BRIDGING TO THE FUTURE

Newsletter on Vattenfall's project on Carbon Capture & Storage | No. 9 December 2007

VATTENFALL

Jan Erik Back
Chief Financial Officer
Vattenfall Group

Carbon capture and sequestration efforts support our strategic ambitions

Vattenfall offers its customers competitive, secure and responsible energy solutions.

Our strategic ambitions are to continue to grow profitably, to be the benchmark of the industry, to be number one for the environment and for the customer and to be the employer of choice. To achieve these ambitions, we must continue to develop our business in line with social values in the markets in which we operate. When making decisions we need to balance all aspects and expectations from the different stakeholders.

Our ambitions in the fields of climate change and carbon capture and storage (CCS) are examples of how we balance these interests. This spring, Vattenfall announced its target for the reduction of CO_2 emissions: a 50 per cent reduction by 2030 compared to emission levels in 1990. To reach this target, we need both CCS and other solutions such as investments in new wind power and biomass. Several activities are under way.

One of our aims is to develop commercial CCS concepts by 2020 to ensure significantly reduced greenhouse gas emissions at a much faster rate than could otherwise be achieved. Competitiveness regarding both price levels and security of supply is important on the liberalised markets for both Vattenfall and its customers. At the same time, something good would be done for the global climate. It would attract customers and future employees, as well as contributing to making us the benchmark of the industry.

About Vattenfall's project on Carbon Capture & Storage (CCS)

Vattenfall AB is the fourth 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 its CCS project, as the technolgy 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 project consists of three sub-projects:

• Capture, where three main approaches for CO_2-separation have been identified: Postcombustion capture, Precombustion capture and Oxyfuel combustion.

• Storage and transport, which investigates the possibilities of storing CO_2 in deep saline formations or old oil and gas fields. Also includes the investigation of long-term effects, safety and transportation of CO_2.

• Environment, which focuses on any environmental problems related to CO_2 capture, storage and transport.

Vattenfall is involved in 7 EU-sponsored CO_2-related R&D-projects.

About the newsletter

The newsletter is distributed three times a year. All editions can be found on the project's website www.vattenfall.com/ccs. There you can also subscribe for future issues by e-mail.

Project manager Göran Lindgren is legally responsible for this newletter.

Altmark – Vattenfall's next logic step towards commercial CCS

On 20 September 2007 Vattenfall and EEG, Erdgas Erdöl GmbH, a wholly owned subsidiary of Gaz de France, signed a contract to cooperate on a joint CO_2 injection project at Altmark in Germany. This is the next logical step for Vattenfall's CCS efforts.

Site for the CO_2 from Vattenfall's pilot plant...

Altmark is a mature gas field in which extraction began in the late 1960s. All necessary infrastructure is available and can support the CO_2-injection-plant on site.

Photo: EEG

In mid 2008 Vattenfall's 30 MW Oxyfuel pilot plant at Schwarze Pumpe will be taken into operation. Where to store the CO_2 captured from this plant has up until now been open to discussion, but this problem has now been solved. At Altmark Vattenfall is able to demonstrate both capture and long-term secure injection of CO_2, even if it is on a very small scale and the pilot plant is still a research and development centre.

The CO_2 captured in the pilot plant at Schwarze Pumpe will be transported to Altmark by truck, as it is only a question of small amounts. It would be too costly to transport the CO_2 from large demonstration plants in this way. Here, the logical choice would be to use a pipeline.

The first CO_2 could be injected at the earliest in December 2008 after 15 months of planning, pre-engineering and preparations. Through the Altmark project Vattenfall takes another important step towards fulfilling its ambition to demonstrate the carbon capture and storage (CCS) technology and develop commercial concepts by 2015–2020.

The partnership between Vattenfall and EEG/Gaz de France is optimal as it enables us to learn from each other without being competitors.

...and also for demo plants!

Altmark's location is of greater importance to the one or two demonstration plants Vattenfall intends to build in Lausitz and other locations in Germany. The storage capacity of maximum 500 million tonnes could be large enough for all the CO_2 that would be captured from both the pilot plant at Schwarze Pumpe and the two possible demonstration plants of 250–350 MW(electricity) during their full lifetime.

Altmark is regarded as a very suitable possible storage site for many reasons, one of the most important being that of safety. The risk of leakage is estimated to be non-existent.

The Altmark gas field is slowly being depleted, makings it doubly suitable as a possible CO_2 storage. In a first step, the CO_2 will be used for EGR, Enhanced Gas Recovery. It will be injected around the natural gas findings to maintain pressure and force out more natural gas than otherwise would be recovered. This will provide an additional benefit for EEG and be a means of reducing the costs for the project. This win-win-situation finally answers the question on what to do with the CO_2 from the Vattenfall Oxyfuel pilot plant.

