

BRIDGING TO THE FUTURE

Newsletter on Carbon Capture & Storage at Vattenfall

No. 16, September 2010



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 (CO₂) 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 Jämschalde power plant, both Oxyfuel and Postcombustion CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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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A few words from the new CCS Manager at Vattenfall

The good progress at our capture pilot plants continues. The injection of CO₂ at European and other storage sites around the world continues to give positive results. There is strong faith that CCS works and that it can be introduced on a large scale at competitive costs. There are still engineering challenges that we must focus on. However, the more important challenges at present are not technical.

Vattenfall has taken the lead in developing CCS. But CCS also needs public support, in general terms as well as financially, to be further developed and realised. For the demonstration plant at Jämschalde we have been awarded EU funding under the EEPR (European Energy Programme for Recovery). Later this year, we will also apply for demonstration project support under the so-called NER 300 regime. Given the size of the investments, and that CCS, being a new technology, is not ready for direct competition in the market yet, this support is necessary to move ahead with demonstration.

Public support is more than financial. General acceptance is important for any activity, and not least for the types of large-scale infrastructure that CCS is an example of. Some people have raised concerns regarding the safety of the storage of carbon dioxide. Questions are raised that we do our best to answer. We welcome this dialogue; it helps us to understand what the concerns are and to find solutions that can promote acceptance.

Laws provide the formal framework for society to evaluate and approve industrial operations such as CCS. In Germany, the government has recently presented a draft CCS law based on the EU directive 2009/31/EG on CCS that is currently under discussion. In order to not lose time, it is important that a German CCS law can be approved by the legislators before the end of this year.

Dr Karl Bergman

Vice President CCS, Vattenfall (who has recently taken over this responsibility from Bjarne Korshøj, who, in turn, has taken up a new position as Managing Director of Vattenfall Denmark.)



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Cover: Lutz Picard, Vattenfall Germany	

Vattenfall participates in a number of EU projects

Vattenfall is playing an active part in several European projects involving CO₂ capture, transport and storage. Vattenfall learns a great deal by participating in these projects and we also believe that this kind of cooperation between equipment suppliers, the research community and energy companies will increase knowledge concerning the whole CCS chain and help to push development forward for CCS to become commercial by 2020. In this article you will find both comprehensive descriptions of some of the projects as well as summaries of the projects that Vattenfall is involved in.

To date, Vattenfall is engaged in a variety of EU projects, all of which have a different focus in the CCS chain. The projects- ECCO, CO₂ EUROPIPE and CESAR - are supported by the European Commission (EC) under the 7th R&D Framework Programme (FP7). Moreover, Vattenfall is and has been an active partner in projects under the 6th Framework Programme and under the Research Fund for Steele and Coal.

ECCO- European value chain for CO₂

A European CCS infrastructure has not yet been built, and options for the most economically-viable establishment of a CCS infrastructure are studied in the ECCO project.

The ECCO project started in September 2008 and will over the next three years involve 19 partners from 8 countries. These are mainly R&D providers, e.g. Norwegian SINTEF, Dutch TNO and Danish GEUS, but also energy companies, e.g. Statoil, Vattenfall and DONG Energy. The main goal in the ECCO project is to provide a methodology and tool for the evaluation of various CO₂ chain options so that qualified decisions can be made. A focal point in the project is to look closer at enhanced hydrocarbon recovery (EOR/EGR) and its financial implications for CCS infrastructure development. The project will therefore try to quantify the European potential for enhanced hydrocarbon recovery and evaluate the technological challenges involved. The total budget amounts to about €5.5 million. SINTEF Energy Research is coordinating the project.

Results so far

A number of scenarios have been developed in the ECCO project to describe alternative views of the future European sectors influencing the development and deployment of CO₂ value chains in Europe.

These scenarios will be used to provide a common base for the case studies, when running them in the financial tool. A first version of the tool is now being tested for improvements before the cases are run this autumn. Another example of deliverables from this first half of the project is conceptual North Sea reservoir models for different geological formations.

CO₂Europipe- Transport infrastructure for large-scale CCS in Europe

The closer to implementation of CCS we get, the more focus will be directed on the transport issue. CO₂Europipe is a research project that aims to address this particular issue. The project is partly funded by the European Commission in the 7th Framework Programme. The project will run from its start in April 2009 through October 2011. The project involves 18 partners, mostly from the industry. Partners in the project include major industrial players such as Schlumberger, Siemens, Shell, RWE, Linde and Vattenfall. TNS is coordinating the project

The aim of the CO₂Europipe project is to pave the way towards large-scale, Europe-wide infrastructure for the transport and injection of CO₂. The project will result in a roadmap for CO₂ transport infrastructure, with 2020 as the target year for the start of large-scale CCS in Europe. The roadmap will be defined for all the levels considered in the project, ranging from technical to organizational, financial and societal. Both pipeline and ship transport are being considered.

Issues studied and results so far

In the first year of the project, the focus has been on CO₂ infrastructure requirements. Examples of issues studied are:

- Existing European production platforms and transport infrastructure, mainly for natural gas, and the possibility to re-use existing infrastructure for CO₂ transport.
- Timing and expected flow rates of CO₂ as well as timing, location and capacity of storage locations, based on different CO₂ transport scenarios.
- The needs and requirements of a future CO₂ infrastructure to define boundary conditions for such an infrastructure.

CESAR - CO₂ Capture: Enhanced separation and recovery

CESAR is a collaborative research project that is aiming for a breakthrough in the development of energy-efficient, low-cost, post-combustion CO₂

capture technology. The 3-year project, which is part-funded by the European Commission 7th Framework Programme, runs from 2008 into 2011 and brings together over 20 European universities, research institutes, technology suppliers and energy companies, of which Vattenfall is one. The CESAR project includes pilot-scale validation at the Esbjerg test facility in Denmark. The other five focus areas of the project include novel solvent development, process models and modifications but also integrated plant configurations.

