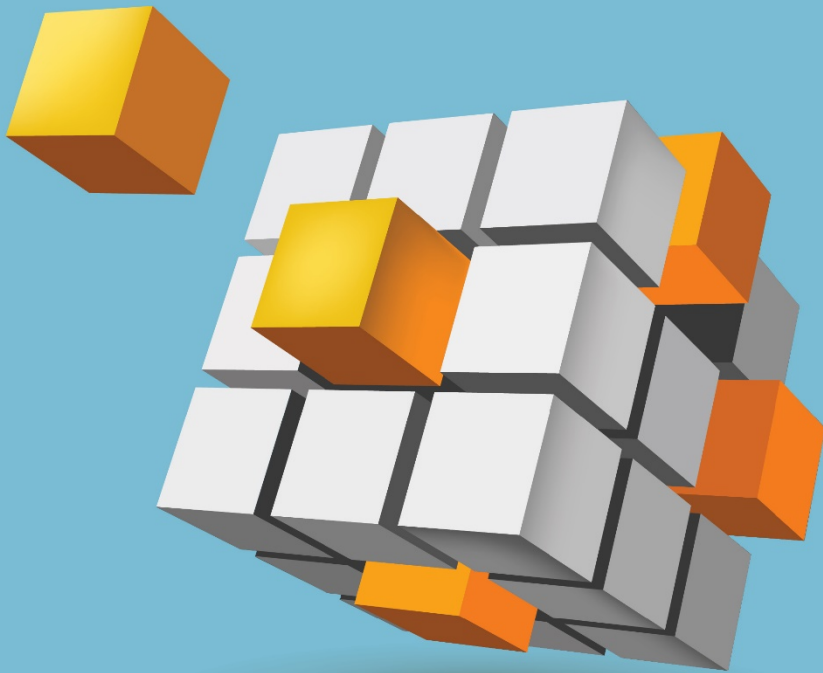




# CO<sub>2</sub> BUILDING BLOCKS

ASSESSING CO<sub>2</sub> UTILIZATION OPTIONS



Briefing – November 30, 2016

**Janet Gellici, CEO  
National Coal Council**

# National Coal Council

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Celebrating 32 years ~ 1984 | 2016

**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

## Members

Appointed to serve  
by Secretary of Energy  
125-150 members

## Reports

~ 35 reports prepared by NCC  
members at no cost to DOE

- **Industry –**  
coal suppliers, utility & industrial  
consumers & coal transportation
- **Support Services –**  
engineering firms, vendors, consultants &  
attorneys
- **Academics**
- **NGOs –**  
environmental & trade association reps
- **Government –**  
PUC & state energy officials

## Extensive Range of Topics

Carbon Management  
Clean Coal Technologies  
Coal & Coal Technology Exports  
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  
CO<sub>2</sub> Building Blocks: CO<sub>2</sub> Utilization



# FOSSIL FORWARD

Revitalizing CCS

Bringing Scale and Speed to CCS Deployment

NCC Report - January 2015





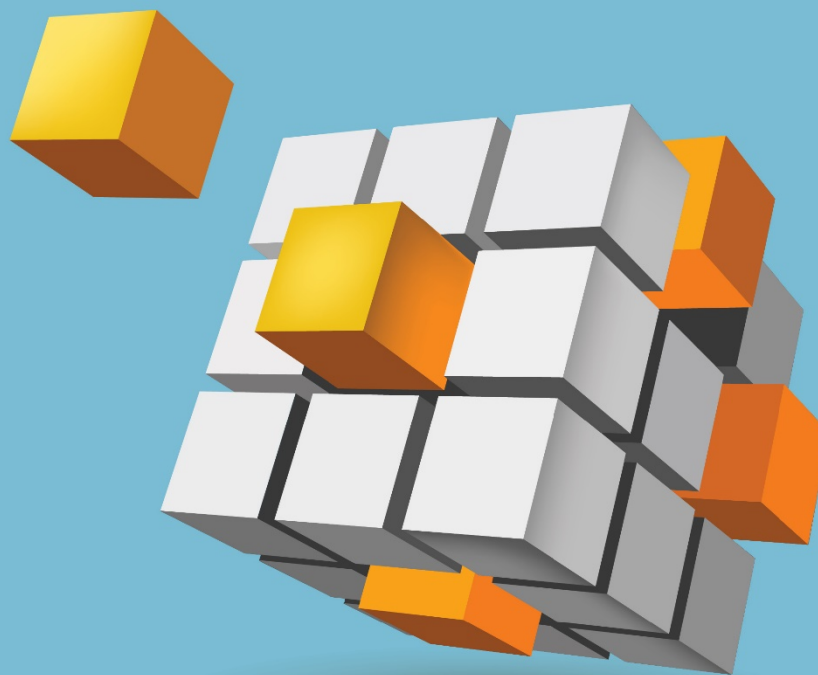
# LEVELING THE PLAYING FIELD

**Policy Parity**  
for Carbon Capture  
and Storage  
Technologies

NCC White Paper – November 2015

# CO<sub>2</sub> BUILDING BLOCKS

ASSESSING CO<sub>2</sub> UTILIZATION OPTIONS



NCC White Paper – August 2016

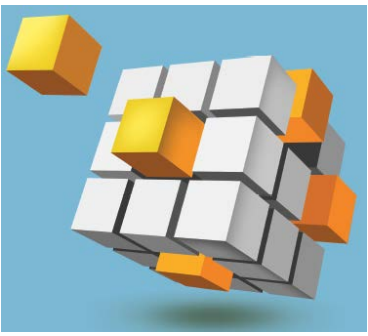




# Request from Secretary Moniz

- Develop an expanded white paper assessing opportunities to advance commercial markets for carbon dioxide (CO<sub>2</sub>) from coal-based power generation.
- Focus on profit-generating opportunities for CO<sub>2</sub> 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<sub>2</sub> 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 +++



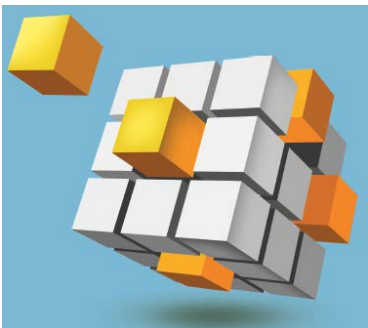


# Report & Presentation Overview

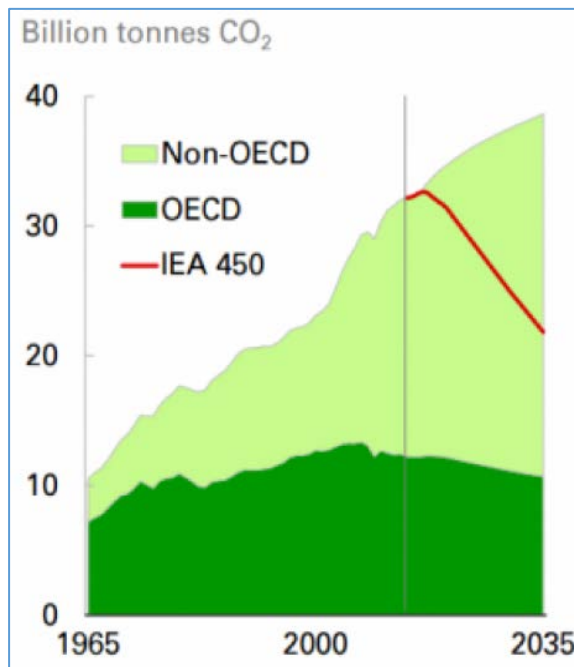
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- Factors Driving Demand for CO<sub>2</sub> Utilization
- Status of CO<sub>2</sub> Utilization Technologies
- Evaluation of CO<sub>2</sub> Utilization Technologies
- Opportunities to Incentivize CCUS Deployment

