

BRIDGING TO THE FUTURE

Newsletter on Vattenfall's project on Carbon Capture & Storage

No. 13, May 2009



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

Climate change is one of the greatest environmental challenges of our time. Being an energy company means that Vattenfall is part of the problem, but also that we are part of the solution. Vattenfall works devotedly to reduce carbon dioxide (CO₂) emissions. Carbon Capture and Storage, CCS, is one method to achieve this, and for this reason we initiated our CCS project in 2001. The project aims to make commercial CCS concepts available in 2020.

CCS is a way of bridging over to other, renewable technologies for power generation in the future energy system. This is why we call our newsletter "Bridging to the Future".

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

Vattenfall's CCS project consists of several parts:

- A full-scale **demonstration** project has started in Denmark, with Postcombustion capture at Nordjyllandsverket. The CO₂ will be transported in a 30-kilometre pipeline to the Vedsted underground structure for storage.
- A **demonstration** project has also been started in Germany. At the Jämschalde power plant, both Oxyfuel and Postcombustion CO₂ capture will be demonstrated on a large scale. Different storage options are currently being investigated.
- **R&D** to support the pilot and demonstration projects is performed in all parts of the CCS chain;

Capture, Transport and Storage. Most recognised is the **Oxyfuel Pilot Plant** in Schwarze Pumpe in Germany that has been in operation since 2008. The CO₂ will be used for Enhanced Gas Recovery (EGR) as it is being stored in gas fields in Altmark, Germany. Environmental issues are also covered by R&D activities. Vattenfall is also an active partner in a number of EU projects.

Bridging to the Future

Bridging to the Future is the CCS project's newsletter and it is distributed three times a year. The newsletter's ambition is to give a comprehensive picture of all parts of the project and keep the readers up to date on research advancements.

All editions can be found on the project website www.vattenfall.com/ccs. There you can also subscribe to future issues by e-mail.

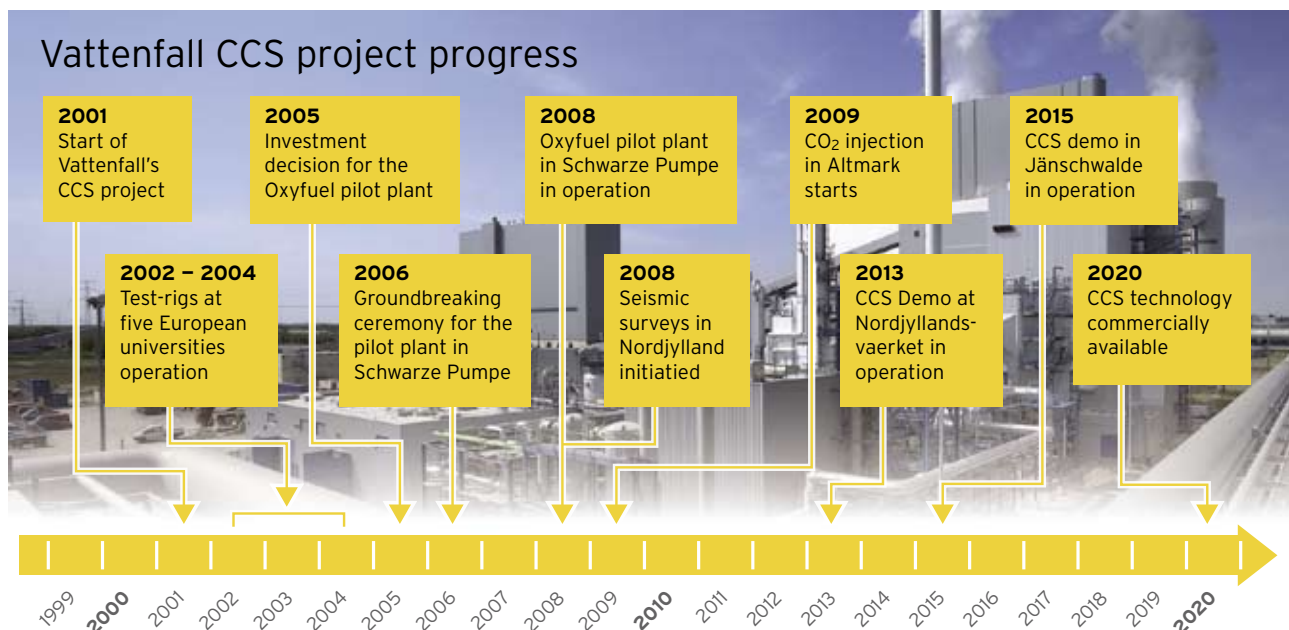
If you have any comments or questions about the newsletter, please contact the editor Stina Rydberg at: stina.rydberg@vattenfall.com.

If you have questions about the project, please contact the project group at: ccs@vattenfall.com

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Stina Rydberg is editor and Staffan Görtz is legally responsible for this newsletter.

Vattenfall CCS project progress



New CCS manager at Vattenfall

CCS is moving forward fast and we at Vattenfall have decided to further enhance our efforts. Consequently, I was offered the position of Manager for the Technology Development Centre CCS. As such I will be working with the operational Business Units to find approaches for the deployment of commercial CCS plants at Vattenfall. This work will be conducted in parallel with Göran Lindgren, who is still responsible for our CCS R&D efforts. I strongly believe that we will succeed and that we will see the first commercial plants some time around 2020 to 2025. By then, we will have had almost a decade's experience of operating full-scale demo plants.

In February 2009, the official 3 to 5-year test programme at the 30 MW Oxyfuel pilot plant at Schwarze Pumpe started. The first results show a capture rate of around 90 per cent with a very high CO₂ purity, well above 99.5 per cent. We are convinced that a capture rate of at least 95 percent lies within reach and that 98 percent will be possible in the future.

In March, we announced the start of investigations for two possible storage sites east of Berlin for the Jämschalde demo plant. The upcoming merger between Vattenfall and NUON will add further knowledge regarding CCS that will strengthen the position of both organisations and further enhance our chances of success in developing commercial CCS concepts by 2020.

