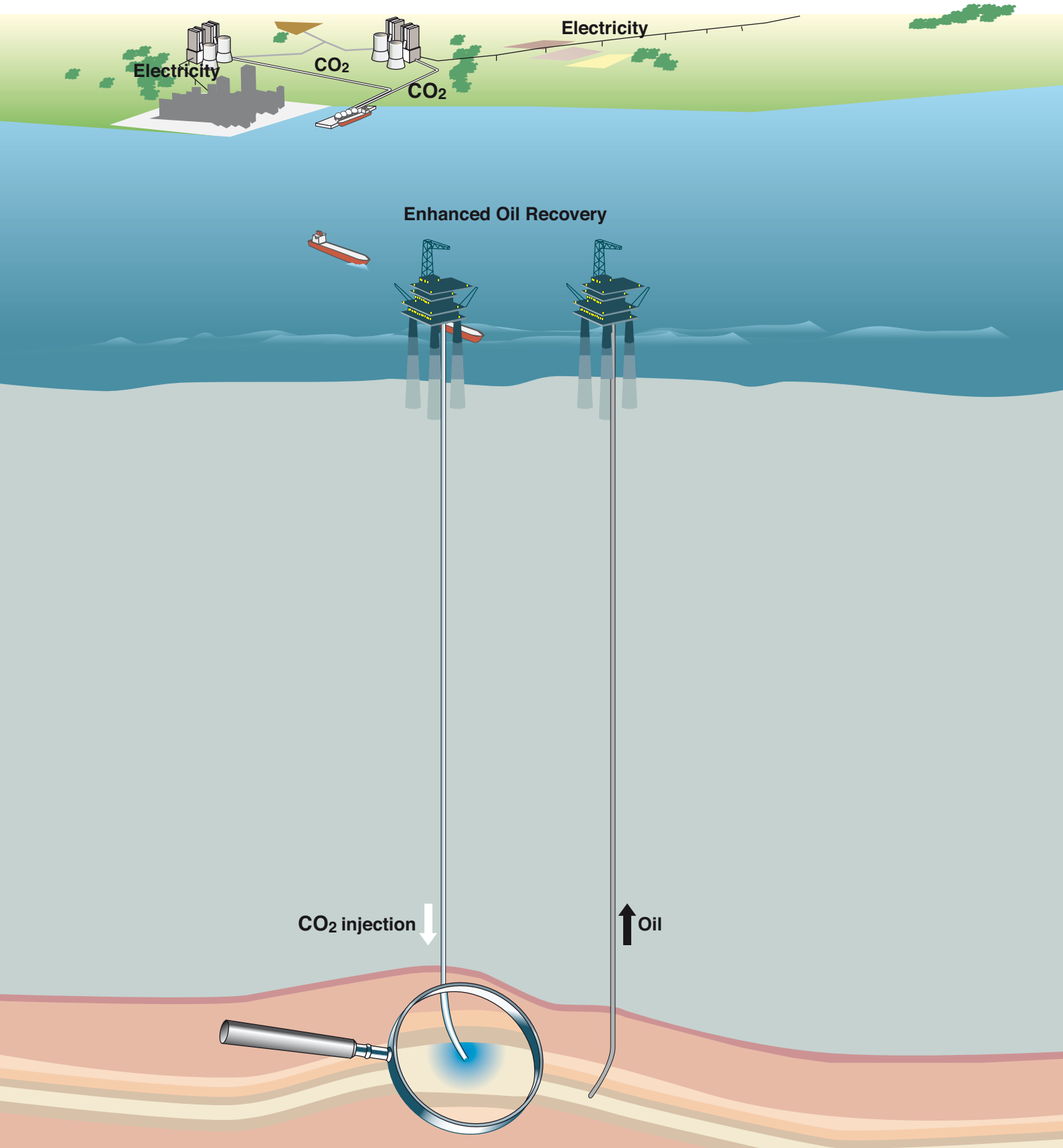


BRIDGING TO THE FUTURE



The European Union's vision is to strengthen Europe's competitiveness on the globalised market. For this, a secure and competitive energy supply is crucial. In parallel, the EU has decided to be in the forefront in curbing climate change.

