U.S. Department of Energy
Office of Fossil Energy
Carbon Capture, Utilization, and Storage

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U.S. Department of Energy, Office of Clean Coal and Carbon Management
Algae Biomass Summit; October 1, 2014
IEA CCS Roadmap 2013: Key Technologies for Reducing Global CO₂ Emissions

This requires an “all of the above” strategy

Source: IEA Roadmap 2013.
Note: Numbers in brackets are shares in 2050. For example, 14% is the share of CCS in cumulative emission reductions through 2050, and 17% is the share of CCS in emission reductions in 2050, compared with the 6DS.
President’s Climate Action Plan: Three overarching themes

Mitigation (emissions reduction)
• ALL OF THE ABOVE
• Efficiency, Renewables, Nuclear, Gas
• Coal with CCS/CCUS

Adaptation and resilience
• Smart, reliable grid
• Key infrastructure investments

International Partnerships
• China and OECD
• Coordinated international efforts
Office of Fossil Energy

Office of Clean Coal and Carbon Management

Office of Oil and Gas

Strategic Petroleum Reserves

National Energy Technology Laboratory

(Not to scale)
## Electric Utility Sector & EPA Regulations

<table>
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<tr>
<th>Issue</th>
<th>Federal Regulation/Compliance</th>
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| **Air** | **SO\textsubscript{x} & NO\textsubscript{x} crossing state lines** | Cross-State Air Pollution Rule (CSAPR) finalized 7/7/2011; 12/30/2011, DC Circuit stay of CSAPR (CAIR in effect); 8/21/2012, DC Circuit decision vacating CSAPR; SCOTUS overturned, EPA Review Pending  
*Compliance: Unknown* |
| | **Mercury and Air Toxics Standards (MATS) Rule for Electric Generation Units** finalized 12/16/2011  
*Compliance: ~2015* |
| **GHG emissions** | **GHG New Source Performance Standards (NSPS)** new rule proposed 9/20/2013  
**Existing GHG Regulation** proposed rule delivered 6/2014; final rule expected 6/2015 (under Presidential Memorandum)  
*Compliance: Unknown* |
| **Waste** | **Coal Combustion Residuals (CCR) Rule** proposed rule 6/10/2010; schedule for final rule expected 1/2014 (court memorandum)  
*Compliance: Unknown* |
| **Water** | **Cooling Water Intake Structures – impact on aquatic life**  
CWA §316(b) Rule proposed rule 4/20/2011; final rule delivered 5/2014 (settlement agreement)  
*Compliance: Within 8 Years* |
| | **Surface water discharges; Surface impoundments**  
Steam Electric Effluent Limitations Guidelines proposed rule expected 11/2012; final rule expected 5/22/2014 (settlement agreement)  
*Compliance: Unknown* |

- Near-term (through 2015-2016) Compliance Horizon for EPA regulations may create potential localized reliability issues
- Local reliability issues can be managed with timely notice and coordination on retirement and retrofit decisions
- States and regions will play a valuable role in addressing EPA regulation impacts
- Non-transmission alternatives can help alleviate reliability impacts when/where available
- EPA regulations are only one aspect impacting the future of our electricity system
RD&D Investment Strategy

