TRANSATLANTIC PLATFORM FOR ACTION ON THE GLOBAL ENVIRONMENT[1]

Carbon Dioxide Capture and Storage[2]

Contents

---

[1] IEEP and NRDC would like to thank the European Commission for part funding T-PAGE under their 2006 budget line 19.050200 'Transatlantic Dialogue at Non-Governmental Level'

[2] Principle Authors - Alex Dewar, International Programme, NRDC; Jason Anderson, Head of Climate Programme, IEEP
Contributors - Melanie Nakagawa, Attorney, International Programme, NRDC

1 THE ROLE OF COAL IN US AND EU ENERGY SUPPLY

U.S. energy supply is intimately tied to coal production. The U.S. has the largest proven coal reserves in the world, it is the second greatest coal consumer by volume next to China, and it is among the top ten coal exporters. Coal is also the largest source of electricity generation in the U.S. as it is responsible for 51% of electricity generation.[3] Over1.5 billion tons per year of carbon dioxide emissions result from the burning of coal in the U.S., or nearly one quarter of annual U.S. GHG emissions.[4] Under a business and usual scenario, annual carbon dioxide emissions from coal are expected to climb by an additional 790 million tons by 2030.[5] Those emissions present a challenge for reducing the US contribution to climate change, but also an opportunity if CCS can be scaled up.

The U.S. will not end its use of coal in the near future. It remains cheap and plentiful in the U.S., and coal producing states continue to be strong political constituencies. Meanwhile, improved efficiency in the construction of new coal plants can only produce limited GHG emissions savings. Thus CCS is the only option to achieve significant GHG emissions reductions from the use of coal in the United States.

The EU is less dependent on coal than the US. Among the EU-25, coal is used to produce 30% of electricity. Much of the coal consumed in Europe is imported: 30% currently, with the IEA projecting that share to rise to 66% in 2030. Nevertheless, as the EU is even more reliant on imports for gas, oil and uranium, coal is considered a domestic resource, particularly in the important large producing States like Germany, Spain, Poland and (though much less than previously) the UK. It is important as fuel in the power sector and as a source of employment in the mining industry – in that sense several countries have quite similar energy profiles to those of coal states of the US, with the exception that these countries (like Germany, and the EU overall) have concurrent strong action on climate policy, resulting in a rather complex situation.

Much of the coal-fired power plant capacity is reaching the end of its life in Europe, as 70% of coal-fired plants are more than 20 years old. This fact puts a very sharp point on the CCS discussions, as renewal of coal power prior to commercialization of CCS could lead to unacceptable lock-in of the carbon emissions implied.

Outside the U.S. and Europe, CCS is needed to not only reduce emissions from current levels, but also prevent future increases in coal power emissions. Global energy consumption is expected to increase by 60% in the next two decades, mostly in rapidly

[3] International Energy Agency. "Reducing Greenhouse Gas Emissions: The Potential of Coal." 2005. http://www.iea.org/textbase/nppdf/free/2005/ciab.pdf
[4] Massachusetts Institute of Technology. "The Future of Coal: An Interdisciplinary MIT Study." March 2007. http://web.mit.edu/coal/
[5] Berlin, Ken and Robert Sussman. "Global Warming and the Future of Coal: The Path to Carbon Capture and Storage." Center for American Progress. May 2007. http://www.americanprogress.org/issues/2007/05/pdf/coal_report.pdf

industrializing states like China and India. If that increase in demand is supplied with coal, global carbon dioxide emissions would increase by 20%.[6]

1.1 Mitigation potential of CCS

CCS has the potential to reduce up to 90% of carbon dioxide emissions from large point sources of emissions. While a plant would need 10-40% more power to operate CCS, available technology can capture up to 95% of carbon dioxide emitted.[7] Because of the significant reduction of GHG emissions from a conventional source, the Intergovernmental Panel on Climate Changes estimates that carbon capture and storage could play a role in as much as 55 percent of the total carbon mitigation effort until year 2100.[8]

The emissions reduction potential from CCS at a given plant is significant, but CCS can on its own only mitigation a portion of the amount needed to limit atmospheric carbon levels to acceptable levels. The more challenging, but also necessary, needs for mitigation are ending the continued reliance on conventional fossil fuels, and meeting future energy demands in a clean way. CCS may enable fossil fuels to be able to meet some of the future energy demand, but it only continues the global reliance on non-renewable energy. Furthermore, CCS will serve to continue and in some cases expand the environmentally destructive practices used to mine coal around the world.

