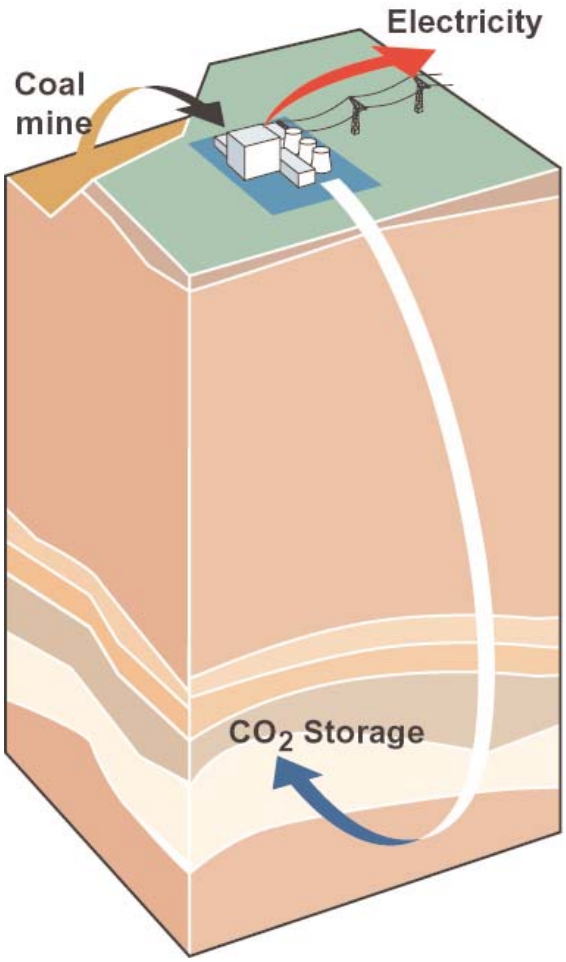
Vattenfall's newsletter on the CO_2-free power plant project

BRIDGING TO THE FUTURE



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From the contents:

VATTENFALL

WELCOME TO THE THIRD ISSUE OF BRIDGING TO THE FUTURE, THE NEWSLETTER ABOUT VATTENFALL'S WORK FOR CO_2-FREE POWER.

In May 2005 Vattenfall decided to build the world's first oxyfuel pilot plant for capturing fossil carbon dioxide. Today we are in the planning and permission state at the location Schwarze Pumpe, near-by the existing lignite fired power plant in eastern Germany. The client team for construction – eight engineers from Vattenfall in Sweden and Germany – is complete and in full operation. The ground-breaking ceremony for the 40 million Euro pilot project is planned for the second quarter of 2006 and will hopefully show Vattenfall's intention to be a responsible corporate group – in word as well as deed.

Markus Sauthoff

Markus Sauthoff, deputy project manager for the CO_2-free power plant project.

Project manager Prof. Lars Strömberg is legally responsible for this newsletter. If you have any questions about the 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 CO_2-free power plant project, as the technology is one of many ways of reducing emissions of CO_2. The capture and underground storage of CO_2 is a way of bridging over to other, renewable technology.

Vattenfall's CO_2-free power plant project consists of three subprojects:

- Capture, where three main approaches for CO_2-separation have been identified; post-combustion capture, pre-combustion capture and oxygen combustion.
- Storage and transport, which investigates the possibilities of storing CO_2 in deep saline aquifers or old oil and gas fields. Also includes investigations of long-term effect, safety and transportation of CO_2.
- Environment, which focuses on any environmental problems relating to CO_2 capture, storage and transport.

Vattenfall is involved in 5 EU-sponsored CO_2-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**

News in brief

ENCAP Latest news

On October 5th 2005, a technical seminar was held in Brussels to review the results of the first 18 months of work within ENCAP. The seminar was the start of the benchmark that will be finished just before Christmas this year. In the benchmark, the 2–3 most promising methods for pre-combustion and oxyfuel capture technology will be selected for further studies and large-scale testing.

ENCAP is a research project for the development of pre-combustion and oxyfuel technologies for ENhanced CAPture of CO_2 in large power plants. The project started in March 2004, is planned to run for five years and is partly sponsored by the European Commission. Vattenfall AB takes part of ENCAP as one of about 30 participants comprising large European fossil fuel end users, universities and RTD providers.