Vattenfall early on the scene...

Vattenfall's storage history began in 1996 when Statoil announced its intention to test-store CO_2 at Sleipner in the Utsira formation in the North Sea. Vattenfall asked to be an observing partner in the project and Statoil agreed. Vattenfall was thus the first energy company to join the SACS I & II projects, whose aim was to investigate injection into the Utsira aquifer and to draw conclusions about long-term retention. Since the start in 1996, one million tonnes of CO_2 annually have successfully been injected into this formation, which has the capacity to store more than 40 billion tonnes of CO_2.

Even the first results from the SACS projects were very promising, providing clear evidence that this method of tackling the climate change issue would at least be technically possible and safe. Early on, Vattenfall started to investigate and assess the potential to also develop a commercial concept for the full CCS chain, including capture, transport and storage. In 2001, Vattenfall had enough knowledge

Photo: EEG

Photo: EEG

to make a decision to start a project. It seemed possible to develop commercial concepts for safe and reliable capture and storage of CO_2 from coal-fired power plants. A system for CO_2 emissions trading in Europe puts the necessary price tag on the CO_2 emissions for CCS to have a chance to be commercially introduced.

...with great focus on CO_2 capture

Since then Vattenfall has focused more on developing capture technologies than on transport and storage. Technology for the transport of CO_2 has been available commercially in North America for decades and therefore does not need to be developed further in technical terms. By 2000 it had already been proved that storage worked, and several other projects have followed. Capture technologies were the weak link in terms of developing commercial concepts for CCS – the technology existed but the financing was too weak and the equipment needed to be scaled up and developed further to better suit application in power plants.

Today, several pilot plants for CO_2 capture technology exist or are under construction. Plans for further plants have been announced. The first demonstration projects on a commercial scale will soon be under way. Vattenfall is one of the most active organisations in the world with its plants under construction, forthcoming demonstration plants and involvement in several test and pilot plants.

Although Vattenfall has focused most of its efforts since 2000 on developing capture technologies, the storage issue has not been neglected. On the contrary, Vattenfall has continued to take part in the injections at Utsira and other storage projects such as CO_2SINK, with its first European onshore storage facility in Ketzin in Germany, where drilling started in June 2007. The time is now right for Vattenfall to demonstrate the possibilities of CO_2 injection at Altmark.

The Altmark gas field

Mature or almost depleted natural gas fields provide great storage potential for CO_2 Capture and Storage Projects. The combination of CO_2 storage with enhanced gas recovery makes such fields an attractive option for natural gas producers as well. The joint CO_2 injection project in the Altmark gas field is the result of this positive synergy and the first step in investigating the possibility of the Altmark gas field for future large-scale CO_2 storage.

Major potential for CO_2 storage

The natural gas fields of northern Germany provide major storage potential for CO_2 emissions from coal-fired power plants. The total storage potential in depleted gas fields in Germany amounts to more than 2,500 million tonnes of CO_2. The Altmark gas field is the second largest onshore gas field in Europe. Its subsurface storage capacity has been estimated to a maximum of approximately 500 million tonnes of CO_2. The Altmark gas field is thus a promising possible candidate for storing all the CO_2 emitted from a large-scale power plant throughout its entire life cycle.

The Altmark gas field is part of a suite of gas reservoirs stretching from the Netherlands, with the large Groningen gas field in the west, to the Altmark gas field in Germany to the east. The Altmark gas field was discovered in 1968 and has been in production ever since. With its peak in 1984, it has been declining steadily since 1996. The present cumulative production amounts to 206 billion m^3 of gas, which means that 78% of the original gas on site has been recovered up to now and economically viable gas production is coming to an end. A recovery rate of 70–80% is expected for gas fields. A gas field like Altmark that is at the end of its production period needs to look at alternative options to increase production beyond the 80% recovery point. The present alternative to extending the field's life and hence reserves is to inject CO_2 into the gas-bearing layers of the reservoir, thereby displacing the remaining gas towards the production wells.

Favourable geology

The natural gas reservoirs of the Altmark region are located in the federal state of Sachsen-Anhalt, approximately 120 km southeast of Hamburg. The gas field is licensed to Erdgas Erdöl GmbH (EEG), a subsidiary of Gaz de France.

