The Potential of CO\(_2\) Capture and Storage for Mitigating Climate Change

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Heinz College, Carnegie Mellon University

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Outline of Talk

- Why the interest in CO\(_2\) capture and storage (CCS)?
- What is the status of CCS technologies?
- How much does it cost?
- What are its secondary impacts?
- What is the potential for improved technology?
- What is the outlook for its use in climate mitigation?
Why the interest in CCS?

The Policy Framework

- 1992 U.N. Framework Convention on Climate Change called 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 now parties to the Convention
- 175 parties have ratified the Kyoto Protocol
- 36 States have legally binding commitments to reduce GHG emissions
Unlike conventional air pollutants, GHGs are not easily removed from the atmosphere.

\[ \tau_{\text{atm, SO}_2} \approx \text{days-weeks} \]
\[ \tau_{\text{atm, CO}_2} \approx 100 \text{ years} \]

Current and projected CO\(_2\) emissions are "filling the bathtub" faster than it is being "drained"—so the atmospheric level keeps rising.

What it Takes to Stabilize Atmospheric CO\(_2\) Concentration

(a) Atmospheric Stabilization Scenarios  (b) Required CO\(_2\) Emissions

This implies a long-term need to drastically reduce CO\(_2\) emissions, no matter what target is selected for stabilization!
Avoiding Serious Climate Change Impacts Requires Action Now

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

<table>
<thead>
<tr>
<th>Global avg. temperature increase over pre-industrial</th>
<th>Atmospheric stabilization CO₂-equiv (ppm) (2005=375 ppm)</th>
<th>Required change in global CO₂ 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>
<tr>
<td>2.8 – 3.2 °C</td>
<td>535 – 590</td>
<td>-30% to +5%</td>
</tr>
<tr>
<td>4.0 – 4.9 °C</td>
<td>710 – 855</td>
<td>+25% to +85%</td>
</tr>
</tbody>
</table>

Source: IPCC, 2007

Lower stabilization levels require earlier action to reduce emissions.

Lower stabilization levels require earlier action to reduce emissions.

CO₂ Emissions from Energy Use are the Principal Source of GHGs

Power generation and transportation together account for 75% of current emissions.

Source: Based on USDOE, 2002
U.S. Electricity Generation by Fuel
(1950–2004 with EIA Reference Case projections to 2030)

Most U.S. electricity comes from coal

U.S. Power Sector CO₂ Emissions
(1950–2004 with EIA Reference Case projections to 2030)
Motivation for CCS

- The policy goal of stabilizing atmospheric GHG concentrations will require very large reductions in anthropogenic CO₂ emissions. But …
- Fossil fuels will continue to be used extensively for many decades to come—alternatives not likely to get large CO₂ reductions in time frames of policy interest
- CCS offers a way to allow fossil fuels to be used with little CO₂ emissions—a potential bridging strategy
- Energy models indicate that the availability of CCS, in addition to other measures, can significantly lower the cost of stabilization

IPCC Assessment of Cost-Effective Global Energy Strategies

Source: IPCC, 2007
Status of CCS technologies

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Carbon Sequestration Defined

- Until recently, the term “carbon sequestration” referred only to the natural uptake of CO₂ by trees, soils and other biomass (terrestrial sequestration), as embodied in UNFCCC protocols.

- Today this term also includes technologies to capture and sequester CO₂ from industrial processes—also widely called CO₂ capture and storage.

- CCS is the acronym now widely used.
Schematic of a CCS System

Carbonaceous Fuels → Energy Conversion Process → CO₂ Capture & Compress → CO₂ Transport → CO₂ Storage (Sequestration)

- Post-combustion
- Pre-combustion
- Oxyfuel combustion

Useful Products (Electricity, Fuels, Chemicals, Hydrogen)

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 –
Status of CCS Technology

- CO₂ capture technologies are commercial and widely used in industrial processes, mainly in the petroleum and petrochemical industries (e.g., for ammonia production and processing of natural gas)
- CO₂ capture also has been applied to several gas-fired and coal-fired boilers (to produce commodity CO₂ for sale), but at scales that are small compared to a large modern power plant
- Integration of CO₂ capture, transport and geologic sequestration has been demonstrated in several industrial applications, but not yet at a full-scale electric power plant, and not yet in the U.S.

