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# Last gasp of the coal industry

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**AIR POLLUTION AND CLIMATE SERIES 21**

**Last Gasp of the Coal Industry**

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Cover illustration: Lars-Erik Håkansson (Lehån).

ISBN: 978-91-975883-4-8

ISSN: 1400-4909

Published in October 2008 by the Air Pollution & Climate Secretariat, Box 7005, 402 31 Göteborg, Sweden. Phone: +46 (0)31 711 45 15. Website: www.airclim.org.

Further copies can be obtained free of charge from the publisher, address as above. The report is also available in pdf format at www.airclim.org.

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## About the authors

The Author, Gabriela von Goerne (PhD) is a geologist, climate policy expert and consultant living in Germany. She received a PhD in Geology from the Technical University in Berlin, Germany in 1996. She has participated as a CCS expert in a large number of scientific bodies including the IPCC, and in hearings of the UNFCCC, the EU, Australia and Germany.

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# Executive Summary

The message is simple: Capturing $CO_2$ from large point sources, its transport and storage in geological formations (CCS) offers the possibility of continuing to use fossil fuels while greatly reducing carbon dioxide emissions. The solution is close, get some pilot projects running and coal power plants equipped with CCS technology will become a viable, commercial mitigation option.

It sounds too good to be true, and probably is. This report takes a look behind the bright vision of CCS given by proponents of this technology. And it shows how the outlook of CCS is used to build new coal-fired power plants today, thus continuously fuelling climate change. The report is not intended to damn CCS but is an appeal for wise decision-making.

The different capture technologies under development, the scope of CCS and potential risks of storing $CO_2$ are described in chapters 3 to 5. Chapter 6 discusses the question of who wants CCS, while the political dimension is outlined in chapter 7. Chapter 8 closes by highlighting four common arguments regarding CCS.

## The great capture-ready swindle

Many of the coal-power plants under planning or construction are so-called capture-ready. "Capture-ready" suggests that coal power plants will be retrofitted. Nobody knows at which point in time this will be the case, if at all. The key factor for CCS is whether or not commercial capture options will be available for coal power plants and at what cost. The simplest way to avoid misuse of the "capture-ready" concept is to say no to all new coal power plants without real, working CCS.

## Capture limits

Whatever $CO_2$ capture system will be chosen, capture technology is expensive, in terms of efficiency loss, fossil fuel and water requirement, as well as costs. Compared to power plants without CCS, the efficiency of a power plant with a capture system is reduced between 8 to 12 percentage points. This efficiency penalty implies a remarkable loss of electricity production. To produce the same amount of electricity much more coal needs to be burnt. The increased fuel requirement is estimated to be between 21 and 27 per cent but could be as much as 40 per cent and this also implies an increase in produced $CO_2$ that needs to be captured, processed, compressed and stored. Carbon capture technologies increase the water demand of coal power plants. Depending on the power plant technology used, the water consumption for cooling devices can increase for example between 10 to 20 per cent for IGCC plants. If water and cooling requirements cannot be met, CCS coal power is not even an option.

One could argue that the impacts of climate change are larger than the environmental impacts due to the use of CCS technology. This however could only be an argument if no other solutions were at hand. But there are – renewable energy sources (in combination with efficiency improvements and reduced energy demand) have been shown to be environmentally safe and sound technologies. This is something CCS still has to prove.

## $CO_2$ emissions

In comparison to conventional coal power plants $CO_2$ emissions can be reduced significantly by using capture technologies. While carbon dioxide emitted directly at the power stations is reduced by 88 per cent, a life cycle assessment shows substantially lower reductions in greenhouse gases totalling 65 to 79 per cent. This translates into $CO_2$ emissions of up to 274 g $CO_2$-eq/kWh. Coal power plants equipped with CCS are thus by no means "$CO_2$-free" as some representatives of industry and policymakers would have us believe.

## Costs

Each of the cost components can vary widely according to the technology used at the power plant, the capture technology used, and the transport distance. Compared to a power plant without capture, the investment costs for a system with capture increase by 30 to 50 per cent. For pulverised coal with post-combustion the capital cost increases by as much as 77 per cent compared to a plant without capture. In addition the cost of electricity almost doubles. The predicted cost lies in the same range as most renewable energies. One cost associated with CCS that is especially difficult to assess is the issue of liability for damage. The question of who will take responsibility in the event of a leak in the future is a tricky, and probably expensive, legal problem.

Harvesting the so-called "low hanging fruits" which means the seemingly cheap CCS opportunities like enhancing oil recovery through injection of $CO_2$ ($CO_2$ EOR) has been shown to be less cost-effective than expected. Two projects were stopped in 2007 due to high costs. Without the promise of economic success it will be hard to find investors to move forward with CCS technology.

So far, over a period of over ten years, around a million tonnes of carbon dioxide per year has been injected into sandstone 1,000 metres below the seabed in the Norwegian Sleipner gas field in the North Sea, for the simple purpose of reducing greenhouse gas emissions to protect the climate. A million tonnes per year may seem like a lot, but it is nothing compared to the total amount of storage that would be needed. Add five zeroes and the problem moves into a different league. It is possible that most of the gas can be kept in place forever, but leakage can never be ruled out completely.

## Risks

At present, information about the potentially detrimental external environmental effects of carbon dioxide storage is far from complete. Storing large amount of $CO_2$ underground could result in modifications of underground geological layers. Such geological modifications and the $CO_2$ injection process itself could lead to seismic activity. Leakage of $CO_2$ into shallower groundwater systems may occur through natural geological faults or fractures, perhaps enhanced by fluid over-pressurisation associated with the injection. Or leakage may occur through human-created pathways such as wells. Some people even say that the question is not whether a well will leak, but when.

Next to local impacts the big question is of course whether carbon dioxide may return to the atmosphere to any significant extent, thus giving rise to delayed global warming. If large amounts of $CO_2$ are stored, even a small amount of leakage from an injection site could compromise long-term efforts toward atmospheric $CO_2$ stabilisation. Strong guidelines and an independent entity capable of overseeing all storage activities are needed to minimise this risk.

## Who wants CCS?

Those pushing for CCS are mainly the coal industry and governments of countries that have a lot of coal and coal power plants, as well as some oil and gas nations. Coal power is the worst method of producing electricity from the climate perspective. A serious climate policy would hit the coal industry and coal-dominated power industry very hard. However, the power industry is well organised in all countries and they are pinning their hopes on CCS, or perhaps more precisely, they hope that enthusiasm for CCS will win them time to continue extracting and using coal.

In many respects CCS is not, as often portrayed, a supplement to renewable energy, energy efficiency measures and lifestyle changes, but an alternative to them – obviously not forever, but for the foreseeable political future. Either we invest a few thousand billion euro in wind power, solar panels, biomass and energy efficiency measures, and make the lifestyle changes needed to meet the emission targets, or we make preservation of our lifestyle the greater goal and invest the same amount in CCS and nuclear power, as the big power companies want us to do. It's either or. The same money can't be spent twice.

It is no surprise that there is a large industrial network that fears radical change. Vattenfall for example is not just an isolated company in a little corner of the planet. Vattenfall is the co-ordinator of the 3C Combat Climate Change project. The alliance between the coal industry, oil-producing countries and certain oil companies is very apparent at sector meetings for the climate convention. In the same way that they constantly push for the recognition of nuclear power as an accepted climate change mitigation option, they are also pushing for CCS. We never hear them pushing for renewable energies. Sixty-three per cent of Vattenfall's electricity production in Germany comes from brown coal, less than one per cent from renewable energy. Between 2007 and 2011 Vattenfall is going to invest a total of around 11 billion euro in its energy production and distribution systems. Most of these investments will go towards the long-term objective of reducing emissions of carbon dioxide from Vattenfall's own plants to zero, i.e. to CCS. Current projects consist of a single 30 MW CCS plant set to start production in 2008, compared with 3,155 MW of conventional coal power capacity that is at the planning and construction stage, but does not include CCS. Following Vattenfall's path means to become trapped in a fossil energy structure with no other way out than to store all the $CO_2$.

## The political dimension

In many of the developed countries, the OECD and the International Energy Agency (IEA), there is also an established view of coal as a strategic resource as opposed to oil and gas, which are mainly produced outside the OECD countries. The IEA's raison d'etre is "security of supply", by which it means that "we" should have as much energy as we feel we need at a price we find reasonable. All the IEA's graphs point upwards, and if you believe in the coal forecasts then you naturally have to believe in CCS, because otherwise everything falls apart.

Which will you choose if you have capacity and budget for a single project but three or more are on the table? Just look at the Intergovernmental Panel on Climate Change (IPCC), probably the most highly accepted global organisation that deals with climate change issues. The loser in this game in the past has been renewable energy. Instead, the world got a Special Report on Carbon Dioxide Capture and Storage, released in 2005.

There is not much published scientific criticism of CCS. This is not especially surprising. The power industry gives its own money to CCS research, and lobbies successfully for public money to be used for the same purpose.

What role CCS will finally play is open to debate. For now, increasing amounts of money are flowing into CCS research to answer many of the questions. This money should not flow at the expense of other areas of research fields, as will definitely happen if research budgets are not extended or if CCS is valued more highly than other truly sustainable mitigation options.

The environmental movement is deeply split on the question of CCS. There is a sense of fear that the world is not able to achieve the 2˚C target; that renewable energy and efficiency improvements cannot deliver enough power. Coal is here to stay, and we have to choose between the threat of climate change and CCS, with CCS acting the part of the joker. In the nuclear debate the principle of choosing the "lesser evil" was abandoned in favour of a more fundamental criticism of the "high-energy society" along with a more pragmatic distrust of scenarios that predicted the rapid and continued growth of energy consumption. Perhaps things will go the same way with CCS.

### CCS is a stepping stone to sustainable development

Sustainable development can only be achieved through renewable energies and efficiency. To get there you must go there. You don't need stepping-stones if you don't plan to cross the river.

### Coal will be used for a long time to come

Every time someone plans a coal power plant, especially in Europe, there is an alternative: wind power, biomass, geothermal energy, solar thermal power, improvements in energy efficiency, conversion of electric heating to another type of heating, conversion of air conditioning to district cooling or passive cooling. There are always alternatives.

### China will continue burning coal whatever we do

China is not stonewalling in the climate negotiations, but naturally wants to see the major industrialised nations show some action, and it justly points to the fact that much of China's rising emissions are due to exports to the same nations that describe China as the problem.

### Renewable energy is too expensive and won't make it

With tighter climate-policies and greenhouse gas reduction targets coming into place it is no longer useful to compare renewable energies with traditional coal-fired power plants. They have to be compared with CCS. The very rapid growth of solar heating in European countries such as Greece and Spain indicate that solar heating can already compete with electricity (coal power) and oil for heating in these countries. Things can change; it all depends on the political will.

# 1. Introduction

The IPCC's fourth assessment report on climate change has made one thing clearer than ever. If the world wants a reasonable chance of avoiding dangerous climate change, the temperature increase needs to be limited to 2°C above pre-industrial levels. This means, global emissions have to peak no later than 2020 and then fall by 50 to 85 per cent by the middle of this century compared to 2000 levels. We do not yet know for certain at what temperature dangerous climate change is reached and how low we need to go to maintain a stable level. New scientific findings indicate that we have to go further down the reduction road we are already facing.

Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels.[1]

One of these mitigation technologies under research, development and deployment is carbon dioxide capture and storage (CCS), a process consisting of the separation of carbon dioxide ($CO_2$), mainly from energy-generation sources such as coal power plants, transport to a storage site and long-term isolation from the atmosphere.

CCS would represent a paradigm shift, a radical departure from the approach of limiting production of harmful emissions, to a path of producing even more of those emissions and then burying them. There is no doubt that renewable energies will make it one day, but for now, reliance on coal is the mantra of the coal industry and governments. Using CCS will buy time; CCS is the bridging technology for the transition to a carbon-free renewable energy system.

