Briefing on Hydrogen Production from Coal and Carbon Dioxide Sequestration

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U.S. Department of Energy

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Arlington, VA
December 18, 2007
Outline

- Hydrogen from Coal
  - Hydrogen from Coal Technology Coordination
  - Hydrogen from Coal Program
  - Budget and Project Portfolio

- Carbon Dioxide Sequestration Program
  - Carbon Management Technology Options
  - Carbon Sequestration Program Structure
  - Regional Partnerships
  - Sequestration Program Budget Statistics
  - Carbon Sequestration Activities
    - Projects in progress
    - Carbon Sequestration Leadership Forum (CSLF)
    - International Energy Agency Greenhouse Gas (IEA GHG) Programme

- FutureGen

- Summary

- More Information
Hydrogen Production . . .  
How Important is Coal?

Key Findings from the National Academy of Engineering study “The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs”... both general, and those specific to coal:

- Hydrogen could fundamentally transform the U.S. energy system; therefore a robust, ongoing hydrogen program is important.

- Fossil fuels will be one of the principal sources of hydrogen for the hydrogen economy. . . but carbon capture and storage technologies will be required.

- The U.S. has vast coal resources. . .hydrogen from coal can be inexpensive. . .and . . .coal must be a significant component of R&D aimed at making very large amounts of hydrogen.
The separation and purification of hydrogen from coal-derived mixed gas streams facilitates carbon dioxide capture and storage.
Hydrogen from Coal Technology Coordination

Key:
- Gasification
- IEP/Coal Utilization By-Products
- Fuel Cells and Turbine Programs
- CO₂ Sequestration
- Coal Fuels & Hydrogen

Optional Pathway

Coal (CH) → Gasification → Synthesis Gas (CO, CO₂, H₂, H₂O, SO₂) → Gas Cleaning → Sulfur Particulate

Air Separator → Depleted Air → SOFC → Combustion Turbine → HRSG/ST Power → CO₂ Sequestration

Air → O₂ → H₂O → HRSG/ST Power → Water Gas Shift & Membrane Separation → Syngas Conversion

CO₂ → H₂O → HRSG → H₂ Delivery → H₂ Storage → H₂ Utilization

Hydrogen from Coal Technologies in the RD&D Program

F-T liquids CH₃OH → Utilize Current Delivery System → Reforming → H₂
Hydrogen from Coal RD&D Plan

- Addresses H₂ from Coal Program:
  - Goals
  - Milestones
- Defines:
  - H₂ from coal pathways
  - Research areas
  - Technical targets
  - RD&D activities
Why Hydrogen from Coal?

- Huge U.S. coal reserves
- Hydrogen can be produced cleanly from coal and provide large, affordable quantities of \( \text{H}_2 \)
- Sequestration technology will remove \( \text{CO}_2 \)
- Bridge to renewable \( \text{H}_2 \) production
The Hydrogen from Coal Program

- The Hydrogen Fuel Initiative is a $1.2 billion RD&D program to develop hydrogen production, storage, delivery, and utilization technologies.
- FutureGen is an integrated sequestration and hydrogen research initiative to test advanced technologies in a world-scale co-production plant.
Hydrogen from Coal Pathways

GASIFICATION
- Coal
- Steam
- Air/Oxygen

SYNTHESIS GAS
(CO and H₂)
- Water-Gas Shift
- Advanced Concept/Process Intensification
- F-T Synthesis
- F-T Liquid Delivery
- Reforming
- Water-Gas Shift
- SNG Production
- SNG Delivery
- Power

H₂ Separation
H₂ Delivery
H₂ Distribution

KEY
- Central Pathway
- Alternate Pathway
- Power

Electricity Transmission and Distribution

U.S. Department of Energy
Miller – Hydrogen Technical Advisory Committee - 12/18/07
Hydrogen From Coal Mission and Goals

Mission: Facilitate the transition to a sustainable hydrogen economy through the development of advanced and novel technologies that produce hydrogen from coal, our largest domestic fossil resource

- Central Production Pathway Goal
  - By 2016, prove the feasibility of a 60% efficient, near-zero emissions, coal-fueled hydrogen and power co-production facility that reduces the cost of hydrogen by 25% compared to current coal-based technology