2 TECHNICAL OPTIONS AND OBSTACLES TO DEPLOYMENT

2.1 Carbon capture technology

The deployment of CCS on a widespread scale will require further advances in available technology combined with retrofits of existing pulverized coal-powered plants or the construction of new Integrated Gasification and Combined Cycle (IGCC) coal plants. There are currently no commercialized coal plants with CCS, and there are only seven coal-fired IGCC plants in the world. The primary goal for research and development of CCS capture technology is to reduce the energy penalty, thereby reducing the cost.

- *Post-combustion* CCS captures the carbon dioxide from the waste stream of a conventional coal-fired power plant. The capture takes place with low CO_2 concentration and pressure since coal combustion takes place with air, which is 78% nitrogen. The result is a large energy penalty in the order of 25-40%. With current technology, CO_2 captured with this method is done using a liquid chemical solvent, such as monoethanolamine (MEA). A process of reheating a cooling the solvent is largely responsibly for the high energy penalty. The coal

[6] European Commission DG Environment. "Sustainable power generation from fossil fuels: aiming for near-zero emissions from coal after 2020." January 10, 2007. http://ec.europa.eu/environment/climat/ccs/pdf/com2006_0843_en.pdf

[7] Intergovernmental Panel on Climate Change. "Carbon Dioxide Capture and Storage: Summary for Policymakers and Technical Summary." 2005. http://www.ipcc.ch/activity/ccsspm.pdf

[8] Ibid. These numbers are strongly dependent on modeled scenarios – the total share could be significantly less.

industry is working on improving cycle efficiency, improved solvents, and new concepts that will reduce the energy penalty and improve the efficiency.

- *Pre-combustion* technology utilizes IGCC coal plant technology. In an IGCC plant, coal is gasified and the hydrogen produced in the process is used to fire the plant. Though this method CO_2 is separated and compressed during the gasification process, occurring prior to combustion. Current IGCC plants do not separate the CO_2, but it is possible to do so with a physical solvent. Pre-combustion technology carries with it a smaller energy penalty of between 14-25%. While the fuel conversion step of an IGCC plant is more expensive than a conventional coal plant, the high CO_2 concentrations produced (between 15-60%) and higher operating pressures make it cheaper to separate the CO_2 than other methods, thus it is the most economically feasible technology at the moment.
- *Oxyfuel combustion* is an experimental technology that has not yet been demonstrated on a large scale. In this process pure oxygen is used for combustion instead of air, which produces a gas stream of mainly water vapor and carbon dioxide. That gas stream can then be compressed, which separates the water vapor and yields a high CO_2 concentration of over 80%.

2.2 Transport

The transportation of carbon dioxide once it is captured is relatively easy as mature technology can be utilized. CO_2 can be transported by truck, ship or pipeline. Because it is cheapest for large volumes, a network of pipelines would most likely be developed for transport. Transporting CO_2 by pipeline would require that it be dried to avoid pipe corrosion, and then compressed. In the U.S. there are already over 2500km of pipelines transport more than 40Mt CO_2/yr.

2.3 Storage

Once captured and transported, carbon dioxide can be stored in a wide range of geological formations. Ample experience already exists with storing carbon dioxide in oil and gas fields for the purpose of enhanced oil recovery, and a handful of new projects are exploring saline aquifers and other options, though experience is much more limited. The options for storage include, from those with the most current experience to the least:

- Oil/gas fields. Storage of CO_2 for enhanced oil recovery could produce revenue, as it results in increased fossil fuel production; after hydrocarbon recovery the same formations can be used for storage alone.
- Deep saline formations (saline “aquifers”). Less is known about them, but the majority of the available carbon storage capacity is in these formations.
- Deep, un-mineable coal seams. This would be a different trapping mechanism due to coal swelling and other problems. More research has to be conducted.
- Basalts. This is a research area, but there are large unknowns.
- Oil shales. Shales are caprocks themselves, so there are also large unknowns.