Vattenfall recognises and supports the European vision on both the Lisbon strategy and the determination to curb climate change. And when it comes to the question of the overall production mix, our statement is very clear: Keep all options open!

We need more efforts to strengthen energy efficiency and we need more renewable energy. However, it will take time for these to be further developed, commercialised and implemented. In the meanwhile we need to do something – we need some kind of bridging solutions.

Today – and tomorrow – Vattenfall as well as Europe and the World are dependent on fossil fuels for its energy supply. Coal is a competitive energy source, it is extracted all over the globe and known resources are large enough to last for at least another couple of centuries. The only problem of coal is its CO₂ emission.

That is why Vattenfall started the CO₂ free power plant project in 2001. We continue to use coal at competitive costs but without CO₂ emissions. The aim is to develop a commercial concept by 2020 and the work is proceeding. Our engineers are hard working, and other colleagues are engaged in further tricky details of the project – less technical details, but nevertheless indispensable prerequisites for the permit of operation. One obstacle for carbon dioxide capture and storage was removed recently after international negotiations, in which the European Union as well as Member States were involved. With effect from 10 February 2007, storage of carbon dioxide under the seabed will be allowed under amendments to the London Protocol.

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: Post-combustion 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.

This newsletter is distributed three times a year and 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



Dr. Reinhold Buttgerit
Director of Vattenfall European
Affairs office, Brussels

What is in the CO₂?

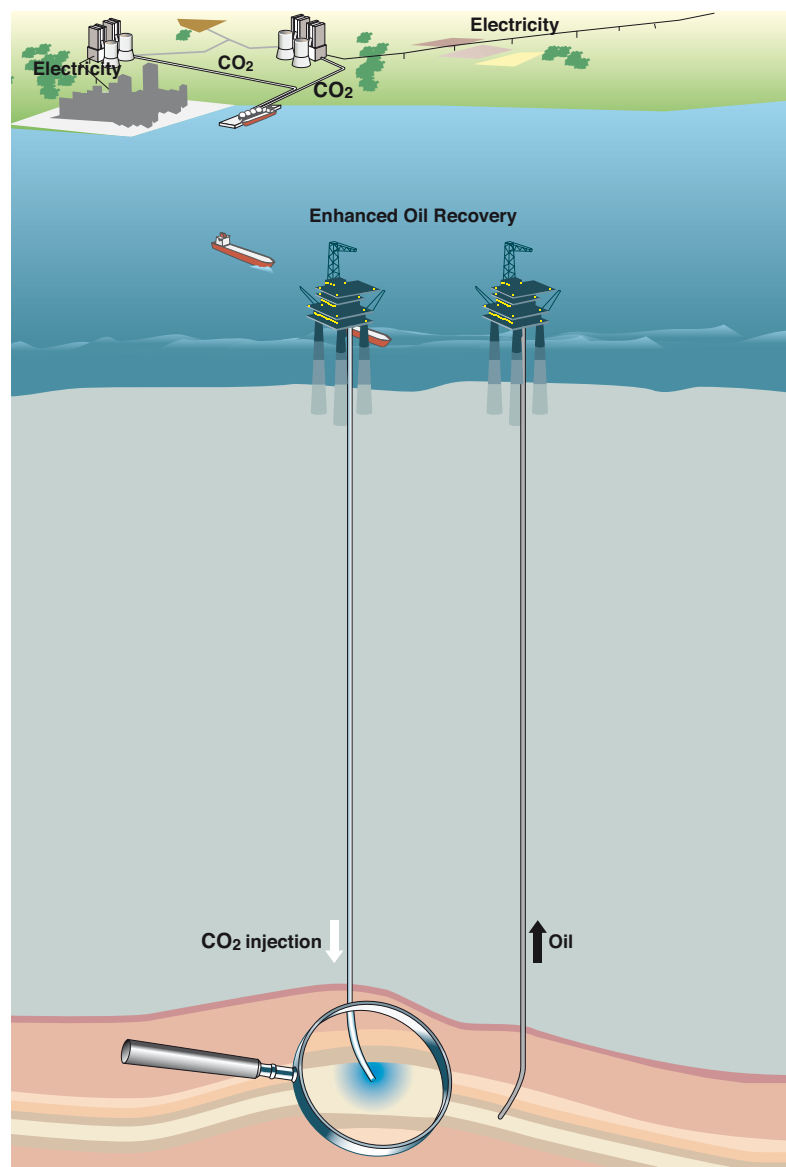
An important but previously not widely discussed aspect of the analysis of a system for CO₂ capture, transport and storage concerns the quality requirements set for the captured CO₂, i.e. the concentration limits for the non-CO₂ components present in the stream sent to the storage site. The non-CO₂ components originate from four main sources:

1. The fuel can contain and/or generate H₂O, CO, SO_x, NO_x, H₂S, HCl, HF, H₂, CH₄, heavy metals, hydrocarbons and particulates.
2. (Excess) air or oxidant used for combustion of the fuel will give rise to O₂, N₂ and Ar in the resulting flue gases.
3. In-leakage of air into the plant and CO₂ capture system will also give rise to O₂, N₂ and Ar in the resulting flue gases.
4. The CO₂ capture or CO₂ clean-up process could introduce traces of NH₃ and solvents.

The composition and concentrations of these non-CO₂ components are in turn dependent on which capture process is used and the selected CO₂ clean-up processes.

This aspect could be seen as both a risk and an opportunity and could have a direct influence on the cost of CO₂ capture and storage. There is an opportunity to co-capture other main pollutants from power plant operations that would otherwise have been emitted to the air and store them together with the CO₂. Thereby, a concept with near zero emissions could be created and, in addition, costly and energy-demanding flue gas cleaning equipment could be excluded. There is also a risk that components other than CO₂ in the captured stream could have a negative effect on the transport and storage system, both from a technical and environmental and health point of view, and therefore need to be removed. However, overly stringent requirements are likely to induce high costs for cleaning of CO₂ and should therefore be avoided.

The question of what the CO₂ should be allowed to contain recently came up in a consideration



from Greenpeace International to the proposed Annex I to the London Protocol. Greenpeace stated that it would like to see a limit of 99.9% CO₂ in CO₂ streams stored underneath the seabed. It is not specified what the other 0.1% of the stream would be allowed to contain. Vattenfall does not, from a scientific point of view, see any justification for this general restriction on the stored CO₂ stream. Vattenfall agrees with Greenpeace that CO₂ of high purity can, at least in theory, be produced, but this has consequences such as:

- Increased energy consumption for the purification process. More fuel has to be used to produce the same amount of electricity.
- Increased investment and operational costs. The cost of CCS will increase putting the technology itself at risk.
- Decreased CO₂ recovery. CO₂ may be lost as a consequence of the clean-up process constraints.

In Vattenfall's opinion, limits on CO₂ purity should not be general but focus on identified harmful components and be based on a limit value that can be motivated. The allowable levels of non-CO₂ components in CO₂ to be stored should be evaluated based on a number of aspects: possible operational problems during CO₂ transport; possible operational problems during CO₂ injection; storage integrity (requires site-specific investigations); environmental aspects over the lifetime of the full capture transport and storage chain; health and safety aspects of the full chain; legal aspects; economic considerations.

It is important to remember that the storage of the CO₂ does not take place in a "clean" environment, as the water contained in these aquifers contains both minerals and heavy metals. The gas-phase in sub-seabed formations naturally often contains both methane and nitrogen.

It should also be observed that natural CO₂ reservoirs occur in the earth crust and are sometimes used as CO₂ sources for enhanced oil recovery in the US oil industry. Nor can these natural CO₂ occurrences be regarded as "clean", as typical other components that are present are methane and other lighter hydrocarbons, nitrogen and H₂S.

What is the London Convention and Protocol?

The London Convention from 1972 is an international treaty that limits the discharge of wastes that are generated on land and disposed of at sea. Currently 81 states have signed, ratified or otherwise acceded to the convention. The 1996 Protocol is a separate agreement that modernised and updated the London Convention, the Protocol will eventually replace the Convention and so far 29 states have acceded to the 1996 Protocol.

