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Summary report prepared by: Torsti Loikkanen, VTT-GTS
Member of the Network for European Techno-Economic Policy Support ETPS AISBL

Administrator: Karin Hyldelund
Policy Department A - Economy and Science
Internal Policies Directorate-General
European Parliament
Rue Wiertz 60 - office number
B-1047 Brussels ATR 0L012
Tel: +32-2-2832234
Fax: +32-2-2849002
E-mail: Karin.hyldelund@europarl.europa.eu

Manuscript completed in December, 2006.

✉ Rue Wiertz – B-1047 Bruxelles - ☎ 32/2.284.43.74 Fax: 32/2.284.68.05
✉ Palais de l'Europe – F-67000 Strasbourg - ☎ 33/3.88.17.25.56 Fax: 33/3.88.36.92.14
E-mail: poldep-esc@europarl.europa.eu

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Part I: Summary Report

EXECUTIVE SUMMARY

The European Parliament's Committee on Industry, Research and Energy (ITRE) on 21 November 2006 held a workshop that focused on Carbon Capture and Storage (CCS) from an EU perspective. The workshop experts presented the scientific background, status of CCS development, discussed a number of technical options and challenges and finally addressed regulatory and policy perspectives specific for CCS.

<u>Scientific background</u>
The context of the workshop was *inter alia* that CCS has been developed as one option for the mitigation of greenhouse gas emissions. CCS means capturing carbon dioxide (CO_2) from power stations and other industrial sources, transporting it and, in order to isolate it from the atmosphere, injecting it into and storing it in deep geological formations. The different CCS elements and technologies are at different stages of development, but overall they constitute a set of interesting options contributing to the meeting of both future demand for electricity and the objectives to limit climate change (thus achieving Kyoto and post-Kyoto targets). CCS is accepted amongst the options for CO_2 and greenhouse gas mitigation in the IPCC Special Report on CO_2 Capture and Storage and also by the 2006 London Convention.

<u>Status</u>
According to the speakers and other experts, CO_2 emissions mitigation cannot be deployed without CCS, although all approaches towards a more sustainable energy production are needed. CCS is considered as a bridging technology to an energy future where fossil fuels are no longer dominant and energy is more effectively used, and it will buy time to bring in non-fossil options to the required scale. Due to the urgency of climate change mitigation, the required actions must be launched immediately.

<u>Challenges</u>
According to the speakers, the major challenges of CCS implementation are related to costs, full-scale demonstration plants, commercial operation, consolidation of storage technology and public acceptance. And roughly two-thirds of the cost of CCS is estimated to stem from CO_2 capture, mainly from energy consumption. Three main capture technologies have been identified but R&D and large-scale demonstrations are needed in order to start learning-by-doing. In CO_2 transportation, pipelines are identified as the main technology. From the stakeholders' perspective, the underground storage of CO_2 and its possible leakages into the atmosphere, with health and related threats, are the most worrying aspects of CCS. According to experts, underground CO_2 storage sites are designed not to leak. The consequences of accidents so far are marginal, and comprehensive scientific and technological research efforts will be carried out to prevent leakages before any large-scale implementation. Moreover, the extensive underground storage experience of the oil industry will be utilised in developing safe CO_2 storage.

<u>Policy perspectives</u>
Looking forward, Commissioner Piebalgs has recently announced a forthcoming Communication in early 2007 on CCS, outlining major policy choices and possible legislative proposals. A debate on the need for further technological development in a European setting, the incorporation of R&D results and the interaction with regulatory requirements is of importance.

The EU is interested in reducing CO_2 emissions and combating global climate change, while at the same time maintaining economic growth and nurturing its competitive position by developing commercial near-zero or zero emission technologies.

In general, the workshop experts were unanimous of the importance of CCS in the mitigation of climate change. Several aspects were however presented as preconditions for successful implementation of CCS by the experts and by the workshop audience. European policy-makers are expected to establish a long-term CO_2 policy to create the basis for private investment and public-private partnerships. The establishment of a regulatory framework with laws, rules and guidelines is among the conditions for CCS implementation. Climate change mitigation instruments, including CO_2 emission trading, are expected to include CCS implementation, and public promotion of R&D and demonstration plants is of importance. The investments in CCS should not endanger other relevant technologies mitigating CO_2 emission but investments of all required investments must be well-balanced. Wide implementation of CCS requires public acceptance, and public hearings and corresponding participatory procedures are necessary. However, the implementation of CCS under the Clean Development Mechanism (CDM) of the Kyoto Protocol is not yet resolved.

1. Introduction

Coal combustion is associated with emissions of air pollutants, especially carbon dioxide (CO_2). Coal is, however, an abundant fuel and will play an important role in energy security and in energy mix, co-utilisation, self-reliance, etc. Many EU Member States hold coal reserves, which create both employment and export opportunities. Given that coal is likely to remain an important fuel for power generation worldwide in the next decades, much has been done to develop the economic and technological potential of clean coal. Clean coal technologies (CCT) have been developed and employed, and still hold potential for further development.

Carbon dioxide Capture and Storage (CCS) has been developed as one option for mitigation of greenhouse gas emissions.[1] The different CCS elements and technologies have reached different stages of development, but overall constitute a set of interesting options for contributing to meet both future demand for electricity and objectives to limit climate change (achieving Kyoto and post-Kyoto targets). An IPCC Special Report on CO_2 Capture and Storage accepted CCS as a CO_2 mitigation option, and, moreover, according to the London Convention (30 October–3 November 2006), CCS is among the options for mitigating GHG emissions.

Commissioner Piebalgs has recently announced a forthcoming Communication from the Commission (2007)[2] on CCS, outlining major policy choices and, where necessary, possible legislative proposals. A debate on the need for further technology development in a European setting, incorporation of the results of R&D and the interaction with regulatory requirements is of importance. Hence, the European Parliament Committee on Industry, Research and Energy (ITRE) organised a workshop that focused on CCS[3] from an EU perspective as regards future prospects for CSS in the energy field. The aim was to provide background information and advice for the members of the European Parliament Committee on ITRE on the current issues related to CCS as a key element in a wider current clean coal discussion. The workshop offered a variety of views that are considered among experts in this field and a description of the workshop is presented in Workshop Specifications (Annex 1).

The summary report is structured according to three interrelated themes of the workshop:

- Scientific background and status of discussion
- CCS: technical challenges and feasibilities, industrial perspectives
- Regulatory and policy perspectives

The report is based on notes made by the invited experts, their presentation material and the discussions in the workshop. The notes of the experts are attached as appendices to give details for the readers.

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[1] Other mitigation options include energy efficiency improvements, a switch to less carbon-intensive fuels, nuclear power, renewable energy sources, enhancement of biological sinks and reduction of non-$C0_2$ greenhouse gas emissions (IPCC Special Report, 2005).

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[3] CCS is the process of separation of $C0_2$ from industrial and energy related sources, transport to a storage location and long-term isolation from the atmosphere.

2. Theme 1: Scientific background and status of discussion

2.1. Key messages of experts

Key messages by Dr Riley

CCS is the only technology dealing directly with fossil fuel emissions and therefore the only sure way of avoiding emissions from fossil fuels in the context of large industrial point sources. CCS needs deploying urgently to deal with CO_2 emissions to avoid the most serious consequences of human-induced climate change, sea level rise and ocean acidification. The major challenges of CCS implementation are socio-political and technological, i.e. whether society realises the urgency and the scale the problem. Is society prepared to pay/adapt and take responsibility? Does society have realistic expectations about solutions or options? CCS will raise the price of fossil energy to consumers and this will encourage demand reduction, efficiency and non-fossil energy alternatives.

Key messages by Dr Pflueger

CO_2 emissions can be returned to current levels through a portfolio of technologies, assuming that the CO_2 emissions price is $25/tonne of CO_2 from 2030 onwards. This effort is huge and it is not evident that best practices will be applied everywhere. But the cost of doing nothing would finally be roughly the same. The major barriers for CCS deployment are cost, the demonstration of full-scale commercial operation and the confidence in consolidating geological storage needs. Substantial increases in the current budget for CCS demonstration and outreach to emerging countries and transition economies are essential. Given the range of technologies under development, CCS demonstration would require at least 10 major power plants with CCS in operation by 2015 to start learning-by-doing, and a legal and regulatory framework for CCS is needed, as are private investments and public acceptance. Governments will have to establish credible, long-term CO_2 policy goals to create the basis for private investment and public-private partnerships. Climate change mitigation instruments including emission trading should include CCS.

2.2. The scientific basis for CO_2 capture and storage (CCS), Dr Nick Riley (BGS/UK)

Dr Riley gave an overview on up-to-date scientific knowledge of different phases and aspects of CSS. He accentuated that CCS is the only technology dealing directly with fossil fuel emissions and hence the only sure way of avoiding emissions in the context of large industrial point sources. The main emissions (about 35%) of this type come from power plants. CCS can make a major contribution to climate change mitigation; however, CCS on its own cannot deliver the total emission cuts required by 2050 but it is one among many ways of increasing the use of non-fossil energy sources, improving energy efficiency and curbing energy demand.

CCS technology captures CO_2 from power stations and other large industrial point sources – CO_2 capture is proven technology, especially in oil gas production. After capture, CO_2 is transported to an injection site and injected into deep geological formations (greater than 700 metres depth) for storage to isolate it from the atmosphere. The most effective form of CO_2 transport is by pipeline and for this the CO_2 is pressurised to a dense gas so that it behaves like a liquid and occupies little space. The injection technology of CO_2 benefits from experience of injecting and storing gases underground across Europe and because underground gas storage is a successful technology and has little surface expression, the public is largely unaware of its existence.

The storage must be deep so that the pressure is sufficient to keep the CO_2 in a dense phase. In this compressed form, CO_2 is injected into porous rocks (reservoirs). The most favoured reservoirs are those found in oil and gas fields, which are able to trap gases and liquids for millions of years. CO_2 injection into depleting oil fields is common practice and in North America this is done for security reasons, not for mitigating CO_2 emissions. In terms of potential volumes for storage, deep saline aquifers have by far the largest capacities. The storage capacities in Europe are likely to meet demand until after 2050.

The main concern of stakeholders is whether the CO_2 will leak back to the surface so in order to prevent leakage the site geology has to be fully researched. Underground gas and CO_2 storage sites are designed not to leak and their prevention is a standard risk management and technique in oil and gas production operations. Out of the thousands of CO_2 injection wells worldwide no CO_2 injection operations have been demonstrated to leak. There have been rare instances of leakage during re-engineering operations in old wells however, but without injury or loss of life to the rig workers. There is a high degree of confidence that leakage events will be very rare and that, if they occur, intervention using existing oil and gas industry practice can deal with the problem. According to Dr Riley, it is unreasonable to assume that all storage operations will leak to some extent or that, if a leak occurs, all CO_2 will come back to the atmosphere.

Various natural processes occur in the reservoir inhibiting the ability of CO_2 to move upwards to the surface, and, according to Dr Riley, over time these processes combine to decrease the risk of leakage, as CO_2 is increasingly immobilised. It may take tens to thousands of years to lock up the CO_2 completely so that it cannot move upwards.

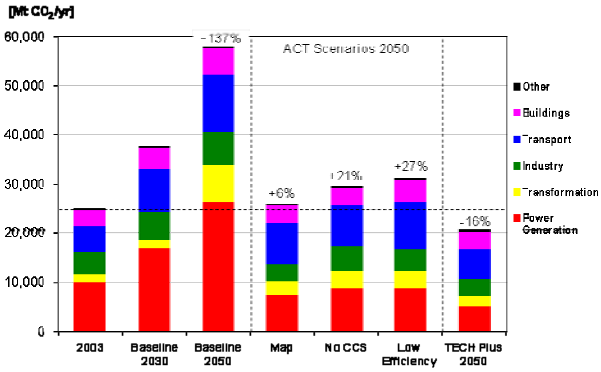
The effects of CO_2 leakage are well known. There is corresponding experience of CO_2 emanating from the ground through natural processes, usually associated with volcanic activity. Many of these releases are larger than could ever happen in the case of a failed CO_2 storage operation and the principal risk to humans, as well as to vegetation, is asphyxiation.

2.3. Status and perspectives of CO_2 capture and storage, Dr Antonio Pflueger (IEA)

Dr Pflueger first presented IEA's energy and related CO_2 emission scenarios for 2003 to 2050 and then moved to discuss CCS technologies, related costs and the future perspectives.

Past IEA analyses indicate that individual technologies can make significant contributions on a path towards a sustainable energy future. Energy technology perspectives (ETP) provide a comprehensive review of technologies across sectors and assess how together they can make a difference. According to the ETP baseline scenario of the world total primary energy supply by fuel in 2003-2050, the primary energy use more than doubles between 2003 and 2050 with a very high reliance on coal and gas: coal becomes the largest primary energy source supplier in 2050, and gas is increasing for environmental reasons and versatility in power production.

The IEA has recently developed scenarios for a more sustainable energy future that well indicate the importance of CCS in mitigation of CO_2 emissions. The chart below on global CO_2 emissions 2003-2050 consists of business-as-usual (baseline) scenario, three accelerated technology scenarios (ACT), and fast-track technology and cost-reduction progress scenarios (TECH plus). The chart shows how global CO_2 emissions in 2050 vary under different scenarios.



The business-as-usual scenarios (columns one, two and three) show how CO_2 emissions climb a massive 137% until 2050. CO_2 emissions grow stronger than energy consumption because of increasing use of coal in emerging economies. The ACT scenarios in 2050 show how global CO_2 emissions can be mitigated by clean-energy technologies, best practice and policy action (assuming CO_2 emissions are given a price of 25$/tonne of CO_2 from 2030 onwards). In the most optimistic map scenario hypothesis ('Map'), CO_2 emissions grow by only 6% due to a wide-ranging combination of various technologies and best practices, including energy efficiency and CCS. Without the projected deployment of CCS technology ('No CCS'), CO_2 emissions growth jumps to 21%. Restoring the projected deployment of CCS technology but assuming lower energy efficiency gains ('Low efficiency') bring CO_2 emissions growth up to 27%. Assuming fast-track technology and cost-reduction progress ('Tech PLUS') changes the picture radically: CO_2 emissions actually fall by 16% against 2003 levels, notably through large improvements in the transport sector (e.g. more deployment of hydrogen fuel-cell vehicles).

IEA scenarios consist of the contribution made by different alternative technologies to reducing CO_2 emissions. According to the ACT scenario, the contribution towards reducing CO_2 emissions from energy efficiency would be 31-53%, and the contribution of CCS would be 20-28%. Commercial deployment of CCS could enable the use of huge coal reserves worldwide with negligible impact on global emissions. Since power plants have a long lifetime, a fast CCS expansion would imply retrofitting highly efficient existing plants. This is, in general, a more expensive option than building new power plants with CCS.

Dr Pflueger gave detailed techno-economic information of CCS. Leading CO_2 capture technologies are post-combustion capture, oxy-combustion and pre-combustion capture. CCS from power plants makes economical sense but only if applied in large, highly efficient plants. The increased use of fossil fuels for CCS in current power plants could be as high as 35-40%, and is expected to decline to between 10 and 30% for next-generation technologies. Efficiency losses due to CCS are in the order of 9-12% for existing coal plants, declining to some 4% for future plants with fuel cells. The establishment of large-scale CCS demonstration plants is necessary to give more detailed experience and related cost information of the CCS chain and, assuming successful demonstrations and emission reduction incentives, CCS could be commercially deployed from 2015 onward. The estimations of the investment cost of a demonstration power plant with CCS range from US$ 0.5 to 1 billion, half of which would be for CCS equipment.

2.4. Theme 1: Discussion

The questions asked after Dr Riley's presentation related to the technological potential of CCS, geological and regulatory aspects of cross-border CO_2 pipelines in Europe, and limits of capacity of CCS in the future. According to Dr Riley, capacity and related costs are challenges but, however, CCS is the fastest approach we have and it makes a major contribution towards mitigating CO_2 emissions to atmosphere.

Geological investigations (e.g. in CO_2 and gas mix in old gas mines) and related regulatory aspects of cross-border CO_2 pipelines will be on the agenda for a CCS strategy outline of Europe in the years ahead. Dr Riley did not see limits for CCS capacity at this time and Dr Heleen de Coninck specified that we do not see limits for CCS capacity in the next 100 years.

The questions asked after Dr Pflueger's presentation related to the needs of consolidating CO_2 storage and the options to transform the material form of CO_2 to something else. Dr Pflueger responded by emphasising the role of full-scale project demonstrations in the consolidation of CO_2 storage. In discussion on the options to transform the material form of CO_2 Dr Pflueger said that the idea of transformation emerges every now and again, and that the process of going 'the whole chain backwards' requires essential energy inputs where, in the end, the costs of transformation become a critical issue. Moreover, Dr de Coninck reminded us that the hypothetical options of CO_2 transformation are discussed shortly in the IPPC report.

3. Theme 2: CCS: Technical challenges and feasibilities – industrial perspectives

3.1. Key messages of experts

Key messages by Dr Strömberg

There is no way to create a supply of energy without fossil fuels within the next 50 years. Coal is by far the most important of all fossil fuels, and we need a solution to use coal for a long time without endangering the environment. It is possible to produce electricity less expensively with coal than with any of the renewables, and here CCS has an important role. The CO_2-free Power Plant Project of Vattenfall is based on the belief that the necessary targets now in place to reduce CO_2 emissions by more than half by 2050 cannot be reached without CCS. The most important barriers for CCS deployment lie in the fact that it is a new and largely unknown technology. There are no laws, regulations or rules written with this technology in mind, no regulatory framework and the permitting authorities have no guidelines. Here the EU can play an important role. There is a need, above all, for demonstration plants that include the whole CCS chain. This implies a monetary input of several billion euros, and a considerable amount of commercial risk taking. The most important part that society can contribute with, except R&D funding, is to reduce the commercial risks. A clear and stable emission trading system is a necessary prerequisite for development, and a long-term commitment by the EU and national governments to keep the situation predictable is an absolute necessity.

Key messages by Mr Thorvik

Kyoto targets are impossible to reach without CCS, and Europe must take the lead is this area. CCS is a safe technology and industry, NGOs and governments at all levels must unite in their activities in the CCS issue.

3.2. CO_2 abatement – the view of a power producer, Dr Lars Strömberg (Vattenfall)

Dr Strömberg presented future perspectives of the power industry to climate change and CCS, technological and cost aspects of CCS, and the CO_2-free power plant project of Vattenfall.

Dr Strömberg affirmed that the power industry takes responsibility for the potential threat of climate change, as multiple investments of the power industry in new energy technologies and announced CCS demonstration plants indicate.

Fossil fuels are needed in the future because no real alternatives exist. Renewable energy sources, in spite of their good availability and their contribution to energy supply, are not large enough and cannot be expanded fast enough. Renewable energy sources available in Europe will play a role in the energy supply for the next 25 years, and have an important role until 2050, but with a limited contribution. According to Dr Strömberg the estimation of 20-30% can be very ambitious, and the question is what contributes to the remaining 70-80%. Nuclear power is a well-established source but many countries have chosen to abandon it, while a few build new capacity. In conclusion, fossil fuels are needed and we need a solution to use them without any emissions to the atmosphere. Large-scale solutions must be commercially available in 2020.

Dr Strömberg stressed that the driving force mitigating climate change lies in the surrounding regulatory and legal system. In Europe, the major driving factor is the Emission Trading Scheme (ETS). Although the ETS can be criticised, according to Dr Strömberg, it is the best we have come up with so far. If we are serious in reducing the CO_2 emissions, we need to set up a stable and global system. The large cuts in emissions are possible to achieve: 35% reductions until 2030 and further cuts reducing it to 60% over the next 20 years seem realistic. However, this all means that we need CCS, and fast.

The power industry has to take a leading role in the development of CO_2 capture. The capture of CO_2 is of great interest for large power plants that are fired with hard coal, lignite and natural gas. There are three main technology options for CO_2 capture from power plants – post-combustion capture, pre-combustion capture and oxy-fuel combustion – which can fulfil the primary goals of being ready for use in 2020 at a reasonable cost. Although most components exist and are in use in other industries, there is still considerable work to optimise, integrate and scale-up the components for capturing CO_2. If we look beyond 2020, some new technologies might evolve, with promising reductions in extra costs for the capture and low electricity-generation costs. If this becomes a reality, work has to start now. Firstly, we have to develop the main technologies, including several demonstration plants, and large-scale testing and optimisation, and secondly, investigate and research new technologies for less expensive capture with a lower energy penalty and higher conversion efficiency. The driving force must, therefore, be future market prospects related to a long-term commitment to a CO_2 reduction system and consequently a reduced CO_2 cost.

Dr Strömberg informed us about the CO_2-free Power Plant Project of Vattenfall. The 10-year project (2001-2010) has been set up to consider the building of a demonstration plant. If the decision is positive the plant will be in operation in 2015. In 2008, the company will decide on the detailed engineering of the plant and initiate permission and purchasing process up to the investment decision in 2010. The plant is devoted to verifying the performance of the oxyfuel combustion process.

The critical line in CCS implementation seems to be the permitting process. The company has performed several studies of 'real' cases in Germany, Scandinavia and Poland, both of geological storage formations and of real case pipelines. An application for a permit cannot be made until one has a considerable knowledge and a clear view of what and where to build something. To be able to keep the target of 2015 for commissioning, having started late in 2005, it is necessary to go through the permission process within three years, which is probably not possible; it may be possible for the power plant but not for the storage and the pipeline. Thus society must give considerable support if industry is to be able to keep the time line.

3.3. Oil industry perspective, Mr Arve Thorvik (Statoil)

CCS is not a future issue but is happening now, began Mr Thorvik by referring to the Sleipner field project on CO_2 treatment and injection launched back in 1996. Mr Thorvik described the offshore storage principles executed at Sleipner and made an overview on the European CCS projects, as of November 2007, by identifying 14 different ones.