CO₂ capture options
Many Ways to Capture CO₂

<table>
<thead>
<tr>
<th>CO₂ Separation and Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Absorption</strong></td>
</tr>
<tr>
<td>- Chemical</td>
</tr>
<tr>
<td>- MEA</td>
</tr>
<tr>
<td>- Caustic</td>
</tr>
<tr>
<td>- Other</td>
</tr>
<tr>
<td>- Physical</td>
</tr>
<tr>
<td>- Selexol</td>
</tr>
<tr>
<td>- Rectisol</td>
</tr>
<tr>
<td>- Other</td>
</tr>
<tr>
<td><strong>Adsorption</strong></td>
</tr>
<tr>
<td>- Absorber Beds</td>
</tr>
<tr>
<td>- Alumina</td>
</tr>
<tr>
<td>- Zeolite</td>
</tr>
<tr>
<td>- Activated C</td>
</tr>
<tr>
<td>- Regeneration Method</td>
</tr>
<tr>
<td>- Pressure Swing</td>
</tr>
<tr>
<td>- Temperature Swing</td>
</tr>
<tr>
<td>- Washing</td>
</tr>
<tr>
<td><strong>Cryogenics</strong></td>
</tr>
<tr>
<td>- Gas Separation</td>
</tr>
<tr>
<td>- Polyphenyleneoxide</td>
</tr>
<tr>
<td>- Polydimethylsiloxane</td>
</tr>
<tr>
<td><strong>Membranes</strong></td>
</tr>
<tr>
<td>- Gas Absorption</td>
</tr>
<tr>
<td>- Polypropylene</td>
</tr>
<tr>
<td>- Gas Separation</td>
</tr>
<tr>
<td>- Ceramic Based Systems</td>
</tr>
</tbody>
</table>

Choice of technology depends strongly on application

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CO₂ Capture Options for Power Plants

Diagram showing different capture options for power plants, including post-combustion, pre-combustion, and oxyfuel processes.

Source: IPCC SRCCS, 2005

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Status of CO\textsubscript{2} Capture Technology

- Pre-combustion and post-combustion CO\textsubscript{2} capture technologies are commercial and widely used in industrial processes.
- Post-combustion capture is also used commercially at several gas-fired and coal-fired power plants, typically treating only a portion of the flue gas (equivalent to about ~50 MW).
- CO\textsubscript{2} capture efficiencies are typically 85-90%.
- Oxyfuel (oxy-combustion) capture is still under development and not yet commercial.

Current CO\textsubscript{2} Capture Projects

Source: IEA GHG, 2007
Examples of Post-Combustion CO₂ Capture at Coal-Fired Plants

- Shady Point Power Plant
  (Panama, Oklahoma, USA)
  (Source: ABB Lummus)

- Warrior Run Power Plant
  (Cumberland, Maryland, USA)
  (Source: IEA GHG)

Examples of Post-Combustion CO₂ Capture at Gas-Fired Plants

- Bellingham Cogeneration Plant
  (Bellingham, Massachusetts, USA)
  (Source: Suez Energy Generation)

- Petronas Urea Plant Flue Gas
  (Keda, Malaysia)
  (Source: Mitsubishi Heavy Industries)
Integrated Coal Gasification Combined Cycle (IGCC) Plant
Polk Power Station, Tampa, Florida
(250 MW, no CO₂ capture)

Source: TECO, 2004

Examples of Pre-Combustion CO₂ Capture Systems

Pet coke Gasification to Produce H₂
(Coffeyville, Kansas, USA)

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

Source: Chevron-Texaco
The Vattenfall 30 MWth Oxy-Coal Pilot Boiler with CO₂ capture at Schwarze Pumpe (Germany), starting mid-2008

Example of Oxyfuel Combustion Capture System

Time Table for Implementation of Oxy-Fuel Project

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Implement Oxy-Fuel Technology</td>
<td>Monitor Plant Performance</td>
<td>Improve Efficiency</td>
<td>Test New Materials</td>
<td>Schedule Maintenance</td>
<td>Calculate Emissions</td>
<td>Upgrade Equipment</td>
</tr>
</tbody>
</table>

Oxy-Combustion Pilot Plant
Vattenfall Schwarze Pumpe Station (Germany)
**CO₂ transport options**

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**Status of CO₂ Transport Technology**

- CO₂ pipelines are a mature technology, used mainly to transport CO₂ for use in enhanced oil recovery (EOR)
- Currently about 4500 km of CO₂ pipelines in U.S.
- Trucks used commercially for small shipments of CO₂
- Transport by ocean tankers has been studied but is not currently used commercially
CO₂ Pipelines in the Western U.S.

