IPCC Special Report on Carbon Dioxide Capture and Storage

Edward S. Rubin
Carnegie Mellon University
Pittsburgh, Pennsylvania, USA

Presentation to the
RITE International Workshop on CO₂ Geological Storage
Tokyo, Japan
February 20, 2006
Structure of the Intergovernmental Panel on Climate Change (IPCC)

Plenary: All Member Countries of UNEP/WMO (>150)

Working Groups I, II, III

Bureau, Secretariat, Technical Support Units

STUDIES

Lead Authors
Coordinating Lead Authors
Contributing Authors

Review Editors

Expert and Government Reviewers
About IPCC Reports

• Provide assessments of scientifically and technically sound published information
• Authors are best experts available worldwide, reflecting experience from academia, industry, government and NGOs
• Policy relevant, but NOT policy prescriptive
• No research, monitoring, or recommendations
• Thoroughly reviewed by other experts and governments
• Final approval of Summary for Policymakers by all member governments
History of this Special Report

- 2001: UNFCCC (COP-7) invites IPCC to write a technical paper on geological carbon storage technologies
- 2002: IPCC authorizes a workshop (held November 2002) that proposes a Special Report on CO$_2$ capture and storage
- 2003: IPCC authorizes the Special Report under auspices of WG III; first meeting of authors in July
- July 2003–June 2005: Preparation of report by ~100 Lead Authors + 25 Contributing Authors (w/100s of reviewers)
- September 26, 2005: Final report approved by IPCC plenary
- December 2005: Presented officially to UNFCCC at COP-11
Why the Interest in CCS?

- The UNFCCC goal of stabilizing atmospheric GHG concentrations will require significant reductions in future CO$_2$ emissions
- CCS could be part of a portfolio of options to mitigate global climate change
- CCS could increase flexibility in achieving greenhouse gas emission reductions
- CCS has potential to reduce overall costs of mitigation
CO$_2$ Capture and Storage System

**Carbonaceous Fuels**
- Gas to domestic supply
- Natural gas + CO$_2$ capture
- Oil

**Capture Processes**
- Electricity generation
- Petrochemical plants
- CO$_2$ capture
- Future H$_2$ use

**Transport and Storage Options**
- Mineral carbonation
- Industrial uses
- CO$_2$ geological storage
- Ship storage (Ships or pipelines)

(Source: CO2CRC)
Structure of the Report

1. Introduction
2. Sources of CO$_2$
3. Capture of CO$_2$
4. Transport of CO$_2$
5. Geological storage
6. Ocean storage
7. Mineral carbonation and industrial uses
8. Costs and economic potential
9. Emission inventories and accounting
Key Questions for the Assessment

- Current status of CCS technology?
- Potential for capturing and storing CO₂?
- Costs of implementation?
- Health, safety and environment risks?
- Permanence of storage as a mitigation measure?
- Legal issues for implementing CO₂ storage?
- Implications for inventories and accounting?
- Public perception of CCS?
- Potential for technology diffusion and transfer?
# Maturity of CCS Technologies

<table>
<thead>
<tr>
<th>Research Phase</th>
<th>Demonstration Phase</th>
<th>Econ. Feasible (specific conditions)</th>
<th>Mature Market</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ocean storage</strong></td>
<td><strong>Enhanced coal bed methane</strong></td>
<td><strong>Post-combustion capture</strong></td>
<td><strong>Industrial separation</strong></td>
</tr>
<tr>
<td><strong>Mineral carbonation</strong></td>
<td><strong>Industrial utilization</strong></td>
<td><strong>Pre-combustion capture</strong></td>
<td><strong>Pipeline transport</strong></td>
</tr>
<tr>
<td><strong>Enhanced oil recovery</strong></td>
<td><strong>Saline aquifers</strong></td>
<td><strong>Gas and oil fields</strong></td>
<td><strong>Tanker transport</strong></td>
</tr>
<tr>
<td><strong>Industrial transport</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CO$_2$ Capture Technology Options
Status of Capture Technology

- CO$_2$ capture technologies are in commercial use today, mainly in the petroleum and petrochemical industries
- Capture also applied to several gas-fired and coal-fired boilers, but at scales small compared to a large modern power plant
- Net capture efficiencies typically 80-90%
- Integration of capture, transport and storage has been demonstrated in several industrial applications, but not yet at an electric power plant
Industrial Capture Systems

Post-Combustion Capture
(gas-fired power plant, Malaysia)

Pre-Combustion Capture
(coal gasification plant, USA)
CO$_2$ Pipelines (for EOR Projects)
Existing/Proposed CO$_2$ Storage Sites

Source: S. Benson, LBNL
Geological Storage Projects

Sleipner *(Norway)*

In Salah /Krechba *(Algeria)*
Large sources clustered in four geographical regions. Fossil fuel power plants account for 78% of emissions; industrial processes (including biomass) emit 22%.
Potential Geological Storage Areas

