BRIDGING TO THE FUTURE

Newsletter on Carbon Capture & Storage at Vattenfall | No. 15, April 2010

VATTENFALL

About Carbon Capture & Storage at Vattenfall

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 part of the solution. Vattenfall is committed to reducing carbon dioxide (CO_2) emissions. Carbon Capture and Storage, CCS, is one method to achieve this, and for this reason we initiated our efforts on CCS in 2001. The aim is 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 is Europe's fifth largest generator of electricity and the largest generator of heat. We currently have operations in Denmark, Finland, Germany, the United Kingdom, Poland, the Netherlands and Sweden. Our vision is to be a leading European energy company.

CCS at Vattenfall in brief:

- A **demonstration** project has been started in Germany. At the Jänschwalde power plant, both Oxyfuel and Postcombustion CO_2 capture will be demonstrated on a large scale. Different storage options are currently being investigated.
- Nordjyllandsværket in Denmark is a possible "early commercial" power plant, with Postcombustion capture. The CO_2 would be transported in a 30-kilometre pipeline to the Vedsted underground structure for storage.
- **R&D** to support the pilot and demonstration projects is performed in all parts of the CCS chain; Capture, Transport and Storage. Most well known is the **Oxyfuel Pilot Plant** in Schwarze Pumpe in Germany that has been in operation since 2008. The CO_2 could 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.

Since the merger with NUON on July 1 2009, Vattenfall also has CCS activities in the Netherlands. The activities comprise additional R&D through a Precombustion CO_2 capture pilot plant at the coal gasification plant in Buggenum and plans for the large-scale Precombustion CCS project at the Magnum plant in Eemshaven, Groningen.

Bridging to the Future

Bridging to the Future is the CCS project's newsletter and it is circulated three times a year. The newsletter's ambition is to give a comprehensive picture of all parts of the projects and keep the readers up to date on advances in research. All the 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 Kristina Leufstedt at: kristina.leufstedt@vattenfall.com.

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

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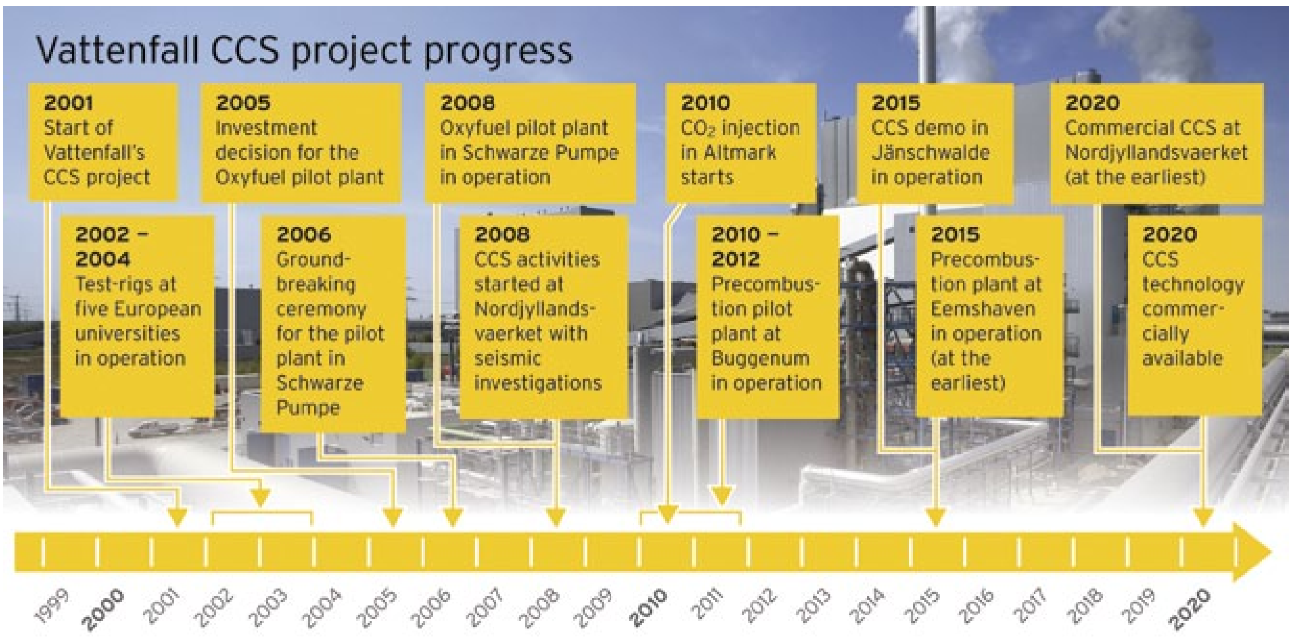
Kristina Leufstedt is editor and Staffan Görtz is legally responsible for this newsletter.



We're Prepared to Demonstrate CCS

On 6 January this year we signed the contract with the European Commission for €180 million of funding from the European Energy Programme for Recovery (EEPR) for our CCS Demonstration Plant at Jänschwalde, Germany.

CCS is now to be demonstrated in full scale at Jänschwalde and other sites all around the EU. The investment in the Jänschwalde Demonstration Plant, including capture, transport and storage, will amount to around €1.5 billion. We are prepared to cover a substantial percentage of this investment, but we are also dependent on additional funding. The €180 million that we have already been awarded is a start, but more is needed for the plant to operate at competitive cost levels.

Once CCS has been successfully demonstrated on a large scale we believe the technology and market will mature for CCS to become competitive by 2020. No additional funding will be needed as soon as CCS has proven to be competitive.

By making large investments in R&D, pilot plants and participating in EU co-funded projects we have shown that we are determined to take part in the development of CCS - all the way from R&D to development in competitive plants that can be erected and operated on a commercial basis. We are convinced that we will succeed with the necessary public support.

Reinhardt Hassa
Head of Business Unit
Mining & Generation

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Further tests at Schwarze Pumpe

The Oxyfuel pilot plant at Schwarze Pumpe has now been running for one and a half years and has given us extensive operational experience of the full Oxyfuel process. Another objective of the project is to perform test measurements and data evaluation for the different parts of the process. The new year has started with intensive test activities on site at Schwarze Pumpe.

The measurements are divided into different packages, so-called test campaigns. Some campaigns are defined with separate test objectives for the individual process components and some campaigns are run to test the overall plant performance.

The coordination of the tests is a true challenge, as there are many teams involved and each team has its own objectives. The timing is also crucial, with some tests running over the whole campaign and others only for six hours. After each campaign there is a lot of work to be done. Each measured part provides a lot of data that has to be processed and analysed to enable presentation of the results in an understandable way. This is difficult work where many answers are given, but also many new questions are raised.