~40 MtCO₂/yr transported

A 200-mile pipeline delivers captured CO₂ from North Dakota to Saskatchewan

Sources: IEAGHG, NRDC, USDOE
**Status of CO₂ Storage Options**

- Geological sequestration is commercial on a limited basis. Four large-scale projects are currently in operation at a scale of ~1 Mt CO₂/yr or more; other projects are being planned.

- Other storage options, including deep ocean storage, mineralization and re-use for industrial products are still in the research and development phase, or of limited potential for climate change mitigation.
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. - IPCC, 2005

<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)
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

More detailed regional analyses required to confirm or assess actual suitability for storage in specific regions.

Global Distribution of Large CO₂ Sources

Large sources are clustered in four geographical regions. Good correlation between major sources and areas with high potential for geological sequestration.
## Existing/Proposed CO₂ Storage Sites

![Map of CO₂ Storage Sites]

**Source:** S. Benson, LBNL

### Large-Scale Storage Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Operator</th>
<th>Storage Reservoir</th>
<th>Injection Start Date</th>
<th>Injection Rate (MtCO₂/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleipner (Norway)</td>
<td>StatoilHydro</td>
<td>Saline Aquifer</td>
<td>1996</td>
<td>1.0</td>
</tr>
<tr>
<td>Weyburn (Canada)</td>
<td>EnCana</td>
<td>EOR</td>
<td>2000</td>
<td>1.2*</td>
</tr>
<tr>
<td>In Salah (Algeria)</td>
<td>Sonatrach, BP, StatoilHydro</td>
<td>Depleted Gas Field</td>
<td>2004</td>
<td>1.2</td>
</tr>
<tr>
<td>Snohvit (Norway)</td>
<td>StatoilHydro</td>
<td>Saline Aquifer</td>
<td>2008</td>
<td>0.7</td>
</tr>
</tbody>
</table>

* Average rate over 15 year contract. Recent expansion to ~3 Mt/yr for Weyburn + Midale field.
Geological Storage of Captured CO₂ in a Deep Saline Formation

**Sleipner Project**
*Norway*

Source: Statoil

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Geological Storage of Captured CO₂ in a Deep Saline Formation

**In Salah /Krechba**
*Algeria*

Source: BP
Geological Storage of Captured CO₂ with Enhanced Oil Recovery (EOR)

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

Sources: IEAGHG; NRDC; USDOE

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Three documents:

- Full Technical Report (~400 pages)
- Technical Summary (30 pages)
- Summary for Policymakers (14 pages)

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”

Different Measures of Cost

- Cost of Electricity ($/MWh)
  \[
  = \frac{(TCC)(FCF) + FOM}{(CF)(8760)(MW)} + VOM + (HR)(FC)
  \]

- Cost of CO₂ Avoided ($/ton CO₂ avoided)
  \[
  = \frac{($/MWh)_{ccs} - ($/MWh)_{reference}}{(CO₂/MWh)_{ref} - (CO₂/MWh)_{ccs}}
  \]

- Cost of CO₂ Abated ($/ton CO₂ reduced)
  \[
  = \frac{($ NPV)_{ccs} - ($ NPV)_{reference}}{(CO₂)_{ref} - (CO₂)_{ccs}}
  \]
Ten Ways to Reduce the Estimated Cost of CO₂ Abatement

10. Assume high power plant efficiency
9. Assume high-quality fuel properties
8. Assume low fuel costs
7. Assume EOR credits for CO₂ storage
6. Omit certain capital costs
5. Report $/ton CO₂ based on short tons
4. Assume long plant lifetime
3. Assume low interest rate (discount rate)
2. Assume high plant utilization (capacity factor)
1. Assume all of the above!

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

Important Reminders

- No one has yet built and operated a CO₂ capture and sequestration system at a large-scale (e.g., 500 MW) power plant
- Hence, all the costs we’re about to see are projections based on other applications; the “true” costs are not yet known
- In the last few years plant construction costs have escalated considerably, resulting in higher CCS costs; future cost trends remain uncertain
Cost of New Power Plants with and without CCS

*2007 costs for bituminous coals; gas price ≈ $4–7/GJ; 90% capture; aquifer storage

Typical Increase in New Power Plant Costs with Current CCS Technology

<table>
<thead>
<tr>
<th>Incremental Cost of CCS Relative to a Similar Plant 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>Increase in capital cost ($/kW) and total generation cost ($/MWh) (w/ deep aquifer storage)</td>
<td>~ 70%</td>
<td>~ 40%</td>
</tr>
</tbody>
</table>

Source: Based on IPCC, 2005; Rubin et al, 2007; DOE, 2007

There is large variability due to differences in site-specific factors. Added cost to consumers will depend on the number and type of CCS plants in the overall power generation mix at any given time.
Typical Cost of CO₂ Avoided
(Based on current technology w/ bituminous coals)

