CO₂ BUILDING BLOCKS
ASSESSING CO₂ UTILIZATION OPTIONS

American Coal Council
Webcast October 12, 2016
Janet Gellicci, CEO
National Coal Council
The National Coal Council provides advice and recommendations to the Secretary of Energy on general policy matters relating to coal and the coal industry.

NCC is a Federal Advisory Committee organized under FACA legislation.
National Coal Council

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- Coal Conversion
- Utility Deregulation
- Climate & Clean Air Regulations
- Building New Coal Power Plants
- Industrial Coal Use
- CCUS for EOR
- Value of Existing Coal Fleet
- Fossil Forward: CCS Technologies
- Policy Parity for CCS
- CO₂ Building Blocks: CO₂ Utilization
LEVELING THE PLAYING FIELD | Policy Parity for Carbon Capture and Storage Technologies

NCC White Paper – November 2015
Request from Secretary Moniz

• Develop an expanded white paper assessing opportunities to advance commercial markets for carbon dioxide (CO$_2$) from coal-based power generation.

• Focus on profit-generating opportunities for CO$_2$ utilization, both for Enhanced Oil Recovery (EOR) and for non-EOR applications.

• Address the following questions:
  ▪ What is the extent to which commercial EOR and non-EOR CO$_2$ markets could incentivize deployment of CCS/CCUS technologies?
  ▪ What economic opportunity does deployment of commercial-scale CCS/CCUS technology represent for the U.S.?
Report Leadership

• NCC Chair – Mike Durham, Soap Creek Energy
• NCC Coal Policy Committee Chair – Deck Slone, Arch Coal
• NCC Report Chair – Kipp Coddington
  School of Energy Resources, University of Wyoming
• Report Chapter Leads
  ▪ Kipp Coddington, School of Energy Resources, Univ. of Wyoming
  ▪ Janet Gellici, National Coal Council
  ▪ Sarah Wade, Wade LLC
  ▪ Robert Hilton, Consultant
• Report Contributors +++
Report & Presentation Overview

• Factors Driving Demand for CO$_2$ Utilization
• Status of CO$_2$ Utilization Technologies
• Evaluation of CO$_2$ Utilization Technologies
• Opportunities to Incentivize CCUS Deployment
The Value of Coal

Source: BP Energy Outlook 2016

Source: International Energy Agency 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 60s.
• Fossil fuels are dependent upon CCUS technologies to comply with U.S. GHG emission reduction requirements.
  - PSD/Title V Permitting
  - GHG Performance Standards for New Coal Power
  - Clean Power Plan
  - International GHG Mitigation Goals
**Key Findings**

- Fossil fuels – including coal, natural gas and oil – will remain the dominant global energy source well into the future by virtue of their abundance, supply security and affordability.

- There is a growing consensus among industry, the environmental community and governments that future CO₂ emission reduction goals cannot be met by renewable energy sources alone and that CCUS technologies for all fossil fuels will have to be deployed to achieve climate objectives in the U.S. and globally and to ensure a reliable power grid.

- CCUS is not exclusively a “clean coal” strategy and will ultimately need to be adopted for all fossil fuels in the power and industrial sectors.
CO₂ Utilization Markets

Source: National Energy Technology Lab, DOE
## Technically Recoverable Domestic Oil and CO₂ Storage Capacity, State of Art and “Next Generation” CO₂-EOR Technology

