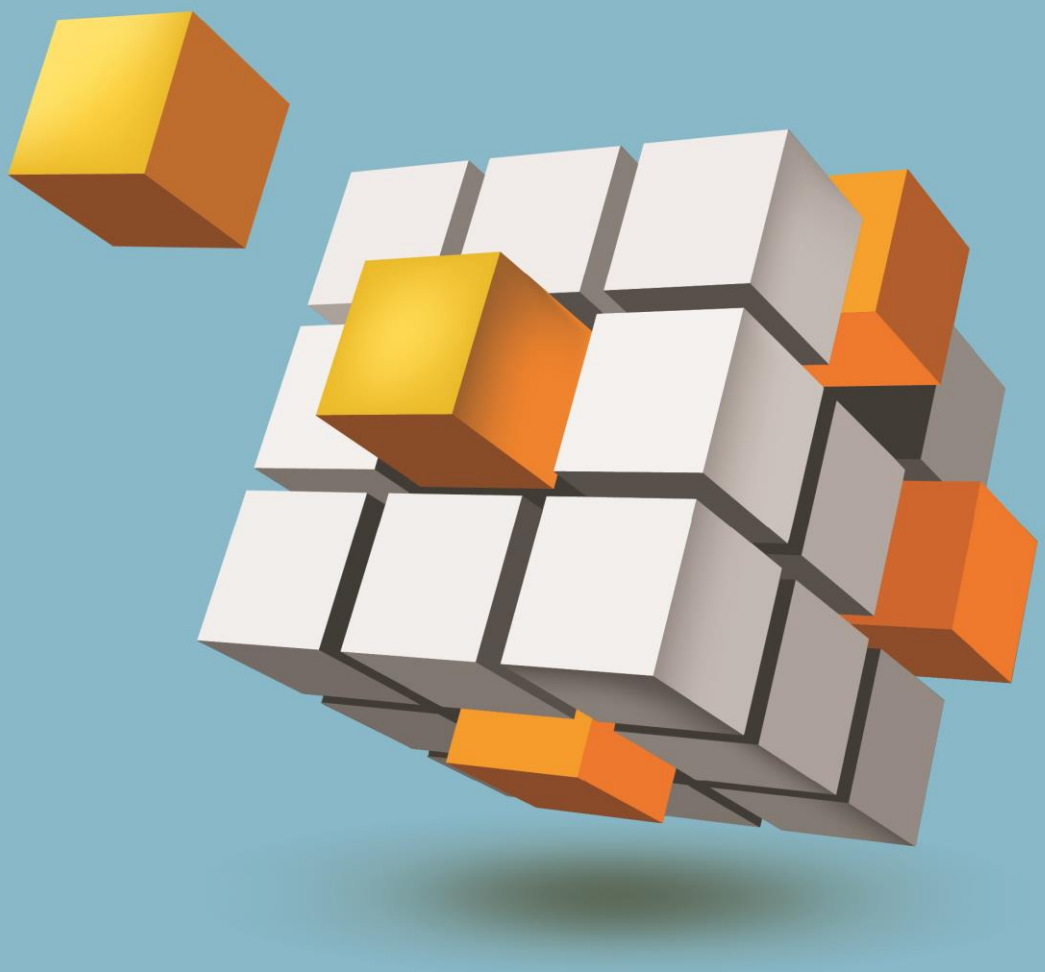
NATIONAL COAL COUNCIL

Executive Summary August 2016

CO_2 BUILDING BLOCKS

ASSESSING CO_2 UTILIZATION OPTIONS



CO_2 BUILDING BLOCKS
Assessing CO_2 Utilization Options

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The National Coal Council (NCC) was chartered in 1984 based on the conviction that an industry advisory council on coal could make a vital contribution to America's energy security. The NCC's founders believed that providing expert information could help shape policies relevant to the use of coal in an environmentally sound manner. It was expected that this could, in turn, lead to decreased dependence on other less abundant, more costly, less secure sources of energy.

