26th Annual Conference on Fossil Energy Materials

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Integrated Coal Program Technology Roadmap

Cross-cutting Research

CCUS R&D & Computational Analysis

CCUS Demonstration (Combustion, Gasification, Industrial)

Materials, sensors, controls & computational tools – a continuum of supporting science & crosscutting technology

Large Scale CO₂ Injection

Post Injection MVA

Integrated 1st Generation Technology (SOTA CO₂ 70-90 $/tonne)

CCUS 2nd Generation Component Technology – ready for Demonstration (CO₂ 30-50 $/tonne)

CCUS Transformational Technology – ready for Demonstration (CO₂ <25 $/tonne)

Storage Best Practice Manuals and Protocols available to facilitate wide scale deployment

1st Generation

2nd Generation

Design

Construction

Operation

Commercial Deployment

Transformational Technology

Storage Best Practice Manuals and Protocols available to facilitate wide scale deployment

Design

Construction

Commercial Deployment

Commercial Deployment

Commercial Deployment

Commercial Deployment

Commercial Deployment
U.S. Energy Challenges

**Energy Security**
- Monthly Spot Price OK WTI

**Competitiveness**
- Global Lithium-ion Battery Manufacturing (2009)
- China: 25%
- South Korea: 27%
- Japan: 46%
- Other: 2%

**Environmental Impacts**
- CO₂ Emissions in OECD vs non-OECD Countries
- Water Withdrawals in % By Category (2005)
- Thermoelectric Power
  - Public supply: 11%
  - Domestic: 31%
  - Irrigation: 1%
  - Livestock: 1%
  - Aquaculture: 2%
  - Industrial: 4%
  - Mining: 1%
Technology Headroom for DOE

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

Clean (Low-Carbon) Power
- Drive down costs
- Improve Plant Efficiency
  - Advanced Materials
  - Sensors and Controls
- Coupling between energy and water use

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

LCOE: Levelized Cost of Electricity

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.
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 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

**Atmospheric and Remote Sensing Technologies**
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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

CFD → Process Simulation → Commercial Plants

NRAP

NETL

Berkeley Lab

Los Alamos National Laboratory

Lawrence Livermore National Laboratory

Pacific Northwest National Laboratory

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CO$_2$-Enhanced Oil Recovery

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

Domestic Oil Supplies and CO$_2$ Demand (Storage) Volumes from “Next Generation” CO$_2$-EOR Technology**
Materials Performance in CO$_2$ and CO$_2$-Steam Environments

• Evaluate oxidation/corrosion performance of metallic structural alloys in pure CO$_2$ and in CO$_2$-steam environments over a wide temperature range

• Establish the kinetics of scaling and internal penetration, if any, and develop correlations for long term performance

• Identify viable alloys for structural and gas turbine applications Evaluate the influence of exposure environment on the mechanical properties (especially creep, fatigue, and creep-fatigue) of the candidate alloys
Breakthrough Concepts Direction

• Computational Materials Design with Experimental Verification

Combine computational materials development with experimental verification to engineer new high performance materials
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.
Questions
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

- 2nd Gen. 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
EOR – How It Works

Oil in reservoir

 Injected CO₂ encounters oil

 CO₂ remains in reservoir

Oil expands and moves toward producing well
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

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

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

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

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

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

**FutureGen**:
- FutureGen

**CCPI Round II**:
- CCPI Round II

**CCPI Round III**:
- CCPI Round III

**ICCS (Area I)**: ICCS (Area I)

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R&D program
Advanced IGCC Systems
Driving Down the Cost

Efficiency (% HHV)

First-Year COE ($/MWh)

Cost of CO₂ Removed ($/tonne)

CO₂ transport, storage and monitoring cost
Advanced Gasification Fuel Cell Systems
Driving Down the Cost

Efficiency (% HHV)

First-Year COE ($/MWh)

Cost of CO₂ Removed ($/tonne)

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

CO₂ transport, storage and monitoring cost
Low Cost Combustion Power Solutions
\(\downarrow\) Power Cost and \(\uparrow\) CCUS Potential

Levelized COE ($/MWh)

- **Post-Combustion**
- **Oxycombustion**

A – Supercritical PC w/Current Amine Scrubbing
C – USC PC w/Amine + Advanced Compression

B – Ultrasupercritical PC w/Current Amine Scrubbing
H – Advanced Oxycombustion Power Cycles

*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

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

Relative to Supercritical PC without capture

- **Post-Combustion**
- **Oxycombustion**

CO\(_2\) transport, storage and monitoring cost