Ocean Carbon Sequestration:

A Watching Brief of the Intergovernmental Oceanographic Commission of UNESCO and the Scientific Committee on Oceanic Research

Version 2, January 2007

Human activities are affecting the Earth's global carbon cycle. Transitioning away from fossil fuel use and finding viable alternatives will be difficult, costly, and long. We are now faced with a scientific and societal challenge of daunting proportions - determining if and how humans can manage the global cycle of one of the Earth's key elements.

One strategy being investigated to mitigate growing CO_2 concentrations in the atmosphere is to enhance the ocean's natural capacity to absorb and store atmospheric CO_2, either by inducing and enhancing the growth of carbon-fixing plants in the surface ocean, or by speeding up the natural, surface-to-deep water transfer of dissolved CO_2 by directly injecting it into the deep ocean. Determining the feasibility, efficiency, and environmental consequences of this process involves significant scientific, technological, economic, and legal investigation. But perhaps more importantly, this will require informing the public about these investigations, providing continuous, clear and unbiased information about the benefits, limitations, and possible consequences of actions and inactions. Public opinion may prove to be the deciding factor in any question of redirecting CO_2 in the environment, and the public must be engaged as critical partners in this decision-making process.

This Watching Brief has been developed for the Member States of the Intergovernmental Oceanographic Commission of UNESCO as well as the general public. Since the first version of the Brief developed in 2001, significant progress has been made by the international scientific community to address these issues and implications. In 2005, the WMO-UNEP Intergovernmental Panel on Climate Change developed a Special Report on Carbon Dioxide Capture and Storage (CCS), which thoroughly covers all aspects of the issue, including ocean storage.

The following documents are available on-line from the IPCC in Arabic, Chinese, English, French, Spanish, and Russian at http://www.ipcc.ch/pub/reports.htm :

Summary for Policymakers Content:

- What is CO_2 capture and storage and how could it contribute to mitigating climate change?
- What are the characteristics of CCS?
- What is the current status of CCS technology?

- What is the geographical relationship between the sources and storage opportunities for CO_2?
- What are the costs for CCS and what is the technical and economic potential?
- What are the local health, safety and environment risks of CCS?
- Will physical leakage of stored CO_2 compromise CCS as a climate change mitigation option?
- What are the legal and regulatory issues for implementing CO_2 storage?
- What are the implications of CCS for emission inventories and accounting?
- What are the gaps in knowledge?

Technical Summary and Full Report Content:

- Introduction and framework of report
- Sources of CO_2
- Capture of CO_2
- Transport of CO_2
- Geological storage
- Ocean storage
- Mineral carbonation and industrial uses
- Costs and economic potential
- Emission inventories and accounting
- Gaps in knowledge

Ocean Storage Content (Chapter 6 of Report)

- Relevant background in physical and chemical oceanography
- Approaches to release of CO_2 into the ocean
- Capacity and fractions retained
- Site selection
- Injection technology and operations
- Monitoring and verification
- Environmental impacts, risks, and risk management
- Legal issues
- Costs
- Knowledge gaps

Ocean Storage Summary (from the Executive Summary of the Ocean Storage Chapter)

Introduction

Captured CO_2 could be deliberately injected into the ocean at great depth, where most of it would remain isolated from the atmosphere for centuries. CO_2 can be transported via pipeline or ship for release in the ocean or on the sea floor. There have been small-scale field experiments and 25 years of theoretical, laboratory, and modelling studies of intentional ocean storage of CO_2, but ocean storage has not yet been deployed or thoroughly tested.