Vattenfall's CEO wins award as "TIME European Hero 2005"

In its Oct. 10 issue, TIME Magazine features Vattenfall's CEO Lars G Josefsson among their TIME European Heroes 2005. The magazine acknowledges Mr Josefsson's global lobbying efforts encouraging the business community to take action for mitigating climate change.

"Through a mixture of high-profile public diplomacy and corporate example, he's on a mission to persuade his peers around the world that they should take radical action on climate change", writes TIME's European correspondent Peter Gumbel.

Mr Josefsson's fellow heroes are celebrities such as pop stars Bob Geldof and Herbert Grönemeyer, filmmaker Pedro Almodovar, or French footballer Thierry Henry. TIME calls their heroes "extraordinary people who illuminate and inspire, persevere and provoke. They take on challenges the rest of the world often prefers to avoid, reminding us all just how much a single person, even in the face of adversity, can accomplish".

Read more on www.time.com/time/europe/hero2005

Environmental impacts of carbon dioxide storage

Experience from natural analogues, such as hydrocarbon reservoirs, show that carbon dioxide (CO_2) can be geologically stored for a very long time (thousands of years). The storage of CO_2 is expected to have a very limited impact on the environment when the concept works according to plan. What remains is to demonstrate that for a chosen storage site, the storage concept will work according to plan. This is a challenge, since the storage time frame comprises several thousand years. Through modelling and studies of natural analogues, very good predictions can be made, but it is also important to consider the potential consequences in the event of a leakage so that no aspects are overlooked.

The main concerns relating to the leakage of CO_2 from an onshore storage reservoir are the risk of changing the groundwater composition and the risk of exposing humans or animals to hazardous levels of CO_2. Carbon dioxide in its normal sense is not considered to be a pollutant or a hazard. The air naturally contains just under 380 ppmv of CO_2, humans and animals exhale CO_2 when breathing and it is an essential part of photosynthesis.

If released into the open atmosphere, the gas would normally be readily dissipated by the wind and not reach hazardous concentrations. Being heavier than air under atmospheric conditions, CO_2 can accumulate in sheltered spaces and depressions, such as caves and the basements of houses, and pose a threat to humans and animals. Through appropriate site selection, monitoring and other measures, these risks can be avoided.

Human health and safety effects due to elevated CO_2 concentrations are relatively well known. Knowledge on the effects of CO_2 at different concentration levels also exists for many individual organism groups, but there is very little information available about impacts at an ecosystem level. The potential impact on marine ecosystems and organisms, relevant for offshore storage in reservoirs deep under the seabed, also requires further research. It is important to be able to answer questions of concern and to have all the information required to make informed decisions. Vattenfall is working actively to fill the gaps in knowledge.

Vattenfall's approach to assessing environmental issues

A Strategic Environmental Assessment (SEA) framework is used to assess the environmental impacts of CO_2 capture, transport and storage. SEA is a systematic process for evaluating the environmental impacts of proposed policies, plans and programmes. Vattenfall uses the SEA methodology to analyse and evaluate technical alternatives for CO_2 capture, transport and storage from an environmental perspective. Before commencing a CO_2 capture and storage project, it is important to consider all aspects of potential environmental impacts that may occur, both during normal operations where the concept works according to plan, and in case of a leakage. The SEA framework ensures that the environmental assessment is comprehensive and that all potential aspects are taken into account.

In the SEA, the identification and prediction of potential environmental effects relating to different technical alternatives are included. The work is divided into four study areas:

- Environmental analysis of potential consequences of increased coal mining due to the increased energy requirements of carbon dioxide capture and compression
- Environmental analysis and comparison between power plant alternatives with and without carbon dioxide capture technology
- Environmental analysis of potential consequences related to carbon dioxide transport
- Environmental analysis of potential consequences related to carbon dioxide storage

The potential consequences of the carbon dioxide capture and storage concept and of using different technical alternatives are evaluated in order to determine the potential impact on environmental objectives. The consequences of doing nothing at all, and the consequences of using other alternatives for climate change mitigation, must also be considered.

The CO2STORE project: Results from the Schwarze Pumpe/Schweinrich study

Vattenfall participates in the European research project CO2STORE (www.co2store.org). The project has included the theoretical evaluation of four different field cases. This article presents results from the German field case, the evaluation of the potential CO_2 storage site structure Schweinrich, which is situated 100 km northwest of Berlin. The project is scheduled to end in January 2006.

