Carbon sequestration, the precautionary approach and the responsibility of scientists

L. Buhl-Mortensen*, A. Myhr** and S. Welin***

*Institute of Marine Research, P.B. 1870 Nordnes, N-5817 Bergen, Norway
(E-mail: lene.mortensen@imr.no)

**Norwegian Institute of Gene Ecology, The Science Park, N-9294 Tromsø, Norway
(E-mail: annem@fagmed.uit.no)

***Department of Technology and Social Change, Linköping University, SE-58183 Linköping, Sweden
(E-mail: stewe@tema.liu.se)

Abstract

This paper reviews problems connected to the use of the deep-sea and sub-sea geological formations for carbon sequestration. We will focus on the risks and dangers involved in using this kind of large-scale engineering approach, which is not yet fully tested, to combat global warming. We will not provide a complete discussion on the technologies involved, but concentrate on a few principal questions, such as the responsibility of environmental scientists involved in this research. We will also discuss carbon sequestration in relation to the precautionary approach. We argue that there may be a place for large-scale engineering attempts, but this should be the last rather than the first option.

Keywords Carbon sequestration; precautionary approach; responsibility of scientists

Introduction

Until recently, most problems facing human communities were solved by a combination of experience and ‘trial and error.’ Due to the lack of capacity to live another way, our early ancestors had to adapt to the natural environment. However, our current technological civilisation does not simply adapt to the environment, but rather uses various technological devices to improve life. Hence, it seems that our engineering approach has finally come to a point where it creates large-scale global effects. The global climate is affected by the emission of greenhouse gases and, in particular, by increasing the amount of carbon dioxide (CO₂) in the atmosphere. Technology is no longer simply a solution to our problems, but it also generates serious problems of its own (Beck, 1999).

Over the past century, the global climate has warmed 0.75°C (Mann et al., 1999). It is widely accepted that the cause of this warming is increasing atmospheric CO₂ levels, estimated as 31% from pre-industrial levels (Houghton et al., 2001). Global CO₂ emissions are expected to rise from 7 GtCy⁻¹ to 15 GtCy⁻¹ by 2050 and a subsequent increase in the rate of global warming is predicted (Marland et al., 2001). If global warming continues unchecked, there is a great risk that there will be serious consequences for our planet. What is the appropriate response to these threats? What are the likely consequences? We will discuss two different ways on how to deal with the threat, including the pumping of CO₂ into the deep oceans and sub-sea formations and aquifers with the purpose to contain CO₂ there.

We argue that some principal questions need to be addressed before these options are considered, which centre around the responsibility of environmental scientists.

Scenarios for the reduction of CO₂ emissions

The optimistic scenario

This scenario represents a successful application of the relevant environmental agreements among the states of the world, and “social engineering” related to equality...
and non-coerced co-operation. It may involve developing highly sophisticated techniques to modernise industry, transportation and heating, together with an increased use of biomass and solar energy. In this scenario, global warming is combated by actually diminishing the emission of greenhouse gases. It is also optimistic in the sense that there will be a good standard of living globally and not just in richer countries.

This will, presumably, be impossible without large-scale political changes. We envision that this scenario demands a steep rise in environmental awareness among the citizens of the rich world, causing a real change of heart among the leaders of the wealthy countries. Strong pressures from NGOs will most likely be part of this process (Beck, 1999). Resolute actions to reduce fossil energy use need to be taken in the rich countries to bring greenhouse gas emission under control. This scenario involves some real sacrifices in the industrialised countries, such as an increase in energy prices, fewer products available that are dependent on long-distance transport, and a change from private to public transportation. Another challenge will be to convince the developing countries to reduce their greenhouse gas emissions, which will imply sacrifices in their transition to Western standard of living.

