Sequestration Program

Dawn Deel – Project Manager
September 15-17, 2009

Carbon Sequestration Program Goals

• Deliver technologies & best practices for Carbon Capture and Safe Storage with:
  – 90% CO₂ capture at source
  – 99% storage permanence
  – < 10% increase in COE
    • Pre-combustion capture (IGCC)
  – < 35% increase in COE
    • Post-combustion capture
    • Oxy-combustion
Key Challenges to Carbon Capture and Storage

**Technical Issues**
- Capture Technology
  - Existing Plants
  - New Plants (PC)
  - IGCC
- Cost of CCS
- Sufficient Storage Capacity
- Permanence
- Best Practices
  - Storage Site Characterization
  - Monitoring/Verification
  - Site Closure
  - Etc etc …

**Legal/Social Issues**
- Regulatory Framework
  - Permitting
  - Treatment of CO₂
- Infrastructure
- Human Capital
- Legal Framework
  - Liability
  - Ownership
  - pore space
  - CO₂
- Public Acceptance (NIMBY → NUMBY)

Projects helping to address both categories of issues

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CARBON SEQUESTRATION PROGRAM

Core R&D
- Capture
- Geologic Storage
- Monitoring, Verification, and Accounting (MVA)
- Simulation and Risk Assessment
- CO₂ Use/Reuse

Benefits
- Reduced cost of CCS
- Tool development for risk assessment and mitigation
- Accuracy/monitoring quantified
- Capacity validation
- Indirect storage

Infrastructure
- Regional Carbon Sequestration Partnerships
  - Characterization
  - Validation
  - Development

Benefits
- Human capital
- Stakeholder networking
- Regulatory policy development
- Visualization knowledge center
- Best practices
- Public outreach and education

Global Collaborations
- North America Energy Working Group
- Carbon Sequestration Leadership Forum
- International Demonstration Projects
- Asian-Pacific Partnership (APP)

Benefits
- Knowledge building
- Project development
- Collaborative international knowledge
- Capacity/model validation
- CCS commercial deployment

Demonstration and Commercialization Carbon Capture and Sequestration (CCS)

Lessons Learned

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Sequestration Program Statistics FY2009

Strong industry support
~ 39% cost share on projects

Federal Investment to Date
~ $631 Million

Diverse research portfolio
~ 80 Active R&D Projects

Recent Achievements

- IEA GHG International Review of the Regional Partnership large scale field tests – March 2008
  - RCSP was recognized as most significant program in the world today
  - Excellent program that will achieve significant results
- Produced 1st in series of Best Practice Manuals – Monitoring, Verification, and Accounting of CO₂ Stored in Deep Geologic Formations
- Numerous Phase II (Field Validation) Regional Partnership Projects Drilling, Injecting, Completed
- Phase III (Development Test) Regional Partnership Drilling, Injection Started
- Pipeline Study underway
- Two Funding Opportunity Announcements
  - Pre-Combustion Carbon Capture Technologies for Coal-Based Gasification Plants
  - Innovative and Advanced Technologies and Protocols for MVA, Simulation, and Risk Assessment in Geologic Formations
- Added 43rd State to Regional Carbon Sequestration Partnerships Initiative
West Coast Regional Carbon Sequestration Partnership
Annual Business Meeting
Scottsdale, AZ
September 15-17, 2009

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**Infrastructure**
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- Characterization
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- Development

**Technology Solutions**
- Lessons Learned

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**Demonstration and Commercialization**
**Carbon Capture and Sequestration (CCS)**

**Core R&D Focus Areas and Supporting Research Pathways**

**Capture (Pre-Combustion)**
- Membrane
- Solvent-Based
- Sorbent-Based
- Novel Concepts

**Geologic Carbon Storage**
- Improved Fundamental Understanding
- Technology Development

**CO₂ Use/Reuse Approaches**
- Conversion of CO₂
- Non-Geologic CO₂ Storage
- Indirect Storage
- Beneficial Use of Produced Water
- Breakthrough Concepts

**Simulation and Risk Assessment**
- Mathematical Models Development and Verification
- Improved Risk Assessment Protocols

**MVA**
- Atmospheric and Remote Sensing
- Near-Surface Monitoring
- Wellbore Monitoring
- Subsurface Monitoring
- Accounting Protocols

**Lessons Learned**
- Human capital
- Stakeholder networking
- Regulatory policy development
- Visualization knowledge center
- Best practices
- Public outreach and education

**North America Energy Working Group**
- Carbon Sequestration Leadership Forum
- International Demonstration Projects
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Research at NETL
(Office of Research & Development)