- Deep ocean sediments. This technology is highly uncertain and potentially problematic. Storing CO_2 in such a way utilizes fewer and less defined trapping mechanisms, leaves little room for remediation, makes the carbon storage sensitive to temperature changes, and could potentially mobilize methane hydrates stored in the same areas.
- Ocean sequestration has also been proposed, but it is not a serious means for storing CO_2. Injecting CO_2 into oceans can cause ocean acidification and harm marine ecosystems. Furthermore, it would not actually store carbon indefinitely as the atmosphere and oceans reach equilibrium. It is likely to be explicitly ruled out by the upcoming EU policy, and aside from limited research efforts in Japan it is essentially not being pursued.

2.4 Reducing costs

CCS is currently expensive relative to conventional coal and other renewable energy technologies. Most of the costs are in the capture of the CO_2, which requires large capital investments. To deploy CCS in the next one to two decades costs must come down through technological improvements and learning-by-doing.

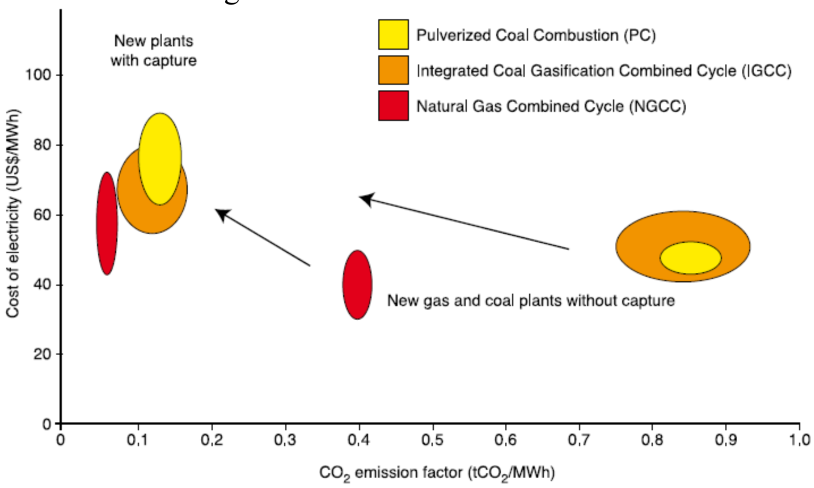
Despite high costs for implementing CCS in the power sector, consumers will not necessarily directly experience large increases in electricity prices. Consumers are insulated because power production costs represent about 60% of the total costs paid by consumers (the remainder being transmission and distribution costs), consumers get electricity from many other sources than just coal, and in the short term CCS would only be applied to a small share of coal-fired plants. To distribute the costs of CCS uniformly, the incremental costs can be spread throughout the coal or fossil fuel sectors. In the US, the incremental costs of including CCS in all new coal plants built by 2020 would amount to a 2% increase in retail electricity rates.[9]

[9] Hawkins, David and George Peridas. "No Time Like the Present: NRDC's Response to MIT's 'Future of Coal' Report." Natural Resources Defense Council. March 2007. http://www.nrdc.org/globalWarming/coal/mit.pdf

A comparison of costs per component of CCS.[10]

Capture from coal/gas power plant	\$15-75/t CO_2 captured
Transportation	\$1-8/t CO_2 transported
Geological storage	\$0.5-8/t CO_2 injected

Costs should also be seen in light of the non-CCS alternative:



3 U.S. POLICY ON CCS

The *Carbon Sequestration Leadership Forum* (CSLF) is an international initiative designed to make CCS technologies broadly available internationally by promoting technical, political, and regulatory environments for the development of CCS. The CSLF consists of 22 member countries, including the EU that seek to deploy the use of CCS. The CSLF seeks to: [11]

- "Identify key obstacles to achieving improved technological capacity
- Identify potential areas of multilateral collaborations on carbon separation, capture, transport and storage technologies
- Foster collaborative research, development, and demonstration (RD&D) projects reflecting Members' priorities
- Identify potential issues relating to the treatment of intellectual property
- Establish guidelines for the collaborations and reporting of their results

