Developing the Concept of Ocean Disposal of CO₂ within the Framework of an International Agreement

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Abstract. The IEA Greenhouse Gas R&D Programme is conducting an initial 3-year study aimed at potential CO₂ mitigation techniques as a response to the issue of global warming. The Programme is currently examining, on a common basis, the options available for capturing and disposing of the CO₂ produced from a range of fossil fuel fired power generation plant types, each with an output of 500 MW(e). Disposing of large quantities of CO₂ in the ocean is compared to other large scale CO₂ disposal options and the results of a specific study on the costs of disposing of the CO₂ product from a 2 GW(e) coal fired power station into the ocean at a depth of 500 m are given. The environmental and legal issues associated with ocean disposal of CO₂ are discussed and proposals for an extension of the IEA GHG R&D Programme, in the specific area of ocean disposal, are presented.

1. The IEA Greenhouse Gas R&D Programme

The IEA Greenhouse Gas R&D Programme is a co-operative research and development programme on technologies relating to greenhouse gases derived from fossil fuels, initiated in response to the issue of global warming. In the debate on cutting emissions of greenhouse gases to the atmosphere, much attention has been focused on fossil fuels and in particular, fossil fuel power stations. Task 1 is an initial three year programme aimed at assessing technologies which produce, capture, utilise and dispose of carbon dioxide generated from the use of fossil fuels in electrical power production. The countries that have agreed to sponsor the work programme are; Australia, Canada, Denmark, Finland, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America. The Commission of the European Communities is also a sponsor. In addition, RWE and DMT from Germany are also participants and membership discussions are taking place with a number of other countries and industrial organisations. A high degree of international cooperation exists through an interactive executive committee and panels of experts representing participants. The project is international, independent and objective and links have been
established with other relevant IEA collaborative projects which ensures access to and transfer of information.

An initial range of technical study activities was agreed by the members and a consistent set of criteria with which to compare alternative technologies in terms of cost, efficiency, and contribution to reduction in the emissions of greenhouse gases. Table 1 illustrates the range of studies planned and in progress; those already completed or being actioned are shaded. Work will include an assessment of risk and overall environmental consequences of application of the technology in question.

The most promising options will be selected for more detailed appraisal as components of two Full Fuel Cycles for power generation. These two cycles will each be examined in an engineering evaluation and other studies which will quantify the overall environmental impact, with particular reference to greenhouse gases, and calculate the cost if they were to be implemented as part of a response to the greenhouse gas issue. The studies would also highlight technical areas requiring further research and development.

2. Capacities of CO₂ Storage Options

CO₂ emissions into the atmosphere from fossil fuel combustion are currently approaching 6 GT carbon/year of which 30% is from large stationary sources such as power stations. To have an impact on the greenhouse effect GT quantities of CO₂ would need to be captured and disposed of. Calculation of storage capacities on a global scale is extremely difficult and the capacities indicated in Table 2 are intended more as an indication of order of magnitude of the potential sinks rather than absolute values.
Table 2. CO₂ storage potentials.

<table>
<thead>
<tr>
<th>DISPOSAL METHOD</th>
<th>POTENTIAL CO₂ STORAGE CAPACITY (GT C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean Disposal</td>
<td>20,000,000 (1)</td>
</tr>
<tr>
<td>Terrestrial Disposal</td>
<td>High - no estimate</td>
</tr>
<tr>
<td>Aquifers</td>
<td>87 (2)</td>
</tr>
<tr>
<td>Exhausted gas wells</td>
<td>83 (3)</td>
</tr>
<tr>
<td>Exhausted oil wells</td>
<td>42 (3)</td>
</tr>
<tr>
<td>Enhanced Oil Recovery</td>
<td>4 (4)</td>
</tr>
<tr>
<td>Global Forest Management</td>
<td>50-100 (5)</td>
</tr>
</tbody>
</table>