These principles continue to guide and inform the activities of the NCC. Coal has a vital role to play in the future of our nation's electric power, industrial, manufacturing, and energy needs. Our nation's primary energy challenge is to find a way to balance our social, economic, and environmental objectives.

Throughout its 32-year history, the NCC has maintained its focus on providing guidance to the Secretary of Energy on various aspects of the coal industry. The NCC has retained its original charge to represent a diversity of perspectives through its varied membership and continues to welcome members with extensive experience and expertise related to coal.

The NCC serves as an advisory group to the Secretary of Energy, chartered under the Federal Advisory Committee Act (FACA), providing advice and recommendations to the Secretary of Energy on general policy matters relating to coal and the coal industry. As a FACA organization, the NCC does not engage in lobbying activities.

The principal activity of the NCC is to prepare reports for the Secretary of Energy at his/her request. The NCC has prepared more than 30 studies for the Secretary, at no cost to the Department of Energy. All NCC studies are publicly available on the NCC website.

Members of the NCC are appointed by the Secretary of Energy and represent all segments of coal interests and geographic distribution. The NCC is headed by a Chair and Vice Chair who are elected by its members. The Council is supported entirely by voluntary contributions from NCC members and receives no funds from the Federal government. Studies are conducted solely at the expensive of the NCC and at no cost to the government.

The National Coal Council values the opportunity to represent the power, the pride, and the promise of our nation's coal industry.

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The Secretary of Energy
Washington, DC 20585

February 23, 2016

Dr. Michael Durham
Chairman, The National Coal Council, Inc.
1101 Pennsylvania Avenue, NW, 6th Floor
Washington, DC 20004

Dear Chairman Durham:

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-base power generation.

The white paper should focus on profit-generating opportunities for CO_2 utilization, both for Enhanced Oil Recovery (EOR) and for non-EOR applications. The questions to be addressed are:

(1) 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?

(2) What economic opportunity does deployment of commercial-scale CCS/CCUS technology represent for the U.S.?

The white paper would be managed under the auspices of the Executive Advisory Board within the NCC. I ask that the white paper be completed no later than August 31.

Upon receiving this request and establishing your internal working groups, please advise me of your schedule for completing the white paper. The Department looks forward to working with you in this effort.

Sincerely,

Ernest J. Moniz

August 30, 2016

The Honorable Ernest J. Moniz
U.S. Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Secretary Moniz:

On behalf of the members of the National Coal Council (NCC), we are pleased to submit to you, pursuant to your letter dated February 23, 2016, the report "CO_2 Building Blocks: Assessing CO_2 Utilization Options." The report's primary focus is to assess opportunities to advance commercial markets for carbon dioxide (CO_2) from coal-based power generation and the extent to which CO_2 markets for enhanced oil recovery (CO_2-EOR) and non-EOR could incentivize deployment of carbon capture, utilization and storage (CCUS) technologies.

There is a growing consensus among industry, the environmental community and governments that future carbon dioxide (CO_2) emission reduction goals cannot be met by renewable energy sources alone and that carbon capture, utilization and storage (CCUS) technologies for all fossil fuels will have to be deployed to achieve climate objectives in the U.S. and globally and to insure a reliable power grid. Advancing CCUS is not just about coal. Rather, it is a sine qua non for achieving stabilization of greenhouse gas (GHG) concentrations in the atmosphere.

The NCC assessment concludes that CO_2-EOR currently represents the most immediate, highest value opportunity to utilize the greatest volumes of anthropogenic CO_2, with the greatest near-term potential to incentivize CCUS deployment. Other geologic storage technologies that provide economic return, such as enhanced coal bed methane (ECBM) and residual oil zones (ROZs) may provide demand for CO_2 under certain oil and gas market conditions.

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. A broadly deployed mix of CO_2 utilization technologies may help to advance CCUS incrementally and may, even if they do not offer full-scale carbon management solutions, provide sufficient incentive to keep CCUS technologies moving forward.