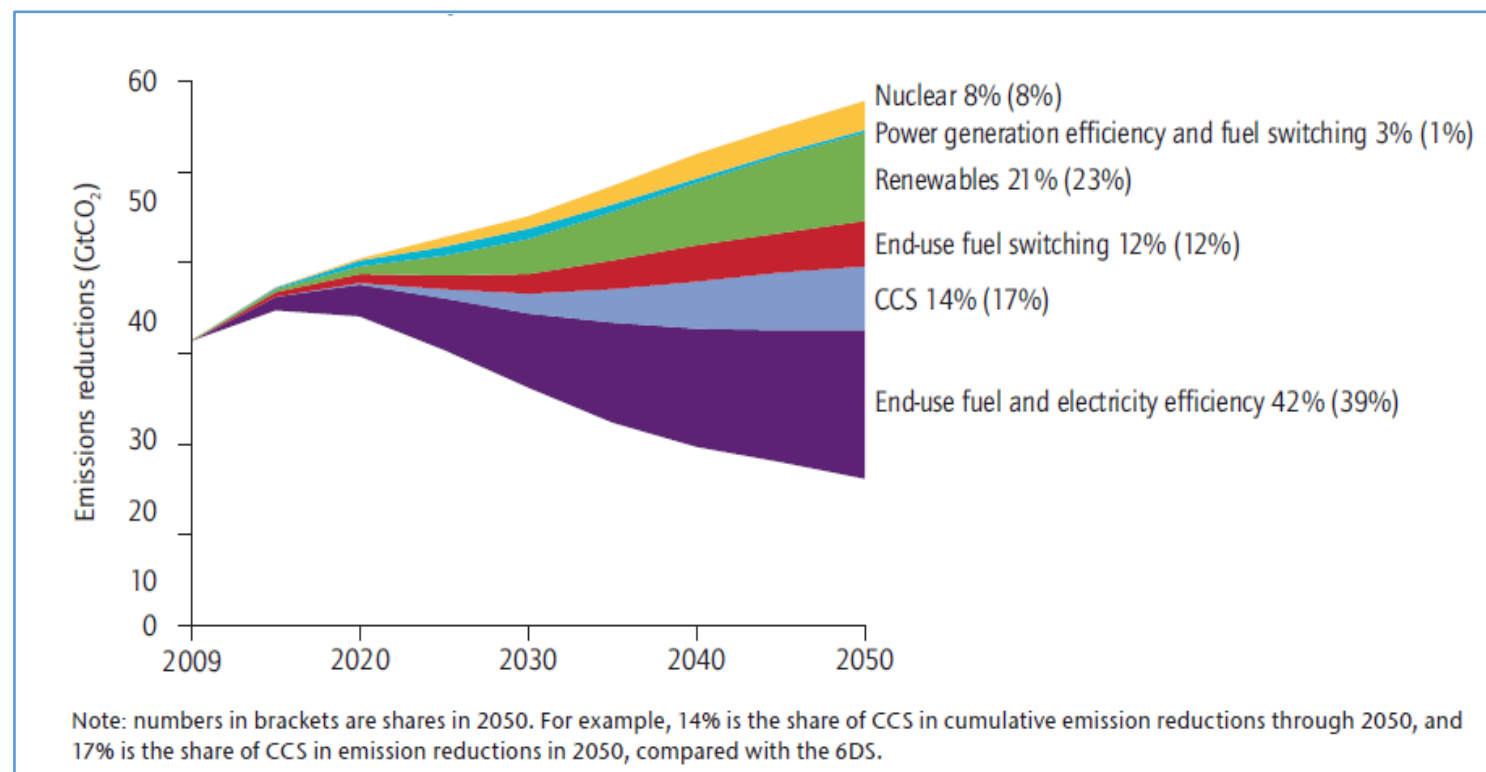




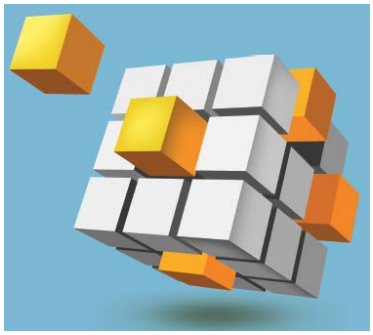
# The Value of Coal



Source: BP Energy Outlook 2016



Source: International Energy Agency 2013



# CO<sub>2</sub> Utilization Imperative Legislative Drivers

- **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



# CO<sub>2</sub>

## Building Blocks

Assessing CO<sub>2</sub> Utilization Options

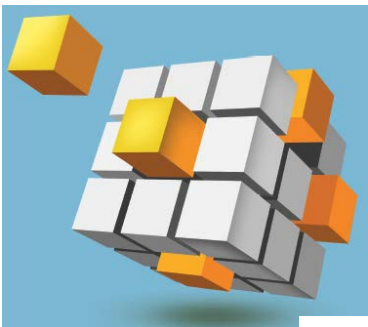
### RECOMMENDATIONS

Build on the expanding consensus in support of CCUS deployment.