[10] Intergovernmental Panel on Climate Change. "Carbon Dioxide Capture and Storage: Summary for Policymakers and Technical Summary." 2005. http://www.ipcc.ch/activity/ccsspm.pdf
[11] http://www.cslforum.org/about.htm

- Assess regularly the progress of collaborative R&D projects and make recommendations on the direction of such projects
- Establish and regularly assess an inventory of the potential areas of needed research
- Organize collaboration with all sectors of the international research community, including industry, academia, government and non-government organizations; the CSLF is also intended to complement ongoing international cooperation in this area
- Develop strategies to address issues of public perception"

The *Carbon Sequestration Regional Partnerships* program seeks to develop public-private partnerships to determine best practices for CCS technologies, regulations, and infrastructure needs in different regions of the U.S.

- In the first phase of the program, which lasted from 2003 to 2005, seven partnerships developed the framework needed to validate and potentially deploy CCS technologies. "They studied which of the numerous sequestration approaches that have emerged in the last few years are best suited for their specific regions of the country. They also began studying possible regulations and infrastructure requirements that a region would need should it be determined that sequestration be deployed on a widescale basis in the future."
- "In Phase II, the partnerships will conduct about 25 field tests and validate [CCS] technologies, evaluate regional carbon dioxide repositories, conduct public outreach, satisfy permitting requirements and identify best-management practices for future deployment. Each partnership is projected to receive about $4 million per year in DOE funding. At least 20 percent of project costs are provided by non-DOE funding. The total value of the projects exceeds $145 million over the next four years."[12]

FutureGen is a $1 billion public-private partnership that seeks to build the world's first coal-fired plant that integrates IGCC technology with CCS. The goal is to produce a coal plant with the least emissions in the world that will serve as a prototype for other CCS plants.[13] The plant is expected to come on line by 2012 and is on schedule thus far. A common criticism of FutureGen is that by grouping all the technology R&D together rather than breaking them into their component parts, the project is slower that it could otherwise be.[14]

---

[12] http://www.fossil.energy.gov/programs/sequestration/partnerships/index.html

[13] http://www.fossil.energy.gov/programs/powersystems/futuregen/index.html

[14] Tester, Senator Jon. Questioning at the Senate Energy and Natural Resources Committee hearing on "Clean Coal Technology." August 1, 2007.

4 EU POLICY ON CCS

4.1 Past and current policy engagement

EU involvement in CCS has primarily taken the form of technology research, through the Fifth and Sixth research framework programmes administered by the Directorate General for Research of the European Commission. This effort is being expanded under the new Seventh Framework Programme, and the European Council of ministers has expressed a desire to see the Commission support the development of 'up to' 12 demonstration plants. As a European budget for this activity is highly unlikely the role for the EU will likely be one of coordination and incentives rather than outright financing, with industry and Member State governments playing a more substantial role.

The EU Emissions Trading Scheme (EU ETS) is the primary means of limiting emissions from large point sources of CO_2 in the EU, but CCS is as yet not an explicitly included activity. The UK has gone some distance toward the development of guidelines for CCS under the ETS, but the Commission indicated its discomfort with approving even interim guidelines until a number of issues are discussed and resolved – most notably related to storage site identification and management. The upcoming EU legislation (see below) is expected to address these perceived gaps.

Member States have varied levels of involvement with CCS. In the UK there are several projects on the drawing board vying for public assistance, while in Germany there is a pilot storage project underway (CO2Sink) and capture projects in planning stages, but the government was relatively late in coming around to the issue. Norway has the most advanced policy, as it is a hydro-dominated system where even gas power is controversial. In exchange for permission to build new power plants, CCS must be employed. Many other countries, like France, are engaged in research but have no significant mitigation plans with CCS.

4.2 Options for the upcoming EU legislation

The major EU-level policy initiative expected on CCS at the moment is the European Commission's upcoming legislation. Existing European law presents apparent restrictions for CCS, made unintentionally because lawmakers were unaware of CO_2 storage while drafting the legislation. Further, the inclusion of CCS in the EU ETS is not yet permitted as such. Thus, the expectation is that the upcoming legislation will at a minimum rationalize legal coverage, in addition to setting up a framework for project development that guarantees and harmonizes environmental health and safety, and in doing so clear the way for including CCS in the EU ETS. However, European lawmaking is anything but straightforward, operating as it does in the context of 27 Member States and the principle of subsidiarity – which means that lawmaking should take place at the lowest appropriate level. The European Commission must therefore be sensitive not to pre-empt or override national law that may be sufficient to address CCS.