The pessimistic scenario
This is based on the refusal to change the present lifestyle of the industrialised western world. This tendency is, at present, most perceptible in the USA, where there apparently is strong support for the decision of the Bush administration not to join the Kyoto protocol to limit greenhouse gases. Among the states that have promised to start in the process of limiting these gases, the real testing time has not arrived. The pessimistic scenario is based on the (pessimistic) possibility that neither the USA nor the rest of the world will be able to face the challenges. Hence, the pessimistic scenario is a possible reaction to such a failure. The world-wide capitalistic market will continue to expand around the world, and new markets for cars and consumer products will be found. The large firms will block any serious environmental efforts, and hence, global warming will not be stopped.

In order to avoid serious climate problems due to global warming, action must be taken. According to the pessimistic scenario, only measures that do not threaten the standard of living in the rich world will be accepted by the rich world. As the total emission of greenhouse gases must be diminished, to avoid too much global warming, the developing world will be forced to radically control their emissions. This means, of course, that their development is severely hampered and they can look forward to abject poverty for centuries to come.

Evaluation of the two scenarios
The optimistic scenario
It seems rather straightforward that we should choose the optimistic scenario, if possible. Scientists and engineers need to pursue research that can make such a scenario possible by developing the small-scale engineering necessary. However, one need not be an expert in political science to realise that one of the absolute largest obstacles is that such a scenario will require a radical change in lifestyle in the rich world, and that such change will be resisted. The need for such change will be even stronger if there is a desire to give everyone the same standard of living. Furthermore, we do not know how wide our window of opportunity is. How soon must these reductions be introduced before irreversible changes take place? The time-lag between the production of compounds and their effect on temperature and impact on humans and environmental welfare are, at present, poorly understood. The change in climate that we experience today is probably an effect of
pollution from the 60s and 70s. Additionally, there is need for global regulatory agencies, although a small glimpse at the international system can turn strong optimists into real pessimists. There is a very high risk that the optimistic scenario will not be realised.

The pessimistic scenario

The pessimistic scenario is scary, ugly, and morally repulsive. It involves the oppression of the poor by the rich. To avoid that the climate game goes completely out of hand, one option will be to keep the poor on a continued low standard of living and force them not to emit too much greenhouse gases. Could this really happen? Obviously, the pessimistic scenario requires massive military means to succeed. Even the pessimistic scenario requires adjustment in the West, but much less than for the optimistic one.

The choice between the optimistic and the pessimistic scenario looks easy, and obviously one should never actively choose the pessimistic one. It may nevertheless be realised if the optimistic fails to gain global support. Unfortunately, the pessimistic scenario is not a solution to the problem of global warming at all. At most, it can postpone the worst adverse environmental effects for some time. If the optimistic scenario cannot be realised and the world starts moving in the direction of the pessimistic scenario, one would really hope for other options.

Is there an engineering solution?

From a precautionary point of view, one could argue that we should look for other options as fast as possible. On the other hand, if such work starts (we will discuss some CO₂ placement proposals below), there is a risk that a perceived possibility of limiting global warming will turn into a political proposal to employ such methods on a large scale.

This may be described as an attempt to avert a global disaster by using engineering when political measures, i.e., starting in the direction of the optimistic scenario, have failed. This scenario is unattractive compared to the optimistic scenario, because of the risks involved in trying a new technology on a large scale, but also may appear more favourable compared with the pessimistic one. The proposed engineering solutions we will present here are direct disposal into the deep sea, and injection into sub-sea aquifers and formations.

Disposal of CO₂ into ocean waters

Since the oceans naturally absorb CO₂, it has been suggested that the human-generated excess could be put directly into the deep ocean, bypassing the atmosphere (Parsons and Keith, 1998). Marchetti (1977) first proposed this idea almost 25 years ago and it is now under active study (Halmann and Steinberg, 1999; Brewer et al., 1999; Soclo, 1997; Herzog et al., 2000; Grimston et al., 2001). Others maintain that widespread ocean dumping of CO₂ could unbalance the aquatic environment (e.g., Barker and Elderfield, 2002; Gruber et al., 2002). Large quantities of CO₂ already dissolves into the oceans, where it apparently has no effect on temperatures. The relatively warm surface waters of the sea are saturated with CO₂, while the colder deep waters of the oceans are unsaturated. The enormous natural carbon buffering system of the ocean (see textbox) suggests that the deep ocean could absorb huge amounts of carbon with marginal effects on the marine ecosystem. The idea is that the high pressures encountered far below the ocean’s surface will ensure that the CO₂ remains trapped down there. Under cool temperatures and high pressures, CO₂ reacts with water to form a solid ice-like compound called clathrate hydrate. The large amounts of dissolved inorganic carbon (DIC) in the oceans (39,000 GtC) would be little changed even if it were to gain all the carbon in known fuel
resources (4,000 Gt) (Grimston et al., 2001). Consequently, compared to the quantity of the atmospheric reservoir of 750 Gt, the oceans seem to have a large storage capacity (IPCC, 1999). The process that returns CO$_2$ from the depths of the ocean back to the surface is slow, and it is estimated that the oceans can retain CO$_2$ for up to 1,000 years.