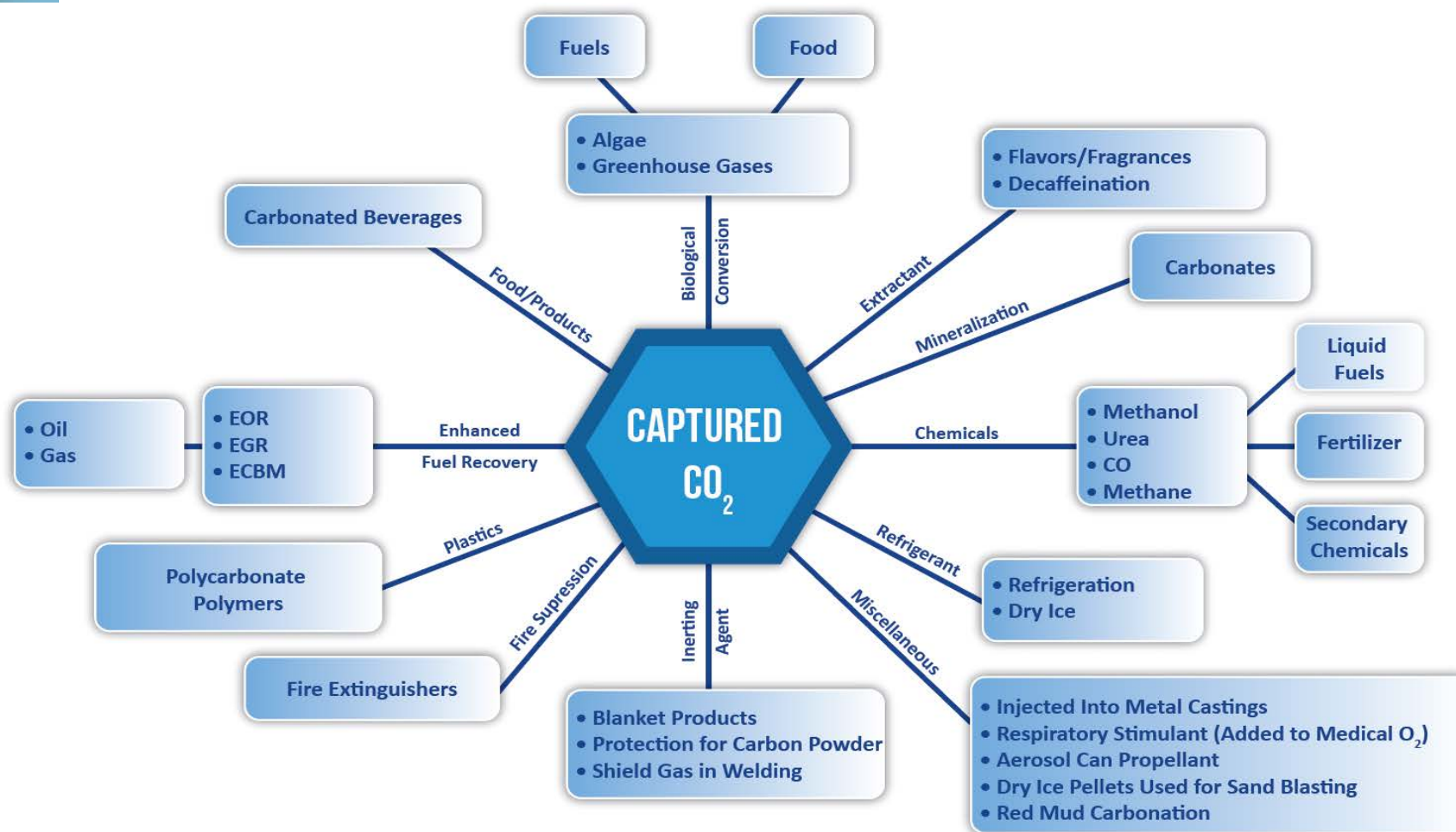
An expanded coalition of fossil fuel users and producers should collaborate to help develop and commercially deploy CCUS technologies on an accelerated time schedule.

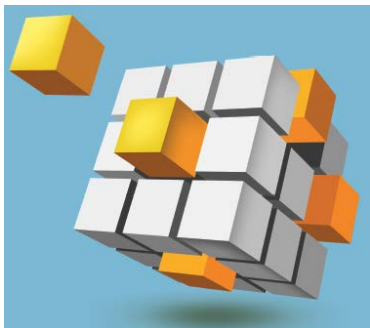
## Key Findings

- 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<sub>2</sub> 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.



# CO<sub>2</sub> Utilization Markets





# CO<sub>2</sub> Markets – Geologic CO<sub>2</sub>-EOR/ROZ

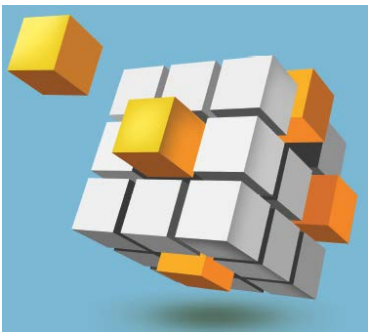
## Technically Recoverable Domestic Oil and CO<sub>2</sub> Storage Capacity, State of Art and “Next Generation” CO<sub>2</sub>-EOR Technology

Basin/Area	Technically Recoverable Oil (Billion Barrels)		Technical CO <sub>2</sub> Demand/Storage (Million Metric Tons)	
	SOA	“Next Generation”	SOA	“Next Generation”
<b>1. Main Pay Zone CO<sub>2</sub>-EOR</b>				
Lower-48 Onshore	55.6	105.5	22,270	33,050
Alaska	5.8	8.8	3,320	4,110
Offshore GOM	23.5	52.9	12,640	15,060
<b>Sub-Total</b>	<b>84.9</b>	<b>167.2</b>	<b>38,230</b>	<b>52,220</b>
<b>2. Residual Oil Zone CO<sub>2</sub>-EOR</b>				
ROZ Fairways*	n/a	25.7	n/a	17,100
Below Oil Fields	n/a	16.3	n/a	8,200
<b>Sub-Total</b>	<b>n/a</b>	<b>42.0</b>	<b>n/a</b>	<b>25,300</b>
<b>Total</b>	<b>84.9</b>	<b>209.2</b>	<b>38,230</b>	<b>77,520</b>

\*Four County Permian Basin San Andres ROZ fairway .

JAF2016\_036.xls





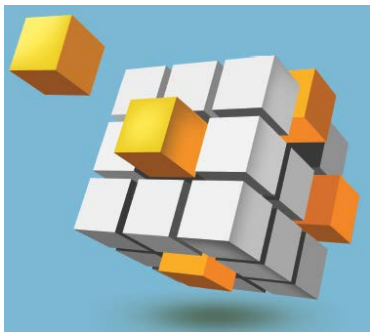
# CO<sub>2</sub> Markets – Geologic CO<sub>2</sub>-EOR/ROZ

	Recipients of CO <sub>2</sub> -EOR Revenues*	Revenues
•	CO <sub>2</sub> Capture and Transporters	\$1,210 billion
•	State, Local and Federal Treasuries	\$1,130 billion
•	CO <sub>2</sub> -EOR Investors (including Return on Capital)	\$1,270 billion
•	General Economy/Mineral Owners	<u>\$2,060 billion</u>
	Total	\$5,670 billion

\* Assuming an oil price of \$70/B.