Another important issue that we are now facing is the intensive and important phase regarding the further development and deployment of CSS. Details about funding mechanisms for EU support to CCS demonstration plants are currently being drawn up and this is a process that we welcome. Our view is that some sort of external funding is necessary to put 10 to 12 demonstration plants into operation in the years around 2015.



Bjarne Korshøj
Vattenfall CCS manager

Read more about Bjarne Korshøj's thoughts and ideas around CCS in the interview on page 6.

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Vattenfall explores CO₂ storage sites in Eastern Germany

Together with Verbundnetz Gas and Schlumberger, Vattenfall has initiated exploration of two different possible storage sites in the German federal state of Brandenburg. The aim is to investigate the potential of these aquifers to store the carbon dioxide, CO₂, from Vattenfall's envisaged CCS demonstration project in Jänschwalde.

One of the focal points of Vattenfall's CCS activities is to establish the CCS demonstration plant in Jänschwalde and usable storage capacity must be identified and developed for this purpose. The sedimentary rocks of the North German Basin offer excellent geological conditions, as there is a high incidence of deep underground sandstone strata. The deep-lying sandstone horizons consist of porous rocks, saline aquifers, that today contain brine, that is water with a high mineral content making it unfit for human consumption. In most cases they are encompassed by solid layers of salt or clay, which are impermeable to liquids and gas. This makes them very good candidates for CO₂ storage, something that will now be closely investigated.

Two exploration sites: Birkholz-Beeskow and Neutrebbin

The sedimentary rocks in the North German Basin were screened between 2004 and 2008 in various studies with the purpose of identifying and ranking possible sites for CO₂ storage. Several geological horizons and different geographical locations have been evaluated.

As a result of the screening process the structures Birkholz-Beeskow and Neutrebbin, both in the east of the state of Brandenburg, were chosen as locations for further exploration.

Both structures are promising in terms of capacity, injectivity and storage integrity. The strata suitable for injection belong to the Volpriehausen and Detfurth formations of the Buntsandstein unit.

The storage capacity of the two structures is estimated to be more than 100 million tonnes. The injectivity is sufficient on account of the 20% porosity and permeability of 200 mD (milliDarcy). Storage integrity is guaranteed by the 200 metre-thick impermeable cover layer, consisting mainly of clay and salt, and a 400 metre-thick secondary cap.

Storage ability proven before

Research into CO₂ storage has been conducted in

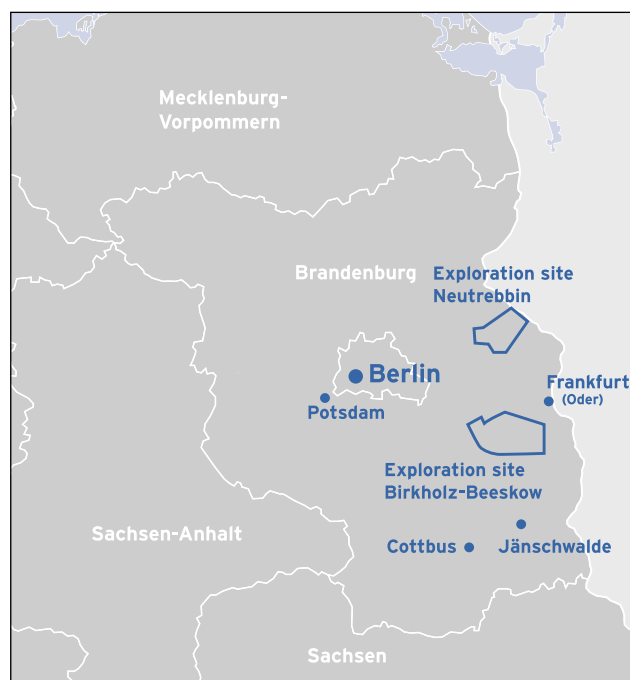
Brandenburg in Ketzin, near Potsdam, since 2004. Eighteen industrial partners and scientific institutions from nine European countries are involved in the EU-sponsored project CO₂SINK. These include Vattenfall and our new collaboration partner Verbundnetz Gas AG (VNG). Since the summer of 2008, CO₂ has been injected into a saline aquifer in Ketzin in Brandenburg. Vattenfall also has a licence to use CO₂ from the CCS pilot plant in 'Schwarze Pumpe' for the project.

Project plan - what will happen now?

The exploration programme to screen the structures best suited for storage will begin in 2009 and end in 2011 and will be implemented in three phases.

The first phase will commence with seismic studies of the Birkholz and the Neutrebbin structures. For both structures a total area of more than 300 km² will be evaluated using vibration seismology. In the studies, special vehicles create vibrations in the subsoil that are reflected and return to the surface. In geophones they are converted into electrical signals from which a geological profile of the subsoil can be created.

The exploration drilling will then be carried out. This begins with the preparation of the drilling sites. Within the framework of the exploration study, four exploration drill holes are planned. Depending on the results, three further injection drill holes per structure may be drilled.



To conclude the exploration, the flow properties within the sediment strata will be simulated in the test programme. The water permeability in particular provides important information on the actual flow conditions here.

If the exploration is successful, the storage sites will be developed.

The connection system between the injection drill hole and the transport pipeline will be implemented in the period 2011 to 2015. The appropriate surface installations for this will be erected.

This will be followed by transport via a gas pipeline from the demonstration plant in Jänschwalde to the storage site. The pipeline, up to 150 km in length, will be built with a distribution system but no pressure boosting system.

One goal - one idea - three strong partners

Vattenfall, Verbundnetz Gas and Schlumberger are partners in the project on CO₂ storage in Birkholz/Beeskow and Neutrebbin.

The energy group Verbundnetz Gas AG (VNG) is an international importer of natural gas with its head office in Leipzig. The core business of the group is trade in natural gas, its transportation and storage and the efficiency of supporting energy services. The VNG group operates an inter-regional gas pipeline network of over 7 000 km in the European natural gas network system.