The extent to which CO_2 utilization technologies may incentivize CCUS deployment is dependent on numerous policy and market factors. U.S. law currently 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. GHG emission reduction targets and deadlines associated with U.S. and international climate goals point towards the use of those CO_2 utilization technologies that are either already commercialized or near commercialization.

With this in mind, the NCC recommends that monetary, regulatory and policy investments in CO2 utilization technologies 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. Full GHG lifecycle assessments of CO_2 utilization technologies should also be conducted with the assessments taking into account the incumbent products' GHG emissions that the new technologies displace.

NCC further notes that there is benefit to establishing an objective technology review process to assess the benefits and challenges of different CO_2 utilization technologies and products. The NCC report identifies specific evaluation criteria that fall into three broad categories: (1) environmental considerations; (2) technology/product status; and (3) market considerations. Using the criteria, a technology ranking system can then be used to prioritize candidates for RD&D and product investment.

We are confident that this country will succeed in meeting our global carbon dioxide emission reduction goals when we commit with urgency to the deployment of CCUS technologies. Such commitment begins with the establishment of policies and incentives to level the playing field for CCUS. Upon this level foundation, the building blocks of CO_2 utilization can be constructed to further expedite the reduction of CO_2.

Thank you for the opportunity to prepare this report. The Council stands ready to address any questions you may have regarding its recommendations and findings.

Sincerely,

Michael D. Durham
Chair
National Coal Council

Kipp Coddington
NCC Report Chair

CO_2 BUILDING BLOCKS
Assessing CO_2 Utilization Options
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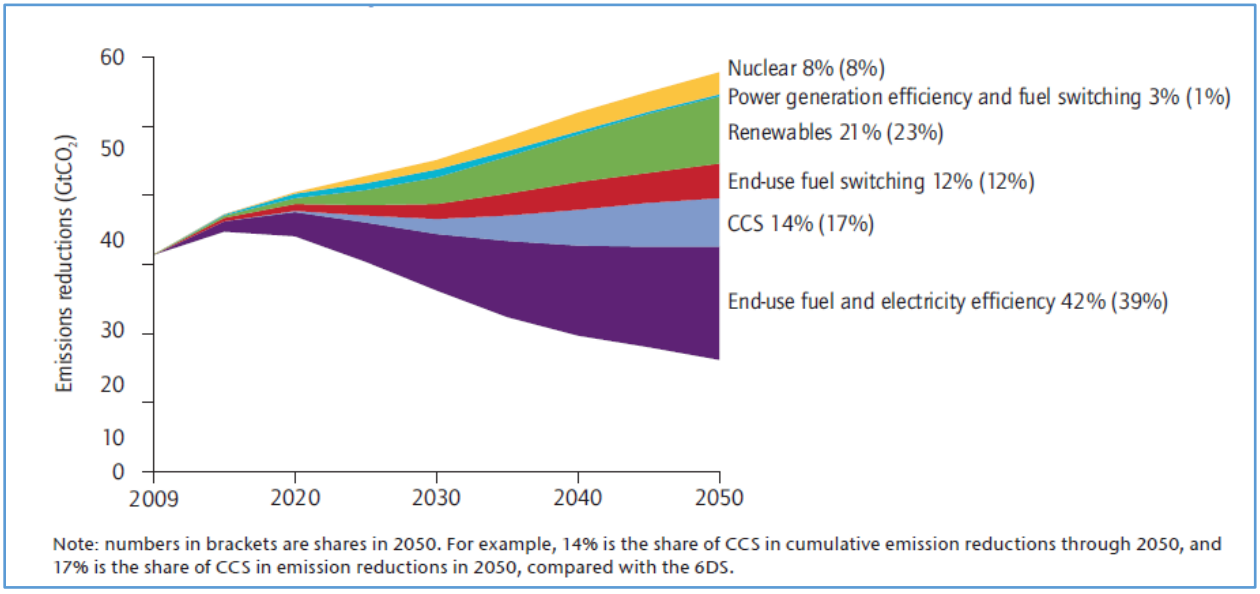
CO_2 Building Blocks: Assessing CO_2 Utilization Options