It almost sounds as if the technology is already at hand and there are no unanswered questions or risks associated with its use. However, until 2007 no full-scale pilot project – consisting of a coal power plant capturing, transporting and injecting $CO_2$ into a storage site – was in operation anywhere in the world. Nevertheless some companies and governments are putting their hopes in the technology becoming commercially viable by 2020. So far there is no guarantee that this will be the case. Even with the most optimistic projections, CCS won't become viable on any convincing scale until well after 2030, and how much additional energy and money would be required to bring the technology into worldwide use remains unknown.

# 2. The promise

The message is simple: CCS offers the possibility of continuing to use fossil fuels while greatly reducing carbon dioxide emissions. Making coal clean, and climate friendly, is the promise one hears whenever the problem of mitigating climate change comes on the agenda. The solution is close, get some pilot projects running and coal power plants equipped with CCS technology will become a viable, commercial mitigation option. Proponents of the technology emphasise that the integration of $CO_2$ capture in coal-fired power plants leads to environmental benefits, not only through the reduction of greenhouse gas emissions but also through reduction of other harmful emissions, thus reducing air pollution.

However even if some CCS technologies offer ancillary benefits through co-capture of some air pollutants, the increases in specific fuel consumption, reagent use, water use, solid wastes are significant.

With the arrival of CCS, coal becomes the new miracle product. It not only allows the production of clean electricity, coal can also be liquefied and hydrogen can be produced from coal, to yield vehicle fuel that produces no carbon dioxide emissions. With a hydrogen distribution infrastructure in place it would eliminate carbon dioxide emissions from traffic, from industry and from power generation. Coal is here to stay.

It sounds too good to be true, and probably is.

So let's take a look behind the bright outlook given by proponents of this technology.

# 3. The technology

Carbon dioxide capture and storage consists of three steps, capture – transport – storage. The $CO_2$ is captured from a gas stream, transported and injected into geological formations for safe and permanent storage.

There are several proposed schemes for carbon dioxide storage, including deep-sea deposition of free $CO_2$. Storing $CO_2$ in deep-sea waters is not regarded as a suitable option, as the environmental impact on the oceans and its organisms would be too high. Therefore this report deals purely with geological storage, in which the gas is injected e.g. into saline water bearing rock formations, and depleting or depleted oil and gas fields. These formations may not only be located on land but also offshore deep below the seabed.

The capture of $CO_2$ is the most complex technical part of the story. Three technologies are under development:

**Flue gas separation**, where $CO_2$ is separated from the flue gases produced by combustion of a primary fuel (coal, natural gas, oil or biomass) in air (post-combustion).

$CO_2$ capture involves $CO_2$ separation and recovery from the flue gas, at low concentration and low partial pressure. The current separation method of choice is chemical absorption with amines, such as monoethanolamine (MEA). The absorbed $CO_2$ must then be stripped from the amine solution. The recovered $CO_2$ needs to be cooled, cleaned, dried, and compressed to a supercritical fluid. It is then ready to be transported for storage.

$CO_2$ removal from flue gas requires energy, primarily in the form of a low-pressure steam for the regeneration of the amine solution. This reduces the steam supply to the turbine and the net power output of the generating plant.[2]

Because of the large coal-based power generating fleet in place and the additional capacity that may be constructed in the next two decades, the issue of retrofitting for $CO_2$ capture is important to the future management of $CO_2$ emissions. However, retrofitting power plants with post-combustion technology is the most inefficient way of capturing $CO_2$ with regard to the other two capture technologies under development and deployment. Nevertheless, post-combustion is probably the only technology to retrofit currently existing power plants.

**Oxy-firing combustion (Oxy-fuel)** uses oxygen instead of air for combustion, producing a flue gas that is mainly $H_2O$ and $CO_2$.

This approach to capturing $CO_2$ involves burning the coal with ~95 per cent pure oxygen instead of air as the oxidant. The flue gas then consists mainly of carbon dioxide and water vapour. Large quantities of flue gas are recycled to maintain design temperatures and required heat fluxes in the boiler, and dry coal-ash conditions. Oxy-fuel technology requires an air-separation unit (ASU) to supply the oxygen. The ASU energy consumption is the major factor in reducing the efficiency of oxy-fuel power plants.

**Gasification or steam reforming (IGCC)** where a gas, liquid, or solid hydrocarbon is reacted to produce separate streams of $CO_2$ for storage and hydrogen ($H_2$). (Pre-combustion).

Integrated gasification combined cycle (IGCC) technology produces electricity by first gasifying coal to produce synthesis gas (syngas), a mixture of hydrogen and carbon monoxide (CO). The syngas, after clean-up, is burned in a gas turbine which drives a generator. Applying $CO_2$ capture to IGCC requires three additional process units: shift reactors, an additional $CO_2$ separation process, and $CO_2$ compression and drying. In the shift reactors, CO in the syngas is reacted with steam over a catalyst to produce $CO_2$ and hydrogen.

Despite recent improvements, one of the significant perceptions regarding IGCC is that that it is complex and unreliable. The DOE Policy Office lists reliability as the number one factor why IGCC (without $CO_2$ capture) has failed to make significant inroads in the power sector. IGCC with $CO_2$ capture is significantly more complex than IGCC without $CO_2$ capture and additional complexity is likely to exacerbate industry concerns regarding reliability. Fassbender[3] comes to the conclusion that the highly integrated series of chemical processes in IGCC plants is where complexity detracts from reliability.

No demonstration coal power plant exists so far that is equipped with capture technology, a transport system and method of storage of $CO_2$. There is a growing realisation among utility industry leaders worldwide that so-called clean coal may not be able to address rising emissions from power generation for at least the next decade. Clean coal technology, involving trapping carbon in waste gases from coal-fired power plants and disposing of it underground, may not be commercially viable until 2025.[4]

### The great capture-ready swindle

Back in 2005 a comprehensive multi-track approach for CCS, including capture-ready technology, was proposed in the G8 Gleneagles communiqué. In 2007 the IEA[5] defined "capture-ready" as a plant that can include $CO_2$ capture when the necessary regulatory or economic drivers are in place, that avoids the risk of stranded assets and carbon lock-in. Developers must also eliminate factors which would prevent installation and operation of $CO_2$ capture. Such factors might include a study of options for capture retrofit, include sufficient space and access for additional facilities, and identification of reasonable route(s) for storage of $CO_2$.

This definition dismisses the fact that no one knows today what the CCS capture technology of choice will be in the future. There is a complication that the capture equipment that might be fitted ten or more years ahead is going to differ from current state-of-the-art technology.

For markets currently with high gas prices and low carbon prices, coal plants without CCS would be the natural market choice for new build. Higher carbon prices in the future are, however, a risk in any market.

"Capture-ready" suggests that coal power plants will be retrofitted. But that's not necessarily the case. The key factor for CCS is whether or not commercial capture options will be available for coal power plants at around the predicted costs in the future. As long as it is more economic, for example, to buy carbon credits instead of reducing emissions, retrofitting of existing coal power plants will simply not take place.

The very least that should be asked of a "capture-ready" plant is that there is a detailed plan and money set aside for CCS, and that the environmental permit should be limited e.g. to five years. Otherwise it just means some extra space for some kind of building. But the simplest way to avoid misuse of the "capture-ready" concept is to say no to all new coal power plants without real, working CCS.

## 3.1. Capture limits

All three technologies are still under development and deployment. While small-scale pilot plants (<40 MW) with capture technology are under construction, larger plants (>300 MW) are in the planning stages, and truly large-scale 1000 MW plants are still a long way off. Much more time and money will be needed to reach the scale that really matters. Whatever system is chosen, the $CO_2$ capture process is expensive, in terms of efficiency, fossil fuel and water requirements, as well as in investment and electricity costs.

### 3.1.1. Efficiency loss

Energy requirements and power consumption of $CO_2$ capture are high, resulting in a significant decrease in overall power plant efficiencies. Compared to power plants without CCS, the efficiency of a power plant with a capture system is reduced by eight to 12 percentage points (see table[6]). The problem increases if existing power plants are retrofitted with CCS. The efficiency then drops to 21–24 per cent compared with a typical 35 per cent baseline for power plants running in many parts of the world today.[7] This efficiency penalty implies a remarkable loss of electricity production. To avoid a shortfall in electricity production it may be advantageous to construct one or more additional plants on sites when they are retrofitted with capture, in order to keep MW output the same.

**Table: Loss of efficiency of power plants equipped with capture technology compared to the same plant w/o capture (table from Viebahn et al., 2006).**

| Type of power plant (in 2020) | Fuel | Loss in efficiency (%) |
|---|---|---|
| Pulverised Coal (post-combustion) | Hard coal | 49 → 40 |
| Pulverised Coal (post-combustion) | Lignite | 46 → 34 |
| Natural Gas Combined Cycle (NGCC) | Gas | 60 → 51 |
| Integrated Gasification Combined Cycle (IGCC) | Hard Coal | 50 → 42 |
| Oxy-fuel | Hard Coal | 49 → 38 |

### 3.1.2. Fuel requirement

The increase in fuel required to produce a kWh of electricity depends on the type of baseline plant without capture. It is estimated at between 21 and 27 per cent but could be as much as 40 per cent.[8] The increase in fuel consumption implies an increase in coal mining activities and related environmental impacts. Although it can be assumed that security of supply will not become an issue for coal as it is for oil and gas, the increasing need for coal will nevertheless put pressure on the market, resulting in further increase in the coal price. Increasing coal use due to capturing $CO_2$ also implies an increase in produced $CO_2$ that needs to be captured, processed, compressed and stored.

### 3.1.3. Water requirement

Water supplies are already a cause of concern in many countries, including large parts of the US and China. The latest IPCC fourth assessment report has made it clear that climate change will make the situation worse. Drought affected areas will likely increase in extent. Water supplies stored in glaciers and snow cover are projected to decline, together with reducing water availability in regions supplied by melt water.[9]

Carbon capture technologies increase the water demand of coal power plants. Depending on the power plant technology used, the water consumption can increase by 10 to 20 per cent (for IGCC) and can more than double in the case of post-combustion of pulverised bituminous coal power plants, because of the large amounts of cooling water needed to run the system.[10] An associated problem at riverside power stations is that of thermal pollution. During periods of protracted heat, there can often be a choice between killing the fish by exceeding the permitted temperature or running the plant at much reduced capacity. In many locations, power demand peaks in summer as well as winter, because of air conditioning.

If a power plant cannot produce full power or is not allowed to do so when power is most needed (best price), the investment is much less attractive. If water and cooling requirements cannot be met, CCS coal power is not even an option.

*CCS – a waste of resources*

While trying to solve one big problem with CCS a number of new problems will be created. CCS implies wasting precious resources, fossil fuels as well as water. Even without CCS, the European Commission has stated that if current patterns of resource use are maintained in Europe, environmental degradation and depletion of natural resources will continue. If the world as a whole followed traditional patterns of consumption, it is estimated that global resource use would quadruple within 20 years. The negative impact on the environment would be substantial.[11]

One could argue that the impacts of climate change are larger than the environmental impacts due to the use of CCS technology. This however could only be an argument if no other solutions were at hand. But there are – renewable energies (in combination with efficiency improvements and reduced energy demand) have been shown to be environmentally sound technologies. This is something CCS still has to prove.

### 3.1.4. $CO_2$ emissions

In comparison to conventional coal power plants, $CO_2$ emissions can be reduced significantly by using capture technologies. A study by Nsakala showed that carbon dioxide emissions can be reduced from about 900 g $CO_2$/kWh for a baseline case coal power plant to 54-120 g $CO_2$/kWh for different capture technologies. Other reference studies yield carbon dioxide emissions of 105-206 g $CO_2$/kWh. However, these are just emissions from the power plant site, excluding emissions related to mining, transport and storage activities.[12]

If a complete life-cycle assessment is taken into account, the emission budget looks different.

While carbon dioxide emitted directly at the power stations is reduced by 88 per cent, a life cycle assessment shows substantially lower reductions of greenhouse gases in total (minus 65 per cent to 79 per cent). This translates into $CO_2$ emissions up to 274 g $CO_2$-eq/kWh. The reason for the higher emissions is due to the fact that capture, transport, and storage require a lot of energy and that $CO_2$ and methane are also emitted in the preceding processes (mining industry, transport). Renewable electricity from wind power plants and solar thermal power plants causes only two per cent of the fossil-fired power plant's greenhouse gas emissions.[13]

Coal power plants equipped with CCS are thus by no means "$CO_2$-free", as some representatives of industry and policymakers would have us believe.