(1) Based on current estimate of dissolved inorganic carbon (DIC) extrapolated to maximum solubility of CO₂ in sea water
(2) Based on dissolving CO₂ in water (Koide et al., 1992)
(3) Based on 1991 proven oil and gas reserves, assuming all oil and gas reservoirs can be refilled with CO₂ (Holt et al., 1992)
(4) Based on 1991 proven reserves with assumptions on the extent to which EOR techniques could be applied. (Tanaka et al., 1992)
(5) Additional sink over 50 year period (Winjum et al., 1992)

The data indicate that the oceans represent a sink for CO₂ which is orders of magnitude greater than any of the others. However, all the options in Table 2 are large enough to make a significant contribution and it unlikely that any one option will be exclusively developed; different countries will be attracted to different options. A major consideration with all storage systems, in addition to capacity, is their ability to control CO₂ release back into the atmosphere; storage times of <100 years would not make a valid contribution to mitigation of the greenhouse effect.

3. Cost of CO₂ Disposal

Literature data on the cost of capturing and disposing of CO₂ from power plant is not consistent, varying between $80/tonne C and > $300/t C. There is a problem of definition as the energy losses associated with the capture processes means that there is 25% or more CO₂ to capture for the same electrical output. It is therefore important to ultimately define costs in terms of CO₂ avoided, rather than captured, but more importantly to determine the increase in the costs of the electricity produced. Our current data suggest a cost of $80/t C avoided would translate to a 30% increase in electricity costs and $300/t C avoided to >100% for coal-fired plant. One of the major objectives of the IEA Greenhouse Gas R&D Programme is to provide, on a systematic basis, costs for electricity generation
Table 3. Implications of the concept of C-avoidance (base case example).

<table>
<thead>
<tr>
<th></th>
<th>WITHOUT CO₂ CAPTURE</th>
<th>WITH CO₂ CAPTURE</th>
<th>WITH CO₂ CAPTURE AND COMPRESSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall efficiency (%)</td>
<td>39.9</td>
<td>28.8</td>
<td>25.4</td>
</tr>
<tr>
<td>C Burnt (g C/kWh)</td>
<td>225</td>
<td>312</td>
<td>355</td>
</tr>
<tr>
<td>C captured (g C/kWh)</td>
<td>281</td>
<td>319</td>
<td></td>
</tr>
<tr>
<td>C avoided (g C/kWh)</td>
<td>194</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>Cost ($/t C captured)</td>
<td>96</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>Cost ($/t CO₂ captured)</td>
<td>26</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Cost ($/t C avoided)</td>
<td>139</td>
<td>282</td>
<td></td>
</tr>
<tr>
<td>Cost ($/t CO₂ avoided)</td>
<td>38</td>
<td>77</td>
<td></td>
</tr>
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Table 4. Estimated CO₂ disposal costs.

<table>
<thead>
<tr>
<th>DISPOSAL METHOD</th>
<th>CO₂ DISPOSAL COST ($/t C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean Disposal</td>
<td>5 (1)</td>
</tr>
<tr>
<td>Terrestrial Disposal</td>
<td>45 (2)</td>
</tr>
<tr>
<td>Aquifers</td>
<td>79 (3)</td>
</tr>
<tr>
<td>Exhausted gas wells</td>
<td>14 (4)</td>
</tr>
<tr>
<td>Exhausted oil wells</td>
<td>14 (4)</td>
</tr>
<tr>
<td>Enhanced Oil Recovery</td>
<td>0 (5)</td>
</tr>
<tr>
<td>Global Forest Management</td>
<td>3.5 (6)</td>
</tr>
</tbody>
</table>

(1) 100km pipeline + injection at 500m, 600kg/s CO₂ (Tecnomare study)
(2) Additional energy costs for solidification only (Siefritz, 1992)
(3) 60kg/s CO₂ (Koide et al, 1992)
(4) On-shore gasfield with transportation (Okken et al, 1992)
(5) Assumed to be justified economically
(6) No CO₂ capture involved (Winjum et al, 199)

when CO₂ capture and disposal are included. Work to date indicates that capture of the flue gas CO₂ from a coal based power plant would increase electricity generation costs by 50% ($130/t C avoided) and attention is now being concentrated on CO₂ disposal.