The 1996 Protocol takes a precautionary approach and prohibits the dumping of wastes at sea, except for certain substances, which are listed in the Annex 1 to the Protocol. On 2 November 2006 the Contracting Parties to the London Protocol adopted amendments to Annex 1 by adding "CO₂ streams from CO₂ capture processes" to this list. This means that a basis has been created in international environmental law to regulate storage of CO₂ in sub-seabed geological formations. The amendment will enter into force 100 days after adoption, i.e. on 10 February 2007.

The London Convention and Protocol have been established within IMO, the International Maritime Organization, which is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships.

For more information: www.imo.org and www.londonconvention.org

ETP ZEP – European Technology Platform on Zero Emission Fossil Fuel Power Plants

Europe is committed to being a leader in combating climate change, and to meet the challenge of reducing European CO₂ emissions by 50 to 80 per cent from today's levels by 2050, the development and deployment of zero emission fossil fuel power plants is considered indispensable. The European Commission and European energy industry, the research community, non-governmental organisations and others have together established the European Technology Platform on Zero Emission Fossil Fuel Power Plants (ETP ZEP) that unites all key stakeholders in this field. ETP ZEP was officially launched on 1 December 2005 and aims at coordinating the establishment and implementation of a Strategic Research Agenda and a Strategic Deployment Document to remove the obstacles to the creation of highly-efficient power plants with near-zero emissions by 2020. This will include CO₂ capture and storage, as well as clean conversion technologies leading to substantial improvements in plant efficiency, reliability and costs.

The platform structure reflects the diverse and complementary activities that are being and will be undertaken:



The Advisory Council, chaired by Kurt Häge from Vattenfall Europe AG, steers and monitors the ZEP work. The Coordination Group takes care of the more practical aspects of implementing the Advisory Council's decisions. The Mirror Group of the member countries represents the relevant political institutions, and its role is to proactively advise the Advisory Council from a political perspective.

Five Working Groups have elaborated reports that provide technical input to both the Strategic Research Agenda and Strategic Deployment Document. Each Working Group is chaired by three co-leaders. The Working Group "Plants & CO₂ Capture" is chaired by Lars Strömberg from

Vattenfall and representatives from RWE and Siemens. Vattenfall is also represented in the Working Groups "Market, Regulation & Policy" and "Communication & Public Acceptance".

In addition, taskforces have been established for more ad-hoc / cross-cutting themes. Currently, there are two taskforces, one with an internal focus on developing the longer-term strategy of ETP ZEP itself, and the other with an external focus on developing a communication strategy for ZEP towards the public at large.

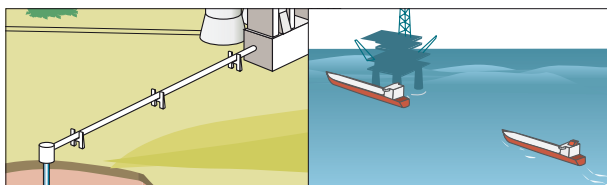
ETP ZEP has to date produced a first set of reports that were presented to and adopted at a General Assembly held in Brussels on 12-13 September 2006.

The Strategic Research Agenda ends with recommendations to urgently further develop and demonstrate all three major first-generation capture technologies, Postcombustion, Precombustion and Oxyfuel, assess the full potential for geological CO₂ storage and demonstrate its safety to the public and implement 10-12 integrated, large-scale CCS demonstration projects Europe-wide. In parallel, R&D is recommended on further improved and new concepts for power plants with CO₂ capture and simple, reliable tools for the long-term modelling and monitoring of CO₂ storage.

The Strategic Deployment Document concludes with recommendations to the EU to, within the next couple of years, clarify the conditions for CCS in the CO₂ emission trading system and various support schemes, establish necessary policy and regulatory frameworks, create early mover funding mechanisms to support the development of 10-12 large-scale CCS projects which demonstrate a diverse range of infrastructure, technologies, fuels and storage locations, and to establish robust R&D funding under the FP7 and national programmes.

All the reports and documentation from a number of ZEP meetings can be found at: www.zero-emissionplatform.eu

Environmental aspects of transporting CO₂



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 process of transporting CO₂ from the CO₂ capture plants to the site where it is injected into the underground formation.

