Steps to Accelerate Deployment of CCS
... Storage

Sally M. Benson
Energy Resources Engineering Department
Director, Global Climate and Energy Project
Stanford University

May 4 -7, 2009  •  Sheraton Station Square  •  Pittsburgh, Pennsylvania
Three Concrete Steps to Accelerate Deployment of CCS

1. Beyond capacity assessment
   … initiate a nation-wide effort to pre-qualify promising storage sites in saline aquifers.

2. Beyond identification of institutional issues
   … form multi-agency teams to expedite resolution of permitting and legal issues.

3. Beyond CCS validation
   … provide financial incentives and institutional support for 5 - 7 commercial scale projects with greater than 4 Mt/yr CO$_2$ storage by 2014.
Capacity Assessment

- Capacity assessments provide
  - global, national and regional estimates of the mass of CO₂ that could potentially be stored underground
  - identification of prospective areas for CO₂ storage

- U. S. capacity is very large
- Broadly distributed
  - but not everywhere
- Saline aquifers have the largest storage capacity
But...

Capacity Assessment ≠ Site Characterization

Site characterization is the collection, analysis and interpretation of data and the application of knowledge to judge, with a degree of confidence, if an identified site will store a specific quantity of CO$_2$ for a defined period of time and meet all health, safety, environmental requirements.”

From Peter Cook, CO2SC 2006

To accelerate deployment of CCS we need to initiate a nation-wide effort to characterize and pre-qualify promising storage sites in saline aquifers.
Current Worldwide Sources and Emissions (~7,500 total > 0.1 MT/yr)

### 2004 Global CO₂ Emissions (Mt C)

- Resource Production, 347
- Transportation, 1,703
- Electricity Services, 2,725
- Heating and Cooking, 2,182
- Material Processing and Manufacturing, 2,296

### Electricity Sector

<table>
<thead>
<tr>
<th>Fuel</th>
<th># of Sources</th>
<th>Average Emissions per Source (MT/source)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2025</td>
<td>3.9</td>
</tr>
<tr>
<td>Nat. Gas</td>
<td>1728</td>
<td>0.8 – 1.0</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>1108</td>
<td>0.6 – 1.3</td>
</tr>
</tbody>
</table>

Source: GCEP Exergy and Carbon Flow Chart, 2007

### Material Processing & Manufacturing

<table>
<thead>
<tr>
<th>Source</th>
<th># of Sources</th>
<th>Average Emissions per Source (MT/source)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>1175</td>
<td>0.8</td>
</tr>
<tr>
<td>Refining</td>
<td>638</td>
<td>1.35</td>
</tr>
<tr>
<td>Other</td>
<td>736</td>
<td>0.15 – 3.5</td>
</tr>
</tbody>
</table>

Source: IPCC Special Report, 2005

### Transportation Sector

Little today. Future Potential?

73% of U.S. light duty transport could be powered with existing fleet of power plants, Kintner-Meyer, PNNL, 2007
# Lifetime Emissions from Typical CO$_2$ Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal-Fired Power Plants</td>
<td>200 MT over 50 years</td>
</tr>
<tr>
<td>Natural Gas Fired Power Plants</td>
<td>50 MT over 50 years</td>
</tr>
<tr>
<td>Refinery</td>
<td>65 MT over 50 years</td>
</tr>
<tr>
<td>Cement Plants</td>
<td>40 MT over 50 years</td>
</tr>
</tbody>
</table>

*Need sites with from 40 to over 200 MT capacity. At typical densities, this mass of CO$_2$ will occupy from 60 to 300 M m$^3$.***
Site Characterization
Injectivity

- Characterize the rate at which CO$_2$ can be injected underground
- Requires adequate permeability x thickness
- Storage formation volume $>>$ injection volume to assure long term injectivity
Storage Efficiency

• Short term
  – Average CO$_2$ saturation in the plume
  – 5%, 10%, 20%?

• Longer term
  – Dissolution
  – Capillary trapping
  – Adsorbed
  – Mineralized

• Footprint of the CO$_2$ plume

Note: The storage efficiency for individual projects is likely to be far greater than the 1-4% used in regional capacity estimation.
CO₂ Containment Effectiveness

- **Seal Characteristics**
  - Capillary barrier
  - Permeability barrier
- **Continuous and thick**
- **Geographically extensive**
  - More extensive than CO₂ plume
- **Absence of conductive faults**
- **Stable during pressure buildup**
  - Avoid hydrofracture, fault reactivation
- **Multiple barriers**
- **Manageable pre-existing wells**
Basin Scale Brine Displacement

• Seal Characteristics
  – Permeability barrier
• Continuous and thick
• Geographically extensive over extent of the pressure buildup
• Absence of conductive faults
• Manageable existing wells

The Challenge: Pressure buildup extends over an area >> CO₂ plume.
Location of Large Point Sources
Saline Aquifers

To accelerate deployment of CCS we need to initiate a nation-wide effort to characterize and pre-qualify promising storage sites in saline aquifers.
Unresolved Permitting and Legal Issues Slow Deployment of CCS

• Access to pore space
  – Clarity on pore space ownership
  – Unitization of storage reservoirs
• Permitting
  – Injection, pipelines, emissions, water rights
  – etc…
• Basin-wide pressure management
• Accounting protocols
• Credits for carbon emission reductions
• Long term liability
  – Financial responsibility
  – Governance

*To accelerate deployment of CCS we need to form multi-agency teams to expedite resolution of permitting and legal issues.*
Lack of Experience and Business Models for CCS Slow Deployment

- Deployment of CCS challenges existing competencies and business models
  - Power generation
  - Capture
  - Transport
  - Storage

- Need to gain experience with integrated capture and storage systems
  - Cost - Performance - Reliability

- Engage the private sector innovation engine to drive down costs and improve performance
  - Begin moving down the learning curve

- One size does not fit all
  - Pre-combustion, post-combustion, oxy-fuel, co-production
  - Regional differences in storage options, costs and drivers

To accelerate deployment of CCS we need to provide financial incentives and institutional support for 5-7 commercial scale projects with greater than 4 Mt/yr CO$_2$ storage by 2014.
Three Concrete Steps to Accelerate Deployment

1. Beyond capacity assessment
   ... initiate a nation-wide effort to pre-qualify promising storage sites in saline aquifers.

2. Beyond identification of institutional issues
   ... form multi-agency teams to expedite resolution of permitting and legal issues.

3. Beyond CCS validation
   ... provide financial incentives and institutional support for 5 - 7 commercial scale projects with greater than 4 Mt/yr CO_2 storage by 2014.