

BRIDGING TO THE FUTURE

Vattenfall's newsletter on the CO₂-free power plant project

No. 7 April 2007



THE TRANSPORT SECTOR

Currently produces 8.8 Gt CO₂
Potential reduction: 2.8 Gt



NORTH AMERICA

Currently produces 8.8 Gt CO₂
Potential reduction: 4.4 Gt



EUROPE OECD

Currently produces 4.7 Gt CO₂
Potential reduction: 2.5 Gt



THE POWER SECTOR

Currently produces 16.8 Gt CO₂
Potential reduction: 6 Gt



CHINA

Currently produces 10.4 Gt CO₂
Potential reduction: 4,6 Gt



Agneta Rising
Head of Environment
Vattenfall Group

Number One for the Environment

Vattenfall has the ambition of being number one for the environment. The aim is high - we strive to be best in class for each energy source and each type of technology. Our engagement in the forefront of developing commercial concepts for carbon capture and storage (CCS) is an important effort within our strategic ambition.

An energy company like Vattenfall has to create value to its customers and thereby also to society as a whole. To us this means that we manage our operations in concordance with the values in society - both today and tomorrow. Environmental protection and tackling climate change are issues of highest value in today's society. We are convinced that they will become increasingly important tomorrow.

We manage many different technologies and have a diversity of energy sources. Our major sources are hydropower, coal, nuclear power, biofuels, peat, wind power and waste. To a lesser extent, we also use gas, oil, geothermal and solar energy.

We are convinced that all of today's energy sources that are used globally will continue to be needed

in the foreseeable future. Energy, especially in the form of electricity is the basis for the modern society and contributes to quality of life. Every energy source and each operation is to be managed in an efficient and responsible way.

The world is dependent on fossil fuels for its energy supply. But we need to seriously start reducing our greenhouse gas emissions. This is where CCS and the "CO₂-free power plant project" come into the picture. We are talking about a bridging technology. With CCS we can continue to use coal over a transition period and also propose an option for significant reduction of CO₂ emissions. It seems that we can manage this to an affordable cost. In the meanwhile, we and others can continue to further develop other technologies so that they become mature for a commercial introduction in massive scale. However, this will still take time.

If we succeed, and we are convinced that we will, we will all be winners; mankind as well as the environment.

About the CO₂-free power plant project

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

Vattenfall puts a lot of effort into the CO₂-free power plant project, as the technology is one of many ways of reducing emissions of CO₂. The capture and underground storage of CO₂ is a way of bridging over to other, renewable technology.

Vattenfall's CO₂-free power plant project consists of three sub-projects:

- Capture, where three main approaches for CO₂-separation have been identified: Postcombustion capture, Pre-combustion capture and Oxyfuel combustion.
- Storage and transport, which investigates the possibilities of storing CO₂ in deep saline formations or old oil and gas fields. Also includes the investigation of long-term effects, safety and transportation of CO₂.

- Environment, which focuses on any environmental problems related to CO₂ capture, storage and transport. Vattenfall is involved in 7 EU-sponsored CO₂-related R&D-projects.

About the newsletter

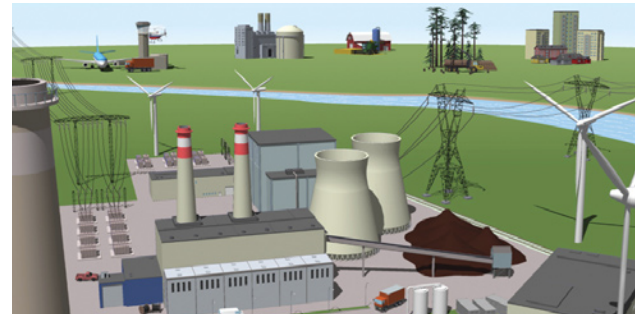
The newsletter is distributed three times a year. All editions can be found on the project's website www.vattenfall.com/co2free. There you can also subscribe for future issues by e-mail.

