U.S. Department of Energy
Office of Fossil Energy

Central Plant Technologies and Carbon Capture Utilization and Storage (CCUS)
What’s the Future

Regis K. Conrad
Director, Division of Cross-cutting Research
Meeting the President’s Energy Goals

“This country needs an all-out, all-of-the-above strategy that develops every available source of American energy. A strategy that’s cleaner, cheaper, and full of new jobs.”

President Barack Obama
State of the Union Address
January 24, 2012

Photo courtesy of the White House, Pete Souza
Advanced 2nd Generation CCS and Transformational Capture Technologies

Lower Cost, Higher Efficiency

- Post-combustion (existing, new PC)
- Pre-combustion (IGCC)
- Oxy-combustion (new PC)
- CO₂ compression (all)

1st Generation physical solvents (CCPI)
1st Generation chemical solvents (CCPI)
Adv. CO₂ compression

- Amine solvents
- Physical solvents
- Cryogenic oxygen

2nd Generation Solvents
H₂ and CO₂ Membranes
Oxygen Membranes

- Chemical looping
- 2nd Gen. Oxyboiler
- Biological processes
- Solid Sorbents

Cost Reduction Benefit

2010 2015 2020

Ready for Demonstration
U.S. Energy Challenges

Energy Security

Monthly Spot Price OK WTI

Competitiveness

Global Lithium-ion Battery Manufacturing (2009)

Environmental Impacts

CO₂ Emissions in OECD vs. non-OECD Countries

Water Withdrawals in % By Category (2005)

Worldwide Shipments of Solar Photovoltaics (MW)

Thermoelectric Power

Share of Reserves Held by NOC/IOC

- Reserves to which International Oil Companies have Full Access: 6%
- Reserves Held by New Russian Companies: 6%
- Reserves Held by National Oil Companies (equity access): 10%
- Reserves Held by National Oil Companies (limited equity access): 78%
Technology Headroom for DOE

Building and Industrial Efficiency
- Data collection and usage
- Integrated systems analyses
- Next-gen processes and products

Grid Modernization
- Communication and data
- Management and control
- Energy storage

Clean (Low-Carbon) Power
- Drive down costs
- Improve Plant Efficiency
  - Advanced Materials
  - Sensors and Controls
- Coupling between energy and water use
Fossil Energy: Helping Achieve DOE’s Mission

**Transform Our Energy Systems**
- Cost-competitive carbon capture, utilization, and storage technology
- Advanced modeling and simulation to reduce upfront cost, risk of CCUS
- Increased efficiency for cleaner use of coal.
- Safe and sustainable development of unconventional oil and gas resources
- International partnerships for clean energy deployment

**Science & Engineering Enterprise**
- Undergraduate, graduate and post-graduate research and internship support

**Secure Our Nation**
- Technology innovation allowing fossil fuels to continue to be part of a diversified, low-carbon energy portfolio
- Strategic Petroleum Reserve and Northeast Home Heating Oil Reserve at full readiness

**Management & Operational Excellence**
- FE-wide business review assessment for mission success
## Times Have Changed

### Then

**2009**
- Strong likelihood of cap-and-trade legislation.
- EOR applications seen as niche opportunity to offset some cost;
- Oil $50 - $60/barrel;
- CCS storage focus with CO₂ tax support.
  
  **Goal by 2020:** + 35% LCOE

### Now

**2012**
- Cap-and-trade legislation unlikely in the near term.
- No deadlines for utilities, no reason to invest in carbon capture and storage.
- Oil more expensive = $100/barrel; global competition stronger.
- CCUS has been successfully developed in FE demos.

**Current Capture Cost:** $70-90/Ton  
**Goal by 2020:** $40/Ton

*Carbon Capture Cost can support a long-term business case to invest.*

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LCOE: Levelized Cost of Electricity
Clean Coal - Major U.S. Demonstrations

- Large-Scale Geologic CO₂ Storage
- CO₂ Capture from Industrial Facilities
- Post-Combustion Capture with Enhanced Oil Recovery
- IGCC with Enhanced Oil Recovery
- Oxy-combustion
- Monitoring, Verification, and Accounting (MVA)
- IGCC with CO₂ Capture (to pipeline)

Advanced Technology for Carbon Capture, Utilization and Storage
Clean Coal - Major U.S. Demonstrations