### 3.1.5. Costs

The costs of CCS are calculated as the sum of $CO_2$ capture, which is the largest cost component, transport and storage. The storage component can be split between injection and post-injection/closure, where costs arise from monitoring and remediation activities in case of leakage. Each of these cost elements can vary widely according to the technology of the power plant, the capture technology used, and the transport distance. Together with the fact that the technology is still under development and deployment, it is almost impossible to give an accurate estimate of the real cost of CCS. Capture costs for coal- or gas-fired power plants are reported in the IPCC Special Report on Carbon Dioxide Capture and Storage (2005) to be in the range 15– 75 US$ per tonne of $CO_2$, with transport accounting for 1–8 US$, and storage (including monitoring) between 0.6–1.1 US$. Because capture is the largest components of the cost equation most economic studies focus on the power plant side.

Compared to a power plant without capture, the investment costs for a system with capture increases by 30 to 50 per cent. For pulverised coal with post-combustion the capital cost increases by as much as 77 per cent compared to a plant without capture. In addition the cost of electricity almost doubles from 4.6 to 8.2 US cents/kWh for pulverised coal and 4.8 to 7.0 US cents/kWh for an IGCC plant.[14] The costs are in the same range as for today's wind energy. They will however be much higher if the power plant is not run at base load. It is questionable whether a coal power plant equipped with CCS would be used to accompany fluctuating renewable energies such as wind, i.e. to balance the electricity needs.

Because of the high costs, CCS is thus best suited to large power plants or centralised industrial facilities such as steel or cement production. In contrary, most CHP (combined heat and power) or biofuel plants are smaller in size, and it is clearly much more expensive to separate carbon dioxide from 25 small plants that are geographically isolated than from one large coal power plant. Getting CCS to work on a large scale could possibly require such tough carbon dioxide restrictions, in the form of high emission right prices or taxes that the problem would be solved anyway as renewable energy and efficiency improvements pushed coal power aside. A scenario analysis by Smekens and Swan (2004)[15] came to the conclusion that with an internalization of climatic external costs, the use of fossil-fuelled power plants, is most heavily affected. Higher costs are incurred as a result of implementing carbon capture processes. It appears that the additional costs involved for fossil fuels are too high, in comparison with non-fossil options that are free of carbon emissions.

One cost associated with CCS that is especially difficult to assess is the issue of liability for damage. The question of who will take responsibility in the event of a leak in the future is a tricky, and probably expensive, legal problem. There is a possibility that this responsibility will be waived in future agreements.

*Cost explosion*

The hope that CCS will arrive soon enough to ensure that emissions peak and begin to decline before 2020 has recently suffered a number of setbacks. Harvesting the so-called "low hanging fruits" which means the seemingly cheap CCS opportunities such as $CO_2$ EOR (Enhanced Oil Recovery) has been shown not to be as cost-effective as expected. In 2007 BP dropped its plan to bury $CO_2$ created by the Peterhead power plant in Scotland in its depleting Miller oil and gas field under the North Sea. BP estimated that pumping the $CO_2$ from Peterhead into the ageing field could boost recoverable oil reserves by up to 60 million barrels, making that project attractive. The consortium's decision to abandon its Peterhead project at the end of 2007 is due to the technical constraints surrounding the Miller field where the $CO_2$ was to be stored. It was expected that costs would be reduced as a result of subsidies from the British Government, which it was obviously not willing to deliver. Another example comes from Norway, where Statoil and Shell stepped back from the idea to enhance oil recovery with $CO_2$ disposal. Oil exploration would need to stop for up to one year while the extended oil coverage rate would just achieve two per cent.[16] The loss would be much higher than the gain.

The latest example comes from the US. FutureGen, the flagship of the Bush Administration's CCS programme collapsed in January 2008 because of a doubling of costs and despite a total of US$1.3 billion in public funds and protection from any legal liability.

Without the outlook of economic success it will be hard to find investors to move forward with CCS technology.

# 4. The scope

What makes the position taken on CCS so critical is the extent of the issue. The estimated capacity for storing carbon dioxide in saline formations alone is between 1,000 and 10,000 billion tonnes of carbon dioxide. Annual emissions are around 30 billion tonnes. It is the argument about winning time that makes the magnitude of these figures interesting.

If there is to be any point in winning time, then it should naturally be a good deal of time, say five years' worth of global emissions – for example 25 per cent of global emissions over 20 years. That means around 150 billion tonnes, and those in favour sometimes quote considerably higher figures. Australian scientists from CSIRO claim at least 3,500 large-scale geosequestration sites across the world would be needed to cut global greenhouse emissions by one billion tonnes of carbon dioxide a year.[17]

Carbon dioxide is a gas, the amount involved is a million times greater than that of radioactive waste, for example, and carbon dioxide will be just as effective a greenhouse gas in a million years or a billion years' time.

So far, over a period of over ten years, around a million tonnes of carbon dioxide per year has been injected into sandstone 1,000 metres below the seabed in the Norwegian Sleipner gas field in the North Sea, for the simple purpose of reducing greenhouse gas emissions to protect the climate. This carbon dioxide does not come from a coal power plant. It is separated from natural gas because this gas contains too much carbon dioxide to be sold on the markets. A million tonnes per year may seem like a lot, but it is nothing compared to the total amount of storage that would be needed. Add five zeroes and the problem moves into a different league. 100 billion tonnes of carbon dioxide potentially stored worldwide. It is possible that most of the gas can be kept in place forever, but leakage can never be ruled out completely.

**Sleipner – a special case**

The Sleipner Field is used as THE storage example. One million tonnes of $CO_2$ are injected annually into a saline formation, known as the Utsira formation. Is this number a viable amount that can be assumed to be achieved everywhere? Probably not: as the injectivity depends on the geological storage site parameters such as rock type, permeability and porosity. Actual operational experience in $CO_2$ EOR projects in North America for example is based on much lower well injection rates averaging 0.2 Mt $CO_2$ per year per well. If we look for example at a typical 1,000 MW coal fired power plant that produces 6 Mt $CO_2$/year, one would need to drill and complete six wells to inject the $CO_2$ if the Sleipner example is taken as approximation. If the US numbers are used instead you would need 30 wells plus the attendant bigger gas distribution system.[18] The US numbers are probably more realistic as Sleipner is an outstanding case, where $CO_2$ is injected into a highly permeable, loosely packed sand formation.

The Utsira formation is also taken as example for huge storage capacities of $CO_2$. However, as in the case of injectivity, we cannot compare the geological situation from one location to the next. Experience with geothermal energy, which also has huge potential, has shown how difficult it is to harvest such potentials.

# 5. The risks

### 5.1. Geological storage safe and sound?

At present, information about the potentially detrimental external environmental effects of carbon dioxide storage is far from complete. To get an idea of the possible impact on human health and safety we can only look at natural analogues. However, it has to be kept in mind that natural analogues are not the same as geological storage sites. Natural $CO_2$ accumulations were established over geological time frames, while $CO_2$ injection represents a compressed and therefore very different thermal, hydrological, geochemical and geomechanical perturbation of a rock system. As a result of underground carbon sequestration, structural changes could occur in geological formations, as well as modifications of the thermodynamic properties – and even dissolution – of underground geological layers. Both such geological modifications and the $CO_2$ injection process itself could involve seismic activity, with uncertain impact above ground, depending both on the site and option chosen.[12]

The impact on human health and safety is dictated by whether the release of $CO_2$ is dispersed or localised and whether the release rate is catastrophic or chronic. Regardless of the release rate, a high risk to human health and safety exists if $CO_2$ builds up in populated areas, in housing, other confined spaces or natural hollows on the ground. In high concentrations (above five per cent) carbon dioxide is deadly to humans and animals. Because carbon dioxide is heavier than air, a large release of the gas could displace the air in a valley and result in a disaster. One well-documented carbon dioxide disaster occurred by Lake Nyos in Cameroon in 1986, when more than 1,700 people died, along with cattle, more than 25 kilometres away from the source. The carbon dioxide was of volcanic origin. The probability of such disasters is likely to be small, particularly in relation to other everyday risks and in the global context. However it could be an important local concern in an environmental assessment.

A study by the International Energy Agency, *Prospects for $CO_2$ Capture and Storage* (2004), proudly points out that no leaks have been detected from the Sleipner field, where carbon dioxide has been deposited since 1996. It is clearly unsatisfactory to base a strategic decision on the fact that there have been no leaks from a given site over a decade, or at least that no one has noticed anything. There are, however, stronger indirect arguments to suggest that the gas will remain in place over geological timeframes – for example, the fact that natural gas has not leaked out, but is still underground. These are natural undisturbed storage sites. Injection of $CO_2$ however is a disturbance as wells are drilled. Although oil and gas have been shown to stay in place, $CO_2$ injection for enhanced oil recovery (EOR) at Rangely, Colorado USA nevertheless has shown that micro-seepage to the atmosphere occurs. The annual amount of $CO_2$ and methane ($CH_4$) dispersed in the atmosphere ranges from 170 to 3,800 tonnes $CO_2$ and 400 metric tonnes of $CH_4$ over the 78 $km^2$ area of the field.[19] Because free-phase $CO_2$ is lighter than formation water, the potential for upward leakage is enhanced by $CO_2$ buoyancy. Leakage may occur through natural geological features such as faults or fractures, perhaps enhanced by fluid over-pressurisation associated with the injection, or it may occur through human-created pathways such as existing wells.

### 5.1.1. Wells

Boreholes are critical. In the state of Texas in the United States, more than 1,500,000 oil and gas wells have been drilled. Precisely assessing the status of these wells is difficult since more than one-third have been abandoned, some more than a century ago. On the UK continental shelf alone the industry drilled about 4,000 wells, resulting in more than 285 producing fields during a 38-year run*. While most of those wells were probably sealed before being abandoned they are still not prepared to deal with $CO_2$. $CO_2$ in contact with water becomes acidic. The result is that cement fillings and bore hole casings can corrode. No one knows how long those plugs will hold. They could break down after 10 years, 100 years or a 1,000 years. Some people even say it is not a question if a well will leak but when.

* North Sea: The geological storage capacity for Europe has been estimated at up to 1550 Gt of $CO_2$, of which up to 1,500 Gt can be stored in deep saline formations, most of which are situated under the North Sea. This capacity is far away from the big clusters of large point sources in Europe[12]. This means that an extensive pipeline infrastructure will be required to transport the $CO_2$ from the various power plant locations in most cases through densely populated areas to the North Sea.

### 5.1.2. Water

Groundwater is a precious resource. It is the largest source of drinking water available, but only 0.62 per cent of the total amount of water on earth.[20] Like surface water, groundwater is vulnerable to contamination from a variety of sources. Leaking $CO_2$ storage sites are one possible source from which $CO_2$ and/or displaced brines can migrate upwards along faults and charge shallower groundwater systems. Groundwater is connected to surface water at the hydrological cycle, and some aquifers feed springs and rivers. $CO_2$ dissolving in groundwater hydrolyses to form carbonic acid, altering the pH of the fluid. Because pH is the important variable in water-mediated chemical (and biological) reactions, a pH shift causes changes in geochemistry, water quality, and finally ecosystem health. Mobilisation of (toxic) metals, sulphates, chlorides and contamination could reach dangerous levels, excluding the use of groundwater for drinking or irrigation purposes. Environmental impacts could be major if large brine volumes with mobilised toxic metals and organics migrated into potable groundwater.

#### 5.1.3. Monitoring and remediation

One problem with storing $CO_2$ in geological formations is the ability to actually monitor what is happening to the gas. Take for example the Sleipner field in the North Sea. Even though highly advanced technology has been developed to study geological formations using seismic methods, small amounts of released $CO_2$ may not be detected, especially when the release occurs far away from the injection site. Small fractures may not have been mapped before injection started. $CO_2$ could also activate old fractures or create new pathways in the cap rock, and escape through it. But even if the storage site is gas-tight, pressure build-up by the injected $CO_2$ is likely to have an impact on overlying formations. Although no $CO_2$ may escape from the storage site, the seabed contains natural $CO_2$ and methane from biological processes that could be squeezed out and released into the water.