- Carbon Dioxide Capture: Advanced Plants
  - CO₂ membranes and ionic liquid solvents.
  - Solid sorbents for CO₂ capture and enhanced water-gas-shift.
  - Phase change sorbents and exploratory CO₂ re-use studies.
- Computational Science/Capture and Power Plant Simulations
  - Computational chemistry to develop capture materials.
  - Virtual scale-up for capture technologies.
  - Dynamic systems modeling for plants w/capture.
- CO₂ Storage (Science needs to ensure success of storage projects)
  - Integrity of seals and wellbores (e.g., cement-CO₂-water reactions)
  - CO₂ tracers with novel collection strategies (NETL designed monitoring packs; bees; airborne methods)
  - Improved assessment of capacity/injectivity w/ site-specific samples
  - Multiphase flow on discrete fractures (experiment and simulation)
  - NETL-led multi-lab initiative on science-based risk assessment
    • LANL, LLNL, LLNL, NETL, PNNL

LANL, LBNL, LLNL, NETL, PNNL

CO₂ Molecular modeling used to optimize CO₂ interaction with polyionic liquid

Experimental models (left) of cement integrity that correctly match field observations (right).

Determining the effect of confinement on coal storage capacity

CO₂

Dynamic simulation of IGCC power plant

FY09 Program Funding Opportunity Announcements (FOAs)

• Pre-Combustion Carbon Capture Technologies for Coal-Based Gasification Plants
  - Funding Opportunity Announcement DE-PS26-08NT00699
  - 9 projects selected;
  - ~$14 M total award value over 3-years ($3.1M Cost-share)
  - Project awards by end of FY09

• Innovative and Advanced Technologies and Protocols for MVA, Simulation, and Risk Assessment in Geologic Formations
  - Funding Opportunity Announcement DE-FOA00023
  - Released Feb 18, 2009; Closing Date May 12, 2009
  - 19 projects selected;
  - ~$34.7 M total award value over 4 years ($8.1 M Cost-share)
  - Awards Sept-Oct 2009

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Regional Carbon Sequestration Partnerships

- Engage regional, state, and local governments
- Determine regional sequestration benefits
- Baseline region for sources and sinks
- Establish monitoring and verification protocols
- Address regulatory, environmental, and outreach issues
- Validate sequestration technology and infrastructure

- 7 Regional Partnerships
- 43 States, 4 Canadian Provinces
- 350+ distinct organizations

Developing the Infrastructure for Wide-Scale Deployment
Regional Carbon Sequestration Partnerships

Program Phases

FISCAL YEAR

<table>
<thead>
<tr>
<th>Characterization Phase</th>
<th>Validation Phase</th>
<th>Development Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characterize all RCSP regions for carbon capture and storage opportunities</td>
<td>Validate technologies through field testing at selected geologic and terrestrial site locations</td>
<td>Complete large-volume development tests of sequestration technologies that will help enable future commercial scale applications</td>
</tr>
</tbody>
</table>

$16 M DOE + $5 M CS

$120 M DOE + $45 M CS

Scale of 100 to 10,000 Tons CO₂

Scale of 1,000,000 Tons CO₂

UPDATED: National Atlas Highlights (Atlas II)

Adequate Storage Projected

Emissions ~ 3.8 GT CO₂/yr point sources

Conservative Resource Assessment

<table>
<thead>
<tr>
<th>Sink Type</th>
<th>Low</th>
<th>High</th>
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<tbody>
<tr>
<td>Saline Formations</td>
<td>3300</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>

Validation Phase Project Status

Geologic Projects

- **Saline formations (3,000 to 60,000 tons)**
  - Projects in Michigan, Mississippi, and Ohio have completed injection
- **Depleted oil fields (50 to 500,000 tons)**
  - Illinois Basin and North Dakota projects complete
  - Currently injecting in Alberta, New Mexico, Utah, Texas, Kentucky, and Mississippi
- **Coal Seams (200 - 18,000 tons)**
  - Central Appalachian project complete
  - Currently injecting in New Mexico, Illinois, North Dakota
- **Basalt formation**
  - Wallula, WA – Grande Ronde Basalt
- **Remaining injection projects scheduled to begin injection by end of 2009**
  - These injection tests lay the foundation and path for larger scale injections and ultimately integrated capture and storage tests
Stage 1. Site selection and characterization; Permitting and NEPA compliance; Well completion and testing; Infrastructure development

Stage 2. CO2 procurement and transportation; Injection operations; Monitoring activities

Stage 3. Site closure; Post-injection monitoring, Project assessment

Scale up is required to provide insight into several operational and technical issues that differ from formation to formation

Developing Phase – 10 years+ (FY2008 -2017+)

Development Phase Goals

• Assess
  – Injectivity and Capacity
  – Storage Permanence
  – Areal Extent of Plume and Leakage Pathways

• Develop
  – Risk Assessment Strategies
  – Best Practices for Industry

• Engage in Public Outreach and Education

• Support Regulatory Development
RCSP Phase III: Development
Large-Volume Geologic Field Tests