Levelized cost in 2008 US$ per tonne CO₂ avoided

<table>
<thead>
<tr>
<th>Power Plant System (same plant type with and 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 /t CO₂</td>
<td>~ $40 /t CO₂</td>
</tr>
<tr>
<td>Enhanced oil recovery (EOR) storage</td>
<td>Cost reduced by ~ $20–30 /t CO₂</td>
<td></td>
</tr>
</tbody>
</table>

Source: Based on IPCC, 2005; Rubin et al, 2007; DOE, 2007

Different choices of reference plant without CCS will yield different avoidance costs

Range of Component Costs

Levelized cost in 2007 US$

<table>
<thead>
<tr>
<th>CCS system component</th>
<th>Cost range (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capture:</strong> Fossil fuel power plants</td>
<td>$20–95/t CO₂ net captured</td>
</tr>
<tr>
<td><strong>Capture:</strong> Hydrogen and ammonia production or gas-processing plant</td>
<td>$5–70/t CO₂ net captured</td>
</tr>
<tr>
<td><strong>Capture:</strong> Other industrial sources</td>
<td>$30–145/t CO₂ net captured</td>
</tr>
<tr>
<td><strong>Transport:</strong> Pipeline</td>
<td>$1–10/t CO₂ transported</td>
</tr>
<tr>
<td><strong>Storage:</strong> Deep geological formation</td>
<td>$0.5–10/t CO₂ net injected</td>
</tr>
</tbody>
</table>

Source: Based on IPCC, 2005

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Analyzing Options for Power Plants
(IECM: The Integrated Environmental Control Model)

• A desktop/laptop computer model developed for DOE/NETL; free and publicly available at: www.iecm-online.com

• Provides systematic estimates of performance, emissions, costs and uncertainties for preliminary design of:
  - PC, IGCC and NGCC plants
  - All flue/fuel gas treatment systems
  - CO₂ capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)

Importance of the CCS
“Energy Penalty”

• CCS energy requirements are defined here as the increase in fuel energy input per unit of net electrical output (relative to a similar plant without capture)

• This directly affects the plant-level resource requirements and emissions per MWh of:
  - Fuel and reagent use
  - Air pollutant emissions
  - Solid and liquid wastes
  - Upstream (life cycle) impacts

• Additional energy/MWh for representative plants:
  - PC = 31%;  IGCC = 16%;  NGCC = 17%
Reducing Environmental Impacts

- New or improved power generation and CO$_2$ capture technologies promise to reduce CCS impacts by:
  - Improving overall plant efficiency
  - Reducing CCS energy requirements
  - Increasing CO$_2$ capture efficiency

What is the potential for improved technology?
Two Approaches to Estimating Future Technology Costs

- **Method 1**: Engineering-Economic Analysis
  - A “bottom up” approach based on engineering process models, informed by judgments regarding potential improvements in key process parameters

Potential COE Reductions ($/MWh) for a PC Plant w/Amine Capture

```
<table>
<thead>
<tr>
<th>Component</th>
<th>Potential COE Reductions ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Derate</td>
<td>87</td>
</tr>
<tr>
<td>Same Output</td>
<td>84</td>
</tr>
<tr>
<td>Cheaper Boiler</td>
<td>81</td>
</tr>
<tr>
<td>Future Amines</td>
<td>71</td>
</tr>
<tr>
<td>Heat Integr.</td>
<td>69</td>
</tr>
<tr>
<td>Amine Capex</td>
<td>68</td>
</tr>
</tbody>
</table>
```
Recent Projections by DOE/NELT

**Latest Analyses for IGCC**

19% - 28% reductions in total cost of electricity

**Latest Analyses for PC Plants**

**Latest Analyses for Oxy-Combustion**

Two Approaches to Estimating Future Technology Costs

- **Method 2**: Use of Historical Experience Curves
  - A “top down” approach based on applications of mathematical “learning curves” or “experience curves” that reflect historical trends for analogous technologies or systems
Example for New Power Systems

Results for Plant-Level COE
(Based on 100 GW of cumulative CCS capacity worldwide)
The future outlook for CCS

Many Government Programs and Public-Private Partnerships Working on CCS

Some of the government programs supporting CCS:

- Australia
- Canada
- China
- European Union
- United Kingdom
- United States

Funding levels and scale of projects vary widely
### CCS Activity Worldwide

- Approximately 65 CCS projects currently planned or proposed in different parts of the world