On land, plants act as tracers for slow seepage. They can be used to detect $CO_2$ seeping into the soil. If the same thing happens on the ocean floor it may remain unnoticed for a long time, if at all. The displacement of brines would be almost impossible to detect.

Even if a leak from a reservoir is eventually discovered, the question then is what can we do about it? What technological options exist for sealing a leak from a reservoir many hundreds of metres beneath the seabed, and what will be the eventual cost? Who will be responsible for monitoring and sealing leaks in the longer term is still unclear.

#### 5.1.4. Global warming

Next to local impacts, the big question is of course whether carbon dioxide may leak out into the atmosphere to any significant extent, thus giving rise to delayed global warming.

Leakage of $CO_2$ back into the atmosphere has been recognised in the context of the global carbon balance as being unavoidable in the long term but acceptable if it is small enough. The IPCC report on carbon dioxide capture and storage states that it is very likely that the fraction of stored $CO_2$ will be greater than 99 per cent over 100 years, and likely that the fraction of stored $CO_2$ will exceed 99 per cent for 1000 years. This may well prove to be true, but risk assessments cannot assume that the most probable event will happen; they must of course also examine scenarios with lower probabilities, of the order of a few per cent.

If large amounts of $CO_2$ are stored, even a small amount of leakage from an injection site could compromise long-term efforts toward atmospheric $CO_2$ stabilisation. Pacala[21] describes this with an example: “If one per cent of sequestered fossil carbon were to leak into the atmosphere annually, then one trillion tonnes of sequestered carbon would create ten billion tonnes of annual emissions, compared to the current annual total of seven billion tonnes". Sizeable leakages can lead to a substantial backlash in the form of an, admittedly delayed, temperature increase of more than 1°C compared to the case of perfect storage.[22]

The definition of what is "small enough" is still under discussion. Acceptable leakage rates in the literature usually vary between 0.01 per cent and 1.0 per cent leakage per year, where the per cent fraction is defined as the volume leaked globally in that year, compared to the total volume stored. Leakage of $CO_2$ back into the atmosphere is also sometimes called "seepage".

The acceptable leakage strongly depends on what stabilisation target is chosen: 350, 450, 550 ppmv or even higher. Seepage rates must be less than 0.01 per cent/year to be acceptable for stabilisation below 550 ppmv, while a seepage rate of less than 0.1 per cent/year would be acceptable for 650 and 750 ppmv scenarios.[23]

However, a study has shown that even 0.01 per cent is not acceptable at all. Haugan and Joos[24] studied the climatic impact of capturing 30 per cent of the anthropogenic carbon emission and its storage. Because of the large amounts of $CO_2$ stored, an annual leakage rate as low as 0.01 per cent would still result in global warming. In the long-term over the coming millennia the impact becomes even larger than in the absence of capture and storage and moving to renewable energies directly. Avoiding dangerous climate change and preventing global warming from exceeding 2°C above pre-industrial levels translates into global greenhouse gas reduction requirements in the range of 85 to 50 per cent in 2050 compared to 2000 emissions.[25] Future allowable emissions would be cut further by leaking storage sites. In the worst case leaking $CO_2$ could equal or even overturn allowable emissions.

The study by Haugan and Joos indicates that global average leakage rates should therefore be less than 0.001 per cent per year. This implies that reservoirs are to be monitored over long time periods (centuries to millennia) to verify the effectiveness of avoiding emissions from carbon capture and storage schemes. Strong guidelines and an independent entity that oversees all storage activities are needed to minimise this risk.

In the end there are still serious concerns. It is relatively easy for unprincipled technical personnel to claim that CCS can be accomplished safely. There is no way to "demonstrate" that $CO_2$ can be stored underground forever. No matter how long you run your test, it could always fail next year as leaks develop. So "successful" $CO_2$ storage cannot be demonstrated. No wonder that industry does not want to take liability.

There is a growing realisation among utility industry leaders worldwide that so-called clean coal may not be able to address rising emissions from power generation for at least the next decade. Clean coal technology, involving trapping carbon in waste gases from coal-fired power plants and disposing of it underground, may not be commercially viable until 2025.[26] And it could take another 15 and 20 years and cost "hundreds of millions of dollars" to retrofit coal-fired power stations with carbon-capture technology.

# 6. Who wants CCS?

## 6.1. The industrial cluster

### 6.1.1. Coal

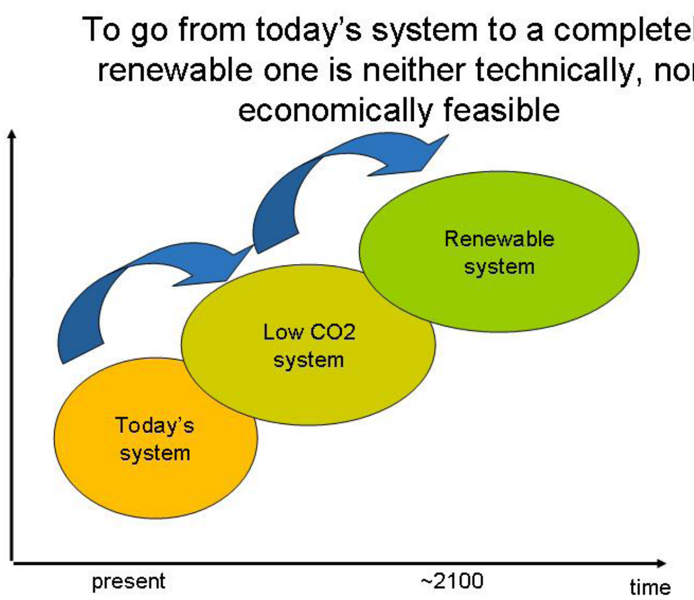
Those who are pushing for CCS are mainly the coal industry and governments of countries that have a lot of coal and coal power plants, as well as some oil and gas nations such as Norway and Canada. One of the main reasons why CCS is also being discussed widely in Sweden even though Sweden has neither coal nor oil is probably explained by the fact that the government happens to own the energy utility Vattenfall, which through its brown coal operations in Germany emits much more carbon dioxide than the whole of Sweden. In 2006 Vattenfall actually emitted 91 million tonnes of $CO_2$ while Sweden emitted 51.5 million tonnes.

Coal power is the worst method of producing electricity from the climate perspective. A serious climate policy would hit the coal industry and coal-dominated power industry very hard.

In the past, the US coal industry has for example often denied that there is any climate problem, and has made donations to opinion-building and lobbying organisations such as the Climate Coalition, Cooler Heads Coalition, Competitive Enterprise Institute to question the science. This approach has mostly failed. Now they are pinning their hopes on CCS, or perhaps more precisely, they hope that enthusiasm for CCS will win them time to continue extracting and using coal.

Coal is politically popular in many countries. Or more to the point: in many circles it is politically highly unpopular to take measures that endanger the coal industry. The power industry is well organised in all countries.

The image below is taken from a presentation that was given by Lars G. Josefsson, CEO of the Swedish energy company Vattenfall, on 13 October 2005 at a climate seminar organised by the Swedish Environmental Protection Agency, at which Al Gore was the main speaker.



It says a lot about how Vattenfall and many other power companies with a large stake in coal power and nuclear power see the future. The timeframe means waiting until around 2075 before we even begin the transition to renewable energy.

Vattenfall and a number of allied companies in the coal and nuclear power industry have also strongly opposed earlier ambitious climate targets for Germany and the EU, pointing to the opportunities that CCS offers if the big reductions are postponed until 2040 instead of 2020.[27]

In many respects CCS is not, as often portrayed, a *supplement* to renewable energy, energy efficiency measures and lifestyle changes, but an *alternative* to them – obviously not forever, but for the foreseeable political future.

**Either** we invest a few thousand billion euro in wind power, solar panels, biomass and energy efficiency measures, and make the lifestyle changes needed to meet the emission targets that follow from the EU's two-degree target to limit temperature rise to two degrees above the pre-industrial level.

**Or** we make preservation of our lifestyle the greater goal and invest the same amount in CCS and nuclear power. At the seminar mentioned above Lars G. Josefsson also expressed his support for "the American way of life", to the obvious irritation of Al Gore.

It's either or. The same money can't be spent twice.

For Vattenfall and other power companies with a large share of brown coal and bituminous coal, such as RWE, a committed climate policy is not just a distant threat. In November 2006 the EU Commission showed that it is serious about emissions trading by sharply cutting allocations of emission rights. There is therefore a real threat that the prices of emission rights will rise, at the same time as the power companies are forced to buy a large share of the rights they need. In January 2008 the EU Commission released with its Energy Package an outline for emissions trading after 2012.[28] The time of free allowances for the energy sector would then be history. It is planned that all emission rights will be sold by auction. This could lead to a 10–15 per cent rise in electricity prices.[29] Assuming, for example, that the price of emission rights in 2013 is 25 euro and that Vattenfall plans to make 90 million tonnes of emissions that year and needs to buy them instead of being allocated for free. This would mean an additional cost of more than two billion euro for Vattenfall per year. This would greatly reduce the value of the brown coal operations of Vattenfall and RWE. It is a pressing issue, as this loss of value will occur pretty soon.

### 6.1.2. Oil

Oil is still the big market. Rising oil prices provide big income for some, but also drive the need for change. Giants such as Shell, BP and Exxon have the opportunity to choose their path. Big demand for various oil products is guaranteed for many years to come, and the oil companies, which have a lot of money and wide-ranging expertise in areas from research to marketing, will also be able to gradually adapt to the requirements of climate policy, and switch to developing biofuels, pellets, wind power and solar power or hydrogen. This does not apply to the oil-producing countries however. BP can survive in a future "Beyond Petroleum", but Saudi Arabia's oil-dependent power cannot, and Exxon believes, rightly or wrongly, that it cannot do so either.

The oil industry, unlike the coal industry, is not compelled to believe in CCS, but it still largely leans that way. This is partly because injecting carbon dioxide into old boreholes is seen as a way of extracting more oil and making money on existing emission rights or through CDM projects in developing countries, while at the same time gaining kudos for environmental efforts. But they are also keen to eke out dwindling oil reserves by producing oil from coal, tar sand and oil shale.

### 6.1.3. Nuclear

The nuclear power industry is also fighting for its future existence, particularly in Germany, but in reality everywhere. A few reactor orders are being placed, but many more are being shut down. The global stock is ageing, and in countries such as Sweden, Belgium, Spain, Great Britain, USA and Canada, slow decommissioning is a likely scenario. It is largely the same power companies that have interests in nuclear power and coal power, and some of the heavy industrial companies that build turbines, generators and the like are also linked with nuclear power and coal power.

It is mostly other sectors of industry that are supporting renewable energy and energy efficiency. They are also less well organised and often satisfied with a supplementary role rather than claiming their place as a strategic alternative.

## 6.2. An unfortunate alliance

It is no surprise that there is a large industrial network that fears radical change. Vattenfall for example is not just an isolated company in a little corner of the planet. Vattenfall is the co-ordinator of the 3C Combat Climate Change project, which involves some of the world's biggest companies, mainly in the coal and nuclear power sector, including companies such as:

- Alcan (an aluminium corporation with almost 70,000 employees and emissions of 41 million tonnes of $CO_2$ equivalents in 2004)
- Alstom (large French builder of power plants, trains, etc.)
- Areva (nuclear power manufacturer)
- Duke Energy (coal power plant with 116 million tonnes of $CO_2$ emissions in 2005),
- Enel (partly state-owned Italian power company operating in several eastern countries, 56 million tonnes $CO_2$ in 2005)
- Endesa (Spanish power company, 46.5 million tonnes of $CO_2$ in 2006)
- EnBW (large German power company, mostly nuclear power and coal)
- E.On (coal and nuclear power dominated German power generator and gas company, 120 million tonnes of $CO_2$ emissions in 2005, in process of buying Endesa, above)
- Eskom (state-owned South African power company, coal-based but some nuclear power)
- General Electric (builder of power plants, including coal, USA)
- NRG (coal-dominated US power company)
- Siemens (builder of nuclear plants, coal power plants, etc.)
- Unified energy systems of Russia (the world's largest or second largest electricity generator with 635 TWh electricity output, state-owned, main supplier of electricity and district heating in Russia)
- Suez – very large Brussels-based international power and gas company

On the surface the message of Combat Climate Change is reasonable. It sounds as if they have an insight into the problems and are proposing measures with a long-term global view. But when it comes to the timeframe they talk about the year 2100, and when it comes to the target for stabilisation they say 550 ppm carbon dioxide equivalents. This is incompatible with the two-degree target, which is more likely to require stabilisation at the 400–450 ppm level. In its new report "The Climate threat" [30] Vattenfall has taken over the 450ppm target that implies a reduction of 27 billion tonnes of $CO_2$ by 2030 globally.

