Carbon Sequestration Overview

Jay Braitsch, PhD
U.S. Department of Energy
Office of Fossil Energy
February 16, 2009
What is Carbon Sequestration?

Capture and storage of CO₂ and other Greenhouse Gases that would otherwise be emitted to the atmosphere

Terrestrial Capture
CO₂ absorbed from air

Terrestrial Storage
Trees, grasses, soils

Point Source Capture
- Power Plants
- Ethanol Plants
- Cement, Steel, Refineries
- Natural Gas Processing

Geologic Storage
- saline formations
- depleted oil/gas
- unmineable coal
- other: basalts, shales
Good News/Bad News/Good News

- Good News -- programs are in place in the U.S. and elsewhere that should, over the next decade, demonstrate that CO2 can be permanently and safely stored in geologic formations. That we are building on decades of petroleum industry experience is key.

- Bad News – the biggest cost for CO2 capture and storage is the cost to capture CO2 at power plants -- 80 to 90% of total cost. This is expensive, and reliance on currently available technology could raise cost of electricity at plant gate by nearly 70%.

- Good News – Current technology was not designed to economically capture the massive quantities of CO2 anticipated. New technology is being developed that should be able to significantly lower costs, but it will take time and money.
Sequestration Program Statistics FY2009

Strong industry support
~ 39% cost share on projects

Federal Investment to Date
~ $631 Million (through FY2009)

Diverse research portfolio
~ 80-100 Active R&D Projects

2009 Carbon Sequestration Program Budget Breakdown

- Simulation and Risk Assessment: 6%
- Geologic Carbon Sequestration: 5%
- Capture of CO$_2$ (Pre-Combustion): 14%
- MVA: 10%
- CO$_2$ Use/Reuse: 5%
- Regional Partnerships: 60%

Fiscal Year

DOE Budget (Million $)

Fiscal Year:
- 1997: $0
- 1998: $0
- 1999: $0
- 2000: $0
- 2001: $0
- 2002: $0
- 2003: $5
- 2004: $15
- 2005: $25
- 2006: $35
- 2007: $45
- 2008: $55
- 2009: $120
- 2010: $160

Graph shows an increasing trend in DOE budget from 1997 to 2010.
Desired Carbon Storage Technology Outcomes

- Deliver technologies & best practices that validate
  - 99% storage permanence
  - +/- 30% storage capacity
Regional Carbon Sequestration Partnerships

Characterization Phase
- 24 months (2003-2005)
- $16M DOE funds

Validation Phase
- 4 years (2005 - 2010)
- 7 Partnerships (43 states)
- 21 geologic field tests
- 50-500,000 tons CO₂
- $120M DOE funds

Development Phase
- 10 years (2008-2017)
- Nine large injection tests in different geology, 1,000,000 tons CO₂ ~4 yrs
- $500M DOE funds

Representing:
- >350 Organizations
- 43 States
- 4 Canadian Provinces
- 3 Indian Nations
- 34% cost share
## Regional Partnerships Participation

160 organizations in Phase I

350+ organizations in Phases II and III

<table>
<thead>
<tr>
<th>Organizations</th>
<th>Number</th>
<th>Organizations</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Companies</td>
<td>5</td>
<td>Land Management/Development Company</td>
<td>2</td>
</tr>
<tr>
<td>CO₂ Trading Organizations</td>
<td>3</td>
<td>Law Firm</td>
<td>2</td>
</tr>
<tr>
<td>Coal Companies</td>
<td>8</td>
<td>Local Agencies</td>
<td>4</td>
</tr>
<tr>
<td>Electric Utilities</td>
<td>53</td>
<td>Media/Outreach</td>
<td>6</td>
</tr>
<tr>
<td>Engineering and Research Firms</td>
<td>44</td>
<td>National Laboratories</td>
<td>10</td>
</tr>
<tr>
<td>Environmental NGOs</td>
<td>11</td>
<td>Oil &amp; Gas Companies</td>
<td>37</td>
</tr>
<tr>
<td>Foreign Government Agencies</td>
<td>10</td>
<td>Other State Agencies</td>
<td>51</td>
</tr>
<tr>
<td>Forest Products Companies</td>
<td>4</td>
<td>Pipeline Company</td>
<td>2</td>
</tr>
<tr>
<td>Governmental Advisory Groups</td>
<td>2</td>
<td>State Geologic Surveys</td>
<td>18</td>
</tr>
<tr>
<td>Native American Organizations</td>
<td>4</td>
<td>U.S. Federal Agencies</td>
<td>6</td>
</tr>
<tr>
<td>Industry Trade Groups</td>
<td>22</td>
<td>University and Academic Institutions</td>
<td>47</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>351</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
National Carbon Sequestration Database and Geographical Information System (NATCARB)