In several EU Member States, the experience of related activities such as oil and gas exploration and natural gas storage means that regulators are often very well versed in much of the technical information. In other places, CCS will be quite new. Two priorities emerge from the current situation: guidelines and capacity building in some countries, and some coherence to the approaches taken nationally, even if these are not dictated in a single European piece of legislation. The coherence will increase information flows and relevance across borders, and decrease barriers for project developers.

In Europe, one can envisage a combination of approaches to achieve some coherence: European legislation defining regulatory requirements, a European level accreditation regime, oversight committee or working group which guarantees minimum standards are followed, and action by Member States, perhaps in coordination with each other to reinforce capacity building and spread of best practices.

5 BRIDINGING THE CCS FINANCING GAP IN THE US AND EUROPE

Thus far the private sector has demonstrated that (with a handful of exceptions primarily for research) they will not make investments in CCS on their own. There is a multi-scale role for government to promote CCS, both by creating an appropriate regulatory framework and by contemplating options for incentives and financial support, both direct and indirect, or, conversely, avoiding financing by imposing direct obligations on industry. Options include:

- *Subsidies for research, development and deployment funds* can share the burden of research with the private sector, thereby bringing down the costs of CCS more quickly. This is the government involvement currently most in evidence.
- *Inclusion in emissions trading:* carbon caps and a market value to reducing emissions may provide an incentive for CCS development. It may take years for a cap and trade market to produce a cost of carbon sufficient to prompt large-scale investment in CCS, but once the price reaches that threshold, investments may switch. It has been widely estimated that the cost of carbon must be at least $25-30 per ton to prompt widespread investment in CCS[15].
- *Direct subsidy to industry*: the UK government has included a direct industry subsidy in its most recent budget, meaning that at least the first CCS facility in the country will have direct support.
- *Command and control policy* requiring no more new coal plants without CCS, or at least the ability to include CCS technology when it is deployed commercially. In the U.S. there is potential to implement this requirement through the new source review of the Clean Air Act, and in the EU under IPPC.
- *Emission performance standards*: an emissions rate that cannot be exceeding could be set at a level that essentially forces CCS, which makes it similar to the previous point.
- *Spreading costs of new CCS plants over entire sectors*: for example through the use of a feed-in tariff, where CCS receives a guaranteed price, the cost of which is borne equally by all ratepayers. If the costs of CCS are kept in the coal sector, it

[15] Note that the EU ETS was in this range in 2005, after which it collapsed – most important is some confidence in the long-term sustained price, which is difficult to guarantee in a market system.

sets up CCS for defeat. The dispatch order for electricity purchase by utilities is currently based on the price of electricity, so any plant with higher costs will be ranked lower in the order.

6 POTENTIAL NGO CONCERNS

CCS is problematic for NGOs for a variety of reasons, from physical leakage risk to impacts on the energy system and competition for renewable energy funding. The following lists some of the primary issues:

6.1.1 Will it work, and can we trust the people who tell us this?

The public and stakeholders not directly engaged in CCS technology development must rely on what they hear from the media or those more informed in order to form opinions about CCS. At this point, those more informed tend to be from the fossil fuel industry, or engaged in research projects funded, co-funded, or co-ordinated by the fossil fuel industry, or in relevant government agencies. Any certainty or optimism among this group may be viewed stakeholders as self-serving, and regarded with either open or reserved scepticism.