- Alternate Production Pathway Goal
  - By 2014, make available an alternative hydrogen production pathway, including a product reforming system, for decentralized hydrogen production from high-hydrogen content liquids and/or SNG
H₂ from Coal Production Technology Challenges

- Reduce the cost / Improve efficiency
  - Clean synthesis gas production
    - Advanced gasification
    - Oxygen production
    - Advanced gas cleaning
  - Water-gas shift
  - Hydrogen separation & purification
  - Process intensification

- Capture and sequester carbon

- Integrate technologies into FutureGen
# Hydrogen from Coal Program Elements

<table>
<thead>
<tr>
<th>H₂ Production Central Pathway</th>
<th>Alternate Production Pathway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produce high-purity hydrogen for fuel cell applications</td>
<td>Produce high-hydrogen content liquids and SNG that can utilize existing infrastructure and be reformed into H₂</td>
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</table>

**Primary Thrusts**
- Hydrogen Separation Membranes and Membrane Reactors
- Process Intensification
- Advanced Concepts

**Primary Thrusts**
- Liquid Fuels and SNG Production
- Fuels Reforming Testing
- Polygeneration of High Value Carbon-Based Materials

**Other Supported Research Thrusts**
- Utilization
  - Advanced Engines
- Storage
  - High H₂ Affinity Materials

**Computational Science & Modeling / Systems Analysis / Supporting Sciences**
## Budget and Project Portfolio

<table>
<thead>
<tr>
<th>($ million)</th>
<th>FY04</th>
<th>FY05</th>
<th>FY06</th>
<th>FY07</th>
<th>FY08 Request</th>
<th>FY08 House</th>
<th>FY08 Senate</th>
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<tr>
<td>H2 from Coal Program Budget</td>
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<td>17.0</td>
<td>21.0</td>
<td>23.6</td>
<td>10.0</td>
<td>10.0</td>
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### Research Area*

<table>
<thead>
<tr>
<th>Research Area*</th>
<th>Number of Projects</th>
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<tr>
<td>Membrane research</td>
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<tr>
<td>Membrane module scale-up</td>
<td>1</td>
</tr>
<tr>
<td>Membrane reactors &amp; process intensification</td>
<td>9</td>
</tr>
<tr>
<td>CO₂ removal</td>
<td>1</td>
</tr>
<tr>
<td>Novel sorbent</td>
<td>1</td>
</tr>
<tr>
<td>Polishing filters</td>
<td>1</td>
</tr>
<tr>
<td>Polygeneration</td>
<td>2</td>
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<tr>
<td>Liquid H₂ carriers</td>
<td>7</td>
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<tr>
<td>SNG production and reforming</td>
<td>2</td>
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<tr>
<td>Storage</td>
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<tr>
<td>Utilization</td>
<td>6</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>38</strong></td>
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</table>

*Complementary projects are supported by the Gasification and Sequestration Programs.*
Carbon Dioxide Sequestration
Carbon Management Technology Options

Pathways for Reducing GHGs – CO₂

Reduce Carbon Intensity
- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency
- Demand Side
- Supply Side

Sequester Carbon
- Capture & Store
- Enhance Natural Sinks

All options needed to:
- Affordably meet energy demand
- Address environmental objectives
What is Carbon Sequestration?

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

Capture can occur
- when absorbed from air
- at the point of emission

Expensive to capture
- Increased capital cost, parasitic energy loss
- cost of energy increase 25-80%

Storage locations include
- underground reservoirs
- converted to solid materials
- trees, grasses, soils, or algae
- dissolved in deep oceans
Requirements for Sequestration

- Environmentally acceptable
  - No legacy for future generations
  - Respect existing ecosystems
- Safe
  - No sudden large-scale CO$_2$ discharges
- Verifiable
  - Ability to verify amount of CO$_2$ sequestered
- Economically viable
- *EPA Regulations on Underground Injection Control*
Overcoming Barriers to Carbon Capture and Storage

- Capture Costs
  - Capital Investments
  - Increases in COE
- Lack of Infrastructure
- Regulatory Requirements
- Public Acceptance
- Human Capital Resources

- FE/NETL Sequestration Program is overcoming these barriers through:
  - Core R&D
  - Technology/Infrastructure Development
  - Government/Industry Partnerships
  - International Collaborations
DOE’s Carbon Sequestration Program Goal

Develop fossil fuel conversion systems that offer 90% CO₂ capture with 99% storage permanence at less than 10% increase in cost of energy services by 2012.

