Carbon Dioxide Capture and Sequestration: Managing the Anthropogenic Carbon Cycle

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GLOBAL CHALLENGES – GLOBAL SOLUTIONS – GLOBAL OPPORTUNITIES
Carbon Dioxide Capture and Sequestration Involves 4 Steps

1. **Capture**
2. **Compression**
3. **Pipeline Transport**
4. **Geological Sequestration**
## Comparison of Capture Options

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<th>Technology</th>
<th>Advantages</th>
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<td>Post-Combustion</td>
<td>• Mature technology&lt;br&gt;• Retrofit possible&lt;br&gt;• Heat recovery/integration</td>
<td>• High energy penalty (~20-30%)&lt;br&gt;• High cost for capture</td>
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<tr>
<td>Pre-Combustion (IGCC)</td>
<td>• Lower capture costs than post-combustion&lt;br&gt;• Lower energy penalties (10-15%)&lt;br&gt;• H₂ production</td>
<td>• Complex chemical process&lt;br&gt;• Repowering&lt;br&gt;• Large capital investment</td>
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<tr>
<td>Oxygen-Combustion</td>
<td>• Avoid complex post-combustion separation&lt;br&gt;• Potentially higher generation efficiencies</td>
<td>• Oxygen separation&lt;br&gt;• Repowering</td>
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Technology Overview

In Salah Project, Algeria

- Compression of CO₂ to a liquid state (about 100 bars)
  - Compression is a mature technology
- Transport of liquid CO₂ in pipelines
  - Pipeline transport is a mature technology with over 2,000 miles of pipelines in the U.S.
U.S. Existing and Planned CO₂ Pipeline Network

Currently transporting about 50 MT/year (equivalent to about 8 1,000 MW coal-fired power plants)
Options for Geological Storage

Overview of Geological Storage Options

1. Depleted oil and gas reservoirs
2. Use of CO₂ in enhanced oil and gas recovery
3. Deep saline formations - (a) offshore (b) onshore
4. Use of CO₂ in enhanced coal bed methane recovery
Basic Concept of Geological Sequestration of CO$_2$

- Injected at depths of 1 km or deeper into rocks with tiny pore spaces
- Primary trapping
  - Beneath seals of low permeability rocks

Image courtesy of ISGS and MGSC

Courtesy of John Bradshaw
Secondary Trapping Mechanisms

- Structural & stratigraphic trapping
- Residual CO$_2$ trapping
- Solubility trapping
- Mineral trapping

% Trapping contribution vs. Time since injection stops (years)

Increasing Storage Security
Risk Evolution and Management

- Injection begins
- Injection stops
- 2 x injection period
- 3 x injection period
- n x injection period

Health Safety and Environmental Risk

- Site selection
- Active and abandoned well completions
- Storage engineering
- Pressure recovery
- Secondary trapping mechanisms
- Confidence in predictive models

Acceptable Risk

Monitor:
- Calibrate & Validate Models

Model:
- Calibrate & Validate Models
Sleipner Project, North Sea

- 1996 to present
- Avoid CO$_2$ tax of $50/tonne
- 1 Mt CO$_2$ injection/yr
- Seismic monitoring

Courtesy Statoil
Why CCS: CCS is Applicable to Many Emission Sources

CCS is applicable to the 60% of CO₂ emissions which come from stationary sources such as power plants, cement plants and refineries.

CCS has broad application across many sectors of the economy.
Why CCS: Large Emissions Reductions with Few Projects

CCS with 90% capture

Increase efficiency from 25 to 50 mpg

One 1,000 MW coal-fired power plant
(6.5 MT CO$_2$/year)

2.8 Million Cars
(10% of California Fleet)

Dramatically reduce the number of actors needed to achieve large emission reductions.
Competition with Natural Gas for Power Generation

Why not forget about CCS and simply replace coal fired generation with natural gas?

Why CCS: Fuel Switching to Natural Gas is Not Enough

Assume:
1. All incremental gas production (~6 TCF by 2035) is used to generate electricity
2. Power generation efficiency of 48.8% (combined cycle gas power generation)

Replace about 45% of existing coal-fired generation (2010 baseline)
Good, but more needed to reduce emissions to safe levels.
EIA predicts a maximum of 20% replacement of by 2035.
Major Challenges Going Forward

Reducing the cost cost of CO$_2$ capture (~50%)

Incremental cost of CCS

- Capture R&D
- Learning by doing

Increasing confidence in CO$_2$ storage

- Demonstration projects
- Monitoring
- R&D
Major Trends: Good News, Bad News

- Global government investment stable for now at $23.5 B
- Large R&D community making good progress
- Capture from industrial sources gaining momentum
- Use of CO$_2$ for EOR
- Progress on regulatory issues
- Approval for use of CCS in the Clean Development Mechanism (CDM)

- Lack of progress toward local, national, and global CO$_2$ reduction commitments has thwarted private investment
- Cost of early projects higher than expected
- Local public reaction is mixed, especially in Europe
Concluding Remarks

• CCS is an important part of managing the anthropogenic carbon cycle
  – Needed for large and rapid emission reductions
  – Large per project emission reductions (e.g. 2.5 million cars)
  – Switching to natural gas is not sufficient

• Progress on CCS proceeding on all fronts
  – Industrial-scale projects
  – Government support
    • Demonstration plants
    • Research and development

• Research is needed to support deployment at scale
  – Capture: Lower the cost of capture
  – Sequestration: Increase confidence in storage permanence

• Serious commitment to CO\textsubscript{2} emission reduction needed to sustain progress and fully re-engage industry