Tests in the furnace

The most important task for the combustion investigations is to quantify important differences between the well-known air combustion process and the new Oxyfuel process. The main areas of interest are possible changes in the heat transfer properties, changes in the coal particles' burnout behaviour and changes in how NOx is formed. So far, tests have been made using two burners with different geometries; a fact that has given different results. Both burners have been in operation in both the air- and Oxyfuel-firing modes.

Tests of the flue-gas cleaning

The flue gases from the combustion chamber are cleaned in three steps. Particles are removed in the electrostatic precipitator (ESP). The flue gas desulphurisation unit (FGD) removes sulphur oxides and the flue-gas condenser (FGC) removes water from the flue gases. The ESP investigations are focused on the efficiency of the particle removal and whether this varies under different operating conditions. The composition and size distribution of the collected ash are also analysed.

In the FGD, limestone is added and forms gypsum together with the sulphur oxides. This is conventional technology, but the question is how the efficiency is affected when the flue gas mostly consists of CO_2 instead of nitrogen. The amount of limestone required and the quality of the gypsum must be thoroughly investigated before the scale-up to demo-plant is made.

The investigations in the FGC are focused on the influence of certain operational parameters on the efficiency of water removal. The water balance and the condensate quality are also studied.

Tests in the CO_2 plant

In the CO_2 plant, the composition of the incoming flue gas and the outgoing CO_2 product will be analysed and the compression to liquid phase will be tested. So far, the focus has been on evaluation of the behaviour of NOx and SOx in the process.

Material tests

Because of the flue gas recirculation in the Oxyfuel process, the levels of sulphur oxides in the furnace and other parts of the process are higher in comparison to conventional lignite combustion. Investigations of corrosion rates and material resistance are therefore of the utmost importance. The corrosion investigations have so far focused on probe exposure tests in the furnace and boiler section.

Some analysis of the build-up and composition of deposits has also been performed. Future material testing will also look into corrosion in the low-temperature parts of the process, i.e. downstream the FGC.

Wintry scenery at Schwarze Pumpe

Co-firing biomass with lignite

In the latest issue of Bridging to the Future, we wrote about an initiated feasibility study on the co-combustion of lignite and biofuel in the pilot plant at Schwarze Pumpe. The study has now been completed and the results show major potential for using biofuels in co-firing in the Oxyfuel process.

The options looks slightly different depending on the fuels, but the common line in this study show that co-firing would be possible. The studied mixing rate is 10 per cent and the results indicate low risks and that there could even be some benefits from using biofuels and lignite together.

The study is based upon four fuels that have similar qualifications to lignite. The fuels are accessible in the area around the pilot plant, at other sites in Germany or in neighbouring countries.

The effects on the CO_2 emissions could be considerable, if the result from this co-firing is to be treated as negative. The feasibility study has identified legislative issues and fuel supply as potential risks involved in realisation of co-firing of biomass.

Support from the European Commission: Vattenfall's CCS Demonstration Project Receives EUR 180 Million

Vattenfall's planned demonstration project for CCS at Jänschwalde in Brandenburg will receive up to EUR180 million of funding from the European Commission. The funding derives from the European Energy Programme for Recovery (EEPR) that was adopted in June 2009. A total of six CCS projects are being supported with money from this source. Vattenfall's project, which includes the building of a 385 MW demonstration plant as well as the construction of a transport infrastructure and the underground storage of CO_2, has been ranked as the most advanced CCS demonstration scheme within the European Union.

This year, the preparations for the foundations of the demonstration plant will commence. The plant will be integrated in an existing 3 000 MW lignite power plant at Jänschwalde, utilizing both Oxyfuel and Postcombustion, thus enabling one of the six blocks of the power plant to run with CCS and making it possible to test the technology on a large scale.

Possible storage sites for the CO_2 have in the meantime been found in the region of Eastern Brandenburg, where the seismic surveys are to begin in September 2010. If the structures prove to be suitable for the underground storage of CO_2 in the years to come, the demonstration project could commence operation and the plant could be connected to the grid in 2015 at the latest.

Investments costs

Vattenfall estimates the investment costs to amount to EUR 1.5 billion. With a CO_2 capture rate of well over 90%, up to 2.7 million tonnes per year of this greenhouse gas could thus be kept out of the atmosphere. Since the company's investigation about capturing CO_2 from fossil-fuelled power plants started in 2001, Vattenfall has already made available and invested over EUR 200 million for the development of CCS technology. The funding now granted by the European Commission will enable an even faster development of the needed technology and will also inure to the benefit of the region.

CCS Activites in the Netherlands –Buggenum Pilot Plant designed for Precombustion technology

As of 1 July 2009, Nuon is part of the Vattenfall Group. Nuon is a Dutch energy company whose 6 000 employees serve around three million consumers, businesses and organisations in the Netherlands and Belgium. Nuon produces and supplies gas, electricity, heat and district cooling and helps customers to reduce their energy use. The partnership between Nuon and Vattenfall has a strong strategic rationale, based on complementary geographies, assets and competences, as well as a strong cultural fit.

With the acquisition of Nuon, all three available CO_2-capture technologies are now represented within Vattenfall. The Oxyfuel technology in the pilot plant at Schwarze Pumpe, the Postcombustion technology that is to be demonstrated at the Jänschwalde demo plant and the Precombustion technology in Buggenum in the south of the Netherlands. In this article you will learn more about the plant in Buggenum, the carbon capture pilot and the Precombustion technology used.

Buggenum, close to Roermond in the Dutch province of Limburg, is the location of the Willem Alexander power plant with a net production capacity of 253 megawatts, enough to supply electricity to 400 000 families. At Buggenum, coal is gasified instead of fired. The power plant at Buggenum was commissioned at the end of 1993. It was originally designed for coal gasification only, but now biomass is also gasified for subsequent co-combustion. This combination is not to be found anywhere else in the world. It allows the power plant to reduce its CO_2 emissions by 22 per cent. This means 300 000 tons of CO_2 a year, roughly equivalent to the annual exhaust emissions of 200 000 passenger vehicles.

Gasification technology - how does it work?

In coal gasification, fuel is first transformed into a combustible gas known as synthesis gas, or syngas for short. This gas is then cleaned and desulphurised. The syngas is then suitable for combustion in a steam and gas turbine (Combined Cycle Gas Turbine – CCGT) where it is converted into electricity.

Benefits and technical challenges of gasification technology

Gasification has the advantage that very low levels of SO_x, NO_x, particulates and mercury are emitted. At the end of the gasification process some residual products remain, which are captured and reused. Slag and fly ash can be used in concrete production and road building. Sulphur can be sold to and processed in the chemical industry.