Purpose of the study

The purpose of the study has been to discover, evaluate and characterise a saline aquifer in Northeast Germany that could be used to store more than 400 million tonnes of CO_2. This corresponds to the CO_2-emissions of a modern, lignite-fired power plant like the 1,600 MW Schwarze Pumpe, operated by Vattenfall, over an operational lifetime of 40 years.

Geological characterisation

In an initial survey, several suitable saline aquifers were identified. Subsequent to a ranking based on several geological and environmental criteria, the anticlinal structure Schweinrich was selected as the best candidate for further investigation.

The Schweinrich structure is situated right beneath the small village of Schweinrich, 250 km northwest of Schwarze Pumpe (see Figure 1). Within the structural closure, the saline water reservoir formations are located at depths between 1,300 to 1,800 metres below sea level. The structure has a lateral extent of about 100 km^2.

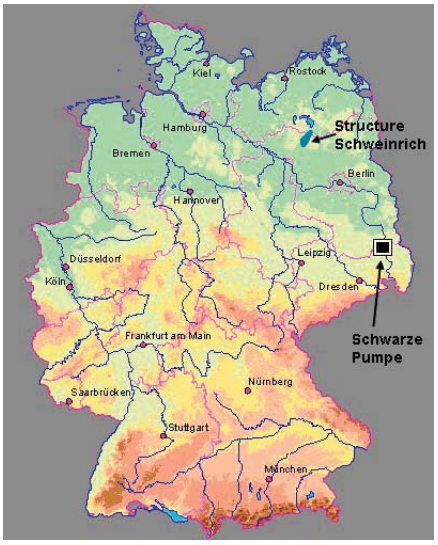

Figure 1. Location of the Schweinrich structure and the power plant Schwarze Pumpe. Courtesy BGR.

The Schweinrich structure holds two reservoir formations, predominantly fine-grained and well-sorted, highly-porous sand and siltstones of the geological time-scales lowest Jurassic (Hettang) and uppermost Triassic (Contorta). The cumulative gross thickness of both reservoir formations ranges between 270 metres in the west to 380 metres in the east.

In order to precisely calculate the storage potential, a geological 3D model has been created (Figure 2). Dependent on different geological interpretations, different scenarios have been taken into account to calculate the storage potential. Accordingly, the calculated storage potential ranges between 500 million tonnes of CO_2 for a low scenario and 840 million tonnes for a more optimistic case.

Thus, the Schweinrich structure would be able to store the CO_2 emissions from a large-scale power plant like Schwarze Pumpe.

Initial safety assessment

An important step in the site evaluation is the assessment of the long-term safety. For the Schweinrich structure, an initial safety assessment has been conducted. This has included the evaluation of features, events and processes (FEPs) that can influence the long-term safety and probabilistic modelling of possible risk scenarios.

Cost analysis of transportation and storage

Vattenfall's financial target for the CO_2 capture and storage concept is 20 €/tonne CO_2. The cost analysis performed for the Schweinrich case, including transportation and storage, shows that the total cost is approximately 5 €/tonne, which leaves a financial target for CO_2 capture of 15 €/tonne CO_2.

Regulatory conditions on CO_2 storage in saline aquifers

The regulatory framework for storing CO_2 in saline aquifers in Germany has been studied in connection with the CO2STORE project. The results from the study are presented in the article about legal issues on the next page.

Future interest in the Schweinrich structure

The results from CO2STORE show that the Schweinrich CO_2 storage site is still a very promising site. Vattenfall currently has no plans to progress this into a "real" storage project. Nevertheless, the site will be studied further from an R&D perspective, as it is an excellent site to learn more from.