Mr Thorvik told us about the transportation of CO_2 through a pipeline to Snøhvit. The pipeline runs 330 metres below ground for160 kilometres. The technology in Snøhvit consists of CO_2 removal from natural gas, CO_2 pipeline transportation and CO_2 injection through subsea as well. Mr Thorvik described Norway as a CO_2-laboratory with several launched and planned projects related to CO_2 from natural gas and CO_2 from flue gas (Sleipner, Snøhvit, Kårstø, and Mongstad). The Halten CO_2 project aims at using CO_2 for value creation and the gas power plant at Tjeldbergodden will be the starting point for the value chain. The CO_2 capture plant will be integrated in the power plant, and this capture plant is 20 times larger than any similar plant in the world today.

Mr Thorvik stressed the importance of public-private partnerships (PPP) in the promotion of the technology company. The emission permit and the agreement between the government and Statoil commit both parties, both economically and judicially, through several stages. The government will invite interested parties to consider part ownership in a technology company, while Statoil will assume 20% ownership from the start. The government will make a substantial investment and the technology company will be responsible for various aspects of the further development of the CO_2 capture technology.

Mr Thorvik concluded that the question is how do we make CCS happen on a large scale, and he listed several issues and what politicians should do. First we should kick-start the CO_2 value chain, meaning the integration of CCS into the Emission Trading Scheme (ETS). We need clarification of the state-aid rules and we must create an easy movers' fund. We must establish a regulatory framework in order to amend regulations on waste and water if necessary, and establish guidelines for storage projects. We need to join industry and NGOs for gaining public support, which means an EU-wide outreach via multimedia and local outreach to support CCS projects. We also need R&D funding under the Seventh Framework Programme (FP7) in order to reduce scale-up risk, mapping of sources and storage possibilities, and to start joint technology initiatives.

3.4. Theme 2: Discussion

The questions asked after the presentations of Dr Stromberg and Mr Thorvik related to the costs of mitigating CO_2 emissions (including the costs of ETS). Dr Stromberg responded that in the mitigation of climate change all available energy technologies are more expensive than CCS, and that all countries must change their energy portfolio respectively in the future. CCS is the cheapest way ahead, he stressed.

4. Theme 3: Regulatory and policy perspectives

4.1. Key messages of experts

Key messages by Mr Hauge
CCS will play a crucial role in enabling the EU to maintain its leadership position in combating climate change, while ensuring global competitiveness for European industry and long-term security for energy supplies. Post-combustion CO_2 capture is the obvious choice for projects due to be commissioned over the next 10 years and these must be supported by FP7 to avoid any delay in announcing CCS projects. CO_2 storage is safe and can be ensured by a proper site selection of geological formations. Wide CCS implementation requires public acceptance.

Key messages by Mr Brockett
CCS has significant potential, both in Europe and internationally, and the EU will encourage demonstration projects to bring the technology to a commercial scale. The legal framework, to be considered, will look at unwanted and unwarranted barriers, environmental risks, incentives and liability. The proposals scheduled for 2007 will include the relationship with EU's Emission Trading Scheme. Several questions on public acceptance are important and the key concerns will be considered.

Key messages by Dr de Coninck
It is of great importance that that IPCC Special Report has established CCS internationally. The IPCC Guidelines acknowledged CCS in emission inventories as 'emission reductions by source'. The Clean Development Mechanism (CDM) has matured significantly over the past year and industry is interested in CCS under the CDM. Design of the CDM, however, implies barriers for CCS: permanence and post crediting-time liability, and political perception of CCS is not conducive to a quick solution to the CDM/CCS issue. The process has been started but the outcome is currently uncertain. The inclusion of CCS under the Emission Trading Scheme (ETS) would help.

4.2. Environmental promise versus risk, Mr Frederic Hauge (Bellona)

By referring to IPCC data, Mr Hauge reminded us that greenhouse gas emissions have made the world 0.6°C warmer and that, without action, the increase will be between 1.4 and 5.8°C by the end of this century. This means serious consequences for all economies and ecosystems, including the EU. According to current projections to 2030, there will be an increasing worldwide demand for coal, oil and gas. Efforts to increase energy efficiency and the use of nuclear and renewable fuels will be required but there is clear evidence that fossil fuel resources will continue to largely dominate the energy supply. The EU is committed to continuing its leadership role in reducing CO_2 emissions, and hence combating climate change. Europe must face this challenge while at the same time maintain economic growth and bolster its competitive position in the global economy.

The European energy sector and related industries therefore face significant challenges and opportunities over the coming decades. The opportunities lie in the competitive edge the European energy industry can gain in the global market from producing innovative and commercially viable technology that eliminates CO_2 emissions from fossil fuels. One example of the responses in Europe is the technology platform entitled Zero Emission Fossil Fuel Power Plants (ZEP).

According to Mr Hauge, the implementation of energy efficiency measures and adapting the switch from fossil fuel to renewable energy at a realistic pace will not be sufficient to meet the required reduction in CO_2 emissions necessary over the next half century. Emissions must be cut rapidly and hence CCS is a bridge to a society where energy production will be based on renewable energy. CCS has the potential to avoid dramatic climate changes and sustain quality of life while maintaining secure power generation for the coming decades. He also presented calculations on a wide implementation of CCS from 2015 onwards. The CO_2 capture potential can reduce emissions in 2050 in the EU by 56% compared to emissions today, and the accumulated CO_2 capture potential in EU by 2050 will be 30 billion tonnes. Globally, CO_2 emissions in 2050 can be reduced by 37% compared to today's emissions.

Mr Hauge called for proper regulatory and policy framework for CCS. The focus will be on an integrated approach embracing technologies, infrastructure and societal issues supporting large-scale deployment of CCS. A critical issue will be the development of a framework and market conditions, and regulations must be long term, beyond 2012, in order to enable commercial investment decisions to be made. Fiscal incentives may be needed to motivate private enterprises to invest in the CCS projects, and the incentives should ensure that CCS receives similar incentive treatment to renewable energy sources and energy efficiency programmes.

Broad public understanding and acceptance of the role of CCS in mitigating climate change will be a prerequisite to its large-scale deployment. Climate change is a global problem and the need for an international approach is clearly recognised. International R&D with India, China and Russia on ZEP technology will offer significant opportunities for CO_2 emission reductions, and also offers vast business opportunities for EU industry.

4.3. Enabling legal framework for CCS, Mr Scott Brockett (DG ENV)

Mr Brockett described the major tasks for deployment of CCS identified by the Commission, i.e. the development of an enabling legal framework and economic incentives for CCS within the EU, and the encouragement of a network of demonstration plants across Europe and in key third countries.

The Sustainable Coal Communication, due for adoption in January 2007 as part of the energy package, will look at how best to meet the twin objectives of energy security and greenhouse gas reduction to meet the EU's goal of not exceeding the 2°C average temperature increase from pre-industrial levels. It will also set out our general strategy with respect to CCS, including our work on the regulatory framework, incentive framework and support programmes, as well as external elements (technology co-operation with key countries on CCS). It will outline the work programme on CCS to be pursued in the coming two to three years.

A Working Group on CCS was established under the European Climate Change Programme II (ECCP II) to review the potential, economics and risks of CCS, to identify regulatory needs and barriers, and to explore the elements of an enabling regulatory framework. The Working Group recommended that the Commission come forward with a proposal for an enabling regulatory framework for CCS during 2007. The Commission is about to begin the Impact Assessment of the options for the regulatory framework which is scheduled for completion in mid-2006.

Mr Brockett informed the workshop that the preparation of the regulatory framework will focus, in particular, on the following issues: first, to manage risks associated with CCS, and second, to remove unwarranted barriers to CCS in existing legislation, which are mainly related to water and waste. There are unwarranted barriers in certain international conventions: the recently-adopted amendment to the London Protocol on the dumping of waste at sea is a very welcome initiative, and the Commission will work with other parties on the OSPAR (Convention on protection of the marine environment of the North-East Atlantic) to resolve the treatment of CCS under it. The framework will also examine any issues regarding long-term liability for the storage site which require action at EU level and, finally, will address the issue of public information on, and acceptance of, CCS. The Commission is examining the possibility for stakeholder consultation as well as a public hearing in 2007.

The major cost/economic factors that need to be considered are the increase in capital investment for CCS activity and the increased operating costs needed to run the capture and storage plants. A key issue is the treatment of CCS under the EU's Emissions Trading Scheme (ETS). The role of CCS under the ETS will be addressed in the review of the ETS post-2012. Enhanced Oil Recovery (EOR) using captured CO_2 is another potential component of a value chain for CCS. However, due to the high cost of retrofitting existing platforms for EOR, it may not be commercially viable for all projects. In developing countries, the admission of CCS projects under the Clean Development Mechanism (CDM) would be an important means of economic incentives, and this issue is discussed in the Conference of Parties to the UNFCCC/Meeting of Parties to the Kyoto Protocol in Nairobi. The Commission is in favour of including CCS under the Clean Development Mechanism with provisions in place to sort out the remaining technical and political issues.

A number of large-scale projects are in the pipeline in Europe, which could form the basis of a range of demonstration projects across Europe and the rest of the world over the next 10-15 years, deploying a range of technologies. The Zero Emissions Fossil Fuel Technology Platform (ZEP) recommends a network of 10-12 integrated, large-scale demonstration projects across Europe and a maximisation of co-operation at the international level.

The EU is interested in supporting near-zero emission coal plants worldwide for climate, energy security and competitiveness reasons. Co-operation is particularly important with a number of fast-growing coal consuming countries including China, the Gulf States, India, South Africa, Russia and Ukraine. The Commission is aware of international work being done on demonstrations in the US (FutureGen initiative) and with similar projects elsewhere, and is committed to pursuing international co-operation on this issue. As part of the EU-China Summit in September 2005, the EU and China agreed to develop a demonstration plan on 'Near Zero Emissions Coal' by 2020.

4.4. CCS: Status of discussion in IPPC in Nairobi convention, Dr Heleen de Coninck (ECN)

Dr de Coninck discussed the on-going processes in the UN climate policy institutions: first, the scientific IPCC documentation, and then the political interpretation in the UNFCCC and its Kyoto Protocol. The starting point is that the success of short and long-term implementation of CCS depends essentially on whether it is accepted under the international climate change regime, in the UN-based bodies, the IPPC and the UN Framework Convention on Climate Change.

In 2003, the IPCC decided to produce a Special Report on CCS and the Summary for Policy-makers was agreed in September 2005 in Montreal. According to the summary, CCS should be seen as part of a portfolio of options to reduce greenhouse gas emissions. The summary considered in detail different parts of the whole CCS chain, related barriers and carriers, cost impacts on energy, global potential, heath and safety risks, legal aspects and public perceptions.

The IPCC Task Force on National Greenhouse Gas Inventories finalised its latest guidelines in April 2006, and the energy chapter includes a section on the geological storage of CO_2. It is important to note that, in the guidelines, CCS is treated as an emission reduction by source, and not as a sink. The captured CO_2 is reported as an emission reduction at the stack, and potential seepage from the reservoir as a fugitive emission. The 2006 Guidelines is the first internationally recognised document to give guidance on how to estimate seepage from a geological storage reservoir, and it also allows for recognition of CCS under the UNFCCC.

Dr de Coninck called for economic incentives for the implementation of CCS. The only incentive for CO_2 storage is climate change mitigation, but structural policy incentives in most individual countries are still absent. CCS will not be deployed on a large scale without policy incentives thus making CCS economically attractive. In the context of the Kyoto Protocol, this can be the project-based flexible mechanisms, i.e. Joint Implementation and the Clean Development Mechanism.

Dr de Coninck described the role of CCS at the discussions of the Conference of Parties to the UNFCCC (COP) and CDM Executive Board. The role of CCS is gradually becoming increasingly recognised and considered in many events organised around CCS. Whether CCS would be eligible under Joint Implementation and CDM was not resolved at the Conference of Parties to the UNFCCC/Meeting of Parties to the Kyoto Protocol in Nairobi. According to Dr de Coninck discussions are, however, evolving. A question related to CDM is whether CCS will be possible as part of the EU’s Emission Trading Scheme.

5. Concluding discussion

In the concluding discussion a member of the European Parliament remarked that the CCS workshop should have included views opposing CCS or least challenging some of the underlying assumptions behind the CCS arguments. The Member warned that African countries should not become a dumping ground and warned that the support they have received in practice does not match the promises made. The Member proposed that the fund for the steel and coal industry be used for financing the CCS requirements. The Member emphasised that the debate of CCS benefits should not overshadow the benefits of other technologies, as this ultimately may lead to a situation where relevant technologies were no longer supported.

Dr de Coninck remarked that countries, such as India, China and Brazil, are not always well informed about CCS technologies, implications, etc., and that there is a need for more workshops about CCS issues.

Mr Brockett expressed on behalf of DG Environment that he agrees that NGOs should be more heavily involved in the discussion. Meetings that give such opportunities will take place as of January 2007. According to Mr Brockett, the Seventh RTD Framework Programme of the EU is also foreseen as a financing source for CCS. CCS should be maintained in the mix of solutions to the energy problem. No technology will be neglected.

According to Mr Hauge, scenarios of Bellona coincide with those of the European Green Party. To this the person wishing to be critical of CCS aspects in the workshop clarified that the point of view of the Green faction in the European Parliament does not necessarily share all of the European green parties' opinions on the issue. Mr Hauge stressed that renewable energy does not conflict with CCS. It is impossible to achieve climate change with one technology alone. Moreover he emphasised that the EC has achieved very good progress in establishing an appropriate legal framework.

Dr Strömberg accentuated that CCS is not the only technology towards the mitigation of climate change. For example, Vattenfall is the largest consumer of bio fuels. The problem with renewable technologies is not in the development of the technologies but in how to integrate the new technologies into existing systems. He gave the example of windmills, where, according to his calculations, 67 000 windmills per year would have to be built to feed 20% of the total European electricity requirements. The costs of demonstration plants are out of reach for most energy producers. Support has to come mainly from government and the EC in the form of simplified procedures, systems, tax relief, etc.

Dr Pflüger stressed that ensuring the availability of adequate financing will be critical to the development of CCS. He also responded to Dr de Coninck's remark with respect to large countries such as India and China. These countries are systematically invited to all CCS workshops and they regularly participate. However, they fail to organise these workshops themselves, probably because they are reluctant to adopt new technologies. For example, Brazil hosted a large CCS workshop last September, which was attended by the top people associated with the CCS issues.

PART II: WORKSHOP PROGRAMME

DG INTERNAL POLICIES OF THE UNION
Directorate A - ECONOMIC AND SCIENTIFIC POLICY

Workshop on Carbon Capture & Storage

Programme

21 November 2006
European Parliament Brussels
Room ASP 3H1
14h00 – 17h30

14:00 **Introduction by the Chair**

Theme 1: Scientific background and status of discussion

14:10 Scientific background
Expert: Mr. Nick Riley, British Geological Survey

14:30 The Status of discussion of CCS
Expert: Mr. Antonio Pflüger, International Energy Agency

14:50 *1st Panel discussion*

Theme 2: CCS: Technical challenges and feasibilities

15:10 Energy industry perspective
Expert: Mr. Lars Strömberg, Vattenfall Europe AG

15:30 Oil industry perspective
Expert: Mr. Arve Thorvik, Statoil

15:50 *2nd panel discussion*

Theme 3: Regulatory and policy perspectives

16:10 Environmental promise versus risks
Expert: Mr. Frederic Hauge & Mr. Paal Frisvold, Bellona

16:25 The role of CCS for combating climate change - EC perspectives: review/forthcoming communications
Expert: Mr. Matti Vainio (or Mr. Scott Brockett), DG Environment, Climate Change & Air

16:40 Status of CCS discussions in IPCC in Nairobi convention
Expert: Ms. Heleen de Coninck, IVM and ECN

16:55 *3rd panel discussion*

17:15 **Concluding discussion and conclusions by the Chair**

17:30 *End of workshop*

The workshop is open to Members, their assistants and services of the EP only

PART III: BRIEFING NOTES FOR WORKSHOP

A. Theme 1: Scientific background and status of discussions

- BRIEFING NOTE BY DR NICK RILEY (BGS/UK) – THE SCIENTIFIC BASIS FOR CO2 CAPTURE AND STORAGE (CCS)
- BRIEFING NOTE BY DR ANTONIO PFLUEGER (IEA) – STATUS AND PERSPECTIVES OF CO2 CAPTURE AND STORAGE

B. Theme 2: CCS: Technical challenges and feasibilities - industrial perspectives

- BRIEFING NOTE BY DR LARS STRÖMBERG (VATTENFALL) – CO2 ABATEMENT – THE VIEW OF A POWER PRODUCER
- PRESENTATION BY MR ARVE THORVIK (STATOIL) – OIL INDUSTRY PERSPECTIVE

C. Theme 3: Regulatory and policy perspectives

- BRIEFING NOTE BY MR FREDERIC HAUGE (BELLONA) – ENVIRONMENTAL PROMISE VERSUS RISK
- BRIEFING NOTE BY MR SCOTT BROCKETT (DG ENV) – ENABLING LEGAL FRAMEWORK FOR CCS
- BRIEFING NOTE BY DR HELEEN DE CONINCK (ECN) – CCS: STATUS OF DISCUSSION IN IPPC IN NAIROBI CONVENTION

The scientific basis for Co2 capture and storage from fossil fuel use (CCS)

By Dr. Nick Riley MBE, C.Geol. FGS, British Geological Survey and co-ordinator of the European Research Network of Excellence on the geological storage of CO_2 "CO2GeoNet"- contact njr@bgs.ac.uk

Introduction.

This briefing document , which is for the purpose of giving background material for MEPs attending the seminar on CCS on 21st Nov 2006, covers the following topics.

- What is CO_2 Capture and Storage (CCS)?
- Why is CCS needed?
- Options for geological storage
- Do we already store gases underground?
- Will stored CO_2 leak back?
- If CO_2 did leak what would be the effect?
- Conclusions

What is CO_2 capture and storage (CCS)?

CO_2 Capture and storage is the capture of CO_2 from large industrial point sources. These include power stations, petrochemical facilities, hydrogen plants, natural gas processing operations, iron/steel works and cement manufacture. About 35% of CO_2 emissions arise from power generation alone. The captured CO_2 from such sources is then transported to an injection site where it is injected into deep geological formations (greater than 700m depth) for permanent storage, thus isolating it from the atmosphere. The most effective form of CO_2 transport is by pipeline, but ship, rail and road tankers can also be used. For transportation, the CO_2 is pressurized so that it becomes a dense gas that behaves like a liquid and occupies very little space. CO_2 in this form occupies less than one five hundredth the space that it would at room temperature and pressure. In this state, CO_2 is also virtually frictionless when it flows along the pipeline. CO_2 is injected into the ground and stored in this state, which explains why the storage has to be deep- so that the pressure is sufficient to keep the CO_2 in this dense phase, and to ensure that underground space is utilised to maximum effect.

Capture of CO_2 is a proven technology, it is already deployed in oil gas production operations, and a few power plants, but there are significant challenges with respect to the scale and cost of capture that will be required for large power plants (e.g. Europe's largest coal fired power plant (Drax, UK, emits over 17million tonnes of CO_2 per year, at only around 14% concentration in the flue gas). Deployment with respect to power generation will include a variety of pre-combustion (where CO_2 is removed after the fuel is gasified) and post-combustion capture (where the CO_2 is removed after the fuel is burnt). Currently, solvents are the main chemicals used in capture and these continue to be improved, but membrane technology is also promising route under development.

On the basis of current costs and technologies the price per tonne of CO_2 avoided to atmosphere is comparable to onshore wind and nuclear options, but of course, the potential scale and capacity to reduce emissions via CCS is very large.

Why is CCS needed?

CCS is the only technology that deals directly with fossil fuel emissions. It is therefore the only sure way of avoiding emissions from fossil fuels in the context of large industrial point sources. Currently the main emissions of this type come from power plants (about 35% of emissions). If surface transport in the future uses either electricity or hydrogen as an energy carrier, then there is potential for CCS to deal with over 50% of CO_2 emissions. It is important to realise that CCS can make a major and rapid contribution to climate change mitigation, indeed it is essential that it is deployed (e.g. Stern Review, UK Gov, Oct 2006). But, by itself, CCS cannot deliver the total emission cuts required by mid-century. Therefore CCS can only be part of a portfolio of approaches, including increasing use of non-fossil energy sources, improving energy efficiency and curbing energy demand. CCS is essentially a bridging technology to an energy future where fossil fuels are no longer dominant and energy is more effectively used. It buys us time to bring in non-fossil options to the scale required.

Options for geological storage

Geological storage is attained by injecting CO_2, in its dense compressed phase, into porous rocks. Such rocks (reservoirs) contain numerous interconnected spaces between the mineral grains. Currently the most favoured reservoirs are those found in oil and gas fields, as these demonstrate their ability to hold gases and liquids and trap them for millions of years. There is also the possibility that CO_2 injection can recover extra hydrocarbons in such settings. CO_2 injection into depleting oil fields is common practice in N. America, not as a climate mitigation option, but for security of supply reasons. An essential characteristic of oil and gas fields is that the reservoir is sealed by impermeable rock layers (seal) preventing fluids from escaping to the surface. Such barriers are usually clays or minerals (e.g. salt). Next favoured are reservoir rocks which, like oil and gas fields, are sealed but contain brine- these are known as deep saline aquifers. Of course, when such deep saline aquifer sites are chosen, it needs to be established why hydrocarbons have not been trapped in them. If it can be shown that the reservoir has never been impregnated with hydrocarbons, then in conjunction with rock testing techniques, assurance can be gained that the seal is effective. In terms of potential volumes for storage, deep saline aquifers have by far the largest capacities, and, as they become better mapped and tested they will likely become the dominant storage reservoir. Capacities in Europe are likely to meet storage demand past mid-century and probably beyond. The world famous CO_2 storage operation at Sleipner (Norwegian sector of the North Sea) is being conducted in a saline aquifer, where injection has been at a rate of approximately 1million tonnes (Mt) of CO_2 per year since 1996.