However, there are some technical issues in connection with gasification that need to be resolved. A challenge for the concept, when CO_2 capture is added as well, is the development of a high-efficiency gas turbine for the combustion of hydrogen-rich fuels. Another frequently discussed issue in connection with gasification is that of reliability, availability and maintenance. Also, there is the higher specific investment (€/kW) compared to a supercritical pulverized coal plant of a comparable size.

The process of CO_2 capture

The first step in the gasification process is transforming coal into syngas. Fly ash and contaminants are then removed. This cleaned syngas is used in the pilot plant. At the syngas treatment section of the pilot plant some of the remaining contaminants found in the syngas are removed. In the water-gas shift section, steam is then added to allow efficient conversion of carbon monoxide to carbon dioxide.

The condensate recovery section then removes and recovers the excess water vapour present in CO-shifted syngas. Next, this CO-shifted syngas is separated into a hydrogen-rich gas stream and a CO_2-solvent mixture in the CO_2 absorption section. Subsequently, in the solvent regeneration section, CO_2 is released from the solvent in flash vessels and the solvent can be reused again.

The CO_2 compression section takes the stream separated from the solvent and supplies it at an adequate pressure back to the normal syngas line. The function of the solvent storage section is to hold and dispose of the spent solvent and to store and accept fresh solvent, enabling stable operation of the CO_2 absorption section.

CO_2-capture pilot

A CO_2-capure pilot plant is set up at the Willem Alexander plant at Buggenum. The pilot will go into operation as from August 2010. The first test results will be available in December 2010.

Through this pilot, the aim is to make the Precombustion CO_2-capture technology suitable for the energy sector and to optimise the process. The knowledge and experience gained focus on ensuring an efficient CO_2-removal process by testing various conditions and solvents and mastering the operation of the CO_2 removal unit. After successful completion of the pilot, CO_2 capture will be applied at the Magnum multi-fuel power plant in the province of Groningen in the north of the Netherlands.

How does the Gasification technology work?

A Coal is delivered from the port to the plant, where it is milled and dried. The pulverised coal is then blended with milled biomass. It is stored under nitrogen to prevent the risk of explosion, brought up to pressure with nitrogen and transported to the gasifier.

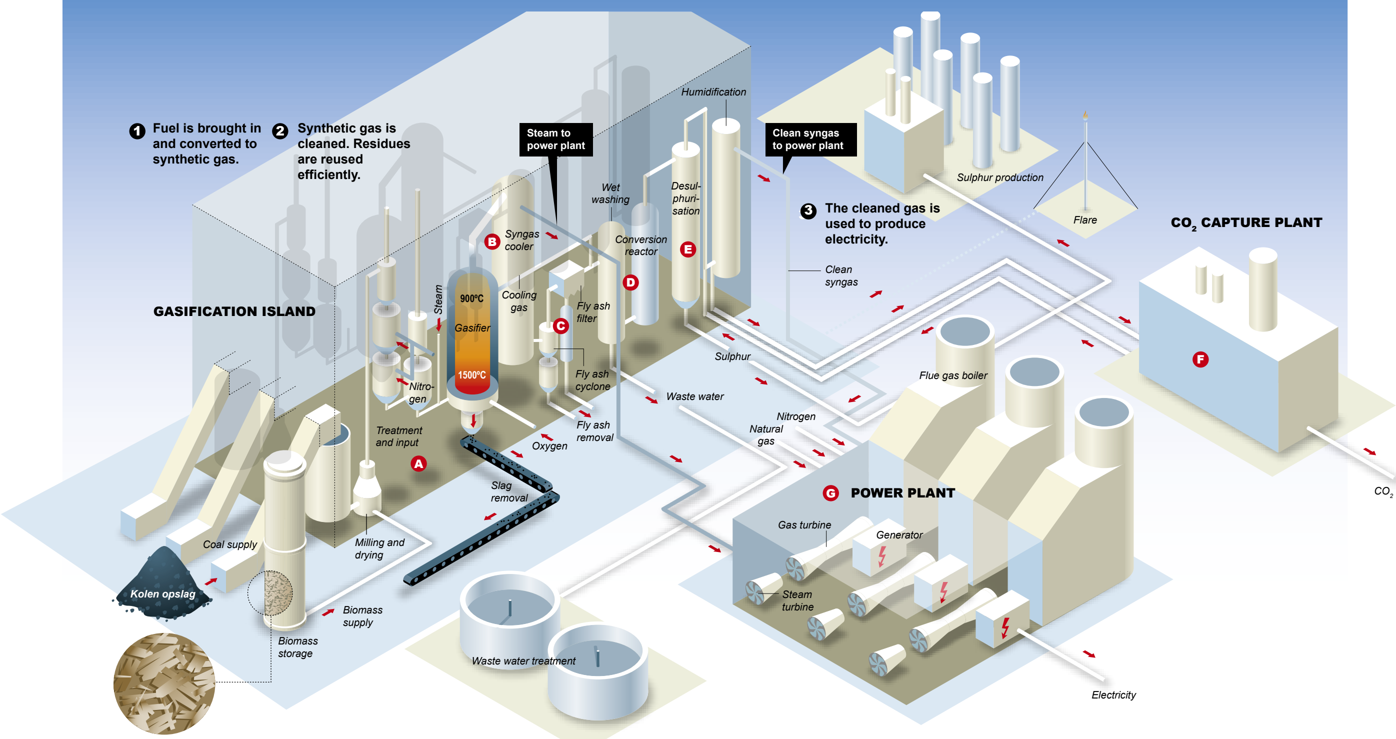
B Oxygen is added to the coal, which is converted into syngas under pressure and at high temperature. The non-combustible part of the coal (minerals) solidifies and is removed as slag. The syngas consists primarily of carbon monoxide and hydrogen and at this stage still contains various pollutants. These pollutants are removed step by step. The syngas is then cooled in the syngas cooler. The heat that is released is converted into steam. In the air separation plant, oxygen and nitrogen are drawn from the atmosphere at very low temperatures. As already stated, these gases are used in the process.

C In two steps the fly ash - fine particles that also contain non-combustible materials from the coal - is removed from the gas.

D The gas is washed with water. This removes the soluble compounds present in the coal, such as chlorides and fluoride, extracting them from the gas.

E During the subsequent sulphur removal process, H_2S (hydrogen sulphide) is extracted from the syngas. In this process over 99% of the sulphur from the coal is bound and converted into pure sulphur. This is reused in the chemical industry. A very small part of the sulphur goes into the air via the flue gas burner as SO_2.