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

Project manager Prof. Lars Strömberg is legally responsible for this newsletter. If you have any questions about the project, please contact the project group at CO2.free.plant@vattenfall.com

Vattenfall's Climate Map

What can be done and what will it cost to drastically cut greenhouse gas emissions over the next 25 years? In January, Vattenfall's CEO, Lars G. Josefsson, presented a new study, "Global Climate Impact Abatement Map", that is a first attempt to cover the entire global economy divided into 6 sectors and 6 geographical regions.



Striking results

The results show an abatement potential of close to 27 billion tonnes CO₂ equivalents per year (CO₂e/a) all over the world, which would stabilise the global concentration of CO₂ in the atmosphere to a level of about 450 ppm (parts per million). That concentration is expected to limit global warming to 2 degrees centigrade. The total cost for this seems to be as little as 0.6% of GDP, if all low-cost opportunities are addressed. This corresponds to an average cost of €15 per tonne CO₂e.

Possible measures in different sectors

For the power sector, the emissions can be reduced through the increased use of renewables, nuclear power, carbon capture and storage (CCS), fuel switching from coal to gas and a reduction in electricity demand. The identified abatement potential is about 6 billion tonnes CO₂e per year. About as much can be reduced in the industrial sector, and the building sector could contribute another 4 billion tonnes CO₂e per year. These two sectors would also contribute by reducing the demand for electricity. All emission reductions are compared with a Business-as-Usual (BAU) case.

The most important emission reduction contributor in the transport sector is identified as increased fuel efficiency and the sector could reduce its emissions by 2.8 billion tonnes CO₂e/a, in comparison to a BAU-case. The forestry and agriculture sectors are also covered by the study.

The whole world is included

The analysis and mapping of abatement potential can also be presented in terms of six regions. The results show, for example, that Europe can decrease its emissions of greenhouse gases by about 2.2 billion tonnes CO₂e/a by 2030, compared with the BAU case showing expected 4.7 billion tonnes CO₂e/a.

Background

The aim of the study is to contribute to a better factual basis for decision-making on many different levels. The main advantage of this study is that a consistent approach has been used across sectors and regions and we believe that new insights are provided by the results of the study. The initial data collection was performed together with McKinsey & Company. All the conclusions and recommendations are the work and responsibility of Vattenfall.

Please visit www.vattenfall.com/climate and www.vattenfall.com/climate for more details!



Increased worldwide interest in Oxyfuel technology

IEA GHG 2nd Oxyfuel Combustion Network Meeting

At the end of January, the 2nd workshop of the IEA GHG Oxyfuel combustion network was held in Windsor (CT) in the USA. The workshop was hosted by Alstom Power and gathered specialists from all around the world. Almost 100 people from the power industry, boiler manufacturers, universities and research institutes participated in the workshop and many applications to attend had to be turned down due to space limitations. Vattenfall was represented by four people and made two presentations regarding the pilot plant in Schwarze Pumpe and the CFD modelling tool (see more on the opposite page).

The workshop opened with an interesting visit to the Alstom Power laboratory facilities in Windsor. Test facilities for both air and Oxyfuel combustion were shown followed by a reception to welcome the participants. Two days full of discussions concerning different Oxyfuel combustion topics then followed.

The presentations and discussions covered both fundamental combustion investigations, such as differences in ignition behaviour in air and Oxyfuel environments and emission studies on a laboratory scale, as well as the latest technology development for air separation. It was, however, concluded that even though combustion is well in focus, very few papers were presented on Oxyfuel specific gas cleaning validation and none on corrosion. These areas will certainly enter the scene as the first larger projects approach their detail design phases.

One session was also dedicated to Chemical looping, a technology recognised as one of the more promising future energy-efficient capture technologies, which has been studied in test rigs by Chalmers University of Technology, Gothenburg, and Alstom, with Vattenfall support.



Photo: Stanley Santos, IEAGHG

As part of the workshop, a brief update of the latest developments at pilot and demonstration plant projects all around the world was given. Prof. Lars Strömberg from Vattenfall presented an update on what's new regarding the Vattenfall Oxyfuel pilot plant.

There is a great deal of interest in the Oxyfuel combustion technology from all around the world. This is leading to a lot of research and to the fact that a number of pilot and demonstration plant projects are planned for the next few years. Several of the larger projects already have the funding arranged.