<table>
<thead>
<tr>
<th>Basin/Area</th>
<th>Technically Recoverable Oil (Billion Barrels)</th>
<th>Technical CO₂ Demand/Storage (Million Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOA (“Next Generation”)</td>
<td>SOA (“Next Generation”)</td>
</tr>
<tr>
<td>1. Main Pay Zone CO₂-EOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower-48 Onshore</td>
<td>55.6</td>
<td>105.5</td>
</tr>
<tr>
<td>Alaska</td>
<td>5.8</td>
<td>8.8</td>
</tr>
<tr>
<td>Offshore GOM</td>
<td>23.5</td>
<td>52.9</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>84.9</strong></td>
<td><strong>167.2</strong></td>
</tr>
<tr>
<td>2. Residual Oil Zone CO₂-EOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROZ Fairways*</td>
<td>n/a</td>
<td>25.7</td>
</tr>
<tr>
<td>Below Oil Fields</td>
<td>n/a</td>
<td>16.3</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>n/a</strong></td>
<td><strong>42.0</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>84.9</strong></td>
<td><strong>209.2</strong></td>
</tr>
</tbody>
</table>

*Four County Permian Basin San Andres ROZ fairway.
### CO₂ Markets – Geologic CO₂-EOR/ROZ

<table>
<thead>
<tr>
<th>Recipients of CO₂-EOR Revenues*</th>
<th>Revenues</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CO₂ Capture and Transporters</td>
<td>$1,210 billion</td>
</tr>
<tr>
<td>• State, Local and Federal Treasuries</td>
<td>$1,130 billion</td>
</tr>
<tr>
<td>• CO₂-EOR Investors (including Return on Capital)</td>
<td>$1,270 billion</td>
</tr>
<tr>
<td>• General Economy/Mineral Owners</td>
<td>$2,060 billion</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$5,670 billion</strong></td>
</tr>
</tbody>
</table>

*Assuming an oil price of $70/B.


The Emission Reduction Benefits of CCUS using CO₂-Enhanced Oil Recovery
CO₂ Markets – Geologic – Shale & ECBM

U.S. Regions with Potential to Produce Oil and Gas from Shales and Other Unconventionally Tight Rock Formations

Enhanced Coal Bed Methane
Schematic of the Flow Dynamics of CO₂ and CH₄ in Coal Seams
CO$_2$ Markets – Geologic Enhanced Water Recovery & Geothermal Storage

**Staged pre-injection brine production**

Multi-fluid Geo-energy System with Four Rings of Horizontal Injection and Production Wells

Source: Buscheck et al. 2016a
Two Pathways to CO$_2$ Non-Geologic Utilization

- Cleaving - Breaking down the CO$_2$ molecule by cleaving C=O bond(s)
- Intact/Fixed – Incorporating the entire CO$_2$ molecule into other chemical structures
• Inorganic Carbonates & Bicarbonates
  ▪ Carbon Products – carbon black, activated carbons, nanofilters, graphene
  ▪ Cement & Aggregate Products
  ▪ Buffers & Other Chemical Products – baking soda, potassium bicarbonate
• Plastics & Polymers
  ▪ Functional Polymers
  ▪ Synthesized Polymers

CO₂ Markets – Non-Geologic
Plastics & Polymers
CO₂ Markets – Non-Geologic Organic & Specialty Chemicals

- Organic & Specialty Chemicals
  - Urea
  - Ethylene & Propylene
  - DMC – Dimethylcarbonate Synthesis
  - Acrylic Acid
  - Solvents – compressed CO₂ cylinders, liquid CO₂, dry ice

Conceptual system for CO₂-based sustainable chemicals and fuels

Source: Satthawong et al. 2013
### CO₂ Markets – Non-Geologic Agricultural Fertilizers

#### Estimated Crop Yield Increase with Carbon Addition in Fertilizers

<table>
<thead>
<tr>
<th>Type of Crop</th>
<th>Estimated Increase in Yield With Carbon Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>3%</td>
</tr>
<tr>
<td>Corn</td>
<td>8%</td>
</tr>
<tr>
<td>Soy Beans</td>
<td>8%</td>
</tr>
<tr>
<td>Potatoes</td>
<td>11%</td>
</tr>
<tr>
<td>Almonds</td>
<td>12%</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>12%</td>
</tr>
<tr>
<td>Sweet Corn</td>
<td>20%</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>25%</td>
</tr>
<tr>
<td>Grapes</td>
<td>30%</td>
</tr>
<tr>
<td>Apples</td>
<td>32%</td>
</tr>
</tbody>
</table>