Schlumberger Carbon Services (SCS) is a company with French and American roots. It has been operating for more than 80 years in the areas of crude oil and natural gas exploration.

Since the mid-1990s, Schlumberger has also been applying its complex experience in the areas of underground assessment and storage site management to the development of geological CO₂ storage. Schlumberger Carbon Service experts are working on numerous CCS projects worldwide.

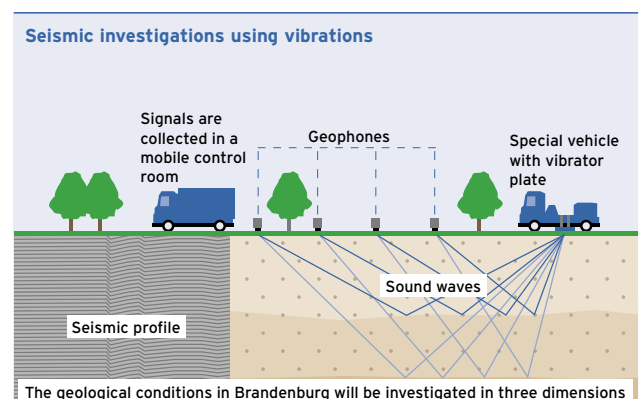
Activities in parallel

The development phases from planning to realisation of the demonstration plants for CO₂ capture and to the development of CO₂ storage in Birkholz-Beeskow and Neutrebbin, will take place in parallel. Several milestones will be observed.

By April 2009, the pre-engineering specification will be prepared, followed by planning, approval, contracting and detailed engineering of the demonstration plant for Jänschwalde by 2011. At almost the same time, the exploration programme in Birkholz-Beeskow and Neutrebbin will take place. This will be concluded in 2010.

2011 will see the start of construction of the demonstration plant in Jänschwalde, installation of the pipeline and development of the CO₂ storage site. The commissioning of the flue gas scrubbing plant, Oxyfuel plant, pipeline and storage site is planned for 2013/2014.

According to the Vattenfall vision (Making Electricity Clean), developing and implementing technologies for CO₂ separation for fossil fuels, in particular for coal, is an essential precondition of large-scale implementation. Continuous operation of the demonstration plant at Jänschwalde power plant is planned for 2015. In 2020, the first commercial Oxyfuel coal-fired power plant will then be operated, with an output of around 1 000 MW_{el}.



“My biggest challenge is to bring about political and local acceptance of CCS”

In this interview, meet Bjarne Korshøj, Vattenfall's new CCS Manager, who recently took up the position. He is pleased with his new role, since this project is important to both society and Vattenfall and is therefore given high priority within the Vattenfall Group. The biggest challenge as Bjarne Korshøj sees it is to bring about acceptance for CCS, both politically and locally.

Bjarne Korshøj will lead the Technology Development Centre for Carbon Capture and Storage (TDC CCS) function, which will organise and coordinate activities and facilitate the implementation of CCS within the Vattenfall Group. The overall objective of the TDC CCS function is to implement the measures necessary to achieve the goal of CCS technologies being commercially available by 2020.

Did you feel that you were entering uncharted territory?

Definitely, but you could also say the opposite. It's a field where many people are doing things really well in isolation but where there is a lack of coherence and coordination, generally speaking. This applies to the way we communicate and approach our suppliers, and it may apply to the technical solutions we choose.

Another important area that would clearly benefit from being coordinated is ensuring there is a coherent overview of financial support options at national and EU levels. Neither pilot projects nor demonstration models are financially profitable in themselves and can only be implemented with support from development funds at both EU and national level.

Better opportunities for transferring technologies from one project to another are also important.

What do you see as your biggest challenge?

The big challenge is to bring about political and local acceptance of CCS. In Denmark, for example, there has been positive political movement within recent months, so we have won political support for our CCS project.

In Germany, we have the political support but we don't know whether we have local support, as we've just started up the project to find a suitable storage location. It's clear that the practical task will be undertaken locally and I see it as my task to draw up a few ground rules for how we proceed.



In the technical field, the biggest challenge is to coordinate the choice of capture technology so that we gain knowledge of all three methods, Oxyfuel, Postcombustion and Precombustion.

If I had to choose the biggest challenge, it would have to be bringing about political and local acceptance of CCS.

When will we see the first commercial CCS plant?

We're aiming for around 2020. It's a tight deadline but it should be feasible. We're in the process of drawing up a timetable for how to achieve the target of being CO₂-neutral in the Nordic region by 2030 and throughout Vattenfall by 2050. Many things will contribute to reaching these targets, and CCS is just part of the solution.

Developing a commercial CCS plant involves many technological challenges. We've reached the stage of development where we need to build a demonstration plant. The EU has decided that 10-12 plants are to be built in Europe, and Vattenfall is aiming to get a licence to build two plants, one in Denmark and one in Germany. Demonstration plants are a necessary precursor of commercial plants.

How do you rate Europe's chances of taking the lead in developing technical solutions for CCS?

A huge change has occurred in many places. Many CO₂-heavy businesses, including those outside the power plant sector, have started to be seriously interested in reducing their CO₂ emissions.

In the technical field, it seems that the European power plant suppliers have not been as quick off the blocks as some international suppliers. It may well be that they've been a little slow starting but things have changed and there is great development potential from a European perspective.

At Vattenfall, we want to compete in as many technical fields as possible. We believe this contributes to developing the best solutions.

Do you believe that CCS will gain a footing throughout the world as a method of reducing CO₂ emissions?

Many people think it's wrong to spend so much money, including public subsidies, on CCS. That the money should be spent on alternative fields. I think it should be spent on both. It's irresponsible not to do both.

But there must be a degree of distribution in this. Western countries must bear a large proportion of the development costs but, unless developing countries follow up and build CCS plants at their power plants, it won't be possible to keep the rise in global warming to max. 2 degrees.

Your new organisation, what does it look like and when will it be in place?

I'm building up an organisation of 10-15 people. So it'll be a small organisation. We will, of course, draw on

the people around us in both the line organisations and engineering and make use of their skills. The organisation I'm building up is a small organisation that will work in a very interdisciplinary way.