More information about the workshop, including the various presentations, can be found at www.co2captureandstorage.info/networks/Oxyfuel2ndMeeting.htm

CFD for Oxyfuel combustion

Computational Fluid Dynamics (CFD) is a modelling technique that is used today in the power industry to analyse the combustion process in boilers designed for ordinary air combustion. The tool is used both for problem solving and optimization of the operation of different units.

Ongoing work

Vattenfall has long experience of CFD modelling and is now working to adapt the models to Oxyfuel combustion. It is foreseen that CFD will also be very useful for analysing the Oxyfuel combustion process. The main areas of interest are to estimate the heat transfer characteristics, the flame shape and length and the burn out of carbon, all parameters that are of great importance in the operation of an Oxyfuel boiler.

When the first simulations of an Oxyfuel flame were compared to measurements, the results showed that some more sub-models need to be developed. The radiation properties in an Oxyfuel boiler change compared to in an air-fired boiler and the radiation model has already been adapted to Oxyfuel conditions. Development work for other sub-models is ongoing in cooperation with a number of universities, for example in OXYMOD, a project financed by the Research Fund for Coal and Steel. Detailed characterisation of the combustion process of the coal particles in Oxyfuel combustion is also ongoing.

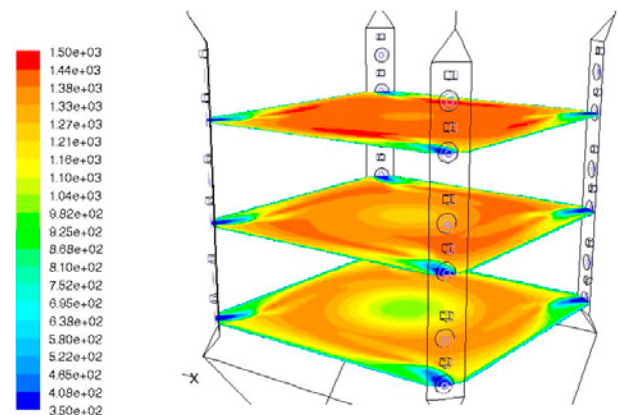
Can we trust the results?

The combustion process inside a furnace is a complex mix of different physical and chemical processes. Fluid dynamics, i.e. the mixing between the fuel and air, as well as the actual chemical reactions and the heat transfer are all of great importance in characterising the process.

In today's commercial CFD software, a combination of models based on pure physics and empirical relations are used. The latter are usually adapted to air combustion and applying them to Oxyfuel combustion will be an extrapolation outside the range of their validity. It is therefore highly desirable to develop and validate models for Oxyfuel combustion in order to be able to use and trust the CFD tool for analysing Oxyfuel combustion.

To validate the models laboratory flames are used, both gas and coal flames. The reasons for using gas flames are to simplify the validation cases as much as possible, to be able to separate the different physical and chemical processes and validate the different sub-models as separately as possible.

All of this work aims to make it possible to use the CFD tool for Oxyfuel combustion in the same way as it is now used for air combustion, i.e. as a tool to analyse and improve the combustion process.



Temperature distribution in a tangentially-fired Oxyfuel boiler designed by Alstom Power. Simulations are performed within the ENCAP project.

CCS Legislation

From Vattenfall's perspective, there are three realistic options for storing CO₂. The first option is to store CO₂ in nearly depleted deposits of oil or gas (together with Enhanced Oil/Gas recovery). The second one is to store it in completely depleted deposits of oil or gas. The last option is to store the CO₂ in deep saline aquifers. All of these options are Vattenfall's preferred options for large-scale CCS power plants because of the existing storage capacities within Vattenfall's core markets. No applied legislation exists for the last two storage options at the national level or at the EU level. If someone should apply for a permit to build a commercial CCS power plant, including storage rights, under the current legislation, this would in most cases result in a permit process for storage under the national water (or waste) law. These laws are in principle restrictive and the chance of obtaining a permit is uncertain. The European Union is working hard to create a regulatory framework for CCS mainly because of the lack of legislation, but also because both the industrial and political spheres share the same understanding of the large CO₂ reduction potential of CCS. DG Environment is planning to develop a proposal for a CCS framework in 2007.