The amount of CO₂ captured represents 90 percent of the carbon in the fuel fed to the power plant or other energy system.

After 100 years, less than 1 percent of the injected CO₂ has leaked or is otherwise unaccounted for.

A 10 percent cost of energy increase will not significantly impact the economy or unduly affect U.S. competitiveness in international markets.

The Program seeks to have pilot-scale unit operation performance results from a combination of CO₂ capture, MM&V, and storage system components that will meet this goal.
Carbon Sequestration Program Structure

**Core R&D**
- Capture of CO₂
- Sequestration
  - Direct CO₂ storage
  - Enhanced natural sinks
- Measurement, Monitoring & Verification
- Non-CO₂ GHG Mitigation
- Breakthrough Concepts

**Infrastructure**
- 7 Regional Partnerships
  - Engage regional, state, local governments
  - Determine regional sequestration benefits
  - Baseline region for sources and sinks
  - Establish monitoring and verification protocols
  - Address regulatory, environmental & outreach issues
  - Test sequestration technology at small scale
  - **Initiated FY 2004**

**Integration**
- Power/Sequestration Complex
  - First-of-kind integrated project
  - Verify large-scale operation
  - Highlight best technology options
  - Verify performance & permanence
  - Develop accurate cost/performance data
  - International showcase
  - **Initiated FY 2003**
# Core R&D Program – R&D Pathways

<table>
<thead>
<tr>
<th>Capture</th>
<th>Sequestration</th>
<th>MM&amp;V</th>
<th>Breakthrough Concepts</th>
<th>Non-CO₂ GHG</th>
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<tr>
<td>Post-combustion capture</td>
<td>Depleting oil reservoirs</td>
<td>Advanced soil carbon measurement</td>
<td>Advanced capture</td>
<td>Landfill methane capture and use</td>
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<tr>
<td>Oxygen combustion</td>
<td>Unmineable coal seams</td>
<td>Subsurface measurements</td>
<td>Bio-accelerated sequestration</td>
<td>Mine ventilation methane capture</td>
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<tr>
<td>Pre-combustion capture</td>
<td>Saline formations</td>
<td>Remote sensing/above-ground MM&amp;V</td>
<td>Niches</td>
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<tr>
<td>Chemical looping</td>
<td>Enhanced terrestrial uptake</td>
<td>Fate and transport models</td>
<td></td>
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<tr>
<td></td>
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</table>
Regional Carbon Sequestration Partnerships
“Developing the Infrastructure for Wide Scale Deployment”

- 350+ Organizations
- 41 States
- 4 Canadian Provinces
- 3 Indian Nations
- Total of 34% cost share
Regional Partnerships
Addressing Key Issues

- Geologic capacity estimates
- Site selection criteria
- Reservoir modeling and validation
- Monitoring, mitigation, and verification (MMV)
- Operational considerations
- Economics of sequestration
- Develop Best Practice Management Plans (BPMP)
Regional Partnership Update
“Developing the Infrastructure for Wide Scale Deployment”

Phase I (Characterization)
- 7 Partnerships (40 states)

Phase II (Field Validation)
- 4 years (2005–2009)
- All seven Phase I partnerships continued
- $100 million federal funds
- $45 million in cost share

Phase III (Deployment)
- 10 years (2008-2017)
- Large Scale Injection Tests in Different Geology
- Injection rates up to one million tons per year for several years
Phase I Highlights

- Thousands of Years of Storage Capacity Identified during Characterization Phase
  - Coal Seams and Shales - ~18 GT
  - Oil and Gas Reservoirs - ~27 GT
  - Saline Formations - >5,000 GT

- Value Added Products in Potential Sinks
  - Oil – 16 billion barrels of oil during sequestration in favorable fields
  - Coal Seams – 126 TCF CBM during sequestration in unmineable coal seams

