CO_2 BUILDING BLOCKS

ASSESSING CO_2 UTILIZATION OPTIONS

NATIONAL COAL COUNCIL

Principal Recommendations

The most impactful action the U.S. can employ to reduce CO_2 emissions is to incentivize the rapid deployment of carbon capture utilization and storage (CCUS) technologies.

- **Build on the Consensus.** Efforts should be undertaken to build on the expanding consensus among industry, the environmental community and governments that future CO_2 reduction goals cannot be met by renewable energy sources alone. An expanded coalition of fossil fuel users and producers should collaborate to help develop and commercially deploy CCUS technologies on an accelerated time schedule with the aim of achieving global climate objectives and insuring a reliable grid.

- **Prioritize CO_2 Utilization Technology Deployment.** Geological CO_2 utilization options, including but not limited to CO_2 for enhanced oil recovery (CO_2-EOR), have the greatest potential to advance CCUS by creating market demand for anthropogenic CO_2. Monetary, regulatory and policy investments in CO_2 utilization technologies should be roughly prioritized from geologic to non-geologic, with exceptions made if non-geologic technologies are found to be as effective as geologic storage.

- **Pursue Non-Geologic CO_2 Markets as Longer Term Opportunities.** Non-geologic CO_2 utilization options are unlikely to significantly incentivize CCUS in the near- to intermediate-term due to technical, greenhouse gas (GHG) lifecycle considerations and lack of scalability. However, a broadly deployed mix of CO_2 utilization technologies may help to advance CCUS incrementally, providing sufficient incentive to keep CCUS technologies moving forward. Non-geologic technologies that can "fix" CO_2 molecules intact, akin to geologic storage, hold the most promise and are worthy of continuing RD&D, including inorganic carbonates/bicarbonates, plastics/polymers, organic/specialty chemicals and agricultural fertilizers.

- **Pursue Impactful Options to Facilitate Regulatory Compliance.** 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. U.S. law recognizes CO_2-EOR and other geologic technologies as compliance options; non-geologic technologies may be used only if EPA determines they are as effective as geologic storage. NCC recommends 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.

- **Establish a Technology Review Process.** There is benefit to establishing a technology review process that is as objective as possible to assess the benefits and challenges of different CO_2 utilization technologies and products. Evaluation criteria fall into three broad categories: 1) environmental considerations, 2) technology/product status and 3) market considerations. Evaluation criteria can be used to prioritize candidates for RD&D and product investment.

http://www.nationalcoalcouncil.org/Documents/CO2-Building-Blocks-2016.pdf

CO₂ BUILDING BLOCKS

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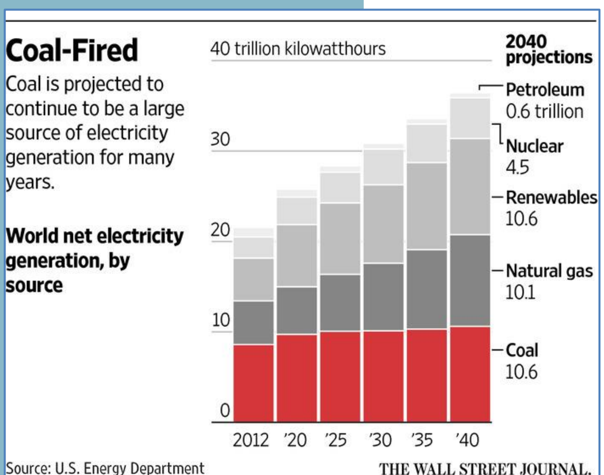
"I am writing to request the National Coal Council (NCC) develop an expanded white paper assessing opportunities to advance commercial markets for carbon dioxide (CO_2) from coal-based power generation. What is the extent to which commercial EOR and non-EOR CO_2 markets could incentivize deployment of Carbon Capture and Storage (CCS)/Carbon Capture, Utilization and Storage (CCUS) technologies? What economic opportunity does deployment of commercial-scale CCS/CCUS technology represent for the U.S.?"

