`RSC submission to the House of Commons Science and Technology Committee consultation: 'Investigating the Oceans'

The Royal Society of Chemistry (RSC) welcomes the opportunity to contribute to the House of Commons Science and Technology Committee's consultation *Investigating the Oceans*.

The RSC is the largest organisation in Europe for advancing the chemical sciences. Supported by a network of 43,000 members worldwide and an internationally acclaimed publishing business, our activities span education and training, conferences and science policy, and the promotion of the chemical sciences to the public.

This document represents the views of the RSC. The RSC's Royal Charter obliges it to serve the public interest by acting in an independent advisory capacity, and the RSC is happy for this submission to be put into the public domain.

Executive Summary

- Manmade emissions of carbon dioxide (CO_2) are causing the oceans to become more acidic
- To-date, the oceans have absorbed approximately half of the carbon emitted into the environment by mankind
- The ability of the oceans to continue to absorb carbon dioxide is not well understood; current carbon levels and changes in global temperatures may have a significant effect.
- Increasing carbon acidity could have a significant impact on many marine organisms, specifically calcifying organisms and larger aquatic animals. The effects of ocean acidification on these, and other organisms, is not completely known.
- The deep oceans have been suggested as potential storage sites for carbon.
- Much research is needed before the viability of deep ocean carbon storage can be evaluated. The effect of such schemes on the oceans, at a local and global scale, and on deep ocean life has not been determined.

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Introduction

The Royal Society of Chemistry is concerned about the impact of human activity on oceanic ecosystems. One of the foremost problems is the acidification of the oceans. This arises as a result of increased carbon dioxide (CO_2) absorption by the oceans as a direct result of an increase in atmospheric CO_2 levels caused by human activity such as the combustion of fossil fuels, agriculture, deforestation and cement production.

The deep oceans have also been suggested as a suitable environment for storing carbon dioxide as a means to mitigate climate change. Many of the scientific questions regarding this are also closely associated with the absorption of carbon dioxide by the oceans and its subsequent acidification.

Ocean acidification

The RSC fully endorses the 2005 report by the Royal Society entitled *'Ocean acidification due to increasing atmospheric carbon dioxide'* in its scientific evaluation of ocean acidification, its discussion of related socio-economic impacts, and its recommendations for future research and governance.[1] The issue of oceanic acidification has also been discussed by the Intergovernmental Panel on Climate Change (IPCC) in its 2001 Climate Change report.[2] The following section highlights some key aspects of ocean acidification.

There is now wide-spread acceptance that carbon dioxide (CO_2) released into the atmosphere through human activities is having a negative impact on global climate. Since pre-industrial times the atmospheric level of carbon dioxide has risen from about 280 ppm to about 380 ppm today, and it is still rising. This increase in atmospheric CO_2 levels does not account for all manmade carbon emissions; over half of total CO_2 emissions produced in the last 200 years have been absorbed by the oceans.[3]

The concentration of carbon dioxide (CO_2) in the oceans directly correlates to that in the atmosphere. When atmospheric CO_2 levels rise then there is a concurrent increase in that absorbed by the oceans. When CO_2 dissolves in the oceans it combines with water to form carbonic acid, H_2CO_3, which in turn dissociates to form carbonate ions, HCO_3^-, and hydrogen ions, H^+. Further ionisation of HCO_3^- leads to the formation of carbonate ions, CO_3^{2-}, and H^+. It is the generation of hydrogen ions, or protons, that leads to the lowering of oceanic pH, *i.e.* the ocean becomes more acidic. The composition of dissolved inorganic carbon (DIC) in the ocean typically comprises aqueous CO_2 (1%, including H_2CO_3), bicarbonate ions (3%) and carbonate ions (CO_3^{2-}, 8%). These ratios will vary according to local conditions including, primarily, temperature and up- welling of CO_2-rich deep water. Over the past 200 years the average pH of the oceans has dropped by 0.1 pH units (a 30% increase in H^+).

The oceans act as a carbonate buffer, which has, to date, been highly beneficial to mankind in minimising damage ocean acidification caused by high levels of CO_2 emissions. The decrease in ocean pH is therefore less than would be expected for the quantity of CO_2 absorbed. However, as increasingly large amounts of CO_2 become absorbed in the oceans then their ability to act as a buffer is lessened.