F The purified syngas is thinned with nitrogen and saturated with water vapour in the saturator so as to achieve low NO_x emissions; it then goes to the gas turbine. Here the coal gas is combusted, driving the gas turbine. The hot flue gases from the gas turbine are cooled in the flue gas chamber. The heat released is used to create steam, which drives the steam turbine. The ultimate electricity generation takes place in the generator, driven by the steam and gas turbines in tandem.



As explained earlier, in gasification the coal is first transformed into syngas, which is cleaned and then used to generate electricity. In the pilot plant, 0.8% of the syngas produced in the Buggenum gasification process is tapped off. This syngas comprises mainly the combustible components H_2 and CO. It is relatively easy and efficient to remove CO_2 from the syngas by means of a so-called CO shift. Steam (H_2O) is added to the syngas, causing a chemical reaction ($H_2O + CO = H_2 + CO_2$) in a catalytic converter and giving rise to a syngas with H_2 and CO_2. About 90% of the CO_2 is then separated by means of a washing solvent.

Research & Development Programme

The pilot programme also contains a complete research and development programme for monitoring and optimising the process of CO_2 capture. The Dutch R&D Programme is also working together with leading parties such as ECN, KEMA, TNO and the Delft University of Technology. The R&D programme is divided into the following work packages: plant operation and optimisation, the water-gas shift section, the CO_2 absorption section and fouling and corrosion.

The ministries VROM (Housing Spatial Planning and the Environment) and EZ (Economic Affairs) have underlined the importance of the trial by granting a targeted subsidy via de Unieke Kansen Regeling (Unique Opportunities Scheme).

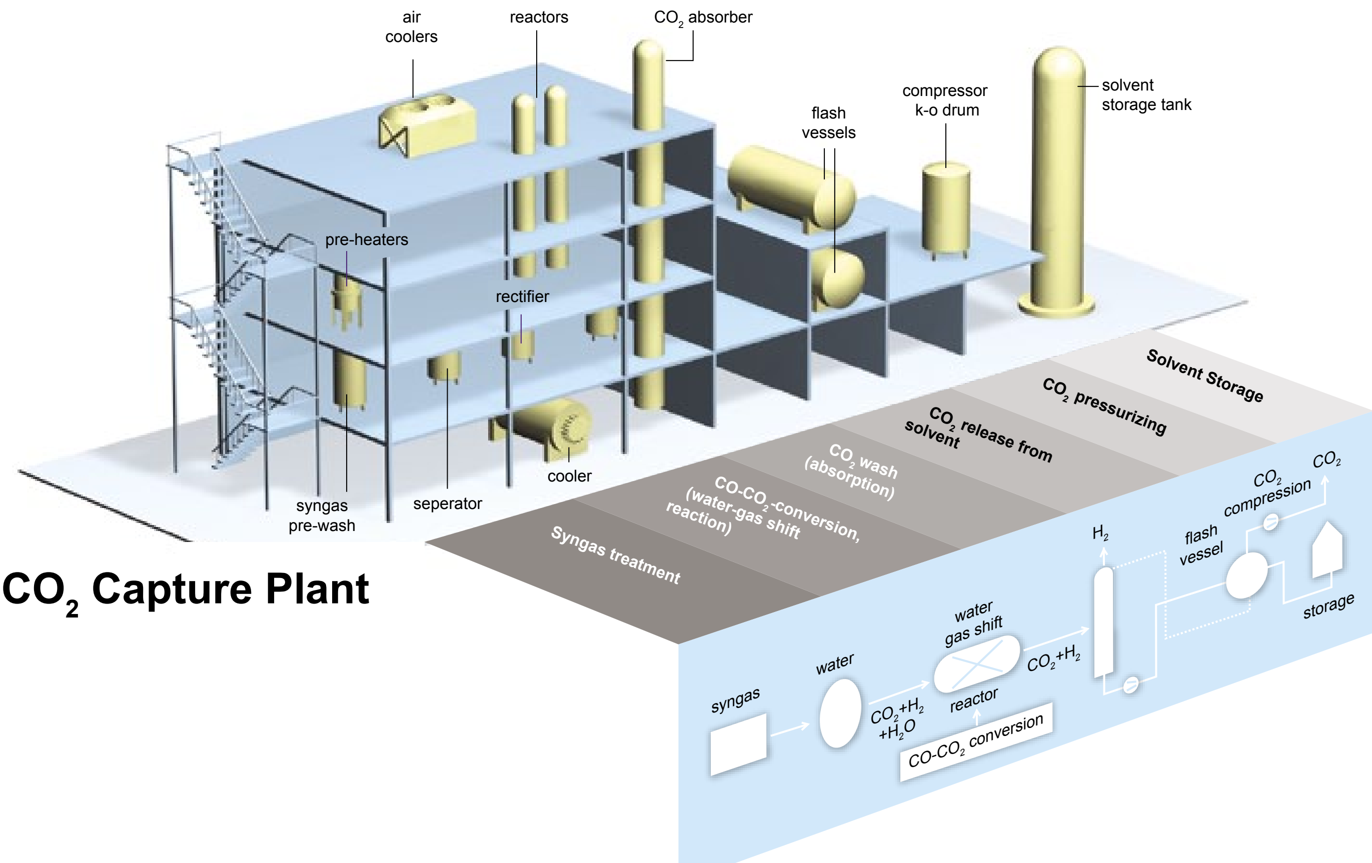
Magnum

The power plant is, like the one in Buggenum, based on the gasification technology and can generate electricity from gas, coal and biomass. This power plant combines sustainability with production capacity. It has a capacity of 1 200 megawatts and can generate electricity for two million households.

Magnum is based on the so-called multi-fuel concept. This is an efficient electricity plant based on a wide range of fuels such as natural gas, coal and biomass. This flexible set-up allows for the generation of electricity but also of products like hydrogen. So if wind energy is abundant, the plant can produce hydrogen instead of electricity.

Willem Alexander plant

253 megawatts
2 000 tons of coal a day
Up to 30% biomass
Start pilot: 1 August 2010
First results pilot: 15 December 2010



CO_2 Capture Plant

CCS Costs and Drivers, part II

In the last issue of "Bridging to the Future", the costs of novel technology and financial drivers were discussed. In this follow-up article, the focal point will be on demonstration plants. The discussion focuses on answering two questions: why are the demonstration plants much more expensive than the later commercial solutions and what are the EERP and NER funds all about?

Together with many other energy companies, Vattenfall is making plans for the next step in CCS development: the demonstration plant (demo plant). Although we have learnt a lot about Oxyfuel operation in the pilot plant at Schwarze Pumpe and other collaboration projects, the demo plant is a necessary step in the scale-up towards a commercial CCS concept. A demo plant is large enough to be able to draw valid conclusions about CCS on a real power-plant scale and about the large-scale transportation and storage of CO_2, the financial situation and so on, but at the same time small enough to minimise risks and costs.