Compression of the captured CO₂ to produce liquid or dense phase CO₂ for pipeline transport is a common requirement for most disposal options. It is also an energy intensive process and early calculations suggest that compression could
equal the cost of capture when expressed in terms of $/t C avoided. It can be seen from Table 3 that, for the example shown, 1.68 t CO₂ have to be disposed of for 1.0 t CO₂ avoided which means that disposal costs expressed in $/t CO₂ have to be multiplied by 1.68 before adding to capture and compression costs expressed in $/t CO₂ avoided. The benefits of increasing the efficiency of the initial electrical generation and CO₂ capture process are clear.

CO₂ disposal costs are difficult to separate from other processing costs when examining data from the scientific literature; it is not always clear whether compression and/or pipeline transport costs are included. However, Table 4 provides some information on the costs of CO₂ disposal when capture and compression costs are excluded.

It can be seen that, in general, disposal costs are small compared to cost of capturing and compressing the CO₂ prior to transport/disposal. In particular ocean disposal of CO₂ is, in principle, a low cost option and this is examined in further detail below.

4. IEA GHG R&D Programme Ocean Disposal Costing Study

This study was carried out jointly by Tecnomare UK and the Institute of Oceanographic Sciences, Deacon Laboratory, UK. An ocean disposal scheme to cater for the CO₂ product from a base case coal fired power generation plant (PF+FGD) with CO₂ capture by an absorption process (MEA), was specified. The scheme was scaled to 2 GW net electrical output to achieve some of the benefits of a large scale disposal system and this involves disposing of 600 kg/s CO₂ (160 kg/s C). A disposal depth of 500 m was chosen to ensure that the design and costing of the scheme would be based on proven subsea technology but, at the same time, being a disposal depth which, with careful site selection and controlled injection, could result in a time in excess of 100 years before re-entry of CO₂ to the atmosphere.

4.1 Injection scheme design

The basic scheme was designed for injection of 600 kg/s liquid CO₂ at a depth of 500 m. The injection unit structure was designed to not only support the valves, associated pipework and injector nozzles during installation, operation and maintenance but also to provide a suitable connection to the seabed and a support for subsea docking of intervention vehicles. The design consists of 5 in line nozzles (1 redundant), spaced at 20 m, each nozzle being above a control valve and supported in a replaceable cradle structure. The framework of the injection unit would be piled into the seabed and raises the injection point 4 m above the seabed to avoid interference from mud and sediment. The nozzle unit, weighing 250 tonnes, would be laid as a final section of a 100 km mild steel pipeline (864 mm diameter, 38 mm thickness), using a pipelay vessel. Inspection, maintenance and repair work on the injector unit would be by a remotely operating
vehicle (ROV) which would in turn operate from a diving support vessel. Suitable ROV tools and manipulators would need to be developed but ROVs with depth ratings up to 1000 m are already in operation. Subsea structures and pipelines have been installed in the North Sea at depths of 350 m and in the Gulf of Mexico at 860 m depth; a depth of 500 m is therefore within the range of existing technology and depths approaching 1000 m would probably be achievable without significant change to the design or recourse to different technology.

4.2 Scheme costs

The scheme costs are given in Table 5. In addition to costing a scheme for injection at 500 m, the cost model has allowed the sensitivity of cost to depth to be assessed. Cost data for depths of 200 m and 3000 m are also given, although the latter is very speculative. The disposal cost for 500 m is estimated at $4.2/t C ($1.1/t CO₂) which represents a low-cost disposal option unless much larger transport distances are involved (Table 4). The costs are, in reality, dominated by the pipeline costs which are around $1.3 M/km for the pipe size required for the basic scheme. To achieve these low costs (in terms of $/t C) large diameter pipes must be used which are associated with several GW(e) of power plant. Recent work (Skovolt, 1993) has proposed pipe diameters of up to 1600 mm which, operating at a higher pressure for disposal at 3000 m, would transport the equivalent of 20 GW(e) CO₂ at a cost of $2/t C/250 km.

