Carbon Capture and Sequestration Technologies for Greenhouse Gas Control

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CEEPR Workshop
Massachusetts Institute of Technology
May 3, 2001
Topics

- Technology Overview
- Current R&D Activities
- A Multi-Pollutant Perspective
- An Evaluation Framework
- Technology Innovation
- Public Perception
Why Bother with CCS?

*CCS technology may be a way to:*

- Have your cake and eat it: use fossil fuels without CO$_2$ emissions
- Minimize the overall cost of reducing greenhouse gas emissions
- Provide a bridge to a more sustainable energy future
CO$_2$ Capture Technology is Commercially Available

Current industrial applications include:

- Enhanced oil recovery (EOR)
- Fertilizer production
- Soda ash
- Food processing
- Hydrogen production
# Scale of CO₂ Capture Applications

<table>
<thead>
<tr>
<th>Process</th>
<th>Year</th>
<th>Location</th>
<th>Status</th>
<th>EOR (ton CO₂/day)</th>
<th>Fertilizer (ton CO₂/day)</th>
<th>Soda Ash (ton CO₂/day)</th>
<th>Food-grade (ton CO₂/day)</th>
<th>Sleipner West (ton CO₂/day)</th>
<th>500MW Coal-based (ton CO₂/day)</th>
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<tbody>
<tr>
<td>EOR</td>
<td>'80s</td>
<td>TX &amp; NM</td>
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<td>1200</td>
<td>150</td>
<td>800</td>
<td>320</td>
<td>3000</td>
<td>9600</td>
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<td>Fertilizer</td>
<td>?</td>
<td>IGFC</td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Food-grade</td>
<td>?</td>
<td>NEEA, MA</td>
<td>operational</td>
<td></td>
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<td>Sleipner West</td>
<td>1996</td>
<td>Norway</td>
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<td>500MW Coal-based</td>
<td>2010?</td>
<td>?</td>
<td>prospective</td>
<td></td>
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<td>9600</td>
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</tbody>
</table>

- EOR: Enhanced Oil Recovery
- Fertilizer
- Soda Ash
- Food-grade
- Sleipner West Gasfield, Norway
- 500MW Coal-based Power plant

- Process: Dow MEA, Kerr-McGee, Dow MEA, MEA based, MEA based
- Location: TX & NM, IGFC, NACC, NEEA, MA, Norway, ?
- Status: shut down, operational, operational, operational, prospective
Effect of CO$_2$ Capture on Cost

- **Capital Cost ($/kW_{gross}$)**
  - Ref. Plant
  - w/CO$_2$ Capture

- **Capital Cost ($/kW_{net}$)**
  - Ref. Plant
  - w/CO$_2$ Capture

- **Cost of Electricity ($/MWh_{net}$)**
  - Ref. Plant
  - w/CO$_2$ Capture
Key R&D Needs

• Reduce the cost of CO₂ separation and capture technology
• Determine the environmental acceptability of CO₂ storage (sequestration) methods
• Evaluate the true cost of alternative sequestration methods
Current R&D Initiatives:
U.S. Department of Energy

• Carbon Sequestration Program
  ($9M FY00, $19M FY01, $21M FY02r)
• 13 projects in first round awards
  ▪ Separation and capture (2)
  ▪ Geologic sequestration (4)
  ▪ Ocean sequestration (2)
  ▪ Terrestrial sequestration (1)
  ▪ Other sequestration concepts (2)
  ▪ Modeling and assessments (2)
• Round 2 projects to be announced
Current R&D Initiatives: Carbon Capture Project

- Consortium of 9 companies:
  - BP, Chevron, ENI, Norsk Hydro, Pan Canada, Shell, Suncor, Statoil, Texaco

- Goals:
  - Reduce the cost of CO₂ capture (by 50% - 75%)
  - Demonstrate CO₂ sequestration
  - Commercial processes within 10 years

- Budget: $20M / 3 years + gov’t grants
Targets of Opportunity

- Oil and gas production
- Petroleum refineries
- Industrial chemicals (hydrogen, ammonia, etc.)
- Fossil fuel power plants
Power Generation Options

- Combustion-based
  - Coal
    - Combustion-based
    - Gasification-based
  - Natural Gas
    - Direct Combustion
      - Gas Reforming
  - Gas Turbines
  - Coal Gasification
  - Fuel Cells
  - Other

- Gas Reforming
- Air
- Oxygen

- Simple Cycle
  - Pulverized Coal Gas Turbines
- Combined Cycle
CO₂ Capture Technologies

CO₂ Separation and Capture

Absorption
  - Chemical
    - MEA
    - Caustic
    - Other
  - Physical
    - Selexol
    - Rectisol
    - Other

Adsorption
  - Adsorber Beds
    - Alumina
    - Zeolite
    - Activated C
  - Regeneration Method
    - Pressure Swing
    - Temperature Swing
    - Washing

Cryogenics

Membranes
  - Gas Separation
    - Polyphenyleneoxide
    - Polydimethylsiloxane
  - Gas Absorption
    - Polypropylene
  - Ceramic Based Systems