Source: FB Sciences, Inc. 2015
CO$_2$ Markets – Non-Geologic

- Food & Beverage = 50% of CO2 used globally for commercial applications
CO₂ Markets – Non-Geologic - Fuels

• Fuels
  ▪ Methanol
  ▪ Hydrocarbon Fuels
  ▪ Biological Processes – algae/microrganisms

Order of Magnitude Estimates for the Worldwide Capacity of CO₂ Utilization

<table>
<thead>
<tr>
<th>Option of CO₂ Utilization</th>
<th>Worldwide Capacity (Order of Magnitude in Giga Ton Carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-chemical Utilization</td>
<td>0.01 – 0.1 GtC per year</td>
</tr>
<tr>
<td>Chemicals &amp; Materials</td>
<td>0.1 – 1 GtC per year</td>
</tr>
<tr>
<td>Synthetic Liquid Fuels</td>
<td>1 – 10 GtC per year</td>
</tr>
</tbody>
</table>

Source: Song, 2002
Key Findings

- Geological CO$_2$ utilization options have the greatest potential to advance CCUS by creating market demand for anthropogenic CO$_2$. Non-geological CO$_2$ utilization options are unlikely to significantly incentivize CCUS in the near- to intermediate-term because of technical, GHG LCA considerations, challenges regarding scalability and related reasons.

- CO$_2$-EOR – including production and storage activities in residual oil zones (ROZ) – remains the CO$_2$ utilization technology with the greatest potential to incentivize CCUS.

**Recommendations**

- Policymakers should continue to focus on advancing geological storage options through support for RD&D and adoption of incentives.

- As part of Mission Innovation, DOE should reinvigorate its RD&D program on advanced (“next generation”) CO$_2$-EOR technologies.

- DOE should sponsor a full evaluation of the technically recoverable and economically viable domestic ROZ resource to more completely understand the market for CO$_2$ from EOR.
Key Findings

- Some non-geologic utilization opportunities are promising incentives for CCUS in that they tend to “fix” CO₂ so have the advantage of potentially serving as preferred carbon management solutions. These include (1) inorganic carbonates and bicarbonates; (2) plastics and polymers; (3) organic and specialty chemicals; and (4) agricultural fertilizers.

- CO₂ may also be utilized through chemical and biological processes to produce transportation fuels, which is a very large market. This pathway is unlikely to incentivize CCUS in the immediate future because 1) these fuels are ultimately combusted and thus release CO₂ to the atmosphere and 2) current U.S. policy favors geologic-based utilization pathways for CAA compliance. And while the case could be made that some CO₂-derived transportation fuels have lower GHG emissions than fossil-based fuels on a GHG LCA basis, non-fossil-based transportation fuels still face significant market competition and displacement hurdles.

RECOMMENDATIONS

- Additional technical and economic research should be directed towards the following non-geologic utilization products and pathways: (1) inorganic carbonates and bicarbonates; (2) plastics and polymers; (3) organic and specialty chemicals; and (4) agricultural fertilizers.

- GHG LCA of all CO₂ utilization options should be undertaken.
CO₂ Utilization Evaluation Criteria

• Global CCS Institute Report (2011)
  ▪ Global demand for CO₂ ~ 80 million tons/year
  ▪ Potential future demand ~ 300 million tons/year
  ▪ CO₂-EOR one of several technologies showing large potential growth

• IEA CO₂-EOR Study (2015)
  ▪ CO₂-EOR could lead to storage of 60,000 MTPY of CO₂
  ▪ CO₂-EOR+ advanced technologies could increase to 240,000-360,000 MTPY

• Evaluation criteria can be used to prioritize R&D and commercial investment in CO₂ utilization technologies
Key Findings

