Carbon Capture and Storage Technology

Edward S. Rubin
Department of Engineering and Public Policy
Carnegie Mellon University
Pittsburgh, Pennsylvania

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Outline of Talk

• Why the interest in CO₂ capture and storage (CCS)?
• Current status and cost of CCS technology
• Potential for improved technology
• Barriers to CCS deployment
• Future outlook
Why the interest in CCS?

The Policy Framework

- 1992 U.N. Framework Convention on Climate Change calls for:
  
  “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”

- 192 countries are parties to the Convention
What it Takes to Stabilize Atmospheric CO₂ Concentration

(a) Atmospheric Stabilization Scenarios

(b) Required CO₂ Emissions

Must drastically reduce future CO₂ emissions

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Unlike conventional air pollutants, most GHGs stay in the atmosphere for centuries

Atmospheric CO₂ Concentration vs. CO₂ Emissions

Current and projected CO₂ emissions are "filling the bathtub" faster than it is being "drained"—so the atmospheric level keeps rising… even when emissions are reduced by a modest amount

E.S. Rubin, Carnegie Mellon

Source: IPCC, 2001

Current and projected CO₂ emissions are "filling the bathtub" faster than it is being "drained"—so the atmospheric level keeps rising… even when emissions are reduced by a modest amount.
Avoiding Serious Climate Change Impacts Requires Action Now

The most recent IPCC assessment indicates potentially serious impacts for more than a 2°C rise in average global temperature

<table>
<thead>
<tr>
<th>Global avg. temperature increase over pre-industrial</th>
<th>Atmospheric stabilization CO$_2$-equiv (ppm) (2005=375 ppm)</th>
<th>Required change in global CO$_2$ emissions from 2000 to 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 – 2.4°C</td>
<td>445 – 490</td>
<td>-85% to -50%</td>
</tr>
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</table>

Source: IPCC, 2007

Fossil fuels provide over 80% of our energy and are the dominant source of CO$_2$ (a third of U.S. emissions is from burning coal for electricity generation)

The Motivation for CCS

- Fossil fuels, especially coal, will continue to be used extensively for many decades to come—alternatives not easily able to achieve large CO$_2$ reductions needed to stabilize atmospheric level of GHGs
- CCS could allow continued coal use as a bridge to a more sustainable future — also a potential link to carbon-free energy for transportation
- Energy-economic models show that including CCS in a portfolio of options significantly reduces the cost of mitigating climate change
CCS Overview

Schematic of a CCS System
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, fuel processing, and petrochemical plants
  - Hydrogen and ammonia production plants
  - Pulp and paper plants
  - Cement plants

  *Main focus is on power plants, the dominant source of CO₂*

Many Ways to Capture CO₂

Choice of technology depends strongly on application
Status of CCS Technology

- Pre- and post-combustion CO₂ capture technologies are commercial and widely used in industrial processes; also at several gas-fired and coal-fired power plants, at small scale (~50 MW); CO₂ capture efficiencies are typically 85-90%. Oxyfuel capture still under development.
- CO₂ pipelines are a mature technology
- Geological storage is commercial on a limited basis, mainly for EOR; several sequestration projects are now operating at scale of ~1 Mt CO₂ /yr
- Integration of CO₂ capture, transport and geological sequestration has been demonstrated in several industrial applications—but not yet at an electric power plant, and not yet in the U.S.
Examples of Post-Combustion CO₂ Capture at Coal-Fired Plants

Shady Point Power Plant
(Panama, Oklahoma, USA)

Warrior Run Power Plant
(Cumberland, Maryland, USA)
Examples of Post-Combustion CO₂ Capture at Gas-Fired Plants

Bellingham Cogeneration Plant (Bellingham, Massachusetts, USA)

Petronas Urea Plant Flue Gas (Keda, Malaysia)

Source: E.S. Rubin, Carnegie Mellon

Integrated Coal Gasification Combined Cycle (IGCC) Plant
Polk Power Station, Tampa, Florida
(250 MW, no CO₂ capture)

Source: TECO, 2004

E.S. Rubin, Carnegie Mellon
Examples of Pre-Combustion \( \text{CO}_2 \) Capture Systems

- Petcoke Gasification to Produce \( \text{H}_2 \)  
  *(Coffeyville, Kansas, USA)*

- Coal Gasification to Produce SNG  
  *(Beulah, North Dakota, USA)*

Example of Oxyfuel Combustion Capture System

- Vattenfall Schwarze Pumpe Station  
  *(Germany)*
Example of Industrial CO$_2$ Capture
(using post-combustion capture technology)

BP Natural Gas Processing Plant
(In Salah, Algeria)

Source: IEA GHG, 2008

CO$_2$ Pipelines in the Western U.S.

~40 MtCO$_2$/yr transported

Source: USGS/DOE

E.S. Rubin, Carnegie Mellon
A 200-mile pipeline delivers captured CO$_2$ from North Dakota to Saskatchewan

Geological Storage Options

Source: IPCC, 2005
### Global Storage Capacity Estimates

<table>
<thead>
<tr>
<th>Reservoir Type</th>
<th>Lower Estimate (GtCO₂)</th>
<th>Upper Estimate (GtCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep saline formations</td>
<td>1000</td>
<td>Uncertain, but possibly ~10⁴</td>
</tr>
<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>
</tbody>
</table>

* Estimates are 25% larger if "undiscovered reserves" are included. (Source: IPCC, 2005)

### CO₂ Sources and Geological Formations

Source: NETL, 2008
Existing/Proposed CO₂ Storage Sites

- Sites currently injecting CO₂
- Planned CCS sites (at least 700,000 t CO₂/yr)
- Sites which have been cancelled or have completed injection