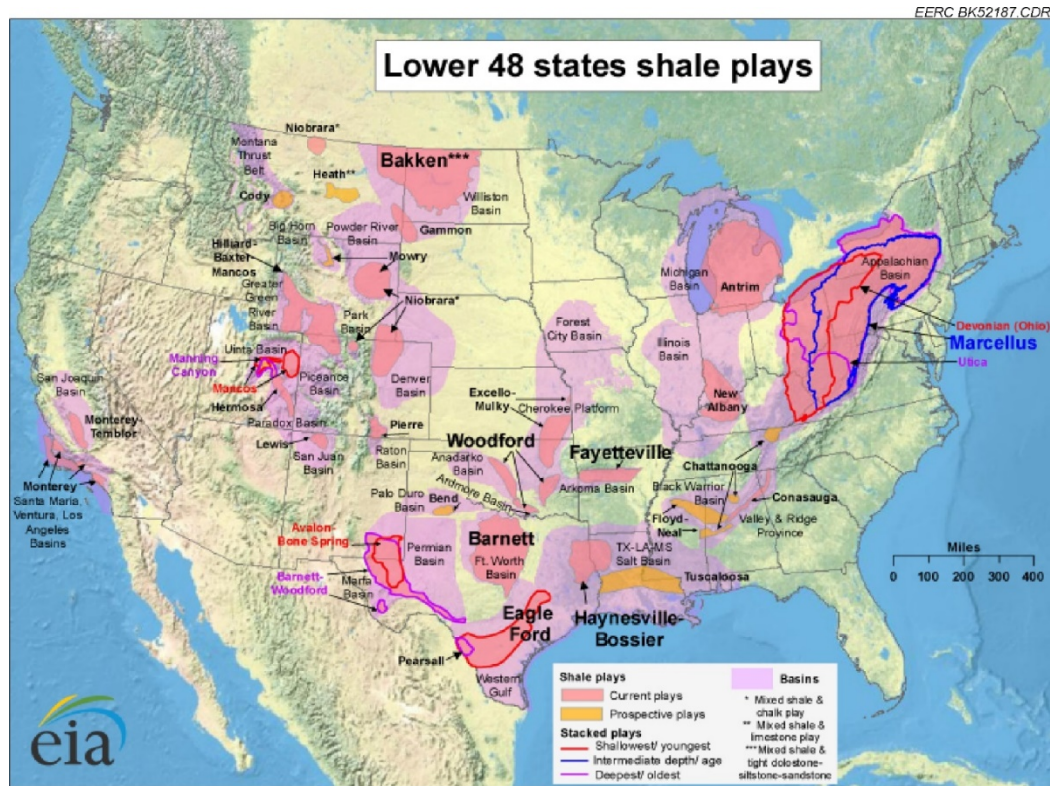
[http://www.catf.us/resources/factsheets/files/CO2\\_EOR\\_Life\\_Cycle\\_Analysis.pdf](http://www.catf.us/resources/factsheets/files/CO2_EOR_Life_Cycle_Analysis.pdf)

The Emission Reduction Benefits of CCUS using CO<sub>2</sub>-Enhanced Oil Recovery

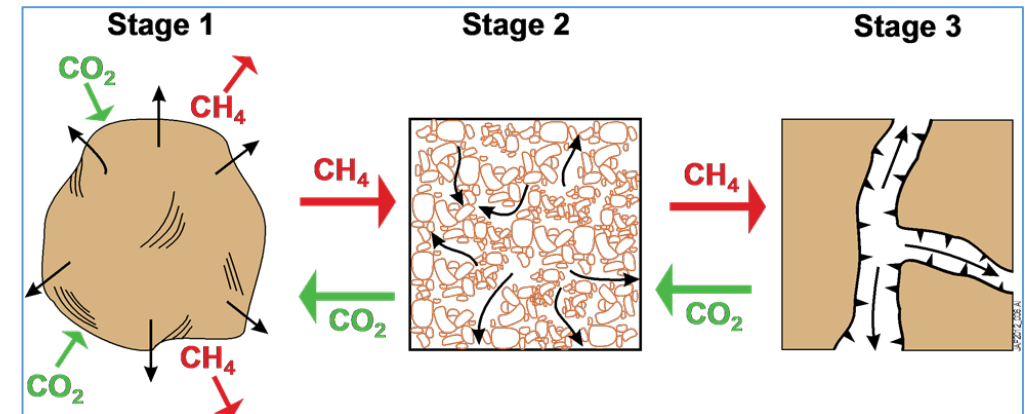


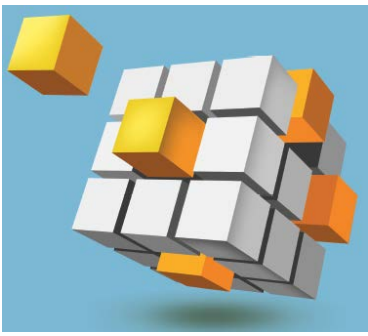
# CO<sub>2</sub> Markets – Geologic – Shale & ECBM

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



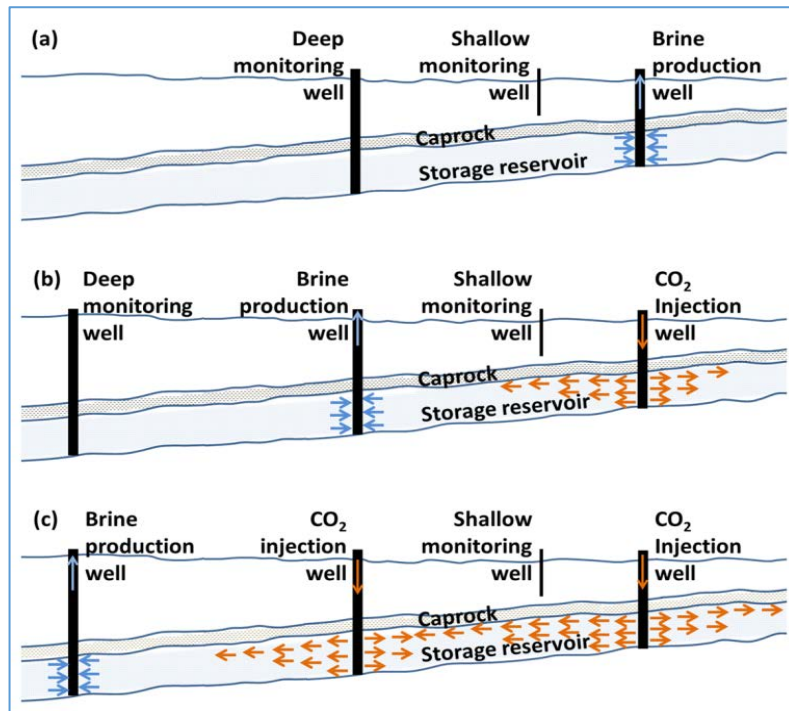
## Enhanced Coal Bed Methane Schematic of the Flow Dynamics of CO<sub>2</sub> and CH<sub>4</sub> in Coal Seams