Other geological settings where CO_2 storage has been considered include injection into coal seams, oil shales and igneous rocks (e.g. basalt). In all these cases the intention is to use natural processes which bind the CO_2 to the rock matrix (either chemically or physically).

Such settings have only been attempted experimentally (e.g. Recopol in Poland) and pose significant challenges to achieving injection and containment on an industrial scale. These options are much less attractive than oil and gas field and deep saline aquifer targets, and even if technological barriers are overcome, these less attractive settings will likely only be niche deployments, as potential storage capacities are very small compared to hydrocarbon fields and deep saline aquifers. It should be noted that with coal and oil shale storage there is also the potential that gas production can be stimulated by CO_2 injection.

Do we already store gases underground?

Yes- natural gas is injected underground and stored across the breadth of Europe. Underground storage is an essential component for maintaining security of supply and safe operation of gas grids. For instance, in the early part of 2006, Italy had to draw on its underground gas storage to meet the shortfall in natural gas supplies entering the European grid from Russia. Storage can be in abandoned gas fields (e.g. UK and Netherlands), salt (e.g. Hungary), and aquifers (e.g. France). Because underground gas storage is a successful technology and has little surface expression, the public is largely unaware of its existence. For instance, how many people watching the 2006 World Cup football final hosted by Germany realised that about 800m below the Berlin stadium natural gas is being stored in an aquifer, in order to meet Berlin's seasonal gas supply requirements? In the UK, even hydrogen is successfully being stored, underground, in salt.

Will the CO2 leak back to the surface?

This is the main concern of all stakeholders. For this reason underground gas and CO_2 storage sites are designed not to leak. Fundamental to storage integrity is a clear understanding of the site geology, where all the features, events and processes are accounted for and characterised in terms of guaranteeing site performance, before injection starts. From this knowledge, appropriate injection, monitoring and verification strategies can be deployed to ensure prediction matches performance during injection. Any departures from predicted performance picked up by the monitoring need then to be assessed and appropriate action taken if required. This is a standard risk management and operational technique in oil and gas production operations. No CO_2 injection operations, out of the thousands of CO_2 injection wells worldwide, have been demonstrated to leak via geological pathways, however, there have been rare instances (less than five) of leakage during re-engineering operations conducted on old wells. These accidents have been quickly dealt with, without injury or loss of life to the rig workers. In these cases, the mistake was a failure to take into account the fact that CO_2 expands rapidly when it rises above a depth at which it no longer remains in its dense phase in the presence of an open and uninhibited pathway to the surface. It is widely accepted that the most likely risk of leakage from storage is through man made pathways, such as boreholes during injection operations. However, it is standard oil industry practice to be able to deal with such events.

Various natural processes occur in the reservoir which - over time - inhibit the ability of CO_2 to move upwards to the surface and leak. An immediate process that locks the CO_2 up is residual gas trapping. This is the effect, where tiny bubbles of gas are so tightly held between mineral grains that they are unable to move, it is akin to soaking a bath sponge - no matter how many times you squeeze it whilst submerged under water, you will never squeeze every last bubble of air out of the sponge. Of course in squeezing a sponge you are deliberately attempting to free the gas- in CO_2 storage this is not the case. Another immediate process is the dissolution of the CO_2 into the fluids in the reservoir. In the case of salt water, this dissolution makes the water heavier, making it sink deeper into the reservoir, moving the CO_2 further away from the surface. Once mixed with water, CO_2 can react with rock minerals to form new minerals which permanently bind the CO_2. All these processes have been observed in CO_2 storage operations and laboratory experiments. Over time these processes combine to decrease the risk of leakage, as CO_2 is increasingly immobilised. Depending on the type of reservoir and volumes of injection these processes together, take tens to thousands of years to completely lock up the CO_2, so that it cannot move upwards. In experimental CO_2 injections in Poland, Japan and N. America- where the injection wells have been deliberately left open to the atmosphere, (and in the Japanese example the well was exposed to an earthquake) no CO_2 has emerged from the storage horizon, principally as a result of early residual gas trapping and CO_2 dissolution.

Concern over leakage is clearly understandable, but there is a high degree of confidence that leakage events will be very rare and that, if leakage occurs, intervention using existing oil & gas industry practice can deal with the problem. It is certainly unreasonable to assume that all storage operations will leak to some extent, or that, if a leak occurs all the CO_2 will come back to the atmosphere. What is clear is that, whilst CCS is not deployed, all the CO_2 from fossil fuel burning is reaching the atmosphere. Therefore, delaying the deployment of CCS due to leakage concerns is counter productive in terms of avoiding the global damage that will ensue if we do not urgently deploy CCS. We also need to gain more confidence and experience through deployment. This is one of the reasons why the strategic deployment recommendations for CCS arising from the European Zero Emission Power Plant (ZEP) Technology Platform (Sept 2006) have ambitions for numerous industrial scale CCS demonstrations in Europe over the next 10 years.

If CO2 did leak- what would be the effect?

Many of these effects are well known in terrestrial settings. Europe has many regions, where CO_2 is emanating from the ground through natural geological processes, usually associated with past or present volcanic activity. This is particularly the case around the Mediterranean region (France, Italy, Greece), but, also, to a lesser extent in other regions (Germany, Hungary) and, of course, Iceland. Many of these natural releases are much larger than could ever happen in the case of a failed CO_2 storage operation. Effects at these natural analogues are very localised, as CO_2 disperses readily in the atmosphere. The principal risk to humans is from asphyxiation, where CO_2 can build up in confined spaces.

People who live in areas where CO_2 is released naturally through the ground into their homes (e.g. in some suburbs of Rome) manage this risk by designing buildings with basement ventilation, and avoid sleeping on ground floors (as CO_2 is denser than air, in calm conditions, it can accumulate close to the ground). The risk to vegetation is asphyxiation of the root systems. This is seen at natural seeps where, immediately over the seep, the land is bare. However, within distances of only a few metres, laterally, vegetation grows. Soil organisms are very tolerant of CO_2, as soils, particularly for soils high in organic content, which consequently have much higher levels of CO_2 than the atmosphere as a result of respiration of soil organisms and the decay of humus.

The effect of CO_2 on aquatic ecosystems is much less well understood. What is known is that aquatic organisms are much more sensitive than terrestrial ones to raised CO_2 levels. Particularly sensitive are those organisms that construct carbonate skeletons and shells (many molluscs, corals, echinoderms and planktonic species) - where the effect of CO_2 is that of lowering the pH of the water- disrupting the ability of these organisms to build their shells and skeletons. Another effect of CO_2, is with respect to very active organisms (predatory fish and squid) or at times in an organism's life cycle (e.g. at egg, sperm and larval stages) where easy availability of oxygen is crucial to growth or activity (it is biologically much harder for an organism to extract oxygen from water than from air).

CO_2 leakage and its effects on ecosystems is a active field of research being investigated by the European Network of Excellence on the geological storage of CO_2 (CO2GeoNet), which is conducting experiments in terrestrial, freshwater and marine settings, using sites where CO_2 is leaking naturally, and through deliberate exposure experiments in the laboratory and the field. The network intends to develop these facilities as established European test facilities for leakage detection and effects.

What is clear is that leakage has only local effects. It is also clear that, despite the uncertainties associated with the possibility of leakage into the marine environment from sub-seabed storage of CO_2, the risk of global marine acidification from continued use of fossil fuels without CCS is far greater. This is the basis on which the parties contracting to London Convention and its Protocol have recently endorsed (November 2006) sub-seabed storage of CO_2 in suitable geological formations.

Conclusions

CCS is an essential technology that needs deploying urgently to deal with CO_2 emissions from fossil fuel use in time to avoid the most serious consequences of human induced climate change, sea level rise and ocean acidification. It has to be part of the portfolio of strategies, alongside non-fossil energy supply, energy efficiency and demand reduction. CCS is being deployed now on a small scale, but we need to rapidly accelerate deployment so that uncertainties can be minimised through learning by doing. Geological storage of CO_2 does pose a very slight risk of leakage. These risks are constrained and manageable. The risk of not deploying CCS has far more dangerous consequences than the risk posed by leakage from underground storage.

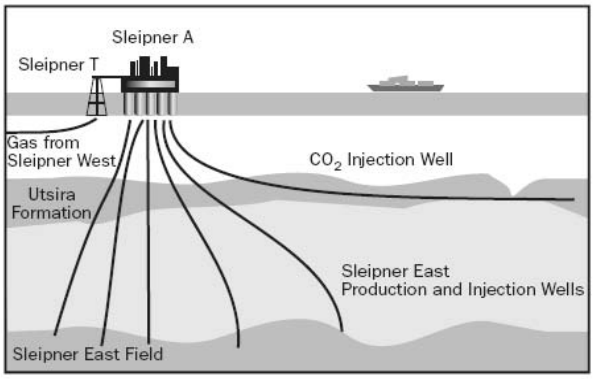
Description – CO2 capture and storage (CCS) could enable large (> 85%) reduction of CO2 emissions from fossil fuel combustion in power generation, industry and synthetic fuel production. CCS involves three main steps: CO2 **capture**; CO2 compression and **transport** (by pipeline or tankers); CO2 **storage** in deep (>600 m) saline aquifers, depleted oil and gas reservoirs or un-mineable coal seams. Capture is possible either before combustion (decarbonisation of fossil fuels) or after combustion (capture from flue gas) using a range of technologies.

Pre-combustion capture (by coal gasification and natural gas shift or reforming) with CO2 separation by physical absorption is currently the most promising technology option that could be applied in Integrated coal Gasification Combined Cycle (IGCC) plants.

Post-combustion capture options include CO2 chemical absorption from flue gas (CCS in Super Critical Pulverised Coal Combustion – SC/PCC and NGCC plants) or oxyfuel (fossil fuel combustion with pure oxygen to produce nearly pure CO2 that can be easily separated). The oxyfuel process requires additional cost for oxygen production from air or from advanced chemical looping. In the long term, gas separation membranes could be used for both pre/post-combustion capture.

After capture, CO2 must be compressed for transportation by pipeline or tankers. Compression is also needed for final geological storage. Several CCS technologies are likely to co-exist in the future, but all options require further R&D to improve efficiency and reduce cost. CO2 storage in the oceans is hampered by environmental risks.

Statoil's Sleipner CO_2 Storage Project



Source: Statoil

Status - Technologies for CCS are rather well known, but system integration and commercial demonstration is needed. If CCS is to play a significant role in the coming decades, demonstration must be accelerated. In particular, safe and permanent CO2 underground storage needs to be proven. Major ongoing demo projects (Australia, Canada EU, US) include the offshore Sleipner project (Norway - 1 MtCO2/y storage in a deep saline aquifer, since 1996) and the Weyburn project (Canada - 2 MtCO2/y storage combined with EOR, since 2001), both using CO2 sources other than power plants.

In both projects, the underground CO2 behaviour is corresponding to the expectations. No leakage has been detected and several natural chemical-physical phenomena, such as CO2 dissolution in the aquifer water are expected to reduce the risk of long-term leakages. The FutureGen project in the US (Carbon Sequestration Leadership Forum, CSLF) aims to demonstrate the CCS technology in marketable IGCC plants. Pilot projects suggest that storage in unmineable coal seams may also be viable. Enhanced oil and gas recovery (EOR, EGR, currently applied at several sites) offer numerous demonstration opportunities and potential revenues that can off-set part of the CCS cost. Existing and planned demo projects are likely to reach only 10 MtCO2/y over the next 10 years. Given the range of technologies under development, CCS demonstration would require at least ten major power plants with CCS in operation by 2015. Substantial increase of current budget for CCS demonstration as well as private/public partnerships and outreach to emerging countries are essential. As CCS implies an incremental cost, an incentive to reduce CO2 emissions is needed for CCS to be commercially demonstrated and deployed.

Performance and Cost - CCS from power plants makes economically sense only if applied in large, highly efficient plants. The increased use of fossil fuels for CCS in current power plants could be as high as 35-40%, and is expected to decline to 10-30% for next generation technologies, and up to 6% for more speculative design concepts. Efficiency losses due to CCS are in the order of 9-12% for existing coal plants,

declining to some 4% for future plants with fuel cells. CO2 compression at 100 bar is included in the efficiency loss. R&D is critical for reducing efficiency losses. In general, high design complexity results in higher loss of efficiency and capital costs. It is estimated that the investment cost of a demonstration power plant with CCS could range US $ 0.5-1 billion, 50 % of which for the CCS equipment.

Today's CCS cost ranges from $ 40 to 90/tCO2 depending on the technology used (best estimates at $ 50/tCO2). CO2 capture using cost-effective technologies ranges $20-40/t. Transportation cost by pipelines depends on flow rate and distance. Large-scale transportation cost ranges $ 1-5/tCO2 per 100 km. Storage cost can be around $1-2/tCO2 depending on the site. Transport and storage cost together can be estimated at less than $10/t CO2. Cost of long-term storage monitoring is of secondary importance. While the total CCS cost is expected to fall to below $ 25/tCO2 by 2030, the use of CO2 in Enhanced Oil Recovery (EOR) offers the opportunity to offset at-least part of the CCS cost and to conduct CO2 storage demonstration projects at low or no cost. Using CO2 in EOR can offer additional 0.1-0.5 ton of oil per ton of CO2. At $ 45/bbl oil price, EOR revenue could range $ 30-150/t CO2. EOR is currently used in the US to improve production in several tens of mature oil wells. However, it holds in general limited global potential in terms of CO2 storage, and CO2 use must be compared with other EOR options. The future cost of CCS depends largely on technology advances and learning. At present, CCS use in new natural gas and coal-fired power plants would increase the current electricity production cost ($ 0.025-0.050/kWh) by some $ 0.02-0.03/kWh. In perspective, this additional cost could be lower for coal power plants than for gas plants. It is expected to decrease to $ 0.01-0.02/kWh by 2030 as the technology will become mature. As the electricity price is considerably higher than production costs - the average price in the year 2000 for households in the OECD countries was $ 0.11/kWh, the CCS would increase consumer prices by only 10 to 20%. While various technologies will co-exist, NGCC and advanced coal power plants (SC-PCC, UC-PCC, IGCC) appear to be amongst the cheapest electricity supply options even if CCS cost is accounted for.

Potential – According to IEA *Energy Technology Perspectives* (ETP, IEA-2006), CCS in power generation, industry and synfuel production could contribute from 20% (some 6.4 GtCO2/y) to 28% of global emission reductions by 2050. Important opportunities for CCS exist in coal consuming countries. CCS commercial deployment could enable the use of huge coal world reserves with negligible impact on global emissions. Since power plants have long lifetime, a fast CCS expansion would imply retrofitting highly-efficient, existing plants. This is in general more expensive than building new power plants with CCS.

While technical and economic feasibility of CCS is being demonstrated, the construction of CO2 *capture-ready power plants* for later retrofitting is a new concept under consideration to deal with the uncertainties of future CCS market. Case studies suggest that an efficiency penalty in the range of only 3% could be incurred for later retrofitting of new gas power plants conceived for CCS integration. Retrofit and capture-ready plants are topics under consideration by IEA in the G8 framework for 2007 and 2008.

CCS in biomass-fuelled power plants may result in net CO2 removal from the atmosphere. However, biomass plant size is in general small (25-50 MW vs. 500-1000 MW coal power plants), thus the CCS cost per kW is roughly twice as high as compared to coal plants. EOR offers opportunities for CCS industrial demonstration at low cost. Assuming successful demonstration and emission reduction incentives, CCS could be commercially deployed from 2015 onward, but large RD&D efforts are needed for CCS to contribute to emission reduction in the next decades.

Barriers – Major barriers for CCS deployment are cost, and the demonstration of full-scale commercial operation and safe permanent CO2 storage. CCS investment cost for a single power plant is in the order of hundreds of millions of dollars and poses a major financing challenge. Pipelines are also needed to connect the power plant and the storage site. A regulatory and policy framework (liability, licensing, leakage, landowner, royalties) is needed, as well as private investment and public acceptance. Governments will have to establish credible, long-term CO2 policy goals to create the basis for private investment and public-private partnerships. A substantial increase of current global budget for CCS demonstration is essential. Climate change mitigation instruments, including CO2 emission trading, should include CCS. Outreach to emerging countries and transition economies are essential.

Data

Data relevance – CCS is currently in demonstration phase with 3 industrial plants in operation using CO2 sources other than power plants. Data below refer to estimates for power plant applications.

Performance	
Input/Output	Energy input to achieve CO2% emission abatement
Efficiency	9-12% loss vs. power plants with no CCS (potential decline up to 4%)
Lifetime	Same as the power plant
Load factor, availability	Same as the power plant - little/no O&M experience with CCS in power plant
Typical Size	Same as the power plant
Installed Capacity	3 demonstration facilities with storage capacity of 3-4 MtCO2 a year. Several demo projects underway. Some 90 EOR applications mainly in the US
Costs	
Investment ($/kW)	Some 50% of the power plant investment cost (demonstration plants with CCS)
O&M ($/kW)	Same as the power plant (4% of the investment cost per year)
Capture cost	$ 20-40/tCO2 for cost effective separation techniques
Transport cost	$ 1-5/tCO2 per 100 km for large-scale transportation by pipeline
Storage cost	$ 1-2/tCO2 depending on the site
Total cost	$ 40 to 90/tCO2 depending on technology used (best estimates $ 50/tCO2)
Impact on electricity	$ 0.02-0.03/kWh (incremental electricity cost due to CCS)
Cost projections	Total CCS cost expected to fall below $ 25/tCO2 by 2030, depending on technology learning/advances, with incremental electricity cost of $ 0.01-0.02/kWh (see Table1)
Environmental Impact	
CO_2 emission reduction	> 85 %
Pollutants reduction	CO2 capture by oxyfuel can considerably reduce NOx, SOx, and PM
Waste (CO_2)	0.32-0.34 kg CO_2/kWh from NGCC and 0.64-0.75 kgCO_2/kWh from coal plants (1 MtCO_2/y for 500MW NGCC plant, 4.5 MtCO_2/y for 1000MW coal plant)
Land use	Same as the power plant plus CO2 capture, transport and storage facilities
Water use	Same as the power plant
Special materials use	Post combustion capture: amines and other chemical CO2 absorbent/solvents, Oxyfuel capture: oxygen
Key Players	
Private sector	To be added
Public sector	To be added

Table 1 – Characteristics of power plants with CO2 capture

Fuel & Technology	Ref. Year	Investm. Cost (US$/kW)	Effic. (%)	Effic. Loss (%)	Additional Fuel (%)	Capture Effic. (%)	Capture Cost (US$/tCO2)	Electricity Cost (US¢/kWh)	Electricity cost noccs (US¢/kWh)
Likely Technologies									
coal steam cycle, CA	2010	1850	31	12	39	85	33	6.8	3.8
coal steam cycle, CA	2020	1720	36	8	22	85	29	6.1	3.8
coal steam cycle, CA	2030	1675	42	8	19	95	25	5.7	3.8
coal IGCC, selexol	2010	2100	38	8	21	85	39	6.7	3.8
coal IGCC, selexol	2020	1635	40	6	15	85	26	5.7	3.8
gas CC CA	2010	800	47	9	19	85	54	5.7	3.8
gas CC oxyfuel	2020	800	51	8	16	85	49	5.4	3.8
black liquor, IGCC	2020	1620	25	3	12	85	15	3.4	2.4
biomass IGCC	2025	3000	33	7	21	85	32	10.1	7.5
Future Technologies									
coal CFB chem.loop.	2020	1400	39	5	13	85	20	5.3	3.8
gas CC chem. Loop.	2025	900	56	4	7	85	54	5.4	3.8
coal IGCC SOFC	2035	2100	56	4	7	100	37	6.0	3.8
gas CC SOFC	2030	1200	66	4	6	100	54	5.4	3.8

Note: 10% discount rate and 30-year technology lifespan. Investment costs do not include interest during construction and other owner costs, which may add 5-40% to overnight construction cost. Coal price = USD 1.5/GJ; Natural gas price = USD 3/GJ. CO2 produced at 100 bar. CO2 transport and storage not included. Capture costs compared to the same power plant without capture. CA = Chemical Absorption. CC = Combined-cycle; CFB = Circulating Fluidised Bed; SOFC = Solid Oxide Fuel Cell; USC = Ultra Supercritical. IGCC data for 2010 refer to hghly-integrated plant based on a Shell gasifier, while 2020 data refer to a less integrated US design based on an E-gas gasifier. Efficiency remains at the same level because new gas turbines will become available in the 2010 to 2020 period (the so-called 'H-class') and result in increased efficiency.

SC/PCC Plants with CO2 Capture from Flue Gas - CO2 is captured from flue gases by chemical absorbents that are then regenerated by heat to release CO2. While amines are the most used chemical absorbents for NGCC flue gas with CO2 concentration of 3- 4%, other absorbents may be used in coal plants where CO2 concentrations (13%) and the level of impurities is higher and may affect solvent degradation. A major issue also is the energy required for regeneration and CO2 compression. Efficiency loss is in the range of 9-12% with net efficiencies of 35 to 36% (LHV). New absorbents with sulfur tolerance may improve performance. In a different process, CO2 can be separated through membranes that separate gas stream and solvent. Membranes for this process are under development. Many other techniques are in early stages of development.