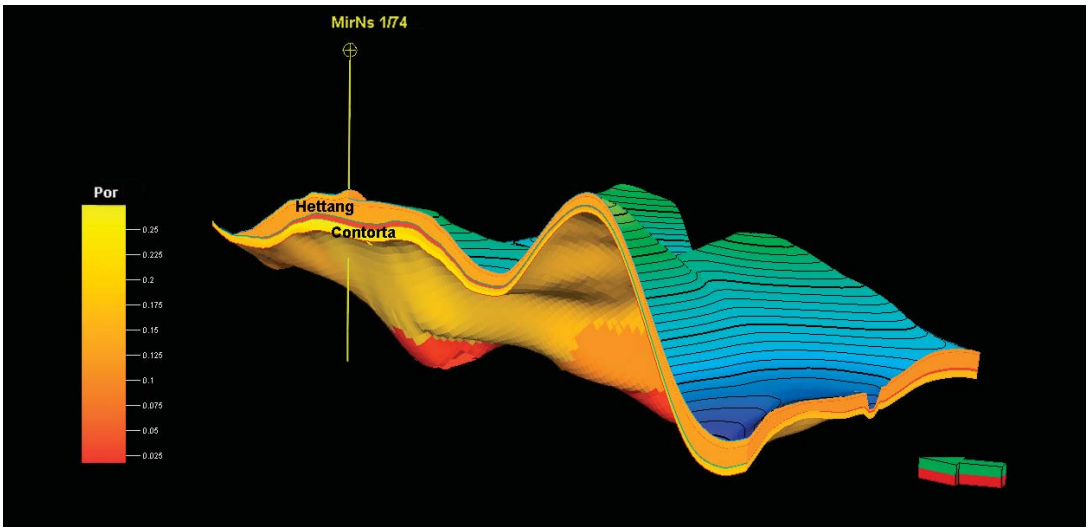

Figure 2. NE-SW trending cross-section through the anticlinal structure Schweinrich showing the porosity distribution of both reservoir formations (Hettang and Contorta). Courtesy BGR.

Legal Issues concerning the Underground Storage of CO_2 in Germany

General Legal Findings

As the option of storing CO_2 is a very new technology, the question arises whether there is a legal framework for this project and, if so, according to which provisions such a project can be permitted. Therefore, Vattenfall Europe Mining and Generation decided to conduct research into the legal issues concerning the underground storage of CO_2 in Germany.

As the natural conditions at the three different storage sites vary, different legal fields might be applicable to each of them so that they have to be examined separately. Nonetheless, there are some general legal findings on the underground storage of CO_2 that can be mentioned before the results for each storage option are presented.

The first general legal finding is that, although the German *Mining Act* provides that the storage of substances underground, irrespective of their physical state, is permissible, the storage of CO_2 does not fall within the scope of application of this provision. The reason for this is that "storage" requires, not only in this context but in general and everyday language, that the substance which is stored is used again at a later date. According to the considerations of the bill, this provision was mainly created to regulate the storage of natural gas to balance seasonal fluctuations in demand. It can be concluded that this provision of the *Mining Act* is not applicable to the permanent storage of CO_2.

Furthermore, a general legal question is whether CO_2 is to be considered as waste according to the German *Waste Act*, which is strongly influenced by the waste directive of the EC. As gaseous substances that are not kept in a receptacle do not fall within the scope of application of the *Waste Act*, only gaseous CO_2 that is put into a receptacle and supercritical CO_2 is waste according to the existing *Waste Act*. In this case, the CO_2 cannot be regarded as waste that requires specific monitoring for its disposal.

Finally, CO_2 is not supposed to be a substance that endangers the water.

Saline Aquifer

The gaseous or supercritical CO_2 might be injected into deep saline aquifers – porous sandstone formations with very salty water in its pore spaces. As a contact between the injected CO_2 and the salty water seems to be highly probable, the German *Federal Water Act* is applicable. According to the *Federal Water Act*, a project is permissible if it has no adverse effect on the quality of the groundwater in the saline aquifer. The effect of an activity on the groundwater cannot be based on general assumptions; moreover, it has to be proven for every particular case.

Here it has to be taken into consideration that the groundwater in the saline aquifer is, because of its high salt content, not useable for the drinking water supply, and it is probable that the aquifer is completely enclosed from the groundwater resources.

The drilled holes that are necessary for the injection of the CO_2 fall within the scope of application of the *Mining Act* if they reach deeper than 100 metres underground. The mining authority in question could therefore ask for a schedule of operation for this activity.

According to the German *Pollution Control Act*, a permit for the above-ground installation for compression is only required if it is a gas-operated installation with a capacity of 50 MW or more. In this case, an Environmental Impact Assessment (EIA), or rather preliminary research, has to be carried out as well. If the compression installation is operated by an electric motor, approval in accordance with this act is not necessary.

EOR/EGR

If gaseous or supercritical CO_2 is injected into active oil or natural gas fields in order to increase the pressure in the cavity and enhance the amount of produced oil or gas, it can be regarded as an acknowledged production measure and therefore falls within the scope of application of the *Mining Act*, which regulates the production of raw materials. According to the *Mining Act*, a schedule of operation and mining rights would be necessary. However, as the EOR/EGR (Enhanced oil/gas recovery) is a tertiary production measure these requirements may already be fulfilled.

