studies has been to serve as an illustration of how a future CCS system could come about. The subject for the transportation analysis was a virtual pipeline with a transported amount of 10 Mt CO₂/y. The fictive but realistic route runs between the Vattenfall-owned power plant Schwarze Pumpe and the saline aquifer structure at storage site at Schweinrich and has a total length of 320 km. Flow simulations have shown that a pipeline diameter of 800 mm is sufficient. The total transportation cost is estimated to be below 4 €/tonne CO₂ using a fixed yearly instalment calculation method with 25 years depreciation at an interest rate of 7.5 per cent.

The storage costs have been analysed using the computer software developed within the European R&D project GESTCO: the GESTCO Decision Support System. The software was developed to meet a need to evaluate the technical and financial

feasibility of CO₂ storage. The analysis gave a storage cost of approximately 1 €/tonne CO₂ for an injection rate of 10 Mt CO₂/y at the Schweinrich structure using a net present value method. The analysis also shows that the financial calculation method and chosen boundaries for the study by far create the largest differences in total costs, which makes it difficult to compare different cost studies in the literature with each other.

Looking at the total cost for transportation and storage, the storage part accounts for about 1 € and transportation for about 4 €. This gives a total cost of approximately 5 €/tonne CO₂, and thus leaves a financial target for CO₂ capture of 15 €/tonne CO₂.

Greenhouse Issues

Vattenfall is playing an active part in the case study of the potential German storage site at Schweinrich, which is included in the European CO₂STORE project. The ongoing work and results from the case study have been published in number 76 and 77 of the IEA Greenhouse Gas R&D Programme newsletter "Greenhouse Issues". The newsletters are available at:

<http://www.ieagreen.org.uk/ghissues.html>

Further information about the CO₂STORE project is available at:

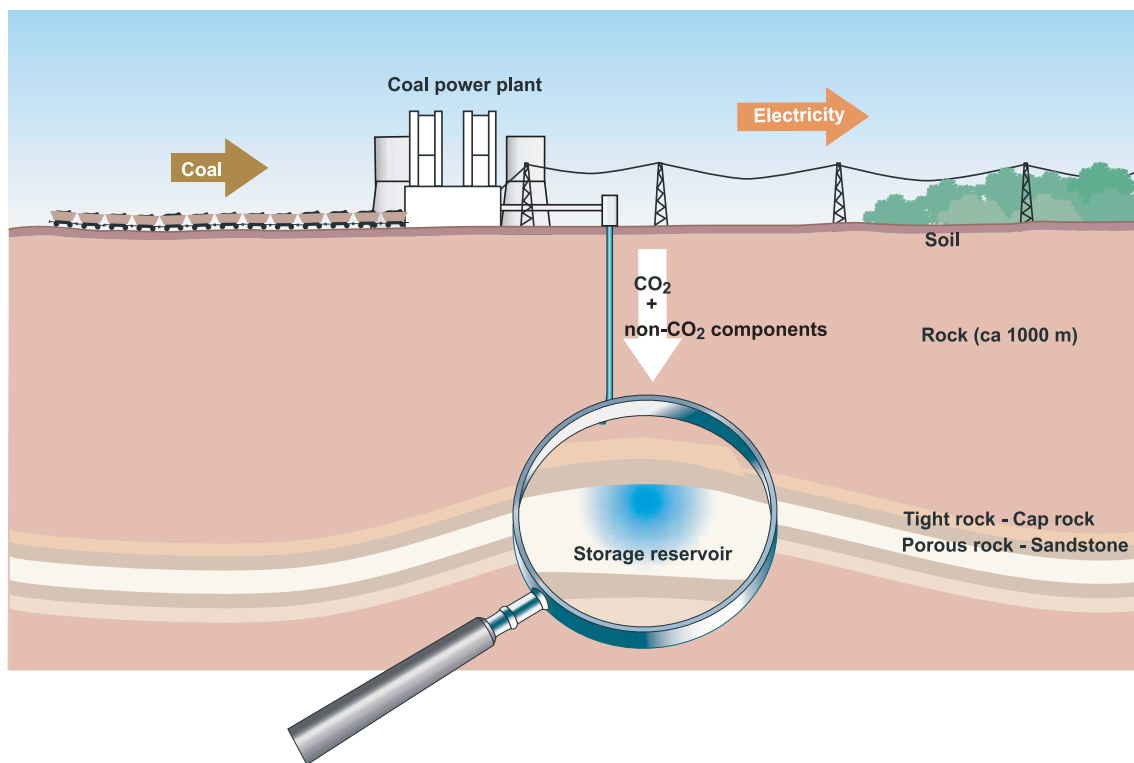
<http://www.co2store.org/>

What are the CO₂ quality requirements?

An important but not very well studied aspect in the analysis of a system with CO₂ capture, transport and storage is the quality requirements placed on the captured CO₂, i.e. the concentration limits for the non-CO₂ components present in the stream sent to the storage site. The CO₂ quality requirements are defined by limitations set by CO₂ transport, storage, safety and environmental regulations. This aspect could be seen as both an opportunity and a risk and could have a direct influence on the cost of CO₂ capture and storage:

An opportunity to co-capture other main pollutants from power plant operations such as SO_x and store them together with the CO₂. Thereby, a concept with near zero emissions could be created and, in addition, costly and energy-demanding flue gas cleaning equipment could be excluded.

A risk that components other than CO₂ in the captured stream could have a negative effect on the transport and storage system, both from a technical and environmental and health point of view, and therefore need to be removed. Stringent requirements are however likely to induce high costs for the cleaning of CO₂.



Vattenfall has in an internal study taken a systematic approach to:

- Evaluate possible components present in the captured CO₂ stream and their approximate levels.
- Summarize the present knowledge of what components could be of concern and for what reason and, when possible, identify a maximum acceptable concentration level.

The results of this initial investigation show that further investigations of the CO₂ specification, especially from the transport, storage and environmental points of view, is needed in order to understand the impacts and limitations of various impurities on different procedures of CO₂ capture and storage. However, even with this uncertainty, CO₂ quality demands for hypothetical CO₂ capture-transport-storage scenarios have been suggested. These scenarios have been further discussed and developed with the partners in the European ENCAP project and now form the basis for the guidelines for CO₂ quality requirements used in the ENCAP project.

The next newsletter will be distributed in
November 2005