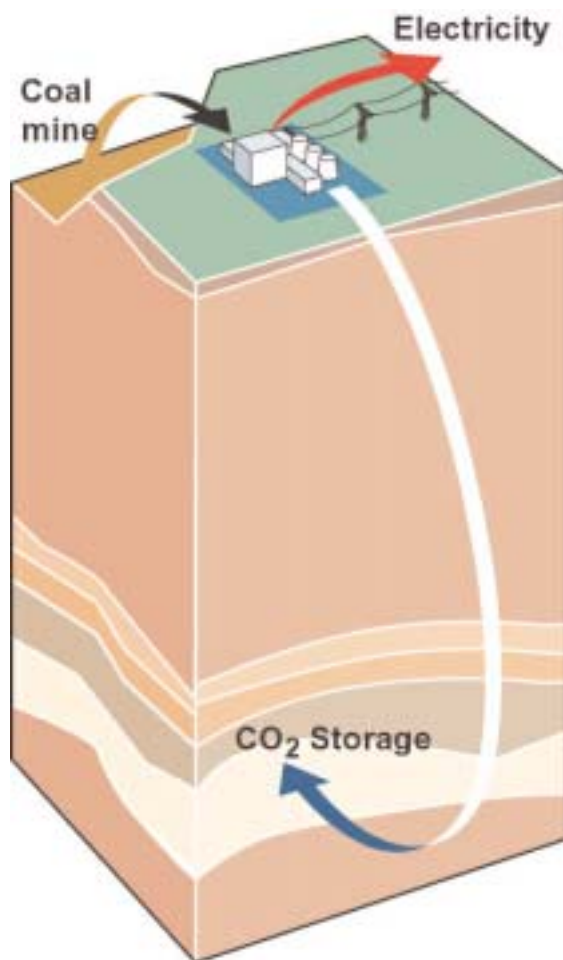


BRI DGI NG TO THE FUTURE



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From the content:

- Presentation of the Vattenfall CO₂-free power project
- First phase of oxyfuel combustion experiments completed
- The assessment of German CO₂ storage potential in deep saline aquifers
- Presentation of CO₂-related projects partly funded by the European commission.

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

Vattenfall's Executive Vice President in R&D, *Lennart Billfalk*:

"The world today depends on fossil fuel for its energy supply, and will do so for quite a long time. In order to bridge over to the future, when the dependence on fossil fuels is replaced by renewable technology, Vattenfall has started a large R&D project, CO₂-free power plant. The project focuses on capture and storage of carbon dioxide, CO₂, from coal fired power plants. The purpose is to achieve secure and feasible technologies for an almost complete elimination of CO₂ emissions and thereby be able to produce clean electricity until the day comes when fossil fuels can be fully replaced!"



Dr *Lennart Billfalk* is Executive Vice President and Head of Group Function Strategies. Group Function Strategies has responsibility for strategic planning, environmental planning and R&D among others.

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 him at:

lars.stromberg@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 put a lot of effort into the CO₂-free power plant project, as the technology is one of many ways of reducing emissions of CO₂. Capture and underground storage of CO₂ is a way to bridge over to other, renewable technology.

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

- Capture, where three main approaches for CO₂-separation have been identified; post-combustion capture, pre-combustion capture and oxygen combustion.
- Storage and transport, that 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, that focuses on any environmental problems involved with 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 *Åse Myringer* at ase.myringer@vattenfall.com

The CO₂ free power plant project

There is a need for more renewable energy sources and more efficient energy systems to meet the targets in the Kyoto Protocol. But to change Europe's energy system will take time, as it today is based on 80 % fossil fuel. Vattenfall runs several projects resulting in decreased CO₂ emissions. Most of Vattenfall's fossil based power plants are modern with high conversion efficiency and several are combined heat and power plants. Further investments in modern plants are made to replace or upgrade older plants. Swedish and Finnish heating plants are converted to use biofuel instead of coal and oil. Vattenfall is Sweden's largest generator of electricity from wind power. Vattenfall also runs and participates in joint venture research, development and demonstration programmes.