Executive Summary

THE CO_2 UTILIZATION IMPERATIVE

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 carbon dioxide (CO_2) emission reduction goals cannot be met by renewable energy sources alone and that carbon capture, utilization and storage (CCUS) technologies for all fossil fuels will have to be deployed to achieve climate objectives in the U.S. and globally and to insure a reliable power grid. 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 greenhouse gas (GHG) concentrations in the atmosphere.

IEA Technology Roadmap



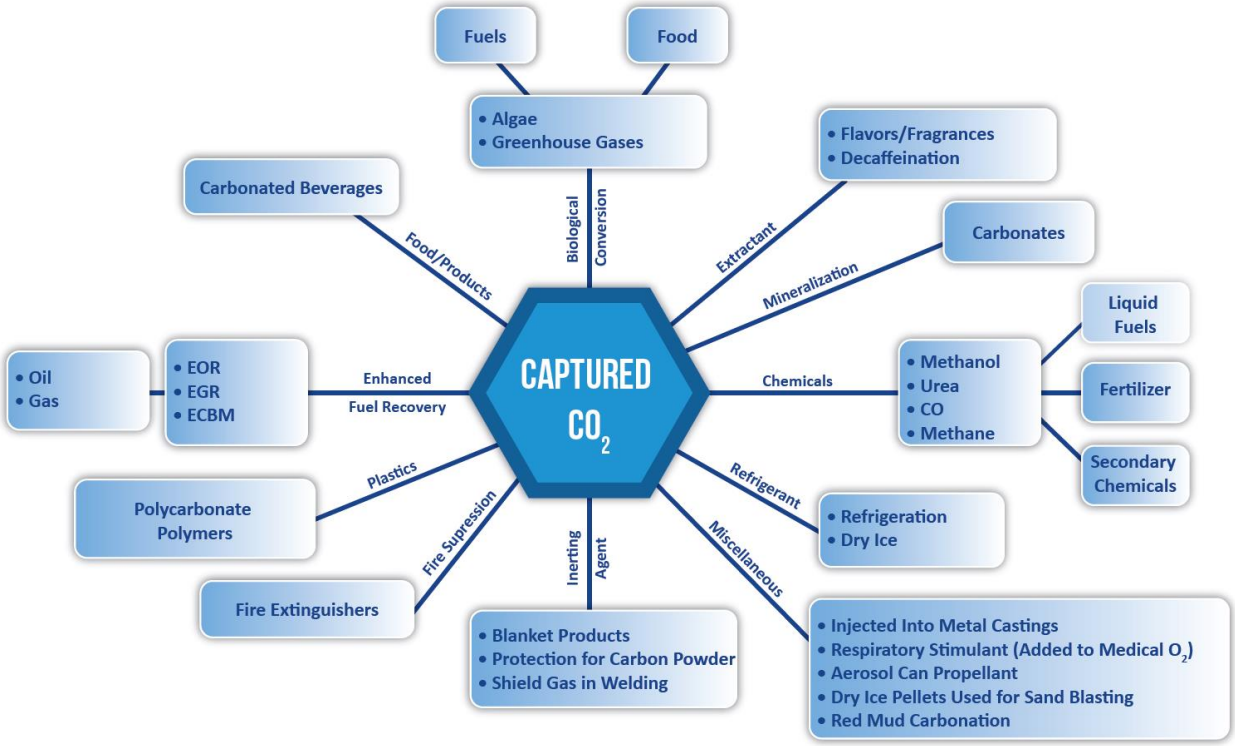
Source: International Energy Agency 2013