In 2006, the European Technology Platform on Zero Emission Fossil Fuel Power Plants (ZEP) finished its work regarding the regulatory situation of CCS in Europe. One of the ZEP reports gives constructive recommendations for a future regulation framework (the report can be downloaded at

<http://www.zero-emissionplatform.eu/website/library/index.html>). The ZEP will continue its work and will draw up some detailed recommendations on how to create a CCS framework.

However, Vattenfall believes that it will be difficult to have the regulatory framework for CCS in place at the right time. The reason for this difficulty is the following time schedule:

Vattenfall is planning to go into operation with a demonstration plant in 2015. Therefore, the construction has to start in 2011. The permit process requires at least two years. This means that the national law for CCS has to be in place in 2009. Facing these facts, Vattenfall is discussing with the national governments in Vattenfall's core markets the establishment of a national legal framework for CCS at least as an interim solution before a European regulatory framework is in place.

Vattenfall has identified two main risks for CCS regarding the regulatory framework. The first risk is that there will be a regulatory framework which allows CCS only theoretically, while in practice there are some regulations that hinder the use of CCS. The second risk is that the CCS technology is not properly included in the Emission Trading Scheme system. This would mean that the energy companies have no incentive to build CCS power plants. The only chance to avoid these problems is a very close cooperation between the energy companies and the political progress.

ETP ZEP continuation



In the December 2006 issue of Bridging to the Future, we wrote about the European initiative for establishing a technology platform for the work on CCS, Carbon Dioxide Capture and Storage. The work performed during 2006 resulted in a Strategic Deployment document, describing the status of both the technology development and the implementation plans across Europe.

This work has now entered a new phase in order to make sure action is taken. Four taskforces have been formed and the terms of reference for these groups have been formulated. Vattenfall is highly committed to this cooperation and participate in three of the four taskforces.

Vattenfall's Prof. Lars Strömberg, project manager of the CO₂-free Power Plant Project, chairs the **Technology Taskforce**, whose responsibility is to accelerate the technology development of both the

storage and capture parts of the CCS chain. The aim is to bring the current technologies to commercial readiness by the year 2020.

The **Taskforce for Demonstration and Implementation** has a clear target to identify and implement 10-12 demonstration projects as quickly and effectively as possible in order to facilitate the wide-scale deployment of CCS in Europe. If possible, the group will also initiate a CCS project in India or China.

Vattenfall is also represented in the **Taskforce for Policy and Regulation**, whose main responsibility is to establish a long-term policy framework to enable a wide implementation of CCS. The group has also been assigned to propose the necessary regulations for the development of economic incentives that will make CCS possible on a commercial basis.

The fourth taskforce, **Public Communication**, will outline a communication strategy that aims to gain clear public support for CCS as a vital solution for combating climate change. Vattenfall plays an active part in this taskforce as well.

Geocapacity Update

The EU FP6 project GEOCAPACITY started in January 2006, so about one year of work has been done so far. The project involves a large group of leading national research institutes that cooperate on expanding the successful work carried out in the preceding FP5 project GESTCO. The end-user group companies are fewer, with Vattenfall being one of them.

The expansion of new data about the CO₂ storage potential in Europe is dominated by the coverage of the new EU member states, but also by efforts to fill in the gaps that were still left following the GESTCO project. One example of the tasks that Vattenfall supports is continuing the case study work from the FP5 project CO₂STORE. For Poland, this work is led by the Polish institutes Meeri Pas and PBG in cooperation with Vattenfall. The need for new electricity generation capacity in Poland is substantial, and therefore CCS is also one means of maintaining the

targets for CO₂ emissions. The results from the case studies will be available by the end of 2007, when they can then be disseminated to the public. Similar case studies are underway in most of the other participating countries. The big group of participating leading national research institutes, with its extensive collective experience and knowledge, makes it very essential and effective to follow the work. Additional information can be found at www.geocapacity.eu.