One way of avoiding emissions of greenhouse gases, while still retaining fossil energy production, is to capture and store carbon dioxide, CO₂, in underground geological formations. In 2003 Vattenfall started a large R&D project to develop the technique into environmental, social and economical sustainability. The project is called CO₂-free power plant and will be conducted in Sweden and Germany. Important input will come from joint EU-funded projects involving several possible end-users and technology providers, all over Europe.

The CO₂-free power plant project consists of three subprojects:

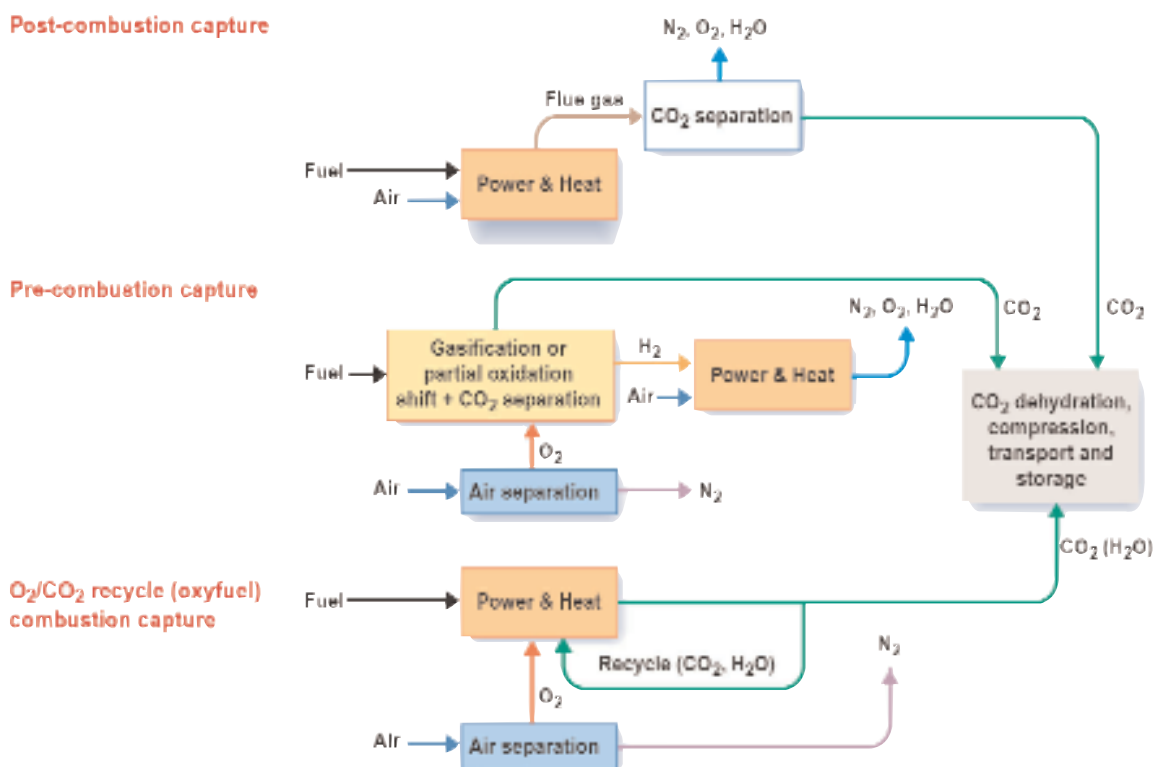
- Capture: Development of concepts and technologies to make CO₂ capture more efficient and less costly.
- Storage and Transport: Investigations of CO₂ storage options in deep saline aquifers or old oil and gas fields. Investigations of long-term effects, safety and transportation of CO₂.
- Environment: Investigations of any environmental problems that could occur due to capture, storage and transport of CO₂.