Geologically speaking the Altmark belongs to the North German Basin, part of the Mid-European Basin. Sandstone and siltstone of the Permian Rotliegend make up the main reservoir unit of the structure. The Permian period occurred 299–251 million years ago. During the Permian, almost all the Earth's major landmasses were collected into a single supercontinent known as Pangaea. Large continental landmasses create climates with extreme weather conditions. Much of the interior of Pangaea was probably arid, with great seasonal fluctuations (wet and dry seasons). Deserts seem to have been widespread on Pangaea.

The geological remnants of this period making up the reservoir rocks in the Altmark region are red sandstone and siltstone intercalated with shale layers. Porosity and permeability are thus highly variable in these stratified terrestrial sediments. The intense compartmentalisation of the field is mainly the result of tectonic faulting.

The reservoir rocks are located at a depth of 3.5 km. They are overlain by several hundred metre thick massive Zechstein salt. This rock type is characterised by a very low permeability, forming an effective barrier to fluid migration, and thus constitutes an excellent cap rock.

The Altmark gas field consists of nine sub-reservoirs in total, the largest being Salzwedel-Peckensen, which is currently being investigated as part of the German geoscientific R&D programme CSEGR (see www.geotechnologien.de). Simplified numerical simulations of CSEGR suggest that the Salzwedel-Peckensen reservoir could be suitable for CO_2 storage.

The selected sub-reservoir for the pilot phase is Altensalzwedel, which is a depleted natural gas reservoir with a limited area. It is isolated from other compartments and has good reservoir quality. The infrastructure is already in place and there are wells for injection, observation and production. Experience of the pilot phase at Altensalzwedel will be of great value in the future, as this small field is representative for Altmark conditions in general.

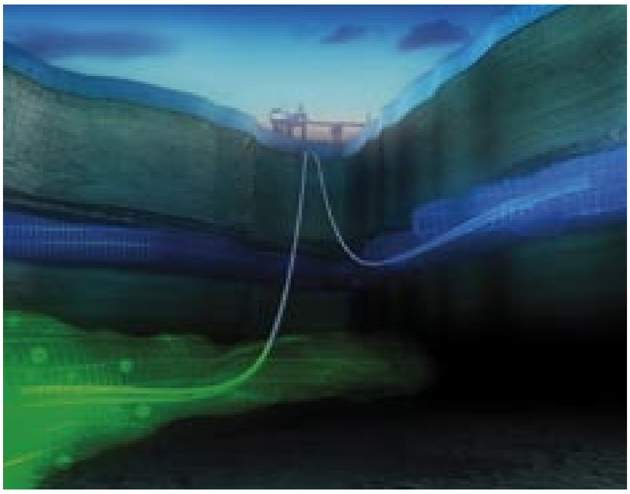
The total injection volume of the pilot phase amounts to 100,000 tons of CO_2 transported from the Schwarze Pumpe pilot plant by trucks to the Altmark gas field. This transport solution will be

specific to the pilot phase, and will require seven or eight CO_2 trailers running in shuttle traffic almost round the clock once the pilot plant is running at full capacity. For a future full-scale power plant operation, it would be necessary to transport the CO_2 in pipelines. The main target for the future is to ensure the suitability of the entire Altmark gas field for large-scale CO_2 storage with the help of this injection pilot project.

CO_2 storage in natural gas reservoirs

A number of CO_2 projects are currently ongoing or being studied from a global perspective. Some of them are using depleted gas reservoirs for storage purposes only, but several projects involving CO_2 storage combined with Enhanced Gas Recovery (EGR) are emerging, the Altmark gas field being one of them. Some storage projects are presented below.

Sleipner: Almost 10 million tonnes of CO_2 have been successfully stored in the sandstone aquifer called the Utsira Formation off the coast of Norway, 1,000 meters below the sea floor. Natural gas from the Sleipner field contains up to 9% CO_2. This level is too high and the CO_2 is therefore separated from the gas produced. The Sleipner project commenced in 1996 when Statoil decided to inject the CO_2 back below the sea floor in an aquifer located above the gas field. The site has been well monitored and after ten years of operation, no leakage of CO_2 from the sandstone formation has been observed.



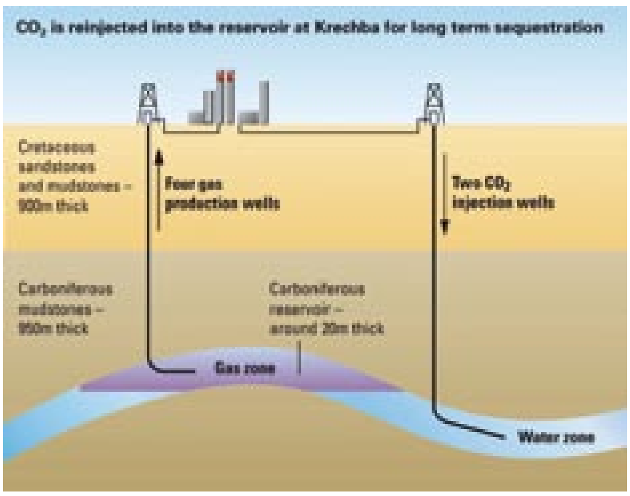
Carbon Storage at Sleipner. Illustration: Alligator film/BOG/StatoilHydro