- NATCARB and Regional Atlases Available Online
Regional Carbon Sequestration Partnerships
Phase II Geologic Field Tests

Injecting between 1,000 – 525,000 tons of CO₂

Over 300 Organizations
In Addition to Geologic - 10 Terrestrial Test
## Projects that are part of the Regional Carbon Sequestration Partnership

<table>
<thead>
<tr>
<th>Partnership</th>
<th>Geologic Province</th>
<th>Total CO₂ Injection (tons CO₂)</th>
<th>Approximate Depth (ft)</th>
<th>Partnership</th>
<th>Geologic Province</th>
<th>Total CO₂ Injection (tons CO₂)</th>
<th>Approximate Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRCSP</td>
<td>Paradox Basin</td>
<td>525,000</td>
<td>5,800</td>
<td>PCOR</td>
<td>Williston Basin</td>
<td>3,000</td>
<td>&gt;500</td>
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<tr>
<td>SRCSP</td>
<td>Permian Basin</td>
<td>300,000</td>
<td>5,700</td>
<td>SECARB</td>
<td>Mississippi Salt Basin</td>
<td>3,000</td>
<td>7,500</td>
</tr>
<tr>
<td>PCOR</td>
<td>Keg River Formation</td>
<td>250,000</td>
<td>4,900</td>
<td>MGSC</td>
<td>Illinois Basin</td>
<td>2,500</td>
<td>1,200-2,800</td>
</tr>
<tr>
<td>SRCSP</td>
<td>San Juan Basin</td>
<td>75,000</td>
<td>3,000</td>
<td>MGSC</td>
<td>Illinois Basin</td>
<td>2,500</td>
<td>Up to 3,150</td>
</tr>
<tr>
<td>MGSC</td>
<td>Illinois Basin</td>
<td>10,000</td>
<td>5,000-10,000</td>
<td>MGSC</td>
<td>Illinois Basin</td>
<td>2,500</td>
<td>2,800-3,150</td>
</tr>
<tr>
<td>MRCSP</td>
<td>Cincinnati Arch</td>
<td>10,000</td>
<td>8,000-10,000</td>
<td>MGSC</td>
<td>Illinois Basin</td>
<td>2,500</td>
<td>2,800-3,150</td>
</tr>
<tr>
<td>MRCSP</td>
<td>Michigan Basin</td>
<td>10,000</td>
<td>4,000</td>
<td>SRCSP</td>
<td>Paradox Basin</td>
<td>2,000</td>
<td>6,000</td>
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<tr>
<td>MRCSP</td>
<td>Appalachian Basin</td>
<td>10,000</td>
<td>2,500-4,000</td>
<td>WESTCARB</td>
<td>Central Valley CA</td>
<td>2,000</td>
<td>5,000</td>
</tr>
<tr>
<td>SECARB</td>
<td>Gulf Coast</td>
<td>7,500</td>
<td>8,000</td>
<td>WESTCARB</td>
<td>Central Valley CA</td>
<td>2,000</td>
<td>4,000</td>
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<tr>
<td>SECARB</td>
<td>Gulf Coast</td>
<td>7,500</td>
<td>10,000</td>
<td>WESTCARB</td>
<td>Kaiparowits Basin</td>
<td>2,000</td>
<td>8,000</td>
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<tr>
<td>Big Sky</td>
<td>Grand Ronde Basalt</td>
<td>3,000</td>
<td>2,700</td>
<td>SECARB</td>
<td>Central Appalachian</td>
<td>1,000</td>
<td>1,000</td>
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<tr>
<td>PCOR</td>
<td>Duperow Formation</td>
<td>3,000</td>
<td>1,000</td>
<td>SECARB</td>
<td>Black Warrior Basin</td>
<td>1,000</td>
<td>2,300-5,000</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>MGSC</td>
<td>Illinois Basin</td>
<td>750</td>
<td>1,000</td>
</tr>
</tbody>
</table>
NETL, RCSPs, and NATCARB worked together to establish common assumptions and methodologies for CO\textsubscript{2} capacity estimates.