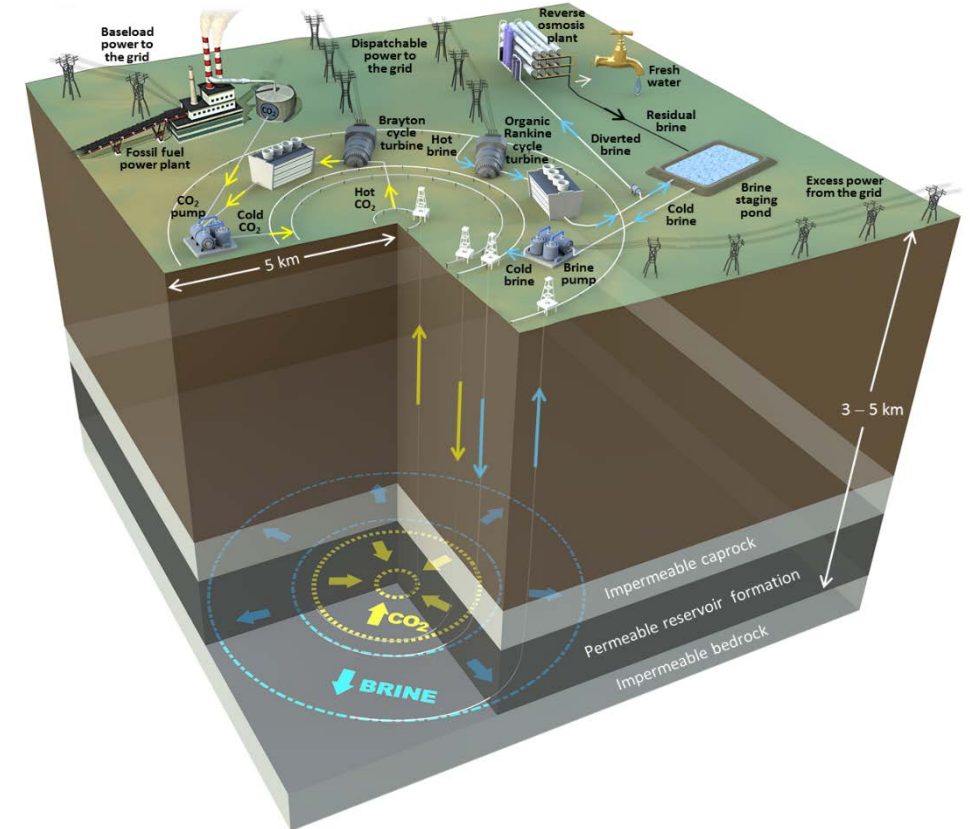


# CO<sub>2</sub> Markets – Geologic Enhanced Water Recovery & Geothermal Storage

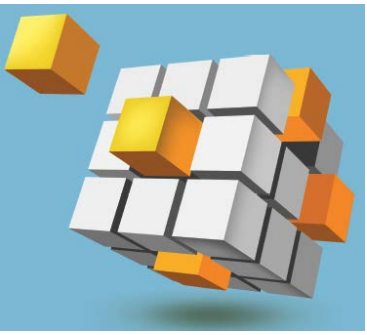
## Staged pre-injection brine production



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



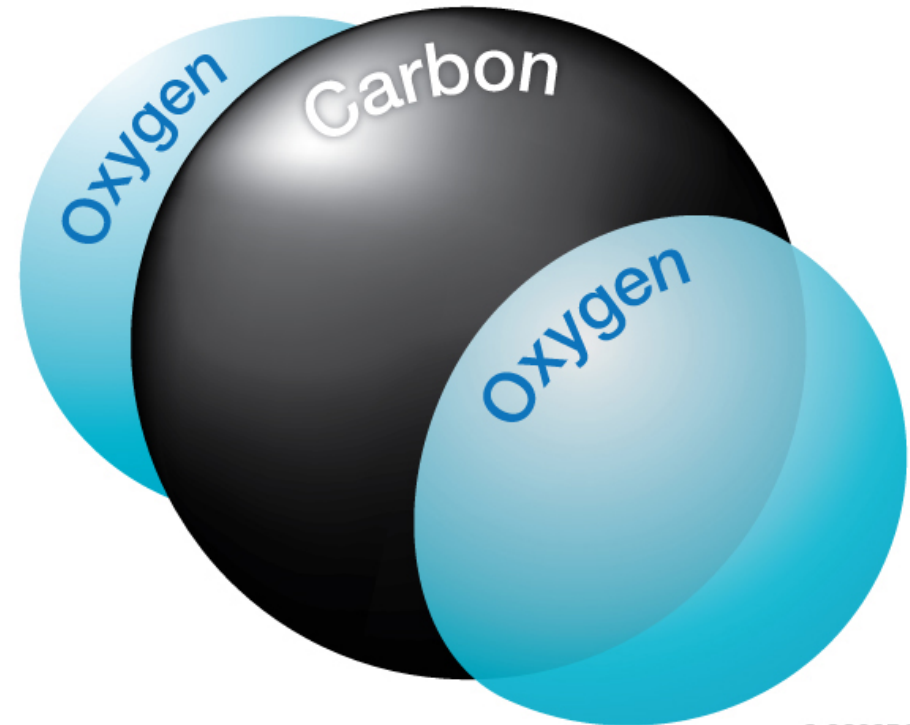




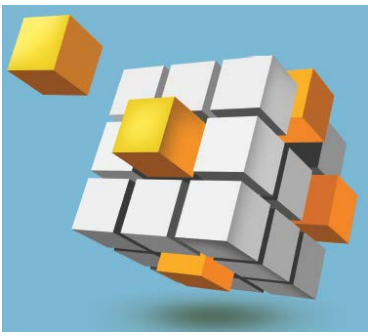
# CO<sub>2</sub> Markets – Non-Geologic

## Two Pathways to CO<sub>2</sub> Non-Geologic Utilization

- Cleaving - Breaking down the CO<sub>2</sub> molecule by cleaving C=O bond(s)
- Intact/Fixed – Incorporating the entire CO<sub>2</sub> molecule into other chemical structures