In brief, the CESAR project has been instrumental in furthering knowledge and understanding of present and next generation post-combustion capture processes in Europe and a key component in the drive to make this technology commercial by 2020. Vattenfall has made a significant and valued contribution, and gained information that will be fundamental in our effort to prepare for the large-scale deployment of such technology and progress towards informed buyer status.



Esbjerg test facility in Denmark

OxyMod

In recent years, mathematical modelling has proven to be a useful and cost-reducing tool for the design and improvement of conventional pulverised coal-fired power plants. The OxyMod project has striven to extend existing combustion modelling capabilities to Oxyfuel combustion conditions, the primary intended output being upgraded CFD codes that include Oxyfuel-modelling capability for industry and research.

During the three-year period 2005 to 2008, Vattenfall cooperated in and coordinated a European Commission-sponsored project in the Research Fund for Steel and Coal. The project consisted of a unique consortium of six partners; Vattenfall as a power company and CFD model user, IVD Universitaet Stuttgart and the National Technical University of Athens as CFD model developers and users, Chalmers University of Technology as an experimental test rig operator, Doosan Babcock Energy Limited as a leading manufacturer of power boilers and Ansys UK Limited as a commercial code developer and manufacturer.

Conclusions

The objective of the OxyMod project was to extend existing combustion modelling capabilities to Oxyfuel combustion conditions. This required combined experimental work, model development and imple-

mentation and initial validation through comparisons with experimental data. An extensive database of Oxyfuel (and air) combustion trials in gas- and coal-fired test rigs (20kW, 100kW and 500kW) has been compiled. Improved sub-models have been developed and implemented in the CFD codes AIOLOS and FLUENT, and in the engineering performance model BWHOT. Initial validation in 20kW, 100kW and 500kW test rigs has proved that the combustion models developed are principally capable of predicting the more moderate combustion under Oxyfuel conditions. Scope for further model development and evaluation work was, however, also identified.

The partner Doosan Babcock Energy Limited designed a reference 600MWe coal-fired supercritical boiler. A final application of the developed CFD models confirmed the initial design intent of introducing Oxyfuel.

This project has been an important step for Vattenfall and the project results are to be used in the upcoming pre-engineering of its Oxyfuel demonstration plant in Europe.

The OxyMod project also indicated the need for further research on CFD Oxyfuel models and sub-models. Vattenfall is at present taking part in one such project named OxyVal.

ENCAP

The ENCAP project was one of the first and also one of the largest Research and Development projects on carbon capture that Vattenfall took part in under the European Commission's 6th Framework Programme. The project was conducted over a period of five years (2004- 2009) by a large consortium including thirty high-ranked European power companies, power plant equipment manufacturers and research institutes and universities. The project achieved important results that are worth highlighting.

The goal of the ENCAP project was to develop and validate a number of CO₂ Precombustion technologies that in large power plants would meet the targets:

- 90 % CO₂ capture rate and
- 50% capture cost reduction - from a level of €50-60 per tonne of CO₂ avoided.

Another goal of the project was to recommend CO₂ Precombustion capture technology for a large-scale demonstration power plant based on the results of the intensive development and validation work carried out over the five years.

Development of concepts for Precombustion Decarbonisation

The significant development of concepts for Precombustion Decarbonisation - IGCC (Integrated Gasification Combined Cycle) for hard coal and lignite (1000 MWe) and IRCC (Integrated Reformer Combined Cycle) for natural gas (400 MWe) - was initiated at the beginning of the project. The further development and validation of H₂-rich fuel combustion concepts for gas turbines based on lean-premixed technology were successfully performed on test rigs.

A number of OxyFuel Combustion Pulverized Coal (PC) concepts using hard coal and lignite were developed and validated. One Circulating Fluidized Bed (CFB) concept for hard coal was also developed. Experimental validation tests of OxyFuel combustion were carried out in 10 kW, 100 kW and 500 kW test facilities.

The development and validation of the IGCC concept and the OxyFuel concept within ENCAP generated knowledge and results that formed part of the information that power companies used to launch plans for design projects in 2008-2009 aimed at setting up large-scale demonstration plants.

Decisions on initiating plans for the pre-design of such demonstration projects have been announced by the ENCAP partner RWE IGCC power plant) and the ENCAP partner Vattenfall a 250 MWe (gross) OxyFuel demonstration plant in Jämschalde).

ENCAP also involved the further development and testing of alternative oxygen production processes and a large number of novel Precombustion capture concepts.

Chemical Looping Combustion

In addition to this, the ENCAP project performed development and research on components for Chemical Looping Combustion. A design concept for a 455 MWe supercritical coal CLC-CFB (Circulating Fluidised Bed) boiler operating with coal and pet coke was developed and sized. The results showed that the CLC CFB is a feasible concept, close to conventional CFB processes. However, it was concluded that much R&D work remains to be done and further steps in scaling-up are therefore needed to support the ENCAP conclusions concerning the chemical looping combustion reactors of full-scale power plant size.

Future development

The further development of CO₂ Precombustion by the ENCAP consortium was carried out during an important period when interest in the overall CCS concept had gradually increased. The knowledge generated and that is now in the hands of the ENCAP consortium and its partners has already been activated in the further development of CO₂ capture technologies in new CO₂ capture projects in FP7 and the EC RFCS programme.

It is assumed that a number of ENCAP partners will take part in the next steps in the development of CO₂ capture demonstration projects. The knowledge archived in the ENCAP project will provide important background information and data for these efforts.

Progress for the CLC capture technology

In recent years, chemical looping combustion (CLC) has emerged as one of the most promising technologies for low-cost CO₂ capture for solid fuels. CLC provides the possibility of an inherent CO₂ capture without the requirement of a large and electricity-consuming air-separation unit, as in the Oxyfuel process, or an absorption process that reduces efficiency, as in the Postcombustion process. Theoretically, the efficiency penalty for CO₂ capture by CLC only comes from the compressors that give the CO₂ stream the right pressure for subsequent transport and geological storage.