**Injection of CO$_2$ into sub-sea aquifers and geological formations**

The disposal of CO$_2$ into geological formations has mainly been investigated for disposal of power station emissions that comprise the greatest proportion of CO$_2$ emissions, as well as being point sources of the gas. Injection of CO$_2$ into a sub-sea bed aquifer is already taking place at an experimental site in the North Sea. This stems from the standard oil industry practice of re-injecting gas separated from oil at the wellhead back into oil reservoirs.

This operation is currently taking place in the North Sea Sleipner field where it was initiated in 1996 by the Norwegian State Oil Company (Statoil). Around 1 million tonnes of CO$_2$ are being pumped annually into the Utsira sandstone formation, a porous saltwater aquifer some 32,000 km$^2$ in extent (IEA, 1998). This formation lies around 1 km below the sea floor above the gas-producing Heimdal formation and below impermeable shale. Seismic monitoring activities have been emplaced to monitor the movement of the gas through the aquifer. The CO$_2$, in this case, is derived from the gas field where the natural gas brought to the surface contains around 9% CO$_2$ (Baklid et al., 1996). This is reduced to about 2.5% by treatment, and the stripped CO$_2$ is injected into the sandstone formation.

A study commissioned under the auspices of the European Community (The Joule II non-Nuclear Energy Programme) suggests that a total of 800 Gt of CO$_2$ could be isolated in this way in the EU and Norway. Six Gt capacity exists in depleted oil reservoirs, 27 Gt capacity in gas fields, while aquifers could, in theory, provide 700 Gt capacity. Against this background, current European production per annum of CO$_2$ from power generation stands at around 1 Gt (Holloway, 1996).

**Uncertainties and risks with the proposals for CO$_2$ placements**

The uncertainties connected with how long the CO$_2$ will stay where it is deposited, and the effects it may have on ocean life, are huge. A recent experiment at 3,627 metres depth showed that, opposite to what scientists expected, the liquid CO$_2$ increased in volume when introduced to these depths (Bary et al., 2002). The hydrate will eventually dissolve but the rate is unknown.

Among factors that need evaluation in relation to injection of CO$_2$ are the potential for dissolution of the rock formation, ground water pollution, and ground stability (Ormerod et al., 1993). One aspect is the inherent escape pathway created by drilling into the formations concerned. In the case of exploited oil formations, these have usually been drilled in several locations depending on the properties of the formation and the oil to be

---

Some chemical facts on the reaction of CO$_2$ in the sea

When CO$_2$ enters the ocean, it reacts as follows:

H$_2$O + CO$_2$ + CO$_2^-$ → 2HCO$_3^-$

The CO$_2$ dissolution in the ocean uses up CO$_2^-$, which in turn lowers pH.

Continued release of CO$_2$ in the same order as today will probably change the pH of surface waters from 8.2–7.8 before year 2100.
recovered. In the case of deep aquifers used for disposal, several injection wells will need to be drilled, introducing potential weaknesses through which escapes could occur. Drilling of formations effectively connects them with contemporary timeframes and processes, and does not leave them isolated and exposed only to processes taking place on geological time scales, as is implicitly assumed in aquifer disposal analyses. Another safety aspect of long-term containment is the risk of a rapid release. Effects of rapid releases of CO$_2$ of volcanic origin have been reported. For instance, in 1986 a release from the crater lake Lake Nyos in Cameroon killed more than 1,500 people and livestock was killed up to 14 km from the site (Hanisch, 1998). Even a slow seep of the gas from an aquifer could have serious implications for marine ecology.