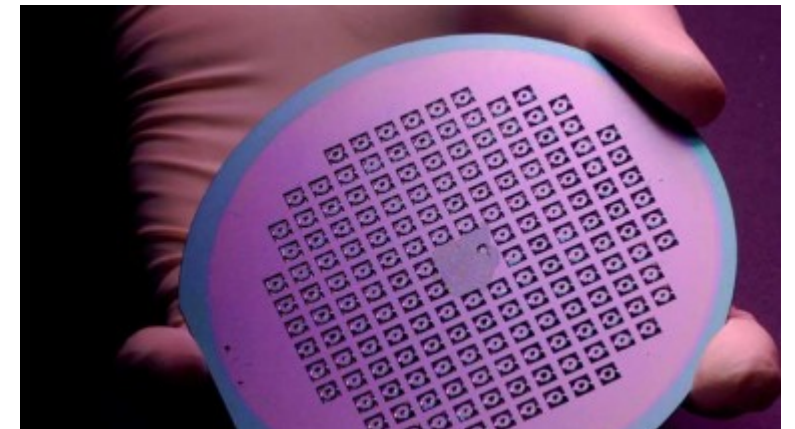
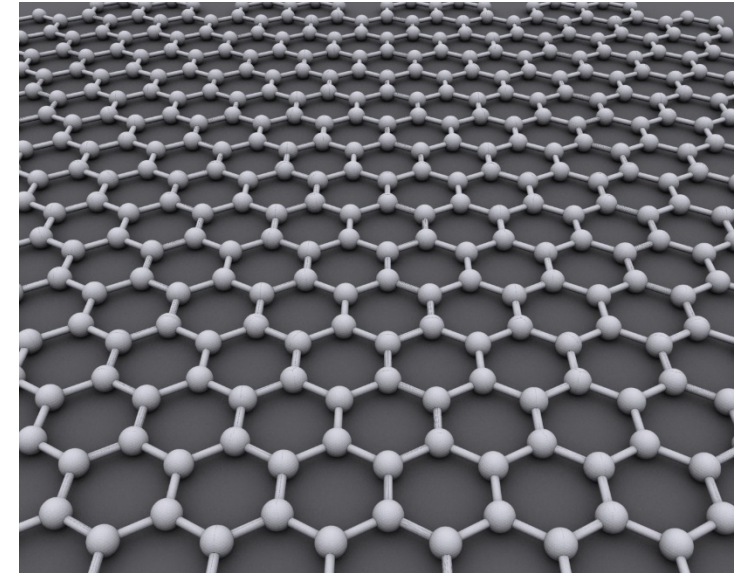


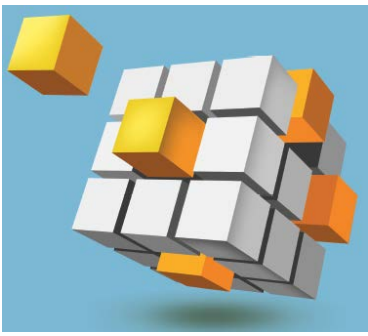
© CO2CRC



# CO<sub>2</sub> 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



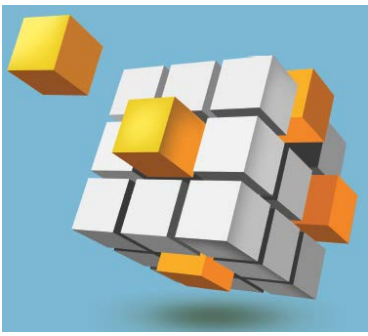


# CO<sub>2</sub> Markets – Non-Geologic Plastics & Polymers

- Plastics & Polymers
  - Functional Polymers
  - Synthesized Polymers

**ASAHI KASEI PLASTICS**  
Advanced Material Solutions



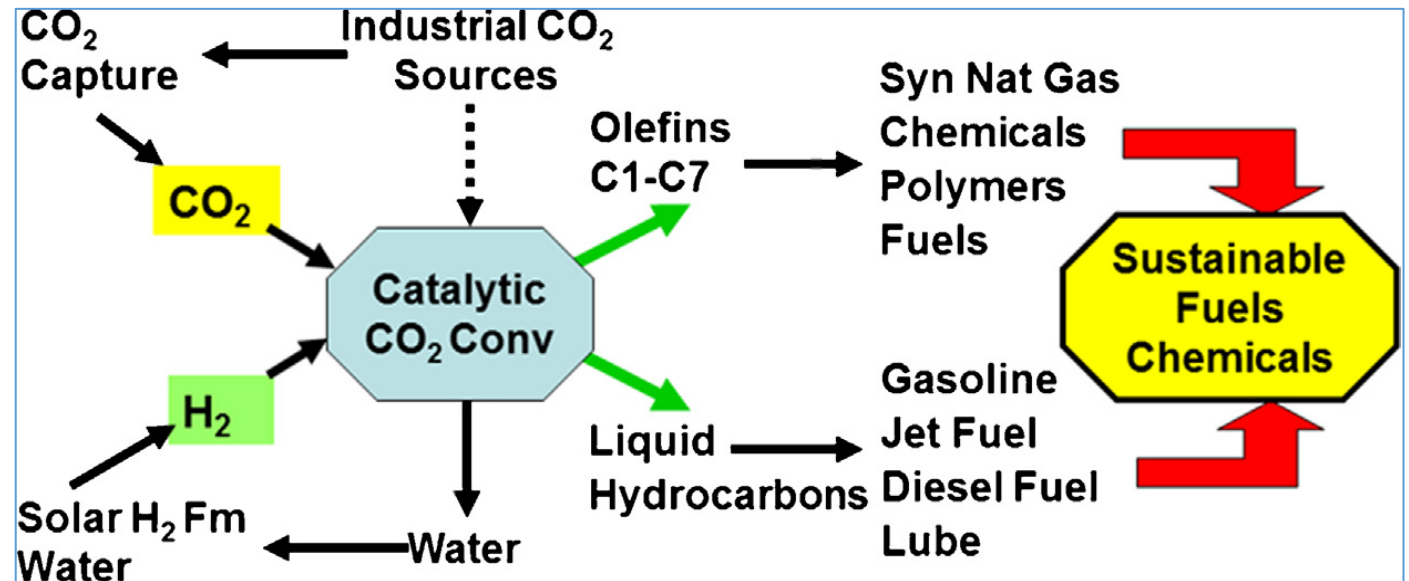


# CO<sub>2</sub> Markets – Non-Geologic Organic & Specialty Chemicals

- Organic & Specialty Chemicals

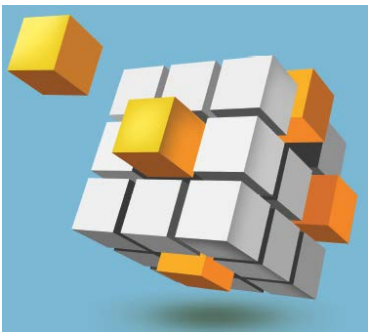
- Urea
- Ethylene & Propylene
- DMC – Dimethylcarbonate Synthesis
- Acrylic Acid
- Solvents – compressed CO<sub>2</sub> cylinders, liquid CO<sub>2</sub>, dry ice

Conceptual system for CO<sub>2</sub>-based sustainable chemicals and fuels



Source: Sathawong et al. 2013

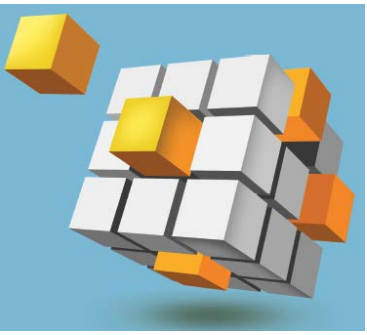




# CO<sub>2</sub> Markets – Non-Geologic Agricultural Fertilizers

## Estimated Crop Yield Increase with Carbon Addition in Fertilizers

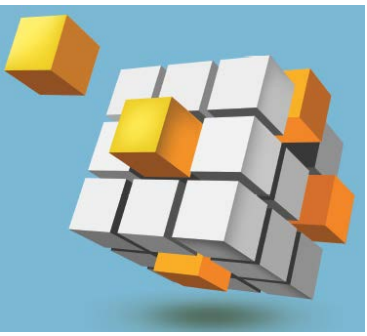
Type of Crop	Estimated Increase in Yield With Carbon Addition
Wheat	3%
Corn	8%
Soy Beans	8%
Potatoes	11%
Almonds	12%
Alfalfa	12%
Sweet Corn	20%
Tomatoes	25%
Grapes	30%
Apples	32%



