BRIDGING TO THE FUTURE

Newsletter on Carbon Capture & Storage at Vattenfall | No. 14, December 2009

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.
- Nordjyllandsverket in Denmark is a possible "early commercial "power plant, with Postcombustion capture. The CO_2 will 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 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.

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 need a broad and open dialogue about CCS

There is no doubt that CCS is necessary as an abatement measure if the world wants to achieve significant reductions in our CO_2 emissions within a reasonable period of time. At Vattenfall, we have confidence in the technology and believe that the commercialisation process will succeed.

One of the challenges that we are facing is the acceptance of CCS, both in general as a principle and of course, local acceptance around the sites that we are now investigating for CCS.

We fully understand the concerns people have regarding CCS; to most people it is a totally unknown concept with high scientific, technical and political complexity.

There have been several manifestations against our plans both in Germany and Denmark. We think this is fair and we welcome the dialogue. In a democracy, the citizens have the right to ventilate their concerns and to get proper answers to all the questions they have regarding CCS. We want to listen to their doubts and uncertainties and we would welcome the opportunity to meet with them to explain our thinking.

Sometimes these dialogues delay our work. This is on the one hand frustrating but on the other hand it is a consequence of running business in a democracy. We would not have it any other way. At end of the day, we need society's acceptance to be able to deploy CCS on a large scale. And we can not earn this acceptance without a dialogue.

Marianne Reedtz Sparrevohn
Head of Communication at Vattenfall Denmark

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Report from the first year's test phase at Schwarze Pumpe

Vattenfall's 30 MW_{th} Oxyfuel pilot plant for CCS, Schwarze Pumpe, celebrated its first anniversary on September 11. The first year's test phase has provided essential knowledge about the entire Oxyfuel process chain. The Oxyfuel pilot plant will remain in operation as a test facility for research and development until 2013 and the next few years will be marked by intensive research on the Oxyfuel concept. Several technical solutions will be tested. These results will supply the experience and knowledge required for a successful scale-up to the 250 MW_{el} Oxyfuel demonstration project in Jänschwalde, which will be ready around 2015.

During 2009, approximately 1 400 tons of CO_2 have been liquefied in the Oxyfuel pilot plant and so far about 3 000 operating hours have been realized. A large number of tests and different measurements have been carried out during this time. The test campaigns have helped to evaluate the Oxyfuel process as a whole, but have also given the test team operating experience.

The outcome of the first year's test phase

One of the most important results from the first year of operation is the fact that the principle of the Oxyfuel process could be verified on an industrially-relevant scale. The pilot plant thus works through the entire Oxyfuel process chain, from the air separation unit to CO_2 purification and compression.

Series of measurements have been performed to investigate various performance issues in the plant, one of which has been to look at and analyze the product quality of the CO_2. The results show that the CO_2 can have a high level of purity, due to the extensive cleaning in the pilot CO_2 purification unit.

The achievable capture rate is greater than 90%, which means that more than 90% of the CO_2 that enters liquefaction can be separated from the flue gas.

Facing new challenges with a newly-installed burner

The most central unit in the Oxyfuel process, the burner, has been exchanged this autumn in order to test a second geometry. Some of the combustion tests that have already been performed will be repeated with the new burner. This will make it possible to study the effect of the burner geometry and thus the combustion on the Oxyfuel principle. Other combustion characteristics for the different burner settings will be measured to further optimize the firing characteristics under Oxyfuel conditions.

Co-combustion

A feasibility study has recently been initiated in order to investigate the potential of co-firing biomass with lignite at the CCS pilot plant Schwarze Pumpe. The feasibility study will look at what types of biomass to combust but also other issues, e.g. transport, logistics and stock on site. If things turn out well, co-combustion will be in operation in a couple of years.

More details about the pilot plant and its first operational period can be found in the paper by L Strömberg, G Lindgren, J Jacoby, R Giering, M Anheden, U Burchhardt, H Altmann, F Kluger and G Stamatelopoulos: "Update on Vattenfall's 30 MW_{th} oxyfuel pilot plant in Schwarze Pumpe", GHGT 9, Energy Procedia, Volume 1, Issue 1, February 2009, Pages 581-589.

The flame

Oxyfuel pilot plant celebrates first anniversary with 300 guests

It was an unusual birthday party for a very special project: on September 11, Vattenfall celebrated the first anniversary of the Oxyfuel pilot plant in Schwarze Pumpe by hosting the first International Conference on Oxyfuel Combustion. Among the guests were 300 scientists and Oxyfuel experts from all over the world.

The IEA Greenhouse Gas R&D Programme (IEA GHG) arranged the first International Conference in Cottbus, Germany, on September 8-11. Vattenfall hosted the conference and, in this context, took the opportunity to outline the achievements of the test phase that have so far been carried out in the pilot plant and mark the first anniversary of Schwarze Pumpe.

Highlights of the conference

Since it was the first conference of its kind, the response was overwhelming: 300 participants from 26 countries travelled to Cottbus to discuss the future of the CO_2-capture technology and to have a closer look at the lessons and outcomes Vattenfall was able to present from the one-year-test phase of the Oxyfuel pilot plant. The common opinion among the participants was that CCS is a promising technology which will be needed to tackle climate change in the future. The technological challenges are sure to be solved. John Topper, Director of the IEA GHG Programme, stressed the relevance of CCS for global climate protection: "We see a lot of CCS pilot plants all over the world nowadays. That proves the importance of the technology."

One of the highlights of the conference, a possibility that Vattenfall offered to the participants on September 11, was to visit the pilot plant and discuss the technology with the engineers working on site.

"We can be proud of what we have achieved," said Tuomo Hatakka, Head of Business Group Central Europe during a site visit. "To put it very bluntly: We are changing the world here with this technology!"

Tuomo Hatakka

Looking ahead: Demonstration project in Jänschwalde

Vattenfall not only used the occasion at the Conference on Oxyfuel Combustion to celebrate what has been done in the past, it also presented the plans for the future. The development of the demonstration project in Jänschwalde is moving rapidly ahead.