6.1.2 Diversion of effort or resources from renewable energy and efficiency

Surveys indicate that the public are very favourably disposed towards renewable energy sources like wind and solar energy, and this favour is reflected in the priorities of environmental NGOs. In their assessments of CCS to date, which tend in most cases to reflect a fairly 'wait and see' attitude toward the technology, NGOs are nevertheless adamant that CCS should not displace effort to develop energy efficiency and renewable energy (EERE). This means that funding originally intended for EERE can not be diverted to CCS, and what is more, that budgets for EERE promotion still need to grow to an adequate size and not be restricted by increasing interest in carving out budgets for CCS. There are multiple rationales in this line of thinking:

- Many EERE options are available on the market today, while CCS is still in the early phase of deployment. Thus any focus on CCS away from today's EERE options could delay mitigation momentum in the short to medium term.
- EERE are largely developed by small industries, trying to innovate to drive costs down. CCS technologies, although not yet widely deployed, enjoy special placement near the core businesses of the world's richest corporations. Renewables need assistance to reach critical thresholds of technological development and price reduction; competition from CCS could keep them from meeting their potential.

More fundamentally, even where seen as playing a necessary role in mitigation of fossil fuel emissions, CCS is seen as a stop-gap, a necessary evil. It is still a fossil-fuel technology and hence not considered part of a long term sustainable energy future.

6.1.3 Possible competition for nuclear power

Opposition to nuclear power is very strong in some countries, with public debates central to decisions to phase it out in Germany, Sweden and Belgium, to avoid introducing it in other countries, and the long-term stagnation in construction in the US. It is also universally opposed by mainstream NGOs working on climate and energy policy. In a Eurobarometer poll on European preferences for sustainable energy, nuclear emerged as the last option

Given the strong feeling about nuclear, CCS is viewed by many as a potential option to supply low-carbon centralised power. The support is viewed very much as a second best option to renewable energy, however. Further, as incentives for low carbon energy could apply to nuclear energy as much as CCS, the decision to restrict nuclear from enjoying these benefits would be entirely political. In a stakeholder session in Belgium (ECN et al., 2006) it was clear that the most vocal anti-nuclear activists view their support for CCS as conditional upon the political guarantee that nuclear will remain on its current downward spiral. For some people it is therefore not a question of promoting CCS in the hopes it will compete with nuclear, but promoting CCS upon the *condition* that nuclear is phased out.

6.1.4 CCS in the context of a broader shift to sustainable energy

As a fossil-fuel based technology, CCS will allow the prolonged use of fossil fuels even in an era of greenhouse gas emission reductions (if one presumes that the alternative future without CCS would be to maintain mitigation goals using other technologies, rather than continuing to use fossil fuels without CCS and hence suffering the climate consequences).

Independent of CO_2 as an issue, fossil fuels are regarded cautiously by the public and NGOs for a range of environmental and social reasons:

- There are environmental problems in extraction, a fact that is the focus of work for NGOs in many countries.
- There are environmental problems in transport; oil tanker and pipeline leaks can have dramatic damaging impacts.
- The power granted to those with fossil fuel profits distorts relationships among governments, industries, and workers, and often leads to unhealthy societies, particularly in resource-rich countries.
- The fossil fuel industry is massively centralised, whereas many have the vision of renewable energy as a decentralising, democratising force.

Particularly when viewed more broadly than the issue of CO_2 emissions, use of CCS is interconnected with problems inherent to fossil fuel use generally.

6.1.5 Long-term leakage that interferes with ability to stabilize concentrations

Any stored CO_2 that makes its way to the atmosphere is undermining the entire point of CCS; hence leak-tightness is a concern. As some measure of leakage is inevitable, whether through accident, injection well failure, migration up abandoned wells, or other causes, one cannot speak of ‘zero emissions’ with CCS. But emissions might be inconsequentially low. This has led to significant effort spent on determining ‘acceptable’ leak rates.

NGOs essentially argue for zero leakage sites over extended time periods. CAN Europe (2006) states storage sites should 'not allow any leakage for thousands of years…' It remains to be seen how this would translate into support or opposition for specific sites or operations, given that there is a very high likelihood of at least some minimal leakage – zero is a very small number indeed. However, the problem is compounded by the difficulty of determining ex-ante how much any particular CCS system (from capture through storage) will leak: probabilistic risk analyses are standard for modelling such systems, but their precision is not yet established for CCS. Further, risk analysis is not only complex for experts, it's nearly incomprehensible for the broader public, making this a difficult aspect to communicate.