The ocean as a CO_2 sink

The increase in atmospheric CO_2 concentrations due to anthropogenic emissions has resulted in the oceans taking up CO_2 at a rate of about 7 $GtCO_2yr^{-1}$ (2 $GtCyr^{-1}$). Over the past 200 years the oceans have taken up 500 $GtCO_2$ from the atmosphere out of 1300 $GtCO_2$ total anthropogenic emissions. Anthropogenic CO_2 resides primarily in the upper ocean and has thus far resulted in a decrease of *p*H of about 0.1 at the ocean surface with virtually no change in *p*H deep in the oceans. Models predict that the oceans will take up most CO_2 released to the atmosphere over several centuries as CO_2 is dissolved at the ocean surface and mixed with deep ocean waters. The Earth's oceans cover over 70% of the Earth's surface with an average depth of about 3,800 metres; hence, there is no practical physical limit to the amount of anthropogenic CO_2 that could be placed in the ocean. However, the amount that is stored in the ocean on the millennial time scale depends on oceanic equilibration with the atmosphere. Over millennia, CO_2 injected into the oceans at great depth will approach approximately the same equilibrium as if it were released to the atmosphere. Sustained atmospheric CO_2 concentrations in the range of 350 to 1000 ppmv imply that 2,300 ± 260 to 10,700 ± 1,000 Gt of anthropogenic CO_2 will eventually reside in the ocean.

Efficiency of ocean storage

Analyses of ocean observations and models agree that injected CO_2 will be isolated from the atmosphere for several hundreds of years and that the fraction retained tends to be larger with deeper injection. Additional concepts to prolong CO_2 retention include forming solid CO_2 hydrates and liquid CO_2 lakes on the sea floor, and increasing CO_2 solubility by, for example, dissolving mineral carbonates. Over centuries, ocean mixing results in loss of isolation of injected CO_2 and exchange with the atmosphere. This would be gradual from large regions of the ocean. There are no known mechanisms for sudden or catastrophic release of injected CO_2.

Environmental impacts of ocean storage

Injection up to a few $GtCO_2$ would produce a measurable change in ocean chemistry in the region of injection, whereas injection of hundreds of $GtCO_2$ would eventually produce measurable change over the entire ocean volume. Experiments show that added CO_2 can harm marine organisms. Effects of elevated CO_2 levels have mostly been studied on time scales up to several months in individual organisms that live near the ocean surface. Observed phenomena include reduced rates of calcification, reproduction, growth, circulatory oxygen supply and mobility as well as increased mortality over time. In some organisms these effects are seen in response to small additions of CO_2. Immediate mortality is expected close to injection points or CO_2 lakes. Chronic effects may set in with small degrees of long-term CO_2 accumulation, such as might result far from an injection site, however, long-term chronic effects have not been studied in deep-sea organisms.

CO_2 effects on marine organisms will have ecosystem consequences; however, no controlled ecosystem experiments have been performed in the deep ocean. Thus, only a preliminary assessment of potential ecosystem effects can be given. It is expected that ecosystem consequences will increase with increasing CO_2 concentration, but no environmental thresholds have been identified. It is also presently unclear, how species and ecosystems would adapt to sustained, elevated CO_2 levels. Chemical and biological monitoring of an injection project, including observations of the spatial and temporal evolution of the resulting CO_2 plume, would help evaluate the amount of materials released, the retention of CO_2, and some of the potential environmental effects.

Cost

For water column and sea floor release, capture and compression/liquefaction are thought to be the dominant cost factors. Transport (i.e., piping, and shipping) costs are expected to be the next largest cost component and scale with proximity to the deep ocean. The costs of monitoring, injection nozzles etc. are expected to be small in comparison. Dissolving mineral carbonates, if found practical, could cause stored carbon to be retained in the ocean for 10,000 years, minimize changes in ocean *p*H and CO_2 partial pressure, and may avoid the need for prior separation of CO_2. Large amounts of limestone and materials handling would be required for this approach.

<u>Legal framework and public perception</u>
Several different global and regional treaties on the law of the sea and marine environment could be relevant to intentional release of CO_2 into the ocean but the legal status of intentional carbon storage in the ocean has not yet been adjudicated. It is not known whether the public will accept the deliberate storage of CO_2 in the ocean as part of a climate change mitigation strategy. Deep ocean storage could help reduce the impact of CO_2 emissions on surface ocean biology but at the expense of effects on deep-ocean biology.