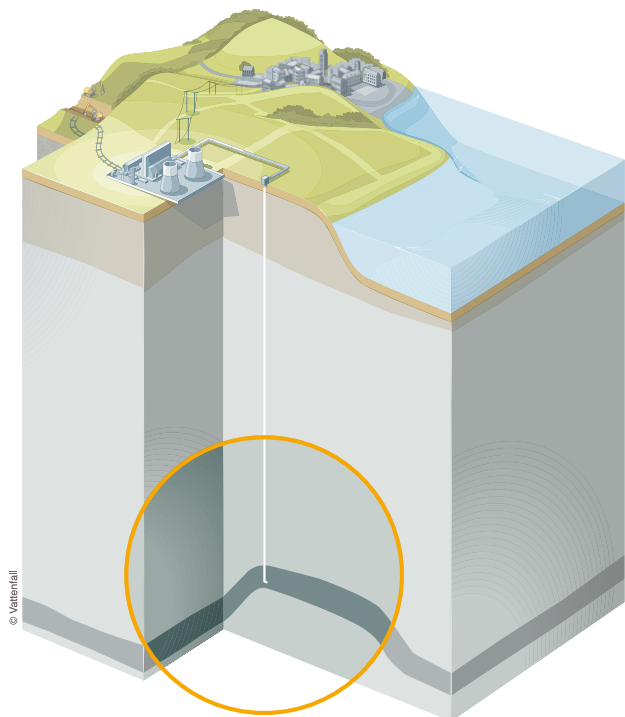
Environmental aspects of CO₂ storage in geological reservoirs

When considering alternatives for the capture, transport and storage of CO₂, environmental aspects are among the most important factors to consider. The focus of this article is on the geological storage of CO₂. After the CO₂ is captured and compressed, it is no longer that voluminous thin gas as in air, but changes in a very dense liquid-like form. As such it is transported to the site of storage and injected pressurized into a geological formation, underneath a gas-tight caprock layer.

Environmental assessments of reservoirs for CO₂ storage are highly site-specific. It is necessary to predict potential environmental consequences during the construction, operational and after-closure phases. The work is focused on identifying critical issues, such as evaluating the consequences of a leakage of CO₂, so that precautionary measures can be taken and risks minimised and avoided.

Through careful and thorough selection of geological storage sites with tight caprock, no CO₂ leakages and, consequently, no major negative environmental effects, are expected. Exploited gas fields are such examples of suitable formations where pressurized gas has been naturally trapped for several millions of years. From a local perspective, the environmental aspects identified mainly relate to the risk of leakage, such as potential changes in groundwater quality. Being heavier than air, leaked CO₂ can also under unfavourable conditions accumulate in depressions or sheltered areas, where it may pose a risk to humans and other organisms. The main effect of a long-term seepage of CO₂ is that it would render storage less effective by releasing a portion of the stored CO₂ back to the atmosphere.

The world of today is largely dependent on CO₂-producing fossil fuels. A change to a more sustainable energy system will take time. The main objective of capturing and storing CO₂ from power plants is to keep it from reaching the atmosphere where it would otherwise boost the greenhouse gas effect and climate change. When considering the environmental consequences and risks of CO₂ storage, they have to be seen in the perspective of the greater consequences and risks associated with the continued emissions of CO₂. Changing the energy system will require a multitude of different measures, of which the capture and storage of CO₂ can be one. The basic requisites are that storage, whether onshore or offshore, is undertaken in a way that does not implicate human health and safety and that does not lead to unacceptable impacts on the environment. If measures are taken to minimise environmental impacts, through a combination of thorough site selection, good operational and monitoring procedures and the utilisation of appropriate safety measures, we are convinced that the capture, transport and storage of CO₂ can be undertaken in a safe way with a minor impact on the environment.



New external R&D collaborations in the environmental field

At the end of 2006, the Vattenfall CCS project initiated two new external R&D collaborations in the environmental area.