6.1.6 Potentially dangerous levels of leakage from storage

Leakage from storage is regularly cited by stakeholders as a potential concern associated with CCS, including among the uninformed public (e.g. Shackley, et al. 2005). Return of CO_2 to the atmosphere undermines the point of CCS, but also forms a potential health and safety risk at local level.

A comprehensive risk management strategy, which would be important to get public acceptance, could include standard techniques to repair wells, detection, interception and extraction of CO_2 in case of a danger for groundwater aquifers standard well repair as well as a commitment to site monitoring over very long periods (IPCC, 2005).

As can be seen from experience with nuclear facilities, the importance of accidents for the formation of public opinion can hardly be underestimated. Not only the Chernobyl disaster, but smaller scale incidents at Three Mile Island and at Monju have had a highly negative impact on the public acceptance of nuclear energy (Melber, 1982, Kaya, 1997). An investigation into the public acceptance of CCS in Australia confirmed the weight people put on the possibility of accidents (Ashworth et al., 2006).

6.1.7 Possible impacts on drinking water

A concern associated with any in- or underground waste disposal, and which is true for carbon capture and storage, is the affect any leakage might have on drinking water (see for example TNO-ECN, 2003; Sharp et al., 2006). A rise in CO_2 concentrations reduces the pH, which can occur at different rates depending on the pH buffering capacity of the aquifer. This could lead to the dissolution of metal, sulphate or chloride ions (Wilson, 2004). In case of an upward gas phase CO_2 migration, trace elements could be eluted from certain kind of rock and have an impact on groundwater environment (Shidahara et al., 2006). Displaced formation waters could cause the groundwater to be more saline (Wilson, 2004). All of these effects could have an impact on the quality of the drinking water as well as on water used for agricultural purposes.

Impacts on drinking water could cover a large area. The quantities of CO_2 injected for storage would be large, leading in particular to significant fluid displacement and subsurface pressure changes (Wilson, 2004). A study calculated that if the CO_2 emissions of a coal power plant producing about 1 GW of power and 8 Mt of CO_2 per year are injected into a zone of 100m thickness over a time period of 30 years, this would cause the CO_2 to have an expansion of roughly 100 km^2, while still having pressure effects larger than 1 bar on an area of 2500 km^2 (Pruess et al., 2003, Tsang et al., 2002, as quoted in Wilson, 2004).

6.1.8 Possible optimism on cost reduction

Modelling future CCS levels depends heavily on assumptions about cost reductions and implementation at commercial scale, as there is little experience to date upon which to base the models. One assumption is that CCS will progress as quickly in cost reduction as sulphur removal (FGD) did; an opposite prediction might be that CCS might become entangled in politics or suboptimal development and not see major price reductions, like nuclear energy, or face technical and economic problems that hinder its forward momentum, as seems to be the case currently for hydrogen and fuel cells.

6.1.9 Possible overconfidence in the ability to find appropriate storage sites

If there were so much certainty in geology, there wouldn't be any 'dry holes.' Billions of dollars have been invested over more than a century of oil exploration, and yet the industry isn't always able to spot the location of oil, which is its entire reason for existing. This should give pause to those claiming that doing good CO_2 storage is 'simply' a matter of finding the right location. In addition, even while it may well be that an appropriate site is possible to locate in every instance, possibility and actual practice may diverge from one another. One example is that it will likely be attractive for industries to look to sites of current or past oil and gas exploitation, or one closer to the capture site, even if, on fully objective criteria, some other site might be more appropriate.

6.1.10 Scale issues

It is often stated that the technology for CCS already exists, it is just a matter of applying it to CO_2 mitigation. This picture may gloss over some important issues of scale, such as:

- Amine scrubbing for post-combustion CO_2 capture has been applied at small scale to date – the largest facility in the world separates 800 tonnes of CO_2 per day; a 1000MW coal fired power plant produces on the order of 25 times that much – and there the equivalent of 1000 such plants in the world, a figure set to nearly double in 25 years under baseline conditions.
- Enhanced oil recovery (EOR) operations have been injecting CO_2 to increase oil recovery, primarily in West Texas, for 25 years. In the United States, where 90% of CO_2 EOR takes place, around 110 MT CO_2 are injected per day (this is reproduced at the surface when it breaks through with the recovered oil). This compares to the nearly 8,000 MT CO_2 produced per day globally from coal fired power – again, set to double in 25 years.