Effects on the marine ecosystem

It’s still not known what are the links between the deep ocean and the shallow ocean. It has therefore been suggested that to minimise impact on pelagic species, CO$_2$ must be released at depths greater than 1,500 m. However, deep-sea organisms inhabit an extremely stable environment and lack the capability to compensate for changing environmental conditions (Childress and Seibel, 1998). Kennett and Ingram (1995) have shown that bottom waters have pH and oxygen levels that are stable over thousands of years. Ocean sequestration on a scale sufficient to stabilise atmospheric CO$_2$ levels could lower the pH of the ocean by at least 0.3 units by year 2100 (Haugan and Drange, 1992). Changes in pH near the CO$_2$ disposal site are suspected to be lethal (Barry et al., 2002; Seibel and Walsh, 2003), although changes further from the site may be less dramatic. These changes may still be sufficient to induce severe physiological stress, as lowering the amount of oxygen deep-sea fish can hold in the blood. These fish may not be able to swim as actively as they could before the CO$_2$ injection. In a smaller-scale experiment with liquid CO$_2$ at 3,700 m, sea urchins and sea cucumbers placed within 50 cm of the CO$_2$ were dead after 3 weeks (Barry et al., 2002).

When CO$_2$ dissolves, it makes the sea more acidic and organisms with calcium carbonate in their body (e.g., deep-sea corals, foraminifers and molluscs) may not be able to generate skeleton or shells (Barker and Elderfield, 2002). These organisms actually represent one part of the process by which the oceans naturally remove greenhouse gases from the atmosphere. They absorb CO$_2$ from the seawater and atmosphere and turn it into organic carbonate to build skeleton or shells. Damage to deep-sea ecosystems could eventually alter the mix of nutrients and chemicals that well-up from the depths.

Some precautionary notes

The substantial lack of scientific understanding demands precaution before application of a large-scale CO$_2$ placement. From a precautionary view, it may be prudent to start investigating various engineering supplements to aid a perhaps failing political process to contain global warming. On the other hand, also from a precautionary view, one should be extremely cautious to apply such new technologies as large-scale solutions before adequate risk-associated research has been carried out.

In this regard, it is important to recognise that the application of a precautionary approach when considering the dumping of wastes at sea is enshrined both within Resolution LDC.44(14), under the London Convention 1972, and in the 1996 Protocol to the Convention. Employment of the Precautionary Principle (PP) entails that one should prevent an environmental option having potential risk of adverse effects until its impact has been more understood. This will be a significant constraint on CO$_2$ sequestration in the oceans because of the complexity of ocean biology and ecology. A similar position is taken in the Ministerial Declaration delivered at the Third International Conference on...
the Protection of the North Sea (1990). Furthermore, in a report from a science workshop on ocean sequestration it was emphasised that the technological capacity was running ahead of our scientific understanding, especially in regard to consequences of marine sequestration. The workshop report concluded:

We lack sufficient knowledge of the consequences of ocean sequestration on the biosphere and on natural biogeochemical cycles. Such knowledge is critical to the responsible use of oceans as a carbon sequestration option. ... The ocean plays an important role in sustaining the biosphere, so any change in ocean ecosystem function must be viewed with extreme caution” (DOE, 1999).

This seems to us a reasonable conclusion and a sound precautionary warning. Hopefully, mankind and the various biological life forms presently inhabiting the earth will be around not only for the next hundred years, but also for a very long time in the future. We must therefore have a much longer time horizon than usual.

The 1992 Rio Declaration on Environment and Development enshrined the principle that “the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations”. The potential for unpredicted, and possibly serious or even irreversible, effects on current or future generations resulting from the CO2 management strategies outlined above violate this principle of sustainability.