- Available “Free-Of-Charge” on Internet
- Porthole to Key Source & Sink Databases
- Decision Support Tools
- Outreach tool
  - Web-site gets 600+ unique visitors every month from around the world

www.natcarb.org
### Geologic Sink Capacity Estimates

#### Adequate Storage Projected

U.S. Emissions ~ 6-7 Gt CO$_2$/yr all sources > 4,600 Stationary Sources Identified

<table>
<thead>
<tr>
<th>Sink Type</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline Formations</td>
<td>3,300</td>
<td>12,600</td>
</tr>
<tr>
<td>Unmineable Coal Seams</td>
<td>160</td>
<td>180</td>
</tr>
<tr>
<td>Oil and Gas Fields</td>
<td>140</td>
<td>140</td>
</tr>
</tbody>
</table>

**Conservative Resource Assessment**

**Estimated North American CO$_2$ Storage Potential (Gigatonnes)**

**Hundreds of Years of Storage Potential**

- **Oil and Gas Fields**
- **Saline Formations**
- **Unmineable Coal Seams**
RCSP Phase II: Validation
Small-Scale Geologic Field Tests

Saline formations
(3,000 to 60,000 tons)
Depleted oil fields
(50 to 500,000 tons)
Coal Seams
(200 – 18,000 tons)
Basalt formation
(1,000 tons)

<table>
<thead>
<tr>
<th>RCSP</th>
<th>Formation Type</th>
<th>Geologic Province</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Sky</td>
<td>Saline 1</td>
<td>Columbia Basin</td>
</tr>
<tr>
<td>MGSC</td>
<td>Oil-bearing 2, 3, 4</td>
<td>Illinois Basin</td>
</tr>
<tr>
<td></td>
<td>Saline 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal seam 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basalt formation 1, 8 (1,000 tons)</td>
<td></td>
</tr>
<tr>
<td>MRCSP</td>
<td>Saline 7, 11</td>
<td>Cincinnati Arch, Michigan Basin, Appalachian Basin</td>
</tr>
<tr>
<td></td>
<td>Oil-bearing 10, 12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal seam 13</td>
<td></td>
</tr>
<tr>
<td>PCOR</td>
<td>Oil-bearing 14</td>
<td>Keg River, Duperow, Williston Basin</td>
</tr>
<tr>
<td>SECARB</td>
<td>Oil-bearing 16</td>
<td>Gulf Coast, Mississippi Salt Basin, Central Appalachian, Black Warrior Basin</td>
</tr>
<tr>
<td></td>
<td>Saline 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal seam 18, 19</td>
<td></td>
</tr>
<tr>
<td>SWP</td>
<td>Oil-bearing 17, 18</td>
<td>Paradox Basin, Aneth Field, Permian Basin, San Juan Basin</td>
</tr>
<tr>
<td>WESTCARB</td>
<td>Saline 20, 21</td>
<td>Sacramento Valley, Colorado Plateau</td>
</tr>
</tbody>
</table>

Data current as of April 2009
RCSP Phase III: Development
Large-Volume Geologic Field Tests

<table>
<thead>
<tr>
<th>Partnership</th>
<th>Geologic Province</th>
<th>Formation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Triassic Nugget Sandstone/Moxa Arch</td>
<td>Saline Depth: 11,000 ft</td>
</tr>
<tr>
<td>2</td>
<td>Mt. Simon Sandstone</td>
<td>Saline Depth: 5,000-7,000 ft</td>
</tr>
<tr>
<td>3</td>
<td>Mt. Simon Sandstone</td>
<td>Saline Depth: 3,000-3,600 ft</td>
</tr>
<tr>
<td>4</td>
<td>Williston Basin</td>
<td>Oil Bearing Depth: &gt;12,000 ft</td>
</tr>
<tr>
<td>5</td>
<td>Devonian Age Carbonate Rock</td>
<td>Saline Depth: 5,000 ft</td>
</tr>
<tr>
<td>6</td>
<td>Lower Tuscaloosa Formation Massive Sand Unit</td>
<td>Saline Depth: 5,000 ft</td>
</tr>
<tr>
<td>7</td>
<td>Regional Jurassic and Older Formations</td>
<td>Saline Depth: 5,000+ ft</td>
</tr>
<tr>
<td>8</td>
<td>San Joaquin Basin</td>
<td>Saline Depth: 7,000+ ft</td>
</tr>
</tbody>
</table>