The technology and potential environmental effects that relate to CO₂ transport are considered to be known to a great extent, from Enhanced Oil Recovery (EOR) operations and analogue activities such as the transport of natural gas. The transport of CO₂ is, however, associated with a lower risk than that of natural gas, since CO₂ is not explosive. The means of transport used will depend on the quantity of CO₂ to be transported, the terrain and the distance between the capture plant and the injection site. Large-scale transport options are ship and pipeline, while truck and train are possible means of transport for small-scale projects in the start-up phase of carbon dioxide capture and storage (CCS).

Pipeline transport may give rise to slight disturbances such as noise and emissions associated with the construction and the potential decommissioning of the pipeline, and to some extent also with the operational phase (maintenance-related traffic). The extent of impact will depend on whether the pipeline is buried under the surface (most existing pipelines are buried at a depth of about 1 m) or placed above ground. A buried pipeline may cause more disturbance during the construction phase, but will not be an obstacle or disturb views once the construction is finished.

Transporting CO₂ using ships, trucks or trains is associated with an increase in the energy requirement that must be evaluated in proportion to the volume of CO₂ transported. Air emissions, such as CO₂ and SO₂, from the transport vehicles will have an impact on the objective of minimising emissions to air. A pipeline is often the best alternative when transporting large quantities of CO₂ onshore (more than 1 million tonnes/year). Environmental effects relating to normal operations are expected to be minimised through appropriate precautions and safety procedures. Emissions to air and water and noise levels will be regulated in the permit. Efforts will be made to keep the energy required by the transport system as low as possible for environmental and cost reasons.

The main concern relating to the transport of CO₂ is the risk of leakage. In the case of a pipeline rupture, there will be safety valves that stop a continuous outflow of CO₂, and only the gas available in the sector before the valves will be released. In the case of seepage from a pipeline, the pressure drop will be detected and the source of leakage attended to. Leakage from a vehicle, due to a containment failure or an accident, will be limited to one vehicle load. Leakage from a CO₂ transport system is therefore unlikely to have impacts on the climate, since larger leaks will be detected and remedied during the operational phase.

The magnitude and type of potential environmental impacts and hazards are very dependent on site characteristics along the transport route. If measures are taken to minimise environmental impacts through a combination of thorough site selection and the utilisation of safety measures and monitoring equipment, the transport of CO₂ can be undertaken in a safe way with a minor impact on the environment.

GEOCAPACITY

– The geological storage capacity in Europe

The determination of whether the geological storage of carbon dioxide captured from large industrial plants is a viable method of reducing greenhouse gas emissions capable of widespread application in Europe was the primary goal of the former European project GESTCO (2001-2003). This was established by a study of fourteen cases that evaluated the CO₂ storage potential of saline aquifers, geothermal reservoirs, coal seams and oil and gas reservoirs.

The European Union has subsequently expanded, which means that there is a need for a better geographical coverage. Furthermore, the work conducted by GESTCO did not cover all of the geographical territory of the participating countries. Nevertheless, the project did confirm the presence of significant CO₂ storage capacity in structural traps in porous and permeable reservoir rocks in onshore and near-shore sedimentary basins, particularly in Denmark and Germany. Significant storage capacity was also judged to exist in the Bunter Sandstone Formation of the UK sector of the southern North Sea. A huge potential exists offshore Norway and it is likely that very large additional offshore aquifer potential exists in British and Danish sectors.

With the enlargement of the EU to 25 member countries, the challenge of reducing CO₂ emissions Europe-wide has increased. This is presently being dealt with in the follow-up project GEOCAPACITY (2006-2008), which focuses on countries in eastern, central and southern Europe not previously covered in detail.

This GEOCAPACITY project will provide the data required for the Europe-wide adoption of CCS. It focuses on applying advanced evaluation techniques and complementing the datasets by carrying out emission, infrastructure and storage-site mapping as well as undertaking economic evaluations. This will enable source-to-sink matching across Europe. Site selection criteria, standards and methodologies will be created and applied to the project.