✓ Nine large-volume tests
✓ Injections initiated 2009 – 2011

<table>
<thead>
<tr>
<th>Partnership</th>
<th>Geologic Province</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>1 Big Sky</td>
<td>Triassic Nugget Sandstone / Moxa Arch</td>
<td>Saline</td>
</tr>
<tr>
<td>2 MGSC</td>
<td>Deep Mt. Simon Sandstone</td>
<td>Saline</td>
</tr>
<tr>
<td>3 MRCSP</td>
<td>Shallow Mt. Simon Sandstone</td>
<td>Saline</td>
</tr>
<tr>
<td>4 PCOR</td>
<td>Williston Basin Carbonates</td>
<td>Oil Bearing</td>
</tr>
<tr>
<td>5 SECARB</td>
<td>Devonian Age Carbonate Rock</td>
<td>Saline</td>
</tr>
<tr>
<td>6 SWP</td>
<td>Lower Tuscaloosa Formation</td>
<td>Saline</td>
</tr>
<tr>
<td>7 WESTCARB</td>
<td>Regional Jurassic &amp; Older Formations</td>
<td>Saline</td>
</tr>
<tr>
<td>8</td>
<td>Central Valley</td>
<td>Saline</td>
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2009 Injection Scheduled
2010 Injection Scheduled
2011 Injection Scheduled

CCS Best Practice Manuals
Critical Requirement For Significant Wide Scale Deployment
Capturing Lessons Learned

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<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Monitoring Verification and Accounting</td>
<td>2009</td>
<td>2017</td>
<td>2020</td>
</tr>
<tr>
<td>Site Characterization</td>
<td>2010</td>
<td>2016</td>
<td>2020</td>
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<td>Simulation and Risk Assessment</td>
<td>2010</td>
<td>2017</td>
<td>2020</td>
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<td>Well Construction and Closure</td>
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<td>2017</td>
<td>2020</td>
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<td>Regulatory Compliance</td>
<td>2010</td>
<td>2016</td>
<td>2020</td>
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<tr>
<td>Public Education</td>
<td>2009</td>
<td>2016</td>
<td>2020</td>
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<tr>
<td>Terrestrial Sequestration Practices</td>
<td>2010</td>
<td>2016 – Post MVA Phase III</td>
<td>2020</td>
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### DOE’s Global CCS Demonstration Role on Six Continents

<table>
<thead>
<tr>
<th>Location</th>
<th>Operations</th>
<th>U.S. Invol.</th>
<th>Reservoir</th>
<th>Operator / Lead</th>
<th>Int’l Recognition</th>
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</thead>
<tbody>
<tr>
<td>North America, Canada</td>
<td>1.8 Mt CO₂/yr commercial 2000</td>
<td>2000-2011</td>
<td>oil field carbonate EOR</td>
<td>Encana, Apache</td>
<td>IEA GHG R&amp;D Programme, CSLF</td>
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<td>Saskatchewan Weyburn-Midale</td>
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<tr>
<td>North America, Canada, Alberta</td>
<td>250,000 tons CO₂, 90,000 tons H₂S demo</td>
<td>2005-2009</td>
<td>oil field carbonate EOR</td>
<td>Apache (Reg. Part.)</td>
<td>CSLF</td>
</tr>
<tr>
<td>Zama oil field</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North America, Canada, British Columbia Fort Nelson</td>
<td>&gt; 1 Mt CO₂/yr, 1.8 Mt acid gas/yr large-scale demo</td>
<td>2009-2015</td>
<td>saline formation</td>
<td>Spectra Energy (Reg. Part.)</td>
<td>CSLF</td>
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<td>Sleipner</td>
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<tr>
<td>Europe, Germany CO2SINK, Ketzin</td>
<td>60,000-90,000 tonnes CO₂ demo 2008</td>
<td>2007-2010</td>
<td>saline sandstone</td>
<td>GeoForschungsZentrum, Potsdam(GFZ)</td>
<td>CSLF, European Commission, IEA GHG R&amp;D Prog</td>
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<tr>
<td>Australia, Victoria Otway Basin</td>
<td>100,000 tonnes CO₂ demo 2008</td>
<td>2005-2010</td>
<td>gas field sandstone</td>
<td>CO2CRC</td>
<td>CSLF</td>
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<td>Africa, Algeria In Salah gas</td>
<td>1 Mt CO₂/yr commercial 2004</td>
<td>2005-2010</td>
<td>gas field sandstone</td>
<td>BP, Sonatrach, Statoil Hydro</td>
<td>CSLF, European Commission</td>
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<td>Asia, China, Ordos Basin</td>
<td>assessment phase CCS</td>
<td>2008-TBD</td>
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<td>Ordos Basin</td>
<td>Shenhua Coal</td>
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