The idea of CLC is to use an oxygen carrier to transport oxygen from air to fuel. In principle, CLC can be applied to gaseous or liquid fuels such as natural gas, syngas or by-products from the oil industry or, most interesting for Vattenfall, a solid fuel such as biomass and coal. In contrast to conventional combustion where the fuel reacts directly with the oxygen content of air, direct contact between fuel and air is avoided in CLC. The process consists of two reactors; an air reactor, where the oxygen carrier is oxidized by the oxygen content of air and a fuel reactor, where the oxygen carrier is reduced by the fuel that is converted to mainly CO₂ and steam.

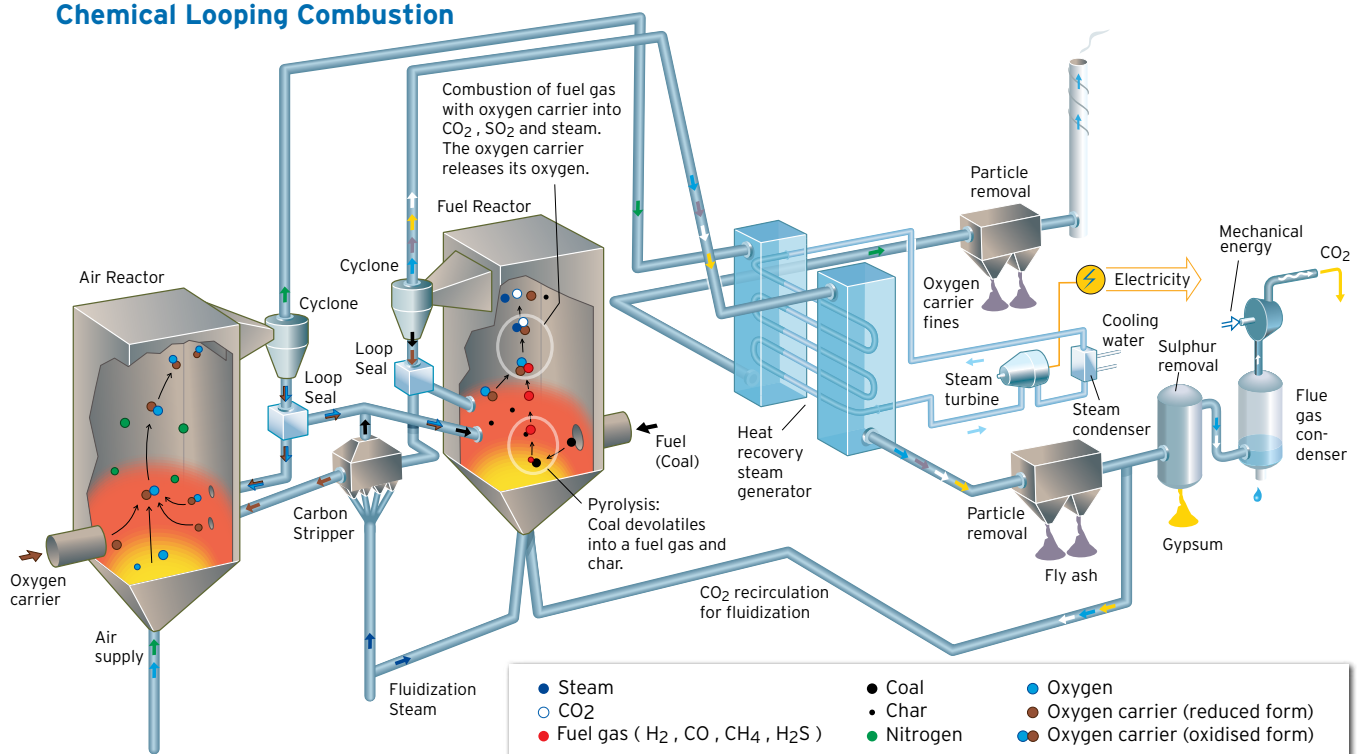
In the case of coal or biomass as fuel, it is expected that the conversion to carbon dioxide will not be complete. Char particles will be formed and exit

the fuel reactor together with the oxygen carrier. In order to avoid the char entering the air reactor a carbon stripper can be used to separate the char particles from the oxygen carrier and recycle them back into the fuel reactor. Simulations have shown that low conversion efficiency in the fuel reactor can be compensated by a high efficiency in the carbon stripper.

The chemical looping combustion process results into two flue-gas streams. The stream leaving the fuel reactor contains mainly CO₂ and steam. The stream leaving the air reactor contains nitrogen and some remaining oxygen. No CO₂ separation unit is required; thus, the separation of CO₂ is inherent in the process, resulting from the fact that the fuel and the combustion air are never mixed.

The performance of the oxygen carrier is essential for the efficiency of a CLC process. Metal oxides are the most promising type of oxygen carrier. For coal combustions, natural ores or waste products from the steel industry containing iron oxides have been tested successfully. The material is cheap and does not contaminate the ash. In this case, the active component is hematite (Fe₂O₃, also known as rust). In the fuel reactor, hematite is reduced ($6\text{Fe}_2\text{O}_3 + \text{C} \rightarrow 4\text{Fe}_3\text{O}_4 + \text{CO}_2$) into magnetite (Fe₃O₄) and then re-oxidised back into hematite in the air reactor ($4\text{Fe}_3\text{O}_4 + \text{O}_2 \rightarrow 6\text{Fe}_2\text{O}_3$).

Chemical Looping Combustion



As important as the oxygen carrier is the reactor system that manages to circulate the oxygen carrier between the air reactor and the fuel reactor. The most promising approach at this stage of the development is two inter-connected circulating fluidized bed reactors that are separated by a carbon stripper. One could say that the reactor is the heart of the process while the oxygen carrier is the blood. The reactor system must pump the carrier through the process and the carrier has a certain capacity to transport oxygen.

Vattenfall works broadly to promote and monitor the development of the CLC technology. There is an extensive cooperation with Chalmers University of Technology on oxygen carrier development and since 2008 we have been involved in the EU-funded ECLAIR project, in which a reactor system is being tested. Vattenfall also performs independent studies, mainly on process design for full-scale power plants with CLC.