For me it's not essential to have a lot of employees with direct reference to the CCS function. The most important thing for me is to have the right skills in the organisation.

My aim is for it to be in place before the summer holidays. But the first few names will be in place within a few weeks. After that things will happen quickly. I'm aiming for the organisation to include employees from Poland, Germany, Sweden and Denmark, so that we're represented in all the countries where we have CCS activities. I see this as a major strength.

Facts on Bjarne Korshøj

Age: 51

Education: Engineering degree in energy and heavy current from the Technical University of Denmark in 1983. Bachelor of Commerce in organisation in 1990.

Professional experience: R&D department of NESAs, 1983; Head of production optimisation and IT manager at Elsam, 1987; Production manager at Studstrupværket, Elsam, 2001; Planning manager responsible for production optimisation and business development of existing plants, Elsam, 2004; Head of Thermal Power, Vattenfall, 2005; Head of TDC CCS, Vattenfall, 1/1/2009

Family: Married and three children. They live in Trelde Næs just north of Fredericia, Denmark.

Spare time: The whole family goes sailing and Bjarne also hunts, and flies ultralights.

Delays in Vattenfall's Danish demo project

According to the very tight time schedule, the 3D seismic investigations of the Vedsted formation roughly 30 km north-west of Nordjyllandsværket would have been performed from May to August this year. Due to different reasons the investigations and the subsequent test drillings have been delayed. It is today too early to say when the activities in the area can be resumed. We are still optimistic regarding the possibilities to have the plant in operation by latest 2015. However, 2013 seems to be out of reach.

There are two reasons for postponing the next phase of seismic investigations. The Vedsted structure is in part located underneath a bird-protection area

and investigations during the breeding season for some threatened species has given highest priorities by both us and the authorities. Also, an increasing number of questions regarding safety and risks of leakage have been raised by local stakeholders.

Therefore we are now focusing our effort on listening to the local stakeholders and try to understand their concerns to better continue the dialogue. The same kind of dialogue is already ongoing with local stakeholders both in Brandenburg and Altmark in Germany.

We intend to continue the seismic studies at Vedsted as soon as possible.

Latest report from Schwarze Pumpe - the first test campaign initiated

Vattenfall's pilot plant is the first in the world of this size covering the entire Oxyfuel process chain from the air separation unit to CO₂ purification and compression. All parts of the CCS chain - capture, transport and storage - are covered. The exciting test period has now been initiated and the first test measurements are being collected and documented.

Objectives

One of the main objectives of the pilot plant is to enable operation of the plant in a flexible manner. Another is to perform the well-defined tests that are necessary to improve our understanding of the dynamics of Oxyfuel combustion for the development of the Oxyfuel process. All this is being done to provide operating information and it will help to make the future scale-up of the technology to 400-600 MW_{th} possible in the demonstration phase.

Other objectives for the test campaigns are to see how the different components act together in operation in the Oxyfuel environment. The combustion atmosphere under Oxyfuel conditions differs considerably from the atmosphere under air-firing conditions. How this affects such important parameters as heat transfer will be investigated. Not least, material and corrosion issues in this new environment are closely monitored. These test results will then serve as a basis for defining further equipment testing and, ultimately, as input for designing the commercial-scale plant.

First experience

In a first test campaign, we are drawing conclusions about Oxyfuel firing in general. Important experience about how to actually conduct the test measurements, how the analysis tools work etc. is also being collected. Examples of measurements that have been performed include the temperature and gas composition in the furnace at different firing modes. Analyses of the fuel and ashes are being made.

These first months of gathering experience are almost at an end. In the next test campaigns, combustion characteristics for different burner settings will be evaluated as well as some detailed corrosion issues. A thorough profile of the temperature and gas composition in the furnace and the downstream components will also be created.

The test team at the site in Schwarze Pumpe is putting a lot of effort into the work right now and they see a lot of work ahead of them. A vast amount of data is being and will be collected and evaluated. The plant now operates around the clock, either in the Oxyfuel or in the air-firing mode.

Results and experience from the first months of operation in the pilot plant will be presented at the Oxyfuel conference in September 2009 in Cottbus.



Pulverised and dried lignite is loaded in the fuel silos.



Probes in the furnace for test measurements.

New technology to be installed in Schwarze Pumpe

In March this year, Vattenfall signed an agreement with Air Products that will install its proprietary carbon dioxide (CO₂) purification and compression system at Vattenfall's Oxyfuel pilot plant in Schwarze Pumpe, Germany. Vattenfall and Air Products have also signed a joint research and development agreement related to the project. Air Products' test facility will be operational at Schwarze Pumpe in December 2010.

At the pilot plant, Air Products will take flue gas directly downstream of the particle separation unit. The slipstream that is needed for the new facility corresponds to roughly 1 MW_{th}, or slightly more than 3% of the flue gas flow from the boiler. The new equipment will purify and compress the CO₂ using Air Products' proprietary sour compression technology. It uses a staged compression process to optimise pressure, hold-up, and residence time to allow the removal of impurities during the compression process.

The original process in Vattenfall's pilot plant will not be influenced; the new installation will operate using only a fraction of the flue gas flow. The stream leaving Air Products' equipment will be re-injected into the large flue gas flow. It will then pass through the present CO₂ purification, compression and liquefaction process for intermediate storage in the two large tanks at the site.

This novel technology implies cost savings in the Oxyfuel combustion process and would, if it proves successful also at this scale, minimize the concentration of acidic components in the CO₂ product. This is important in preventing corrosion in connection with the subsequent transport and injection of CO₂. The installed facility will demonstrate the efficient purification of CO₂, and remove inert gases, in particular oxygen. In addition, it will incorporate innovative membrane technology, targeting carbon capture rates as high as 98 percent.