Snøhvit: The Snøhvit field is located offshore to the north of Norway. Statoil has received approval to inject the CO_2 separated from the gas produced in the Snøhvit field into an aquifer called the Tubåen Formation located below the gas reservoir, in the same manner as has proven successfully for Sleipner. The operation is planned to last for more than 20 years.

K12B: The K12B gas field is located off the coast of the Netherlands. The reservoir is in the Rotliegend, the same stratigraphic level as the Altmark but at a slightly deeper level (3,500–4,000 metres beneath the sea floor). Gaz de France has undertaken a feasibility study for EGR, and since 2004 it has been successfully injecting CO_2 that is separated from the gas produced on site. The operation is planned to last 20 years in total.

Atzbach-Schwanenstadt: The Atzbach-Schwanenstadt gas field is located in north-central Austria and has been investigated as part of the CASTOR project. It is an almost depleted gas field at a depth of 1,400–1,600 metres. The option of turning the gas field into a CO_2 storage site with the possibility of enhanced gas recovery was investigated during the CASTOR project but up until now, no decision has been made by the operator about how to continue.

In Salah: The gas field of In Salah in central Algeria naturally contains up to 10% CO_2. This amount has to be reduced to 3% for commercial reasons. The CO_2 is therefore separated on site and re-injected into an aquifer that is 2,000 meters below the surface. The chosen carboniferous aquifer is characterised by a low permeability. To facilitate injection of the CO_2, the injection well was drilled partially horizontally in the reservoir horizon. There are three injection wells and four producing wells. So far, the operation has been successfully and no CO_2 has yet been observed in the methane produced.



Schematic of CO2 Capture and Storage at In Salah, Algeria developed by BP, Statoil and Sonatrach. Illustration: BP, 2004

Lars Strömberg takes up new position...

Lars Strömberg

Lars Strömberg, who has managed Vattenfall's project on CCS, has a new job. He has been appointed Vice President Research and Development at the Vattenfall Group.

This means that he is now in charge of the entire R&D performed within the Vattenfall Group, of which the project on CCS is one part. He will however chair the project's steering committee and therefore still have a close connection to the project.

He says: "I have been living with this vision for seven years now, and although new forces are taking over, my heart will always be in this project. But I now need to move away from the operative issues."

... and Göran Lindgren takes over

Göran Lindgren

Göran Lindgren will take over as project manager. He has been heavily involved in the project for several years and was formerly group manager at Vattenfall Research and Development AB.

Lars Strömberg wishes Göran Lindgren a warm welcome to his new job and is very happy that the project has been able to get such competent person to take over the leadership.

"The project is progressing with increasing speed and ever-increasing complexity, which is described in this newsletter. It now has a new leadership, but with the same intentions and vision and with the skillful and professional team within Vattenfall growing larger all the time," says Strömberg.

New deputy project manager is Sascha Lüdge.

New power plant in Hamburg with commitment for CCS

On November 14, the City of Hamburg and Vattenfall reached an agreement to start the construction work at the planned coalfired power station at Moorburg. The power station itself will reduce the regional emissions by 2.3 million tonnes of CO_2 annually, when older power stations are taken out of operation.

Hans-Jürgen Cramer, spokesperson for the board of Vattenfall Europe, explained: "There has never been such a highly efficient coalfired power station in a metropolitan region that can produce district heating and power at the same time. With flag-bearing power-generating efficiency and up to 62% fuel efficiency in the case of the power-heat coupling, the Moorburg power station forces older, less efficient power stations out of the market and thereby reduces CO_2 emissions from the power station stock overall."

Commitment for CCS

Vattenfall is committed to build a CO_2 capture plant with the exact date being agreed on by a commission of the state and Vattenfall in 2013. Vattenfall has already obtained an option on the land required to build the capture plant.

Choice of technology and logistics for Vattenfall CCS applications

Ship transport is the logical choice for offshore storage sites, but it might also be a sustainable alternative to pipeline transport, or a temporary and more flexible solution while a pipeline infrastructure is being built, or a complement in logistic chains involving both pipelines and ships.