SC-PCC with CO2 Capture by Oxyfuel Combustion – Burning coal in a mixture of oxygen and recycled flue gas produces a CO2-rich gas from which CO2 can be easily removed by cooling and condensation, and the exhaust stream returned to the boiler. Oxyfuel avoids costly CO2 gas separation but requires additional cost of oxygen production or separation from air. Recent estimates (IEA GHG) suggest a net efficiency of 35% LHV for a SC-PCC plant, similar to post-combustion capture. Without CO2 capture, the efficiency of SC-PCC plants with oxyfuel combustion is lower as compared to conventional SC-PCC because of O2 production. However, oxyfuel combustion holds the potential for further development. Ion-transport membranes and other low-cost technologies for O2 production are expected to be available in 5-10 years. In comparison with post-combustion capture, oxyfuel could also significantly reduce NOx emissions and could become the best system for co-disposal of CO2, NOx, SO2 and to achieve nearly zero emissions. Sulfur concentration in the off-gas requires control to avoid corrosion. Oxyfuel has been demonstrated in test units.

IGCC with CO2 Capture - In IGCC plants, coal is converted into a hydrogen-rich syngas that is cleaned and burned in a gas turbine. Gas exhaust from the gas turbine is then used to power a steam cycle. Extensive gas cleaning is needed to protect the gas turbines and reduce pollutant emissions. When CCS is applied, the syngas is sent to a shift reactor to convert CO into CO2 and further H2. The process produces highly concentrated CO2 that is readily removable by physical absorbents with low efficiency penalty and cost. Hydrogen is burned in a gas turbine. Further R&D is required for hydrogen turbines. In an alternative process with post-combustion capture, oxygen is used to burn the syngas in the turbine. The resulting flue gas consists of CO2 and steam, from which CO2 can be separated easily. This process is expected to be cheaper than use of pre-combustion CO2 removal and hydrogen turbines. It is also cheaper than post-combustion processes used in SC-PCC plants. In principle, IGCC technology offers the cheapest option for CCS. However, IGCC plants are today more expensive than SC-PCC power plants. There is no consensus on which option will be cheaper in the future. Large efforts are in place in the EU and US to bring IGCC with CCS to the market (FutureGen project).

NGCC with CO2 Capture - In NGCC plants with pre-combustion CO2 capture, natural gas is converted into H2 and CO2, hydrogen is used for power generation, and CO2 is removed for storage. Post-combustion capture in NGCC plants is more difficult than in coal plants as the CO2 concentration in the flue gas is lower. While CO2 chemical absorption from NGCC flue gases is a well known process, R&D on better solvents and design optimisation are pursued in demonstration projects (Norway, UK). The current cost exceeds $ 50/tCO2 and reduction below $ 25/tCO2 is unlike. Alternative processes including oxyfuel with chemical looping reactors to supply oxygen, and natural gas reforming are under investigation.

Carbon abatement – the view of a Power Producer

Lars Strömberg
Vattenfall AB
Group Function Strategies
SE-12935 Stockholm Sweden
Tel. +46 8 739 5511
e-mail lars.stromberg@vattenfall.com

A carbon-constrained world

It has become a word in everyman's mouth that we encounter a Climate Change threat. This might take a somewhat non-scientific expression, but no matter the absolute proof, it is a reality. At present, (late 2006), a multitude of investments in wind power, bio fuel combustion and gasification and also in more sophisticated renewable energy generation technologies have been made. In addition also several demonstration plants with Carbon Capture and Storage have been announced. These actions bear witness of that the Power industry takes responsibility for the potential threat of Climate Change, and also that the industry takes the CO_2 issue seriously.

Several reduction targets have been discussed, but the most common is derived from a calculation of the average temperature increase of the Planet, due to the concentration of CO_2 in the atmosphere. A limit of 2 degrees Celsius average temperature increase has been considered reasonable. This can be translated to a certain reduction of the emission. Unfortunately this means that most industrialize countries must reduce their emission with 60 to 80 % within a not too long time period. If the reduction is initiated later, not only must the reduction be deeper, but also must the reduction rate be steeper.

Therefore it is essential that we do not only prepare for a very deep cut in emission in Europe, but also we have to do this quickly. Quickly means that we have to start reaching considerable reductions in about 2020. The problem is of course how to reach large enough reductions and with what.

Recently the IPCC (Intergovernmental Panel on Climate Change) came up with a special report on Carbon Capture and Storage (CCS) www.ipcc.ch. Also the European Commission has initiated a Technology Platform for Zero emission Fossil Fueled Power Plants. www.zero-emissionplatform.eu. Both reports indicate the necessity to do something, and do it fast. Also, both reports identify the most powerful tool to combat Carbon emissions to the atmosphere is Carbon Capture and Storage.

Fossil fuels are needed

Most people agree on, that it would be best if we found renewable energy sources, which can take over from the present non-sustainable energy system. Also there is no doubt that it would be fine if we could reduce the energy consumption in society. The problem lies in the fact, that so far, there exist no real alternatives, which has been realized. Energy consumption increases and the available renewable energy sources are good, they work and do contribute considerably to our energy supply, but they are not big enough and cannot be expanded fast enough.

Wind power works fine as long as it is a marginal contribution to the total supply. The units grow bigger; become more efficient and specific costs decreases. Unfortunately it also has its limitations due to that the system costs will increase considerably when the amount of wind power contributes significantly to the total. Also a limitation is obvious concerning space and permissions. Therefore some 10 % contributions to the energy (or about 25 % of the capacity) seem to maximum in a system.

Biofuels also work fine. We know how to burn it efficiently, how to gasify it and how to handle it. The problem lies in the available amounts, and the costs. Today in a mature market as the one in Sweden some 40 % of the biofuel is imported, and the cost to produce electricity (exclusive of subsidies and taxes) is about three time that for gas or coal. Unfortunately the nature of biofuels makes them less suitable for high efficiency processes and conflicting interests concerning land use and use of the material, limits its availability. Again, some 10 % might be a reasonable level in Europe.

Hydropower is perhaps the most valuable of all renewable energy sources. It is efficient, well functioning and has very good properties in a power system, like easy regulation. In some countries it is well established and produce a significant amount of the energy, like in Austria, Sweden and Norway. Again the problem is the conflicting interests in expanding the amount. It is only very few countries where it is possible to expand. Thus hydropower is also a very limited source of energy.

Hydrogen is only an energy carrier and will not solve any problems. It has to be produced somehow, and is the most difficult of all existing substances to handle and store. It is in most cases better to produce any other type of energy carrier, especially from renewables, than to go around via hydrogen. Without any hydrogen also fuel cells does not improve anything.

Solar power might contribute but at a very high cost and in a very limited volume, the coming three decades.

There are thus three major renewable energy sources available in Europe, which can play a role in the energy supply the next 25 years.

So, renewables will play a very important role up until 2050, but with a limited contribution. 20 – 30 % can be considered very ambitious. The question is then; what will contribute with the remaining 70 – 80 %.

Nuclear power is a well-established energy source, but has its own difficulties. Many countries have chosen to abandon nuclear, while a few build new capacity. As will be discussed later the cost of electricity from nuclear is in the same magnitude as from coal or gas including carbon capture and storage.

To conclude:

- Fossil fuels are needed
- We need a solution to use fossil fuels without any emissions to the atmosphere
- The solutions must be relatively seen not too expensive; a target is set at an abatement cost of 20 €/ton of CO_2.
- The solution must be commercially available within a short time. The target is set; available in large scale in 2020

Who's got the responsibility?

There is no doubt that the industrial countries consume considerably more energy than the less developed and the poor countries in the world. It is also so that the industrialized world has the resources to o something, both in terms of monetary resources and also technical resources. This is also reflected in the burden sharing agreement in the Kyoto protocol.

Further it no doubt that the energy sector, heat and power production stands for the largest single contribution to the emissions, amounting to more than a third of the total. Also it is probably easier to do something radical in the energy sector than in any other sector.

This is something that most power producers have recognized. This results in a number of initiatives, recently announced in Europe. Although only some are financed and only a few are already physically started, but still, the power industry has taken responsibility and is committed to do something.

1.1.1.1.1. A global initiative

The driving force for doing anything lies in the surrounding regulatory and legal system. In Europe the major driving factor is the Emission Trading System. One may criticize the ETS from a number of perspectives, but the conclusion remains, it is the best we have come up with so far. One severe drawback is that we do not know the future fate of it. This is perhaps the most critical for investments decisions. Also the lack of large enough and level playing field is critical, since it not only influence the stability, but also the price for CO_2 reduction credits. If we are serious in reducing the CO_2 emissions, we need to set up a system, which includes the whole world and is stable.

Vattenfall has taken initiative to initiate discussion around a global emission trading system. Such a system must fulfill several requirements as

- It should stimulate reduction of emissions
- It shall be effective worldwide
- It must be fair
- The burden sharing problem between rich and poor countries must be handled

The burdens are proposed to be related to the gross domestic product, and the system could in general be handled like the European system.

It is also clear that the deep cuts in emissions are possible to achieve. 35 % reductions until 2030 and further cuts down to 60 % in next 20 years seem realistic. However, this means that we need CCS, and we need it fast.

Read more on www.vattenfall.com

Carbon capture and storage

The principle behind CCS is rather simple. All fuels create CO_2 when burned. Capture that, clean it up and make it liquid. Pump this liquid down, into the same type of geological formations that contain gas or oil. They are porous rock formations or layers covered with less permeable rock types as clay or shale. The majority of these formations do not contain gas or oil, but only geological water. The layers are typically 1 to 3 kilometers down.

The geological water is heavily contaminated with metals, salts and minerals and it is not mixed with the ground water. If it was, this should be destroyed immediately. This is also proof of that there is no leakage between those deep layers and the surface. The hydrostatical pressure deep down keeps the CO_2 as a liquid-like substance. (It is supercritical) The pressure difference between the storage and the surrounding is also zero after the pumping down has expired.

The storage capacity within Europe exceeds the combined use of fossil fuels until they are extinct. Also storage capacity is available all over the world. Only the Norwegian formation Utsira, where Statoil produce oil has a capacity to store Europe’s all emission for 600 years, if we had fossil fuels that long.

The CCS chain

The CCS chain consists of the Plant with capture technology, a transport system and the storage site. As mentioned the storages are available at many places, but not necessarily below the floor of the power plant. In future we foresee that several plants send their CO_2 into a pipeline system, where the CO_2 is transported to storage. Many storages are connected to the pipeline system. This means that an integrated system is built up, which reduces costs considerably. It also creates continuity.

There also exist many storages offshore, deep under the seabed. These can be connected to a pipeline system, but can also be fed from a hub to which ships deliver the CO_2 from the coast.

Large-scale storage demonstrations exist. The most famous is Statoil's storing of CO_2 under their oil well Heimdal at the Sleipner field in the North Sea. This has been in operation since 1996. BP has a project in the Sahara desert and others run projects in Texas USA and at the USA border in Canada, the Weyburn project. Many more are in progress.

The transport systems are also in place. This is due to that CO_2 is used for some industrial purposes and also for enhanced oil recovery. CO_2 is pumped down to recover more oil from a well that is almost extinct.

In all, it seems that technology both for storage and for transport is available already. However much more work has to be done to create a thorough knowledge of the behavior deep down, to create a confidence in the technology and to create a knowledge in the public about this possibility, and thus get acceptance for perhaps the most powerful tool we have seen so far to combat Climate Change.

Capture technologies

To capture the CO_2 is not easy, and it cost quite a lot. This is also the part of the chain where Power Industry has to take a leading role in the development.

There exist three major technologies, which can fulfill the goals set up above.

They all have some factors in common and this is also where most work and money has to go in:

- Most components exist and have a usage in other industries and for other purposes.
- It is still a considerable work to optimize, to integrate and to scale up the components for the purpose of capturing CO_2 from a power plant
- All processes consume a considerable amount of energy, taken from the mother process.
- All technologies add on to the investment costs

This results in a higher cost to produce electricity from a plant with capture than from one without. Which technology that will be the winner in future is the one with lowest extra cost. Also different technologies will be used probably for gas and for coal. In general coal is considerably cheaper, but produces about double the amount of CO_2 compared to gas. Since a large part of the cost stems from energy consumption for the capture, the cost to capture CO_2 from coal is generally less expensive when calculated as abatement cost in €/ton of CO_2. This is also what the comparison base is, in an emission trading system. However gas might be competitive to coal concerning electricity generation cost including carbon capture due to lower investment costs.

If we look beyond 2020 some new technologies might evolve, with promising reduction of extra costs for the capture and low electricity generation costs. If this shall become a reality, work has to start now. Thus we discuss a two-route development road:

- One route to develop the three main technologies including several demonstration plants and large scale testing and optimization
- A second route to investigate and research new technologies for less expensive capture with less energy penalty and higher conversion efficiency

The major problem is that both cost a large amount of money and time. The driving force must be future market prospects related to a long-term commitment to a CO_2 reduction system, and consequently a CO_2 cost.

The three main technologies, pros and cons

Capture of CO_2 is of most interest for large power plants fired with hard coal, lignite and natural gas. The technologies for large coal fired power plants with CO_2 capture also allow for co-firing with minor fractions of biomass.

There are three main technology options for CO_2 capture from power plants, which can fulfil the primary goals of being ready for use in 2020 at a reasonable cost:

- post-combustion capture
- pre-combustion capture
- technologies where the nitrogen is excluded from the combustion process (more commonly known as oxy-fuel combustion).

These options are schematically illustrated in Figure 1. below.

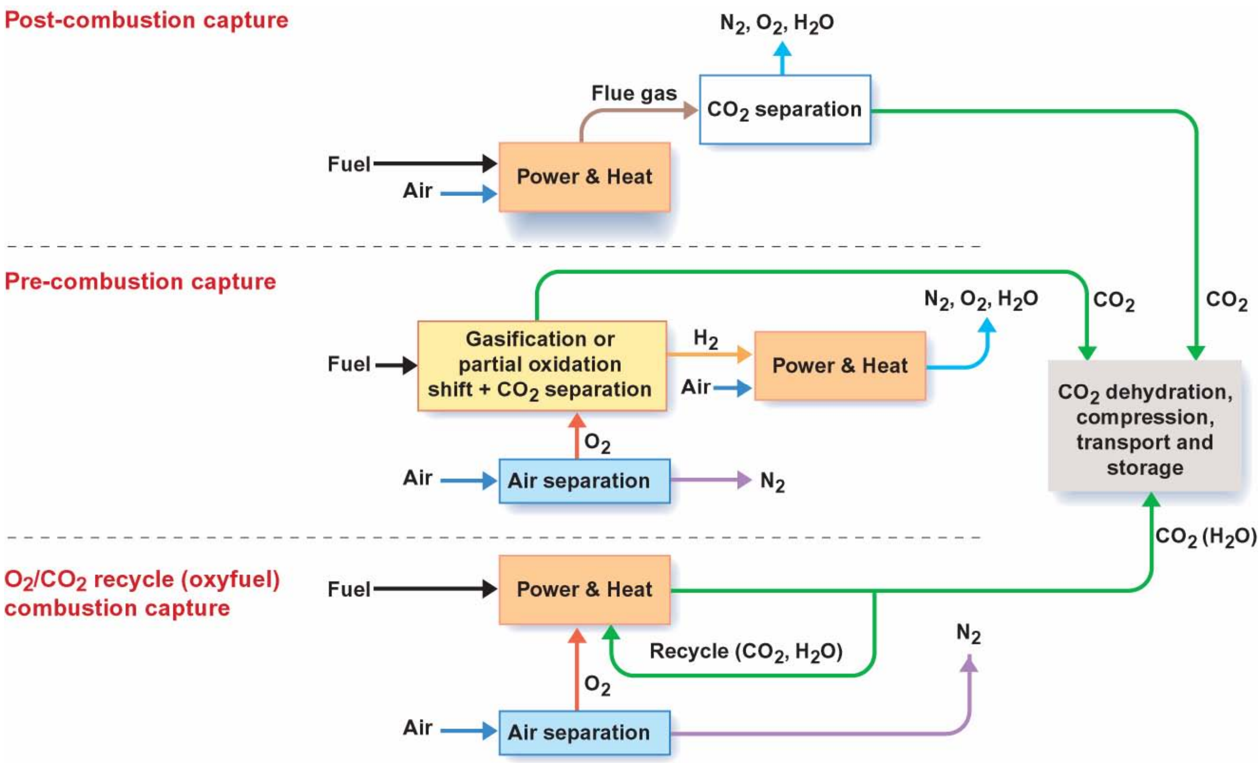


Figure 1. Main technology options for CO_2 capture from power plants

In **post-combustion** capture, the CO_2 is removed from the power plant flue gas. Commercially available technology includes CO_2 capture using absorption in an aqueous amine solution. The CO_2 is then stripped from the amine solution and dried, compressed and transported to the storage site.

In **pre-combustion** capture, the carbon content of the fuel is removed prior to combustion in order to produce a hydrogen rich fuel and a CO_2 by-product stream. For coal this can be done via gasification. After gas cleaning, the synthesis gas is shifted to produce a hydrogen-rich fuel gas mixed with CO_2. The CO_2 is removed by physical absorption and the hydrogen is burned in a gas turbine. A similar scheme can be applied to natural gas, where the gasification step is replaced with a reforming stage to produce the synthesis gas.

In the **O_2/CO_2 recycle combustion process**, nitrogen is removed from the air using, a conventional air separation unit, and the fuel is combusted with oxygen mixed with CO_2, which is recirculated to control the combustion temperature. This gives a flue gas consisting mainly of CO_2 and water vapour. The water is condensed, resulting in an almost pure CO_2 stream for transport and storage.

For all CO_2 capture, technologies **compressor equipment** is indispensable. After the CO_2 is captured, compression is used to bring the CO_2 to a liquid state. Further pressure increase can be done with a pump.

The pros and cons are described in the simplified table below

	Status	**Prospects**	**Fuels**
Post combustion capture	• Tech exists but not competitive and in large scale • Most expensive	- Only tech. for retrofit. - Large development potential	Can be adopted to any plant, no matter fuel or process
Pre combustion capture IGCC	• Tech exists, but not competitive • Large development effort to be first choice	• Can produce H2 or syngas • Huge interest worldwide	No suitable technology for lignite, only bituminous and sub bit. coals
Oxyfuel	• Least expensive • Only combustion process major unknown	If combustion models validated – simple fitting to supercritical PF tech.	Suitable for all coals and biofuels
New technologies	• No candidate to be commercial in 2020	• Chemical looping very promising • Membranes will come	No principal limitations

Based on this evaluation the preferred technology at present in Vattenfall is the oxyfuel combustion technology. It is adoptable to all coals, we can build on our very good experience from our existing, very efficient and reliable supercritical pulverized coal plants, and last but not least it seems the least costly option. We are aware that others do different evaluations, but nevertheless we firmly believe this technology suit our situation.

If we are wrong, no harm done. Then we have investigated an option, but can always buy another technology if that develops better.

Benchmark

The driving force for all technology development in the area of CO_2 capture is to reduce cost. In the process from capture to storage, capture represents the highest costs. Transport costs depend very much on distance but also on volume, since large volumes allow the use of less expensive large-scale solutions. Again, the storage cost depends on the storage structure, location and depth. However, it is considered that the capture accounts for some two thirds of the total cost.

It must be stressed that the technology choice for new investments is governed by the power generation costs for the technology in question, including any CO_2 penalty. This implies that a technology with lower generation costs will be preferred before a more expensive, even if the calculated CO_2 capture cost is higher. Secondary parameter for the choice is the cost for capture/avoidance.

The cost for capture is calculated in several different ways. Most important is to what the comparison is made; a plant of the same kind without carbon capture, or to some other plant. It is common that the calculations results in an increased energy production cost, when comparing the same type of plant without and with carbon capture and storage. Dividing the incremental energy production cost by the reduction of CO_2 emitted to the atmosphere per unit of produced energy yields the unit cost of CO_2 avoided to the atmosphere (not only captured) expressed in EUR/ton of CO_2. To make comparison between different results possible, the calculation must give energy penalties, fuel prices, cost estimation basis, expected lifetime, interest rates, load factor, and if taxes etc. are included.

This implies that reducing cost does not only include reduction of the capital cost, but also energy consumption and unavailability. Therefore the capture cost is sensitive to reduction in energy loss, but also sensitive to fuel price and availability of the overall power plant. Thus external parameters influence the avoidance cost more than the technology choice itself. The energy penalty influences the incremental fuel cost via the incremental fuel consumption. The absolute fuel price thus has a significant influence on CO2 avoidance cost. Therefore the decision on future capture plants will primarily be driven by the fuel choice and only second by the capture technology.

All main technology routes for pre-combustion, post-combustion and oxyfuel have the potential to reach a significant reduction of the relative avoidance cost.

The technology benchmark that is described here is taken from the ZEP report from working group 1. The power plant data, which have been used for the power plant concepts, with as well as without CO2 capture, correspond to current state-of-the-art, in order to not introduce unnecessary uncertainties in the calculations.

Some basic input data are described in the table below. A more detailed background can be read in the ZEP report www.zero-emissionplatform.eu

Financial and other boundary conditions		Natural gas	Hard coal	Lignite
Fuel price	€/GJ (LHV)	5,8	2,3	1,1
Plant size	MWe (Ref)	420	556	920
Specific investment	€/MWe (Ref)	471	1058	1278
Common input				
Life time	Years	25		
Wacc	%	8		

Based on this input data, the following chart shows the expected range of avoidance cost for the three main concepts, which can be developed and demonstrated before 2020.

