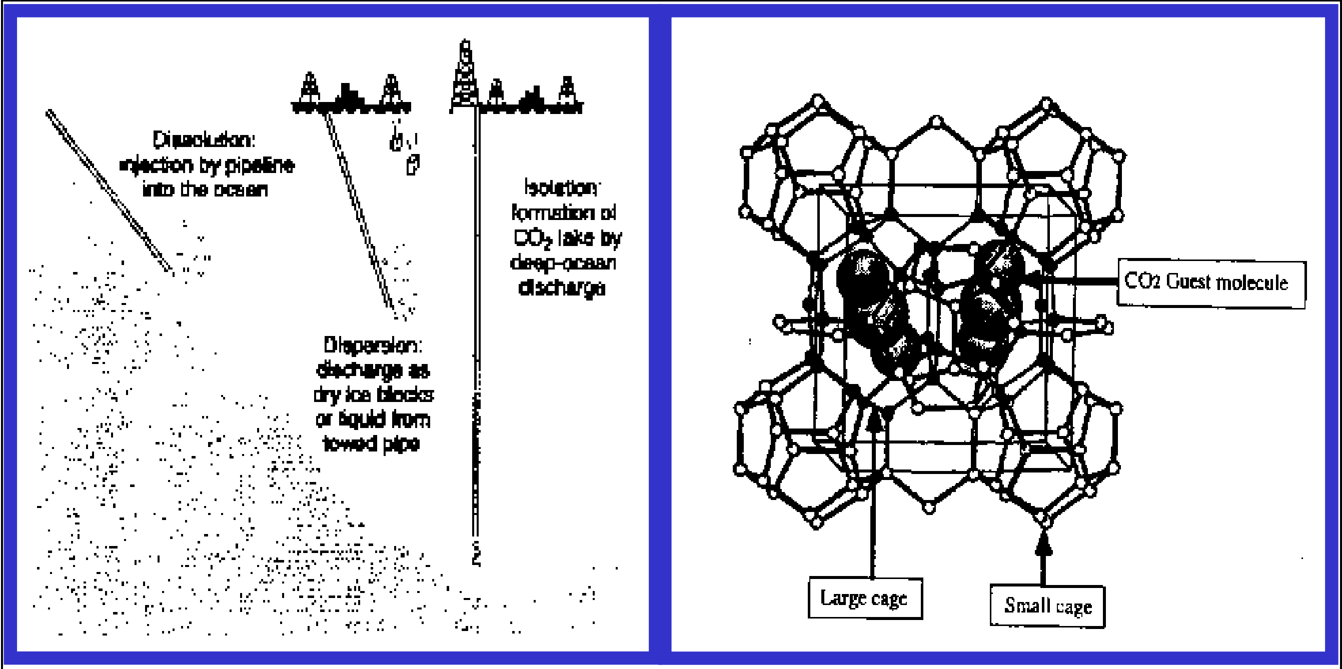
3.3 OCEAN SEQUESTRATION

3.3.1 OCEAN SEQUESTRATION – DIRECT INJECTION

Technology Description



Sketch of various ocean CO_2 disposal options (left). Structure of a CO_2 hydrate (right).

Ocean sequestration technologies strive to reduce carbon emissions by injecting captured CO_2 into the ocean, rather than releasing it into the atmosphere. The captured CO_2 is concentrated, and then pressurized into a liquid state. The physical chemistry of CO_2 is such that at high pressure and low temperatures (which exist at depth in the ocean), the CO_2 molecule reacts with seawater wrapping itself in a cage of water to form a solid compound much like ice (clathrate). This reaction profoundly changes its behavior. However, there are significant environmental questions that need to be examined.

System Concepts

- CO_2 is captured from a large point source of anthropogenic emissions production, transported, and injected into the ocean via pipeline or tanker.
- CO_2 molecules react with seawater wrapping themselves in cages of water to form solid compounds, much like ice (clathrates).

Representative Technologies

- Technologies will potentially be borrowed from the petroleum industry in the areas of drilling simulation and wells; processing, compression, and pipeline transport of gases; and operational experience of CO_2 injection.

Technology Status/Applications

- The injection technology is technically ready for adaptation for mid- to deep-ocean injection. However, technology is not ready for deployment. This is due to insufficient data detailing hydrate interactions with marine community structure, as well as knowledge gaps about physical and chemical behavior concerning dispersion and transport of hydrate plume by ocean chemistry and circulation.

Current Research, Development, and Demonstration

RD&D Goals

- Demonstrate that CO_2 direct injection is safe and environmentally acceptable.
- Improve global circulation simulation by including more accurate biology modules.

RD&D Challenges

- Develop field practices that optimize CO_2 direct-injection retention times.
- Develop the ability to predict plume effects on marine organisms.
- Develop the ability to track the fate of directly injected CO_2.
- Develop a better understanding of the CO_2 chemistry in ocean waters, and its effects on indigenous organisms, e.g. hypercapnia (effects of elevated CO_2 levels), and acidification of plume waters (depressed pH).