Recently Vattenfall has initiated a study of the transport of CO_2 by ship, with consultancy support from Norwegian TelTek-GassTek. The purpose of this study is to further clarify ship transport technology for CO_2 captured in power plants in coastal locations. Possible logistic solutions for these Carbon Capture and Storage (CCS) applications with CO_2 transport to local storage sites or sites in the North Sea will also be studied.

Large volumes

Ship transport of very large amounts of gas is currently used for liquid petroleum and natural gas (LPG and LNG), with a typical payload of up to 100,000 m^3 liquefied gas or more. For the transport of industrial grade CO_2 there are four small ships with a payload of about 1,000 m^3. The CO_2 is today transported in its liquid phase at about -28°C and 15 bar.

Because of the large volumes, transport of CO_2 from power plants would require larger ships, which in turn would need to be developed technically due to the different physical behaviour of CO_2 compared to LNG and LPG. The lowest possible pressure for CO_2 would be about 7 bar at -50°C. In 2003 Statoil and partners put forward a proposal for a ship concept for the transport of CO_2 with an estimated payload of 20,000 m^3, which they regard as a good compromise in terms of size for CCS and EOR logistics.

Other options

Another Norwegian ship concept was presented in 2006, where the idea is to transport compressed CO_2 at considerably higher pressure, about 70 bar. In this "floating pipeline" solution, the CO_2 would be contained in packages made of standard pipeline pieces. The idea is to avoid energy loss in the processing of CO_2 by changing the pressure and physical state. In spite of the lower amount of CO_2 transported per ship, the full logistic chain may prove advantageous.

An additional option has recently been presented by a shipping company which is big in the field of transporting other liquefied gases such as ethylene. Six of their existing ethylene ships were originally designed to also carry CO2, providing an alternative for large scale, low pressure transport of liquified CO_2. These ships can carry up to 10,000 m^3 each.

No standard solution

No optimal, standard solution for the logistics of CO_2 in the CCS chain can currently be identified, and will probably not be identified at a later stage either. The logistics to be preferred depend on a number of parameters such as the geographical prerequisites, power plant and storage site locations, amounts to be transported, timing, choice of technology, ship sizes, etc. Sets of logistic cases need to be formulated and studied in greater depth to improve understanding of the technical and economic characteristics of possible ship transports of CO_2 for Vattenfall.

Financial prospects for CCS technology


Chris Rogers

What are the long-term financial prospects for Carbon Capture and Storage (CCS) technology? Is it an advantage in the energy industry for Vattenfall to have made an early start with CCS through its project and efforts in Schwarze Pumpe? In this interview, Chris Rogers, Head of JPMorgan's European Utilities Research, assesses some financial aspects of this development.

JPMorgan is a leading global banking and financial services firm. It offers its clients asset management services as well as banking, securities and treasury services. It provides global financial soliciting and solutions to help clients achieve their strategic goals.

Chris Rogers closely follows the northern European utilities, analysing every aspect of their development. He produces the bank's "All you ever wanted to know about carbon trading" and "Global Utilities – Trading Climate Change" research series.

"Our customers are concerned by the impact and consequences of climate change. We provide advice and services to them. With a CO2 trading desk and related research on the impact for investors, we have an intellectual property which makes it possible for us to help them allocate their capital, so they can take advantage of the market," he explains.

Chris Rogers means that the climate issue touches upon virtually every sphere of the utility industry: the costs of energy, possible government regulation on energy usage or energy efficiency, and also of course the long term climate effects as such. "There are few areas of business that are not concerned one way or another," he says, "but carbon trading is more important to some than to others. Reducing energy consumption as well as energy security are good things for all kinds of industry." Mr Rogers also holds that the pricing of carbon has big impact on for example investment decisions, in particular for utilities. "But carbon pricing is not the only factor: there are also other issues they have to face, like competition, the access to building capacity to replace old plants and so on", he says.

Your report "Global Utilities – Trading Climate Change" pointed out four ways in which climate change influences utilities: carbon trading, renewable energy, nuclear power development and demand side management. Which of these do you see as most important?

"It is different for each company. Nuclear power has little importance for the future in Germany, but more so in Finland and Sweden. There are also plenty of other factors, like demand side management, the future of the coal industry etc. In the short term, the most immediate influence on trading is carbon trading; its proportion to the earnings of the company will have an impact on profit and value up to 2010."

What significance would you attach to CCS technology?

"CCS is arguably the single largest investment opportunity besides nuclear and renewables to tackle the overall CO2 emissions. CCS may have an impact on emissions perhaps in 2015, whereas renewables are ready for use now. There is a difference between potential and deliverable technology. There are also plenty of side issues which have to be tackled, like transport and storage, legal aspects, long-term liability and other non-technology issues."