The project is, as was the GESTCO project, co-ordinated by GEUS (Geological survey of Denmark and Greenland) and involves leading European geology research institutes and future users from the industry. Vattenfall participated in the GESTCO project as an end-user, and has increased its involvement in GEOCAPACITY.

A project result of interest to Vattenfall is a database accessible through GIS (Geographic Information System) on the distribution and coincidence of thermal CO₂ emission sources and the location of geological storage capacity. This database may provide the backbone of a future atlas of European geological storage capacity. Moreover, this project result enables the calculation of storage costs through a decision support system (DSS), where users can interactively define emission sources and match them with storage sites. The calculated cost is based on basic assumptions, and provides a good means for making sensitivity scenarios.

Electricity and Hydrogen Production from Coal and Natural Gas with CO₂ Capture and Storage

Visions for a future Hydrogen Economy

Hydrogen can be produced from a variety of sources including natural gas and coal as well as biomass. When combusted, only water is produced and no CO₂ is emitted.

The production of hydrogen from natural gas is well established in the chemical industry, since hydrogen is used for the production of ammonia and in oil refineries to increase yields of light hydrocarbon fractions. In the future, the CO₂ separated in the course of hydrogen production could be stored in geologic reservoirs.

The latest issue of this newsletter (September 2006) contained an article about the coal-based integrated gasification combined cycle (IGCC) with the Precombustion capture and storage of CO₂, in which possibilities and the latest developments on the subject were discussed. In such a process, a hydrogen-rich gas from coal will be used as fuel in a gas turbine. The same gas turbine development is also applicable for hydrogen from natural gas.

Future large coal-fired and natural gas-fired plants with the Precombustion capture and storage of CO₂ could produce both electricity and hydrogen for distribution and use as a "CO₂-free" fuel in various other applications. The vision is often referred to as the Hydrogen Economy. Use as a vehicle fuel in car engines or fuel cells is often highlighted, since this in theory could eliminate the CO₂ emissions from road transport, and at the same time reduce its oil dependency – i.e. contribute to resolving two major energy policy issues. This prospect is of course very attractive to policy makers, and the oil and gas industries and automobile manufacturers have also paid attention to hydrogen as a possible future energy carrier.

However, the distribution of hydrogen to consumers such as future vehicle-fuelling stations, as well as

storage, will require energy-consuming compression to high pressures or liquefaction of the hydrogen, since hydrogen has a low specific energy content in distribution and in storage technology for vehicles today. On the other hand, if the ongoing development of vehicles with fuel cells is successful, this will lead to higher vehicle energy efficiencies than if Otto or Diesel engines are used.

HYPOGEN – Visions for a demonstration plant

In the EU, the "Quick-start Programme of the European Initiative for Growth" identifies the Hydrogen Economy as one of the key areas for investment in the medium term. To bring forward the Hydrogen Economy, the HYPOGEN and HYCOM initiatives have been launched.

The HYCOM initiative deals with hydrogen as a future energy carrier in society. HYPOGEN shall, with a budget of EUR 1.3 billion, develop the first large-scale test facility/demonstration plant for the production of hydrogen and electricity from de-carbonized fossil fuels, with the geological storage of CO₂. It is envisaged that such a facility will be in operation by 2012, and a pre-feasibility study has been performed.

It has, however, become clear that a majority of Europe's fuel and power utilities consider that a commercial market for large-scale hydrogen production will need a much longer period of time to develop than has been envisaged for HYPOGEN, and they are thus reluctant to invest significant resources in R&D on hydrogen production at the present time. Consequently, the EU project DYNAMIS, a feasibility study launched in 2006, addresses how to further clarify and handle various non-technical barriers as well as different technical routes to electricity and hydrogen production, combined with the capture and storage of the CO₂ produced.

DYNAMIS – A feasibility study for producing power and hydrogen

The EU project DYNAMIS was launched in early 2006, will run for 3 years and is coordinated by SINTEF Energy Research. The consortium involves major European power companies (Vattenfall, EON, Endesa and ENEL), oil and gas producers (Statoil and BP), equipment manufacturers (ALSTOM, Siemens, Air Liquide, Schlumberger), one leading European bank (Société Générale) and a number of high-ranked European research institutes and universities – all in all 30 partners. The total budget for the project is EUR 7.4 million, of which EUR 4 million is funded by the European Commission.