Vattenfall and CO₂GeoNet

The first example concerns sponsorship of a research programme within the CO₂GeoNet European Network of Excellence. The network was launched in 2004 and is sponsored by the European Commission (EC) with a planned duration of five years. Network and external partners also contribute to the funding. Beyond 2009, the network has to be independent of the EC. Vattenfall is among the first industrial sponsors of the network activities.

CO₂GeoNet integrates thirteen research institutes with key expertise in the area of CO₂ geological storage. It is intended to provide European authorities with technical, impartial, high quality information on the geological storage of CO₂ and in doing so help to inspire public confidence in the technology and the development of regulatory standards. Currently, the main focus of the network is on assessing potential CO₂ leakage processes from the subsurface and their environmental impact, both onshore and offshore, through natural analogues and experimental studies.

Vattenfall is currently sponsoring CO₂GeoNet Joint Research Activities Programme 18 (JRAP 18) "Monitoring near-surface leakage and its impacts". The research work of the programme will start in the second quarter of 2007 and the final results will be presented at the end of 2008. Vattenfall considers the CO₂GeoNet activities as being important and unique in the CCS community. The work in JRAP 18 fits very well into Vattenfall's own work and will provide greater knowledge in an area that has been identified as critical.

Vattenfall and Imperial College London

Vattenfall is also collaborating with external partners in the area of life cycle assessment (LCA). In order to establish a holistic view of the environmental performance of CCS, Vattenfall has together with Imperial College London (Department of Earth Science and Engineering) initiated a partnership to perform LCA studies of the CCS chain. Both Vattenfall and Imperial College London are experienced in performing LCAs.

Already before the collaboration started, Imperial College London had developed a modular Life Cycle Modelling system suitable for CCS and had applied this to the Postcombustion capture technology, and is now continuing with Life Cycle Assessments of the Oxyfuel and Precombustion capture technologies. Vattenfall will sponsor these two LCA-capture work packages during 2007. Imperial College London will seek to raise additional industrial funding from relevant operators for LCA work on the transport and storage of CO₂.

In parallel with the LCA work of Imperial College London, Vattenfall is performing its own LCA work on the total CCS chain. During the collaboration, we will be able to coordinate the details of our work, such as data input, and structure the assessment in accordance with common LCA standards. This means that we will be able to compare our results for quality control.

We expect to be able to present coordinated LCA results for the capture technologies during 2007 and for the total CCS chain during 2008.

Lars G. Josefsson appointed member of Swedish Commission for Sustainable Development

Vattenfall's CEO Lars G. Josefsson will be a member of the Swedish Government's new Commission for Sustainable Development, presented in March by prime minister Fredrik Reinfeldt at the Government's Climate Seminar "Climate Change: Current knowledge and the way forward".

Lars G. Josefsson pointed out in his speech at the seminar that it is quite possible to reduce emissions considerably without jeopardizing continued growth and welfare for the many:

- In fact we have to set a global cap on emissions. This has to be done at the same time as we expect significant growth in the global economy and the global population. But, and that is important, it is fully possible to reduce emissions substantially without endangering continuous growth and welfare for the many.

- No single technology or solution can fill the gap, but the sum of all the possibilities makes the necessary change feasible. The wise handling of this challenge requires global co-operation on many fronts. It is simply not good enough to identify scapegoats and demand that someone else should solve the problem.

- Handling climate change mainly by red tape will be extremely expensive - high costs and poor results are to be expected. Leading representatives of business and industry have to show leadership by pushing for a market based viable global framework, he said.



On the Other Side of the Bridge

Vattenfall's strategy for fighting climate change consists of three parts, where the capture and storage technology is one. The other two are the optimisation of the existing technology and the increased use of energy sources without emissions of fossil carbon dioxide.

On this page, we usually present work performed within the Vattenfall Group on electricity generation from renewable sources. In this issue however, we focus on the electricity that doesn't have to be produced at all.

Energy efficiency at Vattenfall Nordic



Ingrid Willerström

Climate change is everywhere. In the field of energy policy, combating climate change is the governing idea in the EU Energy Package that was launched in January 2007. And the focus is not only on the producer side - the consumer side is just as important. How can we save energy?