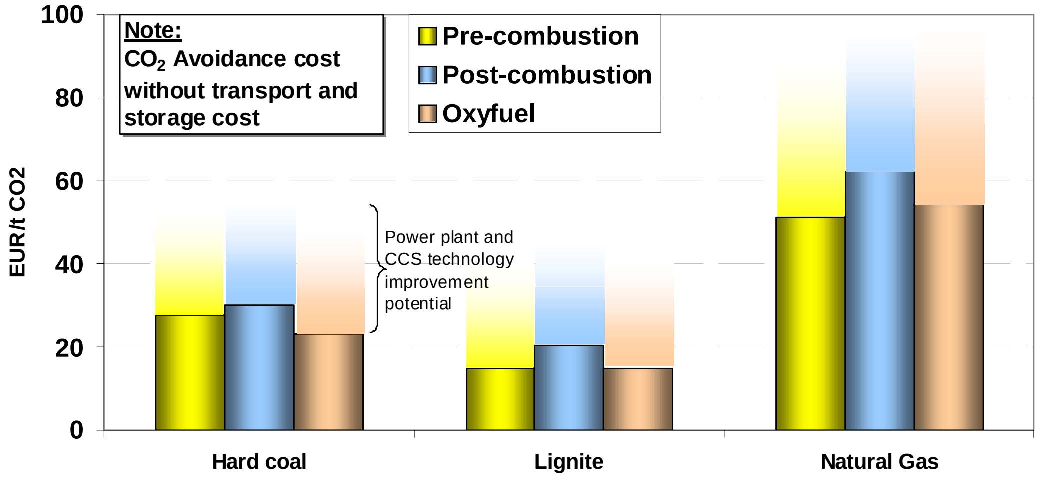


Figure 2 Expected CO_2 avoidance cost for large-scale power plants in operation by 2020.

The power generation cost and the cost increase when comparing to the reference plant without capture are shown in Figure 3

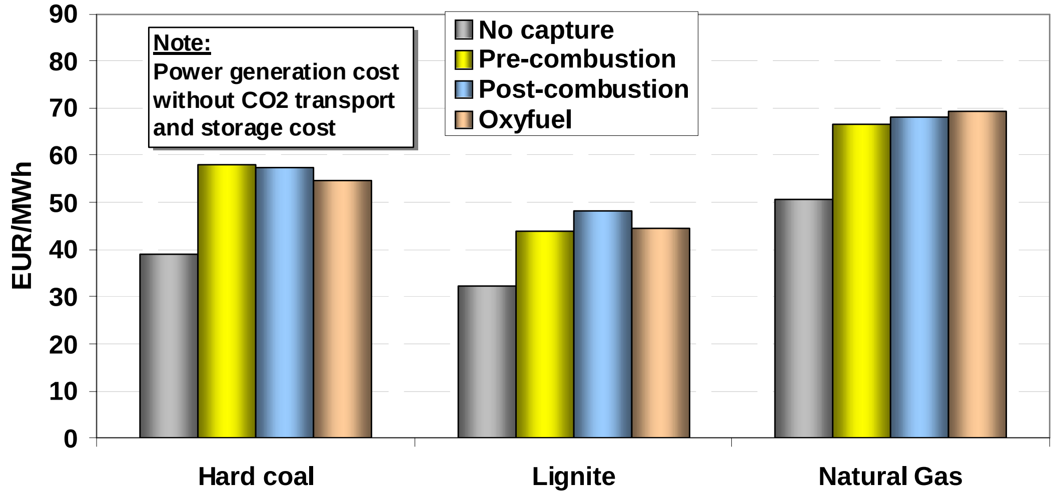


Figure 3 Expected power generation cost for large-scale power plants in operation by 2020

The cost of CO_2 capture and compression is the dominating part of the CCS cost. It seems reasonable that if in case the initiated development path, is followed and enough emphasis is put on large scale demonstration of these technologies, CO_2 capture cost for power plants can drop close to 15EUR/t or even lower after 2020

The CO2 free Power Plant Project

To organize the work, Vattenfall has set up a project, which has a ten-year lifetime. It started in 2001 and will end in 2010, with the decision to build a demonstration plant or not. If so decided the demo plant will be in operation in 2015. This project is called the CO2 free power plant project. It contains six phases.

1. Is it possible? (Answer was yes)
2. Gap analysis
3. Concept development and basic research to cover gaps
4. Engineering phase, continued R&D, Pilot plant
5. Demonstration plant development
6. Construction of a demonstration plant.

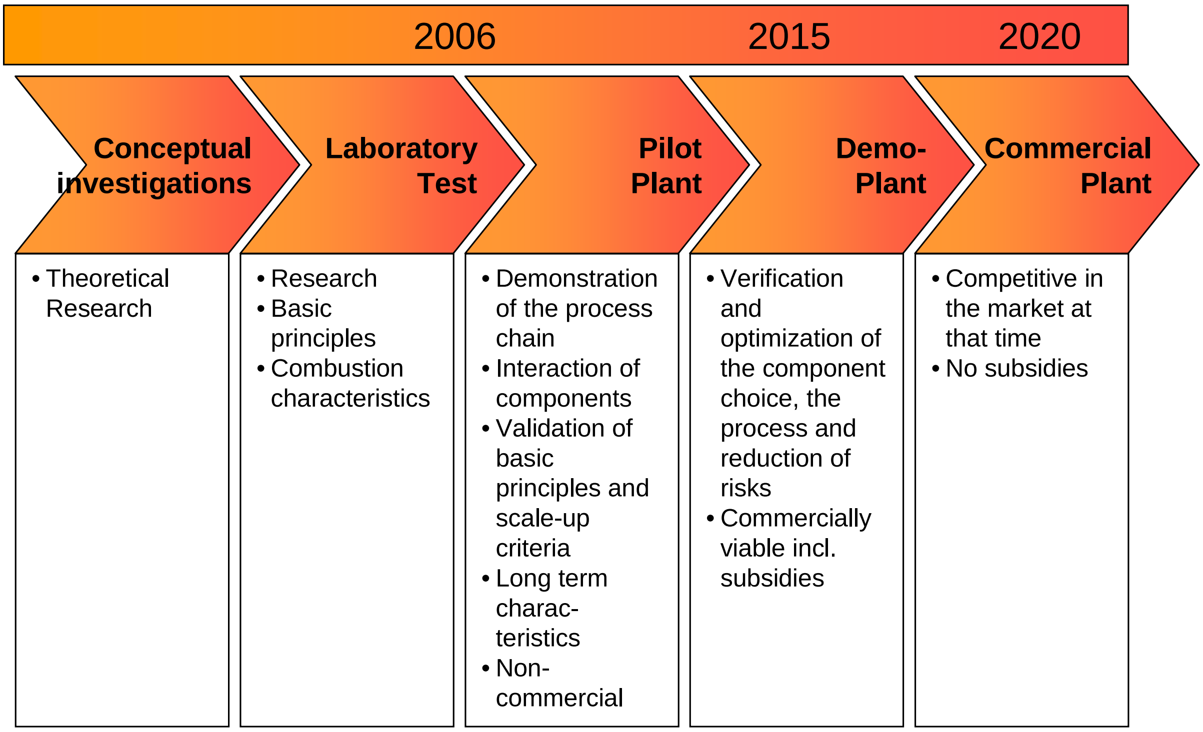
In parallel to this we operate numerous R&D projects in parallel to answer all questions raised in the process. There are more than 100 full time persons involved in the work in 2006, and a lot of knowledge is created. Most of this is public and can be followed on www.vattenfall.com/co2free

The project is organized in six subprojects, described below

Subproject	Work focus and area of responsibility
Capture	R&D three main capture technologies for PP and CHP; New processes post 2020; Support Pilot and Demo plants; Cooperation with Universities
Storage & Transport	R&D storage; Develop real possibilities forPilot and Demo; External cooperation geological R&D and transport
Environment & Regulations	Basic knowledge and R&D on environmental issues; Follow and initiate activities on regulatory issues; Support Pilot and Demo; External cooperation
Pilot Plant	Erect, commission and operate the pilot Plant
Demo Plant	Run a demo plant initiative up to decision on detailed engineering/investment
Communication & Public acceptance	Plan and perform public communication. Follow, implement and initiate initiatives on public acceptance. International cooperation

The road map to realization

The fourth stage described above has been reached. We know by now rather well what a full-scale plant will look like, be equipped with, and what it will cost. Of course, since we are discussing a plant, first of its kind, numerous assumptions and estimations have gone into the work. Therefore a pilot plant is built at present. This is to verify several of the assumptions, validate our scale up models and reduce risks when building the real thing. The stage 6, the demonstration plant development was initiated in spring 2006. It will be concluded in 2010. In 2008 we will take decision on detailed engineering of a plant, and initiate the permission and purchasing process up to the investment decision in 2010.



There are several work processes contained in the different steps, technical as well as administrative and organizational processes to go through.

It seems the critical line is not actually the technical development or the financing, even if they are very important parts of the advancement. The critical line is the permitting process. We have performed several studies of "real" cases in Germany, Scandinavia and Poland both of geological storage formations, and also of real case pipelines. An application for a permit cannot be made until one has a considerable knowledge and a clear view of what and where to build something. To be able to keep the target 2015 for commissioning, and starting late 2005, it is necessary to go through the permission process within three years. This is probably not possible. Maybe for the power plant, but not for the storage and the pipeline.

Thus society must give a considerable support if industry shall be able to keep the time line.

Underpinning Research

Vattenfall cooperate with industry, with the manufacturers and with research facilities. This R&D is necessary for the large-scale development as supporting action. When the larger scale projects passes on, numerous questions arises, of which some has simple answers, but very many need research in order to answer. This work is done within industry itself, but very much is creates in collaboration with others. Several universities are included in such cooperation with Vattenfall, among which can be mentioned:

Chalmers University of Technology, Göteborg	Combustion research
Royal Institute of Technology, Stockholm	Chemical engineering
Stuttgart University, Stuttgart	Combustion research
Technisches Universität Brandenburg, Cottbus	Combustion research
Dresden University, Dresden	Combustion research

University of Newcastle, Newcastle Australia Fuel research

Cranfield University Cranfield UK Combustion Modeling

Massachusetts Institute of Technology, Boston USA System research

Norges Tekniske och Naturvitenskaplige Univ. Trondheim Norway. Systems

Also Vattenfall participate in a number of collaborative R&D efforts in Europe and internationally. Examples are:

ENCAP	EU project capture tech
Castor	EU project storage and capture
CO2 SINK	EU project storage
CO2mod	EU project modelling
Dynamis	EU project H2 production
Cooretec	German project capture
Adecos	German project gasification
Just catch	Norwegian project post comb capture

The Pilot plant

The pilot plant constitutes the single largest effort counted in money and importance. The pilot plant is entirely devoted to

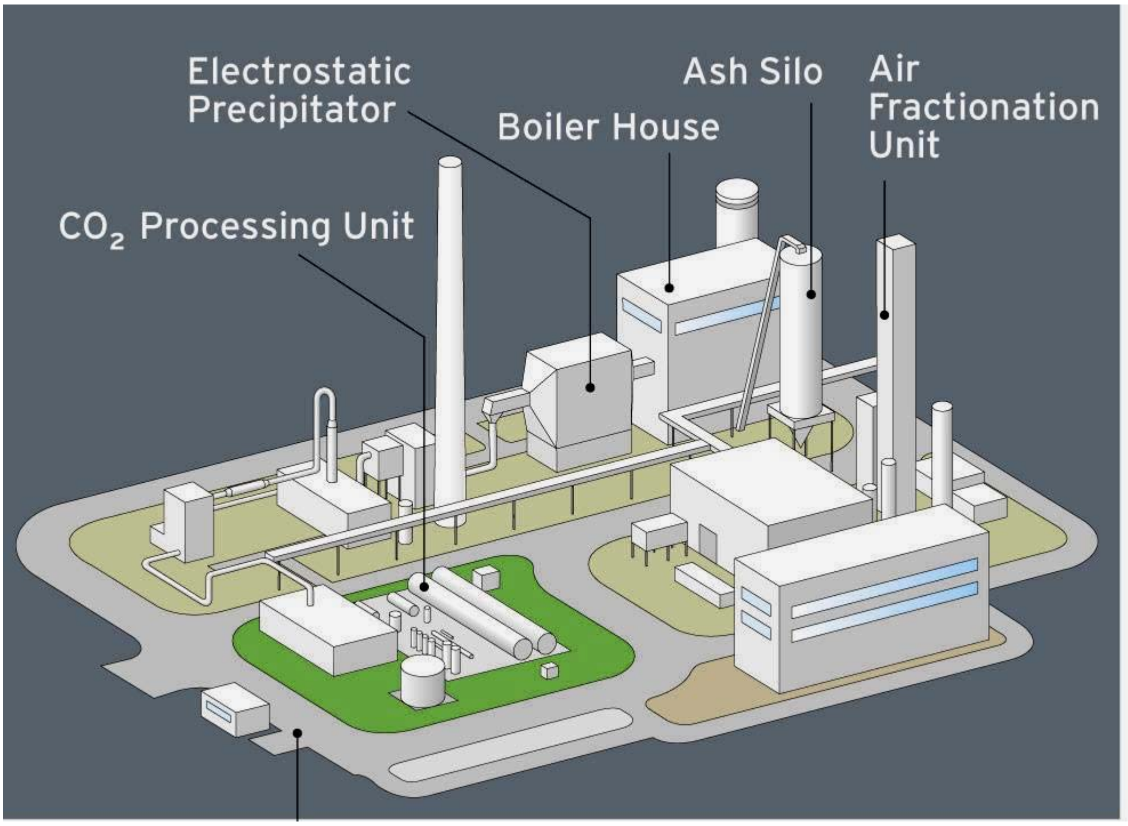
- Verify the performance of the oxyfuel combustion process
- Validate our computerized models and scale up criteria
- Verify process engineering data concerning gas treatment, cleaning, liquefaction and CO2 properties
- Reduce risks in next step
- Create public knowledge and hopefully help to create acceptance of the CCS technology

The pilot plant is a complete combustion plant for coal, both hard coal and lignite, using the oxyfuel principle. The end products will be the usual from a coal plant, like gypsum from desulfurization, ashes from the fuel, but also liquid CO2. The pilot plant does produce useable energy in form of steam, which is fed into the mother plant, the 1800 MW supercritical coal fired Schwarze Pumpe plant. The pilot is built adjacent to the mother plant, from which it becomes water, electricity, fuel, personnel, services and calcium sludge for desulfurization, while it also is able to deliver waste water, gypsum, ashes etc. back.

The plant contains the full chain from the air separation unit producing almost pure oxygen and nitrogen, the conventional boiler, filters, desulfurization, condensing plant for the water vapor in the flue gas, CO2 cleaning and CO2 liquefaction. The CO2 can be stored at site some days in liquid form, before released back in atmosphere or transported to a permanent storage.

At present there exists no geological storage possibility. Vattenfall is though seeking possibilities to do this, after the plant is commissioned and shaken down. It should be pointed out that this plant emits the same amount from a whole year of operation, as does the mother plant in less than two days.

The general layout is described in the picture below.



The timetable is that the pilot plant will be commissioned in mid 2008, and a subsequent test program is planned over a five-year period. Initially it will support the development of the demo plant, while later on it will focus on optimization and development of the concept. The plant is very flexible and we foresee a number of alterations and tests of new and developed components.

The plant is fully financed by Vattenfall. The budget for the investment is around 60 mio €, and for a three year test operation about 25 mio €. In addition to this the parallel research program is continuing with a budget of about 10 mio € annually.

Conclusion and recommendation

To conclude Vattenfall has started an R&D program to develop technology for Carbon capture and storage. We believe that the necessary and ambitious targets we have set up in society, to reduce carbon emissions by more than half until 2050, cannot be reached without CCS. No other reduction means is powerful enough to achieve that goal. At the same time we do not consider CCS the only tool. All means to reduce emissions, including renewables and nuclear must be used. CCS is however a necessary and perhaps the most powerful tool of all.

Further, fossil fuels are necessary for many decades to come. There is no way to create a supply of energy without fossil fuels within the next fifty years. Of the fossil fuels, all have their properties, but coal is by far the most important, and a solution has to be found to use coal for a long time, without endangering the environment. Here, CCS is a clear answer.

It is also probable to produce electricity less expensive without any emissions, with coal than with any of the renewable resources.
At a cost of about 20 €/ton CO2 for abatement of the carbon dioxide, there exist technologies which can be ready for commercial application in 2020. After that date it might be possible to find even more cost effective technologies.

The most important barriers for deployment seem to lie in the fact that this is a new and largely unknown technology. There are no laws, regulations or rules written with this technology in mind. Therefore there exist no legal or regulatory framework, and thus the permitting authorities on national or local level, have no guidelines. Here the EU can play a very important role.

The technical development has started at a very high pace and many power companies, including Vattenfall have announced plans on large projects and efforts. To reach the goals there is a need for R&D, but above all it is a number of demonstration plants needed, including all steps in the CCS chain, capture, transport and geological storage. This implies a monetary input of several billions of Euros, and a considerable commercial risk taking. This amount of money cannot be born by a single company, or by public programs. It must be a combination of all. The most important part society can contribute with except R&D funding is to reduce commercial risks.

A clear and stable system for emission trading is thus a necessary prerequisite for development; a long-term commitment by the EU and national government to keep the situation predictable is also an absolute need.

This work has started very good with the new amendment to the London convention, which clearly allow CCS. The promised communication on CCS in 2007 from the EU, and expressed ambitions to create a constructive work for the continuation after 2012 of the ETS, are also good examples of a promising attitude, towards perhaps the best way we can combat climate change.

CCS is happening now!

The Sleipner field

CO_2 Treatment and Injection

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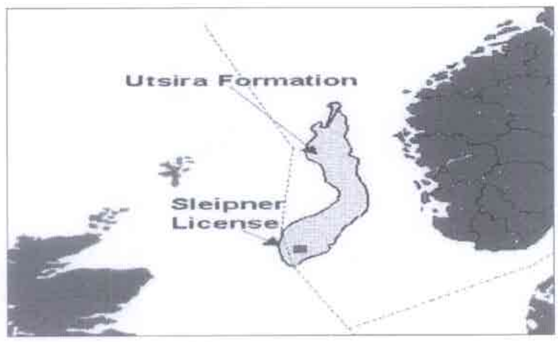

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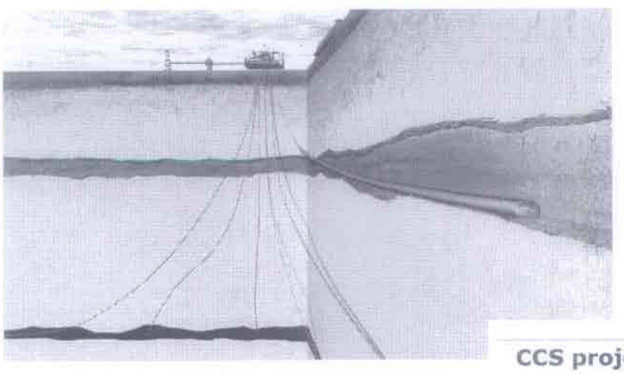
The offshore storage principle: Sleipner



CCS projects in Europe as of November 2007

Year	Company	Country	Project name or location	Size		Form of carbon capture and storage			
				Mill. tons CO2 p.a.	MW	natural gas production	flue gas from gas power plants	CCS from coal power plants	CCS pilots
1996	Statoil	Norway	Sleipner	1	-	x			
2006	Total	France	Lacq	0.1	-				x
2007	Statoil	Norway	Snøhvit	0.7	-	x			
2008	Vattenfall	Germany	Schwarze Pumpe		30				x
2009/10?	Naturkraft	Norway	Kårstø	1.2			x		
2010	Statoil	Norway	Mongstad	0.1					x
2011	Centrica	UK	Teeside		800			x	
2012	Statoil / Shell	Norway	Halten CO2*	2.5			x		
2014	Statoil	Norway	Mongstad	2.2	820		x		
2014	RWE	Germany	IGCC-CCS	2.3	450			x	
2016	RWE npower	UK	Tilbury	?	1000			x	
?	BP	Scotland	Petershead*	1.8			x		
?	Enel	Italy	Bari		5				x
?	E.On	Germany	?					x	

* : with EOR

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Key messages

- *Kyoto targets impossible without CCS!*
- *Europe must take the lead!*
- *CCS is safe!*
- *Industry, NGOs and governments at all level must unite!*

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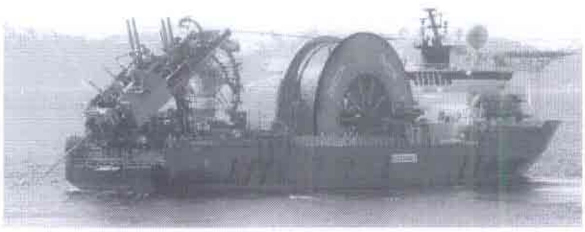
Transportation of CO_2



CO_2 pipeline to Snøhvit

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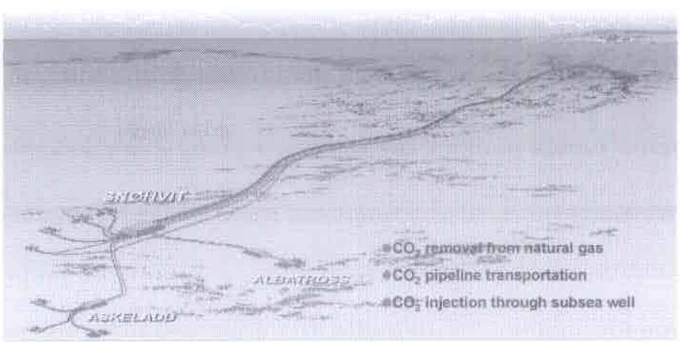
Snøhvit concept



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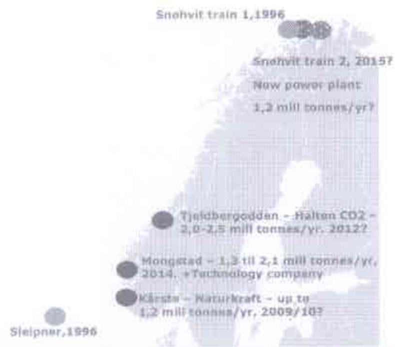
An overview: Norway as a CO_2-laboratory