Achieving global climate objectives will require a portfolio of approaches that balance economic realities, energy security and environmental aspirations. Both the International Energy Agency (IEA) and the United Nation's IPCC have concluded that CCUS is essential to limit global warming to 2°C. IEA estimates that CCUS can achieve 14 percent of the global GHG emissions reductions needed by 2050. In its November 2015 report "*Leveling the Playing Field: Policy Parity for CCS*", the NCC notes that CCUS is the only large-scale technology that can mitigate CO_2 emissions not just from coal-based power plants, but from other fossil generation and industrial sectors. IEA concurs, noting that CCUS is more than a strategy for clean coal and must be adopted by biomass and natural gas power plants, as well as by emission-intensive industry sectors, including cement, iron and steel, and chemicals manufacturing.

CO_2 UTILIZATION MARKETS

In its CO_2 Building Blocks report, the NCC examined various existing CO_2 utilization technologies and potential products that could be generated from CO_2 in two market categories – geologic and non-geologic utilization. Geologic markets include technologies such as enhanced oil recovery (EOR), enhanced coalbed methane (ECBM), and CO_2 shale, as well as less developed options such as storage batteries and enhanced water recovery (EWR). Non-geologic markets include chemical products and other value-added schemes that offer higher potential revenue but are limited relative to the size of potential carbon consumption in geological applications. The report provides assessments of total potential use of CO_2 in each market and a general assessment of the technology required to create the products as well as the state of development. To the extent possible economic potential was also addressed.

CO_2 Utilization Markets



Source: National Energy Technology Laboratory (www.netl.doe.gov)

The NCC assessment concludes that carbon dioxide enhanced oil recovery (CO_2-EOR) represents the most immediate, highest value opportunity to utilize the greatest volumes of anthropogenic CO_2, thereby incentivizing CCUS. Assuming a price for CO_2 of $33/metric ton ($1.75/Mcf) delivered to the oil field at pressure and a $70 per barrel oil price, and using 0.45 metric tons of purchased (net) CO_2 per barrel of recovered oil, utilization of CO_2 for EOR results in a transfer of $14.90 of the $70 per barrel price to firms involved with capture and transport of CO_2. The economic value is sensitive to the price of oil, of course, and will vary in response to oil market conditions.

U.S. Regional CO_2 Utilization/Storage and Oil Recovery Potential
The CO_2 Utilization/Storage and Oil Recovery Potential of Nine Lower 48 Onshore Regions

	Region	Oil Reservoirs Favorable For CO2-EOR	CO2 Demand (MMmt)				Oil Recovery (Billion Bbls)			
			Technical		Economic [4]		Technical		Economic [4]	
			SOA	"Next Generation"	SOA	"Next Generation"	SOA	"Next Generation"	SOA	"Next Generation"
1	Appalachia	103	520	1,160	10	290	1.1	3.4	*	1.3
2	California	89	1,340	2,320	480	1,760	3.1	7.9	1.2	6.7
3	East/Central Texas	193	4,120	6,040	2,120	3,620	11.1	20.9	5.9	13.5
4	Michigan/Illinois	148	660	1,050	330	570	1.8	3.0	1.1	1.8
5	Mid-Continent [1]	183	4,220	6,530	2,120	3,270	12.9	22.5	6.6	12.0
6	Permian Basin [2]	217	6,070	8,620	2,690	4,750	13.6	24.0	6.4	14.6
7	Rockies [3]	146	1,930	2,790	710	1,270	4.5	9.7	1.9	4.7
8	Gulf Coast	209	2,590	3,390	290	1,440	5.4	10.1	0.9	4.8
9	Williston	86	820	1,150	130	360	2.1	4.0	0.3	1.3
Total		**1,374**	**22,270**	**33,050**	**8,880**	**17,330**	**55.6**	**105.5**	**24.3**	**60.7**

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[1] Includes 0.1 billion barrels already produced or proved with CO2-EOR.

[2] Includes 2.2 billion barrels already produced or proved with CO2-EOR.

[3] Includes 0.3 billion barrels already produced or proved with CO2-EOR.