4.3 Mode of injection

Injecting CO₂ at 500 m could result in re-entry to the atmosphere within 50 years unless a sufficiently dense plume of CO₂-enriched water was produced which could, under certain conditions, sink to greater depths (Drange and Haugan,

<table>
<thead>
<tr>
<th>Table 5. Coast of ocean disposal scheme.</th>
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<tbody>
<tr>
<td>Depth (m)</td>
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<tr>
<td>CO₂ flow (Mt/y)</td>
</tr>
<tr>
<td>Pipeline length (km)</td>
</tr>
<tr>
<td>Power loss (MW)</td>
</tr>
<tr>
<td>Cost of pipeline ($M)</td>
</tr>
<tr>
<td>Cost of injection unit ($/M)</td>
</tr>
<tr>
<td>Annualised capital cost ($M/y)</td>
</tr>
<tr>
<td>Maintenance costs ($/M/y)</td>
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<tr>
<td>Power consumption cost ($/M/y)</td>
</tr>
<tr>
<td>Total cost ($/M/y)</td>
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<tr>
<td>Cost ($/t C)</td>
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1992). This would require careful nozzle design to prevent excessive dilution by entrainment and a design which physically constrains the entrainment may be required (Golomb, 1993). These considerations become less important as the depth of injection is increased. Injection at a depth of 1000 m could provide a delay time of 200 years before CO₂ re-enters the atmosphere without any assistance from a sinking plume.

4.4 Site selection

The engineering work carried out in the study suggests that a suitable disposal site would be on mud or clay to allow fixation to the sea bed by piling but the design is able to tolerate a significant slope (10%) which may be a requirement for allowing a dense CO₂ plume to sink to greater depths. There are many places on both the east and west Atlantic coastlines where 500 m depth is reached within 100 km of the coastline and some areas where submarine canyons encroach the continental shelf and are within 100–200 km from the coastline. Northern Spain and the USA coast off New York (Hudson Canyon) are examples. The continental shelf terminates in a shelf break, normally at 200 m depth. The continental slope extends to deep water with a gradient commonly between 0.05 and 0.17. It is far steeper (vertical in places) on the walls of some canyons and far gentler (0.02) on the slopes of large submarine fans. Canyons provide direct access to very deep water (>3000 m) and a closely spaced network of tributary canyon systems is present from near the shelf break to the base of the slope over most of the continental slopes of the North Atlantic. Site selection criteria requires much better definition to determine whether canyons could feature in a CO₂ disposal scheme; steep rugged slopes would make pipelaying difficult and may not satisfy the conditions for dense plume sinking. Pipeline transport over distances several times greater than 100 km would still result in low cost disposal and may be a more feasible route to deeper water. Strong, downward flowing currents (the Mediterranean outflow or the Kuroshio) represent alternative strategies to plume sinking for transporting CO₂ to deep water.

4.5 Biological impact

IOSDL have also made an initial attempt to assess the biological impact of an ocean disposal scheme. Their work has revealed large gaps in knowledge required for a full impact assessment and the data are largely based on waters around the UK. Some initial conclusions can be drawn.