Many of the companies listed above are also members of another initiative known as the Global Roundtable on Climate Change, but this also includes "good guys" such as the World Council of Churches, big reinsurance companies, representatives of renewable energy, Ricoh and a number of academic institutions, as well as a few more of the worst global polluters, including the aluminium company, Alcoa, and the coal and mining giant, Rio Tinto.

Their message is numerically more vague, but gives clear support to CCS and nuclear power alongside renewable energy.

The alliance between the coal industry, oil-producing countries and certain oil companies is very apparent at sector meetings for the climate convention. Always pushing for the recognition of nuclear power as an accepted climate change mitigation option, they are also pushing for inclusion of CCS into the Clean Development Mechanism CDM. A decision is expected at the upcoming United Nations Climate Conference end of 2008 in Poland.

**CCS in the CDM**

The Kyoto Protocol with its Clean Development Mechanism (CDM) provides a way to encourage industrialised countries to undertake cost-effective climate-friendly projects in developing countries in order to achieve sustainable development. Whether CCS could be part of the CDM is under ongoing heavy discussion.

While industrialised countries hope to reduce the costs of this technology by developing, testing and deploying CCS projects in developing countries, a number of environmental NGOs as well as countries like Brazil are against including CCS in the CDM. The reasons for their concern are, for example, that CCS is inherently unsustainable since it increases the loss of fossil resources while increasing environmental impact, as well as burdening future generations with the need to monitor stored $CO_2$ for safety and climate reasons, and remediate in case of leakage. [31]

Instead of putting CCS in the CDM, which would have no net benefit for the climate but instead allow industrialised countries to offset their own emissions, CCS should be placed in a new technology mechanism in the future Copenhagen Climate Agreement.

In the past some industrial stakeholders have tried to deny the scientific basis (IPCC) for climate policy, but that position has become untenable. The climate threat can no longer be denied. It requires a solution. Those who want to defend the existing industrial structure and lifestyle must be able to point to a technological strategy that makes it compatible with reduced emissions. That strategy is CCS.

Behind the grand reasoning there naturally lies a self-serving but understandable will to protect existing investments. It cannot be easy to face the prospect of having to close coal power plants that are 10–20 years old and still have an expected remaining life of 20–30 years.

## 6.3. Vattenfall

Vattenfall,[32] one of the biggest Swedish state-owned companies, seems to be a particularly activist company. Its charismatic CEO, Lars G. Josefsson, is an advisor to the Swedish and German government on climate change. This is amazing. How can a leader of a company whose portfolio is mainly based on brown coal become a climate advisor in Germany?

### 6.3.1. Emissions cut by half in 2030

This is what governments want to hear from an industrial climate advisor: "We have already achieved a reduction of 30 per cent since 1990, and our goal will thus be to cut emissions by a further 20 per cent by 2030," said Vattenfall's President Lars G. Josefsson, in his speech to the annual general meeting (though there is only one shareholder) in April, 2007. This cut was to be achieved while maintaining or even increasing energy production levels.

What's the value of such a statement? At the moment we only see the second part – increasing energy production levels, to move forward. The seeming discrepancy becomes clear if the timeline and numbers are looked at in more detail: Back in the 1990s, Vattenfall benefited from the takeover of inefficient power plants of East Germany. This takeover resulted in a jump in emissions that form the baseline for reduction (Vattenfall estimates its emissions to be 135 Mt $CO_2$ in 1990[33]). It was essential to modernise the system and thus reduce emissions of various pollutants. But $CO_2$ reduction was mainly the result of the de-industrialisation of East Germany. Power demand fell drastically, as in all ex-communist countries. It is easy to be an environmental hero in such a setting.

The more interesting aspect is what has happened since the late 1990s. Emissions rose sharply in 2000 when block IV of the Boxberg lignite power plant started producing electricity. Current emissions are around 75 Mt $CO_2$. To achieve a 50 per cent cut by 2030 Vattenfall would only have to reduce emissions by a further 10 Mt$CO_2$ by 2030.

In its study "Curbing climate change" Vattenfall proposes a global cap and trade system in which national permit allocations are based upon Gross Domestic Product. What Vattenfall is, in effect, claiming is the right to economic growth – even for already wealthy countries. Under such a scenario economies could receive more permits than they need. Put simply, a country like Sweden with a carbon output of about 40 per cent of the world average, if it receives a permit allocation of 90 per cent of the world average, would then have a permit allowance more than twice the size of its current emissions.[34] Could it be that ultimately Lars G. Josefsson is endorsing "the right to economic development" simply for the benefit of his company?

Vattenfall makes good money from its coal power plants and enjoyed its share of the windfall profits that the EU's Emissions Trading System has delivered to the power sector. Vattenfall actively supports nuclear power and CCS. While Vattenfall is still sharing the table with German chancellor Merkel it has lost the trust and acceptance of the public. A series of incidents at its Krümmel and Brunsbüttel nuclear facilities (as well as at Forsmark in Sweden) was the starting point of the decline in 2007 that continued with Vattenfall's rise in consumer electricity prices, its plans to build new coal power plants, and to open new lignite mining areas in Germany. The image loss had personal consequences. Within half a year, two German CEOs lost their posts.[35] A big advertising campaign did not help to recover the damaged image. More than 200,000 customers left the provider that year.

Despite these setbacks, profits rose in the first three quarters of 2007 for the German branch of Vattenfall, whereas profits for the whole group fell. Analysts say that the German increase resulted mainly from increased feed-in of renewable energy (mainly wind from other companies) into the grid Vattenfall owns. This does not mean that Vattenfall is becoming greener, at least not in Germany where the share of new renewable energy (excluding old hydro power) is below one per cent. Sixty-three per cent of Vattenfall's electricity production in Germany comes from brown coal, a total of 7,420 MW. Looking at investment plans the gap between renewable energies and coal increases further even if planned wind energy activities in Sweden are taken into account (as of 02/2008):

*Planned coal power in Germany*
Boxberg[36], Sachsen (brown coal) – 675 MW (5.0 Mt $CO_2$/yr[37])

Lichtenberg, Berlin (hard coal) – 800 MW (4.5 Mt $CO_2$/yr)

Moorburg, Hamburg (hard coal) – 1,680 MW (8.5 Mt $CO_2$/yr)

*Planned wind in Germany*
Alpha Ventus[38], north of Borkum – 60 MW (33% share = 20 MW)

*Planned wind in Sweden*
Lillgrund, Sweden – 48 turbines 110 MW

Kriegers Flak, Sweden – 128 turbines 640 MW

Dan Tysk, Sweden – 80 turbines 400 MW (extension possible)

In the long term (until 2030) Vattenfall Europe plans to cover ten per cent of its electricity production with renewable energies in Germany.[39] This is not the contribution to climate protection one would expect from Vattenfall as a committed fighter for staying below 2°C. In contrast, the German Government plans to increase Germany's share of renewable energy in electricity production to a quarter by 2020. Aiming for just ten per cent by 2030 also contradicts Vattenfall's own studies, in which renewable energies are assumed to amount to 15–20 per cent of power production by 2030.[40]

Between 2007 and 2011 Vattenfall is going to invest a total of around 11 billion euro in the development and renewal of its energy production and distribution systems. This includes improvements to existing plants, life-extensions of nuclear power reactors, new and more efficient coal power plants, CCS, new methods of electricity production without fossil fuels, and research and development. [41] In a press statement in April 2007 Vattenfall is a bit more precise about where the money is primarily going: "A large proportion of these investments will go towards the long-term objective of reducing emissions of carbon dioxide from Vattenfall's own plants to zero". [42]

### The court case "$CO_2$-free"

Vattenfall does not hesitate to promote its CCS-ready power plants as being "$CO_2$-free". In December 2007 the district court of Berlin in Germany finally prohibited Vattenfall from using this term for its pilot project at Schwarze Pumpe. The court followed the arguments of the complainant, a photovoltaic company, that power plants equipped with CCS technology of course produce $CO_2$, even though the gas will not go into the atmosphere but into geological storage formations deep underground. If Vattenfall continues to use the term in German ads a disciplinary penalty of 250,000 Euro is to be expected.

### 6.3.2. Running for brown coal

Nearly 50 million tonnes per year of brown coal are mined by Vattenfall to feed its coal power plants in Germany. The Swedish State, in the guise of the government-owned Vattenfall concern, has already destroyed the listed Wend village of Horno in the Lausitz region. New plans are now on the table to open additional opencast mines and to continue destroying landscapes and displacing people:

- Reopening Reichwalde (closed since 1999) – from 2010 onwards 15,000 t brown coal per day will be needed to feed the new Boxberg block. The existing Boxberg blocks (1,900 MW) will continue to be supplied with from 50,000 t/d by Nochten mine.
- From 2025 onwards opening of a new brown coal mine is planned. The new field of Welzow II would resettle 1,200 people from 2015 onwards.
- A new opencast mine is planned at Jänschwalde-Nord which would deliver brown coal for around 20 years starting in 2028. Resettlement of 900 people would be necessary after 2020.
- In a second step it is planned to apply for two new opencast mines from 2035 onwards. These two fields Bagenz-Ost and Spremberg-Ost could run without resettlement of villages.

Agreement was reached with the state of Brandenburg in September 2007 for three new mines: Jänschwald-Nord, Bagenz-Ost, and Spremberg-Ost. Local protesters, environmental organisations, as well as parties (Lefts and Greens) have started a public request against these plans.

### 6.3.3. CCS lock-in

Vattenfall is pushing strongly for CCS. The result of pilot activity is small so far if compared to the conventional coal power plant activities.

*CCS plans* [43] *:*

- Pilot Schwarze Pumpe Oxyfuel 30 MW under construction start 2008
- Demonstration Jänschwalde Oxyfuel 300 MW around 2015
- Possibility to test retrofit of one boiler in Jänschwalde by middle of next decade
- Between 2020 and 2030 retrofitting of all conventional blocks at Jänschwalde

The Vattenfall Oxyfuel pilot plant at Schwarze Pumpe is 30 MW in size with 40,000 hours operating lifetime over 10 years, starting in 2008. It will prove that $CO_2$ can be produced, separated and stored, but it is not a model-scale power plant.

The power plant would have to compensate for losses through its own feed water production, and supply condensate water. [44] The $CO_2$ from the plant will be transported by trucks to the Altmark, more than 300 km from the plant. 100,000 t $CO_2$ will be injected over three years into an aging gas field to enhance gas recovery. [45]

Vattenfall assumes that CCS will be technologically proven by 2015–2020. [46] An implementation rate of ~85 per cent among coal new-builds is assumed between 2020 and 2030, at a cost of up to 40 euro $CO_2$ abatement cost in 2030. So far this is all theory. Technologically proven does not mean commercially or economically viable. What in reality is on the table are new coal power plants, some of them already under construction (Boxberg), others in preparatory construction (Moorburg) or at the planning stage (Lichtenberg). If Vattenfall's plans go through, additional emissions of 18 Mt $CO_2$ will be added to fuel climate change annually at a time when global emissions are supposed to peak and emissions need to decline. It is highly unlikely that old power plants of the same size will be closed. For example, in the case of Moorburg (1,680 MW) only 300 MW of capacity are expected to be shut down.