The feasibility study has been completed and the timeline is becoming more and more concrete: the demonstration project that is planned to carry forward both the Oxyfuel and Postcombustion technologies on the site of the Jänschwalde power plant is taking shape. With an estimated investment cost of €1.6 billion it will be an important step towards Vattenfall´s ambitious goal of having CCS ready for commercial application by 2020.

But Reinhardt Hassa, Head of Mining & Generation at Business Group Central Europe, stressed that money alone will not be enough to carry the technology forward. "We need acceptance for the issue of underground storage of CO_2," he said during a site visit to the pilot plant in Schwarze Pumpe. "And we need a stable legislation for the different aspects of the technology upon which we as a company can rely."

The European Union set the framework for this legislation in 2008. It has also set up a fund from which CCS demonstration projects from all over Europe will be supported financially. Vattenfall has been listed for this funding with its project in Jänschwalde and is confident that its application will be approved.

Milestones in the Pilot Plant Schwarze Pumpe's history

Planning for the pilot plant began in 2006. Here are three important milestones in the short history of the Pilot Plant at Schwarze Pumpe.

May 2006: Ground-breaking ceremony for the Oxyfuel Pilot Plant

German Chancellor Dr Angela Merkel and Matthias Platzeck, Prime Minister of the German state of Brandenburg, officially launched the construction of Vattenfall's Oxyfuel lignite power plant that was to be the first of its kind worldwide. Also in the Picture: Lars G. Josefsson, President and CEO of Vattenfall AB and Klaus Raushcer, CEO of Vattenfall Europe AG.

In September 2008: the inaguration of Schwarze Pumpe took place

Swedish Minister for Higher Education & Research Lars Leijonborg, CEO of Vattenfall Lars G. Josefsson, Brandenburg's Prime Minister Matthias Platzeck and Head of Business Group Central Europe Tuomo Hatakka pressed the "button" to inaugurate the plant.

September 2009: First anniversary celebration with 300 invited guests

The first anniversary celebration took place during the first Oxyfuel Conference, which Vattenfall hosted.

In the picture: Toumo Hatakka, Head of Business Group Central Europe during the site visit.

Vattenfall gave presentations on the achievement and shared what had been learned from the experience of operating the first Oxyfuel Combustion boiler.

The participants were offered the opportunity to visit the pilot plant and discuss the CCS technology.

Vattenfall postpones the CCS project in Northern Jutland

Vattenfall has postponed its plans for a CO_2 capture and storage (CCS) facility in Northern Jutland. Due to the present financial climate, Vattenfall has decided to focus its future development work regarding CCS on the demonstration plant in Jänschwalde, Germany and other sites. Vattenfall still has plans for underground storage in Northern Jutland and expects the preliminary examinations to resume in 2011-2012. The Danish project team is now continuing its work at slower rate and also documenting and filing the project so as to be able to at this site when the technology becomes commercial in a couple of years time.

"We are glad to have established a technically advanced group in the Danish project that is now supporting the CCS demonstration plant project at Jänschwalde," says Marius Noer, CCS project manager.

CCS is still being planned at Nordjyllandsværket when the technology becomes commercial. The purpose is now to take advantage of the envisaged rapid development of capture technologies that will result from the work at the demonstration plant at Jänschwalde and other CCS sites around the world.

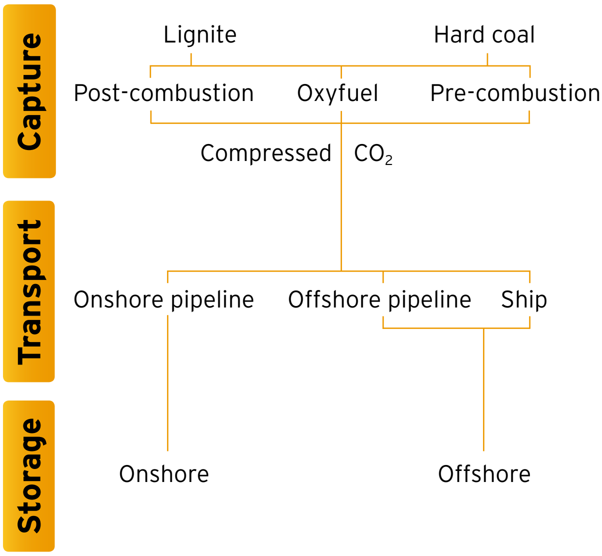
Continued dialogue

Vattenfall still intends to use the Vedsted structure for CO_2 storage, since everything indicates that it would meet the criteria for safe storage of CO_2. Vattenfall is investigating the possibility of continuing a number of storage-specific activities relating to the Vedsted site that in the long run can support the storage of CO_2 underground. It is also Vattenfall´s intention to continue the dialogue with the local inhabitants in Northern Jutland until the work begins again.

Life cycle assessment of CCS

Vattenfall has performed a life cycle assessment (LCA) of the total CCS chain – capture, transport and storage. The purpose of the LCA is to be able to present the environmental performance of CCS over its life cycle. Another objective is to find areas for improvement when looking at the design of a specific CCS system. For example: does pipeline transport have a better environmental performance than ship transport? What design details affect environmental performance the most in pipeline transport?

One basic condition for the study was to use generic CCS data and still be able to compare different main technology choices. The main technology alternatives included in the study are:



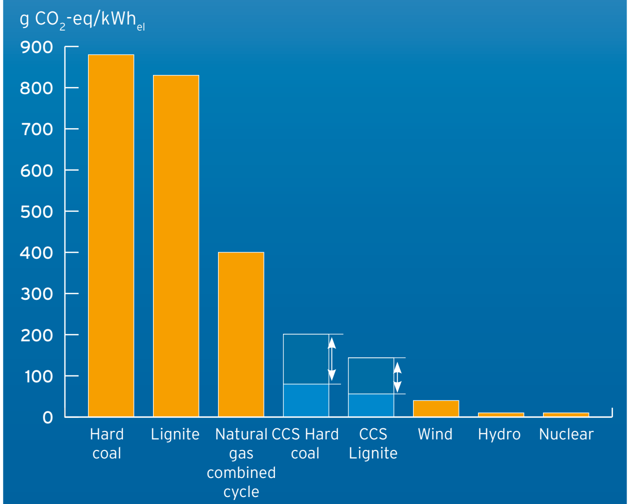
Within these main technology choices there were some variables, such as transport distances and storage depths.