- Evaluation criteria fall into three broad categories:
  1) environmental considerations
  2) technology/product status
  3) market considerations

- Benefits of applying evaluation criteria include:
  1) making relative comparisons among technologies
  2) identifying priority technology candidates
  3) creating a more comprehensive ranking of the suite of CO$_2$ utilization technologies
  4) enabling revisions to technological assessments as market conditions change
CO₂ Markets as Incentives for CCUS

- Monetary, regulatory and policy investments in the following CO₂ utilization and storage technologies, in descending order, are most likely to incentivize the deployment of CCUS technologies:
  - Current CO₂–EOR Technology
  - State-of-the-Art CO₂–EOR Technologies
  - Other geologic storage technologies that provide economic return
  - Saline Storage
  - Non-geologic storage technologies that provide economic return and that are as effective as geologic storage
  - Non-geologic storage technologies that provide economic return yet are not as effective as geologic storage if appropriate EPA research waivers may be obtained
CO₂ Markets as Incentives for CCUS

• U.S. law recognizes CO₂–EOR and other geologic storage technologies for compliance purposes.

• Non-geologic storage technologies may be used only if EPA determines they are as effective as geologic storage.

• U.S. climate goals and non-binding international climate goals require CCUS technology deployment at scale in the near future.
CO\textsubscript{2} Markets as Incentives for CCUS

• CO\textsubscript{2} utilization in non-geologic contexts face the following hurdles:
  ▪ Cost of capture
  ▪ Insufficient scope of market/supply
  ▪ Nearly all non-geologic CO\textsubscript{2} utilization technologies are not yet commercialized
  ▪ Geographic/infrastructure considerations
  ▪ Legal and regulatory considerations
Paving the way — A selection of today’s carbon capture and utilization pathways

Source: Global CCS Institute
Summary Primary Recommendations

- Geological CO₂ utilization options have the greatest potential to advance CCUS by creating market demand for anthropogenic CO₂. Policymakers should continue to focus on advancing geological storage options through support for RD&D and adoption of incentives. As part of Mission Innovation, DOE should reinvigorate its RD&D program on advanced ("next generation") CO₂-EOR technologies.

- Non-geological CO₂ utilization options are unlikely to significantly incentivize CCUS in the near- to intermediate-term because of technical, GHG LCA considerations, lack of scalability and related reasons. Those technologies that can “fix” CO2 molecules intact, akin to geologic storage, hold the most promise and are worthy of continuing evaluation, including inorganic carbonates/bicarbonates, plastics/polymers, organic/specialty chemicals and agricultural fertilizers.

- There is a benefit to establishing a technology review process that is as objective as possible to assess the benefits and challenges of different CO2 utilization technologies and products. Technologies should be evaluated on the basis of: 1) environmental considerations, 2) technology/product status and 3) market considerations.
Summary Primary Recommendations

• U.S. law recognizes CO₂-EOR and other geologic storage technologies as compliance options; non-geologic technologies may be used only if EPA determines they are as effective as geologic storage. Aligning CO₂ production and utilization markets may require relaxing terms of compliance for CO₂ emitting utilities and industrial facilities, as well as providing for establishment of an inventory of unused CO₂ in geologic storage. Appropriate policy and regulatory relief for higher-risk CCUS projects may also incentivize investment from the venture capital community.

• U.S. and international GHG reduction objectives and timeframes dictate the need to employ CO₂ utilization technologies that can be quickly commercialized at significant scale. Monetary, regulatory and policy investments in CO₂ utilization technologies should be roughly prioritized from geologic to non-geologic, with exceptions made for any non-geologic technologies that are found to be as effective as geologic storage. To identify the most expeditious and impactful technology options, NCC suggests applying a reasonable market potential threshold of 35 MTPY, which is roughly equivalent to the annual CO₂ emissions from about 6 GWe or a dozen 500 MWe coal-based power plants.
Questions?