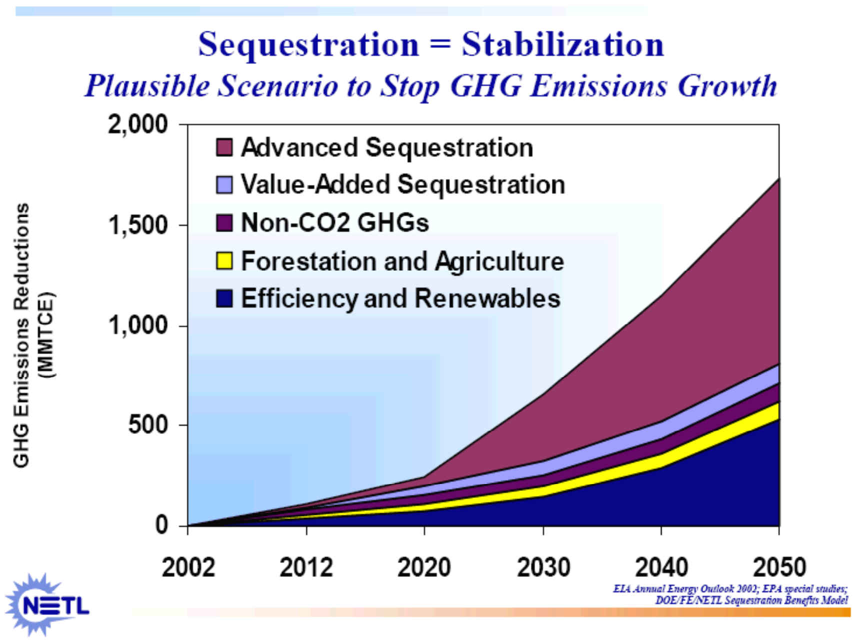
With the new coal power plant plants there is no other way out than to go for CCS, whether this technology is commercially ready or not. What matters is the statements and alibi projects. The German government is more than happy to believe in Vattenfall and its CCS plans. One thing must be clear – following Vattenfall's path means to become trapped in a fossil energy structure with no other way out than to store all the $CO_2$. Big utilities will certainly not be taking over responsibility if CCS fails to deliver in terms of technical, commercial, and economic needs (nor would they be willing to take over liability for $CO_2$ storage sites in the medium to long term). However, we will still be left with coal power plants that are destroying the climate. Josefsson's answer to the question of what would happen if CCS does not work in time:

"Then we have a real problem. Then we must build the dykes higher". [47]

# 7. The political dimension

## 7.1. The big fossils

The EU is very positive towards CCS, and the USA even more so, especially under the current Bush administration. According to the US Department of Energy, the future could look as follows:



It is clear from this diagram that CCS is intended to be the main method for reducing greenhouse gas emissions. This is a welcome message in the USA, which has a large and politically influential coal industry and a power industry that is dominated by coal. It also goes down well in Japan, which is heavily dependent on coal, in Australia, which is the world's biggest exporter of coal, and in Canada, which also produces a lot of coal. In the EU the coal industry is clearly declining, but it has no plans to quit. In Germany the coal industry enjoys massive government subsidies and has strong political support.

Coal is admittedly not a big employment factor in the USA and Germany, but for certain communities and regions it is still a highly emotive issue. CCS offers a sought-after opportunity for politicians to put off dealing with the problems.

Although the US Bush administration has not joined the UNFCCC Kyoto parties and is not willing to accept binding reduction targets it is very active in (co)-launching all kinds of initiatives that aim to improve and transfer coal-technologies for reducing greenhouse gas emissions. The Asia-Pacific Partnership or the CSLF (Carbon Sequestration Leadership Forum) is a forum in which CCS is heavily promoted. In many of the developed countries, in the OECD, and the International Energy Agency (IEA), there is also an established view of coal as a strategic resource as opposed to oil and gas, which are mainly produced outside the OECD countries.

### 7.1.1. Three countries one goal

An aging power plant fleet is the main driver for CCS in countries such as the UK and Germany. In both countries approximately 20 to 25 gigawatts of new power stations "will be needed by 2020". The UK government has started a competition to develop demonstration of carbon capture and storage for power generation on a commercial scale, and has given up its opposition to the construction of new nuclear power stations. However, a large number of new coal-fired power plants is in the planning stage. The theoretical possibility of CCS is being used by government and industry as a wedge to drive through new coal fired power stations. In the UK Kingsnorth 2, and others like Tilbury, Blyth, Ferrybridge, High Marnham, Longannet and Cockenzie, would each emit millions of tonnes of $CO_2$ and are NOT CCS plants. The same is happening in Germany. Up to 25 coal-fired power plants are in the planning or construction stage and would emit, if all built and running on base load, more than 120 million tonnes of $CO_2$ annually.

**Table: Fuel used for electricity production (2007) in UK, Germany, Norway.**

| % | UK[48] | Norway[49] | Germany[50] |
|---|---|---|---|
| Coal | 34 | | 24 (Lignite)<br>22 (Hard Coal) |
| Nuclear | 15 | | 22 |
| Gas | 43 | | 12 |
| Renewables | 1 (Hydro) | 99.3 (Hydro) | 14 (Wind 7, Hydro 3, Biomass <4, Photovoltaics 0.5) |
| Others (include oil) | 5.5 (oil 1) | | 6 |

A large share of coal in electricity production is not the only driver of interest for CCS. This is the case for Norway, whose electricity production is almost entirely based on hydro power. What Norway has is a relative abundance of oil and gas from offshore fields in the North Sea and further north on the continental shelf outside the coast. In

2006 Norway was the 10th biggest oil producer, but the 5th largest oil exporter in the world. The Norwegian oil and gas industry as such may not depend heavily on CCS as part of a long-term solution, as it is expected that oil and gas exploration will peak soon and decline afterwards. Interest in enhancing oil and gas recovery diminished due to the technological complexities of retrofitting existing oil production platforms, where space and time are very costly. The Norwegian government however is still pushing for CCS, as it wants to build gas-fired power plants in Norway. The government's pledge to build full-scale CCS plants at gas fired power stations for general supply; including one currently in operation (Kårstø) and another under construction (Mongstad) has also been a hot issue. On 18 December 2007 it was decided that the planned gas fired power plant at Mongstad will be equipped with a CCS plant, but not from the start of operation. A test plant will be built first, which will probably be operational by 2011. The decision to build a full-scale CCS plant at Mongstad will not be taken until 2012, after analysing the results from the test plant. A full-scale CCS plant will not therefore be operational until 2014, at the earliest.[51] CCS is part of the Norwegian government's plan to fulfil its Kyoto obligations (along with buying emission credits from abroad and explaining its interest in including CCS in the CDM), and in a longer timeframe, become carbon neutral. This goes a long way towards explaining the big interest that Norway is currently showing in CCS. [52]

### 7.1.1. The IEA

The IEA was formed in 1974 as a counterpart to the oil cartel OPEC, and ever since then has been promoting coal and nuclear power, and more recently energy efficiency and renewable energy. The IEA's raison d'etre is "security of supply", by which it means that "we" should have as much energy as we feel we need at a price we find reasonable. This is why the IEA exists; it is why the member countries finance this organisation. The same spirit is reflected in everything the IEA does, in its regular energy studies of member states, its World Energy Outlooks and its technology reviews. Much of the work published by the IEA is good, useful information, but its perspective is incompatible with the insight that the Earth is a planet with limited resources. All the IEA's graphs point upwards, and despite the fact that they have often proved to be very wrong, the IEA's forecasts are usually treated with the greatest respect.

In the IEA's reference scenario in the World Energy Outlook 2006 it is assumed that coal consumption will increase from 2,773 million tonnes of oil equivalents (Mtoe) in 2004 to 4,441 Mtoe in 2030, with a similar rate of growth for oil, gas and hydroelectric power, and slightly lower for biomass and nuclear power.

This is heading straight for the precipice, but it is still taken as the plain truth in public debate.

And if you believe in the coal forecasts then you naturally have to believe in CCS, because otherwise everything falls apart.

The IEA has (by co-ordinating research and development) encouraged the production of liquid fuels from coal and "unconventional" fossil fuels such as tar sand. Such technology is economically now fully viable because of oil price trends in recent years. Environmentally it is, to say the least, problematic, and the carbon dioxide emissions would be even greater than if oil were used instead.

This little problem can now be solved, however, if it is assumed that CCS is on the way.

The same applies to hydrogen extraction from coal. This technology is a little further off, but on the other hand provides a complete vision of how we can move beyond the age of oil. If a hydrogen infrastructure is built up on a fossil fuel base it can then move to nuclear power, fusion or some futuristic solar energy solution – leaving our social structure and lifestyle unchanged.

CCS therefore gives us a clear choice: to use the tools we (humanity) have to quickly reduce emissions of greenhouse gases; to develop what we have within sight but not within reach, and to take the consequences this may have on our lifestyles and social structure – or to invest everything we have in the hope that CCS will deliver.

### 7.2. CCS and the IPCC

The Intergovernmental Panel on Climate Change (IPCC) is probably the most highly accepted global organisation that deals with climate change issues. Its efforts were honoured with the Nobel Peace Prize in 2007. The best known series of reports are undoubtedly the assessment reports on climate change. The fourth assessment report was released 2007.

Established by the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP) in 1988, the IPCC is both an intergovernmental body and a network of the world's leading scientists. It does not conduct new research. Instead, its mandate is to make policy-relevant as opposed to policy-prescriptive assessments of the existing worldwide literature on a given topic. Many hundreds of experts around the globe write the reports. All reports contain a so-called Summary for Policy Maker (SPM) that is approved by government officials.

Governments not only approve the SPM. They also provide the money for the work of the IPCC. In addition they decide what kind of reports are to be prepared. Such decisions are highly political. What choice will you make if you have the capacity and budget for a single project but there are three or more on the table? The loser in this game in the past has been renewable energy. Instead, the world got a Special Report on Carbon Dioxide Capture and Storage, released in 2005. There is no doubt that this report was right on time, as CCS was getting more and more attention, but very important information was missing. Since then the report has been used to push for CCS while a comprehensive report on the worldwide prospects and potential of renewable energies is still missing. It was only recently, in early 2008, that a meeting was held to decide on the scope for preparation of a special report on renewable energies. It is again the dirty coal players and big fossil fuel nations, such as the USA, who are blocking important information that could put the current energy system under question.

### 7.3. CCS and research

There is not much published scientific criticism of CCS. This is not especially surprising. The power industry gives its own money to CCS research, and lobbies successfully for public money to be used for the same purpose. The questions usually asked are:

How can carbon dioxide be separated, transported and stored? What will it cost? What environmental problems will this give rise to and how can they be solved? What are the potential legal problems?

As yet, CCS is far too unspecific to be an obvious target of critical examination. Critical investigation of CCS is not fundamental research, nor is it high-profile research.

At the same time no one can honestly state that it is not possible to separate carbon dioxide, since it can demonstrably be done. Clearly it is also possible to transport carbon dioxide in long pipelines and force it into the ground. It is also possible to quote almost any figure for the likely cost, some 10 to 20 years before the technology is ready for large-scale use.

It is possible to find scientifically well-defined questions that should be highlighted, and to some extent this is being done, such as in models for leakage from different types of strata, or more realistic economic calculations in the form of energy system analyses. But grants are not available for every area of research, and every application does not get a grant.

This could change, and perhaps quite soon. The EU Commission's proposal to build 12 large plants by 2015[53] must be financed either by tax revenues or by compelling the power industry somehow. In the latter case the power industry will mobilise researchers and lawyers to protect itself against unreasonable economic commitments. But even if taxpayers have to stump up, opposition will be unleashed. Consultants' reports will be required and some of these consultants are likely to have or earn doctorates, etc.

This is not to say that the question will find its own solution. Fusion research has consumed vast amounts of money over a period of 50 years without producing a single kWh of useful energy. It is a scientific fiasco, an even worse technical fiasco and an unbelievable economic fiasco, but that has not stopped the money rolling in. For a long time the dream of fusion filled an important ideological role, and now that this has gone there are thousands of fusion experts left to defend their income and their life's purpose, and politicians who are unwilling to admit they have thrown that money away. On the other hand, if you are a politician in a big industrial nation and are told that fusion research could yield large amounts of very cheap energy, it is very difficult to refuse to contribute to research. The consequences could be very costly for a nation if fusion research succeeds and that nation has not invested in the technology. The nation would then have to buy access to this technology from others, or even worse, possibly be shut out and subjected to massive political pressure by those who master the technology. Control over vital resources gives massive political power. Russia's recent sabre rattling and confidence in foreign policy is a current example.