CCS demonstration plants will be more expensive

The demo plant deployment phase will be more expensive than future commercialized projects. Concurrently with the technology development, all players learn more about the implementation of CCS and as the technology matures. McKinsey & Co describe this very clearly in their report "Carbon Capture and Storage: Assessing the economics". One of the biggest reasons for higher costs in the demo phase is scale effects. The relatively smaller-scaled demo projects simply have a higher specific project cost than larger commercial projects.

Another reason is that suppliers need to get coverage for their development costs and the increased risk when engaging in new technologies. This cost is spread over the first plants. Of course, Vattenfall wants to buy equipment at as low a cost as possible. This is a very good reason for making sure that as much technology as possible is tested and validated in pilot scale before the scale-up to demo size. Yet another reason for the cost increase is an expected lower availability of the power plant during the first years of operation, mainly due to the large-scale implementation of new technology.

Building a CCS demo project is a lengthy process; a fully-integrated project can take from 6 up to 10 years. Time is of course a fundamental factor, but the most crucial element of any demo project is the financing. Each CCS demo project requires high capital expenditure due to the demo phase's need for product development, the verification and optimization of the component choice and the processing and reduction of risks.

The Jänschwalde demo plant will, for example, demand EUR 1.5 billion in capital expenditures, while the cost for other projects will be less than EUR 1 billion. Every step is part of the preparation for the realization of a commercially-viable concept in 2020. Vattenfall, among other companies in the industry, is willing and able to demonstrate CCS on a large-scale, but each demo project will incur significant costs and risks for the company.

Transportation and storage

The costs for transporting the CO_2 are much lower than the capture costs. The transport costs are, however, highly dependent on the distance between the power plant and the storage site and whether the storage site is situated on or off shore. Transporting CO_2 by pipeline costs less than transporting it by ship. In an early stage of CCS development, ship transport might nevertheless be competitive, because of its flexibility and short lead times. In the future, it is possible that new power plants with CCS will be built close to the CO_2 storage site in order to simplify the transportation of CO_2. Today, plants are instead built close to where the electricity consumers live and work, which entails greater transport expenditure.

Finally, the storage of CO_2 will entail considerable costs, especially in the start-up phase. Exploration, preparation and setting up a functioning infrastructure at a site costs time and money. If the storage is located offshore, the costs will increase, due to the more complicated infrastructure and availability. Monitoring storage integrity after injection is necessary and also entails a cost that should be taken into account. ▶

Financial support - EEPR and NER300

The need for financial support for actors developing CCS has been recognised by the European Commission and two financial programmes for the support of CCS demonstration projects have been developed, EEPR and NER 300.

EEPR, the European Energy Programme for Recovery supports in total 15 energy projects, six of them are CO_2 capture and storage projects. The selected projects are supposed to contribute towards reaching the binding targets for greenhouse gas emission reduction and renewables by 2020 and beyond. The highest-ranked CCS project was the Jänschwalde demonstration plant, which was granted a maximum of EUR180 million in Community contributions.

In the New Entrants Reserve fund, NER300, up to 300 million allowances from the greenhouse-gas emission allowance trading directive (ETS directive) are set aside to support CCS and innovative renewable technologies. NER300 will most likely finance a minimum of 8 CCS projects in four categories (Oxyfuel, Precombustion, Postcombustion and industrial applications).

Funding is necessary for demo and commercial deployment

Sascha Lüdge works in different parts of the Jänschwalde demo project. He has been involved in the implementation of the EU CCS directive but has also worked with financial schemes for the demonstration projects. When asked why the EERP and NER funds are important for Vattenfall's demonstration project, Sascha explains, "Vattenfall believes that CCS will be commercial by 2020 and that the price of CO_2 will cover the extra expenses for the technology. However, for the moment, the gap between the price of carbon-dioxide emissions and the cost of a CCS demonstration plant is far too big for the industry to bear alone. The gap has to be closed and this is partly done by the EERP and the NER funds".

Up-front payment

Sascha Lüdge continues by saying: "There is also the issue of when the money will be distributed. As is often the case with new technologies under development, CCS demands a lot of investments in an early phase. Considering the nature of the projects, up-front payment is an important factor. Vattenfall therefore appreciates that the EEPR has adopted this idea and hopes that the same will be the case for NER300."


Sascha Lüdge

No CCS without Storage

Professor Niels Peter Christensen has worked with CO_2 storage for almost 15 years. In 2009, Vattenfall formed the Technology Development Centre for Carbon Capture and Storage (TDC CCS) to coordinate CCS efforts in all countries in which Vattenfall is represented, and Niels Peter was naturally asked to become chief geologist. Today he serves as Vattenfall's leading expert in the field, which is a sign that environmental issues has been given the utmost priority.

Niels Peter Christensen is very clear when pointing out the greatest and most critical challenge in the efforts to implement CCS at Vattenfall's coal-fired power plants. He explains the situation as follows: "We know for certain that there are good storage opportunities in the countries where Vattenfall has coal-fired plants. The work, then, consists of turning these storage possibilities into real storage capacity – and that's not as easy as it immediately appears."

In addition to seismic and geological studies – which will be carried out using the latest state-of-the-art technology – the situation is markedly different when it comes to gaining local acceptance for CO_2 storage projects. There is no doubt that CO_2 storage is a controversial idea among local populations, not least in the actual areas where storage facilities could be located.

From Vattenfall's side, we must continue to provide people in the local areas with solid, useful information so that they have an accurate picture of the situation at hand. This also entails sifting through all the myths in order to reach the hard core of useful information.

What's in it for us?

"We're still in need of a clear message from political decision-makers that CCS is part of the portfolio needed to reduce climate change," says Niels Peter Christensen, who continues, "People shouldn't simply see coal as part of the problem; they must also come to recognise that coal is part of the solution!"

Political engagement is important in creating local acceptance for building a CO_2 storage facility beneath the feet of local populations, and we must therefore work hard to find local solutions and create positive value for the people living there. One way forward is to investigate the possibility of generating geothermal heat in the area. Another option may come through supporting local business communities, for instance by CO_2 storage facilities generating an increase in 'expert' tourism.

Involved in international networks

As one of few Danish experts in the field of CO_2 storage, Niels Peter was, and still is, sought after by various European and international networks and organisations. To name just a couple: he served as the chairman of CO_2GeoNet, a European network of excellence for scientists performing research in the area of CO_2 storage, and he is currently a member of the European Commission's Zero Emission Power (ZEP) Technology Platform, which advises the European Parliament on CO_2 storage issues. Niels Peter has furthermore represented both Denmark and the EU in various forums.