Again, a gas-operated, above-ground compression installation requires a permit in accordance with the *Pollution Control Act*, and an EIA is necessary too. If contact with groundwater seems to be probable, a permit in accordance with the German *Water Act* is required and will be given if the activity imposes no adverse effect on the water.

Depleted Oil and Natural Gas Fields

In depleted oil and natural gas fields, the injection of the CO_2 does not serve EOR/EGR purposes so that the link to oil or natural gas production is missing and therefore the *Mining Act* is not applicable.

If the depleted oil or natural gas fields contain groundwater, again the *Water Act* with its above mentioned pre-requisites is applicable. If there is no water in the exploited oil and natural gas fields, the classification of CO_2 as waste has to be taken into consideration. According to the *Federal Waste and Recycling Act*, official approval of a plan for an underground dumping site would be necessary. Furthermore, depending on the capacity of the underground dumping site, an EIA would have to be conducted.

Again, the *Pollution Control Act* requires the gas-operated, above-ground compression installation to obtain a permit and an EIA might be necessary.

Conclusions

It can therefore be concluded that some legal fields might be applicable to the underground storage of CO_2 but there are no specific regulations in Germany as they, for example, exist for the underground storage of natural gas according to the *Mining Act*.

Step-by-step development towards a CO_2 transport and storage system in Germany

Previous newsletters have described how CO_2 captured from power plants can be transported on a large scale, primarily in pipelines, at a calculated cost level that is reasonable for a complete CO_2 Capture and Storage chain (CCS chain). Studies have shown that at a flow rate of 10 million tonnes/year and a distance of about 300 km, a cost level for transportation of about 4 €/tonne CO_2 would be achievable in Germany. Based on this, a continued scenario evaluation on possible power plant and storage locations, with accompanying transportation paths, is being performed.

To get to a large-scale system, a step-by-step development would be necessary. For the Oxyfuel pilot plant that will be built at Schwarze Pumpe, the CO_2 amount would be up to 66,000 tonnes/year, which is a too limited amount for a long pipeline but still a large amount to be transported conventionally (road, train). Road trailers would provide the highest flexibility to the pilot project, and almost scaleable transport costs. The proposed dedicated CO_2 trailers from Cryo AB hold a tare weight of 9 tonnes and have a possible payload of 24 tonnes (refrigerated liquid CO_2) for traffic in Germany. Trailer transport costs for a distance of 200 km (400 km roundtrip) would be in the range of 20–25 €/tonne CO_2 (at cost level date May 2005). An option would be to transport CO_2 from the pilot plant to the R&D storage project CO2SINK at Ketzin, northwest of Berlin.

The investigation company UGS has, at the request of Vattenfall Europe, studied if and how a stepwise development of a pipeline network could be built up in the region south of Berlin (southern Brandenburg and northern Saxony). The preliminary conclusion is that it would be feasible to create a pipeline network, with a trunk pipeline and distribution pipelines connecting several potential storage sites and potential locations of power plants with CO_2 capture, within this region. The preliminary study says that such a CCS-system could be built up and operated in the region in four operational periods from 2015 to 2045.

Successful research on oxy-fuel combustion

On the 7th of June 2005, Klas Andersson, a PhD student at the department of Energy and Environment, Chalmers University of Technology, Göteborg, presented his licentiate thesis entitled "Carbon Capture from Fossil Fuel Power Plants using the O_2/CO_2 Recycle Combustion Process". The work has partly been funded by Vattenfall AB, and Professor Lars Strömberg, project manager of Vattenfall's CO_2-Free Power Plant Project, has acted as assistant supervisor to Klas Andersson. Filip Johnsson, Professor at the department of Energy and Environment at Chalmers, is the head supervisor of the project.

As the title of the thesis reveals, the O_2/CO_2 recycle combustion process has been studied. In this process, also referred to as oxy-fuel combustion, the fuel is combusted in pure oxygen and recycled flue gases in order to reach a high CO_2 concentration in the flue gas product for subsequent storage in e.g. deep saline reservoirs. A high flue gas recycle rate, about 70 per cent of the flue gas product, is necessary in order to reach similar combustion characteristics as for normal air-firing.