The project will develop case studies for possible demonstration plants producing around 400MW of electricity and 25-50MW of hydrogen from hard coal, lignite and natural gas.

Vattenfall takes an active part in several subprojects and is involved in the identification of feasible locations, the evaluation of technical concepts and the performance of pre-engineering studies for demonstration plants fired with hard coal, lignite and natural gas. Vattenfall's work focuses on lignite-fired IGCC concepts. This will generate useful knowledge on the design of large-scale power plants with

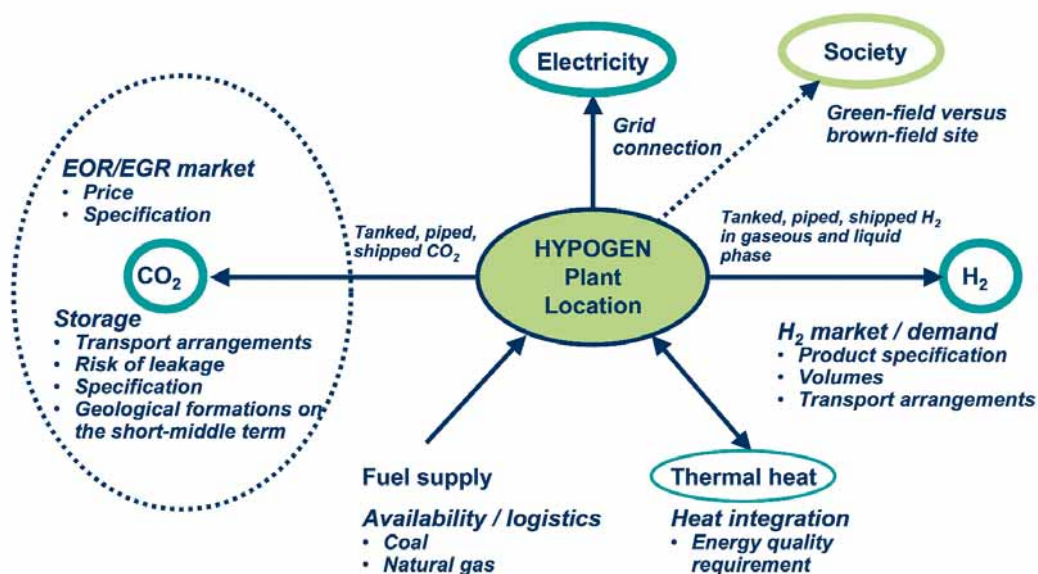
Precombustion CO₂ capture. Since hydrogen but not electricity can be stored, an interesting option is to operate the hydrogen production at constant load and vary the fractions of hydrogen that are used to produce power and that are supplied to consumers respectively. The studies will provide insight into this and other possible synergies between electricity and hydrogen production.

Vattenfall is also involved in the subprojects for the identification and evaluation of suitable storage sites – options for EOR (Enhanced Oil Recovery), EGR (Enhanced Gas Recovery), depleted oil and gas fields and saline aquifers – and transport routes for the captured CO₂. These tasks will result in progress regarding the implementation of large-scale CO₂ infrastructure and storage in Europe including design issues, CO₂ quality requirements and planning and permit procedures.

The market situation will be explored as well as financial options, legal and regulatory issues and public acceptance, as a basis for outline strategies for the “societal anchorage” of a HYPOGEN demonstration plant. This knowledge will also be welcome when developing other large-scale CCS projects.

More information about the DYNAMIS project can be found at: www.dynamis-hypogen.com

Plant location



SINTEF Energy Research / Jens Hetland, 2006



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, one of the technologies used for electricity generation today, or under development within the Vattenfall Group, will be presented in every issue of Bridging to the Future.

Wave Power

Wave power is a renewable energy source with an enormous potential globally and is expected to become commercially viable in the foreseeable future. Vattenfall supports research and demonstration activities relating to new wave power concepts.