Next step in scale-up process

Air Products has been working on developing this technology for some years now. At the GHGT-8 conference in Trondheim in June 2006, Air Products presented a series of reactions that gave a pathway for the removal of SO₂ and NO_x during the compression of the raw CO₂ from the Oxyfuel process. Since then, Air Products has performed a series of activities for practical scale-up and validation. This also

included a paper study for Vattenfall, based on our knowledge regarding flue gas quality. This study was presented in issue eight of this newsletter, in September 2007.

In order to verify the theory presented at GHGT-8, work was carried out within the OxyCoal-UK Project, led by Doosan Babcock Energy Ltd. Bench-scale practical tests were conducted at Imperial College in London and with flue gas from a 160kW coal-fired combustion installation at Doosan Babcock's facility in Renfrew, Scotland, as part of the OxyCoal-UK Project. From these experimental results, which were presented at GHGT-9 in Washington in November 2008, it was clear that the main reaction pathways are viable. The rates of reaction are sufficient to produce the desired results: SO_x and NO_x removal by compression and contact with water.

In 2008, Air Products was awarded a U.S. Department of Energy (DOE) Cooperative Agreement to design and construct its proprietary CO₂ purification system for slipstream pilot-scale tests at the site of a 15 MW_{th} tangentially-fired Oxyfuel combustion test facility. The two-year project is part of the DOE's development of new and cost-effective technologies for the capture of CO₂ from the existing U.S. fleet of coal-fired power plants. This project will allow Air Products to gain a better understanding of the sour compression reactions at a larger scale. With real Oxyfuel-derived CO₂, using a vapour-liquid contacting device equivalent to that foreseen for the full-scale plant, the reactions can be studied when subjected to the expected mass transfer characteristics of the full-scale equipment.

This leads to the project together with Vattenfall that will demonstrate the sour compression technology at around the 1 MW_{th} scale, plus purification with inerts and oxygen removal, together with other aspects of Air Products' Oxyfuel Purification Technology, such as the use of a membrane to recover CO₂ and oxygen normally lost with the inert streams.

Vattenfall is very pleased with the new agreement, as it is crucial for us to qualify a portfolio of optional technologies to use in the coming deployment phase of CCS.

More information on Air Products' CO₂ purification technologies can be found at www.airproducts.com/CO2_capture.

Wrap-up of the Dynamis project

The EU project Towards hydrogen and electricity production with carbon dioxide capture and storage, in brief Dynamis, has recently been completed after three years of work. The project was funded by the European Union's Sixth Framework Programme together with industry. With a budget of €7.4 million it has covered major R&D work by a large group of companies and leading national research institutes, altogether 32 partners, of which Vattenfall is one. The interesting results from the project cover R&D over the entire chain of capture, transport and storage of carbon dioxide, CO₂.

The Dynamis project arose from the HYPOGEN Demonstrator Programme, with its plan to offer electricity, hydrogen and CO₂ on a large scale by 2012-2015. Dynamis has provided research and pre-engineering studies to enable the subsequent commercial construction of power plants in Europe that produce both electricity and hydrogen, and capture and store their CO₂ emissions. The project is based on using coal or gas with the lowest feasible emissions of greenhouse gases, and providing hydrogen for use in society, e.g. for transport, and for industrial use, e.g. in refineries. Hydrogen cars powered by a fuel cell or a combustion engine could thus be provided with bulk hydrogen from coal or natural gas with a minimum of emissions.

Case studies

The objectives for Dynamis have been to elucidate five topical areas: i) The de-carbonisation of fossil fuels, ii) Hydrogen separation, iii) New efficient power cycles, iv) Reliable geologic storage of CO₂, and v) Societal anchorage of CCS plants with hydrogen production. These areas have been illustrated by four case studies of potential HYPOGEN plants with CCS, sponsored by industrial partners and representing a spread of fuel types, storage types and locations, and hydrogen utilisation possibilities. Vattenfall has focused its efforts on the Hamburg region, where a bituminous coal-fuelled IGCC CHP* plant with both onshore and offshore CO₂ storage options was pictured. Three other cases were defined and evaluated by other participants in the project.

Precombustion capture of CO₂

An IGCC* process with pre-combustion CO₂ capture and separation of hydrogen product

*IGCC: Integrated Gasification Combined Cycle. CHP: Combined Heat and Power.

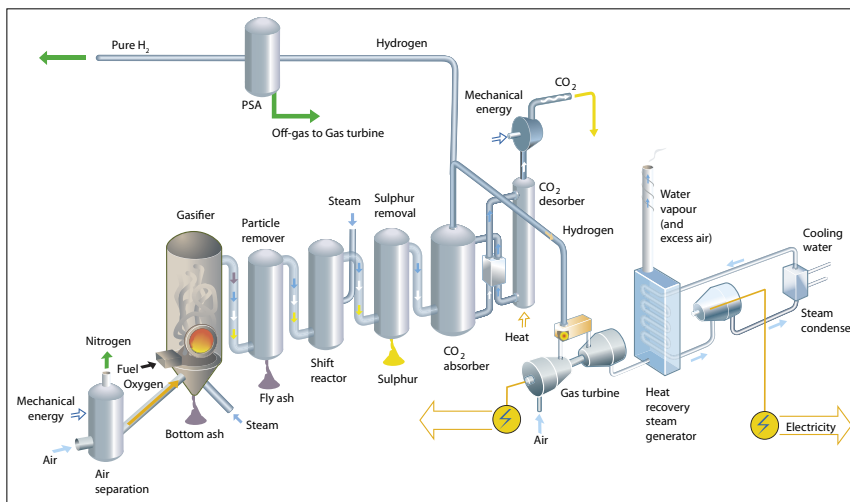
involves several sequential stages. Like most other CO₂ capture technologies, its on-site energy consumption is significant, compared to an IGCC* without CO₂ capture. The Dynamis design focus was therefore on efficiency improvements, including heat and steam integration, and measures like gas turbine air extraction to the air separation unit to reduce separate air compression. The levels of integration were carefully balanced against increasing complexity, so that good/acceptable operability, reliability and maintainability would be maintained.