"The different CCS technologies are all part of the answer. Economic considerations will decide their applicability. Post-combustion technology is not yet ready; it is a non-starter for current investments. Whether it is worth investing in depends on if you build new plants to replace old ones or want to extend the life of existing plants. It would be wrong to rule out one technology. Much depends on the subsidies you get."

"Post-combustion technology has a big potential in developing economies because of the great number of existing plants, especially in China, India and other emerging economies. I can understand why governments want to promote post-combustion CCS technology, so other countries do not mess up the work we are doing in Europe."

When do you think that CCS technology will become commercially viable?

"As an analyst of utilities, I am not an expert on technology. It is a nascent technology, which needs a couple of years to mature. My guess would be by the middle of next decade, and maybe 2020 rather than 2015. But commerciality is a function of the carbon price. You tell me what that will be, and I will give a more precise estimate. It has to do with the break-even level of investments, restrictions on CO_2 emissions, credit from UN sources, the switching from coal to gas or from lignite to coal, and other factors."

What is your assessment of Vattenfall's project on CCS as opposed to other similar projects today?

"With the work Vattenfall has done, we are looking at a margin cost of 24 euro/tonne plus 5-6 euro/tonne for transport and storage. On top of that comes any kind of royalties and long-term liability terms. If these kinds of costs are treated as a public good, the margin for Oxyfuel CCS will be a break-even at 30 euro/ton. In such a perspective it will be economical. But the price on carbon emissions may vary a lot."

Would you say it is an advantage in the industry to have made an early start with CCS technology? If so, in what way?

"The chief consideration is that by being first you are encouraging other companies to follow suit. The advantage depends on whether you can utilise the lead in technology – sell patents to others, or have access to the technology when there is a shortage, like today with the building of wind farms – if you have it."

"It is a function of what your shareholders want you to do. With the Swedish state as 100 per cent owner, Vattenfall can perhaps have a long-term investment horizon, be an early mover and reap benefits in the long term. The same is the case with nuclear investments by EDF. Companies with no long-term investors as owners must have a shorter perspective; it is their management's duty to act in the interests of the owners."

Would you say that the market mechanisms and the general framework today are sufficient to promote new technology in this field?

"The CCS technology in perspective depends on the carbon trading scheme. Yes, it is in place now, and there is a clear commitment from the European Council and the governments to have a carbon-trading scheme beyond 2012. Their target is to achieve a 20–30 per cent reduction of CO_2 emissions, but the mechanisms to get there are not in place. Therefore, you must have more than five years' investment perspective. I don't know what will happen in the long run."

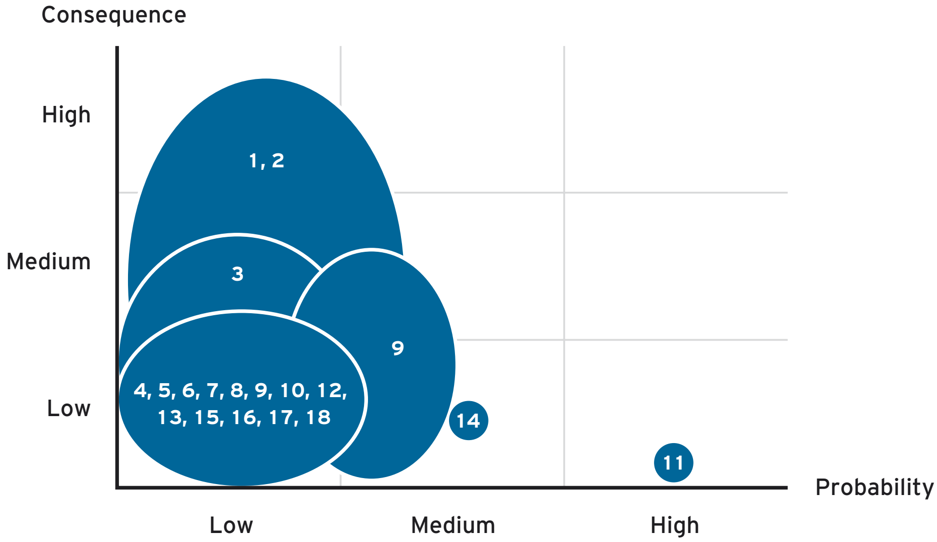
After the interview, Chris Rogers expresses his appreciation "for all the great work and useful resources that Vattenfall have provided on the climate debate over the past couple of years". That is certainly a good testimonial from a renowned financial analyst!