CO2 from natural gas

CO2 from flue gas



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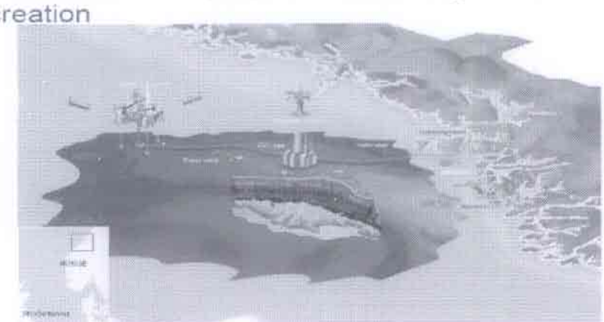
The Halten CO2 project: - using CO_2 for value creation



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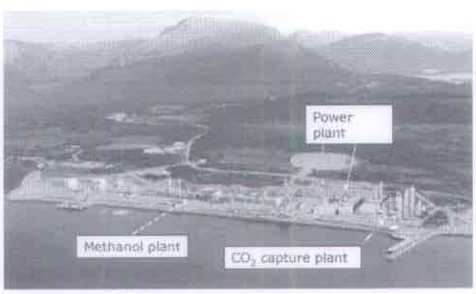
Gas power plant at Tjeldbergodden (TBO)

- the starting point for the value chain

- 860MW gas power plant (CCGT)
- Will need 1 GSm^3 gas annually
- CO_2 capture plant integrated in the power plant
- The capture plant 20 times larger than any similar plant in the world today
- CO_2 compression facilities
- Tight time schedule, technology qualification



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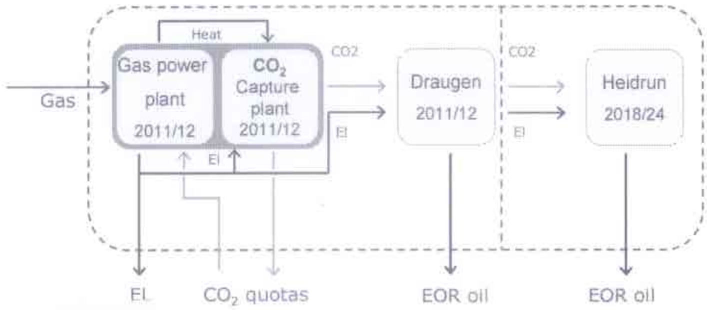
Halten CO2: Simplified commercial model



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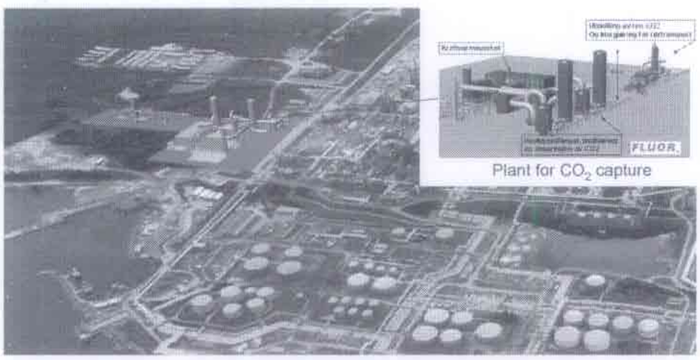
The Mongstad project: CO2 capture, CHP station and cracker



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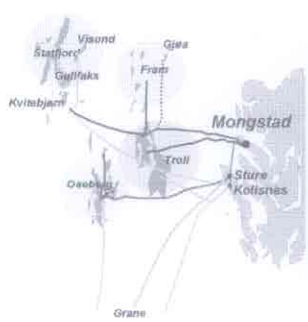
Industrial integration



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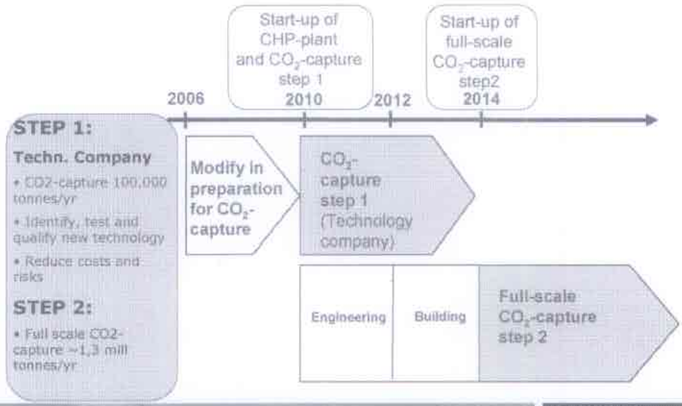
Mongstad CHP Plant and CO_2-capture*



* according to agreement between Norwegian government and Statoil

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A Public Private Partnership:

The Technology Company

The emission permit and the agreement between the Government and Statoil commit both parties both economically and judicially through several stages.

is to be set up at Mongstad.

The government will invite interested parties to consider part ownership in a technology company, while Statoil will assume 20 per cent ownership from the start.

The government will make a substantial investment. The technology company will be responsible for various aspects of the further development of the carbon capture technology.

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So how do we make it happen – on a large scale?

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What politicians should do (1):

Kick-start the CO2 value-chain

- CCS into ETS
- Clarify state aid rules
- Create easy movers fund

Z E P
Zero Emission Fossil Fuel Power Plants

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What politicians should do (2):

Establish a regulatory framework:

- Amend regulations on waste and water if necessary
- Guidelines for storage projects

Z E P
Zero Emission Fossil Fuel Power Plants

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What politicians should do (3):

Join industry and NGOs in gaining public support:

- EU-wide outreach via multimedia
- Local outreach to support CCS projects

Z E P
Zero Emission Fossil Fuel Power Plants

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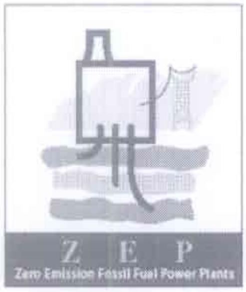
What politicians should do (4):

R&D funding under FP7:

- Reduce scale-up risk
- Mapping of sources and storage possibilities
- Joint Technology Initiative?



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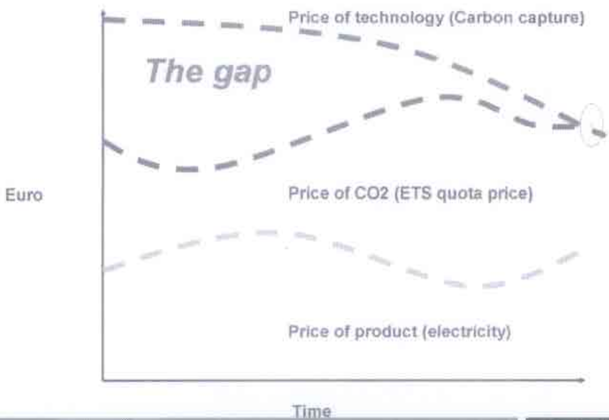

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If we want results by 2020,

we need to act in 2007!

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BELLONA

A Model for the CO_2 Capture Potential

Dr. Aage Stangeland *, The Bellona Foundation
17 August 2006

Summary

Global warming is a result of increasing anthropogenic CO_2 emissions, and the consequences will be dramatic climate changes if no action is taken. One of the main global challenges in the years to come is therefore to reduce the CO_2 emissions.

Increasing energy efficiency and a transition to renewable energy as the major energy source can reduce CO_2 emissions, but such measures can only lead to significant emission reductions in the long-term. Carbon capture and storage (CCS) is a promising technological option for reducing CO_2 emissions on a shorter time scale.

A model to calculate the CO_2 capture potential has been developed, and it is estimated that 30 billion tonnes CO_2 can be captured and stored within the EU by 2050. Globally, 240 billion tonnes CO_2 can be captured by 2050. The calculations indicate that wide implementation of CCS can reduce CO_2 emissions by 56 % in the EU and 37 % globally in 2050 compared to emission levels today.

Such a reduction in emissions is not sufficient to stabilize the climate, however, and the strategy to achieve the necessary CO_2 emissions reductions must be a combination of *(1)* increasing energy efficiency, *(2)* switching from fossil fuel to renewable energy sources, and *(3)* wide implementation of CCS.

1. Introduction

According to The Intergovernmental Panel on Climate Change (IPCC) increasing emissions of greenhouse gasses (GHG) will raise the average global temperature by 1.4 to 5.8 °C from 1990 to 2100 [1].

Climate models established by the IPCC indicate that dramatic climate effects will occur if the global average temperature increases by more than 2 °C. To avoid such a high temperature increase, the IPCC has stated that global GHG emissions should be reduced by 50 to 80 % by 2050.

If no action is taken, the average global temperature will increase by more than 2 °C. The consequences will be melting polar ice caps, a sea level raise of up to one meter by 2100, an increased frequency of extreme climate events, permanent flooding of costal cities, disruption of ecosystems, and extinction of species [2]. Recent studies even indicate that the consequences of global warming could be worse than previously believed.

CO_2 is the most important GHG gas, and the largest source of man made CO_2 emissions

* Dr. Aage Stangeland, Adviser at *The Bellona Foundation*, P.O.Box 2141 Grünerløkka, N-0505 Oslo, Norway. Contact e-mail: aage@bellona.no

is fossil fuel combustion for power production. Fossil fuels are the most important energy source today, and according to the International Energy Agency (IEA), 80 % of the global energy consumption is based on coal, oil, and natural gas [3]. The IEA further predicts that the global energy demand will increase by 30 to 50 % by 2030. Most of this increased energy demand is expected to be covered by fossil energy.

CO_2 capture and storage (CCS) is a technology with the potential to reduce GHG emissions while allowing fossil fuel use [4]. With CCS, the CO_2 arising from combustion of fossil fuel is captured, transported, and finally safely stored in an underground geological formation.

Increasing energy efficiency and energy production from renewable sources have the potential to reduce the GHG emissions in the long term. However, implementing energy efficiency measures and adapting an energy source switch from fossil fuel to renewable energy at a realistic pace will not be sufficient to meet the required reduction in CO_2 emissions. Emissions must be cut rapidly, and, therefore, CCS is a bridge to a future society where energy production will be based on renewable energy. As such, CCS has the potential to avoid dramatic climate changes and sustain quality of life while maintaining secure power generation for the next decades.

The purpose of this paper is to estimate the CO_2 capture potential. Scenarios for future energy demand and CO_2 emissions are presented in Section 2. These scenarios are the basis for modelling the potential for CCS, and calculated CO_2 capture potential are presented in Section 3. The results are discussed in Section 4, and the conclusions are finally given in Section 5.

2. The Energy challenge

Future CO_2 emissions depend on the future energy demand, the share of energy produced from renewable sources, and the policies and incentives implemented to reduce CO_2 emissions.

The IEA has presented several scenarios for future energy demand and CO_2 emissions [3,5]. The IEA Reference Scenario [3] is a business as usual scenario where only political incentives, laws and regulations currently implemented are accounted for when calculating future energy demand and CO_2 emissions. The IEA Alternative Scenario [3], however, accounts for policies and incentives addressing environmental concerns that are currently considered, but not implemented yet. Faster deployment of technologies to reduce energy demand and CO_2 emissions are also accounted for. However, The IEA Alternative Scenario does not account for the potential for CO_2 emission reduction through CCS. The IEA state that the energy path in their Reference Scenario is unsustainable. They also state that the improvement in their Alternative Scenario is, although a good start, not a sustainable path [5].

The IPCC [6] has developed 40 different scenarios with varying models for demographic, economic, and technological developments throughout the world. The IPCC summarized its results into four main scenarios, which show similar trends as the IEA scenarios.

The global energy demand according to the IPCC and IEA scenarios are compared in Figure 1. This figure shows that the IPCC scenarios overlap with the IEA scenarios, which indicates that both the IEA and the IPCC predicts similar trends in future energy demand.

In 2005, the IEA were asked by the G8 leaders and Energy Ministers to advice on new scenarios and strategies aiming at a clean, clever and competitive energy future [5]. IEA have therefore established new scenarios called Accelerated Technology (ACT) scenarios [5]. These scenarios account for deployment of new technologies that could put the world on a more sustainable path. The IEA ACT scenarios addresses a portfolio for a sustainable energy future, including energy efficiency, CCS, electricity production from natural gas, nuclear energy, and renewable energy sources. If policies favouring these options are deployed, the IEA ACT scenarios indicate that the global CO_2 emissions in 2050 will be from 6 to 27 % higher than emissions in 2003.

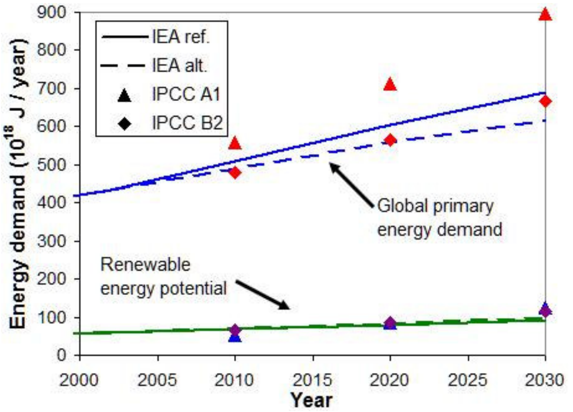

Figure 1 - IPCC and IEA scenarios for global primary energy demand and renewable energy potential. Only the A1 and B2 of the IPCC scenarios are shown. These are the scenarios predicting highest and lowest energy demand of the main IPCC scenarios.

The IEA has also published a scenario called TECH Plus [5] which they characterize as optimistic but speculative. This scenario is more positive regarding wide implementation of CCS and fuel cells than the IEA ACT scenarios.

Predicting energy demand beyond 2050 is difficult due to large uncertainties in how the global energy marked will develop. However, The IEA Act scenarios indicated that primary global energy demand in 2050 could be at the same level as the IEA Alternative Scenario prediction for 2030.

The global energy demand will increase considerable as indicated in Figure 1. Fossil fuel is expected to cover for most of the increase, and a raise in future CO_2 emissions is therefore expected. The IEA Alternative Scenario predicts nearly 30 % increased CO_2 emissions from today to 2030 as indicated in Figure 2. The largest increase in CO_2 emissions comes from the power production and transport section, while industry and other sources show smaller increase.

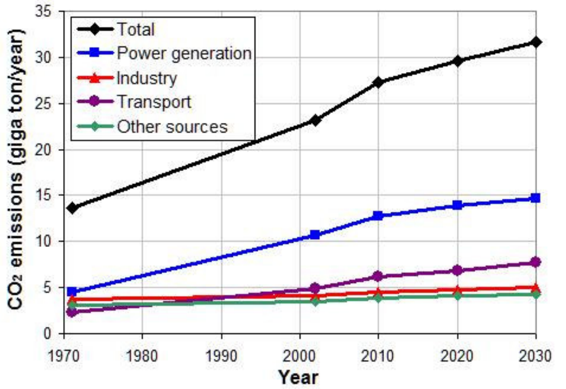

Figure 2 - Predicted global CO_2 emissions based on the IEA Alternative scenario. CO_2 emissions from different sectors are also shown.

The IPCC has also set up several scenarios for future CO_2 emissions [6], and both the IEA and the IPCC scenarios for global CO_2 emissions are compared in Figure 3. This figure indicates that the IEA scenarios fit reasonably with the IPCC scenarios.

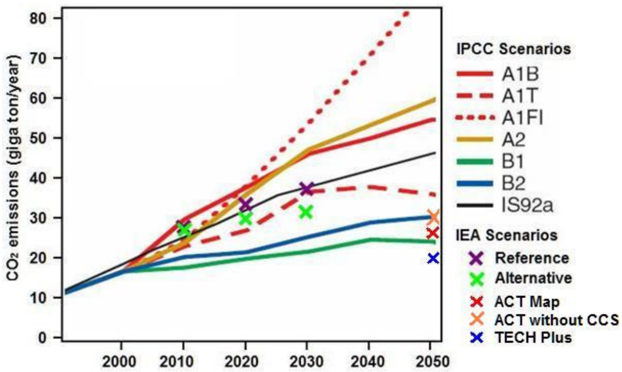

Figure 3 - Predicted global CO_2 emissions based on the IPCC [1] and IEA [3] scenarios.

The IPCC has stated that CO_2 emissions should be considerably reduced by 2050 to achieve less than 2 ^oC rise in the global average temperature. However, most of the scenarios presented in Figure 3 shows that global CO_2 emissions will be higher in 2050 than today. The most optimistic predictions (*i.e.* the IEA TECH Plus scenario) indicate that global CO_2 emissions in 2050 will only be slightly lower than emissions today. It is therefore essential that stronger incentives than accounted for in the IEA and IPCC scenarios are established to reduce the CO_2 emissions.

3. The CCS potential

CCS includes capture of CO_2 from large point-sources, transportation of compressed CO_2 by pipeline or ship, and finally secure storage in underground geological formations as aquifers. A detailed description of CCS is provided by the IPCC [7], and all processes involved in CCS are presented schematically in Figure 5.

Huge storage capacity exists worldwide, and the CO_2 emission reduction potential of CCS is therefore limited by the CO_2 capture potential.

3.1. The CO_2 capture potential

The potential for global CO_2 capture by 2050 is calculated based on the following assumptions:

- Incentives and policies favouring increased energy efficiency and more renewable energy production must be part of the strategy to reduce GHG emissions. CO_2 emission data according to the IEA Alternative Scenario [3] is therefore the starting point for calculation of the CO_2 capture potential.
- The IEA Alternative Scenario does not provide any data beyond 2030. Total CO_2 production* is therefore assumed to be constant between 2030 and 2050.
- CO_2 capture from CCS projects will start in 2015.
- The European Union (EU) Technology Platform for Zero Emission Fossil Fuel Power Plants is aiming for power plants capable of capturing their CO_2 emissions by 2020 [4]. Most CO_2 capture processes are capable of capturing at least 90% of the CO_2 emitted, and, conservatively, it is assumed that 80 % of CO_2 produced in the power sector will be captured in OECD countries by 2050.
- In the transport sector, 50 % of the CO_2 produced will be captured in OECD countries by 2050, based on the EU Hydrogen and Fuel Cell Technology Platform which aims to make hydrogen a major transport fuel for vehicles with a market share up to 50 % in 2050 [8].
- It is assumed that CO_2 capture from industrial sources amounts to 50 % of the CO_2 produced in OECD by 2050.
- It is also assumed that CO_2 capture from other sources amounts to 20 % of the CO_2 produced in OECD by 2050.
- The rate of CO_2 capture will increase faster in the period 2030 - 2050 than in the period 2005 - 2030 due to increasing implementation of technologies for CO_2 emissions reduction after 2030.
- CCS will develop faster in OECD countries than non-OECD countries. CO_2 capture in non-OECD countries will start in 2020 and is assumed to reach ¾ (or 75 %) of the level in OECD countries by 2050.

The calculated global CO_2 emissions and capture based on the above assumptions are presented in Figure 4. The calculated CO_2 capture potential by 2050 is provided in Table 1. Further details on assumptions and calculations are given in Appendix A.

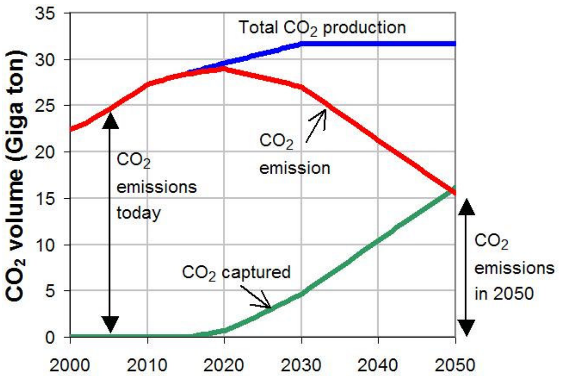

Figure 4 - Global CO_2 production based on IEA [3] and calculated CO_2 emissions and CO_2 captured.

* The phrase "CO_2 production" is in this work used for the CO_2 emissions given by the IEA Alternative Scenario, which does not account for CCS. The CO_2 emissions calculated in this study is the difference between "CO_2 production" and CO_2 captured. Please note that the "CO_2 production" is assumed to be constant between 2030 and 2050.