# CO<sub>2</sub> Markets – Non-Geologic

- Food & Beverage = 50% of CO<sub>2</sub> used globally for commercial applications





# CO<sub>2</sub> Markets – Non-Geologic - Fuels

- Fuels
  - Methanol
  - Hydrocarbon Fuels
  - Biological Processes – algae/microorganisms

## Order of Magnitude Estimates for the Worldwide Capacity of CO<sub>2</sub> Utilization

Option of CO <sub>2</sub> Utilization	Worldwide Capacity (Order of Magnitude in Giga Ton Carbon)
Non-chemical Utilization	0.01 – 0.1 GtC per year
Chemicals & Materials	0.1 – 1 GtC per year
Synthetic Liquid Fuels	1 – 10 GtC per year

Source: Song, 2002



# CO<sub>2</sub> Building Blocks

## Assessing CO<sub>2</sub> 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”) CO<sub>2</sub>-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<sub>2</sub> from EOR.

## Key Findings

- Geological CO<sub>2</sub> utilization options have the greatest potential to advance CCUS by creating market demand for anthropogenic CO<sub>2</sub>. Non-geological CO<sub>2</sub> 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<sub>2</sub>-EOR – including production and storage activities in residual oil zones (ROZ) – remains the CO<sub>2</sub> utilization technology with the greatest potential to incentivize CCUS.



# CO<sub>2</sub>

## Building Blocks

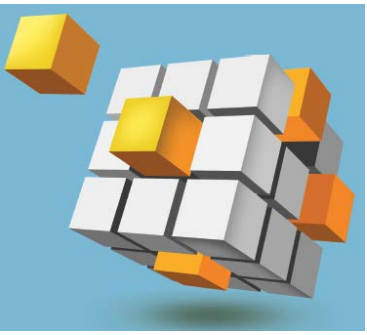
### Assessing CO<sub>2</sub> Utilization Options

#### 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.
- GHG LCA of all CO<sub>2</sub> utilization options should be undertaken.

## Key Findings

- Some non-geologic utilization opportunities are promising incentives for CCUS in that they tend to “fix” CO<sub>2</sub> 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.
- CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub>-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.



# CO<sub>2</sub> Utilization Evaluation Criteria

- Global CCS Institute Report (2011)
  - Global demand for CO<sub>2</sub> ~ 80 million tons/year
  - Potential future demand ~ 300 million tons/year
  - CO<sub>2</sub>-EOR one of several technologies showing large potential growth
- IEA CO<sub>2</sub>-EOR Study (2015)
  - CO<sub>2</sub>-EOR could lead to storage of 60,000 MTPY of CO<sub>2</sub>
  - CO<sub>2</sub>-EOR+ advanced technologies could increase to 240,000-360,000 MTPY
- Evaluation criteria can be used to prioritize R&D and commercial investment in CO<sub>2</sub> utilization technologies

# CO<sub>2</sub> Building Blocks

Assessing CO<sub>2</sub> Utilization Options

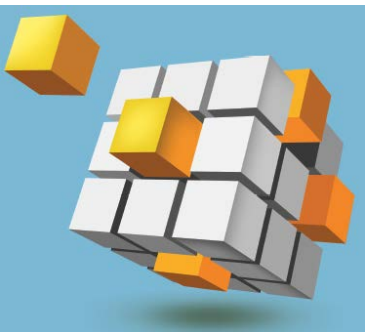
## RECOMMENDATIONS

Evaluation criteria should be used to gather info about and compare CO<sub>2</sub> utilization technologies.

A technology ranking system can be used to prioritize candidates for RD&D and product investment.

## 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<sub>2</sub> utilization technologies**
  - 4) **enabling revisions to technological assessments as market conditions change**

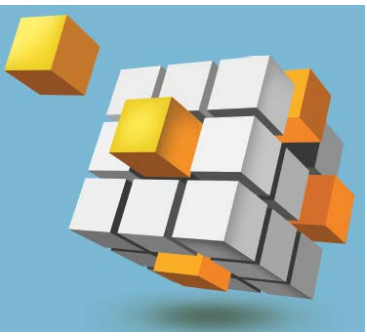


# CO<sub>2</sub> Markets as Incentives for CCUS

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- Monetary, regulatory and policy investments in the following CO<sub>2</sub> utilization and storage technologies, in descending order, are most likely to incentivize the deployment of CCUS technologies:
  - Current CO<sub>2</sub>–EOR Technology
  - State-of-the-Art CO<sub>2</sub>–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

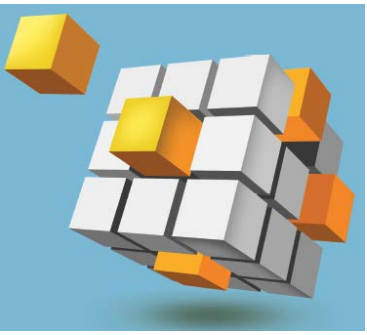




# CO<sub>2</sub> Markets as Incentives for CCUS

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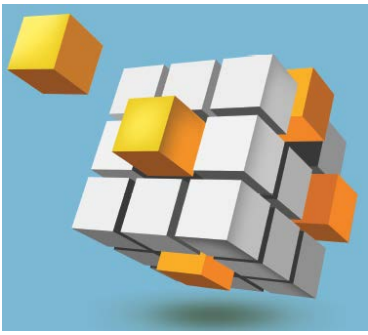
- U.S. law recognizes CO<sub>2</sub>–EOR and other geologic storage technologies for compliance purposes.
- Non-geologic storage technologies may be used only if EPA determines they are as effective as geologic storage.
- U.S. climate goals and non-binding international climate goals require CCUS technology deployment at scale in the near future.