Beginning of Injection Phase

- 2009
- 2010
- 2011
- 2012
Monitoring, Verification, and Accounting Technologies & Protocols Are Emerging
Geologic Storage
Ground Surface Deformation Monitoring In Salah

Ground surface displacements derived from satellite-based Interferometric Synthetic Radar (InSAR) measurements

Courtesy LBNL
## CCS Best Practice Manuals

Critical Requirement For Significant Wide Scale Deployment  
*Capturing Lessons Learned*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring, Verification and Accounting</td>
<td>2009</td>
<td>2017</td>
<td>2020</td>
</tr>
<tr>
<td>Site Characterization</td>
<td>2009</td>
<td>2016</td>
<td>2020</td>
</tr>
<tr>
<td>Simulation and Risk Assessment</td>
<td>2010</td>
<td>2017</td>
<td>2020</td>
</tr>
<tr>
<td>Well Construction and Closure</td>
<td>2010</td>
<td>2017</td>
<td>2020</td>
</tr>
<tr>
<td>Regulatory Compliance</td>
<td>2010</td>
<td>2016</td>
<td>2020</td>
</tr>
<tr>
<td>Public Outreach and Education</td>
<td>2009</td>
<td>2016</td>
<td>2020</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>2010</td>
<td>2016 – Post MVA Phase III</td>
<td></td>
</tr>
</tbody>
</table>
Risk assessment underpins a number of factors that must be addressed for a successful CO₂ storage project.

**Five NRAP Working Groups**
- Wellbore integrity
- Natural flow pathways
- Protection of groundwater
- MVA
- Multi-scale (system) modeling
The risk timeline for leakage is heavily-laden in early times.
American Recovery & Reinvestment Act of 2009
Provisions for Fossil Energy CCS Projects

“To prevent the worst effects of climate change, we must accelerate our efforts to capture and store carbon in a safe and cost-effective way.”
— DOE Secretary Steven Chu, May 15, 2009

<table>
<thead>
<tr>
<th>Fossil Energy ($ in Millions)</th>
<th>Funding Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Energy Research and Development</td>
<td>$1,000</td>
</tr>
<tr>
<td>Clean Coal Power Initiative – Round 3 FOA</td>
<td>$800</td>
</tr>
<tr>
<td>Industrial Carbon Capture Solicitation (ICCS)</td>
<td>$1,520</td>
</tr>
<tr>
<td>Geologic Formation Site Characterization</td>
<td>$50</td>
</tr>
<tr>
<td>Geologic Sequestration Training &amp; Research</td>
<td>$20</td>
</tr>
<tr>
<td>Program Direction</td>
<td>$10</td>
</tr>
<tr>
<td>Total, Fossil Energy</td>
<td>$3,400</td>
</tr>
</tbody>
</table>
ICCS Large Scale CCS Projects
11 Projects Selected for Feasibility Studies 10/2/2009, Down-Select Mid-2010, Capture 75% of CO₂ from Treated Industrial Stream ($1.32 billion)

C6 (Shell); H₂ Production; Saline, ADIP-X Amine, Solano, CA

Cemex,; Cement; EOR, Saline, RTI Dry Carbonate Odessa, TX
Conoco Phillips; IGGC-Pet coke; Depleted NG/EOR, Selexol, Sweeny, TX

Praxair; H₂ for Refinery; EOR, VPSA, Texas City, TX

Univ of Utah; Ammonia & Cement; EOR & Saline, Dehydration, Coffeyville, KS

Wolverine, CFB Power; EOR, Hitachi Amine, Rogers City, MI

Archer Daniels Midland; Industrial Power & Ethanol; Saline, DOW Alstom Amine, Decatur, IL
Leucadia Energy; SNG from pet coke; EOR, Rectisol, Mississippi
Shell; Refinery Products; EOR/Saline, Dehydration, New Orleans, LA
Leucadia Energy; Methanol; EOR, Rectisol, Lake Charles, LA

