ENVIRONMENTAL IMPACTS OF OCEAN DISPOSAL OF CO_2

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Introduction

One option to reduce atmospheric CO_2 levels is to capture and sequester power plant CO_2. Commercial CO_2 capture technology, though expensive, exists today. However, the ability to dispose of large quantities of CO_2 is highly uncertain. The deep ocean is one of only a few possible CO_2 disposal options (others are depleted oil and gas wells or deep confined aquifers) and is a prime candidate because the deep ocean is vast and highly unsaturated in CO_2. Peak atmospheric CO_2 concentrations expected to occur in the next few centuries could be significantly reduced by ocean disposal. The magnitude of this reduction will depend upon the quantity of CO_2 injected in the ocean, as well as the depth and location of injection.

Ocean disposal of CO_2 will only make sense if the environmental impacts to the ocean are significantly less than the avoided impacts of atmospheric release. We are concluding our examination of these ocean impacts through a multi-disciplinary effort funded by the U.S. Department of Energy designed to summarize the current state of knowledge. The end-product will be a final report to be submitted in August, 1996, consisting of two volumes: an executive summary (Vol. I) and a series of six, individually authored topical reports (Vol II). The six topical reports cover the following subjects:

(1) CO_2 Loadings and Scenarios
(2) Environmental Impacts of CO_2 Transport Systems
(3) Near-Field Perturbations and Organism Experience
(4) Far-Field Environmental Impacts
(5) Environmental Impacts of CO_2 Release into the Ocean
(6) Policy and Legal Implications of CO_2 Release

In this paper, we review our methodology and present some results for the near-field perturbation modeling (Caulfield, 1996) and its related environmental impact (Auerbach, 1996).

Methodology

Near-Field Perturbations. Three primary injection scenarios were evaluated using separate models to describe 3-D concentration distributions of excess CO_2 and trace gases such as SO_2 and NO_x. The scenarios are:

(1) Dry ice injection from the ocean surface.
(2) Unconfined release at 1000-1500 m forming a droplet plume.
(3) Confined release at 500-1000 m forming a dense plume.

Additional scenarios of a very deep release below 3000 m forming a CO_2 Alake@ and release from a dangling pipe of a trawling tanker were also examined, but are not discussed here.

For each scenario, two different loadings were considered: emissions from a single standard plant and emissions from ten standard plants. A standard plant is defined as a 500 MW_e (net after CO_2 capture and compression) coal-fired power plant capturing 90% of its CO_2, resulting in 130 kg/s of CO_2 being injected into the ocean. Next, the values of engineering and geophysical parameters were set for each scenario. For example, engineering parameters for the droplet plume scenario include number of diffuser ports and initial droplet size, while the ambient ocean current and initial pH profile are some of the necessary geophysical parameters. Reasonable values of the parameters were chosen to form the base case and sensitivity studies were performed on key parameters. For example, at a depth of 1000 m, ocean currents of 5 cm/s (base case) have been modeled along with 2 and 10 cm/s currents.

For a given scenario and set of parameters, the models were run assuming steady-state to yield a spatial distribution of CO_2 concentration around the injection point. These concentrations were then converted to pH and compared with ambient pH profiles. The result was a map of the change in pH near the injection point, as illustrated in Figure 1 for the one-plant droplet plume scenario. Table 1 summarizes the base case scenarios with some useful physical properties of the resulting pH distributions.

Table 1. Summary of results of modeled scenarios

	Volume of Water with pH < 7 (km^3)	**Distance to pH of 7.0** (km)	**Minimum pH** (after dissolution)	**Minimum pH** (diffusion regime)
Dry Ice				
1 plant	0.001	0.09 (at 1000m)	6.3 (at 1000m)	7.4 (at 1000m)
10 plants	1.1	2.2 (at 1000m)	5.8 (at 1000m)	6.1 (at 1000m)
Droplet Plume				
1 plant	1.8	23	5.5	6.0
10 plants	130	60	5.5	6.0
Dense Plume				
1 plant	7.2	94	4.0	5.7
10 plants	510	690	4.0	5.5

Environmental Impacts. We developed a model to evaluate the near-field environmental impact of pH exposures on marine life exposed to the plume. The model is based on literature studies of pH toxicity to zooplankton (see Figure 2), coupled with new methods to integrate the varying time exposures, account for species compensation, and characterize overall risk. These methods are potentially applicable to many related problems and are currently under consideration by the U.S. Environmental Protection Agency (Region I) as a possible basis for refinement of toxicology-based concentration standards for aquatic discharges.