**Approaches**
- Technology Development
- Commercial Readiness
- Market Penetration

**Programs**

**RESEARCH & DEVELOPMENT**
- Core Coal and Power Systems R&D
- DOE – FE – NETL

**TECHNOLOGY DEMONSTRATION**
- FutureGen 2.0
- Clean Coal Power Initiative
- Industrial CCS
- DOE – FE – NETL

**FINANCIAL INCENTIVES**
- Tax Credits
- Loan Guarantees
- DOE – LGO – IRS
Carbon Capture, Utilization, and Storage

**Terrestrial Capture**
- CO₂ absorbed from air

**Terrestrial Storage**
- Trees, grasses, soils, algae

**Utilization**
- EOR
- Beneficial Reuse

**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

**Supercritical CO₂**
1/300 th of Atm. CO₂
Coal-Fired Power Plant

550 MW_net ≈ 18,400 TPD CO₂

-90% carbon capture
-Compress to 2200 psi
-Transport & store/utilize

Flue Gas
CO₂ 14.5 vol%
H₂O 8.7%
N₂ 74.1%
O₂ 2.5%

Post-combustion capture goes here
A technology pipeline for affordable CCS

We need more 2nd generation pilots!
Major CCS Demonstration Projects

**Project Locations & Cost Share**

- **FutureGen 2.0**
  - Large-scale Testing of Oxy-Combustion w/ CO₂ Capture and Sequestration in Saline Formation
  - Project: ~$1.65B – Total; ~$1.0B – DOE
  - SALINE – 1M MTPY 2017 start

- **Summit TX Clean Energy**
  - Commercial Demo of Advanced IGCC w/ Full Carbon Capture
  - ~$1.7B – Total, $450M – DOE
  - EOR – ~2.2M MTPY 2018 start

- **HECA**
  - Commercial Demo of Advanced IGCC w/ Full Carbon Capture
  - ~$4B – Total, $408M – DOE
  - EOR – ~2.6M MTPY 2019 start

- **Southern Company**
  - Kemper County IGCC Project
  - Transport Gasifier w/ Carbon Capture
  - ~$4.12B – Total, $270M – DOE
  - EOR – ~3.0M MTPY 2014 start

- **Air Products and Chemicals, Inc.**
  - CO₂ Capture from Steam Methane Reformers
  - EOR in Eastern TX Oilfields
  - $431M – Total, $284M – DOE
  - EOR – ~0.93M MTPY 2012 start

- **Archer Daniels Midland**
  - CO₂ Capture from Ethanol Plant
  - CO₂ Stored in Saline Reservoir
  - $208M – Total, $141M – DOE
  - SALINE – ~0.9M MTPY 2015 start

- **FutureGen 2.0**
  - Large-scale Testing of Oxy-Combustion w/ CO₂ Capture and Sequestration in Saline Formation
  - Project: ~$1.65B – Total; ~$1.0B – DOE
  - SALINE – 1M MTPY 2017 start
CO₂ Utilization

• Fossil Energy R&D Program supporting projects coupling CO₂ storage with Enhanced Oil Recovery (EOR)
  – “Value-added” proposition aimed at kick-starting CCS
• 5/7 major demonstration projects have an EOR component
• Small R&D program focused on CO₂ conversion
  – Mineralization, Chemicals Production, Biological capture (algae)
• Utilization approaches should:
  – Provide reasonable opportunities to reduce significant amounts of CO₂
  – Offset cost of CCS by providing value-added co-products
Benefits & Challenges of reusing CO$_2$

- **Improves Carbon Efficiency**
  - Utilize carbon twice
  - Significantly lower CO$_2$ emissions possible

- **In contrast to CCS:**
  - Minimizes primary energy penalty
  - Produces value-added products
  - Addresses mobile emissions
  - Provides revenue stream to offset the costs of CCS

- **Additional wedge for CO$_2$ emission reductions**
  - Can be a transitional technology for moving towards GHG emissions reductions and CCS
  - Large impact possible
  - Unexplored potential

- **Technologies unproven on large-scale**
  - Difficulty in integrating technologies with a full-scale power plant
  - Costly when scaled-up

- **Performance Uncertainty**
  - Existing technologies not good enough
  - Alternatives not well characterized

- **Non-Sustainable**
  - Carbon is not permanently stored

- **Could require a non-fossil energy source for CO$_2$ conversion**

- **Oversaturation of product markets due to large quantities of CO$_2$ which must be utilized**

- **CO$_2$ transportation issues**
Potential Algae Integration with CCS

- Pulverized Coal
  - Boiler Feed Water
  - NOx Control
  - Air Preheat
  - PM Control
  - Hg Control
  - Flue Gas
  - CO2 Capture System
  - N2 to Stack
  - Reduced quantities for transport and storage
  - Flue Gas
  - CO2 in Flue Gas
  - CO2 in Solution
  - G/L transfer
  - Algae Pond or PBR
  - L/L transfer
  - HCO3-
  - Algae Products
  - Make-Up Water containing nutrients
  - Waste Heat Recovery