The thesis presents results from a process evaluation of an 865 MWe lignite-fired oxy-fuel combustion unit. Process and cost data, directly received from manufacturers and plant owners, were used in the study. Vattenfall Europe's own lignite-fired power plant Lippendorf, situated outside Leipzig, was used as reference power plant in the study. The study was conducted in order to obtain information on the design, efficiency, environmental performance and the associated costs with this process. With the suggested process layout, the electricity generation cost ended up at 49.5 €/MWh compared to 32.4 €/MWh for the reference plant Lippendorf using the IEA cost assessment criteria. This increase corresponds to a cost of around 20 € per ton CO_2 captured (transport and injection costs are not included).

The main focus of the thesis is, however, on the flame and radiation characteristics of gas-fired O_2/CO_2 combustion. Results are presented from both modelling and experimental work, the latter being performed on a 100 kWth propane-fired O_2/CO_2 test unit, located at Chalmers University of Technology. Different compositions of the feed gas entering the primary and secondary registers of the burner have been tested in order to evaluate the differences between air and O_2/CO_2 combustion; air for reference, 21 vol% O_2 and 79 vol% CO_2 (same O_2 concentration as air) and 27 vol% O_2 and 73 vol% CO_2. As an example, it is shown from the experiments that the radiation intensity of the 27 vol% O_2 oxy-fuel flame is significantly increased compared to the air-fired flame despite similar in-flame temperature conditions. Furthermore, the gas radiation modelling shows that the increased radiative flux can partly, but not solely, be explained by an increased band radiation originating from the high in-furnace CO_2 concentration.

Klas Andersson will continue his work at Chalmers with both experimental and modelling work on O_2/CO_2 combustion. The test facility was recently equipped with a coal-firing system and new tests are currently being performed using the Lausitz lignite as test fuel.

More information about Klas Andersson's work can be obtained by direct contact at e-mail: klas.andersson@me.chalmers.se
phone: 0046 (0)31 772 52 42

Lars G Josefsson in discussions on climate change

The CEO of Vattenfall, Lars G Josefsson, is active in the debate on climate change and how to handle this problem.

Joined forces required to combat climate change

At the beginning of July 2005, in connection with the annual Almedal week in Visby, Sweden, Vattenfall arranged a well-attended Climate Seminar at Gotland University College. The lecture hall was virtually filled to capacity when climate change and its consequences were discussed by the former IPCC Chairman Bert Bolin, EU Member of Parliament Anders Wijkman, Vattenfall President Lars G Josefsson and representatives of political parties and organisations.

The unanimous opinion at the seminar was that in order to overcome the problems relating to the observed climate changes, stable measures of a long-term nature must be taken.

Longer perspective

Lars G Josefsson emphasized that emissions must be priced, and that the price has to be global. The issues also have to be viewed in a much longer perspective than they are at present.

"The Kyoto perspective is too short. It is almost meaningless to define a problem up to the year 2012 – the time horizon should be set at 2100", he said, and noted at the same time that the Vattenfall project on CO_2 Capture and storage aroused general appreciation among the delegates to the seminar.

Industrial leadership

At a seminar held at the Grand Hotel in Stockholm in October 2005, Lars G Josefsson discussed climate change with, among others, Al Gore, former Vice of the USA and Lena Sommestad, Sweden's Minister for the Environment. The topic for the seminar, hosted by the Swedish Environmental Protection Agency, was the role of trade and industry in climate change.

Al Gore opened the session with an absorbing speech on what is happening with the climate around the world. Gore thinks that we are now in a period where we are witnessing the consequences of a collision between population growth, the scientific and technical revolution and our way of thinking. The consequences can be seen already, but will be more and more severe as time passes.

Lars G Josefsson emphasized in his speech that global warming is the most serious problem of today. He said that it has taken mankind 200 years to create this problem and that it will take 100 years to solve it. There is no time to waste however, the

Photo: Stina Rydberg

Al Gore, former Vice President of the USA, Lena Sommestad, Swedish Minister for the Environment and Lars G Josefsson, CEO Vattenfall.

situation is extremely urgent, but the solution must be long-term and concentrate on strategic issues.

One conclusion from the seminar was that companies that have the courage to take the lead and develop products for a better environment can be winners in the new century. Lars G Josefsson and the Swedish Minister for the Environment also agreed that industry and the political sphere should push each other in the right direction.

Read more about the seminar on www.naturvardsverket.se/klimat

The next newsletter will be distributed in April 2006