There are several examples that scientific uncertainty and disagreement work in the direction of hindering an application of PP because of lack of scientific understanding. The European Environmental Agency published a report that pointed out that few lessons have been learned from recounting previous experiences of emerging adverse effects from technology adopted in other industries (EEA, 2001). Many of the case studies in the report suggest that employment of the PP may trigger innovation of eco-efficient technologies and science to counterbalance or reduce the adverse effect by the 20th century technologies. Consequently, initiatives are needed for the optimistic scenario. Disregarding a precautionary approach may worsen the climate change effects and the only possible option left may be the scenario with large-scale dangerous engineering solutions.

**The moral problems and the ethical responsibility of scientists**

Scientists working in the area of carbon sequestration face two kinds of moral problems. One may be called a *first order moral problem* and is related to the impacts of the research into new technology and later possible large-scale applications. The other kind of problem may be called a *second order moral problem*, and deals with the possible “political” impacts of this kind of research.

A typical *first order moral problem* is the risk of causing damage to the ecosystem by employing a new technology. For example, leaking CO2 may make the sea more acidic and adversely affect organisms with calcium carbonate. There are also long-time risks associated with the attempts of carbon sequestration in the oceans or in geological formations. Another kind of long-time risk is that the technology may not be powerful or effective enough to hamper the rise of the global temperature.

*Second order moral problems* are not directly related to the new technology as such but concern possible impacts on a wider societal scale. The most serious second order moral problem is the enthusiasm for carbon sequestration shown by some actors (e.g., oil industry and scientists) (Department of Energy (DOE), 2000; Herzog et al., 2000). The prestige of the scientists involved will lend credibility to the vision of a large-scale engineering solution. If this is not counteracted by research and other activities underpinning the optimistic scenario, this may give the political leaders and the public a reason for going on with “business as usual.” Thus, few steps will be taken to reduce the
release of carbon dioxide, and no measure to lower the standard of living in the wealthy part of the world will be taken. After all, politicians need to be reelected. It will not be easy for them to move against a scientific community, which seems to declare that global warming can be combated by large-scale carbon sequestration.

Why is this a moral problem at all? If global warming can be contained without changes in our present way of living, transport, and production, is this not good? Yes, but the large-scale solution may fail to solve the problem or simply not be enough, and it may create new problems of its own, typical of new technologies. The moral responsibility of scientists is to be aware of both first order and second order problems and communicate them to the public. There is a need to develop an ethical concept of scientists’ responsibilities, which is not limited to the conduct of research, but includes research initiation and communication of risks and uncertainties as well (Buhl-Mortensen and Welin, 1998; Gibbons, 1999; Rotblat, 1999).

Can we compare the situation to the development of other dangerous technologies, for example the development of the atomic bomb in the 1940s? There are some similarities, but also some discrepancies. The atomic scientists and the decision-makers were afraid that World War II could not be won without the bomb. Mere conventional means would not be enough, and actually, the fear was that the Germans developed the same device. In a similar way, scientists working with carbon sequestration may fear that conventional means will not be enough to contain global warming. On the other hand, not all of the atomic scientists were happy about the actual use of the bomb, and after the war, some worked hard to get the new technology under control and hinder a possible nuclear war. The area of carbon sequestration is obviously different from nuclear weapons, but nevertheless we are worried about the widespread enthusiasm for large-scale applications of new technology.

Can a morally responsible scientist, aware of both the first order and second order moral problems, take part in research in carbon sequestration? Our answer is the following: it may indeed be right to explore and investigate the possibilities of CO2 placement. However, it is wrong to present this as the ideal solution for the future. Furthermore, such research should go hand in hand with risk-associated research and attempts to develop more sustainable societies making this technology redundant.

Conclusion
It is important to have an early, open, and critical discussion of the pros and cons of various proposed large-scale solutions to solve global climate problems. This places a high responsibility on the scientists involved in the research on long-term CO2 placement.

Accordingly, we should have a humble attitude towards possibilities to apply large-scale engineering solutions, and remember that we should care not just for the next hundred years but also for an extended future. There is indeed a need for a precautionary approach.

References