Currently the quantity of CO_2 absorbed by the oceans per year is 2 Gt (Gt = gigatonne; 1 Gt = 10^9 tonnes). For comparison, a fully laden supertanker weighs approximately 250 000 tonnes. As oceanic carbon dioxide levels increase, this rate of absorption will drop. Increases in average global temperature will potentially lead to increased vertical stratification (decreased mixing), thus decreasing the amount of CO_2 that can be absorbed (it may also decrease the flow of nutrients). If CO_2 emissions continue as at present then the pH of the oceans is predicted to drop by approximately 0.5 units by 2100, corresponding to a three fold increase in H^+ ions since pre-industrial times. Importantly, reversing current changes in ocean pH could take tens of thousands of years, *i.e.* it is essentially irreversible in our lifetimes. This is because oceanic mixing between surface and deep waters, which is required in order to bring up ocean sediments to buffer acidity changes, is a very slow process.

There is the potential for ocean acidification to have a significant impact on aquatic life. The greatest detrimental effect may be felt by those organisms that produce structures made from calcium carbonate ($CaCO_3$). Calcifying organisms include molluscs, corals, echinoderms, foraminifera and calcareous algae. The calcium carbonate produced by these organisms is used in external and internal structures, and in one of two forms: calcite or aragonite. Crucially, calcium carbonate will dissolve into seawater if the surrounding concentration of carbonate ions (CO_3^{2-}) is not high enough. It also becomes more soluble at lower ocean depths as a result of decreasing temperature and increasing pressure. A 'saturation horizon' can therefore be defined; in waters above this depth $CaCO_3$ does not dissolve but below this depth it does. Currently calcifying marine organisms live above the saturation horizon, however, lowering the pH of seawater will result in a decrease in the concentration of CO_3^{2-} and the saturation horizon will be elevated closer to the ocean surface. Aragonite is more soluble than calcite, and its saturation horizon is closer to the ocean surface than it is for calcite.

The acidification of the oceans may also have an impact on non-calcifying organisms. Most photosynthetic organisms, such as phytoplankton, obtain inorganic carbon from dissolved CO_2 or bicarbonate ions. As it is an active process then increases in dissolved inorganic carbon is likely to have only a small effect on photosynthesis and, in turn, on growth rates. The effect of increasing dissolved carbon concentrations on non-photosynthetic organisms is less well-understood, although it is anticipated that they will respond to increased CO_2 concentrations.

Larger oceanic animals may also be adversely affected by increased CO_2 concentrations. The respiratory system of such animals relies on obtaining oxygen from water, in which it is present in only very low levels. This is also accompanied by removal of CO_2, to a much lower level than that required by land mammals. Large aquatic, water breathing mammals are therefore highly sensitive to the concentration of carbon dioxide in the oceans; increased CO_2 can lead to acidification of bodily tissues and fluids.

There is also some concern that ocean acidification will have a direct impact on the availability of nutrients and the presence of toxins in the aqueous environment. The modification of ocean chemistry could have significant impacts on sea life. In the oceans metals can either be in complexed or free dissolved forms; the latter is considered to be toxic. Decreasing the pH of the oceans is anticipated to result in an increase in the concentration of free metals. Predicting the impact of this change is highly problematic though, with the role of trace elements in aquatic biochemical processes still an area of ongoing research.

Key questions that may need to be addressed include:

- How will CO_2 absorption by the oceans be affected in the future by current absorption and by increased global temperatures?
- Do climate change models need to be addressed with regards to changes in rates of CO_2 absorption?
- To what extent will calcifying organisms be affected at current CO_2 levels and at future projected levels?
- What research needs to done to identify the effects of ocean acidification on non-calcifying organisms?
- How will ocean acidification affect the ratio of complexed to freely dissolved metals in the oceans, and what impact will this have on aquatic organisms?
- What effect will ocean acidification have on the availability (concentration, speciation etc.) of nutrients such as phosphates, silicates and ammonium ions.
- Will the corrosion of ship hulls be adversely affected by increased ocean acidity?