* (here is a sample)

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Location</th>
<th>Feedstock</th>
<th>Size MW</th>
<th>Capture Method</th>
<th>CO2 Fate</th>
<th>Startup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Lacq</td>
<td>France</td>
<td>Oil</td>
<td>25</td>
<td>Day</td>
<td>Seq</td>
<td>2008</td>
</tr>
<tr>
<td>Brentfield Coal</td>
<td>Germany</td>
<td>Coal</td>
<td>30/300/1000</td>
<td>Day</td>
<td>Undecided</td>
<td>2008</td>
</tr>
<tr>
<td>Colstrip Oxy Fuel</td>
<td>USA</td>
<td>Coal</td>
<td>22</td>
<td>Day</td>
<td>Seq</td>
<td>2009</td>
</tr>
<tr>
<td>GreenGen</td>
<td>China</td>
<td>Coal</td>
<td>250/300</td>
<td>Pre</td>
<td>Seq</td>
<td>2009</td>
</tr>
<tr>
<td>Kimsan</td>
<td>USA</td>
<td>Coal</td>
<td>200</td>
<td>Pre</td>
<td>Seq</td>
<td>2004-10</td>
</tr>
<tr>
<td>KISCO</td>
<td>China</td>
<td>Coal</td>
<td>Undecided</td>
<td>Undecided</td>
<td>Seq</td>
<td>2010</td>
</tr>
<tr>
<td>S Oh Kington</td>
<td>UK</td>
<td>Coal</td>
<td>120</td>
<td>Pre</td>
<td>Seq</td>
<td>2011</td>
</tr>
<tr>
<td>AEP Avison Northeastern</td>
<td>USA</td>
<td>Coal</td>
<td>300</td>
<td>Post</td>
<td>Seq</td>
<td>2011</td>
</tr>
<tr>
<td>Anglo America</td>
<td>Norway</td>
<td>Coal</td>
<td>400</td>
<td>Pre</td>
<td>Seq</td>
<td>2011</td>
</tr>
<tr>
<td>Statkraft So Eerrybridge</td>
<td>UK</td>
<td>Coal</td>
<td>300</td>
<td>Post</td>
<td>Seq</td>
<td>2011</td>
</tr>
<tr>
<td>Teesside Kivenum</td>
<td>Norway</td>
<td>Gas</td>
<td>120</td>
<td>Pre</td>
<td>Seq</td>
<td>2011</td>
</tr>
<tr>
<td>GDF Suez</td>
<td>France</td>
<td>Coal/Petcoke</td>
<td>800</td>
<td>Pre</td>
<td>Seq</td>
<td>2011</td>
</tr>
<tr>
<td>Italian Power</td>
<td>USA</td>
<td>Coal</td>
<td>620-750</td>
<td>Pre</td>
<td>Seq</td>
<td>2012</td>
</tr>
<tr>
<td>TNO Yellow Nides</td>
<td>NL</td>
<td>Coal</td>
<td>680</td>
<td>Post</td>
<td>Seq</td>
<td>2013</td>
</tr>
<tr>
<td>Teesside</td>
<td>UK</td>
<td>Coal</td>
<td>400</td>
<td>Post</td>
<td>Seq</td>
<td>2014</td>
</tr>
<tr>
<td>P7 Rio Tinto Bakers</td>
<td>Australia</td>
<td>Coal</td>
<td>300</td>
<td>Pre</td>
<td>Seq</td>
<td>2014</td>
</tr>
<tr>
<td>Vattenfall project</td>
<td>UK</td>
<td>Coal</td>
<td>300-400</td>
<td>Pre</td>
<td>Seq</td>
<td>2014</td>
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*Source: MIT, 2008*

### Barriers to CCS Deployment

- No current policy mandate or strong incentives for large reductions in CO₂ emissions
- High cost of current technology
- Lack of a regulatory framework for licensing large-scale geological sequestration projects
- Unresolved legal issues related to sub-surface property rights and long-term liabilities
- Uncertainties about public acceptance
- Lack of experience in utility applications
Key Needs to Move CCS Forward

- Multiple large-scale geological sequestration projects to get data and experience needed for regulatory, legal and public acceptance issues
- Build and operate several full-scale CCS systems at power plants in different settings to demonstrate reliability, safety and effectiveness
- Sustained R&D to reduce costs
- Private/public financing for all the above

Recent Cap & Trade Bills
Included Incentives for CCS

But no agreement on policy in 110th Congress;
Action on climate change will take time
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 sufficiently strong policy driver

• SO STAY TUNED!

Thanks

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