Microbial/Algal Systems
CO$_2$ Sequestration Options

**CO$_2$ Disposal / Storage Options**

**Geological Sequestration**
- Deep Saline Reservoirs
- Depleted Oil and Gas Wells
- Abandoned Coal Seams

**Ocean Sequestration**
- Very Deep Ocean Injection
- Unconfined Release (@ ~ 1000 m)
- Dense Plume Formation (shallow)
- Dry Ice Injection

**Biological Sequestration**
- Forests and Terrestrial Systems
- Marine Alga

**Other Methods**
- Storage as a solid in an Insulated Repository
- Utilization Schemes (e.g. Polymerization)
Some Questions to be Addressed

- How do alternative CCS options and technologies compare in terms of performance, emissions and cost?
- What are the key parameters that most affect the performance and cost of a given option?
- What are the uncertainties and technological risks of different options?
- What are the priorities and payoffs of R&D to reduce key uncertainties?
- What are the most promising markets for advanced separation and capture technologies?
A Process Assessment Framework

Focus on fossil fuel power systems

• Develop a flexible, easy-to-use computer model to evaluate the performance and cost of CCS options at the level of an individual plant
• Incorporate both current (baseline) technologies plus potential future options
• Characterize key uncertainties in performance and cost parameters
• Integrate carbon management technologies with other environmental control systems
Multi-Pollutant Interactions

Criteria Air Pollutants
- PM
- SO₂
- NOₓ

Hazardous Air Pollutants
- Hg
- HCl
- H₂SO₄

Greenhouse Gas Emissions
- CO₂
- CH₄
Process Evaluation Framework

Energy Conversion

CO₂ Capture

CO₂ Transport

CO₂ Storage or Disposal

Coal or Natural Gas

Air or Oxygen
Model Software Package

**Fuel Properties**
- Heating Value
- Composition
- Delivered Cost

**Plant Design**
- Conversion Process
- Emission Controls
- Solid Waste Mgmt
- Chemical Inputs

**Cost Data**
- O&M Costs
- Capital Costs
- Financial Factors

**Power Plant Models**

**Graphical User Interface**

**Plant and Fuel Databases**

**Plant & Process Performance**
- Efficiency
- Resource Use

**Environmental Emissions**
- Air, Water, Land

**Plant & Process Costs**
- Capital
- O&M
- COE
The Model is Available at . . .

- Web Access:
  
Gasification Combined Cycle System

Gasification Options
Gasifier: KRW
Oxidant: Oxygen
Gas Cleanup: Hot

Post-Combustion Controls
NOx Control: SCR
CO2 Control: None

Solids Management
Slag: Landfill
Sulfur: Sulfur, Landfill, Sulfuric Acid

Plant Diagram
NGCC Plant with CO$_2$ Capture

**Gasification Options**
- **Plant Type:** Combined Cycle

**Post-Combustion Controls**
- **NOx Control:** SCR
- **CO2 Control:** None, Absorption - MEA

**Solids Management**
- **Slag:** Landfill
- **Sulfur:** Landfill
Geologic Sequestration (EOR)
Applications

- Process design
- Technology evaluation
- Cost estimation
- R&D management
- Risk analysis
- Environmental compliance
- Marketing studies
- Strategic planning
Benefits of R&D

Cumulative probability vs. Mitigation cost ($/ton CO₂ avoided)

- **At present**
- **Hypothetical R&D case**
Role of Technological Innovation

- How will the cost and performance of CCS technologies change over time?
- How will improvements in CCS technologies compare to those in other domains?
- What factors will most influence (or inhibit) the rate of technology innovation?
Inventive Activity in SO$_2$ Capture
(Class-Based Patent Dataset)
Improvements in SO$_2$ Capture Efficiency

$y = 5.6917 \ln(x) + 68.449$

$r^2 = 0.9561$
Reductions in FGD System Capital Cost
(500 MWe, 3.5% sulfur coal, 90% SO₂ removal)

\[ y = 0.0005x^3 - 0.0767x^2 + 1.2978x + 249.07 \]
\[ r^2 = 0.9992 \]
The Bigger Picture

- How does carbon capture and sequestration compare to other options for greenhouse gas mitigation?
- Under what circumstances is CCS most attractive?
- What is the carbon sequestration potential of this technology?
A Hierarchy of Policy Analysis Models

Options for a single facility (tech feasibility, efficiency, emissions, cost)

Multi-facility (or multi-sector) optimization or simulation (dynamic)

Integrated assessment models (including measures of impacts)
Role of Public Perception

Will the public accept CO₂ sequestration as a viable method of GHG control?

• Preliminary (pilot) study (C. Palmgren, G. Morgan, D. Keith, 2000) showed mixed public attitudes toward CO₂ sequestration

• Principal concerns of critics:
  - CO₂ pipeline issues
  - Slow leaks over long time
  - Hydrogen safety
  - Fast “burps” in short time
  - Ocean ecology
Conclusions

• Carbon capture and sequestration technology is a potentially important player in GHG control
• Its role will be shaped largely by:
  ▪ The stringency of future emission reduction requirements for greenhouse gases
  ▪ The success of R&D efforts to lower the costs of CO₂ capture and sequestration
  ▪ Public acceptance of sequestration as a safe and viable approach to greenhouse gas control
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