Niels Peter is moreover skilled at communicating scientific matter in easy-to-understand lay terms. It is therefore not surprising that he is often asked to give technical presentations and academic lectures on CO_2 storage.

In his spare time

Despite a busy professional life, Niels Peter makes room for his leisure pursuits. Whenever the opportunity arises, he and his wife head to their old merchant's house in the town of Klitmøller, in Northwest Jutland. They purchased the house several years ago and renovated it themselves. Just a few steps from the beach and the North Sea, it is an ideal place for the couple to feel the wind in their hair and take a refreshing morning dip in the cold water.

"A CO_2 storage facility is quite similar to natural gas storage or to oil or natural gas deposits: they have not leaked for thousands of years and I'm convinced that, with our knowledge of the subsurface, we can find CO2 storage capacity that is just as effective," concludes Niels Peter Christensen.

Background and Experience: Professor Niels Peter Christensen,

Age: 57

Education: Geologist who graduated from Copenhagen University's Geological Institute in 1980.

In November of 2006, Niels Peter was named an honorary professor in CO_2 storage by Herriot-Watt University in Edinburgh, Scotland

Professional experience: Until 1990, Niels Peter worked in the oil industry on research, consulting and developing oil and natural gas fields in the North Sea. He also taught classes in oil geology at the university.

In 1990, Niels Peter joined GEUS, the Geological Survey of Denmark and Greenland, where he first became interested in CO_2 storage.

Since 1997, he has also been actively involved in a number of Danish and international research and development projects in the same field, including the Norwegian-based Sleipner Project.

In 2008, Niels Peter joined Vattenfall to lead the geological work of the company's underground CO_2 storage project in Denmark.

Since 2009, Niels Peter is Chief Geologist at Vattenfall's CCS Group Function

One voice for CCS – Gaining local acceptance for CO_2 storage

Vattenfall has plans to examine two geological structures in East Brandenburg that could be suitable for the underground storage of CO_2. The saline aquifers that expand over an area of 150 km² are located more than 50 km away from the planned Demonstration Plant Jänschwalde and could close the CCS chain within the years to come.

The possible storage sites are located in two rural regions near the Polish border: Neutrebbin and Beeskow. Although only sparsely populated, they are home to around 30 000 citizens. Ever since Vattenfall went public with its plans to explore the structures in March 2009, the public have been engaged in the discussion about the potential and risks of CCS and the underground storage of CO_2. The reactions, however, have been diverse: some residents dismissed the plans initially whilst others were open for a dialogue from the beginning.

The discussion intensified during the election campaigns at the federal and regional levels in the autumn. In the meantime, the dialogue between the residents and Vattenfall has returned to a factual basis and promises to remain there. One reason for this development is that Vattenfall has decided to establish a local information office in Beeskow, one of the central cities within the region.

The information office in Beeskow

One voice for CCS - Elvira Minack

By having the information office located physically in the region, the questions and concerns of the local people can be answered directly and in person. Elvira Minack has headed the information office since August 2009. Her regional provenience has proven to be a natural door opener and, according to her, the reason why people do not hesitate to contact her with their questions. Having lived in the region for more than 15 years, explaining the necessity of examining potential storage sites has become more than just a job for Elvira: "Of course the topic comes up when sitting over a glass of wine with the neighbours as well. But that does not bother me. Quite the opposite: this direct contact enables me to show and prove that I am one of them, that I speak their language."

Speaking the local language is one pillar of her work. What also helps the 56-year-old journalist in her work is the regional network that she considers to be of special value in order to get in contact with critics and opponents: "My target is not to convince my counterpart and change his or her position fundamentally. I rather prefer an open exchange of thoughts and information. Only those who know enough about the technology and its advantages and disadvantages will be able to build a profound opinion. I personally consider knowledge to be a vital ground for acceptance."

There is no lack of activity in the information office in Beeskow: Besides the weekly office hours and a newsletter that is sent out to those interested in the project's progress, every two weeks scientific and economic experts hold public presentations on different aspects of CO_2 storage and climate protection. The office has established itself as a place for the local dialogue, but has also attracted visitors from all over the world: Guests from countries such as Japan, Norway, Denmark and Sweden have taken the chance to learn about the project and the region.

Although she is positive, Elvira Minack remains realistic: "We are progressing step by step. Just as CCS is not commercially viable yet, gaining acceptance for CO_2 storage is a process that we need to work on continuously together with the political and scientific spheres."

Elvira Minack

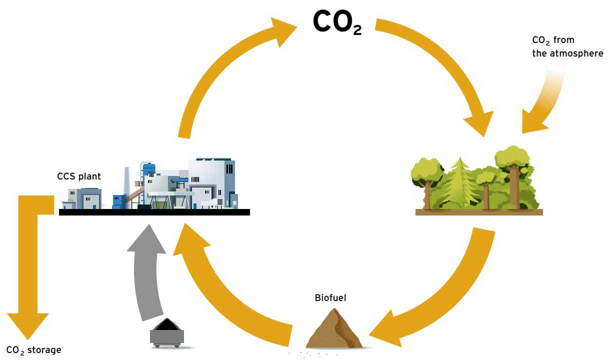
Positive Synergies Relating to CCS

The discussion about CCS in Europe mainly concerns fossil-fuel power production, due to its large CO_2 emissions. However, what are rarely discussed are other applications and interesting synergies relating to CCS. Large-emitting industries such as cement, iron and steel will, according to the IEA, have problems reducing their emissions to sufficiently low levels without capturing CO_2. Another argument in favour of CCS has increasingly come to the fore and concerns biomasses combined with CCS, which in fact can reduce the net amount of CO_2 in the atmosphere. An additional interesting area discussed in this article is how geothermal energy and CCS could benefit from each other.

Industry accounts for one-third of global final energy use, which signifies almost 40 per cent of total energy-related CO_2 emissions. Industry thus constitutes an area with a great potential for cutting emissions. According to the IEA, CCS is one of the most significant cross-cutting technologies that can potentially decrease emissions in a range of sectors. In one of the IEA's scenarios, approximately 30 per cent of the industrial sector's CO_2 reductions are achieved by applying CCS. Large-emitting branches where CCS will be needed to cut emissions sufficiently include, according to IEA, iron and steel, cement, chemicals and petrochemicals, as well as pulp and paper. Within cement production alone, the estimates are that CCS will be able to reduce CO_2 emissions by 1.0 GT by 2050.