The Hamburg case study was based on an air separation unit from Air Liquide, a gasifier from Shell, Selexol acid gas (CO₂ and hydrogen sulphide) removal and a single F-class gas turbine combined cycle from Mitsubishi Heavy Industries. This generates, in condensing mode, about 400 MW electricity net, and in CHP mode delivers district heat with a temperature of 135°C to Hamburg City. The design achieved a yearly average net electric efficiency in condensing mode of 36%.

Transport and storage issues were also studied

The case studies have provided considerable knowledge on the transport of CO₂, and on the injection and storage of significant volumes of CO₂ based on best practice for the specific locations with their various types of storage sites. Two candidate storage sites, one onshore and one offshore, have been assessed as part of the Hamburg case study:

The onshore structure Hamburg South is representative of a number of similar structures in the area, with the Buntsandstein as the main reservoir and a several 100 metres thick halite layer as an excellent sealing rock.



Precombustion IGCC combined with simultaneous hydrogen production is the CO₂ capture technology studied in the Dynamis project.

The second storage site that was assessed by the case study is located offshore Jutland, that is off the west coast of Denmark. This structure is a domal closure with a reservoir of layered sandstone and several 100 metres thick claystone forming the top seal. Despite lack of data, numerical simulations have shown that the structure is a promising candidate storage site.

Interesting results

All in all, the Dynamis project has provided a lot of interesting results in all parts of the CCS chain. A public report that summarises these results is underway and will be available later this year at www.dynamis-hypogen.com, together with additional information of the Dynamis project.

Investments granted for demo-project Jänschwalde

The plans for Vattenfall's German demonstration plant in Jänschwalde are picking up speed. Another € 50 million have been granted to further investigate and develop the next step of the CCS project, i.e. the building of two CCS boilers on the site of the lignite-fired power plant Jänschwalde. The construction of the plant is scheduled to start in 2011 and the plant is expected to be in operation in 2015.

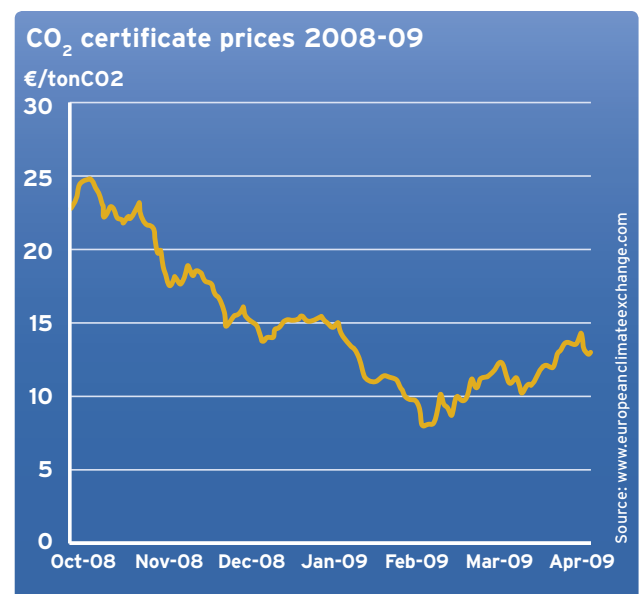
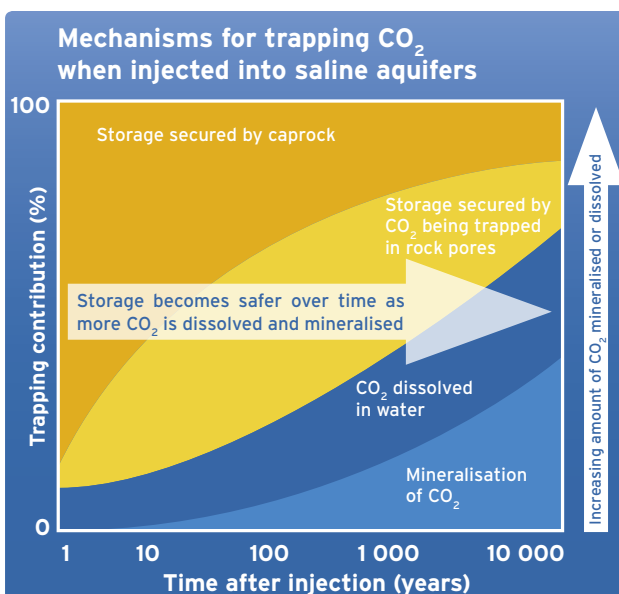
Jänschwalde has been chosen to carry out the demo-phase of Vattenfall's CCS project in Germany. Jänschwalde is an existing 3 000 MW, lignite-fired power plant situated about 150 km south-east of Berlin, close to the Polish border. It consists of six 500 MW blocks, each comprising two boilers and one steam turbine. One of these blocks will be equipped with CCS, which in this case means that one of the two boilers will be retrofitted with Postcombustion equipment and one new Oxyfuel boiler will be added.

Thereby both CO₂ capture methods will be tested intensively and eventually the plant in Jänschwalde will supply electricity generated using CCS technology to around 750 000 households in the region. Compared to a conventional plant, the new CCS block will reduce the CO₂ emissions at Jänschwalde by approximately 2.7 million tonnes per year.



Jänschwalde power plant

Did you know?



Natural analogues to geological carbon dioxide storage

In nature one can find several analogues that can provide useful information regarding the sustainability of the long-term storage of carbon dioxide (CO₂) in geological formations. There are numerous examples of geological formations where large amounts of oil, water and gas have been safely stored for tens of millions of years. These places can provide information about which types of environment could provide safe storage sites that have the potential to contain CO₂ for a very long time.

One good example of a natural accumulation is the Pisgah Anticline northeast of the Jackson Dome in the United States, which traps 200 million tonnes of CO₂. The CO₂ is thought to have been formed more than 65 million years ago and the formation shows no evidence of leakage. The analogue provides evidence that, with appropriate site selection, CO₂ can be successfully stored in geological formations for geological time periods.

