Full Council Meeting
August 30th, 2016 – 2-3 pm Eastern
NCC Webcast Meeting Agenda

• Welcome – NCC Chair, Mike Durham
• Anti-trust Advisory – NCC Legal Counsel, Julia d’Hemecourt
• “CO₂ Building Blocks: Assessing CO₂ Utilization Options”
  • Introduction of Report – NCC CPC Chair, Deck Slone
  • Presentation of Report – NCC Report Chair, Kipp Coddington
• Discussion & Action on NCC Report
• Adjourn
Report Introduction

Deck Slone, Chair
NCC Coal Policy Committee
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 Timeline

- February 2016 – Secretary’s Request
- March 2016 – NCC Scoping Meeting
- April 2016 – Report Outline Developed/Chapter Leads Secured
- May-July 2016 – Report Drafting
- August 5-22, 2016 – NCC Coal Policy Committee Review
- August 25, 2016 – Report Draft to NCC Members
- August 30, 2016 – Full Council Meeting
• Executive Summary
• Chapter A. Key Findings & Recommendations
• Chapter B. Introduction: The Value of Coal
• Chapter C. The CO₂ Utilization Imperative
• Chapter D. Criteria for Review of CO₂ Utilization Technologies
• Chapter E. CO₂ Utilization Market Review
  ▪ Geologic Options
  ▪ Non-Geologic Options
• Chapter F. Extent to Which CO₂ Utilization Technologies/Markets May Incentivize CCS/CCUS Deployment
• Chapter G. Economic Opportunity for the U.S. Associated with Commercial-Scale CCS/CCUS Deployment
Report Presentation
Kipp Coddington, Chair
NCC CO₂ Building Blocks Report
The Value of Coal

Source: BP Energy Outlook 2016

Source: International Energy Agency 2013
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 CO\textsubscript{2} 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.
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-based Power
- Clean Power Plan
- International GHG Mitigation Goals
CO2 Building Blocks
Assessing CO2 Utilization Options

RECOMMENDATIONS
Continue to focus Federal policy on encouraging geologic utilization and storage pathways.

Some non-geologic pathways – such as polymers - hold promise as niche opportunities; additional research should be pursued.

Key Findings

- CO2-EOR still represents the most immediate, highest value opportunity to utilize the greatest volumes of anthropogenic CO2.
- Aside from CO2-EOR and other geologic pathways, research is underway on two general CO2 utilization pathways – breaking down the CO2 molecule by cleaving C=O bond(s) and incorporating the entire CO2 molecule into other chemical structures. The latter pathway holds relatively more promise as it requires less energy and tends to “fix” the CO2 in a manner akin to geologic storage.
- Utilizing CO2 in non-geologic applications faces hurdles, including yet-to-be resolved issues associated with thermodynamics and kinetics involved in the successful reduction of CO2 to carbon products.
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 CO₂ utilization technologies
  4) enabling revisions to technological assessments as market conditions change
CO₂ Utilization Markets

Source: National Energy Technology Lab, DOE
CO₂ Markets – Geologic CO₂-EOR/ROZ

<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 &quot;Next Generation&quot;</td>
<td>SOA &quot;Next Generation&quot;</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>Sub-Total</td>
<td>84.9</td>
<td>167.2</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>Sub-Total</td>
<td>n/a</td>
<td>42.0</td>
</tr>
<tr>
<td>Total</td>
<td>84.9</td>
<td>209.2</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.
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
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 CO₂ Non-Geologic Utilization

- Cleaving - Breaking down the CO₂ molecule by cleaving C=O bond(s)
- Intact/Fixed – Incorporating the entire CO₂ molecule into other chemical structures
CO₂ Markets – Non-Geologic

Inorganic Carbonates & Bicarbonates

- Inorganic Carbonates & Bicarbonates
  - Carbon Products – carbon black, activated carbons, nanofilters, graphene
  - Cement & Aggregate Products
  - Buffers & Other Chemical Products – baking soda, potassium bicarbonate
CO₂ Markets – Non-Geologic Plastics & Polymers

• Plastics & Polymers
  ▪ Functional Polymers
  ▪ Synthesized Polymers
CO\textsubscript{2} Markets – Non-Geologic Organic & Specialty Chemicals