Steep environmental gradients are present in the water column as a result of light attenuation; plant growth supports all marine life and even in the clearest waters no light can be detected below 1000 m. Biomass concentration is much higher in the epipelagic zone (<200 m depth) but the small size of the phytoplankton (μm) means that the zone is largely occupied by small marine animals. A substantial proportion of both the planktonic community and the larger micronektonic community (fish and prawns of body length 1–30 cm), which
occupy the shallow mesopelagic zone (200–700 m depth), migrate daily to the epipelagic zone during the spring and summer months. During the winter months this migration stops and many species winter in the mesopelagic zone. The deep mesopelagic zone (700–1000 m) is occupied by more specialised fish and biomass concentration is only a tenth of that found in surface waters; this represents the limit to any vertical migration by plankton. Below 1000 m (bathypelagic zone) the only link to the biological activity in the shallow waters is by sedimentary processes which suggests that whatever happens in this zone is unlikely to affect the biological activity in the zones above it. Benthic biomass undergoes an exponential decrease with depth in the same way as pelagic biomass but species diversity is at a maximum in the benthic environment and at depths >1000 m.

The shelfbreak region is an area of intense biological activity and is occupied by many stocks of commercial fish. Exploratory commercial fishing has been conducted down to depths of 1000 m and the spawning grounds of many of these potentially commercial species is not well known. Certain commercial species are abundant at depths of 400 m and some of the large species (blue-fin tuna and swordfish) move to depths approaching 1000 m. Flagship species, such as the sperm whale, can dive to depths of 800 m.

There is little known about the physiological effect of elevated CO₂ concentrations on marine organisms. It is known that CO₂ effects the metabolism of marine animals and can be used as a method of narcotisation; it is thought to affect the transport of respiratory gases and salt exchange in the bloodstream. The pH of seawater normally shows little variation (7.6–7.7); marine algae and bacteria show a 50% reduction in growth rate when pH is reduced by 1.0 and molluscs are known to become physiologically distressed at pH < 7.0. Lowering pH could also disrupt the formation of calcareous skeletons and it is reported that a 0.3 reduction in pH results in death for the Japanese pearl oyster. The US EPA has recommended a maximum deviation of pH for coastal waters of 0.3 units. Injection of CO₂ at depths of 500 m is therefore likely to have an effect on animals living at or below the depth of discharge; a release of CO₂, designed to create a dense, sinking plume, could result in initial pH of 4 with a pH of 5 persisting over several km of travel.

The tentative conclusion from this assessment is that injection of CO₂ at 500 m, by a method designed to produce high CO₂ concentrations, would have a significant biological impact. Injection at depths below 1000 m would be more acceptable.

4.6 Environmental legislation

Environmental legislation is now tending towards the Precautionary Principle whereby the party wishing to intervene in the environment is required to demonstrate, prior to beginning the activity, that no environmental damage will ensue. This trend in environmental management will make it harder to gain international acceptance for any new intervention in pristine environments such
as the deep ocean, even if it can be demonstrated that the overall global environment is improved. The ocean ecosystem is however very robust, as its environmental capacity is huge, and damaging effects can be minimised by containing contaminants or by dilution to harmless concentrations. More substantive data on the impact of either mechanism on the physiology of marine organisms will be required as the basis of an environmental impact assessment of ocean disposal of CO₂. GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Pollution) have published a management framework for providing an impact assessment statement and the first requirement in this process is to describe the existing environment. IOSDL, in their contribution to the Study, have in fact started this stage of the process.

Disposal at sea is governed by the Global London Convention and the Oslo Convention which prohibit the dumping of wastes or other matter listed in Annex I, require a special permit for substances in Annex II and require a general permit for dumping of all other wastes or matter. CO₂ is not listed in Annex I or II but a general permit would only be issued after careful consideration of all factors in Annex III, including prior studies of all the characteristics of the material and the disposal site. The factors listed in Annex III require a comprehensive knowledge of the impact of elevated CO₂ concentrations on marine life and on the water characteristics. The practical availability of alternative land-based disposal methods is also to be considered. Formally the London Convention only covers dumping from ships; discharges into the sea from pipelines is governed by the legislation of the country from which the pipeline originates, but it would be unwise to think that this would lessen the need for environmental impact data.