ÉCLAIR: Construction of a pilot plant

The purpose of the EU-funded project ÉCLAIR, Emission Free Chemical Looping Coal Combustion Process, is to develop CLC for coal combustion with CO₂ capture and to reach an efficiency penalty of less than 3 percentage points and a CO₂ avoidance cost of about €10 - 15 /ton CO₂.

An important milestone on the way to reaching these goals is the construction of a 1 MWth prototype. In March 2009, the cornerstone was laid at the CLC pilot plant construction site at the Technical University of Darmstadt in Germany. Construction has been carried out since then and was completed this spring. This summer it is time for cold commissioning of the plant, followed by hot commissioning during the autumn. The first tests for the whole reactor system are scheduled to begin in February next year.

Different tracks in the ÉCLAIR project

To complement and support the activities in the Darmstadt pilot plant, the ÉCLAIR project also includes the construction of a smaller test rig at Chalmers Technical University in Gothenburg, Sweden. This test reactor has a thermal capacity of 100kW and, due to its smaller size, a greater flexibility. In addition, less material is needed for experiments; thus, it will be possible to conduct more tests with more different types of oxygen carrier and coal than will be possible in the 1 MW pilot plant.

The ÉCLAIR project is led by Alstom. Other partners are Air Liquide, the Spanish research institute CSIC, SINTEF and Vattenfall.

Burner replacement in Schwarze Pumpe

During the spring, a burner was replaced in Vattenfall's oxyfuel pilot plant in Schwarze Pumpe. The burner is the device which injects fuel and oxidant into the furnace, where the combustion takes place. The design of the burner is crucial to, for example, combustion efficiency, the formation of CO, CO₂ and NO_x and heat transfer.

The new burner, delivered by Hitachi Power Europe, is at present being commissioned and Vattenfall initiates the test campaigns again during the summer.

The tests to be performed are about the same as the ones that have already been conducted using the two previous burners, in order to make a proper comparison. The composition of the flue gas and the effect that it has on the downstream equipment, electrostatic precipitator, flue gas desulphurisation and condensation and the CO₂ compression unit will be thoroughly investigated. The Vattenfall personnel who are performing the actual tests have improved their skills along the way and tests that will be carried out this summer are even better and more precise than the ones performed earlier.

Guidelines for CCS

CO2QUALSTORE and CO2PIPETRANS

Unified guidelines on how to identify, evaluate and manage risks associated with CO₂ transportation and storage are a way of assisting both the developers of CCS projects and the authorities handling the approval and authorisation of these projects. Such guidelines have been developed by two joint industry projects, CO2QUALSTORE and CO2PIPETRANS, in which Vattenfall has taken an active part. Both of the projects were led by DNV (Det Norske Veritas).

Guideline for Selection and Qualification of Sites and Projects for Storage of CO₂

Vattenfall is one of the industrial sponsors of the project CO2QUALSTORE, which was recently finalised. The CO2QUALSTORE project has developed a guideline for the safe storage of CO₂. The guideline outlines a step-by-step approach when selecting and granting permits for storage sites, ensuring that the CO₂ storage sites are qualified following a safe, consistent and cost-effective process.

Vattenfall has as a sponsor of the CO2QUALSTORE project made further efforts to identify and develop processes to assess CO₂ storage-related risks. The guidelines elaborated in the CO2QUALSTORE project provide a procedural framework that aims to support the safe implementation of storage in accordance with regulations, codes and standards. The guidelines on CO₂ storage site qualification establish a common basis regarding methodologies and workflows to constantly secure high quality and safety.

Accordingly, the guidelines aim to provide common generic workflows when selecting and qualifying sites and projects for CO₂ storage. A qualification process is defined for each stage - from the first site screening stage to the final closure stage. The guidelines contribute to a smoother implementation of CO₂ storage in accordance with regulations and international standards and directives. This means that the standardised method of working generates no additional documentation and reporting and the project can therefore be handled in a more cost-effective manner.

Regulators have been invited to closely follow the development of the guidelines in order to ensure that they are easy to use when verifying safety aspects. The guidelines include a workflow procedure that

is intended to help regulators to verify that sites have been selected and assessed as suitable for the geological storage of CO₂ according to valid regulations, codes and standards. The CO2QUALSTORE guidelines will be updated periodically, concurrently with CCS development. A process to update the guidelines has been set up by DNV.

The guidelines support the dialogue with the general public

The guidelines could also be used as a tool in the work to provide assurance to the general public. The guidelines explain in a pedagogical way that the specific storage site has been selected in a safe and responsible manner in accordance with the guideline processes.

Implementation of the guideline within Vattenfall

Vattenfall is about to implement the guidelines developed in the CO2QUALSTORE project as a standard in its development of CCS demonstration projects in the period ahead. The methodology elaborated in the project is about to be implemented in Vattenfall's demonstration project in Germany. The guideline will be used to design the programme on characterising the Birkholtz/Neutrebbin storage sites. It will also be applied at the Vedsted storage site in Denmark, as well as for quality assurance for work underway at Vattenfall Benelux.

CO₂PIPETRANS:

Guideline for transportation of CO₂

There is a growing awareness among authorities and in the industry of CO₂ as a substance for transmission in large and geographically-interconnected pipeline systems. Therefore a joint industry project named CO2PIPETRANS has been initiated with the aim of identifying and filling-in gaps in knowledge, technology and practice on the subject. Together with other industrial partners, Vattenfall actively contributed in 2009 to the development of a guideline for the large-scale transmission of CO₂ for CCS. The guideline will ensure that CO₂ is transmitted in offshore and onshore pipelines in a safe, reliable and cost-effective manner.

The guideline builds on the continuously-increasing scientific and industrial knowledge of the technical difference between the transmission of large volumes of CO₂ in pipelines and the transmission of hydrocarbons, like natural gas. Vattenfall's R&D work on CCS has generated important knowledge, ques-

tions and topics that have had a vital impact on the work with the guideline in the joint industry project.