Three types of geologic formations:
- Oil and gas reservoirs
- Unmineable coal seams
- Deep saline formations

Capacity estimates produced using these methodologies are based on technically available capacities that have not been reduced by economic constraints, land use, or regulatory constraints.
Oil and Gas Reservoirs

- Mature oil and gas reservoirs held crude oil and natural gas over millions of years
- Layer of permeable rock with dome shaped layer of non-permeable rock (caprock)
- Value added benefit - CO₂ can enable incremental oil to be recovered - EOR
- CO₂ allows recovery of additional 10-15% of OOIP

**CO₂ Capacity Estimates by Partnership**

<table>
<thead>
<tr>
<th>Partnership</th>
<th>Billion Metric Tons of CO₂</th>
<th>Billion Tons of CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIG SKY</td>
<td>0.75</td>
<td>0.83</td>
</tr>
<tr>
<td>MGSC</td>
<td>0.44</td>
<td>0.49</td>
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<tr>
<td>MRCSP</td>
<td>2.50</td>
<td>2.80</td>
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<tr>
<td>PCOR</td>
<td>19.60</td>
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<tr>
<td>SECARB</td>
<td>32.40</td>
<td>35.70</td>
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<tr>
<td>SOUTHWEST</td>
<td>21.40</td>
<td>23.60</td>
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<tr>
<td>WESTCARB</td>
<td>5.30</td>
<td>5.80</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>82.39</strong></td>
<td><strong>90.82</strong></td>
</tr>
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</table>
Unmineable Coal Seams

- Unmineable coal seams are too deep or too thin to be mined economically.
- Coalbed methane (CBM) can be recovered by sweeping the coalbed with CO₂.
- Depending on the rank of the coal, 3-13 molecules of CO₂ adsorbed for each molecule methane released.

**CO₂ Capacity Estimates by Partnership**

<table>
<thead>
<tr>
<th>Partnership</th>
<th>Low</th>
<th>High</th>
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<tbody>
<tr>
<td></td>
<td>Billion Metric Tons of CO₂</td>
<td>Billion Tons of CO₂</td>
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<tr>
<td>BIG SKY</td>
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<tr>
<td>MGSC</td>
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<td>2.5</td>
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<td>MRCSP</td>
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<td>SECARB</td>
<td>57.4</td>
<td>63.3</td>
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<td>SOUTHWEST</td>
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<td>WESTCARB</td>
<td>86.8</td>
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<td>Total</td>
<td>156.1</td>
<td>172.6</td>
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Deep Saline Formations

- Saline formations are layers of porous rock that are saturated with brine
- Represent enormous potential for CO₂ storage
- Saline formations contain minerals that can react with injected CO₂ to form solid carbonates over a long period of time

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
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</thead>
<tbody>
<tr>
<td>BIG SKY</td>
<td>271</td>
<td>1,085</td>
</tr>
<tr>
<td>MGSC</td>
<td>29</td>
<td>115</td>
</tr>
<tr>
<td>MRCSP</td>
<td>47</td>
<td>189</td>
</tr>
<tr>
<td>PCOR</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>SECARB</td>
<td>360</td>
<td>1,440</td>
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<tr>
<td>SOUTHWEST</td>
<td>18</td>
<td>64</td>
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<tr>
<td>WESTCARB</td>
<td>76</td>
<td>304</td>
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<tr>
<td><strong>Total</strong></td>
<td>898</td>
<td>3,294</td>
</tr>
</tbody>
</table>

CO₂ Capacity Estimates by Partnership (Billion Metric Tons of CO₂ and Billion Tons of CO₂)
## CO₂ Sources and Storage Potential

### CO₂ Capacity Estimates by Partnership

#### Deep Saline Formations

<table>
<thead>
<tr>
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#### Unmineable Coal Seams

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<td>MGSC</td>
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#### Oil and Gas Reservoirs

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<tr>
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<tr>
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<tr>
<td>MRCSP</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>PCOR</td>
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<td>8.0</td>
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<td><strong>Total</strong></td>
<td>156.1</td>
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---

**Note:** The maps and tables above illustrate the CO₂ capacity estimates by partnership for different storage formations: deep saline formations, unmineable coal seams, and oil and gas reservoirs. The data shows the estimated capacity in billion metric tons of CO₂ for each partnership.
DOE releases the first version of the Carbon Sequestration Atlas of the U.S. and Canada