5. Proposed Extension of the IEA Greenhouse Gas R&D Programme

Task 1 of the Programme is scheduled for completion in 1994 and proposals are currently being formulated for a further 3-year programme of work. Support for an extension of the work programme in the areas of ocean disposal of CO₂, chemical utilisation of CO₂, methane emissions and full fuel cycles is being sought.

The need for international collaboration, particularly in work leading to some form of demonstration of ocean disposal, is recognised in the objectives of the proposed programme on ocean disposal, which are:

to evaluate the technical feasibility and environmental impact of the various technologies for disposing of CO₂ in the ocean, the evaluation to be conducted on the basis of information produced by the work programmes of participating countries, shared with other Participants,

to provide a formal mechanism for Participants to exchange scientific data in the field of ocean disposal of CO₂, to avoid unnecessary duplication of effort,

to disseminate technical information on ocean disposal and the results of technical evaluations,
to prepare, on the basis of evaluations carried out, a proposal for a pilot-scale
demonstration of ocean disposal of CO₂.

The proposed programme, based on job-sharing, would develop a consensus
for collaborative action through information exchange, dissemination of results
at workshops and by keeping participants updated on developments. An interna-
tionally recognised ocean scientist would join the IEA GHG R&D Programme
Team (on a part-time basis) to lead the technical programme and workshops and
monitor, internationally, technical progress in this work area. In this way, the
areas of research and development vital to the final objective of planning a
demonstration of ocean disposal, would be identified and representations for
international support can be made.

6. Conclusions

Large quantities of CO₂ could be injected into the ocean, using existing
technology, at depths approaching 1000 m. The costs are dominated by transport
costs but if transport distances are modest and advantage is taken of large scale
pipelines, ocean disposal represents one of the cheapest disposal options in a
fossil fuel/CO₂ capture/CO₂ disposal/power generation cycle. Depths of 500 m
can be reached within 100 km of the coastline in many places on both sides of the
North Atlantic and tributary systems leading to submarine canyons with depths
in excess of 3000 m encroach into the continental shelf in places. Site selection
criteria requires better definition to determine whether canyon systems could
have a useful role in ocean disposal of CO₂; pipeline transport over distances
several times greater than 100 km would still result in low cost disposal and may
be more feasible in practice.

Injection of CO₂ at a depth of 500 m, without producing a dense sinking
plume could result in CO₂ re-entering the atmosphere within 50 years. However
a dense CO₂ plume could have a serious impact on the marine environment which
would be reduced if injection was at 1000 m. The International Conventions and
national legislation, covering disposal of substances in the sea, require a com-
prehensive environmental impact statement to support any application to dispose
of CO₂ in the ocean; much of the data required for such a statement is not currently
available and research programmes to provide such data need to be initiated. The
IEA GHG R&D Programme could provide an international framework for
formulating the necessary R&D programmes.

REFERENCES

Mgmt, 34, 967–976.
DISCUSSION

Wilde:
Have you considered the problem in your costing for the forest, of the problem of agricultural burning in the tropics. I was just in a meeting in Hong Kong and a NASA people said major cause of global smog is not deforestation but agricultural burning of fields in tropics, particularly in Africa. Which I think be a real contribution to CO₂ and would probably change the cost on that of forest.

Ormerod:
Yes. I am not quite sure what is hidden under this number for deforestation to the extent what they include. But basically deforestation, if you did not burn it, then would mean no liberation of CO₂. So I think a large proportion of deforestation is accounted for by burning.

Wilde:
Yes. But this is after the fair. These areas already have been deforested. Every year in tropical regions, they reburn the field.

Ormerod:
I am not an expert in agrosystem, but that needs to be looked at very carefully. We know all sorts of implications of how much carbon below ground, what stored, and different workers come up with different numbers for this sort of thing.

Wilde:
Significant enough. They are seeing it in satellite pictures. This is the NASA people, they were really surprised that you can actually see the burning.