Guidance and criteria for transportation of CO₂

The guideline provides guidance and sets out criteria for the development, design, construction, testing, operation and maintenance of steel pipelines. It applies to new offshore and onshore pipelines for the transportation of fluids containing overwhelmingly CO₂, but also to the conversion of existing pipelines. The project has covered the transportation of CO₂ from different origins; CO₂ captured in combustion processes, CO₂ separated from hydrocarbon streams, for example natural gas, and CO₂ from a natural, geological origin that has been extracted to be used for EOR, Enhanced Oil Recovery. Gaseous, liquid and dense-phase operation conditions are included.

The guideline will supplement current pipeline standards and it will provide important and necessary support relating to specific CO₂ transportation issues for CCS developers and pipeline engineering and construction companies. Pipeline operating companies, authorities and certification companies will also benefit from the new guideline.

The work on the guideline has also identified further gaps in technology or knowledge, which has led to a continuation of the industry collaboration.



Pipelines running through sparsely and densely populated areas involve different kinds of risk, which can be mapped using a GIS-based risk analysis methodology.

Exploring conditions for CCS technology implementation in Poland

The Polish Clean Coal Technology Platform (PPCTW) has the task of working on the implementation of low-carbon coal-combustion methods in Poland. The Platform carries out technical and economic analyses related to the use of low-carbon coal-combustion technologies in Poland. It also renders expert support to the legislative process of transferring relevant EU Directives to the Polish legal environment. The platform includes industry partners and Vattenfall is one of the leading members. PPCTW recently hosted a two-day seminar on the topic "Conditions for CCS technology implementation in Poland".

The seminar gathered the members of the Polish Clean Coal Technology Platform (PPCTW), as well as representatives of the Ministry of Economy, the Ministry of Environment, the Silesian University of Technology, the Polish Geological Institute and the National Centre for Research and Development. The

two-day seminar was mostly devoted to presentations and discussions. "I'm glad that the institution which we have created has become a real platform for the exchange of experience," with these words Jacek Piekacz, Head of Vattenfall Poland and President of PPCTW, greeted the participants.

CCS construction site - PGE Bełchatów

As part of the seminar, the participants visited the PGE Bełchatów CCS construction site, integrated with a new 858 MW block. Tadeusz Witos, the CEO of PGE Bełchatów, revealed the technical parameters of the CO₂ capturing installation: 1.8 million tonnes of CO₂ will be captured per year and 235 tonnes will be captured per hour, the CO₂ capture efficiency is 90% and the amount of flue gas purified equals 260 MW of power. According to the implementation timetable, the CO₂ storage facility will be finished in 2014, the decision on the launch of CO₂ storage will be passed in December 2014 and the whole site will be put into

operation in December 2015. At the moment, the most urgent activities include the financial management of the project, geological works and social consultation. The cost of the installation is PLN 2,303.1 million¹.

The Polish coal policy

Elbieta Wróblewska from the Energy Department of the Ministry of Economy presented the Polish coal policy. "Currently it is necessary to invest in the development of clean coal technologies that would allow for an increased efficiency of coal-derived power generation and curb the greenhouse gas emissions," she said. CCS technology shows the biggest potential for CO₂-emission reduction, but - as of today - its efficiency has not been proven on a commercial scale. In order to test the CCS technology, the European Commission plans to launch a Flagship Programme involving the construction of nine such sites around the European Union. One of the Polish governmental initiatives in the CCS area is a programme of the Ministry of Economy called "The Directions of CCS Development in Poland". Its goal is to identify and eliminate barriers for the implementation of CCS in Poland. The programme is to be approved by the Council of Ministers in the autumn.



Storage potential in Poland

Henryk Jezierski, Vice-Secretary of State in the Ministry of Environment and the Chief National Geologist, presented potential locations for CO₂ geological storage facilities. These sites are depleted gas reservoirs and underground reservoirs with a high salinity factor.

He spoke about the global and European experience of CO₂ geological storage. Polish experience in the field of CO₂ storage includes the oldest industrial acidic gas storage installation, located in Borzęcin. Over 12 years, almost 3 million cubic metres of gas containing CO₂ was pumped in there. This site is a scientific testing ground for the pumping of natural gas into the ground in land conditions.

The seminar also included a presentation by Adam Wójcicki from the Polish Geological Institute about the storage potential in Poland. He presented potential reservoirs, divided into several districts, such as Budziszewice-Zaosie, Skoczów-Czechowice-Cieszyn, Mazowsze and Rzeszów. Central Poland is believed to

provide good potential. Answering a question about the threat to underground water, Mr. Wójcicki said, "geological storage poses no threat of ground water contamination. Thanks to the sealing layer, CO₂ will not permeate to the ground water".

CCS directive into Polish law

Ewa Gasiorowska, Vattenfall Poland, represents the PPCTW Legal Team and she described the activities aimed at the introduction of the CCS Directive into Polish law. In Poland, the authority responsible for the preparation of the regulations is the Ministry of Environment. The Ministry has prepared a draft proposal of changes to the Geological and Mining Law, which is to be amended by provisions on the geological storage of CO₂. The Law should enter into force in the middle of 2011. The scope of regulation is to include, above all, such issues as the rules for granting licenses for the exploration and operation of reservoirs, the regulations for monitoring and shutting down facilities, the liability regulations for CCS and regulations on fees, as well as the issue of CO₂ transportation from the source of emission to the storage facility.



Information campaign on the CCS technology

The platform also informs society on all aspects related to the clean-coal technologies. Andrzej Siemaszko from the National Contact Point (Governmental-EU entity supporting R&D programmes) stressed the necessity of conducting a wide information campaign on the CCS technology in Łódzkie voivodship. "You have to talk to the citizens. Łódź is the Polish capital for geothermy, maybe we should go towards joining these two technologies?"

In addition, Małgorzata Świdorska from the National Centre for Research and Development talked about the need for wise social consultations. She suggested that young people should also be included in such discussions.

The platform was appointed in February 2008 and includes: Vattenfall, PGE Polish Energy Group, PKE, EDF Poland, Dalkia Poland, CEZ Poland, GdFSuez Poland, Fortum Heat and Power.