The LCA results show that all CCS technologies achieve a high reduction of greenhouse gas emissions also from a life cycle perspective. Other types of emissions may also be reduced thanks to a high level of flue gas cleaning (Post-combustion) and combustion in pure oxygen (Oxyfuel and Pre-combustion). Impacts from the capture phase dominate the overall LCA results, as can be expected.

Greenhouse gas emissions from the mining of hard coal have been identified as having a relatively high impact on the global warming potential of the system, assuming that methane emissions from the mine are vented to the atmosphere. Another factor of importance for the life cycle results are emissions from the ship transport of CO_2 to an offshore storage location. These are examples that indicate areas for improvement when looking at designing a specific CCS system. Methane emitted in mining operations can be captured and utilized, instead of released to the atmosphere, and emissions from the transport system need to be considered during the design phase.

The initial assessment shows promising results from a life cycle perspective. However, CCS is still a new technology under development and the LCA study has only been performed at a generic level. The results are therefore to be considered as preliminary. At this stage, the LCA results will mainly contribute to the identification of critical aspects in the processes that have a significant influence on the results, and highlight data uncertainties that need to be further defined. Vattenfall will continue to work with refining processes and data, for example through research at the Oxyfuel pilot plant at Schwarze Pumpe in Germany.

Indicated CO_2 emissions from a life cycle perspective



The diagram shows a comparison of CO_2 emissions from a life cycle perspective from different electricity generation technologies. The data used is on a generic level and based on Vattenfall's life cycle assessments and environmental product declarations (EPDs). The bars for all generation technologies in the diagram, including hard coal and lignite, represent state-of-the-art power plants. Older plants generally have higher life cycle emissions. Results and data for CCS plants can vary a lot depending on technology options. Since it is a technology under development, there are also uncertainties in the data, and life cycle CO_2 emissions for CCS are therefore represented as a range.

Large natural CO_2 releases – the accidents at Lake Nyos and Lake Monuon

Throughout history, there have been a few well-known accidents due to large natural releases of CO_2. Among the most well known are the tragic accidents at Lake Monoun and Lake Nyos in Cameroon. Both accidents were a result of exceptional circumstances in combination with the lakes' location in a volcanic area, circumstances that can easily be avoided when the industrial CCS storage sites are carefully selected with regard to storage capacity and safety. These accidents can therefore not be considered natural analogues to risks in CCS.

Carbon dioxide occurs naturally in the atmosphere (380 ppm) and is a relatively non-reactive and non-flammable compound. At room temperature, carbon dioxide is an invisible and odourless gas with a higher density than air. If it is released in large amounts and not re-mixed and dispersed by winds, this property will allow it to flow downwards into pits and sinks where it substitutes the lighter air. Carbon dioxide is not considered to be toxic, but if released in large amounts or allowed to accumulate due to specific conditions of release, surface topography and weather it may be harmful. Such an unfortunate combination of circumstances led to the carbon dioxide leakage-related accidents at Lake Monoun and Lake Nyos. In August 1984, an explosion-like sound was heard, followed by an earthquake occurring near Lake Monoun. The next morning, a whitish cloud was seen hanging over the lake and people and animals were found dead nearby. A couple of years later, a similar accident caused by natural carbon dioxide leakage killed both people and animals near Lake Nyos.

The cause of the accidents

Both lakes have been formed within the crater of a volcano, and at the bottom of the lakes carbon dioxide is released from the earth and is dissolved in the water. The elevated amount of CO_2 in the water leads to an increase in the water's density; hence, it sinks to the bottom of the lakes. In lakes in northern Europe, the change of seasons and temperature cause a temperature difference between water layers and hence also a variation in water density. The density variations trigger a mixture of the water. In the tropical areas where Lake Monoun and Lake Nyos are located, crater lakes can be deep and still, factors which along with a stable tropical climate lead to a decrease in the seasonal mixing. Little seasonal mixing in these cases allows the deeper parts of the water to become supersaturated with carbon dioxide. Normally, the carbon dioxide diffuses little by little upwards into shallow water where bubbles that are formed as pressure decreases can escape to the atmosphere. However, this was not the case on the days of the accidents at Lake Nyos and Lake Monoun. A rapid, forced water turnover in the lakes led to a pressure decrease in the saturated CO_2-water mixture, which then led to a rapid outburst. At Lake Monoun, the turnover was probably triggered by a landslide, caused by an earthquake. What caused enormous amounts of carbon dioxide to escape at Lake Nyos is not clear, but the carbon dioxide cloud spilled over the crater rim and continued flowing down two narrow valleys that prevented wind and weather from dispersing the gas.

Today, the lakes are continuously degassed by using vertical pipes that lead carbon dioxide from the bottom of the lakes to the surface, preventing carbon dioxide build-ups and ensuring that the accidents can never happen again.

CCS storage sites are carefully selected

Both of the accidents at Lake Monoun and Lake Nyos were triggered by a combination of exceptional circumstances where CO_2 concentrations were allowed to build up in very deep tropical crater lakes with little or no seasonal mixing. These kinds of lakes are very uncommon and can easily be avoided when selecting industrial storage sites. The accidents can therefore not be considered analogous to risks in CCS.