Ormerod:
One of the problem I have in looking at the field is the colossal amount of literature risen; biological work and forestry things and so on. You know that every university in the world seems to have a forestry department or some sort of agricultural department, and you see it is almost impossible to keep up with literature.

Wilde:
My second question is with respect to the pipeline cost. Have you considered the use of natural turbidity or density currents instead of pipelines. This has been used in ocean disposal of mine waste and there are three or four examples of this. Where you essentially create a density current, put it in a submarine canyon, and it flows down well below thousand meters.

Ormerod:
Yes. I am sure that topic we are talking about. That sort of things. Our study
was, we need hard numbers just to compare options and we I think the conclusion we come to is that you can build large pipelines and they are not prohibitively expensive.

*Wadsley:*

Are your costings based on the adoption of an existing power station, or are they based on a completely new integrated power station carbon dioxide recovery?

*Ormerod:*

The technical costing shown there. They are base, what we call a base case which is a simple coal fired power station, and therefore costing is for building a new power station of that type with capture and the cost, you know, whether you could retrofit an existing station, well that will be reasonable thing to do, there is no reason why not. Except you get in troubles about space and a way you can actually put things on an existing plant. So I do not think that my costing is much excess unless you can prolong the existing the life of an existing station for a significant length of time. You would not go to that to the extent of installing an expensive plant and energy or sort consuming plant like that on a station which is not in first place efficient and in second place had a reasonable life expectancy. So they are based on a new plant really.

*Wadsley:*

Are they particularly based on integrating energy systems of the power stations with carbon oxide recovery?

*Ormerod:*

No. Not really. That base case is the simplest possible base case. There is a lot of work on newer generation systems, IGCC and a sort of shift reactions and these sort of things which is, you know, I did not go into, but there are options which put so work out cheaper than that in particular case. One of the things is that different people tend to come up with different costings. And some people come up with what we think very optimistic costings. We try to keep our feet on the ground.

*Question:*

I have a question on what kind of step, one need to achieve international consensus, ocean dumping. Beside London convention, are there any other organizations one has to go to?

*Ormerod:*

Well, it is not straight forward. The London Convention is signed by most developed countries. And that means that they in fact agree to abide by its
conventions. But it is not legal in any sense. There are no laws. That there are, the United Nations are beginning to try to develop laws of the sea. And they may come into operation at some stage. It is very much a case countries agree to participate in an agreement and once they have done that, they are a sort of morally bound to do that. As far as the procedures are concerned, the procedures are laid down to some extent. But it is not clear whom you submit your environmental impact data to. It is a completely unknown sort of territory. Countries will agree not to do certain things. For example, they agree not to dump sewage into sea. That is a sort of thing which after much debate they agreed they would phase that out. And so the laws in this area are extremely loose, but you can be sure that some concrete proposal was made to dispose of CO\textsubscript{2} into the sea, you would begin to have to go through some sort of process where you submit your reasons and your environmental data through those sort of bodies. I think we are on a learning curve as far as that is concerned.

\textit{Question:}

Would you please compare the cost of pipeline and ground installation? And if there is a big difference between the cost, ... or ground, what is the reason of that difference?

\textit{Ormerod:}

This is a sensitivity study, in which it is assumed that if you go to a deeper depth you would have to go a greater distance and so not only the comparison of depth, where you need a thicker pipeline and greater installation costs. You would also be travelling a longer distance. So the distance of pipeline, the distances are 100 km, 50 km, and 500 km. So that largely affects the cost of disposing at the sort of depth.

\textit{Question:}

So if you install the same type of pipeline on ground, then the cost of the pipeline exceed, is that right?

\textit{Ormerod:}

You would go further out to get to the greater depth. It is very approximate. But it is just an assumption they put into it. They estimate the cost of pipeline to be about 1.3 million dollars per km, and it is higher for a greater depth, but not significantly so.