Recent Developments in CO$_2$ Capture and Storage

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Outline of Talk

• The IPCC Special Report on CO$_2$ Capture and Storage (CCS)

• Recent development of the IECM computer model
Why the Interest in CCS?

• The UNFCCC goal of stabilizing atmospheric GHG concentrations will require very large (e.g., 70–90%) reductions in future CO₂ emissions. However, ....

• Fossil fuels will continue to be used for many decades—alternatives not likely to achieve large CO₂ reductions in time frames of policy interest

• CCS could be part of a portfolio of options to mitigate global climate change in a way that could increase flexibility in achieving greenhouse gas emission reductions

• CCS has potential to reduce overall costs of mitigation
Can We Have Our Coal Without CO$_2$?
The IPCC Special Report on Carbon Dioxide Capture and Storage
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**

**Coordinating Lead Authors**

**Lead Authors**

**Contributing Authors**

**Review Editors**

**Expert and Government Reviewers**
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
Key Questions for the Assessment

- Current status of CCS technology?
- Potential for capturing and storing CO$_2$?
- Costs of implementation?
- Health, safety and environment risks?
- Permanence of storage as a mitigation measure?
- Legal issues for implementing CO$_2$ storage?
- Implications for inventories and accounting?
- Public perception of CCS?
- Potential for technology diffusion and transfer?
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
The IPCC Process

• Meeting 1 (July 2003)
• Zero-order draft—comments from other authors
• Meeting 2 (December 2003)
• First-order draft—comments from expert reviewers
• Meeting 3 (August 2004)
• Second-order draft—comments from experts + governments
• Meeting 4 (April 2005)
• Final draft of full report; gov’t. comments on revised SPM
• Plenary meeting of IPCC delegates—governments finalize and adopt SPM (plus any associated revisions to TS)
Two days before IPCC Plenary — Finalizing the Proposed SPM
Day 1, IPCC Plenary— Not Much Progress
Day 2 — Making Some Progress

Huddle with Co-Chairs

Closing a Deal
Day $3^+$, Midnight — Mission Accomplished!
Report is Available from IPCC
(www.ipcc.ch)

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

- Also available from Cambridge University Press
Structure of the Report

1. Introduction
2. Sources of CO₂
3. Capture of CO₂
4. Transport of CO₂
5. Geological storage
6. Ocean storage
7. Mineral carbonation and industrial uses
8. Costs and economic potential
9. Emission inventories and accounting
# Maturity of CCS Technologies

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<thead>
<tr>
<th>Capture</th>
<th>Post-combustion capture</th>
<th>Industrial separation</th>
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<td>Oxyfuel combustion</td>
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<td>Pre-combustion capture</td>
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<td>Tanker transport</td>
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<td>Gas and oil fields</td>
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<td>Enhanced oil recovery</td>
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<th>Demonstration Phase</th>
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<th>Mature Market</th>
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<td>Ocean storage</td>
<td>Enhanced coal bed methane</td>
<td>Saline aquifers</td>
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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 CO₂ 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)

Storage prospectivity
- Highly prospective sedimentary basins
- Prospective sedimentary basins
- Non-prospective sedimentary basins, metamorphic and igneous rock

Data quality and availability vary among regions

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.

(Source: Geoscience Australia)
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$/tCO$_2$)

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<th>CCS System Component</th>
<th>Cost Range</th>
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<tr>
<td><strong>Capture</strong>: Fossil fuel power plant</td>
<td>15–75 US$/tCO$_2$ net captured</td>
</tr>
<tr>
<td><strong>Capture</strong>: Hydrogen and ammonia production or gas processing plant</td>
<td>5–55 US$/tCO$_2$ net captured</td>
</tr>
<tr>
<td><strong>Capture</strong>: Other industrial sources</td>
<td>25–115 US$/tCO$_2$ net captured</td>
</tr>
<tr>
<td><strong>Transport</strong>: Pipeline/tanker/250 km</td>
<td>1–8 US$/tCO$_2$ transported</td>
</tr>
<tr>
<td><strong>Storage</strong>: Geological</td>
<td>0.5–8 US$/tCO$_2$ net injected</td>
</tr>
<tr>
<td><strong>Storage</strong>: Ocean</td>
<td>5–30 US$/tCO$_2$ net injected</td>
</tr>
<tr>
<td><strong>Storage</strong>: Mineral carbonation</td>
<td>50–100 US$/tCO$_2$ net mineralized</td>
</tr>
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</table>
Estimated CCS Cost for New Power Plants Using Current Technology

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

<table>
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<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>
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<tbody>
<tr>
<td>Reference Plant Cost (without capture) ($/kWh)</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)

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<th>Integrated Gasification Combined Cycle Plant</th>
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<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 plants have a wider range of avoidance costs; site-specific context is important
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

Produced oil or gas
Injected CO₂
Stored CO₂

Carnegie Mellon University
## Geological Storage Capacity

<table>
<thead>
<tr>
<th>Reservoir Type</th>
<th>Lower Estimate (GtCO₂)</th>
<th>Upper Estimate (GtCO₂)</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 ~10⁴</td>
</tr>
</tbody>
</table>

* Estimates are 25% larger if “undiscovered reserves” are included.

Available evidence suggests that worldwide, it is likely that there is a technical potential of at least about 2000 GtCO₂ (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.
Security of Geological Storage: Estimates of Fraction Retained

• Storage security defined as fraction retained = percent of injected CO\textsubscript{2} 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.”

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\(^{*}\) “Very likely” is a probability between 90 and 99\%.

\(^{**}\) “Likely” is a probability between 66 and 90\%.
Trapping Mechanisms Provide Increasing Storage Security with Time

• Storage security depends on a combination of physical and geochemical trapping

• Over time, residual CO₂ trapping, solubility trapping and mineral trapping increase

• Appropriate site selection and management are the key to secure storage

Source: S. Benson, LBNL
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 (especially if fraction retained is 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
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
Impact of the IPCC Special Report

- Established CCS as a technically viable and potentially important option for climate change mitigation
- IPCC, SBSTA and others working on detailed procedures needed to establish CCS as an option within the UNFCCC
- Other groups working to develop national regulations and guidelines for geological storage projects
Recent IECM Developments
The IECM

- A desktop computer model developed for DOE/NETL
- Provides preliminary design estimates of performance, emissions, costs and uncertainties:
  - PC, NGCC and IGCC plants
  - Emission control systems
  - CO$_2$ capture and storage options (pre- and post-combustion, oxy-combustion, transport, storage)
- Hundreds of users worldwide
New Oxyfuel Combustion Plant Model
New CO₂ Pipeline Transport Cost Model

- Models based on data set of 236 onshore pipelines constructed in the US between 1994 and 2003
- Separate **region-specific** models for 6 US regions:
  - Materials
  - Labor
  - Engineering & Overheads
  - Right-of-way
  - AFUDC
- Linear in pipe diameter (manufactured sizes); logarithmic function of length
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• http://www.iecm-online.com