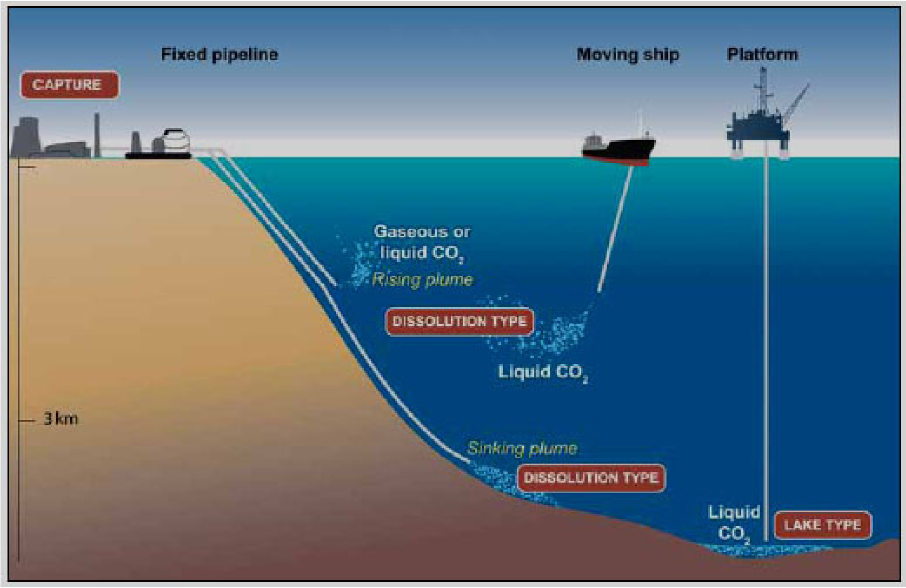
What role CCS finally will play is open. For now, increasing amounts of money are flowing into CCS research to answer many of the open questions. This money should not flow at the expense of other research fields, which will definitely happen if research budgets are not extended or if CCS is valued higher than other truly sustainable mitigation options.

### 7.2.1. Even wilder ideas: Ocean Uptake and Ocean Fertilisation

Research is also taking place in such unlikely areas as ocean storage (uptake), and ocean fertilisation. Countries such as the US and Japan have expressed their interest in these technologies.

Ocean Uptake involves pumping carbon dioxide down to great depths, where the gas is assumed to be stable vertically but can migrate sideways, naturally killing all oxygen-dependent organisms in its path. It is also expected that the $CO_2$ plume in the water column will be covered by an ice-like sheet of $CO_2$- hydrates that will prevent the liquid $CO_2$ from escaping or being diluted in the seawater. However, if the carbon dioxide eventually dissolves in the water it will contribute to the already observed acidification of the oceans (the pH has dropped by 0.1) and there are concerns that it will be a major problem in any situation.

**Figure from IPCC Special report Carbon Dioxide Capture and Storage (2005). SPM Fig.5 page 7: Overview of ocean storage concepts.**




Iron or Nitrogen Fertilisation of the Ocean is intended to stimulate phytoplankton growth. This naturally carries the risk that organisms that live on plankton will grow in numbers. If the plankton are not eaten but fall to the seabed instead, they will consume large amounts of oxygen and could cause bottom death, a phenomenon that is well known during intentional nitrogen fertilisation.

Enhanced Photosynthesis is likely to be difficult to achieve. The effect of the rising $CO_2$ level is more likely to favour the less efficient C3 group of plants at the cost of the C4 group. The above ideas are controversial in the research society, but they have been put forward since the 1980s and the US government takes them seriously at least.

## 7.4. The environmental movement

The environmental movement is deeply split on the question of CCS. WWF International, for example, wants to impose "strict requirements", as does EEB, while Greenpeace is critical. Many of those in the environmental movement who are perceived as examples and leaders in the climate issue, such as Al Gore, Amory Lovins, Thomas B. Johansson, Sir Nicholas Stern and Christian Azar, have expressed positive views.

The explanation for this lies partly in the role of the emission models. Modelling is an expensive and specialised business, and the model assumptions are often inherited from bodies such as IIASA[54] or IEA, and exclude many of the possibilities and threats, particularly when it comes to lifestyle changes.

The whole approach has an element of **prediction** of the future (with a fatalistic perspective), in contrast to the idea that the future can be **created** through a series of decisions. It is naturally hard to imagine the changes that will be needed to reduce global greenhouse gas emissions of 60 per cent by 2050, especially if there is an unspoken assumption that this must not cost anything! This is what makes CCS attractive to modellers, as a variable they can use to balance their equations. For people in the environmental movement outside this exclusive circle of modellers, it is almost impossible to make constructive criticism of the models. There is a sense of fear that the world is not able to achieve the 2°C target; that renewable energy and efficiency improvements cannot deliver enough power. Coal is here to stay, and we have to choose between the threat of climate change and CCS, with CCS acting the part of the joker. Another side of the same coin is that the environmental movement is sensitive to criticism of technophobia, and that it is generally disagreeable to reject a technology.

It is as if the burden of proof lies with the sceptic, not with those who are demanding an inconceivably big investment in a technology that does not exist, with the attitude that "it should be good if it works".

But CCS is not one of several options. It is not one of five or six eggs in the basket. It is more like the cuckoo's egg. As long as the young cuckoo is there the rest of the brood will not get enough resources to leave the nest (assuming they are not kicked out before then).

CCS places the environmental movement before a strategic decision that can only be compared with the decision over nuclear power in the 1970s. At that time many environmental organisations were fairly positive towards nuclear power, which was seen as an alternative to further hydroelectric plants, coal power and oil. But from the mid-1970s onwards almost the entire environmental movement around the world decided against nuclear power, and has generally stood by this decision ever since.

The principle of choosing the "lesser evil" was abandoned in favour of a more fundamental criticism of the "high-energy society" along with a more pragmatic distrust of scenarios that predicted the rapid and continued growth of energy consumption.

This paradigm shift was lasting. Within the environmental movement there has always been a tension between radical vision and the close contacts with the establishment that are necessary to achieve concrete goals. It has to be this way, but almost all environmental movements in the world have been critical of nuclear power for a long time.

Perhaps things will go the same way with CCS.

# 8. Common arguments for CCS

## 8.1. Argument 1: CCS is a stepping stone to sustainable development

Its advocates put CCS in a very special strategic niche.

CCS is obviously not an ultimate solution to the climate issue in the same way as renewable energy, or for that matter fusion power. Fossil fuels are an immense but limited resource. No one is saying that this is a lasting solution, since it cannot be sustainable to first dig up around 300 billion tonnes of coal, burn it, and then force 1,000 billion tonnes of gas into a hole in the ground and hope that it will stay there. Future generations have to take care of the storage sites. Wasting resources, fossil fuels and water, increasing environmental impacts due to mining, the need to build even more power plants to achieve the same output of electricity – that's not the idea of sustainable development. Wasting precious resources and creating storage sites to capture and bury $CO_2$ create a double burden for future generations. CCS contradicts the Brundtland definition of sustainable development that is meant to meet the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable development can only be achieved by renewable energies and efficiency. To get there you must go there. You don't need stepping-stones if you don't plan to cross the river.

### Digression: What could CCS be a stepping stone to?

The question then is what technological development could CCS provide a bridge to?

It is obviously not wind power, a technology that already provides an alternative to new coal power plants in many countries and is growing very rapidly. In the period to 2030 there may of course be technical and economic developments in wind power, but it works right now.

The same cannot be said of CCS. Retrofitting existing coal power plants with capture technology requires a number of rearrangements in the power plant. Because of the costs, efficiency loss, and space required, CCS will probably only be used in new coal power plants, oil refineries etc., and even then scarcely on a large scale before 2020 or later.

Similarly, CCS does not provide a stepping stone to solar heating, which is already a mature technology that is experiencing rapid growth. Neither it is much of a bridge to photovoltaics, which work well, but are usually much too expensive to compete with traditional power sources. The prospect of costs and prices coming down to an acceptable level within a decade or at least two decades must be judged as good, at least as good as for CCS.

Again, CCS is not a stepping stone to biofuels. A lot of development is clearly still required, for example in black liquor gasification, in second generation biofuels, in cultivation techniques, harvesting and refining energy crops, and in green chemicals technology. Improving the economics of biomass and improving its potential also requires other system solutions and greater integration with other areas of industry. But it is still difficult to conceive what type of development can be achieved in 70 years that cannot be achieved in 20 years.

This also applies to geothermal power and heating, and to hundreds of other types of energy efficiency measures. There is no convincing reason why something that cannot be solved in 20 years could be solved in 70 years.

*Why wait?*

The IEA's review of technologies[55] that could be important beyond 2030 also lists zero-energy buildings. However, buildings that do not need heating systems already exist. Much the same technology can be used to minimise the need for cooling in hot countries.

It is true that, considered individually, wind power, solar heating, geothermal energy and even biomass do not have enough potential to replace fossil fuels and nuclear power today. But in combination, along with improvements in energy efficiency and some changes in lifestyle, they can at least do most of the job – cutting global emissions by more than 50 per cent by 2050 compared with 1990 levels (or up to 80% compared to 2000 levels) as demonstrated in Greenpeace's energy [r]evolution.[56]

Solar energy on the other hand has almost unlimited potential. Solar cells and photovoltaics have been working since the 1950s and have improved greatly since then. Solar cells that collect and convert solar energy into electricity or heat for example are now produced on a large scale, in thousands of megawatts per year. Global production of solar cells in 2007 was 62 per cent up on 2006. The pace of development is also rapid, and there are many competing solar panel technologies and systems. This means there is potential for quite a steep learning curve, with costs falling for every doubling in production capacity. Improvements in performance and production technology are now also being encouraged by subsidies as a result of political decisions, etc. So far it is mainly a "political market". But that holds true also for its principal competitor, coal power.

The price of coal power is also determined by political decisions in areas such as the rules for emissions trading.

*Solar cells could arrive before CCS*

How long it takes before solar cells become competitive with coal power on a large scale in sunny latitudes depends mainly on political decisions, although there is also an element of chance. Large solar thermal power plants are already running in Spain. In the Mediterranean region a balanced mix of renewable energy technologies, including solar thermal power plants can displace conventional peak, intermediate, and base load electricity and thus contribute to truly sustainable development. [57] With scale-up, volume production, and technology development, the cost of concentrated solar thermal power plants is expected to drop to less than $0.05/kWh in 2012. [58]

It seems reasonable to assume that given the present political and economic trends, solar cells could become a commercial alternative to coal power in 10–15 years. If it does not "succeed" then there is no reason to believe that a further 50 years would make any great difference.

Wave power is an embryonic technology that has excellent potential if it is successful, but which requires unprecedented investment. As a result it has been something of a joker in the development of renewable energy. If it works then it works. But the factor that decides whether it works or not is not time in years, but investment. Once again: what can be done in 70 years can just as well be done in 20 years.

*A chance for nuclear power and fusion?*

To find good candidates for zero carbon technology that really can benefit from the CCS "stepping stone", we have to look beyond the renewable energy sources.

Fusion fits the bill perfectly, for example. We already know that fusion will not yield a useful kilowatt-hour before the end of the 2030s. Work could begin on the construction of the experimental ITER facility in 2008, and it is planned to be fully operational (produce fusion power) by 2021.[59] It will then take around 10 years of operation to produce the design basis for the next facility, the first that could generate electricity. Optimistically this could be done by 2040. However, this plant is hardly likely to be optimised for commercial operation, so a few more intermediate steps will be needed. If fusion research succeeds in producing a useful supply of energy on a large scale (many power plants) this is unlikely to happen before the 2070s.