Capture

CO₂ only makes up a small part of the flue gas emitted from a power plant. Typically, flue gases emitted from power plants contain about 3-15 % of CO₂, depending on fuel and power plant process. In order to store only the CO₂, some method to separate it from the other flue gas constituents is needed. Three different approaches for CO₂-separation have been identified:

1. The flue gas approach or post-combustion capture where CO₂ is separated from the power plant flue gas
2. The hydrogen/syngas approach or pre-combustion capture where fuel, coal or natural gas is processed to produce a gaseous fuel consisting of mainly hydrogen and CO₂. The CO₂ is then separated from this mixture before the hydrogen is combusted in the power plant. Combustion of hydrogen results in a flue gas consisting of water vapour only.
3. The O₂/CO₂ recycle (oxyfuel) combustion capture approach including technologies where the nitrogen is excluded from the combustion of the fuel, resulting in a flue gas with CO₂ and water vapour as main components. It is then easy to further concentrate this mixture to get an almost pure CO₂ product stream.

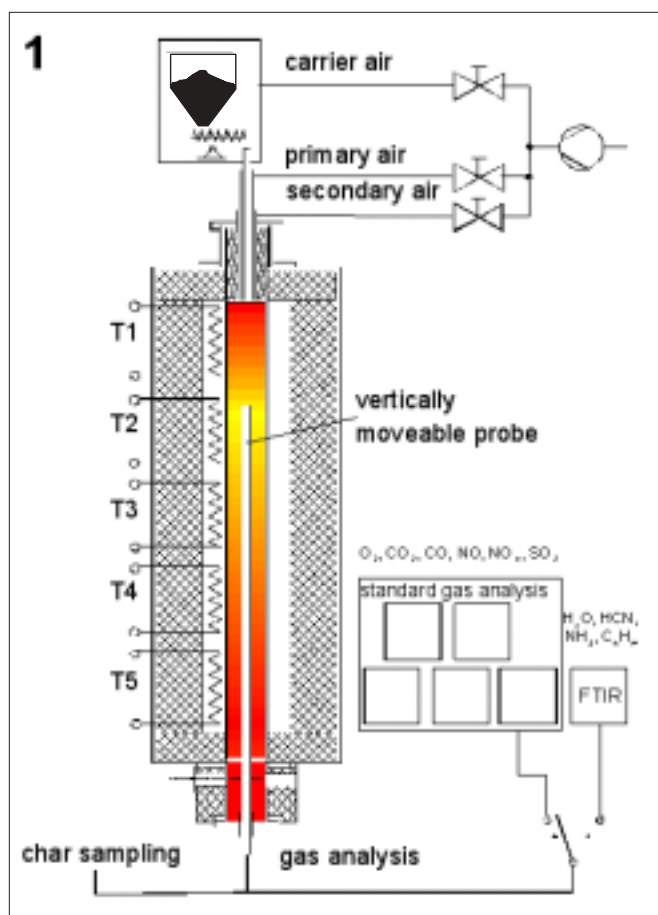
Capture is the technical part that has the largest potential to improve and that is why Vattenfall has agreed to take the lead in the EU-funded ENCAP project. More information about ENCAP is to be found further below in this newsletter.



Three approaches for CO₂-separation.

FIRST PHASE OF OXYFUEL COMBUSTION EXPERIMENTS COMPLETED

The first phase of the co-operation between Vattenfall, the University of Stuttgart (IVD) and Chalmers University of Technology in Gothenburg, Sweden, to experimentally investigate oxyfuel combustion for CO₂ capture was completed in early 2004. The objectives of the co-operation were to get a first set of experimental data on combustion behaviour under oxyfuel conditions and to see the difference compared to combustion in air. The collected data has been used to validate and develop CFD modelling tools that are being used within Vattenfall for boiler evaluations. The work has provided a first valuable insight into the difference in behaviour between combustion in air and



combustion using pure O₂ in an environment consisting of mainly CO₂. For instance, a high local concentration of CO has been measured in the combustion zone, which might have implications on the NO_x formation. This will be further investigated in upcoming experiments. It has also been able to identify sub models in the modelling tools and some parts in the experimental facilities that need improvements. However, most importantly it has brought together a number of persons active in different scientific and engineering disciplines to discuss and work on a common topic. The work performed will give a good foundation for continued future co-operation between the partners within the ENCAP project.