Air Products, H₂ Production; EOR, BASF’s aMDEA Port Arthur, TX;
2009 ARRA CCS Training Project Grants
7 Projects Awarded 11/16/09 to Train Professional, Trades, and Public about CCS Technologies ($6.9 Million)

- Environmental outreach and Stewardship Alliance, Seattle, WA
- Board of Trustees of the University of Illinois, Champaign, IL
- New Mexico Institute of Mining and Technology, Socorro, NM
- University of Wyoming, Laramie, WY
- University of Texas at Austin, Austin, TX
- Southern States Energy Board, Norcross, GA
- Petroleum Technology Transfer Center, Tulsa, OK
2009 ARRA Geologic Research and Training Grants

43 Projects awarded 12/1/2009 to train students for future careers in CCS industry ($12.8 million)
2009 ARRA Geologic Site Characterization Projects
10 Projects Awarded 12/8/2009 to characterize 10 “high-potential” geologic basins ($49.8 million)

- North American Power Group, Ltd; Powder River Basin; NE Wyoming; Saline and Oil
- University of Wyoming; Rock Springs Uplift / Moxa Arch; SW Wyoming; Saline
- University of Utah; Cretaceous, Jurassic, and Pennsylvanian Sandstone; Colorado and Utah; Saline
- Terralog Technologies USA Inc.; Wilmington Graben; Offshore Los Angeles; Saline, Oil, & Gas
- University of Illinois; Cambro-Ordovician Strata; IL, IN, KY, MI; Saline
- University of Kansas Center for Research Inc.; Ozark Plateau; SW Kansas; Saline and Oil
- Sandia Technologies, LLC; Triassic Newark Basin; NY and NJ; Saline
- University of Alabama; Black Warrior Basin; NW Alabama; Saline
- University of South Carolina Research Foundation; South Georgia Rift Basin; South Carolina; Saline
- University of Texas at Austin; Gulf of Mexico Miocene; Offshore Texas; Saline
THE END
Stabilizing CO₂ concentrations means fundamental change to the global energy system.

- **History and Reference Case**
  - **2100 CO₂ Concentration**: ~740 ppm
  - **Present CO₂ Concentration**: ~380 ppm

- **Stabilization of CO₂ at 550 ppm**
  - **History**
  - **Future**
  - **2100 CO₂ Concentration**: ~550 ppm
  - **Present CO₂ Concentration**: ~380 ppm

The graph shows the energy consumption (EJ/year) from 1850 to 2100, categorized by different energy sources such as Oil, Natural Gas, Coal, Biomass Energy, Nuclear Energy, and Non-Biomass Renewable Energy. The graph compares the energy consumption under historical and reference cases with the stabilization case at 550 ppm CO₂ concentration.
FutureGen Restart

- FutureGen project first announced: 2/2003
- DOE Awarded Cooperative Agreement to Alliance: 12/2005
- DOE announced it was withdrawing due to cost escalation: 01/2008
- FutureGen Restructured: 03/2008
- Original FutureGen project restarted: 07/09
- New Limited Scope Cooperative Agreement issued to Alliance (7/09 – 3/10)
  - Preliminary Design, Revised Cost Estimate & Funding Plan
  - Estimated Cost $17.8 million
    ($14.3 million DOE share)
- Go/No-Go Decision 1/29/2010
  - $1.073 billion maximum DOE contribution for remainder of project
  - Project currently estimated at ~$2.4 billion
Public Outreach and Education

- Public outreach and education is essential
- Each RCSP has developed a team approach consisting of technology and communications experts
- Phase I and II provided significant “learning by doing” in approaches and materials
- Lessons for Phase III:
  - Learn about stakeholders’ concerns and perceptions
  - Develop materials that speak to the stakeholders (not just to the research team)
  - Trust – gained through openness and transparency key
- Research and Coordination:
  - Focus groups and interviews with stakeholders and partners
  - Mediated modeling
  - Outreach Working Group (OWG) calls
ARRA Industrial Carbon Capture Program
(“ICCS” – $1.52 Billion)

