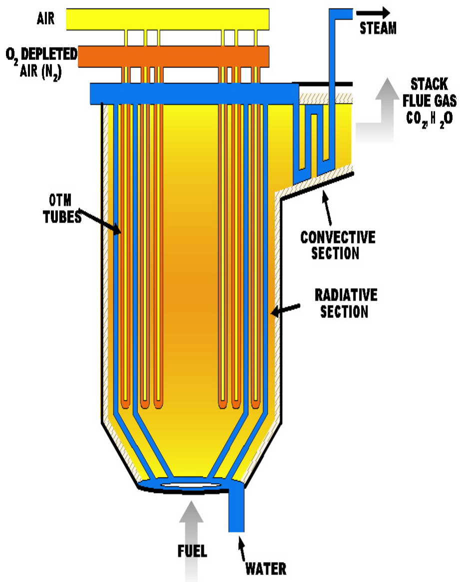
3.0 CAPTURING AND SEQUESTERING CARBON DIOXIDE

3.1. GEOLOGIC SEQUESTRATION

3.1.1 CO_2 CAPTURE AND SEPARATION

Technology Description



Oxyfuel Technology

Integrates air separation, using O2 Transport Membrane (OTM) and oxygen combustion

Fossil- and biomass-based energy conversion processes convert hydrocarbon materials (i.e., substances consisting mostly of carbon and hydrogen) into carbon dioxide and water while releasing energy. The goal of CO_2 capture and separation is to produce relatively pure CO_2 from these processes, preferably at pressures suitable for transport, storage, or reuse.

System Concepts

- *Post-combustion capture*. A chemical or physical separation process extracts CO_2 from the flue gas of a conventional air-fired combustion process. CO_2 is present in concentrations ranging from 3% to 12%. The focus is on technology for retrofitting or repowering existing power plants and industrial processes.
- *Oxy-fuel combustion.* Pure oxygen rather than air is charged to the combustion chamber, producing a flue gas of CO_2 and water. A portion of the CO_2 is recycled and mixed with the oxygen to absorb heat and control the reaction temperature.
- *Precombustion decarbonization*. The hydrocarbon feedstock is gasified to produce a synthesis gas made up primarily of hydrogen and carbon dioxide. The CO_2 is separated from the hydrogen before it is combusted or charged to a fuel cell.
- There are other advanced-system concepts in which fuel processing and CO_2 capture are integrated into a single stage using, for example, membranes or reduction-oxidation agents.

Representative Technologies

- The conventional technology for post-combustion capture (removing CO_2 from flue gas) is amine scrubbing. A solution of amine and water is contacted with flue gas. The amine and the CO_2 undergo a chemical reaction forming a rich amine that is soluble in the water. The rich amine solution is pumped to a desorber where it is heated, reversing the reaction and releasing pure CO_2 gas. The recovered amine is recycled to the flue-gas contactor.
- Other technologies for post-combustion capture include cryogenic distillation, membranes (polymer, ceramic, palladium, mine, or ionic liquid coated), carbon absorbents, sodium absorbents, hydrides, and lithium silicate.

Technology Status/Applications

- Amine systems are used in numerous industrial applications to capture CO_2 from flue gas for use as a commodity chemical. Cryogenic and carbon absorbent systems have been built commercially.
- Other post-combustion capture technologies are being developed at the laboratory and pilot scale.

Current Research, Development, and Demonstration

RD&D Goals

- The metrics and goals for CO_2 capture research are focused on reducing the cost and energy penalty, because analysis shows that CO_2 capture drives the cost of sequestration systems. Similarly, the goals and metrics for carbon storage and measurement, monitoring, and mitigation (MM&V) are focused on permanence and safety. All three research areas work toward the overarching program goal of 90% CO_2 capture, with 99% storage permanence at less than 20% increase in the cost of energy services by 2007, and less than 10% by 2012.

RD&D Challenges

- CO_2 exists in air-combustion flue gas at low concentration, 3-12 volume percent, which makes post-combustion removal very expensive using current approaches.
- Flue gas contains reactive impurities that can adversely affect CO_2 capture systems.
- Transport and/or storage systems may require highly pure CO_2 product, which would increase cost.
- Loss of CO_2 temperature and pressure across the capture system.
- Wide-scale application of any one capture technology will be difficult, due to real estate constraints, availability of pollutant-control equipment, resource limitations, and economic and load demographics.
- Significant cost associated with compressing CO_2 for transportation and storage.