Source: SCCS, 2009

Geological Storage of Captured CO₂ in a Deep Saline Formation

Sleipner Project (Norway)

Source: Statoil
Geological Storage of Captured CO₂ in a Deep Saline Formation

Snohvit LNG Project (Norway)

Geological Storage of Captured CO₂ in a Depleted Gas Reservoir

In Salah /Krechba (Algeria)
Geological Storage of Captured CO₂ with Enhanced Oil Recovery (EOR)

Sources: IEAGHG; NRDC; USDOE

Weyburn Field, Canada

Dakota Coal Gasification Plant, ND

Trapping Mechanisms Provide Increasing Storage Security with Time

- Storage security depends on a combination of physical and geochemical trapping mechanisms
- Over time, CO₂ trapping mechanisms increase the security of storage
- Appropriate site selection and management are the key to secure storage

Sources: E.S. Rubin, Carnegie Mellon
**The cost of CCS**

**Many Factors Affect CCS Costs**

- Choice of Power Plant and CCS Technology
- Process Design and Operating Variables
- Economic and Financial Parameters
- Choice of System Boundaries; *e.g.*,  
  - One facility vs. multi-plant system (regional, national, global)  
  - GHG gases considered (CO₂ only vs. all GHGs)  
  - Power plant only vs. partial or complete life cycle
- Time Frame of Interest  
  - Current technology vs. future (improved) systems  
  - Consideration of technological “learning”
Ten Ways to Reduce the Estimated Cost of CO₂ Abatement

1. Assume all of the above!

...and we have not yet considered the CCS technology!

Representative CCS Costs for New Power Plants Using Current Technology

Levelized costs in constant 2007 US$ (based on current technology w/ bituminous coals)

<table>
<thead>
<tr>
<th>Incremental Cost of CCS relative to same plant type without CCS based on bituminous coals</th>
<th>Supercritical Pulverized Coal Plant</th>
<th>Integrated Gasification Combined Cycle Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increases in capital cost ($/kW) and generation cost ($/kWh)</td>
<td>~ 60–80%</td>
<td>~ 30–50%</td>
</tr>
</tbody>
</table>

VERY IMPORTANT TO NOTE:
The added cost to consumers will be much smaller, reflecting the number and type of CCS plants in the power generation mix at any given time.
## Typical Cost of CO₂ Avoided

(Relative to a SCPC reference plant w/o CCS)

Levelized cost in 2007 US$ per tonne CO₂ avoided
(based on current technology w/ bituminous coals)

<table>
<thead>
<tr>
<th>Power Plant System (relative to a SCPC plant without CCS)</th>
<th>New Supercritical Pulverized Coal Plant</th>
<th>New Integrated Gasification Combined Cycle Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep aquifer storage</td>
<td>~ $70 /tCO₂</td>
<td>~ $50 /tCO₂</td>
</tr>
<tr>
<td>Enhanced oil recovery (EOR) storage</td>
<td>Cost reduced by ~ $20–30 /tCO₂</td>
<td></td>
</tr>
</tbody>
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*Source: Based on IPCC, 2005; Rubin et al., 2007; DOE, 2007*

- Capture accounts for most (~80%) of the total cost
- Different choices of reference plant without CCS will yield different avoidance costs

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### Important Reminders

- No one has yet built and operated a CCS system at a large (e.g., 500 MW) power plant. Hence, “true” costs are unknown.
- Construction costs have escalated rapidly in recent years but are now leveling off; future trends are uncertain.
What is the potential for improved technology?

Potential Cost Reductions for CCS

19% -28% reductions in total cost of electricity

Source: DOE Office of Fossil Energy, 2006
Technology innovation tends to lower costs as experience is gained from manufacture and use of a technology, and R&D is sustained.

Cost reduction estimates are similar to those from “bottom-up analyses.”

Current Activity
• A variety of CCS projects are proposed or planned in different parts of the world (here is a sample)
Many Government Programs and Public-Private Partnerships Are Already In Place

Some of the government programs supporting CCS:
- Australia
- Canada
- China
- European Union
- United Kingdom
- United States

Funding levels and scale of projects vary widely

Full-Scale Projects Are Needed to . . .

- Establish the reliability and true cost of CCS in commercial power plant applications
  - For different technologies, coal types, and geological settings
- Help establish legal and regulatory requirements for geological sequestration at large scales
- Reduce future cost of CCS via learning-by-doing plus sustained R&D

Financing large-scale CCS projects has been a major hurdle; not clear where/when we’ll see the first large power plant demo
It might be the GreenGen Project
(Tianjin, China)

Barriers to CCS Deployment
Barriers to CCS Deployment

- No current policy mandate or strong incentives for large reductions in CO₂ emissions
- High cost of current technology
- Lack of experience in utility applications
- No established regulatory framework for licensing large-scale geological sequestration projects in U.S.
- Uncertainties about public acceptance
- Unresolved legal issues related to CO₂ pipelines, sub-surface property rights and long-term liabilities

The CCSReg Project is examining these issues in detail

Project website: www.CCSReg.org
Future outlook

Recent Cap & Trade Bills
Included Incentives for CCS

No agreement on policy in 110th Congress; new efforts by 111th Congress and USEPA are works in progress

Source: Pew Center on Global Climate Change
Will CCS be Used to Mitigate Global Climate Change?

- Will very likely see successful demo of CCS technology in next ~5 years; but …
- Widespread CCS deployment will not occur without a strong policy driver
- **WATCH THIS SPACE FOR UPDATES**

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Thank You

rubin@cmu.edu