7 ARE THE RISKS CONCERNING ENOUGH TO INHIBIT ACTION?

The previous discussion characterizes a range of concerns NGOs and others have expressed. The question is what their significance is for support or opposition to promoting large scale use of CCS as a mitigation activity.

A thought experiment by Hawkins and Bachu (2006) concludes that an extended period of R&D into storage as a way of minimizing risks prior to engaging in commercial scale projects will only marginally improve what is probably already a relatively effective technology. Emissions occurring from relevant facilities while we continue research (including emissions from new non-CCS facilities, which are coming online quickly) will far overwhelm the impact of any potential leakage from 'imperfect' projects done without the benefit of further R&D.

This conclusion is intuitively obvious if one simply considers that current emissions are the same as 100 per cent leakage, while leakage from storage will be less than 100 per cent. Two issues have to be contended with to make this conclusion true however:

- Even at a slow leak rate, is it possible that we will eventually see significant leakage from imperfect storage such that we are simply delaying the same amount emission to later? Does the atmosphere have a discount rate?
- The local impacts of leakage could be significant even if much less than 100 per cent. Are we incurring local risks following such a line of reasoning?

The answer to the first question is two-fold: first, the concept of a 'leak rate' is an imprecise way of viewing the likely process of leakage from storage. Most leaks will come from specific features or failures, which are among the risks already known and can be identified, avoided, and if necessary remediated. Other processes, such as the migration of CO_2 through caprock, are inevitable but very slow, and likely to be low-volume. Over relevant time scales CO_2 is trapped in pore paces, dissolved in ground water and even mineralised, so that much less than the total amount of stored CO_2 is even available for migration.

The answer to the second question is similar: local risks are mostly likely due to significant releases through specific pathways: where these pathways are large enough to transport quantities of CO_2 that could be hazardous, they are also likely to be identifiable and hence avoidable.

What is crucial then is to be able to employ what is already known about site selection and management to avoid likely leakage pathways. That is why the emphasis should be as much on management procedures as on our understanding of the physical processes leading to hazards.

A possible conclusion from this discussion is that although identification, avoidance, and minimisation of risks is important, it may be better to start large scale CCS now with the imperfect regulatory regimes and technology we have, instead of waiting 15-20 years to perform comprehensive R&D, piloting and demonstration projects and developing the "perfect" regulatory regime based on accumulated experience. Instead, our efforts at R&D, piloting, commercial projects, policy initiative and regulatory oversight need to proceed in parallel. Given the pressure the global climate is under and the difficulty in mitigating emissions, delay is a serious risk to take. This approach does *not* absolve project developers and regulators, however, from avoiding risks already identified, and from engaging in a process of continuous evaluation and improvement based on evolving knowledge.

Others may take a different view, however, which is that we can essentially force the end-game of energy technology closer to the present with a concerted effort on renewable energy and efficiency. In this view, time and money spent on CCS and nuclear is essentially a diversion (and a potential environmental hazard) from the eventual goal.

It would be nice to be able to say there is an empirical means of answering the question of whether CCS is necessary. Attempts to prove with modelling that CCS is or is not necessary rely on two important factors: physical limits to certain energy sources, and cost minimisation. There are often assumptions made about the amount of, for example, biomass that can be employed due to land area constraints, or the speed with which current infrastructure can change – these assumptions have massive implications for the modelled outcomes. Similarly, any models that seek lowest-cost options will discard many alternatives that may be only marginally more expensive. Ultimately, it may well be the case that whatever we choose to focus on gets cheaper and proves ex-post to appear to have been the right choice, despite the view ex-ante.

The problem with this optimistic assumption, however, is that we are faced with short-term decisions about, in particular, construction of new or replacement coal fired power stations that will put significant inertia into the system and resist change for decades. Secondly, not everyone agrees on the path forward, not least those with vested interests in the status quo, a factor that everyone may have to accommodate. Hence there is an ongoing debate between the idealistic and realpolitik worldviews, one that NGOs are clearly debating themselves.