The development of nuclear fission, as used by current nuclear power plants – could follow a similar timeframe. Existing nuclear power is not a sustainable solution for many reasons, including the fact that the resource base (uranium) is too small for major expansion beyond the current level. The next generation of nuclear power stations ("generation IV") could radically increase the resource base by using uranium 60–80 times more efficiently, or using a different element, thorium, which is available in greater amounts than uranium. The long lead times and the need for demonstrable operational safety and economics mean that it will take a long time to develop the technology, if it is feasible at all.

It is of course conceivable that an entirely new technology will be found, but it would naturally not be a good idea to gamble the future of humanity on that chance.

*Hydrogen society still a long way off*

The "hydrogen society" will also take a long time to realise, if it can or should be realised at all. There are no practical fuel cells available yet, and when they do arrive, car manufacturers will take time to make the switch, especially if this requires the simultaneous building of hydrogen production plants, distribution piping and fuel stations. If hydrogen is to be produced from any type of nuclear power or from coal in IGCC-CCS plants it will require a massive and complex infrastructure in order to match production to demand. This need will be even greater if hydrogen is produced by solar cells thousands of kilometres from consumers. A large-scale breakthrough for hydrogen is therefore most likely to take place after 2030.

In more general terms it will naturally take many decades to realise or at least come close to a sustainable society. It takes time to convert or replace transport systems, cities and homes, to expand district heating and district cooling, etc. But the rate of transformation will also depend largely on the resources that are devoted and on the effectiveness of political control. Whatever happens we cannot expect CCS to automatically mean a reduction in the number of out-of-town shopping centres, better building standards or better public transport in the short term, medium term or long term.

### 8.1.1. CCS – a bridging technology?

Proponents of CCS argue that renewable energies need more time to play a large role. Therefore coal with CCS is needed to bridge that time span. But CCS is not a short-term option either. The technology will require a number of years of research and development, followed by a long period of implementation. In the meantime renewable energies are making their way and keep on avoiding millions of tonnes of $CO_2$ year by year. In Germany alone renewable energies have so far eliminated 115 Mt of $CO_2$ emissions, and their growth in 2007 resulted in the avoidance of 14 Mt $CO_2$.[60] To achieve the same reduction with CCS at least 14 wells would need to have been drilled (assuming good geological storage conditions, as in Sleipner) and pipelines built. Is this a realistic scenario?

CCS supports a centralised energy structure that blocks the implementation of renewable energies beyond a certain share. The big fossil fuel utilities naturally have no interest in changing the balance in favour of renewables by reducing production or simply providing back-up for renewable energy. It would mean loss of profit, especially if such coal power plants operate with CCS. Change will not take place unless policies are put in place to push development in the right direction.

Back in 2007 the EU Commission's energy package proposed that carbon dioxide storage should be obligatory for new coal power plants from 2020. The Directive now under consideration in 2008 does not foresee mandatory CCS any more. However, new coal-fired power plants need to be capture-ready.[61] But even if this deadline had been maintained and carbon dioxide storage were made obligatory for all new power plants around the world, let's say in 2030, it would still take a few decades before the technology reached its full potential (see diagram above from the US Department of Energy). The various scenarios depict CCS as reaching its peak effect in the second half of this century at a time when the demands for a working energy system have changed already. What is CCS really bridging?

### 8.2. Argument 2: Coal will be used for a long time to come

Every time someone plans a coal power plant especially in Europe there is an alternative: wind power, biomass, geothermal energy, solar thermal power, improvements in energy efficiency, conversion of electric heating to another type of heating, conversion of air conditioning to district cooling or passive cooling.

There are always alternatives. There are alternatives whenever the initial investment is made and there are alternatives every second a coal power plant is in operation. If there is a cheaper alternative, a coal power plant will run at reduced capacity.

Whether coal "is going to be used" or not depends on the political playing rules, including the climate convention. Within the EU and a number of states outside the EU the framework and formulation of the emissions trading system will have the greatest significance, although taxation rules and subsidies will also have an effect. Of course, it is not possible to shut down all the coal power stations overnight. And this is where the statement "coal is here to stay" at least for a while is true. But it is possible to close a lot of old coal power plants and downgrade many others from base supply to reserve supply.

The existing coal power plants will in most cases not be equipped with CCS. It would thus make sense for those plants to be replaced, for example with gas combined cycle power plants and wind power, but also with efficiency improvements. If this can happen, why reintroduce coal power with CCS?

### 8.3. Argument 3: China will continue burning coal whatever we do

This assumes that China will not make any emission undertakings at all; that the country acts like an outlaw in the international community.

But while it assumes that China cannot be persuaded to accept the costs of reducing emissions, it takes for granted that they will acquire "our" CCS technology – a technology that is absolutely sure to be much more expensive than coal power without CCS. Why should they do that?

It is contradictory to assert that China is too mean to worry about the climate, but still willing to pay large sums of money for new technology that does not deliver any other benefits.

This has to be repeated: in most cases CCS only has costs. It significantly increases fuel use, by around 20 per cent for the same amount of electricity. It also entails high capital costs for separation, transport and storage. In certain cases the carbon dioxide may be a useful product, mainly where it is used to force out more oil or gas from a borehole. However there is no widespread potential to use the separated carbon dioxide as a useful product, either in the world in general or in China.

China is not stonewalling in the climate negotiations, but naturally wants to see the major industrialised nations show some action, and it justly points to the fact that much of China's rising emissions is due to exports to the same nations that describe China as the problem.

For the moment China goes for absolutely everything in energy: coal, gas, efficiency, nuclear and renewable energies. China is now the world champion of solar heating, and runner up for photovoltaics and wind power. They are an option, whereas CCS is currently not an option for existing coal power plants, nor for the coal power plants that will be commissioned over the next decade at least.

When (if) CCS becomes an option, China will already have built most of its power stations many years previously. China's emissions need to be cut, but of all the diplomatic and technical options that are available to achieve that goal, CCS is currently the least available. Even faster growth of renewables and efficiency is an immediate option that can cut hundreds of millions tonnes of $CO_2$.

### 8.4. Argument 4: Renewable energy won't make it – it is too expensive

No one can honestly tell which of the following will produce the cheapest kWh for a power station commissioned 2012: coal, wind, nuclear or gas. It depends on a large number of unknowns. If we can't be cheap, let us do the right thing!

There are a lot of unknowns for nuclear. An accident or a bad incident can overturn the rules of the game in a minute.

The unknowns for coal are mainly about politics. If there is a serious climate commitment, coal power will be expensive to run even if coal is cheap. Electricity will probably become more expensive as emission prices increase. But as governments will sell the permits, the taxpayer will win what the consumer loses.

There are no great unknowns for wind power. The technology can improve and become cheaper but it can't really deteriorate and become dearer.

Photovoltaics produce electricity during the daytime, which is when most schools and offices are open. They produce more when it is hot, which is when air-conditioning draws most power.

Combined heat and power from biofuels is not expensive and can be used to stabilise the power system.

Some of the renewables will have extra system costs. Wind power needs backup, which does not come free. But in most of the world this is a very distant problem. The power system can swallow a lot of wind power.

In any case efficiency is always cheapest. Low-energy lamps cost about three dollars at Ikea and save 49 watts for 6,000 hours compared to the incandescent bulbs they can replace.

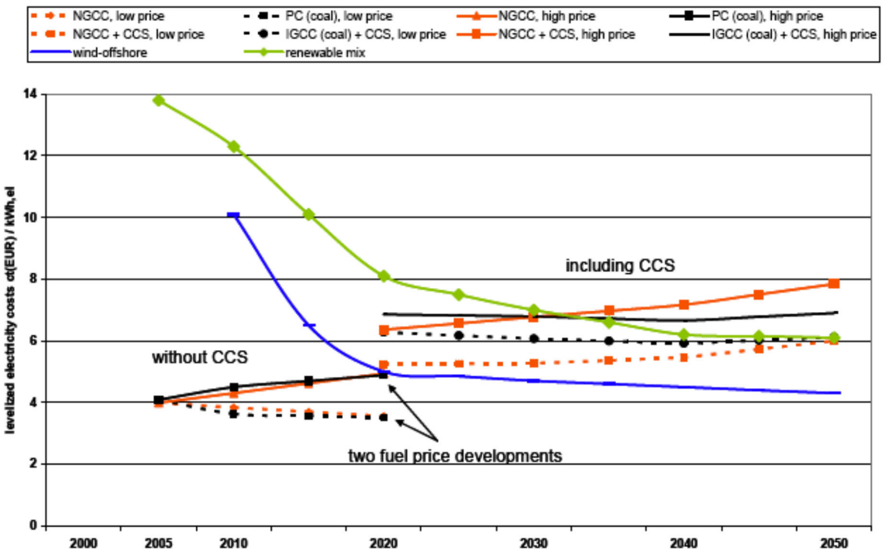
Sustainability costs what it costs. Everything else is rather like EU fishery policy: it eats more than there is.

#### The cost of electricity in Sweden

In April 2007 the price of electricity in Sweden is expected to be just under SEK 0.40 (market prices Nordpool for 2010–2012) and renewable subsidies add almost SEK 0.20, giving a total of just under SEK 0.60/kWh or 8.5 US cents. At this level, and probably even at a lower level, wind power and biofuel heating are clearly profitable, since they are experiencing a boom. Energy efficiency measures are often very profitable already. There are many companies that make a living from helping other companies to save energy. In Sweden, Siemens Building Technology and TAC both offer energy-saving agreements known as Performance Contracting, and both have similar operations in many other countries. They also coped well in the past when electricity prices reached a low of SEK 0.10–0.15 in 1997–2001 and oil prices were also low. Low prices of course are unlikely to happen again. Such companies often succeed in making savings of 20–30 per cent and sometimes more than 50 per cent of energy costs, mainly though simple measures such as optimising and controlling heating, cooling and ventilation, and training operating personnel. [62]

With tighter climate policies and greenhouse gas reduction targets coming into place it is no longer useful to compare renewable energies with traditional coal-fired power plants. They have to be compared with CCS. A study by Viebahn et al. (2006) shows that renewable energies will be competitive with electricity from CCS power plants from the beginning of CCS technology in 2020 (wind power) or from 2030–2040 (mix of all renewable energies), depending on price increases for fossil fuels.[63] Other factors include the average lifetime of power stations, the availability of CCS technologies and the development of energy demand over time. Although everyone is talking about CCS being commercial (which does not mean being economically viable) by 2020 this remains an unknown until pilot plants and demonstration plants prove that the deadline can be met.

**Figure: Electricity production costs – comparison between power plants with CCS and renewable power plants between 2020 and 2050 (each with low and high development of fossil fuel process). From: Viebahn et al.**




The very rapid growth of solar heating in European countries such as Greece and Spain indicates that solar heating can already compete with electricity (coal power) and oil for heating in these countries. It is therefore hardly likely that energy efficiency measures and renewable energy could be less cost-effective than CCS, in the short term, medium term or long term. The argument that renewable energy is too expensive no longer holds water in a carbon-constrained world. Things can change; it is all a matter of political will.

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AirClim

## Air Pollution & Climate Secretariat

(former Swedish NGO Secretariat on Acid Rain)

The essential aim of the Secretariat is to promote awareness of the problems associated with air pollution and climate change, and thus, in part as a result of public pressure, to bring about the needed reductions in the emissions of air pollutants and greenhouse gases. The aim is to have those emissions eventually brought down to levels that the environment can tolerate without suffering damage.

In furtherance of these aims, the Secretariat:

- Keeps up observation of political trends and scientific developments.
- Acts as an information centre, primarily for European environmentalist organizations, but also for the media, authorities, and researchers.
- Produces information material.
- Supports environmentalist bodies in other countries in their work towards common ends.
- Participates in the lobbying and campaigning activities of European environmentalist organizations concerning European policy relating to air quality and climate change, as well as in meetings of the Convention on Long-range Transboundary Air Pollution and the UN Framework Convention on Climate Change.

# 21

This report takes a look behind the bright vision of carbon capture and storage – CCS – given by proponents of this technology. It shows how the outlook of CCS is used to build new coal-fired power plants today, thus continuously fuelling climate change. The report is not intended to damn CCS but is an appeal for wise decision-making.

The different capture technologies under development, the scope of CCS and potential risks of storing carbon dioxide are described. It discusses the question of who wants CCS, and the political dimension is outlined.

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