U.S. Secretary Ernest J. Moniz – February 2016

The National Coal Council's "CO_2 Building Blocks" report acknowledges the growing consensus among industry, the environmental community and governments that future CO_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 in the near term to achieve U.S. and global climate objectives.



* 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.

* Advancing CCUS is not just about coal, nor is it just about fossil fuels generally. Rather, it is a sine qua non for achieving stabilization of GHG concentrations.

* CO2 for enhanced oil recovery (CO_2-EOR) represents the most immediate, highest value opportunity to utilize the greatest volume of anthropogenic CO_2, thereby incentivizing CCUS.

* Aside from CO_2-EOR and other geologic CO_2 utilization options – including CO_2 in natural gas shale formations, enhanced coal bed methane (ECBM), enhanced water recovery (EWR) and geothermal energy storage – research is underway on two general utilization pathways. The first breaks down the CO_2 molecule by cleaving C=O bonds while the second incorporates the entire CO_2 molecule into other chemical structures. The latter holds relatively more promise as it requires less energy and tends to "fix" the CO_2 in a manner akin to geologic storage.

*Utilizing CO_2 in non-geologic applications faces hurdles, including yet-to-be resolved issues associated with thermodynamics and kinetics involved in the successful reduction of CO_2 to carbon products. Still these technologies are worthy of continuing evaluation and many hold long-term potential in specific applications.

* An objective technology review process that assesses the challenges and benefits of different CO_2 utilization technologies and products could be used to prioritize candidates for RD&D and product investment.

* Current U.S. policy favors geologic-based utilization pathways for Clean Air Act compliance. 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.

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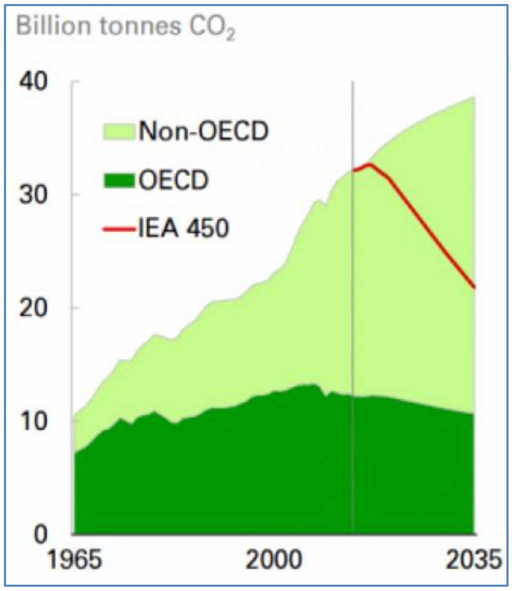
CO_2 Emissions – BP Energy Outlook 2016



The BP Energy Outlook 2016 notes that the level of CO2 emissions is expected to continue to grow, increasing by 20% between 2014 and 2035. The gap between the projected path for CO_2 emissions and the International Energy Agency's (IEA) 450 Scenario demonstrates the challenge associated with reducing GHG emissions.

Both the IEA and the United Nation's Intergovernmental Panel on Climate Change (IPCC) have concluded that CCUS is essential to limit global warming to 2^0C. IEA estimates that CCUS can achieve 14% of the global GHG emissions reductions by 2050.

Fossil fuels generally and coal specifically are dependent upon CCUS technologies to comply with U.S. GHG emissions reduction requirements. U.S. law requires new major stationary sources and major modifications to existing sources of GHG to reduce their emissions with geologic storage options – specifically including CO_2-EOR – as preferred mitigation technologies. These U.S. legal requirements are reinforced by the 2015 Paris Agreement which largely envisions the decarbonization of major energy systems through the use of CCUS and other technologies by 2050.

CO_2-EOR still represents the most immediate, highest value opportunity to utilize the greatest volumes of anthropogenic CO_2.