¹ Euro = 4 PLN

The construction of the pilot plant for CO₂ capture in Buggenum is finalised

The construction of the CO₂ pilot plant at the Willem Alexander power plant in Buggenum was recently finalised. Currently, the finishing touches are being put to the instrumentation and the plant is being tested.

The construction of the CO₂ pilot plant was recently finalised. There will now be a number of tests to ensure that the unit is properly coordinated with the gasification unit. The start of the pilot will be in mid October and the initial test results will be announced in mid-December.

The unit was recently brought in by ship - in modules, like a sort of Meccano set. The modules have been put together elsewhere, for three reasons:

1. Safety: Buggenum is a working power plant. That is why it was necessary to limit the construction hours at the plant as much as possible
2. To limit the nuisance to the immediate environment: if all the parts were to be brought in separately, there would be a lot of freight traffic

3. To shorten the building period: building the modules and the civil engineering work on the ground has now occurred simultaneously.

The CO₂ capture pilot project in Buggenum will last a total of two years. The experience gained in Buggenum will then be used to build the CO₂ capture unit at Nuon Magnum in Eemshaven.



Longer project term for CCS at Nordjyllandsværket

On 1 March 2010, Vattenfall submitted a revised application to the Danish Energy Agency for permission to store CO₂ in the Vedsted structure in North Jutland.

On the basis of the 2D seismic surveys of the Vedsted structure in 2008, the structure is considered to be suitable for the storage of CO₂, both in terms of safety and geology. For this reason, Vattenfall is retaining the project for a CCS plant at North Jutland Power Plant. The reprioritisation in the CCS field that took place following the financial crisis means, however, that the CCS facility at North Jutland Power Plant is being postponed and is now planned as an early commercial plant for commissioning in around 2020. This means that planned geological and geophysical preliminary studies of the storage structure will take place over a longer period of time.

Preliminary studies divided into different periods of time

Vattenfall's application to the Danish Energy Agency involves operations during two periods of time that will together lead to a decision on whether the structure is suitable. For Vattenfall, it is essential that we are able to document that safety in the storage of CO₂ in the Vedsted structure is optimum.

In the first period, from 2010 to 2012, there will be another analysis of the Vedsted structure and its properties on the basis of the existing data. This will be supplemented by small-scale studies related to the area's drinking water resources, and a groundwater model will be prepared. Studies of the variation in natural emissions of CO₂ in the area will also be carried out.

In the second period of time, from 2013 to 2015, 3D seismic surveys will be carried out. At the end of the period of time, preparations will begin to carry out deep drilling in the structure to study the rock types' physical properties and test the hydraulic conditions in the store.

Only when all the preliminary studies have been carried out and the necessary data has been generated, can a final professional and technical decision be made on whether the structure is well suited for storage of CO₂.

Political processing of the application

The Minister for Climate and Energy can grant permission for the storage of CO₂ under the Danish Subsoil Act. Prior to this, the case must be examined and discussed on the Folketing's Energy Policy Committee, which has representatives from by far the majority of the parties in the Folketing [Danish Parliament].

The European Power Sector – today and tomorrow

The European Union can meet stringent CO₂ emission reduction targets at a reasonable cost to society. This is one of the conclusions that researcher Mikael Odenberger at Chalmers University of Technology has come to after running his techno-economic model of the development of the European power sector. Another conclusion drawn from the runs is that the CCS technology constitutes a great potential for reaching abatement targets.

Mikael Odenberger is doing research on energy system development at Chalmers University of Technology, Gothenburg, Sweden. Mikael has devoted most of his time at the department of Energy and Environment to creating a techno-economic model for analysing the development of the European electricity supply system. The model has been used to investigate possible pathways for the European electricity supply system to meet stringent CO₂ emission targets. The primary objective of the model is to find the most cost-efficient investment strategies for the transition from today's electricity supply system to one that meets the emission goals set for 2050, in terms of both timing and choice of technology. Jenny-Ann Nilsson, member of the editorial office met Mikael Odenberger and discussed his techno-economic model of the development of the European power sector.

How does your model work?

"The model is based on the Chalmers Energy Infrastructure Database, which is a database that maps the existing European power sector, including factors such as capacity, lifetime and fuel types, but also planned power plant investments. In the model, this set of data is combined with certain assumed prerequisites for the power sector and different technologies, as well as existing macro-economic scenarios for power demand over time. By comparing existing and planned power capacity to the future demand, the model presents how the gap between power generation and demand can be filled in the most cost-efficient way while meeting stringent CO₂ emission targets as well as European goals for renewables and energy efficiency.

What are the most interesting results from running your model and what has aroused the most interest among readers of your articles and thesis?

"For me personally, every development step and sign of progress has been exciting and still is," Mikael says.

"What has generated the most interest or attention among readers is probably that it is possible and fairly simple to reach European emission targets at a reasonable cost. Carbon dioxide emissions from the European power sector can be decreased by 85 per cent by 2050 at a cost not exceeding €50/ton of abated CO₂. Technology development and costs should not be the biggest challenge. Yet, it is a gigantic system with embedded inertia and complexity that must be transformed, which means that it will still be a major challenge to facilitate the changes required in time. The good thing is that the possibilities are really there and that is what makes it so exciting to study in depth."

How important is CCS according to your studies?

"That differs in the different studies, depending on what is assumed and accounted for in the model. According to the earlier cost-optimisation studies, CCS had a very big role in reaching stringent emission reductions by the most cost-efficient means. In later versions of the model, load variations during the year were included as well as ambitious goals for renewable electricity and energy efficiency. Results from running this version of the model showed that power plants equipped with CCS were still generating 15 per cent (about 500 TWh) of the total electricity supply in the EU by 2030 and 30 per cent (1000-1100 MWh) by 2050.

15 and 30 per cent are not insignificant shares I would say. Do you agree?

"Certainly. However, for CCS to make up this 15 per cent share of power generation by 2030, CCS has to be commercially available by 2020 and that includes not only capture but also the transportation system and storage must be economically viable by then."

So, what are the prerequisites for CCS to become one of the potential solutions for climate mitigation as it is presented in your thesis?