Building and updating knowledge on HSE issues

Vattenfall is continuously following the results and progress of the research community with respect to environmental aspects of capture, transport and storage of CO_2. Vattenfall also cooperates with external partners and participates in international projects to build knowledge. The work focuses on identifying and assessing potential risks to health, safety and environment (HSE), how to address these and how to communicate them clearly. Most environmental risks can be eliminated or minimised by gaining knowledge of the issues and implementing preventative measures.

Potential critical areas have previously been identified (as published in Bridging to the Future no. 5, Sept 2006). What the areas designated as critical have in common is that they are difficult to manage due to a lack of knowledge, standards, guidelines and regulations. The risks have since then been analysed with respect to the magnitude of potential environmental consequences and how likely they are to occur. The potential for launching preventative measures or neutralising risks by gathering background information and knowledge has been taken into account in the evaluation.

Mapping of potential incidents/activities in relation to health, safety and environmental (HSE) risks
(18 risks identified as potentially critical among 100+ surveyed HSE risks)



1. Seepage from on-shore storage.
2. Seepage from offshore storage.
3. Large point leakage from on-shore storage.
4. Leakage from on-shore pipeline to freshwater body.
5. Natural/induced seismic activity.
6. Large point leakage from offshore storage.
7. Large point leakage from ship (accident).
8. Accident at power plant.
9. Large point leakage from on-shore pipeline
10. Large point leakage from offshore pipeline.
11. Brine displacement.
12. Large point leakage from truck/train (accident)
13. Accident at injection plant.
14. Drilling phase environmental impact.
15. Seepage from on-shore pipeline.
16. Seepage from offshore pipeline.
17. Seepage at power plant.
18. Seepage at injection plant.

The most critical HSE risks relate to the consequences of a potential leakage of CO_2 from a geological storage reservoir, or from a pipeline used for transporting CO_2, as illustrated in the figure below. The probabilities are in some cases estimated to be medium to high, but the resulting consequences are still expected to be limited (little or very localised impact). The sizes of the circles in the diagram illustrate the spread of uncertainty in the evaluation. Environmental work is focused on decreasing the uncertainty, but in order to eliminate unknown factors, a site-specific investigation will in many cases be required.

The success of a CO_2 capture, transport and storage project depends on us making the right choices regarding aspects such as proper site selection methods and criteria, use of best available technology, thorough monitoring and plans for mitigation and remediation. When the work moves on to site-specific evaluations and the realisation of a CO_2 capture, transport and storage project, uncertainties associated with potential risks will be addressed through thorough investigations and studies, and measures will be taken to minimise risks.

It is Vattenfall's conviction that capture, transport and storage of CO_2 can be undertaken in a safe and acceptable way with good environmental performance. The dominating environmental effect of the technology will be significant reductions of CO_2 emissions to air.

PhD thesis on Oxyfuel completed

Klas Andersson

Research into Oxyfuel combustion has been carried out at Chalmers University of Technology for several years, and the first PhD thesis is now available. Klas Andersson, who we have previously written about here in Bridging to the Future, has completed his work at Chalmers.

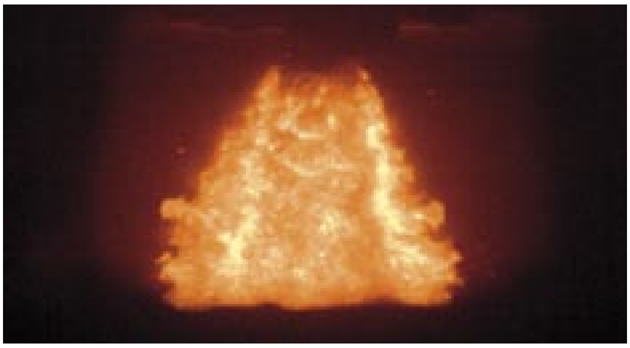


Photo: Chalmers

The work presented includes the design and construction of a 100 kW Oxyfuel test unit, at which extensive test campaigns have been carried out using both gaseous and solid fuels. Among other results, a detailed description of Oxyfuel flames with emphasis on their composition and radiative heat transfer characteristics has been presented.

The Oxyfuel research group at Chalmers will continue their work at the test unit to increase knowledge on combustion fundamentals. The aim is to develop both descriptive and predictive modelling tools to be used in the design of Oxyfuel combustion systems.

Investigating CO_2 quality requirements for CCS projects

An important aspect in the analysis of a system with CO_2 capture, transport and storage is the quality requirements for the captured CO_2, i.e. the limits set for the concentration of the non-CO_2 components present in the stream sent to the storage site.