For electricity-intensive industries, energy-efficiency measures have been important for many years. Vattenfall Power Consultant is one of the big players on the Swedish market in the field of energy audits and a concept called EPE, Energy and Process Efficiency. Interest in energy-efficiency measures among small energy consumers is also much more apparent today.

Vattenfall recently decided to launch a new energy-efficiency programme within the Nordic Business Group, starting up in April 2007. The programme is headed by Ingrid Willerström, who previously worked at Business Unit Distribution at Vattenfall Nordic. Mrs. Willerström has acquired many years of experience in different management positions in the energy business.

This is a long-term commitment, and the programme will run for several years. The programme is an integrated part of Business Group Vattenfall Nordic's aim to be Number One for the customer as well as to increase the focus on environmental and climate issues. More information about the design and the content of the programme will be published later this spring.

Vattenfall also ran a campaign during March 2007 in which all the electricity customers and the employees in the Nordic countries received a low energy light bulb. The purpose of the campaign was to contribute to the awareness of energy efficiency for each and everyone and further strengthen Vattenfall's position as being Number One for the environment.

TILLSAMMANS KAN VI GÖRA NÅGOT FÖR KLIMATET.

För klimatets skull måste vi hjälpas åt. Därför förser vi nu alla våra drygt 600 000 elhandelskunder med varsin lågenergilampa. Det bytet motsvarar strömförbrukningen hos alla hushåll i hela Flen under ett år. Dessutom sparar varje lampa in 50 kronor i strömförbrukning under ett år. Fler små tips som får stora effekter om alla gör dem, hittar du på vattenfall.se

VATTENFALL
EL FÖR MÅNGA BÄCKAR SMÅ

Everybody is just talking about the weather. Together we can do something about it.

Tour of the Oxyfuel Pilot Plant Model

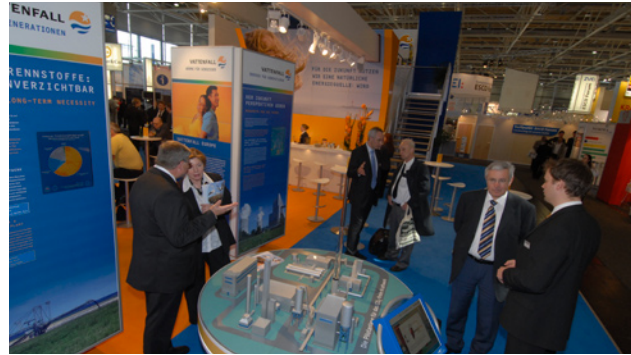


Photo: Frank Schnelle

Vattenfall's model of the Oxyfuel pilot plant has toured Germany during the spring. It was shown in Vattenfall's exhibition stand at the E-world fair in Essen in February, at the Enertec fair in Leipzig at the beginning of March and at the large industry fair in Hannover in April. It attracted a lot of interest from business colleagues, journalists and other visitors.

Next stop for the Oxyfuel pilot plant model will be Schwarze Pumpe, south of Berlin, at the Vattenfall Oxyfuel pilot plant Open House on the 12th of May.

Inauguration of test rig for Oxyfuel combustion in Jänschwalde power plant

On the 5th of April 2007, Vattenfall together with the Technical University of Brandenburg in Cottbus (BTU) officially inaugurated an Oxyfuel test rig in Jänschwalde south-east of Berlin. This lignite fired test rig has a capacity of 0,5 MW_{th} and has delivered the first results from the application of the Oxyfuel combustion method on a miniature scale. It was introduced by Dr. Klaus Rauscher, CEO of Vattenfall Europe, Ulrich Junghanns, minister of economic affairs of Brandenburg, and Professor Hans Joachim Krautz from the BTU. The presentation and the following press conference were attended by a number of journalists from various newspapers, TV and radio stations.

The launch of this test facility marks another step towards a successful implementation of Oxyfuel combustion of coal. The BTU test rig is the fifth of



its kind that Vattenfall teams up with. The previous years close cooperation was established with yet four other universities in Europe; Stuttgart, Dresden, Hamburg-Harburg in Germany and Chalmers in Sweden.