Biomass and CCS

Biomass is considered to be a carbon-neutral substitute for fossil fuels, since it sequestrates carbon in the terrestrial ecosystem. The combining of CCS and power generation from biomass (or partly from biomass) can not only deliver energy but also remove the carbon dioxide from the natural carbon cycle by storing it at the geological storage sites. Another positive effect that this combination can offer is the possibility to offset emissions from other parts of the economy where it is harder or more expensive to do so.



Schematic of CCS combined with biomass

In principle, all the basic capture technologies under development today, such as gasification and Oxy-fuel combustion, can be applied to biomass systems. As mentioned in the article on page 5, Vattenfall has performed a feasibility study of the potential and possibility to co-fire lignite and bio fuels in the Oxyfuel process and the results are promising. Depending on the fuels, the options look slightly different but the common line in this study shows that it is feasible. The studied mixing rate is 10 % and the results show that the risks are small. It is even possible that there could be benefits with this co-firing of biomass and lignite.

In the Netherlands, co-firing biomass in fossil-fuelled power plants is fairly common. Nuon is running a number of projects aimed at increasing biomass co-firing rates. The Buggenum CCS pilot plant, near Roermond in Limburg, is co-firing biomass with a goal of 15 per cent biomass on a mass basis (10% on an energy basis) and it is intended that the planned Magnum pilot plant will use a multi-fuel concept in which biomass is one of the fuels.

Biomass production is, however, a great limiting factor due to restrictions on the land fit for the purpose. Biomass should never compete with food production and the degradation of the land and biodiversity are additional issues that have to be considered when buying and using biomass.

CCS in combination with Geothermal Energy?

The greatest potential for the geological storage of CO_2 is storage in deep saline aquifers as this offers the sufficiently-large storage potential that is needed to achieve major cuts in CO_2 emissions. Deep-lying saline aquifers are generally not considered suitable for any other large-scale use and are widespread around the world. However, society should consider and treat CO_2 storage sites as natural resources, just like other natural resources. Whatever intrinsic values these deep, porous formations may have, this must be weighed against other means of exploitation. For example, disused or depleted gas fields may have a priority use for natural gas storage projects.

For deep saline aquifers, it has been argued that CO_2 storage projects could become a barrier to future possibilities to develop geothermal projects in local areas or even in the same formations. At Vattenfall we actually see this as an opportunity rather than a problem: it is most likely that CO_2 storage projects will need to consider water and pressure management and, with a bit of innovative thinking, this can be combined with geothermal activities. It is thus in many cases possible to create a synergy effect where geothermal projects and CO_2 storage projects alike could benefit from one another

A CO_2 storage site must meet a number of requirements, both in the short term during operation and in the long term during the closure and abandonment phases. Two important functional requirements are a CO_2-impervious seal – often in combination with a structural trap[1] – and adequate injectivity. Geothermal energy recovery also requires adequate injectivity but needs no trap. This difference means that the areas of interest for CO_2 storage form a minor subset of the areas that are of interest to geothermal projects.

Large investments are needed

Both the screening of CO_2 storage sites and the screening of areas suitable for geothermal projects are challenged by the difficulty of obtaining detailed information on deep saline aquifers. Occasionally it is possible to generate CO_2 storage prospects from dry oil or gas exploration wells or from geothermal exploration investigations of the past. As the existing data is often scarce, the evaluation of the storage capacity and overall quality of the potential storage site becomes challenging. Many deep saline reservoirs confined by appropriate permeability barriers could be used for CO_2 storage.

However, large investments are needed to develop projects from the screening stage to the stage where a candidate site for CO_2 storage, as well as for geothermal energy utilisation, can be deemed fit-for-purpose. Economies of scale make this investment possible for large power plant projects, whereas the same investment for a much smaller geothermal project is a significant burden to the project. Vattenfall, which is interested in both CCS and geothermal energy, is pursuing research on the perspectives of using site investment activities to characterise and test a CO_2 storage structure concurrently with enabling the early development of geothermal energy production.

[1] In petroleum geology, which can be regarded as an analogue to the prerequisites for CO_2 storage, a trap is considered to be any geometric arrangement of layers that permits the accumulation of oil or gas, or both, in commercial quantities. The most common traps, by far, are anticlines. The term anticline means a structure in which flanks slope away from one another.

"CCPilot100+" Vattenfall joins Postcombustion CO_2-capture project in the UK

Vattenfall is involved in a fast-track project to capture 100 tons of CO_2 per day from a slipstream of the flue gas from Ferrybridge power station in Yorkshire, UK. The main project partners are SSE (Scottish and Southern Energy), the company that owns and operates the power plant, and Doosan Power Systems, which provides the capture technology.

The CCPilot100+ project, which is strongly supported by the UK governmental Technology Strategy Board, is located in the heart of one of England's most industrial and energy-intensive areas - an area that makes a major contribution to the UK's CO_2 emissions. The carbon-capture pilot plant is one of the projects selected to enable this area's development towards a carbon-lean future.

"The participation in CCPilot100+ is the ideal option," says Göran Lindgren, R&D programme manager for CCS. Vattenfall has previously qualified for European funding to build and operate a large-scale demonstration plant including Postcombustion CO_2 capture in 2015 at its Jänschwalde power plant. "The pilot project – about 25 times smaller in scale – will help us to learn vital lessons before going large scale".

Flue gas is extracted in a slipstream equivalent to approximately 5 MW of electric power after the newly-commissioned flue gas desulphurisation unit at Ferrybridge. An amine solution is used to wash the flue gas in a packed scrubbing column, thus absorbing the CO_2 into the liquid. In a separate column, this washing solution is boiled to release the CO_2 and it is recycled back into the absorber.

The Vattenfall team comprises a blend of staff from our research and engineering offices in Germany, Sweden and Denmark and contributes actively to the planning and realisation of the project. Our previous R&D experience from various internal and collaborative projects in recent years is brought into the design discussions and staff will be onsite when the two-year period of operation and testing starts at the beginning of 2012.

Ferrybridge power station in Yorkshire, UK

Monitoring a CO_2 Storage Site

Thorough site selection and good monitoring procedures are keys to securing a successful storage of CO_2. Only storage sites with very good characteristics will be chosen for CO_2 storage, thereby minimising the risk of unwanted events such as leakage of CO_2. According to the EC Directive on the geological storage of carbon dioxide (2009/31/EC), the surrounding environment should be monitored for the purpose of "...detecting significant adverse effects for the surrounding environment, including in particular effects on drinking water, for human populations, or for users of the surrounding biosphere." Candidate storage sites will thus be carefully monitored to make sure that everything develops according to plan. The starting point for a monitoring programme is to establish thorough understanding of baseline conditions.