- Organic & Specialty Chemicals
  - Urea
  - Ethylene & Propylene
  - DMC – Dimethylcarbonate Synthesis
  - Acrylic Acid
  - Solvents – compressed CO\textsubscript{2} cylinders, liquid CO\textsubscript{2}, dry ice

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

• Food & Beverage = 50% of CO2 used globally for commercial applications
CO$_2$ Markets – Non-Geologic - Fuels

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

Order of Magnitude Estimates for the Worldwide Capacity of CO$_2$ Utilization

<table>
<thead>
<tr>
<th>Option of CO$_2$ 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
CO2 Building Blocks
Assessing CO2 Utilization Options

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”) CO2-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 CO2 from EOR.

Key Findings

• Geological CO2 utilization options have the greatest potential to advance CCUS by creating market demand for anthropogenic CO2. Non-geological CO2 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.

• CO2-EOR – including production and storage activities in residual oil zones (ROZ) – remains the CO2 utilization technology with the greatest potential to incentivize CCUS.
**CO2 Building Blocks**

Assessing CO₂ Utilization Options

**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.

- 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.

**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.

- GHG LCA of all CO₂ utilization options should be undertaken.
CO\textsubscript{2} Markets as Incentives for CCUS

- Monetary, regulatory and policy investments in the following CO\textsubscript{2} utilization and storage technologies, in descending order, are most likely to incentivize the deployment of CCUS technologies:
  - Current CO\textsubscript{2}–EOR Technology
  - State-of-the-Art CO\textsubscript{2}–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$_2$ Markets as Incentives for CCUS

- CO$_2$ utilization in non-geologic contexts face the following hurdles:
  - Cost of capture
  - Insufficient scope of market/supply
  - Nearly all non-geologic CO$_2$ utilization technologies are not yet commercialized
  - Geographic/infrastructure considerations
  - Legal and regulatory considerations
Key Findings

- U.S. law currently favors geologic storage/utilization technologies; laws mandate that non-geologic CO$_2$ uses demonstrate that they are as effective as geologic storage.
- Timing of U.S. and international climate goals point towards the use of CO$_2$ utilization technologies that are either already commercialized or near commercialization.
- There is a misalignment of needs between industries who would utilize CO$_2$ and the power sector.
- CCUS technology deployments face a host of unresolved impediments that are unlikely to be mitigated by market demand for CO$_2$ alone in any near- to intermediate-term scenario.
- With the exception of geological utilization under appropriate circumstances, CO$_2$ utilization is unlikely by itself to incentivize CCUS technologies.
CO2 Building Blocks
Assessing CO2 Utilization Options

RECOMMENDATIONS

• More economic and technical research and analysis need to be conducted on CO2 utilization in non-geologic options, including chemicals and fuels.

• The focus of this additional research and analysis should take into account the criteria for review of CO2 utilization technologies detailed in this report.

• Additional research should be supported regarding advancing the following technologies toward commercialization: 1) inorganic carbonates and bicarbonates; 2) plastics and polymers; 3) organic and specialty chemicals; and 4) agricultural fertilizers.

Key Findings
Economic Opportunities

• Applying various evaluation criteria, the primary economic opportunity for the United States associated with commercial-scale CCUS deployment remains geologic storage associated with energy production. These include: 1) CO2-EOR; 2) ROZ; 3) organically-rich shales; and 4) ECBM.

• The economic incentive potential of all other pathways (to include all non-geologic options) is largely unquantifiable based on publicly available data. Moreover, such options face a host of known technical, economic and policy hurdles.
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 CO\(_2\)-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 CO\(_2\) production and utilization markets may require relaxing terms of compliance for CO\(_2\) emitting utilities and industrial facilities, as well as providing for establishment of an inventory of unused CO\(_2\) 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 CO\(_2\) utilization technologies that can be quickly commercialized at significant scale. Monetary, regulatory and policy investments in CO\(_2\) 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 CO\(_2\) emissions from about 6 GWe or a dozen 500 MWe coal-based power plants.
Questions?
NCC Members’ Supplemental Comments

Due Friday September 2, 2016
3-page limit
Submit to jgellici@NCC1.org