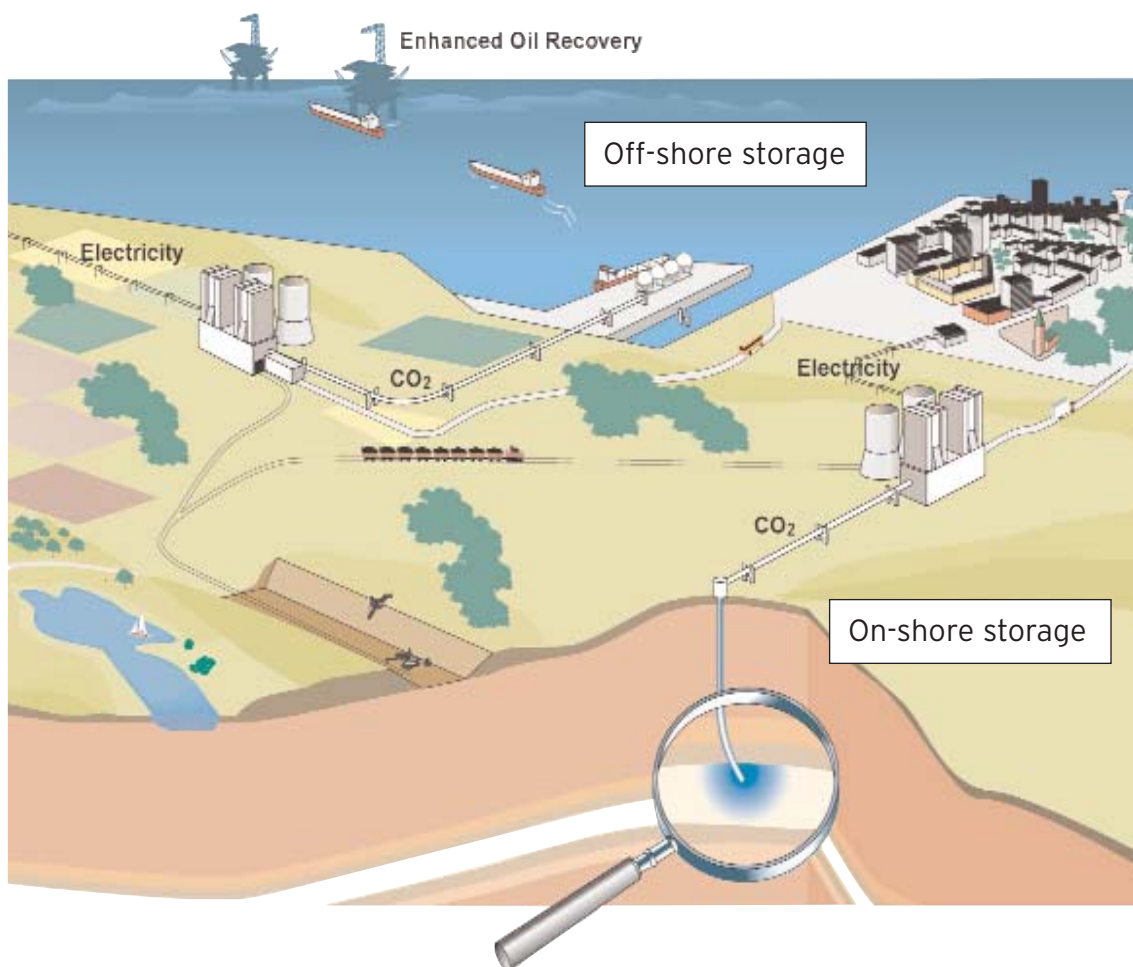
The project continues with a second phase that, preliminarily, will focus on the closer investigation of gas-phase reactions and radiation. The present plan is to also include experimental work at the gas-fired oxyfuel test rig at Chalmers University of Technology.