Result of cooperation and coordination among carbon sequestration experts from local, state, and government agencies, as well as industry and academia

Atlas presents the first coordinated assessment of carbon capture and storage (CCS) potential across the majority of the U.S. and portions of western Canada

Atlas provides introduction to CCS process, summarizes DOE’s Carbon Sequestration Program, and gives information about the CCS contributions from each Regional Carbon Sequestration Partnership (RCSP)

All data were collected before December 2006

Data sets are not comprehensive, however, it is anticipated that CO₂ capacity estimates and formation maps will be updated as new data are acquired
Sequestration Program Statistics FY2007

Strong industry support
~ 39% cost share on projects

Federal Investment to Date
~ $360 Million

Fiscal Year

Diverse research portfolio
~ 70 Active R&D Projects

House: $131.6 MM  Senate: $132 MM

FY2007 Budget

Regional Partnerships 48%
Cross-cutting 10.5%
Capture of CO2 14%
Non-CO2 GHG Mitigation 1%
Storage 13%
Breakthrough Concepts 2%
CDP/Asia-Pacific 4.5%
MMV 7%
Regulatory Framework for Injection of CO$_2$ into Geologic Formations Underway

- EPA to propose regulations under the Safe Drinking Water Act Underground Injection Control (UIC) Program
- Workshop held Dec. 2007
- 2$^{nd}$ Workshop in February 2008
- Proposed Rule – July 2008
- Public Comment Period for Proposed Rule – July-October 2008
- Notice of Data Availability (if appropriate) – 2009
- Final UIC Rule for Geologic Sequestration of CO$_2$ – late 2010/early 2011
Geologic Sequestration Is Already Under Way

- Statoil injects $1 \times 10^6$ tons per year at Sleipner
- BP to inject $0.8 \times 10^6$ tons per year at In Salah
- EnCana EOR project with CO$_2$ storage in the Weyburn field
Combining CO₂ storage research with oil production
Assess long term fate of CO₂ sequestered via EOR
200-mile CO₂ pipeline from Dakota Gasification Plant

- 4 year monitoring project using latest modeling & geophysical techniques
- Injecting 1 million metric ton CO₂ per year for 20 years
- Equivalent to ~ 150 MW average, coal power plant

Participants: EnCana, Apache, IEA GHG Programme (DOE)
<table>
<thead>
<tr>
<th>Project Name</th>
<th>Total CO₂ Injection (tons CO₂)</th>
<th>Formation Depth (m)</th>
<th>Geologic Province</th>
<th>Partnership</th>
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<td>TBD/TBD</td>
<td>2004</td>
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</table>

**Legend**
- **Project Name**: Total CO₂ injection, tons CO₂, Formedation depth/thickness, inches
- **Storage formation**
  - Green: Oil field
  - Red: Gas field
  - Blue: Saline aquifer
  - Pink: Coal seam
  - Yellow: Shale
- **Project size (total CO₂ injection)**
  - Commercial (greater than 1 MMtCO₂)
  - Large pilot (100 ktCO₂ to 1 MMtCO₂)
  - Pilot (11 ktCO₂ to 99 ktCO₂)
  - Micro-pilot (10 ktCO₂ or less)

* Assumed minimum project life of 10 years
## Worldwide CO₂ Storage Projects

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Injection Start Date</th>
<th>Total CO₂ Injection (tons CO₂)</th>
<th>Approximate Depth (ft)</th>
<th>Project Name</th>
<th>Injection Start Date</th>
<th>Total CO₂ Injection (tons CO₂)</th>
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<td></td>
<td>RECOPOLE</td>
<td>2003</td>
<td>10</td>
<td>3,600</td>
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</table>
Worldwide Geologic Storage Capacity
(Thousands of Years of Potential Storage Capacity)

Storage Options

Deep Saline Formations
Depleted Oil & Gas Fields
Coal Seams

Capacity (Gigaton CO₂)

0 200 400 600 800 1,000 1,200 1,400

200,000

Maximum Capacity Potential

Annual World Emissions

24 Gigatons CO₂

Storage Options: IEA Technical Review (TR4), March 23, 2004
World Emissions: DOE/EIA, International Energy Outlook 2003, Table A10
CSLF Members