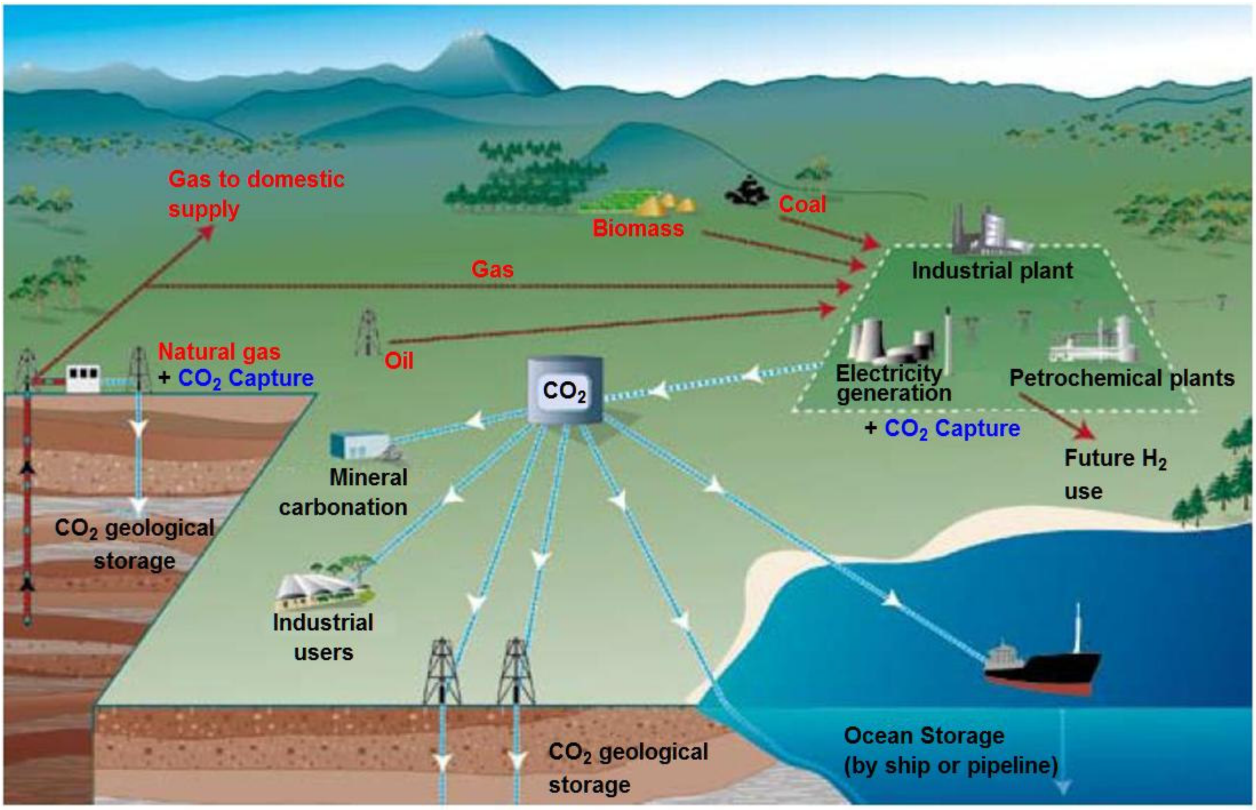

Figure 5 - Schematic presentation of CCS infrastructure, including CO_2 capture from large point sources, transportation of CO_2, and storage options. Source: CO2CRC and IPCC [7].

Table 1. Potential for CO_2 capture and CO_2 emissions reduction.

Area	Potential for CO_2 capture by 2050	Reduction in CO_2 emissions*
EU	30 billion ton	56 %
World	240 billion ton	37 %

* *Reduction in CO_2 emissions in 2050 compared to CO_2 emissions in 2005.*

The results presented in Table 1 indicate that a realistic global potential for CO_2 capture is 240 billion tonnes CO_2 by 2050. In the EU, the potential is 30 billion tonnes by 2050. The CO_2 emission reductions are 37 % globally and 56 % in the EU in 2050 compared to emissions today.

The results in Table 1 show that the IPCC suggestion of more than 50 % reduction in GHG emissions by 2050 can *not* be met by only implementing CCS. Large reductions in CO_2 emissions can therefore best be achieved through a combination of *(1)* ensuring increased energy efficiency, *(2)* a transition of energy production to renewable energy sources, and *(3)* a wide implementation of CCS.

3.2. New fossil fuelled power plants

The European Commission Joint Research Centre has analyzed the demand for new power plants in the EU onwards to 2030 [9]. Based on their data, the CO_2 capture potential is calculated by assuming that CCS will be a part of new fossil fuelled power plants from 2020 and onwards. The calculations are performed as described in Appendix B.

The calculated CO_2 capture potential is presented in Table 2 (indicated as Method B). In this table, the results are compared to similar data obtained from the model presented in Section 3.1 (indicated as Method A in Table 2)

The capture potential from Method B in Table 2 is calculated as an interval due to uncertainties regarding the policies that may be implemented to assure more energy production from renewable sources instead of fossil sources. The uncertainties in Method A are not estimated, but uncertainties is believed to be equal to that in Method B.

Table 2. Potential for CO_2 capture from power production in EU.

Calculation method*	CO_2 capture by 2030
Method A	2.2 billion tonnes
Method B	1.6 – 3.0 billion tonnes

** Method A is based on the IEA Alternative Scenario as presented in Section 3.1. Method B is based on analysis of demand for new power plants in EU, c.f. Appendix B.*

The CO_2 capture potential from power production in the EU calculated by the two different methods presented in Table 2 gives similar results. The fact that both methods provide comparable results strengthens the confidence in the calculated CO_2 capture potential.

4. Discussion

The potential for CO_2 capture strongly depends on which policies that are implemented to set the world on a sustainable energy path. In this study, the IEA Alternative scenario is chosen as the baseline (*i.e.* predicted CO_2 emissions before the potential of CCS is accounted for). This scenario is selected because it, to some degrees, accounts for policies favouring energy efficiency and renewables, which is essential for sustainable future energy production.

Stronger incentives favouring energy efficiency and renewable energy than accounted for by the IEA Alternative Scenario are required for a sustainable energy path [5]. It can therefore be argued that the IEA ACT scenario without CCS could be a more suitable baseline* for calculation of the CCS potential. However, the development of CO_2 emissions from different sectors and regions onwards to 2050 is not reported by IEA [5] for the ACT scenarios. Only predictions for 2050 are given, and calculation of CO_2 capture based on IEA ACT would therefore be very inaccurate. The baseline in this study is the IEA Alternative Scenario onwards to 2030 and then constant total CO_2 emissions between 2030 and 2050. As seen from Figure 3 this would give nearly similar global CO_2 emissions in 2050 as the ACT scenario without CCS. It is therefore reasonable to believe that the calculated CO_2 capture potential would not change significantly if the IEA ACT scenario without CCS was the baseline.

The most optimistic IEA scenario, *i.e.* the TECH Plus scenario, estimates that CCS can contribute to global CO_2 emission reduction in 2050 equal to 7.5 billion tonnes CO_2 annually. This is far less than the CO_2 capture potential calculated in this study which corresponds to 16 billion tonnes CO_2 captured annually in 2050 worldwide (*c.f.* Table 6). The current study therefore presumes much stronger policies, economic incentives and technology development to reduce CO_2 emissions than accounted for by the IEA TECH Plus scenario.

The optimistic approach in the current study can give a 37 % reduction in global CO_2 emissions. This is not sufficient to reach the IPCC suggestion of more than 50 % CO_2 emission reduction by 2050. Therefore, even stronger policies favouring energy efficiency, renewable energy and CCS than accounted for in this study are required to avoid dramatic climate changes.

* Please note that the baseline for calculating the CO_2 capture potential must be a scenario that do not account for CCS. The "IEA ACT without CCS" is the only of the IEA ACT scenarios that do not account for CCS.

5. Conclusion

The potential for CO_2 capture has been calculated. In the EU, the CO_2 capture potential is 30 billion tonnes captured and stored by 2050. The global potential is 240 billion tonnes CO_2 captured and stored by 2050. This corresponds to a 37 % reduction in global CO_2 emissions in 2050 compared to emissions today.

CO_2 capture and storage as the only strategy for combating climate change is therefore not sufficient to reach the IPCC suggestion of 50 - 80 % reduction in CO_2 emissions by mid-century.

The best strategy to reduce CO_2 emissions is therefore a combination of policies and technological development favouring: *(1)* increased energy efficiency, *(2)* a transition from fossil fuel to renewable energy as the major energy source, and *(3)* wide implementation of CO_2 capture and storage.

Acknowledgement

This paper has been prepared as a part of Bellona's work related to the EU Technology Platform on Zero Emission Fossil Fuel Power Plants (ZEP). The Norwegian Research Council has funded parts of Bellona's involvement with the ZEP.

Appendix A – Calculating the CO_2 capture potential (Method A)

The CO_2 capture potential is calculated as described in Section 3.1. CO_2 production is based on the IEA Alternative Scenario [3], and the CO_2 capture is calculated separately for the EU, OECD countries and non-OECD countries. Calculations are performed separately for the following four sectors: *(1)* power production, *(2)* industry, *(3)* transportation, and *(4)* other sources.

The calculations are based on the assumptions given in Section 3.1. In addition, the CO_2 capture from the different sectors is assumed to develop as shown in Figure 6. Resulting data for CO_2 emissions and CO_2 capture are listed in Table 3 to Table 7. Data for CO_2 emissions and capture for the EU, OECD, and non-OECD countries are given in Figure 7 and Figure 8. Global data, which is the sum of OECD and non-OECD countries, is given in Figure 4 in Section 3.1.

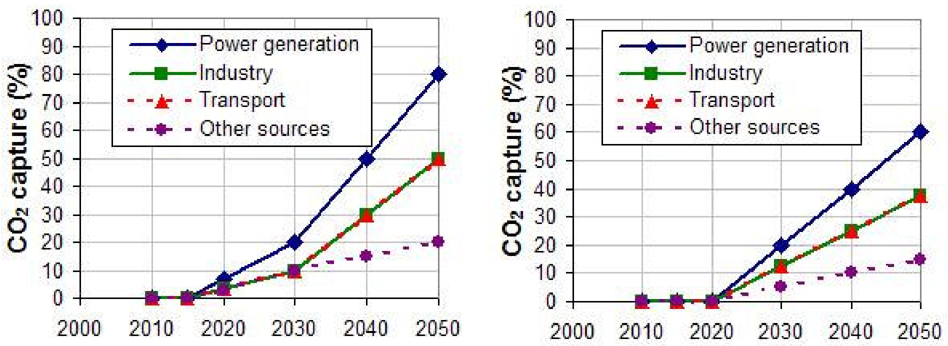

Figure 6 – Assumed percentage CO_2 capture from different sectors in the EU and OECD countries (left), and non-OECD countries (right).

Table 3. Predicted CO_2 production, capture and emissions in the EU. All data are given in million tonnes CO_2.

Type of data	Sector	2010	2020	2030	2040	2050
CO_2 emission	Power production	1 485	1 388	1 014	634	254
	Industry	600	579	540	420	300
	Transportation	1 013	1 036	931	724	517
	Other sources	746	727	664	627	590
	Total	**3 844**	**3 730**	**3 148**	**2 404**	**1 660**
CO_2 capture	Power production	0	99	254	634	1 014
	Industry	0	20	60	180	300
	Transportation	0	36	103	310	517
	Other sources	0	21	74	111	147
	Total	**0**	**176**	**491**	**1 235**	**1 979**
Accumulated CO_2 capture	Power production	0	297	2 182	6 811	15 243
	Total for all sectors	**0**	**528**	**4 069**	**13 068**	**29 507**

Table 4. Predicted CO_2 production, capture and emissions in OECD countries. All data are given in million tonnes CO_2.

Type of data	Sector	2010	2020	2030	2040	2050
CO_2 emission	Power production	5 685	5 435	4 246	2 654	1 061
	Industry	1 792	1 769	1 634	1 271	908
	Transportation	3 864	3 985	3 869	3 009	2 150
	Other sources	1 944	1 906	1 711	1 616	1 521
	Total	**13 286**	**13 094**	**11 459**	**8 549**	**5 639**
CO_2 capture	Power production	0	388	1 061	2 654	4 246
	Industry	0	61	182	545	908
	Transportation	0	137	430	1 290	2 150
	Other sources	0	56	190	285	380
	Total	**0**	**643**	**1 863**	**4 773**	**7 683**
Accumulated CO_2 capture (all sectors)		**0**	**1 920**	**15 153**	**49 787**	**113 520**

Table 5. Predicted CO_2 production, capture and emissions in non-OECD countries. All data are given in million tonnes CO_2.

Type of data	Sector	2010	2020	2030	2040	2050
CO_2 emission	Power production	7 041	8 027	7 538	5 654	3 769
	Industry	2 765	2 987	2 773	2 377	1 981
	Transportation	2 310	2 731	3 013	2 582	2 152
	Other sources	1 918	2 102	2 213	2 096	1 980
	Total	**14 034**	**15 846**	**15 536**	**12 709**	**9 881**
CO_2 capture	Power production	0	0	1 885	3 769	5 654
	Industry	0	0	396	792	1 188
	Transportation	0	0	430	861	1 291
	Other sources	0	0	116	233	349
	Total	**0**	**0**	**2 828**	**5 655**	**8 483**
Accumulated CO_2 capture (all sectors)		**0**	**0**	**14 859**	**58 686**	**130 789**

Table 6. Predicted CO_2 production, capture and emissions globally. All data are given in million tonnes CO_2.

Type of data	Sector	2010	2020	2030	2040	2050
CO_2 emission	Power production	12 726	13 463	11 784	8 307	4 831
	Industry	4 557	4 756	4 406	3 647	2 888
	Transportation	6 174	6 715	6 882	5 592	4 301
	Other sources	3 862	4 007	3 923	3 712	3 500
	Total	**27 320**	**28 940**	**26 996**	**21 258**	**15 521**
CO_2 capture	Power production	0	388	2 946	6 423	9 899
	Industry	0	61	578	1 337	2 096
	Transportation	0	137	860	2 150	3 441
	Other sources	0	56	307	518	730
	Total	0	**643**	**4 690**	**10 428**	**16 165**
Accumulated CO_2 capture (all sectors)		**0**	**1 920**	**30 013**	**108 473**	**244 309**

Table 7. Reduction in CO_2 emissions in 2050.

Area	**CO_2 emission reduction***
EU	56 %
OECD countries	56 %
non-OECD countries	16 %
Global	37 %

* *Reduction in CO_2 emissions in 2050 compared to CO_2 emissions in 2005.*

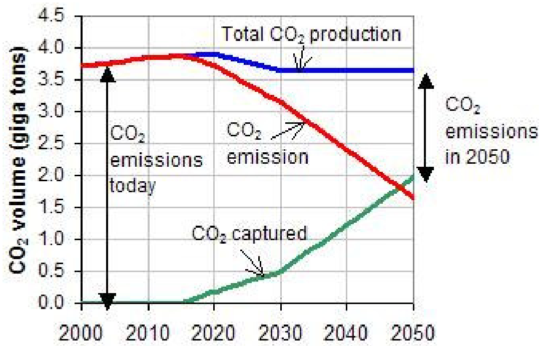

Figure 7 – Predicted CO_2 production, capture and emissions in the EU.

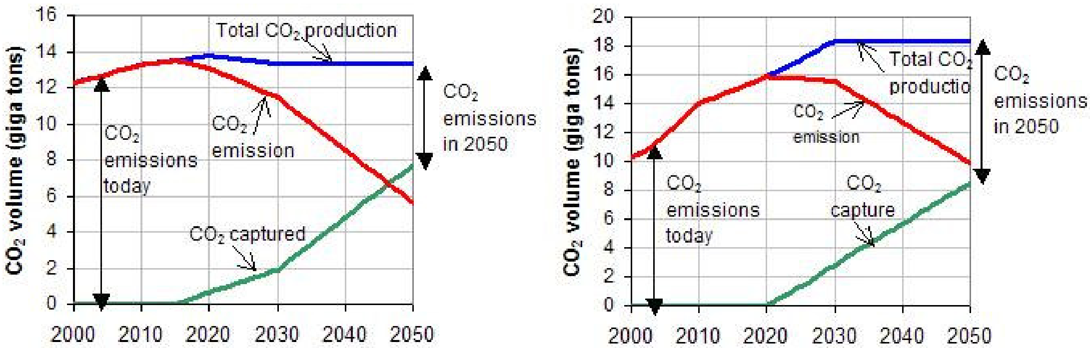

Figure 8 – Predicted CO_2 production, capture and emissions in OECD countries (left), and non-OECD countries (right).

Please note that the results provided above do not account for existing CCS projects like the Sleipner CO_2 injection in the Utsira formation and CO_2 injection in the Permian Basin in the USA. Only the potential for CCS capture projects installed after 2006 are accounted for.

Appendix B – Analysis of CO_2 capture potential from power plants in the EU (Method B)

The CO_2 capture potential in the EU can be verified by analyzing the demand for electrical power in the EU. The European Commission Joint Research Centre has analyzed the electricity demand in the EU onwards to 2030 [9]. They have also estimated to which extent different energy sources will contribute to meet the demand. As seen in Figure 9 fossil fuel will be the most important source for electrical power up to 2030. Figure 9 also indicates how much of today's installed capacity will contribute to the total electricity capacity. Existing power plants will have a limited life-time, and as the plants becomes too old they will be closed down and replaced by new power plants. By 2030 there has to be built new capacity equal to 875 GW in the EU.

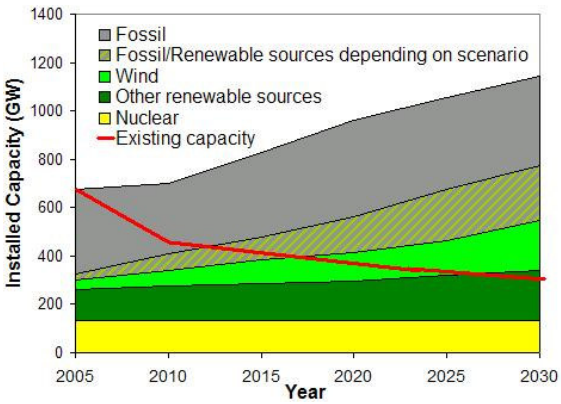

Figure 9 - Estimated electricity capacity in the EU [9] from different sources. Future electricity production from power plants existing in 2005 is indicated by the red line.

CO_2 emissions and thereby the CO_2 capture potential depends on how much fossil fuel will contribute to meet the electricity demand.

As indicated in Figure 9 there is a large uncertainty as to how much electricity will be produced from renewable energy sources by 2030. This is due to uncertainties regarding the policies and incentives that may be implemented. The need for new fossil power capacity in the EU is illustrated in Figure 10. In this figure the demand for new fossil capacity is given for two scenarios. In Case 1 all capacity marked as "fossil/renewable" in Figure 9 is assumed to be produced from renewable sources. In Case 2, all this capacity is assumed to be produced from fossil fuel.

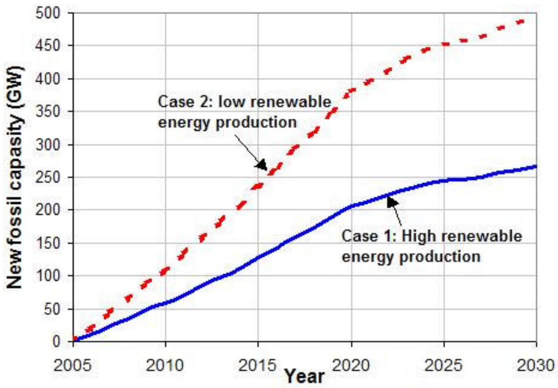

Figure 10 - Estimated new electricity capacity in the EU produced from fossil fuel. The red dotted line represents a scenario where all capacity marked as "Fossil or renewable" in Figure 9 is produced from fossil fuel. The bold blue line is a scenario where all this capacity is produced from renewable sources.

The CO_2 capture potential from power production in the EU by 2030 is calculated based on the following assumptions:

- The vision of the EU Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) [4] is to make new fossil fueled power plants to have near zero CO_2 emissions by 2020. New fossil fueled power plants introduced after 2020 are therefore assumed to have 85 % CO_2 capture.
- One half of the new fossil fueled power plants introduced after 2005 is coal fired. The other half is natural gas fired.
- The plant efficiency of coal and oil fired power plants are assumed to increase from 40 % in 2005 to 50 % in 2030.
- The plant efficiency of natural gas fired power plants is assumed to increase from 55 % in 2005 to 60 % in 2030.
- The power plants run for 7000 hours per year.

- Combustion of coal, oil and natural gas release 86.1, 77.5, and 56.1 g CO_2 per MJ, respectively [10].
- The possibility of retrofitting existing power plants to include CCS is not accounted for.

CO_2 capture from power production in the EU is calculated based on the assumptions above. The results are presented in Figure 11 for both cases, and the accumulated CO_2 capture potential is summarized in Table 8.

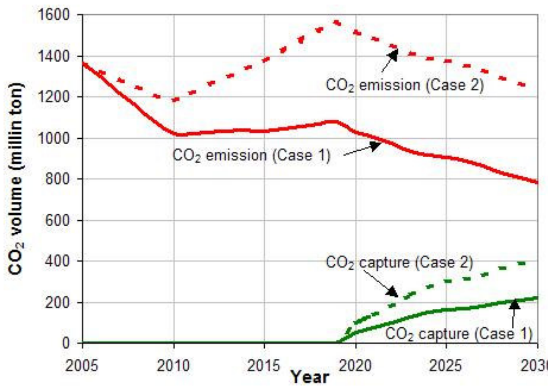

Figure 11 - Estimated CO_2 emissions and CO_2 capture from power production in the EU. Data is given for the same cases as in Figure 10.

Table 8. Potential for CO_2 capture from power production in EU by 2030.

Case	**Renewable vs Fossil fuel***	**CO_2 capture potential in EU by 2030**
Case 1	Renewable	1.6 billion ton
Case 2	Fossil fuel	3.0 billion ton

* *Identifies how the capacity in Figure 9 marked as renewable or fossil fuel is produced.*

The CO_2 capture potential in the EU by 2030 is calculated to be in the range 1.6 to 3.0 billion ton, as shown in Table 8. Please note that this is the CO_2 capture potential only from power production. CO_2 capture from transport, industry or other sources is not included.

The model presented in Section 3.1 can also be used to estimate the CO_2 capture potential in the EU by 2030. This model gives a potential of 2.2 billion tonnes CO_2 captured in the EU by 2030. This result is in the range of the CO_2 capture potential presented in Table 8.

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State of Play on Work on Carbon Capture and Storage in the EU

Scott Brockett & Matti Vainio,
DG Environment, European Commission[1]

A comprehensive EU approach to CCS

1. The Commission has identified two major tasks for deployment of Carbon Capture and Geological Storage (CCS):

   - Developing an enabling legal framework and economic incentives for CCS within the EU, and
   - Encouraging a network of demonstration plants across Europe and in key third countries.

2. The Sustainable Coal Communication, due for adoption in **January 2007** as part of the energy package, will look at how best to meet the twin objectives of energy security and greenhouse gas reduction to meet the EU's goal of not exceeding 2°C average temperature increase from pre-industrial levels. It will also set out our general strategy with respect to Carbon Capture and Storage, including our work on the regulatory framework, incentive framework, and support programmes, as well as external elements (technology co-operation with key countries on CCS). It will outline the work programme on CCS to be pursued in the coming 2-3 years. The main issues are outlined in more detail below.