"To start with, CCS can definitely help us as a bridging technology and it has the advantages of diversifying our energy mix and subsequently decreasing the EU's dependence on a few oil and gas producing countries. In addition, coal power and CCS ease the increasing pressure on biofuels. Rules and regulations that actually enable CCS and the investment decisions in time are probably most important right now. As well, a broad consensus that we are to do this is needed. If the industry has to drive this development alone, then there might be a problem in reaching economies of scale in time."

But the ETS price on CO₂ must also influence the development of CCS?

"Yes, definitely! That is one of the issues that has been acknowledged in Pathways to Sustainable Energy Systems." Mikael explains that PATHWAYS is a multidisciplinary project that has been running for over five years, focusing on the development over time of the stationary energy system (power, industry, housing and facilities). Two scenarios are used for the analysis; one policy-driven scenario with several different policies acting in parallel and another scenario that is more market driven with the ETS system as the main driver. "In this project, I have been looking at the power sector", Mikael adds. "According to my runs, CCS is a central player in the European power sector if we are to reach 85 per cent

emission reductions by 2050 in a cost-efficient manner. Naturally, CCS will begin to develop in carbon-intense countries with an existing coal infrastructure. However, if CO₂ emissions become expensive enough, say more than €60/ton, CCS will also be interesting for CO₂-intense industries, such as pulp and paper, steel and the cement industry. Suddenly, countries like Sweden will probably also open their eyes to CCS."



Mikael Odenberger

"A cornerstone for Europe's industrial culture"

CCS demonstration projects presented in Brussels - Energy Commissioner Günther Oettinger and Brandenburg's Economics Minister Ralf Christoffers advertise for climate protection technology.

Six CCS demonstration projects will be developed in Europe over the next few years: they will be funded by the European Energy Programme for Recovery (EEPR) and include Vattenfall's planned CCS power plant in Jämschwalde. Other power plants will be built in Poland, the UK, Italy, Spain and the Netherlands, designed to promote the further development of carbon dioxide capture and storage (CCS) technology. A workshop entitled "Making CCS work - the road to success", organised by the Representation of the Federal State of Brandenburg on June 28 in Brussels, aimed at bringing these six projects together and initiating a dialogue. Representatives of the individual projects and regions met for the first time to discuss the opportunities, future prospects and challenges of the technology.

"A good idea at the right time"

Among the sixty guests from the European Parliament, Commission and economy, who learnt about the latest developments in this sector, were European Energy Commissioner Günther Oettinger and Brandenburg's Minister of Economic and European Affairs Ralf Christoffers. In his opening speech, Christoffers stressed the necessity of a broad-based and stable energy mix as well as a proactive approach to ensure the successful introduction of new technologies for climate protection. He pointed out that CCS could be used in industry as well as in power plants. Oettinger welcomed the initiative of putting together a workshop as "a good idea at the right time" and outlined the future of CCS technology in clear terms: "We

must find ways and means to ensure that Europe can remain a centre of coal and steel production without sacrificing climate protection. Brandenburg and the leading pan-European energy company Vattenfall are key partners for us in this project." He noted that coal and steel had been the twin founding pillars of the European Community, and that the discussion about CSS is highly up-to-date sixty years after the Schuman Declaration.

Similar challenges

A guided tour of the exhibition presenting the status of the six demonstration projects revealed parallels between them: social acceptance, financial support and further technological development were named as the greatest challenges faced by all of them. The subsequent panel discussion, in which members of the European Parliament were joined by representatives of the various regions, showed that in addition to economic and infrastructure questions, mutual exchanges between the projects and dialogues within politics are particularly vital for the further development of the technology. The development of a standardised infrastructure for the transport and storage of CO₂ and funding for the projects were at the centre of the discussions.

The Commissioner stressed the intention of the Directorate-General for Energy to include the CO₂ infrastructure in the energy infrastructure package planned for autumn 2010. Minister Christoffers summed up the day with a positive outlook: "CCS is essential for the further development of Europe's industrial culture. However, the social acceptance of the technology in the respective regions is of crucial importance. That is why the dialogue must be and will be actively pursued."

On the other side of the bridge - Almere Sun Island

Vattenfall is committed to reducing carbon dioxide emissions and CCS is one method of achieving this. Increasing renewable energy sources is another vital part of the strategy to dramatically cut carbon dioxide emissions. Other alternative energy sources, such as solar power development within Vattenfall BG Benelux and ocean power are part of the R&D investments of the combined companies. Vattenfall in the Netherlands is for instance investing in the innovative project called Almere Sun Island.

In February 2008, Nuon and the municipality of Almere signed the contract to build Almere Sun Island. Construction started in September 2009 and completion is planned for the summer of 2010.

The city of Almere has an ambitious sustainability programme. One of the elements of this programme is district heating. The way the island works is simple: water in the solar collectors is heated by the sun's rays. The heated water will then be pumped directly into the district heating network that will supply heating and hot tap water to the new residential area Noorderplassen-West. With a collector area of around 7 000 m² the Almere Sun Island will be the fourth largest solar collector field in the world.