The quality requirements may have a significant impact on the cost of CO_2 capture, transport and storage. CO_2 capture combined with other emission reductions may provide a cost- and energy-efficient solution for overall emission control in power plants. However, the co-capture of other components into the CO_2 stream may increase the risk of negative impact on capture, transport and storage systems. This will eventually increase the overall costs of power generation and should be avoided as much as possible. Requirements on the quality of the CO_2 stream should be based on scientific and technical knowledge of CO_2 mixture properties, impurity behaviours and their interactions with the main components of the systems and the environment. The objective should be, as is the case with other industry applications, to reach an acceptable balance between minimising the potential for increased costs and environmental impact. An initial article on this topic was presented in newsletter no. 6, 2006.

CCS is not EOR

Vattenfall started looking into the CO_2 quality issue in 2003 and has since then worked to increase knowledge in the field to avoid arbitrary limits being introduced. The CO_2 specifications considered range from CO_2 mixtures of about 95% CO_2 content to up to 99.9% CO_2. Existing specifications from projects related to EOR (Enhanced Oil Recovery) operations provide a good knowledge base; however, they are not directly transferable to CCS projects for several reasons. One important difference is that most EOR projects are located in remote areas with pipeline transport of CO_2 through vast unpopulated areas, which makes it easier to handle risks related to the unlikely event of a pipeline rupture and release of CO_2 and the other components. In addition, CO_2 injection for EOR is part of an industrial operation, while CCS is related to environmental control, with the main aspects linked to the long-term safe storage of CO_2.

Experimental data is lacking

During the work it has been identified as important that the thermo-physical properties of the CO_2 gas mixture can be accurately predicted, so that the fluid behaviour regarding storage capacity estimations related to phase equilibrium, density and solubility properties can be estimated. Today, experimental data in this field is to some extent lacking. In addition, the interaction between brine and rock in the CO_2 storage reservoir in relation to the redox potential of the mixture and the presence of acidic or basic components needs to be accounted for. Geochemical experimental data is needed to calibrate geochemical numerical simulations. Aspects related to the corrosion of equipment in the CO_2 capture plant, pipeline and injection equipment also need to be considered when determining a suitable standard for CO_2 quality and may require experimental qualification of materials. These aspects and others are investigated by Vattenfall and also by several universities and institutes such as the Royal Institute of Technology in Stockholm, TU Hamburg-Harburg, BGR in Germany, SINTEF in Norway, BRGM in France, and EU projects such as ENCAP, DYNAMIS and CO2ReMoVe.

On the other side of the bridge

Vattenfall's strategy for fighting climate change is made up of three prongs, of which capture and storage technology is one. The other two are the optimisation of existing technology and the increased use of energy sources without emissions of fossil-fuel carbon dioxide.

On this page, we present work performed by the Vattenfall Group on electricity generation from renewable sources, and the topic for this issue is hydropower.

Hydropower – premier renewable energy

Hydropower plays a very important role in electricity generation in the Nordic countries, representing about 50 per cent of the total supply in the region. In Sweden, Vattenfall has about 100 hydropower plants, about 50 of which are small-scale, while in Finland Vattenfall operates ten hydropower plants, also mostly small-scale. During a year with normal rain and snowfall, the plants in Sweden and Finland provide about 33 TWh. In Germany, Vattenfall operates six hydropower plants and eight pumped storage power plants. The latter constitute a very useful tool, for example, for the integration of wind energy into the system by storing energy when the wind is blowing and generating power when there is no wind.

Major investments

Vattenfall is currently engaged in a major re-investment programme in its hydropower plants to the tune of around € 675 million. The investments will secure long-term production, improve dam safety and environmental performance, decrease maintenance costs and increase generation. As a result of the upgrade, an additional 300 GWh will be produced per year by 2013, without any CO_2 emissions whatsoever.

For years and generations to come, hydropower will definitely continue to play an increasingly important role in renewable energy generation.

Construction progress at Schwarze Pumpe

One of the CO_2 storage tanks is lifted into its final position after delivery

On 20 september Vattenfall successfully installed the furnace at the construction site for the Oxyfuel pilot plant. The combustion chamber, which weighs 230 tonnes, was lifted into the boiler house by a 500-tonne crane. The Oxyfuel boiler has an overall height of 25 metres, which made the process a logistical challenge. The whole process took about two hours and 30 people were involved. On the same day, the two CO_2 storage tanks were installed.

A couple of weeks later, parts of the air separation unit (ASU) also arrived at the pilot plant site in Schwarze Pumpe.

With these two events, Vattenfall has reached another important milestone in the construction phase, and the project is therefore in keeping with the construction schedule.

Watch how the project progresses on the project website: www.vattenfall.com/ccs

The furnace is lifted by a huge crane into the 25-metre high boiler house

Assembly of the ASU coldbox