An industrial storage site is carefully selected with regard to geological layers that prevent the upward and lateral movement of carbon dioxide. Before a new storage site is chosen, years of thorough investigations are performed to determine the storage capacity and safety. This includes characterisation of the storage site and the surrounding area, risk assessments and the development of short/medium/long-term monitoring plans, as well as remediation strategies. The locations considered are those that have proved their ability to hold gases for thousands of years, e.g. depleted oil and gas fields or deep saline aquifers. Sites that are considered as candidates for geological storage are overlain by impermeable rock layers, so-called cap rocks, that do not allow CO_2 to escape upwards. Both physical and geochemical mechanisms ensure that the carbon dioxide stays underground. After injection, when the injection wells are sealed, the sites will still be monitored to ensure the sustainable and safe removal of carbon dioxide from the atmosphere.

Borzecin in Poland – A CO_2 storage site since 1996

Poland is one of the countries in the EU in which Vattenfall has operations. Coal constitutes around 95 per cent of the Polish fuel mix for electricity generation today and is expected to play a significant role in the foreseeable future. This is why low carbon technologies, particularly CCS, are essential for both the energy sector and for economic development in Poland. Some of the first experience of underground CO_2 storage comes from Borzecin, where injection started in the mid-nineties.

The first research and design work on gas injection at Borzecin was performed by the Oil and Gas Mining Institute and was co-financed by the Polish Scientific Research Committee. Later, the Polish Oil and Gas Company (PGNiG) also became a co-financer of the project. This work resulted in an industrial installation for the injection of acid gas, which was constructed in 1995 at Borzecin in the Upper Silesia Region, near the City of Wrocław. The installation started operation in January 1996. This was just before the Sleipner injection started, the Borzecin injection is, however, much smaller.

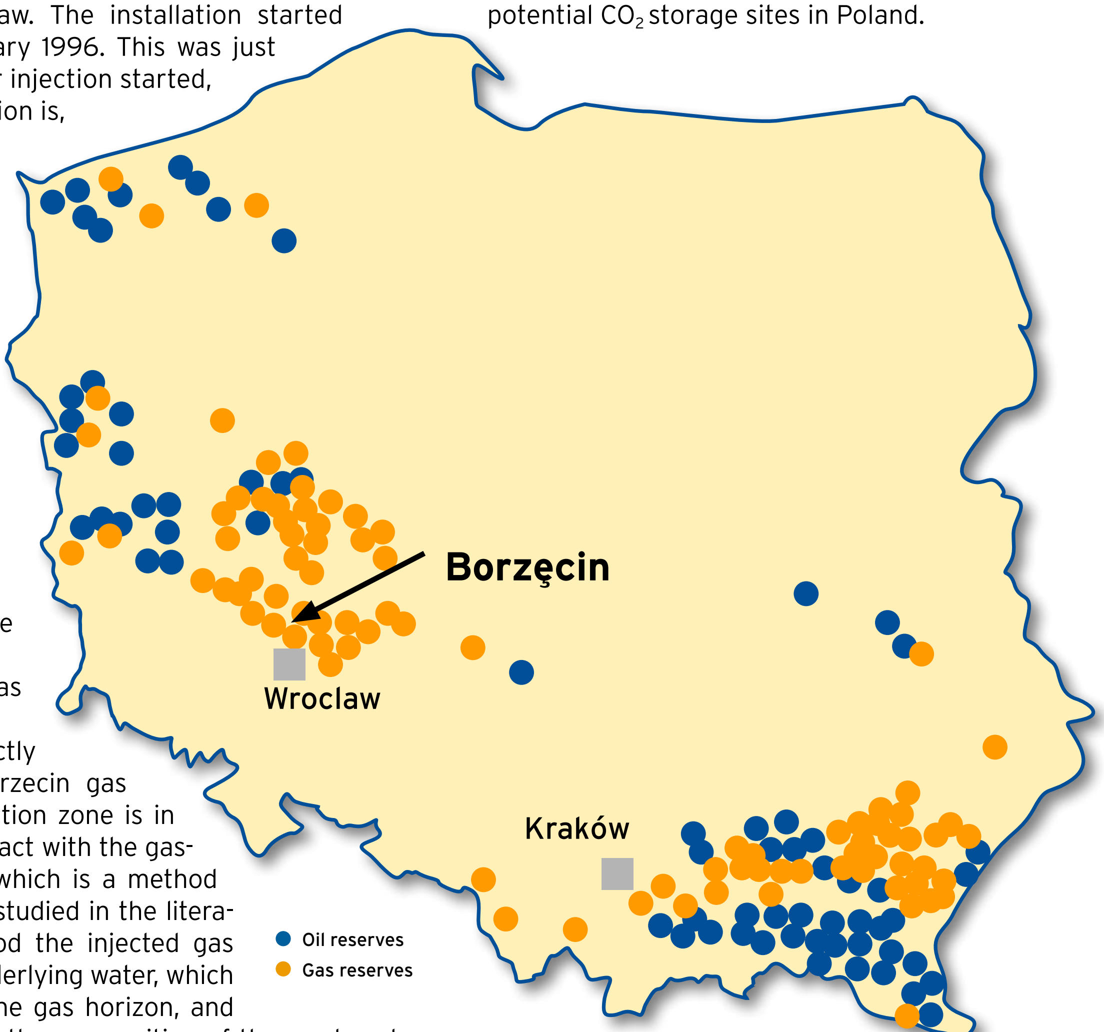
The operations at Borzecin

The gas injected at Borzecin is acid gas, which contains 60% carbon dioxide (CO_2) and other injected gases. The gas is a by-product from natural gas production, specifically from the amine gas sweetening process. The acid gas is re-injected into an aquifer directly underlying the Borzecin gas reservoir. The injection zone is in hydrodynamic contact with the gas-bearing reservoir, which is a method that has not been studied in the literature. In this method the injected gas dissolves in the underlying water, which has contact with the gas horizon, and may thus influence the composition of the produced gas. The acid gas re-injection in Borzecin started when 67% of the natural gas in the reservoir was produced.

Results and conclusions

The results of the project indicated that the upward movement of carbon dioxide to the gas cap would be very slow, because their solubility in the reservoir water was 8.4 times higher than that of the native gas.