CSLF Member Countries represent:

- 58% of world population
- 70% of world energy production
- 75% of world energy consumption
- 76% of world CO$_2$ emissions
- 76% of world GDP

Sources: IMF (GDP 2005 data) and EIA (2004 data)
Carbon Sequestration Leadership Forum

- An international climate change initiated focused on development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage
- Established: June 2003
- Member Nations: 21 plus EU
- Registered Stakeholders: 100
- Active Projects: 17
- Completed Projects: 2
- Organizational/Operational data at www.cslforum.org
International Energy Agency Greenhouse Gas
(IEA GHG) R&D Programme

- IEA GHG works to improve understanding of how to:
  - Reduce emissions of greenhouse gasses from power plants and other sources
    - Organized in 1991
    - Carries out technical and economic evaluations of technology
    - Estimates costs on transparent, consistent, and comparative basis
    - Identifies technology gaps and duplications of effort on global basis
    - Maintains awareness of progress and developments
  - Sponsored by 15 countries, the European Commission, and 15 industrial sponsors
  - Organizational/Operational data at www.ieagreen.org.uk
# International Energy Agency Greenhouse Gas (IEA GHG) Participation

IEA GHG brings together contributions and perspectives of its national and industrial representatives involve both developed and developing countries.

<table>
<thead>
<tr>
<th>Countries</th>
<th>Industries</th>
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<td>Australia</td>
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<td>Total</td>
</tr>
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<td>United States of America</td>
<td>Vatten Fall</td>
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</tbody>
</table>
FutureGen Project

Key Features

- Commercial-scale 275-MWe plant
- 1 million tons/year CO₂ captured and sequestered
- Co-production of H₂ and electricity
- “Living laboratory” to test and validate cutting-edge technologies
- Public-private partnership
- Stakeholder involvement
- International participation
FutureGen Membership

- FutureGen Industrial Alliance
  - American Electric Power
  - Anglo American
  - BHP Billiton
  - China Huaneng Group
  - Consol Energy
  - E.ON
  - Foundation Coal
  - Luminant
  - Peabody Energy
  - PPL Corporation
  - Rio Tinto
  - Southern Company
  - Xstrata Coal

- International Government Participation
  - United States
  - India
  - South Korea
  - Continuing discussions with other interested parties
FutureGen Project

Value Proposition

- Supports a technology-based climate change strategy
  - Mitigates the financial risks of climate change
- Validates the cost and performance of an integrated near-zero emission coal-fueled power plant
  - Advances IGCC technology
  - Advances carbon capture, sequestration, and hydrogen production technologies
  - Sets groundwork for CO₂ sequestration siting and licensing
- Creates the technical basis to retain coal in U.S. energy mix with a long-term goal of zero emissions
- Enables the public and private sector to share the cost and risk of advanced technology demonstration
  - Platform for emerging technology demonstration
Summary

- Hydrogen from coal can play a key role in the future hydrogen economy and contribute to GHG emission reductions.
- When used in tandem with carbon sequestration, the central station production of hydrogen from coal would result in virtually no greenhouse gas and pollutant emissions.
- Hydrogen from Coal R&D Program will reduce production costs and can provide technology to test in FutureGen.
  - Goals are to reduce cost and complexity of processes, 25% cost reduction in hydrogen production cost is achievable.
- Initial bench-scale success in H₂ separation membranes shows progress toward 2015 technical targets.
- Alternative production pathway provides options and contributes to liquid-carriers and SNG technology.
Summary

- Current knowledge strongly supports carbon sequestration as a successful technology to dramatically reduce CO₂ emissions
  - Current science and technology gaps appear resolvable
- Deployment issues, including regulatory, legal, and operational concerns, can be addressed through development of operational protocols advised by science
- Large-scale tests are crucial to understanding successful deployment of carbon capture and sequestration and creating appropriate policy/economic structures
  - No test to date is sufficient with respect to scale, duration, monitoring, and analysis
More Information

- Hydrogen from Coal RD&D Plan

- FutureGen

- NETL Hydrogen from Coal Website

- DOE/FE Carbon Sequestration Program

- NETL Carbon Sequestration Program