RD&D Activities

- Laboratory-scale experiments with advanced amines, ceramic membranes, high-temperature polymer membranes, vortex gas/liquid separator, ammonium and sodium bicarbonate, carbon absorbents, ionic liquids, aqueous ammonia, and electrochemical pumps.
- Pilot-scale tests with a novel oxy-fuel boiler, a CO_2/water hydrate process, a sodium-based CO_2 sorbent, aqueous K_2CO_2 promoted by piperazine, an oxygen-fired circulating fluidized bed, and a metal reduction-oxidation power generation process.

Recent Progress

- During a short three-year period, a strong portfolio of research projects for the existing and future power-generation fleet has been developed by DOE with more than 40% private-sector cost-share.
- The international community has been successfully engaged through participation in the International Energy Association Greenhouse Gas Programme, the CO_2 Capture Project with the European Commission and other international participants, and other collaborations with Canada, Australia, and Japan.
- Analysis by the Carbon Sequestration Regional Partnership on the likely and probable application of various technologies to different point sources has been conducted and will continue in Phase II (utility and nonutility).

Commercialization and Deployment Activities

- Roughly 15 Mt/yr of CO_2 is captured from anthropogenic emissions sources in the United States and used as a commodity chemical.

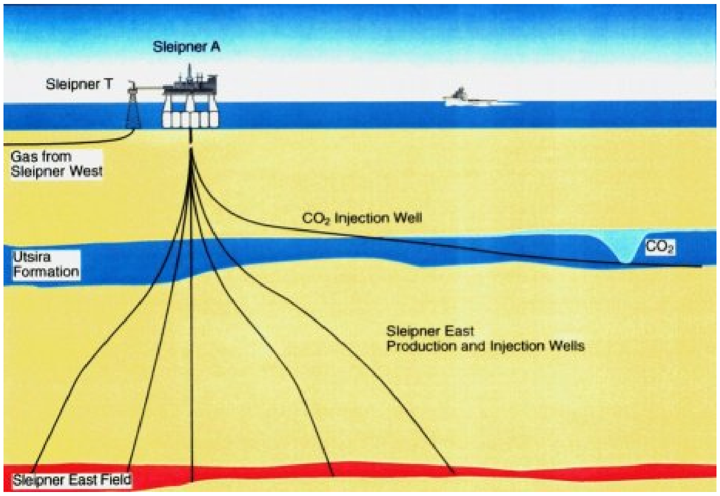
Market Context

- Development of approaches for economically decarbonizing fossil fuels will allow the carbon-free production of electricity and hydrogen, and will take advantage of an existing fossil fuel infrastructure that accounts for more than 80% of the energy consumed in the United States and internationally.

3.1.2 CO_2 STORAGE IN GEOLOGIC FORMATIONS

Technology Description

Sleipner North Sea Project



Large amounts of CO_2 (about a billion tons per year) may need to be stored as a part of a future global atmospheric stabilization strategy. CO_2 can be injected into depleting oil fields, gas fields, and unmineable coal-bearing formations to enhance resource recovery. A portion of the CO_2 remains underground, although current industry practices are geared strongly toward minimizing the CO_2 left underground – and little or no attention is paid to the CO_2 that is not recovered. R&D is focused on revamping conventional enhanced oil recovery, gas recovery, and enhanced coalbed methane processes so that they can serve a dual purpose: resource recovery and CO_2 storage. Other high permeability formations filled with brine, organic-rich shale beds, and other nonconventional geologic structures have potentially enormous CO_2 storage capacities. Research is focused on learning more about these formations and developing the capabilities needed to use them as CO_2 repositories.