(Prospective areas in sedimentary basins where suitable saline formations, oil or gas fields, or coal beds may be found)

Good correlation between major sources and areas with potential for geological storage. More detailed regional analyses required to confirm or assess actual suitability for storage.
Leading Candidates for CCS

• Fossil fuel power plants
  – Pulverized coal combustion (PC)
  – Natural gas combined cycle (NGCC)
  – Integrated coal gasification combined cycle (IGCC)

• Other large industrial sources of CO₂ such as:
  – Refineries and petrochemical plants
  – Hydrogen production plants
  – Ammonia production plants
  – Pulp and paper plants
  – Cement plants
## Typical Component Cost Ranges

(All values in 2002 US$/tCO₂)

<table>
<thead>
<tr>
<th>CCS System Component</th>
<th>Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capture:</strong> Fossil fuel power plant</td>
<td>15–75 US$/tCO₂ net captured</td>
</tr>
<tr>
<td><strong>Capture:</strong> Hydrogen and ammonia</td>
<td>5–55 US$/tCO₂ net captured</td>
</tr>
<tr>
<td><strong>Capture:</strong> Other industrial sources</td>
<td>25–115 US$/tCO₂ net captured</td>
</tr>
<tr>
<td><strong>Transport:</strong> Pipeline/tanker/250 km</td>
<td>1–8 US$/tCO₂ transported</td>
</tr>
<tr>
<td><strong>Storage:</strong> Geological</td>
<td>0.5–8 US$/tCO₂ net injected</td>
</tr>
<tr>
<td><strong>Storage:</strong> Ocean</td>
<td>5–30 US$/tCO₂ net injected</td>
</tr>
<tr>
<td><strong>Storage:</strong> Mineral carbonation</td>
<td>50–100 US$/tCO₂ net mineralized</td>
</tr>
</tbody>
</table>
Estimated CCS Cost for New Power Plants Using Current Technology

(Levelized cost of electricity production in 2002 US$/kWh)

<table>
<thead>
<tr>
<th>Power Plant System</th>
<th>Natural Gas Combined Cycle Plant</th>
<th>Pulverized Coal Plant</th>
<th>Integrated Gasification Combined Cycle Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Plant Cost (without capture)</td>
<td>$0.03–0.05</td>
<td>$0.04–0.05</td>
<td>$0.04–0.06</td>
</tr>
<tr>
<td>Added cost of CCS with geological storage</td>
<td>$0.01–0.03</td>
<td>$0.02–0.05</td>
<td>$0.01–0.03</td>
</tr>
<tr>
<td>Added cost of CCS with EOR storage</td>
<td>$0.01–0.02</td>
<td>$0.01–0.03</td>
<td>$0.00–0.01</td>
</tr>
</tbody>
</table>

Variability is due mainly to differences in site-specific factors.
Added cost to consumers will depend on extent of CCS plants in the overall power generation mix.
**Cost of CO₂ Avoided**  
**(Based on Current Technology)**

(2002 US$ per tonne CO₂ avoided)

<table>
<thead>
<tr>
<th>Power Plant System</th>
<th>Natural Gas Combined Cycle Plant</th>
<th>Pulverized Coal Plant</th>
<th>Integrated Gasification Combined Cycle Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same plant with CCS (geological storage)</td>
<td>40–90</td>
<td>30–70</td>
<td>15–55</td>
</tr>
<tr>
<td>Same plant with CCS (EOR storage)</td>
<td>20–70</td>
<td>10–45</td>
<td>(-5)–30</td>
</tr>
</tbody>
</table>

*Other industrial processes have roughly similar costs*

*Different combinations of reference plant and CCS plant types have avoidance costs ranging from $0–270/tCO₂ avoided; site-specific context is important*
Advanced Technology

• R&D programs are underway worldwide to develop lower-cost capture technologies

• New or improved systems under development have the potential to reduce capital and operating costs of CO$_2$ capture by about 20–30% in the near term, and significantly more over the longer term
  – Advanced power systems
    (IGCC, PC, NGCC, Oxyfuel, SOFC, hybrids, etc.)
  – Advanced capture technologies
  – Other advanced plant components
Economic Potential of CCS

- Across a range of stabilization and baseline scenarios, models estimate cumulative storage of 220–2200 GtCO₂ via CCS to the year 2100
- This is 15–55% of the cumulative worldwide mitigation required to achieve stabilization
- Cost is reduced by 30% or more with CCS in the portfolio
Geological Storage Options

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
Available evidence suggests that worldwide, it is likely that there is a technical potential of at least about 2000 GtCO$_2$ (545 GtC) of storage capacity in geological formations. Globally, this would be sufficient to cover the high end of the economic potential range, but for specific regions, this may not be true.