# CO<sub>2</sub> Markets as Incentives for CCUS

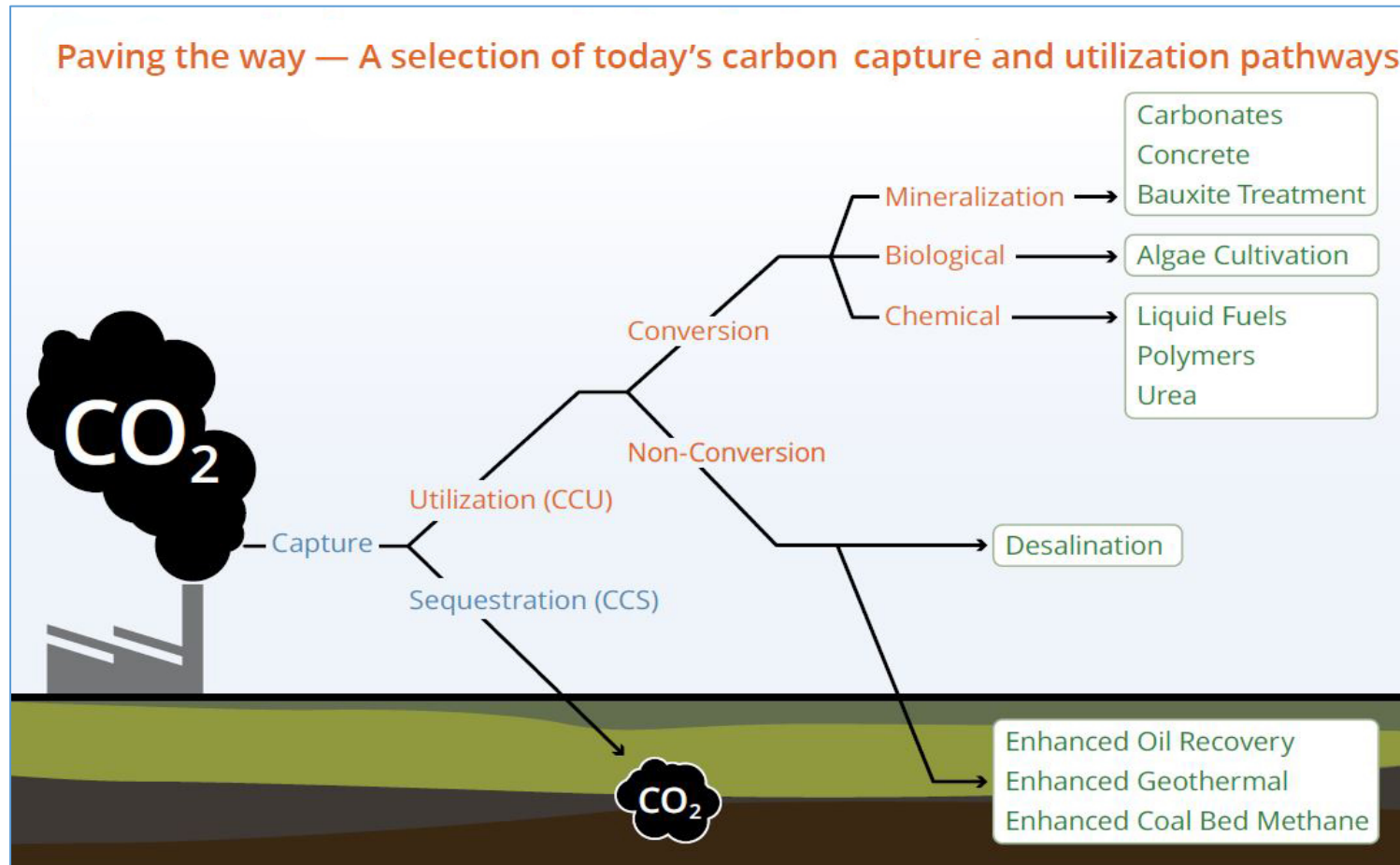
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- CO<sub>2</sub> utilization in non-geologic contexts face the following hurdles:
  - Cost of capture
  - Insufficient scope of market/supply
  - Nearly all non-geologic CO<sub>2</sub> utilization technologies are not yet commercialized
  - Geographic/infrastructure considerations
  - Legal and regulatory considerations



# CCUS – Building a Climate Change Solution

Source: Global CCS Institute



# CO<sub>2</sub>

## Building Blocks

Assessing CO<sub>2</sub>  
Utilization  
Options

## Summary Primary Recommendations

- Geological CO<sub>2</sub> utilization options have the greatest potential to advance CCUS by creating market demand for anthropogenic CO<sub>2</sub>. 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<sub>2</sub>-EOR technologies.
- Non-geological CO<sub>2</sub> 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” CO<sub>2</sub> 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 CO<sub>2</sub> utilization technologies and products. Technologies should be evaluated on the basis of: 1) environmental considerations, 2) technology/product status and 3) market considerations.



# CO<sub>2</sub>

## Building Blocks

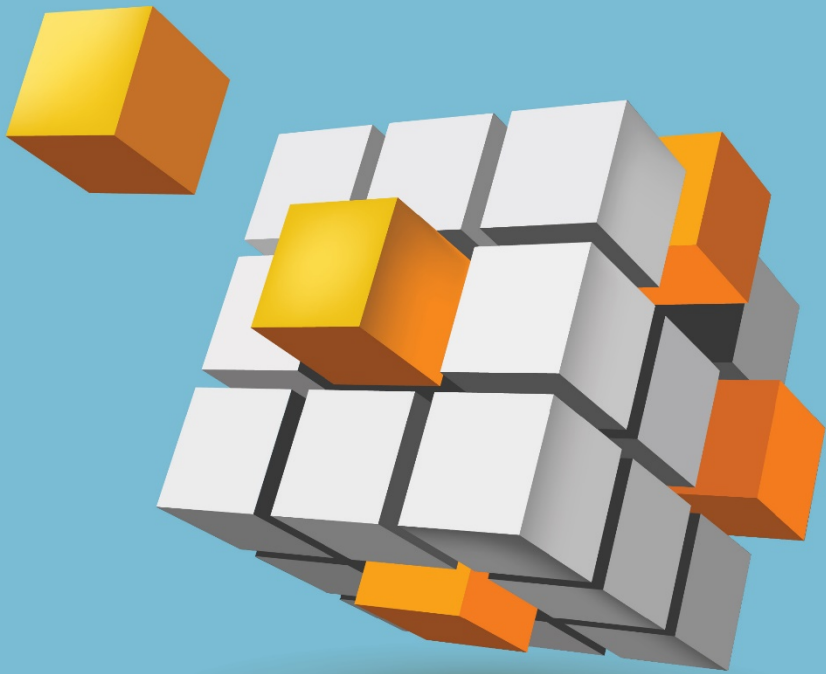
Assessing CO<sub>2</sub>  
Utilization  
Options

# Summary Primary Recommendations

- U.S. law recognizes CO<sub>2</sub>-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<sub>2</sub> production and utilization markets may require relaxing terms of compliance for CO<sub>2</sub> emitting utilities and industrial facilities, as well as providing for establishment of an inventory of unused CO<sub>2</sub> 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<sub>2</sub> utilization technologies that can be quickly commercialized at significant scale. Monetary, regulatory and policy investments in CO<sub>2</sub> 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<sub>2</sub> emissions from about 6 GWe or a dozen 500 MWe coal-based power plants.

# CO<sub>2</sub> BUILDING BLOCKS

ASSESSING CO<sub>2</sub> UTILIZATION OPTIONS



## Questions?



Janet Gellici, CEO  
[jgellici@NCC1.org](mailto:jgellici@NCC1.org)  
[www.nationalcoalcouncil.org](http://www.nationalcoalcouncil.org)