Developing an enabling legal framework within the EU

3. A Working Group on Carbon Capture and Storage was established under the European Climate Change Programme II to review the potential, economics and risks of CCS, identify regulatory needs and barriers, and explore the elements of an enabling regulatory framework. The WG met four times between February and June 2006 and agreed its final report on 1 June 2006[2]. The final report recommended that the Commission come forward with a proposal for an enabling regulatory framework for CCS during 2007.

4. The Commission is about to begin the Impact Assessment of the options for the regulatory framework, which is scheduled for completion in mid 2007. The Commission's proposals is intended to be brought forward by end 2007.

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[1] This paper has been produced only for information purposes. It does not necessarily express the views of the European Commission or its services.
[2] See final report of ECCS WG 3 http://forum.europa.eu.int/Public/irc/env/eccp_2/library?l=/geological_storage/final_reportdoc/_EN_1.0_

5. Work on preparation of the regulatory framework will focus in particular on the following issues.

   i. To **manage risks** associated with CCS. That is, to ensure that CO2 is stored in safe sites that are properly permitted, where the environmental impacts have been assessed, and where provisions for management and abandonment of the site ensure that stored CO2 is retained in the long term. A number of existing frameworks exist that could be adapted to include the relevant requirements, or a stand-alone framework could be developed. The Impact Assessment on CCS will examine the technical and legal options.

   ii. To remove **unwarranted barriers** to CCS in existing legislation, mainly related to water and waste. These are cases where CCS may be restricted by current drafting, but would not in fact affect achievement of the legislation's environmental objectives. There are also unwarranted barriers in certain international conventions: the recently-adopted amendment to the London Protocol on dumping of waste at sea is a very welcome initiative, and the Commission will work with other parties to the OSPAR Convention (on protection of the marine environment of the North-East Atlantic) to resolve the treatment of CCS under it.

   iii. To examine any issues regarding **long-term liability** for the storage site which require action at EU level.

   iv. To address the issue of public information on, and acceptance of, CCS. The Commission is examining the possibility for stakeholder consultation as well as a public hearing in 2007, possibly in co-operation with other interested parties.

Economic incentives for CCS

6. The major cost/economic factors that need to be considered are the increase in capital investment for the CCS activity and the increased operating costs needed to run the capture and storage plants. With certain technologies the latter generates an energy penalty – more fuel is needed per useful unit of energy generated, because some of it is used in capture and storage of carbon dioxide.

7. A key issue is the treatment of CCS under the EU Emissions Trading Scheme (ETS). The role of CCS under the EU ETS will be addressed in the review of the EU ETS post-2012. The Commission is aware, however, that a number of commercial CCS projects are expected become operational well before 2012. These include projects in Member States as well as in Norway (which we hope will link with the EU ETS through the EEA agreement from 1 January 2008). The Working Group on the ETS set up under the Commission Communication 'Building a Global Carbon Market'[3] will address to what extent to recognise CCS, having regard to the need for comparable treatment of low or non-CO2 emitting activities and a level playing field both between various CCS options and across the EU for investment in CCS technologies.

[3] http://ec.europa.eu/environment/climat/emission/review_en.htm

8. Enhanced Oil Recovery (EOR) using captured CO2 is another potential component of a value chain for CCS. However, due to the high cost of retrofitting existing platforms for EOR, it may not be commercially viable for all projects. In any case, because of the expense of building and running capture plants, it may be that projects are not commercially viable even with EOR. The Commission is aware that some Member States as well as Norway are considering the provision of support in such cases, and the Commission will clarify the treatment of any such assistance under the EU state aid rules.

9. In developing countries, the admission of **CCS projects under the Clean Development Mechanism (CDM)** would be an important means of economic incentives, and this issue is discussed in the Conference of Parties to the UNFCCC/Meeting of Parties to the Kyoto Protocol in Nairobi. The EC is in favour of inclusion of CCS under the Clean Development Mechanism with provisions in place to sort out the remaining technical and political issues.

Facilitating a network of demonstration projects

10. A number of large-scale projects are in the pipeline in Europe which could form the basis of a range of demonstration projects across Europe and internationally, over the next 10-15 years, deploying a range of technologies. The Zero Emissions Fossil Fuel Technology Platform (ZEP) which produced in September a research agenda for CCS and a programme for strategic deployment, recommends i.a. a network of 10-12 integrated, large scale demonstration projects across Europe and a maximisation of co-operation at the international level.

11. The EU is extremely interested in supporting near-zero emission coal plants worldwide for climate, energy security and competitiveness reasons. Co-operation is particularly important with a number of fast-growing coal consuming countries including China, the Gulf states, India, South Africa, Russia and the Ukraine. The Commission is also aware of international work on demonstration in the United States -- through the **FutureGen** initiative (http://www.futuregenalliance.org/) – which is well advanced, and with similar projects in Australia and elsewhere, and is committed to pursuing international co-operation on this important issue.

12. As part of the EU-China Summit in September 2005, the EU and China agreed to develop a demonstration plan on "Near Zero Emissions Coal" by 2020. The EU-China MoU on NZEC, which relates largely to the first phase of the project (feasibility study) was signed by the Chinese Ministry of Science and Technology (MoST) and the Commission in January 2006. Phase 1 of the project was started at a conference in July 2006, with around €10 million in funding in place, half of which provided by the UK and the other half through funding under the Commission's 6th Research Framework Programme. The Commission and several Member States are examining the potential funding options for Phases 2 and 3 of the NZEC project (planning and design, and construction and operation), and for a network of demonstration projects open to third-country participation in general.

CO_2 capture and storage in the United Nations climate agreements

By Heleen de Coninck, Energy research Centre of the Netherlands, P.O. Box 37154, 1030 AD Amsterdam, Netherlands. Tel: +31 224 564316; Email: deconinck@ecn.nl.

Whether CCS is accepted under the international climate change regime is essential for the success of its short- and long-term implementation. The publications and developments in the UN-based bodies, the Intergovernmental Panel on Climate Change, and the United Nations Framework Convention on Climate Change, are discussed. The processes currently ongoing on in the UN climate policy institutions are discussed by first going into the scientific IPCC documentation, and later the political interpretation in the UNFCCC and its Kyoto Protocol.

Intergovernmental Panel on Climate Change (IPCC)

The IPCC assesses scientific, technical and socio-economic aspects of climate change. Every five years, the IPCC produces an Assessment report; the Fourth is planned for 2007. Besides the regular Assessment Reports, the IPCC produces Special Reports, on particular topics. It aims to provide "policy-relevant but not policy-prescriptive" information to policymakers. The exception to this is the Task force on National Greenhouse gas Inventories, which produces best practice guidelines for national inventories.

IPCC Special Report on CO_2 capture and storage (2005)

In 2003, based on draft request by the COP/MOP, the IPCC decided to produce a Special Report on CO_2 capture and storage (SRCCS). About a hundred authors from over 30 countries were involved and the report was reviewed by hundreds of experts and governments. The Summary for Policymakers was eventually agreed in September 2005 during an IPCC session in Montreal. It was subsequently welcomed during COP/MOP1, later that year, also in Montreal.

The main results of the SRCCS can be summarised as follows:

- CO_2 capture and storage should be seen part of a portfolio of options to reduce greenhouse gas emissions; it is not a silver bullet to address the climate change problem.
- Some types of CO_2 capture and storage are operational and commercial, whereas others are still in the research phase. A full CCS system can now be composed of components that have demonstrated their practical implementation.
- On the capture side, the energy penalty and costs are the main barriers. The capture of CO_2 (including compression) can cost 10 to 40% additional energy compared to the same output. The cost of CO_2 capture make out a large part of the total CCS costs: at least 15 US$/t$CO_2$ in the electricity sector.
- Transport requires significant infrastructure investments, but costs can be kept low if sources of CO_2 can be planned in the proximity of suitable storage reservoirs and the transported volumes are large.
- Storage is normally not so costly, but there are remaining issues on how long the CO_2 will have to be stored, with what certainty the performance of underground reservoirs can be predicted, and what monitoring techniques are good enough to reliably determine permanence.

- Overall, CCS in the electricity sector would add 2-3 US$ct/kWh to electricity production costs, corresponding to about 25 – 30 US$/t$CO_2$. Costs can be much lower or even negative if ready sources of CO_2 can be combined with short transport distances and storage options that generate revenues, notably Enhanced Oil Recovery (EOR).
- The global potential for the negative-cost early opportunities is estimated to be 360 MtCO_2/yr. The overall storage potential in geological formations is likely[1] to be at least 2000 GtCO_2.
- The cumulative global economic potential for CCS over the course of this century is estimated between 220 and 2200 GtCO_2.
- Health and safety risks of capture and transport are small. Risks of CO_2 storage are difficult to estimate because of lack of direct experience. However, given appropriate site selection, a monitoring program to detect problems, a regulatory system, remediation methods to stop or control CO_2 releases if they arise, the risks are probably comparable to similar operations, such as EOR, natural gas storage or acid gas disposal.
- Public perception of CCS remains uncertain, as the public is not well-informed on CCS. International legal issues also need to be resolved for CO_2 capture and storage[2].

2006 IPCC Guidelines on National Greenhouse Gas Inventories

The IPCC Task Force on National Greenhouse Gas Inventories has finalised its latest guidelines in April 2006. The former version, from 1996, did not contain any guidance on CCS. The 2006 Guidelines have included a section that addresses geological storage of CO_2, in the energy chapter. It is important to note that CCS is treated as an emission reduction by source, and not as a sink. The captured CO_2 is reported as an emission reduction at the stack, and potential seepage from the reservoir as a fugitive emission. Because the 2006 Guidelines are the first internationally recognised document to give guidance on how to estimate seepage from a geological storage reservoir, and it also allows for recognition of CCS under the UNFCCC.

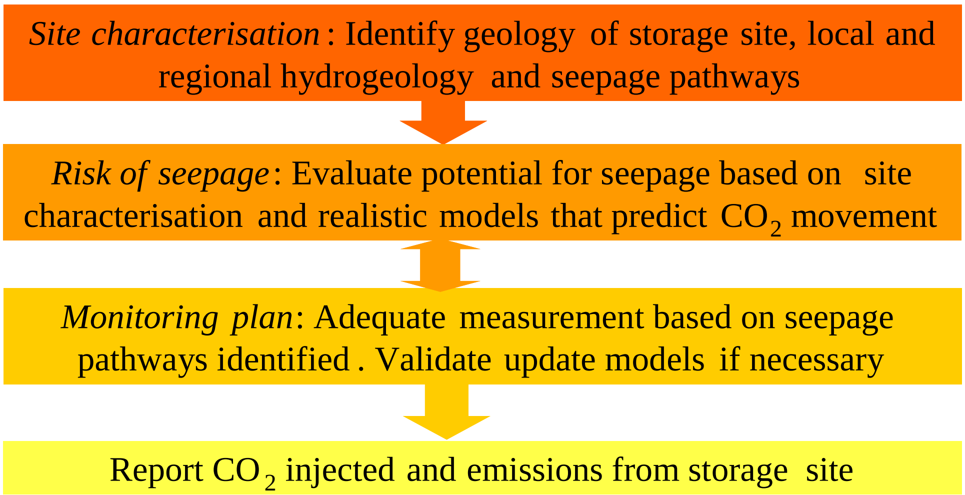

Figure 1 Framework of steps to be taken to estimate the potential seepage from CO_2 storage reservoirs in the IPCC 2006 Guidelines on National Greenhouse Gas Inventories.

[1] “Likely” is a probability of 66 to 90%.
[2] Although recently, it was decided to amend the Annex of the London Protocol in order to allow for CO_2 storage in the sub-seabed.

The framework requires the storage site to be characterised in detail, and seepage potential to be estimated based on underground modelling of CO_2 migration, as well as potential seepage routes (such as old well bores, faults, reservoir pressure increases). It is important that the monitoring techniques are applied with an eye on the most likely seepage routes. If monitoring shows different results than the geo-modelling, the procedures require the models to be updated to reflect the new insights. This iteration is thought to increase the flexibility of the framework procedure, and allows for updates if new information and developments become available.

United Nations Framework Convention on Climate Change (UNFCCC)

The Kyoto Protocol

Given the cost and - apart from enhanced resources production - the general lack of co-benefits, the only incentive for carbon dioxide storage is climate change mitigation. Structural policy incentives for carbon dioxide capture and storage in most individual countries are still absent, although some countries are undertaking efforts. CCS will not be deployed on a large scale unless a policy incentive is installed which makes CCS economically attractive. In the context of the Kyoto Protocol, this can be the project-based flexible mechanisms: Joint Implementation and the Clean Development Mechanism.

The Kyoto Protocol entered into force in 2005, which made the greenhouse gas emission reduction targets binding for those countries that have ratified the Protocol. Also, the flexible mechanisms have become legal instruments. Although the Kyoto Protocol acknowledges “carbon sequestration technologies” as a mitigation measure, it has until recently not been discussed within the UNFCCC.

Convention discussions

The Conference of Parties to the UNFCCC (COP) meets every year to discuss and negotiate climate policy in its different bodies. In addition to the COP negotiations, plenary meetings of the Subsidiary Bodies take place (the Subsidiary Body for Scientific and Technological Advice (SBSTA) and Subsidiary Body for Implementation (SBI) meetings). A COP takes 2 weeks and is built around the climate negotiations of the UNFCCC. In addition to the negotiations, in the so-called “high-level segment” in the last three days, the meeting consists of several parallel processes. Attendance is on the order of thousands of government delegates and representatives from observer organisations. In parallel to the official UNFCCC-related meetings, side-events are organised by observer organisations and Parties. Because of these meetings, the COPs are also podia for research and policy discussions related to climate change. Since the ratification of the Kyoto Protocol, the “Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol”(COP/MOP) are held in parallel.

Up to COP10, CCS received little attention in both the international negotiations or during the side-events, although there was one book presentation by the International Energy Agency on “Prospects of CO_2 capture and storage” in 2004. In the climate negotiations, the focus has almost exclusively been on non-carbon energy sources and energy efficiency, non-CO_2 greenhouse gases, flexible mechanisms of the Kyoto Protocol and on national policies, and also increasingly on adaptation and development issues.

COP11 broke the silence on CCS, mainly because the IPCC SRCCS was first released during that COP, and because of the CDM methodologies submitted (see later section). The SBSTA had an agenda item on the publication of the IPCC Special Report, but this agenda item was removed as a result of an initiative of the United States. This focussed attention on the subject in the corridors.

The report was eventually still considered but it was hidden under a different agenda point (report by IPCC to SBSTA). All delegations supported the conclusions of the Special Report, and the European Union (represented by the United Kingdom), supported by Norway, proposed to follow up on the report and the Revised Guidelines (to be published end of April 2006) in a workshop. The United States, Canada, Australia and the G77 & China declared their support of the report, but did not name any consequences. Saudi Arabia (normally unwilling to engage in any mitigation discussion) was particularly positive on the report, calling it "the best mitigation option". The session concluded with a workshop, held in Bonn at SBSTA-24 on May 20th, 2006. The workshop contained presentations on different aspects of CCS, but focussed very much on the storage of CO_2. During COP12, the workshop report was noted, but no decision on the use of the 2006 IPCC Guidelines for National Inventories was taken[3]. Discussions on CCS continued in side-events (notably those sponsored by business and industry observer organisations) and in the context of the Clean Development Mechanism.

Clean Development Mechanism and CCS

The Clean Development Mechanism (CDM) is one of the flexible mechanisms of the Kyoto Protocol and has two purposes: to assist non-Annex B in achieving sustainable development and to allow Annex B countries to comply with their Kyoto obligations through emission reductions generated in non-Annex B countries. The CDM Executive Board, along with the Designated National Authorities in the host countries, are responsible for the fulfilment of those objectives, but in addition, numerous evaluations have been done on whether the CDM lives up to the expectations. The CDM is currently growing rapidly in importance, with only 63 projects passing

In 2005, two methodologies for CO_2 capture and geological storage were submitted to the CDM Executive Board[4]. The first project ("White Tiger Field") is an offshore EOR project using CO_2 from new-built natural gas combined cycle (NGCC) plants in Vietnam. The second one ("Petronas"), submitted almost simultaneously, takes place in Malaysia and involves the injection of CO_2 from an offshore gas processing operation and its co-injection with H_2S in an offshore saline formation. Table 1 gives an overview of the most important characteristics of both projects.

[3] This is important as the 1996 IPCC Guidelines are officially the guidelines that need to be used to establish the inventory that counts for Kyoto compliance. Because the 1996 Guidelines make no mention of CCS, emissions reduced by CCS might not be eligible for Kyoto compliance.

[4] There was also a methodology submitted on the storage of CO_2 by enhancing sedimentation in ocean water, but this was very experimental.

Table 1 Overview of submitted CDM methodologies for CO_2 capture and storage. Between brackets the methodology number in the UNFCCC CDM process.

	White Tiger Field (NM0167)	Petronas (NM0168)
Description	CO_2 capture from NGCC plants, pipeline transport, storage in offshore/ onshore oil field, EOR operation	CO_2 and H_2S co-capture from offshore gas well, storage in aquifer (no EOR)
Host country	Vietnam	Malaysia
Project boundary	Capture, compression, transport, storage reservoir	Compression, transport, storage reservoir
Leakage	Leakage from EOR not considered	No leakage identified
Seepage	Assume 0.1% p.a. during crediting period	Estimated & based on monitoring procedures
Monitoring	3D & 4D seismic	4D seismic
Baseline	Seawater EOR	Venting of CO_2
Site Selection	Already selected; criteria not clear	
Permanence	Beyond scope of methodology, if seepage is significant no Certified Emission Reductions	Discount CERs for seepage beyond credit period

After receiving the methodologies, the CDM Executive Board asked COP/MOP1 for more guidance. The COP/MOP decided to hold an in-session workshop during SBSTA-24, on May 22nd. During the workshop, views were expressed on issues related to the project boundary, seepage, permanence and other issues. For instance, the question whether the emissions resulting from the use of the additional oil through EOR should be accounted for was extensively discussed. The report of the workshop, along with Party submissions on CCS and CDM, was submitted to COP/MOP2 for further discussion. Also, the Methodologies Panel of the CDM Executive Board identified a number of technical and policy issues. The policy issues are:

- The question of acceptable levels of long-term physical leakage (seepage) risk and uncertainty (e.g. less than X% seepage by year Y with a likelihood of Z%);
- Project boundary issues (such as reservoirs in international waters, several projects using one reservoir, etc) and national boundaries (approval procedures for projects that cross national boundaries);
- Long-term responsibility for monitoring the reservoir and any remediation measures that may be necessary after the end of the crediting period (i.e. liability);
- Accounting options for any long-term seepage from reservoirs (e.g. new modalities and procedures such as those for LULUCF).

And the issues which require geological, petroleum engineering, and other specific expertise to address include:

- The development of criteria and a step-wise guidance for the selection of suitable storage sites with respect to the release of greenhouse gases, and how this relates to applicability conditions for methodologies;
- Guidance on the development of adequate and appropriate monitoring methodologies for physical leakage (seepage) from the storage site;

- Guidance related to the operation of reservoirs (e.g. well sealing and abandonment procedures) and remediation measures and how these may need to be addressed in baseline and monitoring methodologies.

COP/MOP2 had difficulties reaching agreement on the further process of CCS under the CDM, with Brazil vehemently against the consideration, and the AOSIS and Least Developed Countries emphasising the uncertainties. Japan, Saudi Arabia, Kuwait and Qatar were very much for CCS under the CDM, and the EU and Norway supported its inclusion but only after the issues were resolved in a credible way. Recent studies[5] have not given enough help to develop a framework consistent with the technical characteristics of CCS or with the UNFCCC rules for mitigation options. Eventually, it was decided that the Executive Board was to continue considering proposals for CCS "with a view to gaining further knowledge and understanding". Further decisions in the document (Decision FCCC/KP/2006/CMP.2) included encouragement of capacity building efforts and workshops by Parties and non-governmental organisations, and the provision of information, by 31st May 2007, to the Secretariat on the following topics:

(a) Long-term physical leakage levels;

(b) Project boundary issues;

(c) Long-term responsibility for monitoring and remediation;

(d) Long-term liability for storage sites;

(e) Accounting options for any long-term seepage from reservoirs;

(f) Criteria and steps for the site selection;

(g) Potential leakage paths and site characteristics;

(h) Operation of reservoirs;

(i) Any other relevant matters, including environmental impacts.

This list gives a good idea on where the main concerns and uncertainties around CCS and the CDM are. The implementation of CCS under the CDM, so in host countries with often relatively weak institutions, even when there are no rules yet on it in industrialised countries, is perceived as a risk. Also, the finite crediting time of 10 or 3x7 years, after which the transaction is done and the profits have been made, also if the reservoir starts leaking after 50 years, is seen as a barrier. The topics above attempt to address these problems, although there are not yet ready solution.

After the submissions on the topic list above are received, the Parties are requested to make submissions on the topics by 21st September 2007, after which the 27th session of the SBSTA would prepare a recommendation for including CCS under the CDM. COP/MOP3 would then consider this, after which COP/MOP4, in 2008, would have to make a decision.

Whether CO_2 capture and storage (CCS) would be eligible under JI and CDM is therefore not yet resolved, although discussions are evolving. A question related to CDM is whether CO_2 capture and storage will be possible as part of the EU Emission Trading Scheme. A study commissioned by DG Environment to a consortium of ECN, NortonRose, ERM and the Central Mining Institute will start work on a regulatory framework for CCS shortly, and will finish before autumn.

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[5] E.g.; GCSI (2004), Haefili et al. (2004), ERM/DNV (2005) and Bode and Jung (2004, 2005).