System Concepts

- CO_2 is captured from a large anthropogenic point source, and transported and injected into a depleting oil field, unmineable coal seam, saline formation, depleting gas field, shale, or other geologic structure amenable to CO_2 storage. There are five different mechanisms that can trap CO_2 in geologic formations:
    - Structural trapping: A layer or "cap" of impermeable rock that overlies the formation of porous rock into which the CO_2 is injected prevents upward flow of CO_2. This is the mechanism that caused natural deposits of crude oil, natural gas, and CO_2.
    - Capillary trapping: The surface of sandstone and other rocks preferentially adheres to saline water versus CO_2. If there is enough saline water within a pore (75-90% of the pore volume), it will form a capillary plug that traps the residual CO_2 within the pore space.
    - Dissolution in saline water: CO_2 is soluble in saline water, and will dissolve in solution on contact.
    - Mineralization: Over longer periods of time, dissolved CO_2 can react with minerals in the formation to form solid carbonates. There may be ways to enhance this reaction.
    - Adsorption: Coal and other organically rich formations will preferentially absorb CO_2 onto carbon surface as a function of reservoir pressure. In some cases, such as coal beds, CO_2 displaces methane, which can be recovered to enhance economics.
- In an oil field, the CO_2 displaces the oil in place and also dissolves in the oil, decreasing the oil viscosity and enabling more of it to be recovered. A portion of the injected CO_2 remains stored in a reservoir as a free gas, in brine or oil solution, or in carbonate minerals.
- Leakage of sequestered CO_2 back to the surface may occur through faults, active or abandoned wells, and microseepage.

Representative Technologies

- Natural gas storage fields provide experience of injecting significant quantities of gas into geologic formations.
- Technologies will borrow extensively from the petroleum industry in the areas of drilling simulation; completion of injection wells; processing, compression, and pipeline transport of gases, including acid gases; operational experience of CO_2 injection for enhanced oil recovery and natural gas storage; and subsurface reservoir engineering and characterization.
- Enhanced coal bed methane recovery using nitrogen.

Technology Status/Applications

- The Mount Simon reservoir underlying Illinois, Indiana, Michigan, Kentucky, and Pennsylvania has been approved for industrial waste disposal and underlies a region with numerous fossil energy power plants.
- Industry has experience with more than 400 wells for injecting industrial wastes into saline formations.
- The petroleum technology is readily adaptable to subsurface CO_2 storage.

Current Research, Development, and Demonstration

RD&D Goals

- Develop domestic CO_2 underground storage repositories capable of accepting around a billion tons of CO_2 per year.
- Demonstrate that CO_2 storage underground is safe and environmentally acceptable, and an acceptable GHG mitigation approach.
- Demonstrate an effective business model for CO_2 enhanced oil recovery and enhanced coalbed methane, where significantly more CO_2 is permanently stored than under current practices.
- Develop cost-effective methods to survey large land areas and locate zones of potential CO_2 leakage.
- Provide monitoring techniques that can reliably evaluate the stability, capacity, rate of leakage, and permanence of carbon dioxide stored in geologic formations.
- Develop publicly accepted monitoring protocols.

RD&D Challenges

- Develop the capability to inject CO_2 into saline formations with low permeability.
- Harness geochemical reactions to enhance containment.
- Develop injection practices that preserve cap integrity.
- Develop an understanding of the properties of shales and other unconventional hydrocarbon-bearing formations that determine how they will react to CO_2 injection.
- Develop the ability to track CO_2 transport.
- Develop field practices that optimize CO_2 storage and resource recovery.
- Develop the ability to predict the CO_2 storage capacity and potential resource recovery of a particular formation.
- Develop models that are able to simulate the fate and transport of CO_2 in geologic formations and along potential migration pathways.
- Develop the ability to track the fate and transport of injected $CO_{2.}$
- Develop methods to locate well bores, with and without casing, that might potentially leak.
- Develop surface and near-surface monitoring technologies that will allow public demonstration of the safety of CO_2 storage.
- Develop a better understanding of the chemistry of coal and CO_2, and conduct comprehensive R&D program on all physical and chemical aspects of CO_2 interactions with reservoir phases.

RD&D Activities

- Study geochemical reactions involving CO_2 in a laboratory.
- Study the natural analogs of geochemical CO_2 conversion. Study rock samples from CO_2 bearing geologic formations to better understand in situ geochemical/geobiological reactions.
- Develop CO_2 tracking technology, e.g., sonic, chemical tracers.
- Study CO_2 transport in the Sleipner Vest gas field, via the International Energy Agency's Greenhouse Gas Programme.