RD&D Activities

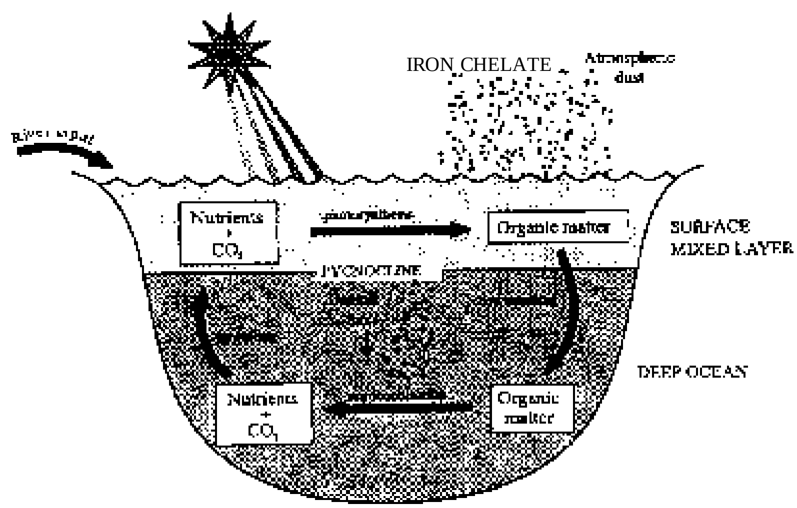
- Key DOE activities are targeted to determine physical, chemical, and biological impacts of direct injection.
- Conduct an appropriate-scale field experiment to adequately assess unit operations and potential impacts on marine environment at a sufficient scale downstream of injection zone.
- Formulate future experiments to evaluate ecological community effects (long term) and the total impact on the ecology of multiple regions of deep oceans.
- Develop other small-scale field experiments to understand fundamental biogeochemical cycles**.**
- Current expenditures for field experiment estimated to be $6 million.

Recent Progress

- A survey cruise of Hawaiian biology occurred during the summer of 1999.
- Small-scale release (one liter) at 3,600 m off the California coast demonstrating hydrate formation.
- Properties of hydrate formation determined in lab utilizing high-pressure, low-temperature reaction vessels.
- Conducted 10-day cruise off Loihi seamount (Hawaii) during December 2002, to determine effect of natural analogues of CO_2 on amphipod community in vent waters**.**
- Measured *in situ* penetration of added CO_2 into the seabed at 3,200 m depth (2004-2005)

3.3.2 OCEAN SEQUESTRATION – IRON FERTILIZATION

Technology Description



CONCEPT OF IRON FERTILIZATON

It is hypothesized that the rate of carbon dioxide fixation by microscopic plants called phytoplankton that live in the surface waters of the oceans may be limited by the availability of iron. In particular, field experiments in high nutrient, low chlorophyll (a measure of plant biomass) ocean waters such as the Southern Ocean and the Equatorial Pacific have shown that addition of iron increased the rate of removal of carbon dioxide through the process of photosynthesis. The carbon dioxide has thus been incorporated into plant biomass (phytoplankton), some of which will sink to deeper waters (export) where it may be sequestered for a period of time. Industry has developed a strong interest in using iron fertilization as a potentially low cost technology to offset carbon dioxide emissions. Many fundamental questions, however, remain as to the long-term effectiveness and potential environmental consequences of this carbon sequestration strategy.

System Concepts

- Iron chelate "fertilizer" is mixed into the ocean via vessel propellers. The release stimulates phytoplankton bloom.
- The phytoplankton bloom increases the rate of carbon fixation or photosynthesis, thus reducing the levels of carbon dioxide dissolved in the surface waters, which increases the uptake of atmospheric CO_2 by those surface waters (the CO_2 gradient gets bigger, so the flux into the ocean should increase). Having converted carbon dioxide to plant biomass, some of the phytoplankton will sink to deeper waters where the carbon will be sequestered.

Representative Technologies

- Technologies will be borrowed extensively from the unit operations of the maritime industry and existing instrumentation systems.

Technology Status/Applications

- Three previous research demonstrations have been performed. The Southern Ocean Iron Fertilization Experiment (SOFEX) occurred in January-February 2002. This research, which was cofunded by the National Science Foundation and the Department of Energy, aimed to quantify carbon export – that is, how much carbon sinks to deeper waters, after fertilization with iron. The major goal was to quantify the extent of export production of carbon.

Current Research, Development, and Demonstration

RD&D Goals

- Determine whether iron-induced phytoplankton blooms result in the vertical flux (transport) of carbon from the surface waters (export production) to the deep waters.

RD&D Challenges

- Determine the overall short-term environmental consequences of release of iron as iron chelate.
- Determine the long-term consequences of iron enrichment on the surface water community, midwater community, and ocean processes.
- Determine the best proxy for carbon.

• Quantify the efficiency of the long-term storage of carbon. **RD&D Activities** • Continue data reduction from SOFEX cruise. • Determine magnitude of carbon export from surface layer from SOFEX. • Prepare for proposal selection from current solicitation.
Recent Progress
• Previous cruises of research vessels IRONEX I and II, and SOIREE, confirmed the stimulation of phytoplankton bloom by the addition of iron chelate. • Measurements of vertical profiles of carbon indicated that some of the additional phytoplankton contributed to the stream of sinking organic carbon.