One major difference between an engineered storage site and a natural accumulation of CO₂ is that natural accumulations occur without the careful site selection that would precede an engineered storage site. Natural accumulation of CO₂ normally occurs over long periods of time in various types of environment. Some may prove to be able to store the CO₂ without any leakage over tens of millions of years, while some will be in places with a continuous leakage of CO₂ towards the surface.

Natural leakage provides information

Sites that have a natural leakage of CO₂ are therefore not suitable as natural analogues for the storage of CO₂. Natural leakages of CO₂ are also primarily found in seismically-active areas with volcanic activity, which would not be selected as suitable storage sites. They are, however, useful in that they may provide information about leakage pathways and mechanisms, which can be used for risk prevention. At natural leakage sites, the CO₂ often surfaces from a variety of sources including natural springs, wells and through the soil. CO₂-rich natural springs are often exploited to produce mineral water, and the places are sometimes used as spa resorts and tourist attractions.

Mammoth Mountain, a seismically-active volcano in California, is an example of a site with a natural leakage of CO₂. After a swarm of earthquakes in 1989, large areas of dead trees were found in the area. At Mammoth Mountain, the CO₂ accumulates seasonally under the snow. In 1989, a park ranger showed signs of CO₂ asphyxiation and in 1998 a man died in a deep snow cave due to high levels of CO₂. However, the national forest and ski resort of Mammoth Mountain is still a popular recreation area, but people who visit are warned about digging holes and lying on the ground face down in certain areas.

Another example is the city of Ciampino, located 30 km southeast of Rome in the Albani hills in Italy. The city lies on the flanks of an extinct volcanic complex, which is rapidly growing. A significant amount of CO₂ is released from numerous points within the community. Even though houses are built within areas with high fluxes of CO₂, measurements show that the indoor air in investigated houses contains less than 1% CO₂, which is probably due to the Italian custom of keeping the windows open in homes during the daytime. To minimize the risks associated with high gas concentrations in homes, the University of Rome is working together with the regional government and the local civil protection agency to develop zoning bylaws, identify risk areas and educate residents.

Conclusions

The main conclusions that can be drawn from the natural analogues are that CO₂ can be safely trapped inside geological formations for long periods of time. The lessons learned from the mentioned studies of locations with large natural surface releases of CO₂ show that the hazard to human health, even in cases with large releases of CO₂, is small. The examples of areas where CO₂ leaks naturally to the surface also show that education and monitoring are effective in minimizing the hazard to human health.

On the other side of the bridge

Vattenfall aims to be carbon neutral by 2050. For the Nordic countries, this should be accomplished as early as 2030. Vattenfall's strategy for curbing climate change is made up of many elements, of which CCS technology is only one. Increasing the use of biomass fuels, while using new or improved technology in biomass-fuelled plants, is another important measure.

In every issue of Bridging to the Future we present work performed within the Vattenfall Group, other than our CCS activities, that aims to reduce emissions of greenhouse gases. The topic for this issue is our commitment to increasing the Group's use of biomass.

Short-term and long-term goals

2009 marks the official start of Vattenfall's Group-wide Biomass Programme, which will address the issue of getting more biomass fuels into the Vattenfall system. The objective of the Biomass Programme is to reduce Vattenfall's carbon dioxide emissions by increasing the amount of biomass fuels in the Vattenfall fuel mix. A number of activities must be implemented if Vattenfall is to achieve this objective.

The plan is that the Vattenfall Group will replace 6 million tonnes of coal with 10 million tonnes of biomass annually. This will significantly reduce emissions of fossil carbon dioxide. In the short term, Vattenfall is already able to use or increase the use



Wood chips fed to the CHP plant in Motala, Sweden

of biomass fuels in several existing coal-fired plants.

If the development in this field continues to move towards significantly increased volumes of biomass fuels, there are realistic possibilities to convert additional coal-fired plants to biomass combustion, or to build new plants.

Our use of biomass today and in the future

An increased use of biomass fuels will pose technical challenges, but Vattenfall has been pursuing research and development work in the field of biomass fuels for more than twenty years. Thanks to this, Vattenfall already has an advanced position in the field, with more than 30 biomass-fired power plants and specialized knowledge in the area.

Vattenfall's position needs to be strengthened even further though, to reach our goals for the increased use of biomass fuels. Therefore, our R&D in the field has now shifted from being problem-oriented to being more focused on how we can significantly increase the amount of biomass fuels used in our generation system. New and effective business solutions, as well as technical solutions, need to be found. As of today, the business aspect presents a greater challenge than the technical part.

Strategy for securing fuel supply

When starting up the Biomass Programme, it is important to decide what strategy should be used to supply our energy system with more biomass fuels. For example, Vattenfall is analyzing the potential of cooperating with different prospective partners. When there is a supply shortage, we must search globally and avoid contributing to spiralling prices for biomass fuels.



Straw is frequently used as biofuel in Denmark

CO₂ transport in Weyburn – A comparison with CCS

In North America, CO₂ transport in pipelines has been practised for decades. The reason for this is EOR, Enhanced Oil Recovery. In EOR, CO₂ is used as an agent for increasing the amount of oil that can be recovered from an oil well. Vattenfall has had direct contact with the Weyburn project in the US and Canada for several years. Early this year it was time for another visit. In this article, we will discuss similarities and differences between CO₂ transport for EOR in America with CO₂ transport for CCS in Europe.

Examples of how CO₂ is captured, transported and injected underground are important to identify and study; especially good examples where the operations are established, accepted and work well. In Weyburn, the CO₂ in question is one of several by-products in the Great Plains Synfuels Plant, where synthetic methane is the major product from lignite. The plant is run by Dakota Gasification Company and located in North Dakota.



Travel along pipeline route through a sparsely-populated area.

The captured CO₂ is then transported across the border to the Weyburn oil field in Canada, where it is utilised for EOR. The transport is conducted at a pressure of 145-200 bar in a pipeline with a diameter of 300-350 mm, for a distance of 320 km. These operations show both similarities and differences compared to the demonstration cases that Vattenfall is planning for CCS from power plants.