- Assessment of techniques for finding abandoned wells near a potential sequestration site.
- Develop models to simulate migration of CO_2 through multiple subsurface formations.
- Novel injection techniques to increase CO_2 storage in saline formations.
- CO_2 storage in coal beds. Laboratory measurements of CO_2/CH_4 sorption and coal swelling under confined and unconfined conditions, ARI and industry consortium, commercial-scale field demonstration in the San Juan Basin; Consol – horizontal drilling, Alabama geologic survey, screening model for Black Warrior.
- Apply surface and near-surface monitoring techniques such as surface CO_2 flux, injection tracers in soil-gas, and changes in shallow aquifer chemistry for CO_2 leakage.
- Study chemical reactions involving CO_2 and cement from new or existing wells as a possible source of leakage.
- CO_2 storage in oil reservoirs. Weyburn, reservoir mapping, West Pearl Queen, CO_2 monitoring and simulation.
- Airborne reconnaissance of a 38,000-acre EOR/sequestration site to locate wells, faults, and other potential CO_2 leakage zones.
- Other RD&D activities in DOE, Australia, the European Union, Japan, etc.

Recent Progress

- Major saline formations underlying the United States have been identified.
- Initiated a pilot-scale test of CO_2 storage in a depleted oil reservoir.
- Completed pilot-scale injection of CO_2 into the Frio deep saline aquifer and field tested near-surface monitoring techniques.
- Initiated several field tests with key industrial companies participating and providing cost-share: Consol Inc. CBM,-Appalachia ARI, CBM-San Juan Basin; Strata Production C. – Permian Basin; Pan Canadian Resources EOR-Canada.

Commercialization and Deployment Activities

- Since 1999, Statoil has been injecting CO_2 at a rate of 1 Mt/yr into the Sleipner Vest gas field in a sandstone aquifer 1,000m beneath the North Sea.
- About 70 oil fields worldwide use CO_2 for enhanced oil recovery.
- Another project uses CO_2 from Dakota Gasification for enhanced oil recovery in the Weyburn field in Canada. CO_2 is transported via pipeline.
- The pipeline enables extensive use of CO_2 for enhanced coal bed methane recovery in the San Juan basin.
- There are plans for using CO_2 for enhanced oil recovery in Kansas, using CO_2 from ethanol production.
- Planned test in Kansas using landfill gas for enhanced coal bed methane recovery.

Market Context

- Development of approaches for economically decarbonizing fossil fuels will allow the carbon-free production of electricity and hydrogen, and will take advantage of an existing fossil fuel infrastructure that accounts for more than 80% of the energy consumed in the United States and internationally.

3.1.3 NOVEL SEQUESTRATION SYSTEMS

Technology Description

In the long term, CO_2 capture can be integrated with geologic storage and/or conversion. Many CO_2 conversion reactions are attractive but too slow for economic chemical processes.

System Concepts

- Using impurities in captured CO_2 (e.g., SO_x, NO_x) or additives enhances geologic storage. This is a possible opportunity to combine CO_2 emissions reduction and criteria pollutant-emissions reduction.
- Conducting reactions on CO_2 while it is being stored underground can alleviate the problem with slow kinetics.
- In situ mineralization is an important trapping mechanism, that there may be ways to enhance it.
- Rejected heat from electricity generation and CO_2 compression can help drive CO_2 conversion process.
- Air capture of CO_2.

Representative Technologies

- Capture of CO_2 from flue gas and algal conversion to biomass.
- Capture of CO_2, storage in a geologic formation, and in situ biological conversion to methane.

Technology Status/Applications

- Conceptual.

Current Research, Development, and Demonstration

RD&D Goals

- Demonstrate viable chemical or biological conversion approaches at the laboratory scale.
- Develop robust conceptual designs for integrated capture, storage, and conversion systems.

RD&D Challenges

- CO_2 conversion reaction kinetics are slow, energy requirements are high.
- For biological in situ CO_2 conversion, must provide food and remove waste.
- Truly novel concepts may be required to meet the ultimate "stretch" goals of the program. Technology breakthroughs could come from concepts associated with areas not normally related to traditional energy technologies (e.g., nanotechnology). Tapping areas where current researchers do not have an energy mindset will require new approaches for soliciting proposals for R&D projects.

RD&D Activities

- Laboratory and pilot-scale experiments with biological and chemical conversion.
- Conceptual studies of integrated systems and in situ CO_2 conversion.

Recent Success

- Several cost-shared research projects have been initiated.

Commercialization and Deployment Activities

- None.