- Hydrogen Energy California
  - IGCC with EOR
  - $408 Million - DOE
  - $4.0 Billion - Total

- Summit Texas Clean Energy
  - IGCC with EOR
  - $450 Million - DOE
  - $1.7 Billion - Total

- NRG Energy
  - Post Combustion with CO₂ Capture and EOR
  - $167 Million – DOE
  - $339 Million - Total

- Air Products
  - CO₂ Capture from Steam
  - Methane Reformers with EOR
  - $284 Million - DOE
  - $431 Million - Total

- FutureGen 2.0
  - Oxy-combustion with CO₂ capture
    - (saline injection)
  - $1.0 Billion - DOE
  - $1.3 Billion - Total

- Southern Company Services
  - IGCC-Transport Gasifier
    - (CO₂ to pipeline)
  - $270 Million - DOE
  - $2.67 Billion - Total

- Leucadia
  - CO₂ Capture from Methanol
    - with EOR
  - $261 Million - DOE
  - $436 Million - Total

- Archer Daniels Midland
  - CO₂ Capture from Ethanol
    - (saline injection)
  - $141 Million - DOE
  - $208 Million - Total

- FutureGen

- CCPI Round II

- CCPI Round III

- ICCS (Area I)
Regional Carbon Sequestration Partnerships

**Phase III: Development**

- Large-volume tests
- One injection commenced April 2009; another in November 2011
- Remaining injections scheduled 2012-2015

<table>
<thead>
<tr>
<th>Partnership</th>
<th>Target Injection Volume (tonnes)</th>
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<tr>
<td>1 Big Sky</td>
<td>1,000,000</td>
</tr>
<tr>
<td>2 MGSC</td>
<td>1,000,000</td>
</tr>
<tr>
<td>3 MRCSP</td>
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<tr>
<td>4 PCOR</td>
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</tr>
<tr>
<td>6 SECARB</td>
<td>2,402,000</td>
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<tr>
<td>7 SWP</td>
<td>1,000,000</td>
</tr>
<tr>
<td>9 WESTCARB</td>
<td>TBD</td>
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</tbody>
</table>

- Injection Started April 2009
- Injection began November 2011
- Injection Well Drilled
- Injection Well Initiated
- Large-volume tests
- Reservoir modeling initiated
- Characterization Well Initiated
- Core Sampling Taken

Note: Some locations presented on map may differ from final injection location.
Addressing Storage Challenges: Regional Carbon Sequestration Partnerships

- Large-scale injection wells
- Establishing monitoring and verification protocols.
- Addressing regulatory, environmental, and outreach issues.
- Establishing Best Practices
- Assessing risks
- Validating sequestration technology and infrastructure.
- Engaging regional, state, and local governments

Note: Some locations presented on map may differ from final injection location.
Carbon Capture Utilization and Storage R&D program
Key Gasification R&D Areas

Oxygen Membrane
- Hot Compressed Air
- Lean Air
- Oxygen
- Reduces Capital Cost by 25% and 5.0% reduction in COE

Warm Gas Cleaning
- Efficiency increases by 2.9 %pt
- COE decreases by 12.0%

Fuel Gas

Water-Gas Shift*
- Process improvement and intensification

H₂/CO₂ Membrane

H₂ Rich Stream

CO₂

Low-rank Coal*
- Energy security
- Carbon footprint reduction

Alternative Feedstocks*

Low-rank Coal*
- Energy security
- Carbon footprint reduction

Alternative Feedstocks*

Improve RAM*
- Refractory durability
- Feed system reliability
- Heat removal/integration
- Temperature measurement & control

Dynamic simulator
- CFD gasifier modeling
- Slag model development

* Advanced Gasification
Combustion System
Pulverized Coal with CCS

Boilers
- Compact Boiler Designs
- Advanced Materials (USC)
- Advanced Burners
- Sensors/Controls

Advanced Compression
- Supersonic Compression
- High Pressure Turbo Pump
- Enhanced Compressor Design

Post Combustion Capture
- Multi-pollutant capture
- Advanced Sorbents
- Advanced Membranes

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Combustion System
Oxycombustion with CCS

Advanced Process Integration
- Reduce CO₂ Recycle
- High Temperature Materials
- Efficient Water Use
- Sensors and Controls