Storage and Transport

Initial work in the project shows that the ability to store CO₂ in Europe seems to exceed the amount of fossil fuels available, which gives a good base for the CO₂-free power plant project. The work for storing CO₂ is focused on three case scenarios:

1. on-shore geological storage nearby the power plant
2. on-shore geological storage on far distance from the power plant somewhere in Europe
3. off-shore, under the sea bottom, storage in the North sea

A full CO₂ capture and storage system must handle CO₂ from several plants and it is therefore important to have a safe and effective way of transporting large amounts of CO₂. Needs, possible solutions, costs and other conditions for transport are now to be identified.



Different scenarios for transport and storage of CO₂.

THE ASSESSMENT OF GERMAN CO₂ STORAGE POTENTIAL IN DEEP SALINE AQUIFERS

The total CO₂ emissions in Germany are about 850 million tonnes annually, of which roughly 40 % originates from heat and power supply. The storage capacity of depleted gas fields can, based on gas production figures and remaining reserves, be reasonably well calculated at 2,600 million tonnes. Clearly, this capacity is small in comparison to the annual emissions and does not motivate investments in the technology.

The complementary option is deep saline aquifers. However, in contrast to gas fields, estimates of storage capacity of aquifers are subject to preconditions and assumptions that impose a larger range of uncertainties on these estimates. The national estimate that is valid today was arrived at in the European project GESTCO, finalised in 2003. It covers the storage capacity in traps of deep saline aquifers onshore Germany, giving an estimate of 33 Euro 10 billion tonnes CO₂.

The process of increasing the knowledge of the storage potential continues. This work includes estimates for geological or geographical objects of different size scales, i.e. local, regional and national.

STUDY ON STORAGE SITE IN GERMANY

In March 2004, a study, performed at UGS1 in Germany, on possible storage sites for CO₂ emitted from a demonstration plant in Lusatia was finalised. The area of investigation was Central and Southern Brandenburg. In this region, all potential aquifer structures as well as oil and gas fields had to be evaluated to find a suitable site capable of storing about 10 million tonnes of CO₂. Additionally, alternative transport concepts had to be proved. The study shows that there are several suitable options for storing that much CO₂ in the target region. However, before a decision on the best choice can be made, all the criteria (geology, transport routes, conflicting interests, costs etc.) have to be evaluated very carefully.

Environment

LOCAL ENVIRONMENTAL ASPECTS OF CO₂ STORAGE

Capturing and storing CO₂ in geological structures, instead of emitting the gas to the atmosphere, is a project for the global environment. However, it is also important to remember the local environmental questions, for example human and animal health, clean soils and lakes, healthy fields and forests. New serious, local environment problems cannot be accepted, although the purpose is to reduce the consequences of a global one.

One important issue is to consider what effects a CO₂ leakage from e.g. pipelines or storage structures would have. A literature study has been carried out on how an increased concentration of CO₂ affects different organisms and ecosystems.

The study shows that basic knowledge about the effects of high CO₂-concentrations on various organisms and plants is available. Especially for humans, effects at different concentrations are well known. Some knowledge gaps exist concerning effects on microorganisms and fungi.

The sensitivity of soil, surface water, and fresh water to high CO₂-fluxes has been studied as well. One main conclusion is that these effects are highly site specific. If the quality of ground water and fresh water in river and lakes is known, evaluations of how these waters will be affected if CO₂ is released into them can be performed. Potential consequences are related to the risk of increased acidity in surface or ground water. How ecosystems deep in the ground are affected by an increase in CO₂-concentration is not known and the group has not found any studies on this topic.