- **Objectives**
  - Capture 75% of the CO\(_2\) from the treated industrial stream
  - Store 1 million TPY of CO\(_2\) in a saline formation or other value-added options
  - Investigate novel CO\(_2\) use / reuse technologies

- **Planned Competitive Awards**
  - Large-Scale CCS Projects ($1.32 B)
  - Innovative Concepts for Beneficial Uses of CO\(_2\) ($100 M)

- **Staged Competition**
  - Phase I Project Feasibility/Definition
  - Competitive down-select after 7 months
  - Award Phase II projects by Sept. 30, 2010
  - Complete project by September 2015

- **Cost Share**
  - Private cost share > 20%
  - Target 50% for commercial scale projects

Selections Announced: OCT 2, 2009
<table>
<thead>
<tr>
<th>Project</th>
<th>Product</th>
<th>Capture Technology</th>
<th>Sequestration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Products and Chemicals, Inc.</td>
<td>Hydrogen Production</td>
<td>Amines</td>
<td>EOR</td>
</tr>
<tr>
<td>Archer Daniels Midland Corporation</td>
<td>Ethanol (fermentation) unit</td>
<td>Dow/Alstom Amine</td>
<td>Sandstone Reservoir</td>
</tr>
<tr>
<td>Battelle Memorial Institute</td>
<td>Paper Mill</td>
<td>Econamine Plus</td>
<td>Basalt Formation</td>
</tr>
<tr>
<td>CEMEX USA</td>
<td>Cement Plant</td>
<td>Dry Carbonate Technology</td>
<td>EOR or EGR</td>
</tr>
<tr>
<td>ConocoPhillips</td>
<td>IGCC 685 MW Petcoke Plant</td>
<td>E-Gas with Selexol</td>
<td>Depleted Natural Gas Field</td>
</tr>
<tr>
<td>C6 Resources</td>
<td>Refinery/Hydrogen Plant</td>
<td>MDEA Technology</td>
<td>Saline Reservoir</td>
</tr>
<tr>
<td>Leucadia Energy – Lake Charles</td>
<td>Petcoke to Methanol Plant</td>
<td>Rectisol</td>
<td>EOR</td>
</tr>
<tr>
<td>Leucadia Energy – Mississippi</td>
<td>Petcoke to SNG</td>
<td>Rectisol</td>
<td>EOR</td>
</tr>
<tr>
<td>Praxair, Inc.</td>
<td>Refinery/Hydrogen Plant</td>
<td>Vacuum Pressure Swing</td>
<td>EOR</td>
</tr>
<tr>
<td>University of Utah</td>
<td>Ammonia, Ethanol &amp; Cement Plants</td>
<td>Amine</td>
<td>EOR and Saline Basins</td>
</tr>
<tr>
<td>Wolverine Power Supply Cooperative, Inc.</td>
<td>300MW Petcoke/Coal Fired CFB</td>
<td>Hitachi &amp; Dow Amine</td>
<td>EOR</td>
</tr>
</tbody>
</table>
Summary of CCS Training Projects

- 7 Projects awarded 11/16/2009
- Projects awarded to train Professional, Trades, and Public about CCS Technologies
  - Develop curriculum related to all aspects of CCS technologies
  - Establish steering committees
  - Seek professional certifications for continuing education credits
  - Become self sustaining organizations
  - Develop outreach programs
  - Support regional/basin technology transfer

- Total ARRA Funding $6,963,188
Summary of Geologic Research and Training Projects

- 43 Projects awarded 12/1/2009
- Representing 23 States
- Projects Awarded in Targeted Research Areas (# projects)
  - Simulation and Risk Assessment (20)
  - Monitoring Verification and Accounting (13)
  - Pre combustion capture and transport (5)
  - Post Combustion Capture (5)
- Objective is to train students for future careers in CCS industry
- Total ARRA Funding $12,783,846
Summary of Geologic Site Characterization Projects

- 10 Projects Awarded 12/8/2009
- Representing 10 different “high-potential” geologic basins
  - Saline formations, depleting/depleted oil fields, and gas fields
  - Focus on a minimum of one specific site, formation, or area not previously characterized with public data
  - Represents a significant storage opportunity in the region with adequate seals that could be developed commercially in the future
  - Increasing knowledge of the potential for these formations to safely and permanently store CO$_2$
- Provide additional data to NATCARB and Regional Partnerships
- Total ARRA Funding $49,750,000