[4] Evaluated using an oil price of $85/B, a CO2 cost of $40/mt and a 20% ROR, before tax.

Source: Advanced Resources International

NCC recommends that policymakers continue to focus on advancing geological storage options through support for research, development and demonstration (RD&D) and adoption of incentives. As part of Mission Innovation, the U.S. Department of Energy (DOE) is encouraged to reinvigorate its RD&D program on advanced ("next generation") CO_2-EOR technologies. Deployment of these advanced technologies could more than double the market for CO_2 – from 11 billion MT with today's technologies to 24 billion MT with next generation technologies. DOE should sponsor a full evaluation of the technically recoverable and economically viable domestic residual oil zone (ROZ) resource to more completely understand the market for CO_2 from EOR. Regulatory impediments to the expansion of CO_2-EOR should be reduced.

Non-geological CO_2 utilization options are unlikely to incentivize CCUS in the near- to intermediate-term because of technical, greenhouse gas (GHG) life cycle analysis (LCA) considerations and challenges associated with scalability. Despite these barriers, further investments in non-geologic CO_2 utilization technologies may, on a case-by-case basis, hold promise for turning an uneconomic CCUS project into an economic one. A broadly deployed mix of CO_2 utilization technologies may help advance CCUS deployment incrementally, providing sufficient incentives to keep CCUS technologies moving forward.

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.

Within the non-geologic market sector, research is underway on two general CO_2 utilization pathways – breaking down the CO_2 molecule by cleaving C=O bond(s) and incorporating the entire CO_2 molecule into other chemical structures. The latter pathway holds relatively more promise as it requires less energy and tends to "fix" the CO_2 in a manner akin to geologic storage. Non-geologic utilization opportunities that tend to "fix" CO_2 include 1) inorganic carbonates and bicarbonates; 2) plastics and polymers; 3) organic and specialty chemicals; and 4) agricultural fertilizers. While various technical and economic challenges confront these commercially immature technologies, they may, however, have an advantage over other non-geologic markets, such as fuels, which require cleaving of the CO_2 bond through chemical and biological processes.

Transportation fuels do represent a significant market opportunity. They are, however, unlikely to incentivize CCUS in the immediate future for various reasons, including the fact that transportation fuels are ultimately combusted and thus release CO_2 to the atmosphere and current U.S. policy favors geologic-based utilization pathways for Clean Air Act (CAA) compliance. 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.

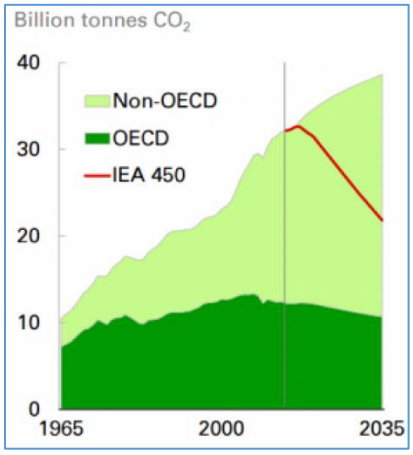
CRITERIA FOR REVIEW OF CO_2 UTILIZATION OPTIONS

NCC recommends 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. Collecting data on these evaluation criteria should be undertaken. Using the criteria, a technology ranking system which can then be used to prioritize candidates for RD&D and product investment should be developed.

INCENTIVIZING CCUS DEPLOYMENT

The extent to which CO_2 utilization technologies may incentivize CCUS deployment is dependent on numerous policy and market factors. 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. U.S. and international GHG reduction objectives and timeframes (2050) further dictate the need to employ CO_2 utilization technologies that can be quickly commercialized at significant scale.

CO_2 Emissions



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

Source: BP Energy Outlook 2016

CO_2 utilization markets may not be well aligned with the regulatory or investment requirements of the power and industrial sectors. For example, a technology developer offering a utilization opportunity would likely require a return on investment in less than 10 years, while the plant owner would require a CO_2 control technology that will allow the plant to operate for the remainder of its useful life – which may be another 40 years or more for a power plant. Additionally, an owner of a CO_2-emitting facility must consider whether a CO_2 user may discontinue the project due to bankruptcy, market changes or other reasons, leaving the facility owner without a viable regulatory compliance strategy.