The Borzecin site is not large, about 3 million m^3 of CO_2-containing gas have been injected there to date. The Borzecin underground storage is, however, the only industrial on-shore project in Europe for the investigation of the capture and storage processes. The experience gained there has been used in another Polish CO_2 storage in Kaniow and is also utilized in a new Vattenfall project that is searching for available potential CO_2 storage sites in Poland.



Location of Borzecin Carbon and Capture site.

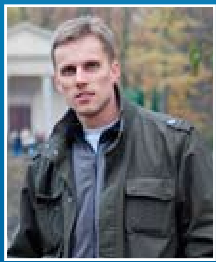
Common Questions about CCS

One of the challenges with new, complex and large-scale technologies such as CCS is to bring about acceptance, both from a local point of view as well as politically. Vattenfall is therefore seeking a broad and open discussion about CCS. Our intention is to straighten out fears, concerns and uncertainties by giving proper answers to questions that arise in our dialogue with politicians, local residents, co-workers and the public.

Here are some examples of common questions that often arise and cause confusion in our dialogue with people around Europe.

1 What kind of challenges relate to storing CO_2 right under people's feet?

The most important challenge is to bring about local acceptance of the CCS technology. Many people have never heard of the CCS concept before and their first instinct therefore tends to be sceptical. One of the attitudes that often arises around the sites that Vattenfall investigates for CCS storage is "not in my backyard". This natural and understandable reaction has been called "nimbyism". Given this scepticism, it is very important for Vattenfall to inform and start a dialogue with the local public and politicians about CCS. Without the acceptance of the local public, Vattenfall cannot deploy the CCS technology on a large scale. To earn full acceptance is therefore one of the most important challenges to overcome and better general knowledge about the technology can decrease the risk of confusion and misunderstanding.



Questioner: Tomasz Surma
From: Poland
Job: Works with Regulatory Affairs at Vattenfall Heat Poland

The concerns raised are often based on misunderstanding, especially in relation to the safety of the handling of CO_2. Many perceive CO_2 as dangerous because they believe that the CO_2 stored could explode and start burning, which is not possible since CO_2 is a non-flammable gas. But what if there is a leakage - at the power plant, along transport routes or during injection? Smaller pipeline leakage can be easily detected and repaired due to a sharp temperature drop near the fault. If under very rare circumstances, say a strong physical impact, a larger rupture should occur at the pipeline or injection site, it can be quickly terminated by automatic shut-offs and safety devices that react to the sudden loss of pressure. And that would certainly not be a silent, unnoticed event: CO_2 that is expelled under strong cloud and dry ice formation will mix turbulently with the surrounding air and not gather invisibly on the ground. Think of natural CO_2 geysers that are marvelled at by tourists standing close by.

2 What are the international regulations concerning CCS?

The establishment of international and national regulations and incentives are very important to accelerate the development of the CCS technology; and therefore global leaders as well as national politicians will play an important role in the further progress. Dedicated legal frameworks enable CCS activities either through licensing regimes or by providing regulatory support for the financing of demonstration projects.

In recent years, the international community has amended legal instruments to advance the development of CCS. The first country to establish regulations that allow the injection of CO_2 was Australia. The EU followed with the European Union 2009 CCS Directive, which is also a regulatory framework for the safe geological storage of CO_2. Additional regulations are currently being pursued in the United States, Canada, Norway and Japan.

Two international regulations concern the protection of the marine environment of the North-East Atlantic; the OSPAR Convention and the London Protocol. A recent amendment to the London Protocol permits the trans-boundary movement of CO_2.

The United Nations Framework Convention on Climate Change does not include a firm commitment for parties with regard to CCS. Hopefully, the next UN COP 15 meeting in December 2009 will result in ambitious CO_2 emission-reduction targets. One way to achieve the targets is to include the CCS technology as a concept to decrease the CO_2 emissions.

In parallel with the regulations already mentioned, many countries are developing comprehensive domestic regulatory frameworks for CCS.

3 When burning 1 kg of coal, 2.6 kg of CO_2 is emitted. How is it possible that more CO_2 is emitted than the initial amounts of coal burnt? Is it possible to go the other way, i.e. bond the CO_2 to something else?

Questioner: Karl Schröder
From: Denmark
Job: Member of the city executive board in the Municipality of Jammerbugt, Northern Jutland. Also a member of the local CCS group in Northern Jutland

Let us assume that the fuel for a power plant is coal that consists of 65-70 % carbon. When the coal is burnt, the carbon (C) with an atomic weight of 12 g/mol reacts with the oxygen (O_2) in the air (atomic weight = 2x16 g/mol). Two oxygen atoms are attached to every carbon atom and the weight of the CO_2 will therefore become higher than that of the coal. The combustion of the carbon with oxygen releases heat, which we use in our power plants to produce steam for electricity generation. Burning 1 ton of coal generates around 2.6 tons of CO_2 and around 7 MWh of heat. CO_2 is the "final" product when burning carbon; CO_2 itself cannot be burnt to release any more heat.

To go "the other way" - to let CO_2 react "back" to carbon (C) and oxygen (O_2) - would theoretically mean that you would have to supply exactly the same amount of heat to the CO_2 as was released when you burnt the coal; i.e. this obviously makes no sense and is never done in practice.

In nature, the photosynthetic process in the green plants and trees form hydrocarbons (CHx) and oxygen (O_2) from carbon dioxide (CO_2) and water (H_2O), using energy from the sun. Green plants and trees can be used as fuels - so called biofuels - and will combusted release the same quantities of energy (heat) and CO_2 as was consumed in the photosynthesis process. Vattenfall and other energy companies are using more and more biofuels, but the quantities that can be obtained can only supply a minor fraction of the global primary energy demand.