Similarities

The size of the Weyburn project corresponds to the demonstration cases that Vattenfall plans for; the mass flow in Weyburn is about 2 million tonnes annually and the diameter of the pipeline is about the same as we will probably use. However, in our Danish CCS demo project the distance is significantly shorter and in our plans for Germany the distance will probably also be a lot shorter than in Weyburn.

The temperature and pressure levels are also about the same, even if Weyburn utilises a higher pressure because of the longer distances and the minimum miscibility pressure in the oil field. The compressors used to reach these very high pressures are of the same large size in Weyburn as planned for in Vattenfall's demonstration projects.

Other similarities are that the transport is conducted on-shore in a buried pipeline and the fact that the major system components are an industrial CO₂ source and CO₂ injection in a geological formation on-shore.

Differences

Although there are many similarities between the activities in Weyburn and the plans that Vattenfall has for CCS demonstration plants in Europe, there are also differences. Weyburn normally has a constant flow of CO₂ from the source. In the Vattenfall cases, the flow will be a result of the fast load changes in electricity generation that sometimes are required. This is especially the case in Denmark, where the high amount of wind power in the electricity mix makes heavy demands on power from coal-fired power plants as control power. Wind power is also extensive in Germany and it is not excluded that the case will be the same there too eventually.

The Weyburn pipeline is located in a very sparsely-populated area, whereas the European cases will be more populated. The areas that Vattenfall are looking closer into, the northern part of Jutland in Denmark and the eastern parts of Germany, are not densely populated, but still more populated than the prairies of North America. The people who do live in the Weyburn area have a long tradition of oil- and gas operations, and the CO₂ pipeline and CO₂ injection was in this context an unproblematic addition. This may not necessarily be the case for Vattenfall's demonstration projects, although we are working in

close cooperation with landowners and other residents in the areas in question.

One final, identified difference is that in Weyburn the CO₂ is injected for EOR, and also recirculated, which is different to aquifer storage. This has an impact on the transport and the pipelines through the CO₂ quality requirements, which are specified for EOR purposes. The requirements for aquifer storage CO₂ will probably be somewhat different, but this has still not been specified.



Weyburn central receiving terminal for CO₂ pipeline.

Planned Oxyfuel Conference in Cottbus in September 2009

The International Energy Agency Greenhouse Gas R&D Programme (IEA GHG) will hold the first International Conference on Oxyfuel Combustion between 8-11 September in Cottbus, Germany. The three-day conference was born out of the rising demand for more worldwide Oxyfuel workshops, which IEA GHG has organised earlier. Vattenfall will host the planned conference and is involved in the present planning process.

The objective of the conference is to provide a forum for engineers, scientists, power plant operators, equipment manufacturers and service providers to discuss various issues relevant to Oxyfuel combustion technologies. Another objective is to share experience and discuss information obtained from various large-scale Oxyfuel combustion technologies in the Oxyfuel community. The conference will also provide opportunities for young researchers to present their work and meet with industry experts.

Visits to the Schwarze Pumpe Oxyfuel pilot plant will be organised on day four for interested conference

participants. Presentations on the achievements in the pilot plant will be given during the conference.

More information can be found on IEAGHG's website at: www.co2captureandstorage.info/networks/oxyfuelmeetings.htm



Why is Schwarze Pumpe called Schwarze Pumpe? – The interesting history of the German village

For most readers of Bridging to the Future, Schwarze Pumpe is the name of both a lignite-fired power plant and the CCS pilot plant in the German federal state of Brandenburg. But since the German power plants are named after the villages they are situated in, Schwarze Pumpe also stands for a part of the town of Spremberg that has an interesting history.

The name of the village Schwarze Pumpe was first mentioned in 1852 and came from the name of a restaurant called "Die Schwarze Pumpe", "The Black Pump" in English. According to a legend, a watering whole (a "pump") for horses was erected next to the then nameless restaurant back in the early 17th century. This was at the time of the Thirty Year's War when Swedish troops under King Gustaf II Adolf ravaged in the area. In 1630, the Swedish army had landed on the shores of Usedom, a peninsula in Mecklenburg-Vorpommern, defeated the German troops and forced them into an alliance. The Swedish troops advanced and reached the southern parts of Germany during the following year. In 1634, the German army was able to win over the Swedes and force them back up north.

To protect the restaurant and the residents close by from the itinerant Swedish mercenary soldiers, the pump was painted black. The reason for this we can find in the meaning of the colour black. The colour black indicated the ravages of the feared "Black Death", the plague, in the region at this time. The action was successful; the Swedish soldiers avoided the place and plundered elsewhere.

The 20th century and its emerging industrialization marked the start of the mining activities and the first power plant in the region. The coal-fired power plant Trattendorf - Schwarze Pumpe grew and became a settlement with a few hundred residents, but the Second World War stopped the development. From 1955 on, the mining activities in the region continued and the first power plants in Schwarze Pumpe were built. In 1998, the existing power plant Schwarze Pumpe was commissioned and ten years later the CCS pilot plant was officially inaugurated.

People in the region still know the legend about the "black pump" and how it prevented the Swedes from entering the village and destroying it. Today they joke that the colour of the pump did not stop them coming back 350 years later. This time, the Swedes' presence in the area has other objectives; the development of the region and a joint fight against climate change.



A black pump outside the power plant Schwarze Pumpe to remind of the history of the village.

The editor signs off

After having worked with Bridging to the Future since the start in 2004/2005, and as the editor since issue number 2, that is for 12 issues now, it is high time to hand over to new talents and to take on new challenges. The first challenge is of a private nature; that is becoming a parent, which I am looking forward to with a mixture of delight and trepidation.

I would like to take this opportunity to thank everyone who has contributed to the newsletter over the years in the form of textual or pictorial material, ideas, checking or comments and so on. This applies to you all whether you are colleagues within

the Vattenfall Group or other external contacts. Without you it would not be possible to produce a newsletter! I would also like to thank the readers of Bridging to the Future for their comments and the interest they have shown in our work on CCS. Finally, I would like to wish my successor Kristina Leufstedt every success with the work that awaits her.



Stina Rydberg, Editor