CO₂ Purification
- 2 Stage Purification
- Removes SOₓ, NOₓ, O₂, inert
- Smaller Compression Plant

Oxyfuel Boiler
Elevated Pressure Combustion

Oxygen Plant
Reduce Cost and Load

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Advanced IGCC Systems
Driving Down the Cost

Efficiency (% HHV)

First-Year COE ($/MWh)

Cost of CO₂ Removed ($/tonne)

Current State-of-the-Art
- Coal Pump
- 85% Availability
- Warm Gas Cleanup
- Hydrogen Membrane
- Adv. H₂ Turbine
- Ion Transport Membrane
- Conventional Financing

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CO₂ transport, storage and monitoring cost

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### Advanced Gasification Fuel Cell Systems

**Driving Down the Cost**

#### Efficiency (% HHV)

- IGFC with Carbon Capture
- Supercritical PC without capture
- IGCC with capture

#### First-Year COE ($/MWh)

- IGFC with Carbon Capture
- Supercritical PC without capture
- IGCC with capture

#### Cost of CO₂ Removed ($/tonne)

- IGFC with Carbon Capture
- Relative to Supercritical PC without capture

**CO₂ transport, storage and monitoring cost**

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Low Cost Combustion Power Solutions

\[ \downarrow \text{Power Cost and} \uparrow \text{CCUS Potential} \]

**Levelized COE ($/MWh)**

- A – Supercritical PC w/Current Amine Scrubbing
- B – Ultrasupercritical PC w/Current Amine Scrubbing
- C – USC PC w/Amine + Advanced Compression
- H – Advanced Oxycombustion Power Cycles

**Cost of CO\(_2\) Removed ($/tonne)**

- Relative to Supercritical PC without capture

*USC = Ultra-supercritical PC (5,000 psig/1,200°F/1,200°F)
*Adv. USC PC = 5,000 psig/1,350°F/1,400°F

Advanced Power Systems Enable CCUS Opportunities
Carbon Storage Program – Core R&D

Monitoring, Verification, and Accounting
- Atmospheric and Remote Sensing Technologies
- Near surface monitoring of soils and vadose zone
- Subsurface monitoring in and near injection zone
- Intelligent monitoring systems for field management

Geologic Storage
- Wellbore construction and materials technologies
- Mitigation technologies for wells and natural pathways
- Managing fluid flow, reservoir pressure, and brines
- Geochemical effects of CO₂ injection
- Geomechanical effects on reservoirs and seals

CO₂ Utilization
- Enhanced Oil Recovery
- Conversion to commodities into chemicals and plastics
- Non-geologic storage in cement and minerals
- Beneficial use of produced waters

Simulation and Risk Assessment
- Thermal and hydrologic fate and transport
- Geochemical simulations
- Geomechanical simulations
- Predicting biologic impacts on storage formations
- Risk assessment and quantification

Image Background Source: Courtesy of Schlumberger
Carbon Capture Simulation Initiative (CCSI) and National Risk Assessment Partnership (NRAP)

Science-Based Computational Tools for Accelerating CCS Technology Development & Deployment

First Principles

Identify promising concepts

Develop optimal designs

Quantify technical risk in scale-up

Accelerate learning during development & deployment
The “Un-Mined Gold” Story for Energy and Jobs

Benefits\(^1\) of CO\(_2\)-EOR:

- $10 trillion in economic activity over 30 years;
- 2.5 million jobs
- 30 – 40 percent reduction in imported oil

\(^1\) Source: U.S. Carbon Sequestration Council
EOR – How It Works

- Oil in reservoir
- Injected CO₂ encounters oil
- CO₂ remains in reservoir
- Oil expands and moves toward producing well

Produced Fluids (Oil, Gas and Water Separation and Storage Facilities)

Injection Well

Water Injection Pump

Carbon Dioxide

Production Well
Parting Thoughts

- **Energy Security:** Promote U.S. energy security by increasing domestic oil production and reducing imports.
- **Jobs:** Create millions of new high paying jobs in the energy and related sectors.
- **Revenues:** Provide trillions of dollars of new domestic revenues and economic activity.
- **Trade:** Improve the U.S. balance of trade by significant reductions in oil imports.
- **CCS and Climate Change Impact:** Help achieve a meaningful and significant reduction in U.S. CO₂ emissions through safe and permanent geologic storage for EOR operations.