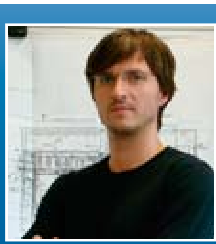
It is sometimes suggested that we should let CO_2 react with hydrogen (H_2) to produce methanol (CH_3OH) that could serve as a fuel for vehicles. However, this CO_2 will be released to the atmosphere when the methanol is combusted in the vehicle. To produce the hydrogen will require (at least) the same amount of energy as will be released when burning the methanol. If the energy to produce the hydrogen came from a renewable source - solar energy has been suggested - this could be regarded as a way of eventually producing a liquid fuel from solar energy, but not as a way of permanently removing CO_2 from the combustion of a fossil fuel.

Other small fields of application for CO_2 can be found in the chemical or even the food industry - e.g. to carbonate drinks - but the quantities of CO_2 from fossil fuel combustion are several times higher than these needs.

4 There is a need for energy when capturing the CO_2 from the power plant's flue gases - energy that is produced, for example, using bio fuels. In addition to the energy needed for capture, compression and transport, the facilities also demand energy. Since energy is not free, what does the financial balance look like? How big are the additional costs and who will pay for them?

Every CCS chain is different. The chains are applied at different power plants and involve different fuels and they also differ when it comes to capture technology, the location of the plant and storage, transport routes and modes, type of storage location etc. Hence, it is not possible to come up with a general figure for the total additional energy usage or the total cost of a CCS chain. What can be said is that the capture process is the dominating part when it comes to both cost and energy loss/usage. When applying CCS on the first commercial plants, the efficiency of a coalfired power plant is expected to be reduced by approximately 10 percentage points. This is, however, a share that is expected to decrease as technologies improve and mature further. Vattenfall is performing techno-financial optimisations for different combinations of capture technology, transport and storage and we - like many other European companies - believe that the additional cost of CCS for commercial plants from 2020 will be compensated for by avoiding costs for buying CO_2 Emission Allowances within the European Union Emission Trading System (EU ETS). Read more about the costs of CCS on page 13.

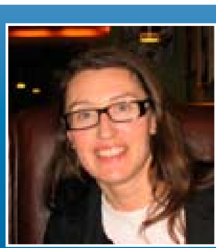
5 Power Plants in Eastern Germany are state of the art with competitive net efficiencies. CCS demands more energy input at new generation units. How will you compensate the loss of efficiency?



It is correct that CCS entails additional internal energy consumption in new generation power plants and that this reduces the level of efficiency. Nevertheless, engineers all over the world are working continuously on the optimization of power-plant efficiency and this will eventu-ally make up for the losses that stem from a clean technology like CCS. In German power plants, new methods in fuel provision and the optimization of power plant parameters are first steps in this direction. In fact, it is envisaged that advanced steam cycles that include CCS will have about the same net efficiencies in the 2020s that conventional new power plants without CCS had just about ten years ago, say 40%. This is still clearly above today's average efficiencies even in western countries – and for a very good cause.

Questioner: Matthias Huster
From: Germany
Job: Construction Engineer at Schwarze Pumpe Power Plant

6 How can one be sure that the storage sites do not leak CO_2?



Work is constantly underway to collect experience and data to make sure that the probability of leakage should be as small as possible. The geological storage of CO_2 is performed today in Canada and in Algeria and beneath the seabed in the North Sea. The experience collected from these storage sites indicates that the CO_2 will in all probability remain safely stored.

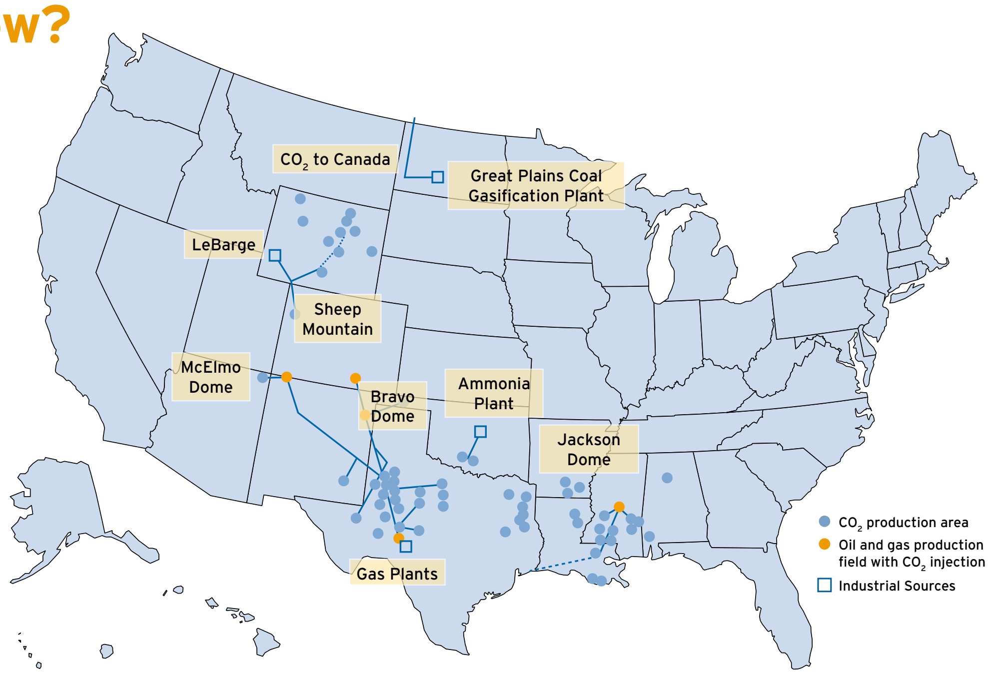
The storage site location is of great importance. If proper characterization of the storage site location is performed prior to CO_2 injection, the probability of leakage is small. The CO_2 must only be injected into storage sites that have been well characterized and classified as safe. A safe storage site in this case means that the CO_2 will be injected into a layer deep underground with porous rock, where CO_2 can be stored in the pores. To avoid the CO_2 diffusing upwards to the surface and leaking, there must be solid, impermeable rock on top of the porous layer.