Potential

The best conditions for wave energy extraction in Swedish waters are found off the west coast, where the area is open to the more energetic North Sea wave climate. These waves are highly energetic and the production pattern is assumed to be more predictable than, for example, wind power. This is due to the fact that waves/swells continue to reach the coast long after the wind has dropped, which is favourable from a system perspective. The annual wave energy potential is estimated to be 15-20 TWh (gross) around the coasts of Sweden.

Vattenfall is also investigating sites with higher potential outside of Swedish waters. The European west coast is of great interest and countries like Norway, Portugal and the UK are examples of countries with very good wave power conditions.

Many different technologies

Many different wave energy devices are currently under development by companies and academic research groups around the world. So far, only a minor part of these concepts have been tested in full-scale sea trials, and only a few are likely to reach commercialisation. Most of these concepts include constructions that are placed on the surface, which also make them vulnerable to waves and they thus have to be over-dimensioned for the most extreme weather conditions.

Point absorbers with linear generators

The combination of point absorbers (buoys) with linear generators is an innovative wave energy concept developed at Uppsala University. In contrast to many other concepts, this technique is designed to work also in more moderate wave climates such as along the Swedish coasts. The concept involves surface-following buoys and point absorbers connected to three-phase permanent magnetized linear generators placed on the sea-

bed. The motions of the buoys drive pistons in the generators, converting the energy of the waves into electric energy.

Pilot project and plans for a demonstration plant

A pilot project, partly funded by Vattenfall, was initiated by Uppsala University and tests have started on the west coast of Sweden, 2 km west of the lighthouse Islandsberg, in the municipality of Lysekil. The project is expected to be fully equipped by 2008 and to remain in operation until 2014.

In cooperation with Seabased AB, an innovation company connected to Uppsala University, Vattenfall is also performing a localization study aiming at constructing a wave power demonstration plant. The plant will be placed somewhere off the Swedish west coast and consist of 1000 buoys connected to one linear generator each. The buoys will be placed 20 metres apart and the total power output will be approximately 10 MW.



Buoys and point absorbers connected to linear generators.
© O. Danielsson

The CO₂-free power plant homepage – A statistical review

The launch of the CO₂-free power plant homepage has been a success so far. Since 29 May this year, it has been visited by almost 3 000 guests. During the same period, the number of “hits” (matches generated by search engines) has reached over 11 000. It is worth noting that some 75 per cent of all visitors came from countries other than Sweden and that all the continents of the world are represented.

The most active day was 1 June 2006 (4 days after the launch), when 750 people visited the homepage.

Among the different sub-pages, the most popular are the main page, the technology page, the pilot plant page and the Oxyfuel combustion page. This is where the most project-specific information is to be found.

The website is still in its infancy and we believe that its recognition will be even greater in the future. Keep your eyes open for upcoming events and find more information with reference to the project on the CO₂-free power plant homepage.

www.vattenfall.com/co2free



Lars G Josefsson to advise German Chancellor on climate issues

German Chancellor Angela Merkel has appointed Vattenfall Group CEO Lars G Josefsson as advisor to her government on climate change issues.

In 2007, Germany is to chair both the G8 and EU, and it is in this context that Lars G Josefsson is to act as a government advisor on international climate protection issues. His principal task in this role will be to try to persuade industry to become more actively involved in finding solutions to the problem of climate change and developing concepts whereby climate issues can be integrated into the market economy and help stimulate economic growth.

“We have to take climate issues seriously and focus more on initiatives aimed at developing proposals that enable us to bring the greenhouse effect

under control. I am totally convinced that the involvement of industry is an absolutely essential part of the process of creating cost effective climate solutions in partnership with politicians and NGOs,” said Lars G Josefsson in association with the announcement of his appointment in Berlin.

“Without determined action, we are not going to succeed in curbing climate change. Here we do act. Earlier this year Vattenfall presented a plan for a global trading system designed to effect the necessary cuts in CO₂ emissions via market instruments. The next step is to develop a concrete plan of action setting out the technological and economic tools required if we are to be able to achieve this global target. Vattenfall is actively striving to obtain a broad consensus amongst industry worldwide on principles that could help contribute to a solution to the greenhouse effect.”