The array of potential bases for misalignment of needs highlights the fact that even if a CCU project is deemed economically viable, access to geological storage may be necessary to advance the project. In this way, CCU may be helpful to the deployment of a broader CCUS infrastructure by providing some revenue and also encouraging characterization and well permitting activities for geological CO_2 storage.

PRIORITIZING CO_2 UTILIZATION INVESTMENTS

The NCC recommends that research investments in CO_2 utilization technologies should be prioritized according to the following criteria – the ability of the CO_2 utilization technology to:

- Make use of CO_2 at scale.
- Make use of CO_2 at scale in the 2020-2030 time frame.
- Be commercially demonstrated prior to 2020 or as soon as possible thereafter.
- Be deployed onsite at fossil fuel-based power plants and CO_2-emitting industrial facilities.
- Have realistic market potential, taking into account displacement considerations.
- Be as effective as geologic technologies.
- Provide non-trivial economic returns.
- Favorably score under existing and forthcoming GHG LCA.

The Council further notes that monetary, regulatory and policy investments in the following CO_2 utilization and storage technologies, in descending order, are most likely to incentivize the deployment of CCUS technologies:

1) ***Current CO_2-EOR technology.*** It is imperative for the government to clarify the existing regulatory structure, provide support for infrastructure, such as pipeline networks, and offer financial incentives for carbon capture deployment so that the promise of this existing commercial technology is fully realized.

2) ***"Next Generation" CO_2-EOR technologies.*** Advances to existing CO_2-EOR technologies would enable ROZ resources to be efficiently recovered.

3) ***Other geologic storage technologies that provide economic return.*** ECBM and CO_2 injections into ROZs provide market demand for CO_2 under certain general oil and gas market conditions. They also fit within the current U.S. legal framework that gives preference to geologic storage over non-geologic uses of CO_2. Not all geologic formations (ECBM, for example) have access to protocols and/or methodologies to document storage.

4) ***Saline storage.*** Saline storage remains EPA's gold standard for CO_2 storage and may be required to provide a back stop for CO_2 utilization projects. The hurdles facing saline storage are primarily economic and regulatory, which current DOE policy recognizes – i.e., the new CarbonSAFE program. The fact remains, however, that the federal government needs to: 1) put more resources into these projects and 2) reduce the regulatory impediments currently facing them.

5) ***Non-geologic storage technologies that provide economic return and that are effective as geologic storage.*** The current U.S. legal framework prefers geologic storage over other CO_2 uses. However, non-geologic technologies that keep the CO_2 out of the atmosphere may be credited for the purposes of federal programs with appropriate evidence of atmospheric benefit.

6) ***Non-geologic storage technologies that provide economic return yet are not as effective as geologic storage if appropriate EPA research waivers may be obtained.*** On a case-by-case basis, a CO_2 utilization technology may exist or emerge that provides an economic return to a fossil fuel-based power plant or a CO_2-emitting industrial facility. The technology nonetheless could be helpful in lowering the cost of capture. Appropriate legal recognition would be needed, however, for purposes of compliance with emission reduction obligations.

CONCLUSION

In sum, 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. Full GHG lifecycle assessments of CO_2 utilization technologies should also be conducted with the assessments taking into account the incumbent products' GHG emissions that the new technologies displace.

Aligning CO_2 production and utilization markets may require relaxing the temporal 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.

The U.S. enhances its chance of success in meeting its CO_2 emission reduction goals when it commits with urgency to the deployment of CCUS technologies. That commitment begins with the establishment of policies and incentives to level the playing field for CCUS. Upon this level foundation, the building blocks of CO_2 utilization can be constructed to further expedite the reduction of CO_2.