Technically Recoverable Domestic Oil and CO_2 Storage Capacity, State of the Art and "Next Generation" CO2-EOR Technology

Basin/Area	Technically Recoverable Oil (Billion Barrels)		Technical CO2 Demand/Storage (Million Metric Tons)	
	SOA	"Next Generation"	SOA	"Next Generation"
1. Main Pay Zone CO2-EOR				
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
Sub-Total	**84.9**	**167.2**	**38,230**	**52,220**
2. Residual Oil Zone CO2-EOR				
ROZ Fairways*	n/a	25.7	n/a	17,100
Below Oil Fields	n/a	16.3	n/a	8,200
Sub-Total	**n/a**	**42.0**	**n/a**	**25,300**
Total	**84.9**	**209.2**	**38,230**	**77,520**

*Four County Permian Basin San Andres ROZ fairway.

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With a potential for 81 billion barrels of economically viable oil recovery from mature oil field and residual oil zones (assuming the use of "Next Generation" technology), the various CO_2-EO stakeholders would gain valuable revenue and economic benefits.

Recipients of CO_2-EOR Revenues*	Revenues
• CO_2 Capture and Transporters	$1,210 billion
• State, Local and Federal Treasuries	$1,130 billion
• CO_2-EOR Investors (including Return on Capital)	$1,270 billion
• General Economy/Mineral Owners	$2,060 billion
Total	**$5,670 billion**

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

Other geologic options include utilization of CO2 in natural gas shale formations, for production of enhanced coal bed methane (ECBM), for enhanced water recovery (EWR) and for enhanced geothermal energy and subsurface energy storage.

Non-geologic CO_2 utilization options may hold long term potential but are unlikely to significantly incentivize CCUS in the near- to intermediate-term because of technical challenges, GHG lifecycle considerations and issues associated with scalability.

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.

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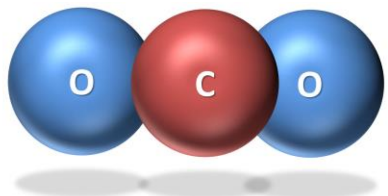
CO_2 may also be utilized through chemical and biological processes to produce transportation fuels, which is a very large market. This pathway is unlikely to incentivize CCUS in the immediate future because 1) these fuels are ultimately combusted and thus release CO_2 to the atmosphere and 2) current U.S. policy favors geologic-based utilization pathways for CAA compliance. And while the case could be made that some CO_2-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.



It can be challenging to compare CO_2 utilization technologies because they face different growth and economic challenges. For example, some are more mature than others; some require infrastructure while others require RD&D; and some create large potential demand for CO_2 while others are more modest. The development of an objective technology/product review process can help to identify technology strengths and weaknesses, therefore contributing to a more robust technology development and investment strategy. Important factors for consideration should include:

*** Environmental Considerations**

For example, what is the security, reliability and longevity of associated CO_2 storage or reductions?

*** Technology/Product Status**

For example, is the technology at or near commercial status?

*** Market Considerations**

For example, is the potential market for CO_2 on a scale commensurate with coal-based power plants or other alternative uses of coal?

National Coal Council

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THERMODYNAMICS & KINETICS OF CO_2

The CO_2 molecule is particularly stable and has a Gibbs energy of formation of -394.4 kJ/mol – which must be overcome.

Thus, breaking the C=O bond(s) and forming C-H or C-C bond(s), or producing elemental carbon, is possible. However, such molecules are at a much higher energy state, meaning that a tremendous amount of energy must be used. Converting CO_2 to fuels or other high energy state molecules requires more energy input than could ever be derived from the end products.

CO_2 can also be incorporated into various chemicals as a C_1 building block. This is not thermodynamically challenged because the entirety of the CO_2 molecule is used and thus the C=O bonds are not broken. For this application, the principal challenge is the scale of available reactants and market for products, both of which are dwarfed by global CO_2 emissions.

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