<table>
<thead>
<tr>
<th>Reservoir Type</th>
<th>Lower Estimate (GtCO$_2$)</th>
<th>Upper Estimate (GtCO$_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and gas fields</td>
<td>675*</td>
<td>900*</td>
</tr>
<tr>
<td>Unminable coal seams</td>
<td>3–15</td>
<td>200</td>
</tr>
<tr>
<td>Deep saline formations</td>
<td>1000</td>
<td>Uncertain, but possibly ~$10^4$</td>
</tr>
</tbody>
</table>

* Estimates are 25% larger if “undiscovered reserves” are included.
Security of Geological Storage

• Lines of evidence for duration of storage:
  – Natural CO$_2$ reservoirs
  – Oil and gas reservoirs
  – Natural gas storage
  – CO$_2$ EOR projects
  – Numerical simulation of geological systems
  – Models of flow through leaking wells
  – Current CO$_2$ storage projects
Trapping Mechanisms Provide Increasing Storage Security with Time

- Storage security depends on a combination of physical and geochemical trapping
- Over time, residual CO$_2$ trapping, solubility trapping and mineral trapping increase
- Appropriate site selection and management are the key to secure storage

Source: S. Benson, LBNL
Estimates of Fraction Retained

• Storage security defined as fraction retained = percent of injected CO₂ remaining after \( x \) years

• “Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely* to exceed 99% over 100 years and is likely** to exceed 99% over 1,000 years.”

* “Very likely” is a probability between 90 and 99%.
** “Likely” is a probability between 66 and 90%.
Would Leakage Compromise CCS as a Climate Change Mitigation Option?

• Studies have addressed non-permanent storage from a variety of perspectives
• Results vary with methods and assumptions made
• Outcomes suggest that non-permanent storage can still be valuable for mitigating climate change if fraction retained on the order of 90–99% for 100 yrs, or 60–95% for 500 yrs
• All studies imply an upper limit on amount of leakage that can take place
Local Health, Safety and Environmental Risks

- **CO₂ Capture**: Large energy requirements of CCS (10–40% increase per unit of product, depending on system) can increase plant-level resource requirements and some environmental emissions; site-specific assessments are required

- **CO₂ Pipelines**: Risks similar to or lower than those posed by hydrocarbon pipelines

- **Geological Storage**: Risks comparable to current activities such as natural gas storage, EOR, and deep underground disposal of acid gas, provided there is:
  - appropriate site selection (informed by subsurface data)
  - a regulatory system
  - a monitoring program to detect problems
  - appropriate use of remediation methods, if needed
Ocean Storage Options

- Dispersal of CO₂ by ship
- CO₂/CaCO₃ reactor
- CO₂/CaCO₃ mixture
- Refilling ship
- Rising CO₂ plume
- Sinking CO₂ plume
- CO₂ lake
- CO₂ lake
- Captured and compressed CO₂
- Flue gas
Ocean Storage

• Storage potential on the order of 1000s GtCO$_2$, depending on environmental constraints

• Gradual release over hundreds of years
  (65–100% retained at 100 yrs, 30–85% at 500 yrs, depending on depth of injection)

• CO$_2$ effects on marine organisms will have ecosystem consequences; chronic effects of direct injection are not known
Mineral Carbonation Storage
Mineral Carbonation & Utilization

• Mineral carbonation storage potential cannot currently be determined, but large quantities of natural minerals are available
• Environmental impacts from mining and waste disposal
• Best current processes have high cost and energy requirements
• Storage via Industrial Utilization:
  – Little potential for net CO₂ reductions; also possible increase in net CO₂ emissions
Legal and Regulatory Issues

• **Onshore Storage: National Regulations Apply**
  – Some existing regulations apply, but few specific legal or regulatory frameworks for long-term CO₂ storage
  – Liability issues largely unresolved

• **Offshore Storage: International Treaties Apply**
  – OSPAR, London Convention
  – Sub-seabed geological storage and ocean storage: unclear whether, or under what conditions, CO₂ injection is compatible with international law
  – Discussions on-going
Inventory and Accounting Issues

• Current IPCC guidelines do not include methods specific to estimating emissions associated with CCS
• 2006 guidelines are expected to address this issue
• Methods may be required for net capture and storage, physical leakage, fugitive emissions, and negative emissions associated with biomass applications of CCS
• Cross-border issues associated with CCS accounting (e.g., capture in one country and storage in another country with different commitments) also need to be addressed; these issues are not unique to CCS
Gaps in Knowledge

- **Technologies**—CCS demonstrations for large-scale power plant and other applications to reliably establish cost and performance; R&D to develop new technology concepts
- **Source–storage relationships**—more detailed regional and local assessments
- **Geological storage**—improved estimates of capacity and effectiveness
- **Ocean storage**—assessments of ecological impacts
- **Legal and regulatory issues**—clear frameworks for CCS
- **Global contribution of CCS**—better understanding of transfer and diffusion potential, interactions with other mitigation measures, and other issues to improve future decision-making about CCS
Report is Available from IPCC (www.ipcc.ch)

- IPCC Web Site provides:
  - Summary for Policymakers
  - Technical Summary
  - Full Technical Report