An important step in this work is to establish a set of models that describes the conditions for the local areas investigated. In practice, this is done by using a reservoir model of the storage structure itself, with its surroundings, and a groundwater model. The models are built-up on the basis of the existing state-of-knowledge in combination with comprehensive new gatherings of data from, for example, drilling projects, geophysical investigations, and laboratory investigations of drill cores and water samples. Vattenfall is conducting studies in Denmark and Germany in cooperation with local partners to develop these models, taking into account potential risks and measures to minimise and eliminate them. The risk assessment is an important part of the Environmental Impact Assessment.

Theoretical and research studies

Vattenfall has contracted Uppsala University to conduct a theoretical study of the potential impacts of the unlikely event of CO_2 leakage to groundwater and surface water systems. The study indicates that potential impacts on surface water are expected to be very limited, due to the large natural CO_2 exchange between surface water bodies and the atmosphere. In lakes in Northern Europe, there is seasonal mixing of the water, which effectively eliminates any risk of the long-term build up of CO_2 in the water body. For groundwater, local conditions at the site, such as buffering capacity, soil type and groundwater flow rate, are important to factor in when assessing potential impacts in the context of a risk assessment.

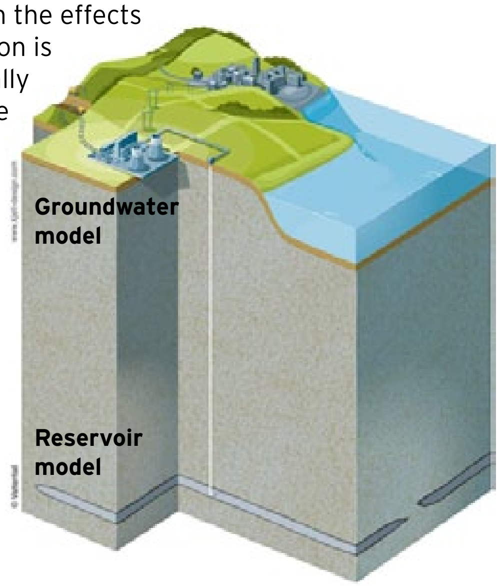
A number of research studies supported by the EU are addressing monitoring and impact issues as described above and involve partners from all over Europe. CO_2SINK, CO_2REMOVE and RISCS are examples of such projects where Vattenfall participates.

Monitoring Plan

Experts in the field who are involved in projects like this have created the Network of Excellence CO_2GeoNet. Vattenfall has contracted CO_2GeoNet to develop a first design of a Monitoring Plan for the monitoring programme of the Vedsted storage site in Denmark. This Monitoring Plan consists of the description of a number of tools along with recommendations for the combinations of tools, the placement and the time-schedule of measurements during the lifetime of the storage site. The overall aim of the Monitoring Plan is to demonstrate safe containment of the CO_2 in the reservoir.

The Monitoring Plan is based on a risk assessment that has been carried out by Det Norske Veritas. Furthermore, the details of the Plan are based on the current state of knowledge on model simulations of the plume development during injection. A number of objectives are considered in the plan, including the sealing behaviour of the capping rock and groundwater quality. For each objective, different monitoring scenarios have been developed with recommendations for tools and measuring campaigns.

For example, groundwater measurements must be conducted before injection starts to map the natural content of CO_2 and its variation over time and seasons. Moreover, the current pressure regime in the groundwater system must be modelled with respect to the border between saline and sweet groundwater. The Monitoring Plan needs to be continuously developed and updated as new data are collected and new knowledge on the effects of CO_2 injection is obtained locally at the storage site but also worldwide as more storage sites are established.



Developing CCS – People working with CCS at Vattenfall

Many people are involved in the R&D work within different areas of Vattenfall's work with CCS. One of them is Nicklas Simonsson in Sweden, who works with conceptual design studies, process development and the benchmarking of power plant concepts with CO_2 capture.

The introduction of CCS would have a huge technical and economic impact on power plant performance. For Vattenfall, it is therefore of the utmost importance to continuously work with technology development and also follow what other actors are doing in the area of CCS, as this increases the understanding of the impact that CO_2 capture has on plant performance. This understanding is important input to strategic decisions on where we should focus our R&D efforts, what we need to technically validate and how we should construct our demonstration plant(s).

Process simulations – an unbeatable tool

A very important part in this work is the process simulation tool in which detailed models of the power plant concepts can be built. "Process simulations, or more specifically heat & mass balance calculations, are today used in a wide number of different areas within the Vattenfall Group; from the planning and design of new power plants to the condition-based maintenance and performance optimisation of existing plants. Today, there are a large number of highly-skilled colleagues throughout the Vattenfall Group working with this type of simulation tool," says Nicklas Simonsson.

In the CCS project, process simulations have played and will continue to play an extremely important role; from the initial conceptual studies back in 2001-2004, the planning and design of the pilot plant at Schwarze Pumpe and the ongoing demonstration project at Jänschwalde to the future full-scale commercial units.

In close cooperation

Today, there are a lot of ongoing process development activities and conceptual design studies that aim to further evaluate and improve the three main technologies for CO_2 capture, i.e. Oxyfuel, Post-combustion and Precombustion capture. From a Vattenfall perspective, all three technologies are of interest and it would be preferable if they all became commercially available. The studies are carried out in close cooperation with the different business units within the Vattenfall Group that are going to own and operate the plants. Close cooperation with external equipment suppliers is also a crucial part of this work. Sometimes, the aim of this cooperation is to compare and benchmark the performance of what is offered, but more importantly it entails working together to find better technical and more economical solutions for the future. Nicklas Simonsson explains this further:

"Although we have come a long way compared to when the project started, I'm convinced that there is still a lot more that can be done on the technical side. The energy integration can be optimised and process solutions to minimise the energy penalties can probably be found. There are also different ways to reduce costs, both capital and O&M."

Present focus and future development

At the moment, a lot of effort is being devoted to evaluating the results from the Oxyfuel pilot plant at Schwarze Pumpe, which provides invaluable experience and support for the design of future CO_2-capture plants as well as model validation. This is especially true for the ongoing Jänschwalde demonstration project. "In this project too, I'm convinced that process simulations will play an important role in evaluating different process alternatives and establishing the final process layout," Nicklas Simonsson continues.

At the same time, it is also very important to look further ahead at the different kinds of CO_2 capture technology that can be expected to become available beyond 2020 and that may help to further reduce Vattenfall's carbon dioxide emissions. "We are already evaluating and working on the development of a number of new concepts for CO_2 capture that show very promising potential. So if we can continue to push technology development at the same pace as we have done so far, especially in terms of smarter overall plant solutions and the reduction of energy penalties, I believe that the future of CCS technology looks very bright," Nicklas Simonsson concludes.

Nicklas Simonsson shows a process simulation