- Bottom Ash
  - Boiler
  - Steam
  - Air

- Plant Wastewater
  - Feed Water
  - Steam
  - Boiler
  - Feed Water

- CO2 to Storage
Synergies with Existing CCUS R&D Program

- **Carbonic Anhydrase Development**
  - Akermin/Codexis, Novozymes
  - Accelerate CO\(_2\) hydration

- **CO\(_2\) Capture Solvent Development**
  - In particular, aqueous solvents such as carbonate/bicarbonate & amino acid salts (potential short-term storage & transport option)

- **Gas/Liquid Membrane Contactors**
  - GTI and others
  - Improved mass-transfer, as well as lower CO\(_2\) losses
  - CO\(_2\) enriched air

- **SLIP-STREAM TESTING ON COAL-DERIVED FLUE GAS**
  - National Carbon Capture Center (NCCC)

*Novel solvents, sorbents, and membrane materials could increase productivity and lower cost of biological CO\(_2\) conversion technologies*
Key Priorities

• Deliver large CCS projects to maximum scientific and technical benefit
• Provide key decision makers the technical and economic information needed for investment, regulation, and policy
• Support a diverse clean coal research program likely to bring to market large improvements in cost, efficiency, and performance
• Increase the pool of potentially viable technologies that can serve commercial and industrial needs
• Reduce the risk of technical failure for public investments
• Ensure excellence in program design and execution
• Find solutions to maximize carbon efficiency and offset costs of CCS
Acknowledgements

- Mike Matuszewski, NETL
- John Marano, JM Energy Consulting
- Erik Shuster, NETL

Thank You
Backup Slides
Carbon Capture Pathways

Pre-combustion capture pathway

Post-combustion capture pathway

Oxy-combustion capture pathway
Carbon Storage

Capture: Power plants and industrial sources
- Pre-combustion
- Post-combustion
- Oxyfired combustion

Storage: > 1km depth
- Porous & permeable units
- Large capacity
- Good seals and cap rock

Two main targets
- Saline formations (~2200 Gtons capacity in N. Am.)
- Enhanced oil recovery (~100 B bbls addl. recovery)
Regional Carbon Sequestration Partnerships

- Recognized as global leader and one of most ambitious CCS programs by IEAGHG Program
- Characterizing regional sources and sinks
- Valuable to process/development of scaling up CO₂ geologic storage projects
- Adding significantly to knowledge base of saline formations, depleted hydrocarbon, and their respective geologic storage
  - Detailed reservoir characterization, reservoir modeling, addressing risks and mitigation, major R&D investments in monitoring
- Key role in outreach and education on CCS to public, regulators, and stakeholders
- Initiating large scale CO₂ injection

Seven Regional Partnerships
400+ distinct organizations, 43 states, 4 Canadian Provinces

Phase I: Characterization Phase (2003-2005)
Phase II: Validation Phase (2005-2011)
Phase III: Development Phase (2008-2018+)
# Brief history and roadmap for CCS

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<th>Then</th>
<th>Now</th>
<th>Future (2030)</th>
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<td>CCS Program Initiated (1997)</td>
<td>Progress to Date</td>
<td>Broad Commercial Deployment</td>
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| **CCS R&D** | • Niche commercial efforts  
• 1930’s and 1970’s tech for capture  
• Little known for storage | • Much knowledge gained  
• Major tech development  
• Tools being developed and tested | • “Commercial toolbox” developed  
• Dramatic cost reductions  
• 1000’s of sites worldwide |
| **Storage Infrastructure/Field Tests** | • Little known outside of oilfield services  
• Sleipner project initiated | • Increased visibility;  
• Knowledge gained and lessons learned  
• 12 large projects world-wide | • Market frameworks in place  
• Novel regulatory mechanisms  
• Turnkey operation |