Legal aspects and more

INTERNATIONAL LEGAL ASPECTS ON CARBON DIOXIDE STORAGE IN UNDERGROUND GEOLOGICAL FORMATIONS

In order to establish the consequences of international and EU law, a study has been conducted as a first step to cover this area. The study concludes that no international convention or agreement is directly applicable to carbon dioxide sequestration and storage in underground geological formations and the effects and impacts originating from it. Some of the conventions accounted for might, however, be applicable as the result of extensive interpretation.

The study gives an account of international conventions and EU directives that might have an impact on projects concerning CO₂ storage in geological formations onshore. These include conventions on climate change, transboundary air pollution, environmental impact assessment and EU directives on water, air, integrated pollution prevention and control and potentially waste.

The study emphasizes the importance of risk assessment and identifying the risks associated with normal operational circumstances and those associated with accidents. It is also important to identify what kind of accidents might happen and what impact they might have. The risk and environmental impact assessments will help in the evaluation and prediction of the future legislation applicable to CO₂ sequestration and storage.

PRESENTATIONS FROM VATTENFALL ABOUT CAPTURE AND STORAGE OF CO₂

During 2004 Vattenfall has been present at several national and international conferences and seminars, in order to discuss the CO₂-issue and to present progress within the CO₂-free power plant project.

As example can the GHGT 7, The 7th International Conference on Greenhouse Gas

Control Technologies, be mentioned. At the conference, that was held in Vancouver, Canada, over 700 delegates were present, of which 8 represented Vattenfall. Two presentations were held and three posters shown. For more information, see www.ghgt7.ca.

In September Vattenfall's General project manager for the CO₂-free power plant project Professor Lars Strömberg visited CSLF, Carbon Sequestration Leadership Forum, in Melbourne, Australia. CSLF is an international climate change initiative that is focused on development of improved cost-effective technologies for separation and capture of carbon dioxide. Prof. Lars Strömberg held two speeches during the conference. More information at www.cslforum.org.

Projects partly funded by the European Commission

The European Commission supports CO₂-related R&D projects and Vattenfall takes part in several of them.

	Aim	Vattenfall's role
ENCAP	Development of CO ₂ capture technologies that meet the target of at least a 90 % CO ₂ -capture rate and a 50 % cost reduction. More information is to be found at the website www.encapco2.org .	Vattenfall coordinates the whole project and has responsibility for two out of six subprojects.
CASTOR	Focuses on post-combustion capture technologies for CO ₂ and confidence building concerning storage.	Vattenfall takes an active part.
CO₂ SINK	In order to advance understanding on the area of CO ₂ underground storage, approximately 30,000 tons of CO ₂ are planned to be injected in an aquifer in Ketzin in eastern Germany.	Vattenfall is one of 14 European participants in this project.
CO₂ STORE	Experience from injection into the Utsira aquifer in Germany will be transferred to potential storage cases, among them a Vattenfall project in Germany.	Vattenfall takes an active part.
CO₂ NET	This European Network of researchers, developers and users of CO ₂ technology facilitate co-operation between the participants.	Vattenfall takes part as one of about fifty companies, universities and research institutes from 14 European countries.

ENCAP MOVES FORWARD FOR ENHANCED CAPTURE OF CO₂

ENCAP, ENhanced CAPture of CO₂, is one of the projects partly funded by the European commission that Vattenfall is involved in.

All technology needed for capture and storage already exist, however in 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 larger potential to be further developed, than technologies for storage of CO₂.

The aim of ENCAP is a 90 % CO₂ capture-rate at a 50 % lower cost than today. Vattenfall believes that this is a possible way to go, in order to bridge over to renewable technologies and has therefore agreed to take the lead in the ENCAP project. Vattenfall coordinates the whole project and acts as project leader in two out of six sub-projects.

The next newsletter will be a special feature issue on the EU-funded project ENCAP, with

- the latest development within the project
 - an interview with the coordinator of ENCAP
- and much more...

The next newsletter will be distributed in April 2005.