Integration of Mortality Assessment with Plume Modeling. Monte Carlo simulations involving random walk diffusion models were used to describe the probabilistic time-varying pH experienced by passive, entrained organisms in such a way that these experiences could be used with the environmental impact assessment method just described. Some representative results are presented below.

Results

Dry Ice Organism Experience Exposures to a dry ice plume are so brief that no mortality occurs.

Droplet Plume Organism Experience The results for a one plant droplet plume are illustrated by the map of zooplankton deficit in Figure 3. The most important result is that the maximum deficit is only about 10%

of the total population. This deficit occurs downstream of the CO_2 injection ((0,0) on the figure), because there is a threshold exposure before which there is no mortality. In this scenario, this delay is a substantial fraction of the exposure time; hence the dead organisms are reasonably well spread out due to diffusion.

Dense Plume Organism Experience. The results for a one plant dense plume are illustrated by the map of zooplankton deficit in Figure 4. Here an area exists with greater than 50% mortality. The area with greater than 5% mortality is also very large. Because the effect of pH is non-linear and time dependent and a greater number of organisms are exposed to lower pH's for longer periods in this scenario, the effect is greater than that from a droplet plume.

Table 2 summarizes the mortality resulting from the base case scenarios in terms of maximum deficit, mortality flux (m^3/s) and integrated mortality (m^3). Note that the ten plant scenarios do not scale linearly with the corresponding one plant scenarios, and that the relative impact of the dense plume and the droplet plume depends on the magnitude of the CO_2 release. We may express these results in a more absolute measure by dividing the integrated mortality figure (which represents roughly a total water volume of zooplankton lost in the steady state) by a relevant reference water volume to find a percentage loss. If we choose our reference to be the Northern Atlantic ocean between 900 and 1100 m depth, (the impact of a 1000 m CO_2 release should be contained within this depth range) and envision 100 plants discharging CO_2 (as ten 10-plant droplet plume releases) we arrive at a figure of 0.02% loss.

Table 2. Summary of results of assessment. Mortality flux and integrated mortality represent mortality as equivalent flow rates or volumes of water, respectively, for which all contained organisms would be lost.

	Maximum spatial deficit (fraction) of zooplankton	**Maximum mortality flux (m^3/s)**	**Integrated Mortality (km^3)**
Dry Ice			
1 plant	0	0	0
10 plants	0	0	0
Droplet Plume			
1 plant	0.11	307	0.45
10 plants	0.69	27500	162
Dense Plume			
1 plant	0.50	1980	11
10 plants	0.95	46900	800

Conclusions

While there are several important environmental impacts of ocean disposal of CO_2, the acidification around the release point may be the most important. Our results indicate that the size and severity of the impacted area will depend on the release technology. For example, the dry ice release scenario has negligible impacts, while the dense plume scenario has large impacts, but only over a limited area.

The results presented here are just one piece of information that is required in doing a comprehensive analysis of the CO_2 ocean disposal option. Other important pieces include: I) effects of the localized impacts presented here on larger ocean ecosystems, ii) benefits of reduced atmospheric CO_2 emissions in terms of reduced risk of possible climate and ocean ecosystem change (Roemmich and McGowan, 1995; Barry *et al.*, 1995) and iii) the cost of ocean disposal compared to alternate mitigation options. By doing objective and comprehensive studies of these issues, we are building a knowledge base that will allow informed decisions to be made if and when more stringent CO_2 emission controls are required.

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Figure 1. pH distribution at a depth of 1000 m for a one-plant droplet plume release in a 5 cm/s current

Figure 2. Mortality of marine animals (zooplankton, benthos) due to exposure to low pH.

Figure 3. Deficit of zooplankton due to mortality from a one-plant droplet plume.

Figure 4. Deficit ofzooplankton due to mortality from a one-plant dense plume.