This geological way of storing CO_2 is in fact the same way that has trapped oil and natural gas underground for millions of years. After hundreds, or up to thousands of years, the injected CO_2 will react with other minerals and form limestone, which is a solid rock. This is also a good indication that, as time goes by, the CO_2 storage will become even safer.

Questioner: Helena Pettersson
From: Sweden
Job: Systems Architect at Cision AB

Did you know?

Since the early 1970s, CO_2 has been transported and injected in the US for EOR, Enhanced Oil Recovery. Over the years 5,900 kilometres of pipelines has been laid, transporting about 41 million tonnes CO_2 annually.



CCS – Costs and drivers

CCS, as a new developing technology, is associated with a number of increased costs compared to conventional fossil power. Even though the considerable gain to the environment and the climate is a motivation for developing CCS, financial incentives are necessary for this technology to become commercial. Incentives such as CO_2 taxes, emission trading or other legislative systems would help speed up the development and implementation of CCS, especially for early movers. In this and the following issue of Bridging to the future, we will discuss the costs of CCS and the financial drivers for novel technology, starting with the drivers.

Drivers for new technology

The reason why the energy mix in different countries and continents looks the way it does depends on a number of factors, such as local fuels, geographical conditions, political will and decisions over the years, different policy instruments etc. The threats posed by climate change require that we drastically change the way we generate electricity, as this activity was responsible for more than 30% of the greenhouse gas emissions in the European Union in 2006 (Source: EEA). Today, 54 % of the electricity generated in Europe comes from coal, oil or gas (2006; Source: Euro coal).

One solution to the climate change problem is CCS, but new technologies always suffer the disadvantages of high initial costs and investments connected with great uncertainties and risks. Taking a new technology from the idea stage via the laboratory and to the market is a long and uncertain process. However, in the longer run, if a new technology can get through this process, mechanisms such as economies of scale, learning by doing as well as incremental product development will lower the costs of the technology. Hence, what is needed is something that can give new technologies the initial push in the right direction so that eventually they can thrive on their own.

Political incentives are required

Climate-neutral electricity is often more expensive to generate than electricity based on fossil fuels. If this were not the case, our energy mix would already look different. If electricity is to be generated in a way more adapted to the environment and the climate, the right incentives are required from our politicians and political institutions. There is also a need for a public understanding that CCS and other environmentally adapted solutions will entail a cost to society.

Industry has declared that it is willing to cover a large part of the cost and risk of implementing CCS, but the entire cost is too high to be justified to stakeholders. The rest of the cost has to be covered by public funding (as traditionally has been the case for technological breakthroughs). Defraying the cost can be done in different ways. An emission trading scheme is one solution, taxes on CO_2 emissions is another. Not only can such policies create revenues to society, they are also important because they make polluters account for their emissions. A well-considered policy system must lead to the abatement of emissions where this is the most cost efficient for society. The companies with the lowest abatement costs will be the first ones to take action.

Conclusion

By putting a price on carbon emissions, the competitiveness of CO_2 emission free technologies increases. Not only does the policy instrument itself create incentives for energy producers to take action against climate change, but some policies also create revenues that can be used for necessary subsidies in an initial development phase. Eventually, economies of scale, increased adoption and learning effects will lower the price of CO_2 emission free technologies, such as CCS. Vattenfall believes that CCS would develop rapidly and that it will become commercial under the EU ETS by 2020.

On the other side of the bridge – Smart Grids

Developing the CCS technology is one of the elements in Vattenfall's strategy for fighting climate change. One of the other elements is the optimisation of existing technology. Smart Grids is the next stage of evolution in electricity distribution networks and will constitute a tool for achieving Vattenfall's goal of reducing the emission of greenhouse gases by 2050. In smart electricity networks, Information Technology and advanced Power Technology are used to facilitate the increasing use of renewable energy sources. Smart Grids also offer consumers new incentives to save energy, integrate small-scale energy generation and more actively participate in the energy system.

The overall objective for the development of Smart Grids is to make sure that Vattenfall will be able to continue to fulfil long-term customer satisfaction by offering secure and cost-effective electricity supply. Smart Grids are also a prerequisite for Vattenfall to be able to fulfil its vision "Making Electricity Clean" and to become carbon-dioxide neutral by 2050.

New demands on distribution networks

Today's electricity networks have mainly been designed for large-scale electricity generation and one-way distribution from power plants to consumers. The systems are also designed to adapt the generation according to the load. However, in power systems with an increasing share of time-varying generation (such as wind and wave power), it will be increasingly important to be able to quickly adapt the load to the generation.

The move towards Smart Grids will increase the flexibility of the network and facilitate the integration of renewable and distributed energy resources, as well as provide new means for customer interaction on the market. It will also allow for bi-directional distribution all the way down on the low-voltage network from customers who will increasingly act both as small-scale producers and as consumers, so called "prosumers".

Smart Metering

An important part of the Smart Grid technology is the integration of Smart Meters. These meters will allow automatic monitoring of electrical consumption down to 15-minute intervals. Apart from meter functionality, Smart Meters will also provide information on power quality, outage information and many other customer parameters, thus paving the way for a number of new services and "demand side participation". Smart meters will also play a key role in the integration of "household" generation, for example wind and solar power.

Vattenfall already has a leading position in Smart Metering for its customers. In some regions, customers today receive exact invoices and new, more advanced services are being tested in large-scale pilot projects. Examples of these are the online presentation of instant and historic energy consumption, advice from energy experts and more efficient outage management.

Sustainable Road Transports

The development of Smart Grids will also promote a quick transition towards sustainable road transports, increasingly based on electric vehicles. Electric vehicles will represent a new load, which may change the demands on the electrical system and call for Smart Grid technology and metering solutions. Furthermore, Smart Grids will feature intelligent power and fault management functionality with intelligent, maintenance-free and self-healing networks and substations in order to further increase the uptime of the network.

Vattenfall has an ambitious R&D programme in the field of Smart Grids and Intelligent Networks.

Smart Grids will increase the efficiency of the distribution network and facilitate the integration of both small and large-scale renewable energy sources.