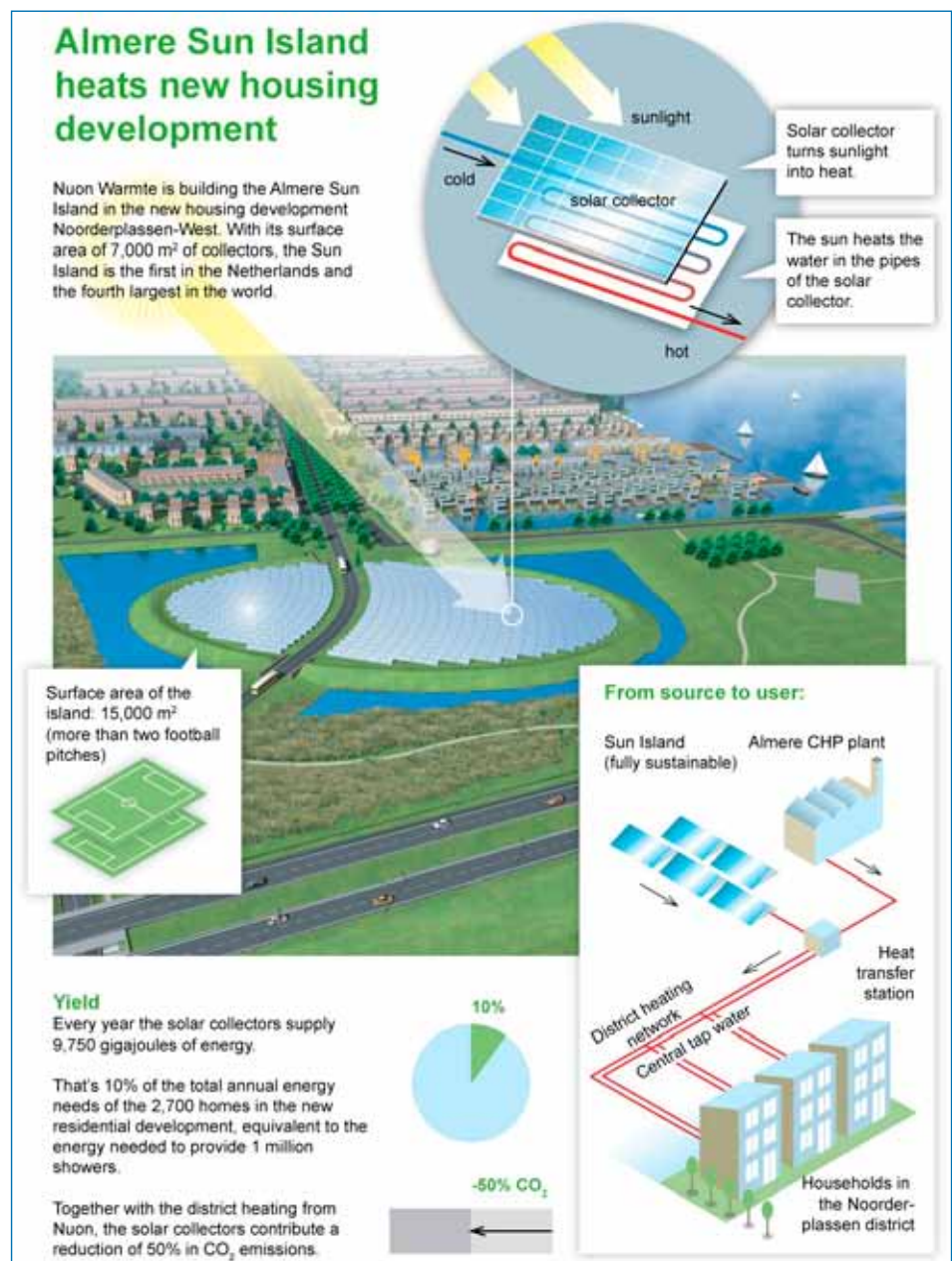
One million showers a year

The solar island will supply 9.750 Gigajoules of sustainable energy annually. That is 10% of the district's annual heating needs and equates to

the energy used by taking a million showers. The remaining heat requirements will also be supplied by Vattenfall BG Benelux, using residual heat from the nearby power plant in Almere.

50% reduction in CO₂ emissions

The solar collectors and district heating will together reduce CO₂ emissions by 50%. For every home that uses district heating the annual CO₂ reduction is equivalent to driving 12 000 fewer kilometres.



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 Lutz Picard in Germany. He joined the CCS Project in 2009 and his duties include working with guided tours at the Oxyfuel pilot plant for CCS, Schwarze Pumpe.

Since the inauguration of the Oxyfuel power plant Schwarze Pumpe in September 2008, nearly 6 000 visitors from more than 50 countries have visited the site. In 2009, it had 4 400 visitors from both Germany and many other countries, as well as from several branches: politicians and representatives from authorities, journalists, TV and radio teams, technicians, students, Vattenfall employees, members of associations and particularly interested people.

Goal with guided tours

It is crucial that local authorities and politicians, the general public and inhabitants in the vicinity of the pilot plant feel well informed about the ongoing activities. Therefore, Vattenfall is putting a lot of effort into providing information about the pilot plant by offering guided tours. Lutz Picard describes this more in detail. "The overall goal in guiding visitors around the plant is to create understanding of the technology and show that Vattenfall as a company is open and very confident about CCS. Furthermore, we want to create sympathy for our climate protection goals and of course make a good impression of the project we are so proud of. Of course we also want to provide profound technical information, up-to-date figures and data for those visitors that are already experts themselves."

Biggest challenges

Lutz Picard has worked in Schwarze Pumpe for almost 25 years, in the field of Research and Development concerning lignite refining. For several years he was responsible for public relations at a medium-sized company producing synthesis gas from coal and waste in the neighbourhood of the pilot plant. That kind of knowledge and experience is invaluable when working as a guide.

Lutz Picard continues describing the challenges that comes with the job. "The biggest challenge is to always be well-informed about the dynamic technical process in the pilot plant and also about the CCS activities within Vattenfall in general and to always be prepared to answer the varied range of questions

that arise." The most common questions among the visitors are:

- What results have been gained so far?
- What are the technical challenges of the project?
- How can CO₂ be handled safely?

Another tricky thing, as Lutz Picard sees it, is to make every tour individual, impressive and interesting by adjusting it to the visitors' individual needs, interests and backgrounds.

Impressions after the tour

In general, the majority of the visitors say that they have received positive impressions from the guided tours. "I receive positive feedback about the tours we are offering," says Lutz Picard. "The visitors especially like the clean and nice-looking outer appearance of the plant and some even admit that they had imagined lignite-fired plants to be dirty and dusty. And most visitors wish us all the best for the success of our project after the tours."

Future plans

"We aim at stabilizing and improving the level of our guided tours while working on better technical preconditions. In the long term, we would like to continue the good cooperation with the neighbouring power plant Schwarze Pumpe. In the short term, I personally would like to find the time to update our small flyer about the pilot plant and to add a technical chart concerning CO₂ applications," Lutz Picard concludes.



Lutz Picard