Deep ocean storage of carbon dioxide

Carbon capture and storage has been proposed as a means to decrease the quantity of carbon dioxide emitted by human activities, thus helping minimise the impact on global climate. Using deep oceans as repositories for carbon dioxide has been proposed and a detailed study of this concept has been carried out by the IPCC and is included in their Special Report *Carbon dioxide Capture and Storage*.[4]

The two main concepts include ‘dissolution’, in which CO_2 is injected at depths of 1000 m or more and the CO_2 subsequently dissolves, or by ‘lake’ deposition in which CO_2 is injected onto the sea floor at depths of greater than 3000 m where it is anticipated that, being denser than water, it would form a lake and dissolution would be delayed.[5] Both schemes rely upon the slow mixing of ocean water of differing depths.

There is general agreement that carbon stored by this method would remain isolated for several hundreds of years, although not permanently. Fractions stored at greater depths will be retained for longer periods of time, and this can be extended further by the formation of solid clathrates or liquid CO_2 lakes.

The environmental effects of such schemes remain poorly understood. As dissolution of CO_2 progresses the acidity of the ocean would decrease, as outlined in the previous section. If the quantity of CO_2 injected was limited to only a few Gt then significant perturbations in ocean chemistry would only occur locally. Injection of hundreds of $GtCO_2$ would likely result in measurable changes over the entire ocean volume.

Although life is perceived to be sparse at such ocean depths, the effects of such high levels of CO_2 could have significant implications for what benthic (floor dwelling) organisms are present. There are suggestions that such organisms, and deep ocean microbial populations, may be highly susceptible to changes in CO_2 concentrations and pH.[6]

A third option is the conversion of carbon dioxide into bicarbonates or hydrates. This has the potential of minimising the impact on pH and avoid the need for prior separation of CO_2. However, wider environmental impacts include the use of large amounts of limestone and the need to require large material volumes.

A final option is to sequester carbon in crop residue and place large bales of biomass into the alluvial fan areas of the ocean basin. This could result in rapid burial of the bales into silt on the sea floor, and therefore the biomass could be stored for a long time.

Although deep ocean storage of carbon dioxide must be considered, there are many questions that need answering in order to be able to judge its viability.[7]

- Is deep ocean storage economically viable, environmentally safe and socially acceptable?
- What are the legal ramifications of injecting CO_2 into the oceans?
- How will CO_2 interact with water and ocean sediments at such extreme depths?
- What effect will high levels of CO_2 have on organisms living on or near the ocean bed?
- Will the stratification of the oceans be affected by current CO_2 emission and global warming and what effect will this have on potential deep ocean storage?

The RSC does not feel that sufficient data exists presently on this subject. Until these key questions are addressed satisfactorily then the RSC cannot condone deep ocean storage of CO_2.

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[1] Royal Society, *Ocean acidification due to increasing atmospheric carbon dioxide,* 30 June 2005, http://www.royalsoc..ac.uk/document.asp?tip=0&id=3249.
[2] IPCC, *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Chapter 6 Coastal Zones and Marine Ecosystems. http://www.grida.no/climate/ipcc_tar/wg2.index.htm.
[3] T. Takahashi, The Fate of Industrial Carbon Dioxide, *Science,* **2004**, *305*, 352-353.
[4] Intergovernmental Panel on Climate Change Special Report on *Carbon dioxide Capture and Storage*, Chapter 6 Ocean Storage. http://arch/rivm.nl/env/int/ipcc/pages_media/SRCCS-final/IPCCSpecialReportonCarbondioxideCaptureandStorage.htm
[5] Sea sediment proposed for carbon dioxide, *Chemistry World,* August 2006, http://www.rsc.org/chemistryworld/news/2006/August/07080604.asp; Can we bury our carbon dioxide problem?, *RSC Policy Bulletin,* Issue 3, http://www.rsc.org/ScienceAndTechnology/Policy/Bulletins/Issue3/CarbonDioxide.asp.
[6] B. A. Seibel and P. J. Walsh, Potential impacts of CO_2 Injection on Deep-Sea Biota, *Science*, **2001**, *294*, 319-320.
[7] Intergovernmental Oceanographic Commission of UNESCO, *Watching Brief: Ocean Carbon Sequestration.* http://ioc.unesco.org/iocweb/co2panel/CaptureStorageOcean.htm.