With smart charging solutions, the batteries in the electric vehicles could be used to store excess electricity produced from wind or solar power.

Grand opening of OxyCoal UK test facility – Vattenfall present at the formal inauguration

On 24 July, the UK Energy Minister Joan Ruddock formally inaugurated the Doosan Babcock test facility used in the OxyCoal UK project. In her speech, Ms. Ruddock said "Cleaning up coal power is a must if we're to meet our climate change goals whilst keeping the lights on".

As one of the participants in the OxyCoal UK collaboration, Vattenfall was invited to the opening and was represented by Göran Lindgren, CCS R&D manager. He was clearly impressed by what he saw: "This is a high-quality test facility and Doosan Babcock has put a lot of hard work into the conversion. We are looking forward to taking a closer look at it in operation and are full of expectation regarding the test results that are due during the early autumn".

Conversion into a CCTF

The 40 MW_{th} test facility in Renfrew was originally designed for the development and demonstration of Doosan Babcock's burners fired by coal, gas, oil and other fuels. Within the OxyCoal UK collaboration project the rig has now been equipped with an oxygen supply system and a system for flue gas recirculation. Thereby it has been transformed into an Oxyfuel combustion test facility, or CCTF (Clean Coal Test Facility), as Doosan Babcock chooses to call it.

A first round of tests is planned for the late summer and early autumn and a second round of Oxyfuel tests will probably take place in early 2010.

OxyCoal UK test rig.

New editorial office

Since Stina Rydberg, the former editor of Bridging to the Future signed off, a new editorial office has been formed. Here, the new editorial office members briefly introduce themselves.

Jenny-Ann Nilsson

I have a background in Mechanical Engineering and Industrial Ecology, and at Vattenfall I represent the company in various EU-funded CCS projects. ECCO (European Value Chain for CO_2) and CO_2Europipe are two projects with the goal of facilitating the commercial development of CO_2 value chains. In the ZEP project (Zero Emission Platform), I am part of a working group that is calculating the costs of transporting CO_2. I am delighted to be a part of the editorial staff, which I joined in August 2009.

Moritz Köpcke

Since 2005, I have worked with Postcombustion-related technical process analysis and development in our Stockholm-based R&D offices. Originally from Berlin, and with energy, process and environmental degrees from Sweden and Germany, I try to be a link between our many country teams and divisions as well as between technology and communication.

Kristina Leufstedt

I have gathered experience in the editorial area for a couple of years now, both as the editor of a newsletter and of materials published on the web and Intranet. In my list of qualifications I bring with me studies in communication theory and economics plus a keen interest in new technology, which of course includes CCS.

Feedback has shown us that our newsletter on CCS, Bridging to the Future, is highly appreciated by its readers and this success is very gratifying to us. Your opinion as a reader is needed if we are to achieve our ambition to openly inform you about the progress of our CCS project – in other words, simply to always produce an interesting newsletter. Can we, the new editorial office, do better? Is there something that you as a reader lack regarding the content? I would therefore like to take the opportunity to invite you as a reader to comment on the content. Please do not hesitate to contact me, the editor Kristina Leufstedt at: kristina.leufstedt@vattenfall.com

Communicating CCS
– People working with CCS at Vattenfall

Many people are involved in different areas of Vattenfall's work with CCS. One of them is Jacek Piekacz from Poland, who works at Vattenfall's office in Brussels. Our politicians in the EU play an important role in the future development of CCS and an important part of this is the establishment of regulations and incentives to accelerate the development of the technology. Vattenfall's Jacek Piekacz is striving in the EU and at the national level to create acceptance for the further development of the CCS technology.

Political interest in CCS has been growing ever since the EU endorsed the energy package in December 2008. The energy package is a set of new directives that aims at improving the energy sector in Europe. The package also seeks to promote the development and safe use of the CCS technology. The Commission has proposed a new EU directive with guidelines for CO_2 storage, which will establish a long-awaited regulatory framework for CCS in Europe.

Open and trustful dialogue to build long-term relations

One of the biggest challenges for the development of CCS, as Vattenfall sees it, is to bring about political acceptance of the technology. It is therefore of the utmost importance for Vattenfall to have an open and trustful dialogue with its key stakeholders, both in Brussels and at the local level. Since a number of politicians in the EU are still sceptical of CCS, Vattenfall is putting a lot of effort into being a communicator, an educator and a source of information regarding Carbon Capture and Storage. One of the Vattenfall staff working with these issues is Jacek Piekacz. "Apart from my job with regulatory affairs in Poland, I am also working part-time in Brussels," says Jacek Piekacz. "In Brussels I present Vattenfall's views regarding environmental questions, CCS and energy efficiency to the "Polish community" in Brussels. Poland is a big voter in the European Parliament with its 50 votes, apart from people working in the European Commission and other EU agencies," Jacek continues.

"I regularly meet the key Polish parliamentarians in the energy sectors and it is important to build long-term relations. By now, the "Polish community" in Brussels knows me and knows that I can provide support and I must say that the awareness of CCS has increased little by little. The implementation of the climate package and the CCS directive on the geological storage of carbon dioxide is one of the biggest challenges", says Jacek Piekacz. "People are beginning to understand the importance of making the technology commercial."

Acceptance for CCS in Poland

Part of Jacek Piekacz's job is also to inform about CCS at the national level in Poland. "We cooperate with seven other large energy companies in the organisation called "The Polish Clean Coal Technologies Platform", which was set up on the initiative of Vattenfall Poland. Our objective is to increase the awareness of CCS and change the Polish energy sector, which is based to 95 per cent on fossil fuels. In order to achieve our objective we arrange meetings and seminars and we usually bring a geologist with us to explain the hard facts. We need the acceptance and support of society. To achieve this, the Polish government has to provide strong support for the development of CCS.

This is wide-ranging and interesting work and I am happy to meet so many people from different countries, but you must never forget that you have to be open-minded. It is important to communicate your key message and present it in a nice package, so that the receiver can easily understand it," concludes Jacek Piekacz.